ETH zürich

Department
of Earth Sciences

Earth and Climate Sciences in Zurich

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DERDW
EARTH SCIENCES

Cover photo: Breiðamerkurjökull, Island / Léon Frey

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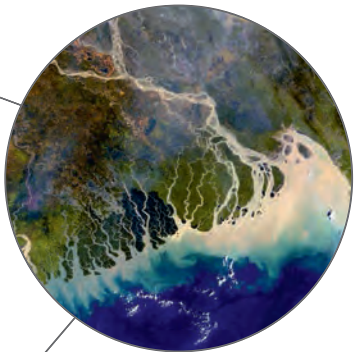
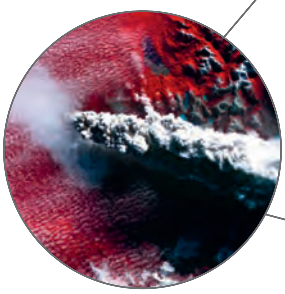
EARTH AND CLIMATE SCIENCES IN ZURICH

Welcome to the Department of Earth Sciences (D-ERDW) in our beautifully renovated building located on the Sonneggstrasse in the heart of Zurich. The faculty, scientists and students of the Earth Sciences Department (D-ERDW) at the Swiss Federal Institute of Technology ETH strive to gain a better understanding of our planet – including the interior of the Earth, the continents, oceans and biosphere as well as the atmosphere. We study Earth's materials from an atomic to a planetary scale and try to understand the evolution of the planet and the processes which shape it, with respect to the past, present and future. This understanding is of increasing importance to humankind and has a growing influence on the way we see the "earth system" on a regional and a global scale. The future development of the Earth in regard to the availability of geological resources like petroleum and fresh water, or the disposal of radioactive waste and carbon dioxide are issues that need to be solved. A chair in Geothermal Energy has been established in the department, reflecting the changing situation concerning energy policy. The establishment of the chair reflects the desire of the ETH to meet the current energy challenges and of D-ERDW to play an active role in shaping the future.





One of our most important tasks is the education of the future stakeholders in science, technology, politics and public administration. This encompasses instruction about natural resources, protection of water supplies, natural hazards, energy resources, climate and environmental challenges, existing waste deposits, and structural and civil engineering topics including building ground and tunnelling. Our department is externally oriented. Teaching and research activities are closely linked to the departments of agricultural sciences, life sciences, engineering sciences as well as physics, chemistry, and materials science. In order to face future challenges, our courses offer subjects in both fundamental and applied natural sciences. The study is enhanced by close contact to research, collaboration with industry, and partnerships with other universities worldwide.

We invite you to browse through our brochure and find out more about ongoing activities in our department.

Prof. Dr. Johan Robertsson, Head of department

Research

To reach our goals, we carry out laboratory experiments, extensive field campaigns, computer simulations and remote sensing using satellites, for example. Earth provides us with an archive, which we use to understand complex global processes. The exploration of this archive, which includes rocks, deep-sea sediments, glaciers and ice sheets, is essential for the understanding of our current problems: "The key to the future lies in the past."

Earth scientists at ETH Zurich, together with scientists from the University of Zurich, try to find answers to the following questions:

- How can we find essential resources which are buried deep in the earth, or how can we gather geothermal energy in an economical way?
- Why are earthquakes an issue in Switzerland and why can't we predict the next rock fall or landslide in the Alps?
- Where can we safely deposit waste and how can we undertake new building developments and traffic infrastructure without risk to our groundwater or to future generations?
- How did Earth form in the solar system, and how did life develop on our planet – from the first DNA to microbes, and from dinosaurs to the first humans?
- What is the origin of Earth's magnetic field and how can we assess earthquake hazards and volcanic eruptions?
- What can meteorites tell us about the origins of the planets, what is the history of the moon and the earth?
- Why, and how did the Alps and other mountain ranges form, and what determines their development and their topography?
- Will the Gulf Stream loose its intensity in the coming millennia? And if so will this lead to Europe disappearing underneath an ice sheet? Will the atmosphere warm up and cause worldwide flooding? Given this situation – what can we do?

STUDY PROGRAMME

Why Study Earth and Climate Sciences?
The study programme imparts fundamental knowledge of all aspects of our planet at an academic level. Core topics are the formation and long-term evolution of the earth system as well as the interplay between rock, oceans, climate and atmosphere, with Earth serving as a sort of repository of historical information. Students learn how to explore its mysteries and to forecast further developments. This task is of increasing importance as we prepare to face the challenges posed by climate change and the management of resources and radioactive waste.

The Earth and Climate Sciences study programme offers not only a very practical approach to the core topics, it is also unrivalled in Switzerland for providing a broadly based scientific university education.

Prerequisites
The ideal prerequisite for embarking on a study path in earth sciences is a passion for all aspects of the natural sciences, as well as an avid curiosity about the complexities of the earth system. Would you like to be involved in investigating all kinds of earth materials, and dimensions from the atom right up to planets? Are you interested in deepening your knowledge of the past evolution of planets and current and future physical processes? Do you enjoy working closely with experts in other fields, and thinking beyond the boundaries of your own particular discipline? – Then you are in the right place!

Do you like to be outside and active amidst the wonders of nature? Are you also fascinated by what high technology has to offer, such as computer simulation? Earth sciences offer much more: experimental geochemistry and rock deformation laboratories with ultra-modern equipment, and the opportunity to participate in the building of large-scale structures such as base tunnels through the Alps, bridges or mountain railways; to drill deep down below the sea or to study the ocean depths first-hand.

How the Programme of Studies is Set Up

Bachelor Studies

The Bachelor's programme in Earth- and Climate Sciences includes theory, analysis and application of methods, experimentation and lab- and fieldwork. The three semester course "Integrated Earth Systems" aims at specific topics within the Earth Sciences that utilize an interdisciplinary approach. Students gain an in-depth knowledge of the chosen topics with the help of diverse methodologies and practical work that is relevant within the Earth Sciences.

In the third year students are offered two specialisations for individual selection:

Geology and Geophysics: The Major in Geology and Geophysics gives an in-depth understanding of the composition, formation and structure as well as the processes that formed and will continue to form the Earth and other planetary bodies. Topics covered are Geology, Mineralogy, Geochemistry and Geophysics. Teaching comprises lectures with computer and laboratory exercises, case studies, excursions and field courses. The Major in Geology and Geophysics offers a well-founded qualification for all four majors of the consecutive Master's programme in Earth Sciences.

Climate and water: The Major in Climate and Water provides an in-depth knowledge of the interactions between climate, cryosphere, hydrosphere and weather. The primary goal of climatology is to understand the processes that drive the climate and its variations. Hydrology deals with questions regarding water management and provides basic knowledge about water cycle and its relations to climate, vegetation, soil and solid rock interactions. This elective course provides an ideal introduction to the specialised Master's programme in atmospheric and climate sciences, where special topics serve as a focus for the specialised Master Degree in Atmospheric and Climate Science.

Master Studies

The Master's Study, is generally two years in length, and consists of: one-third core subjects, one-third optional subjects, and one-third Master's thesis. Master's degrees are offered in the following disciplines;

- Master in Earth Sciences
- Joint Master in Applied Geophysics
- Master in Atmospheric and Climate Sciences

The **Master in Earth Sciences** is a broadly based modular program of academic studies which trains the candidate for the widely varied challenges of a career in the sciences or a practical profession. Students choose a major in geology, mineralogy and geochemistry, geophysics or engineering geology.

- **Geology:** The Geology Major focuses primarily on the history of our planet, its current state and its potential evolution in the future. Core subjects encompass tectonics, sedimentology, geomorphology, material cycles, as well as the history of Earth including the evolution of life and the climate on Earth.

- **Geophysics:** The Major in Geophysics is directed toward the study of the processes and structures in Earth's interior, integrative observations at the surface, and the modelling of physical processes and material properties in the interior of our planet. Geophysicists seek answers to questions such as: What is the driving force of plate tectonics? What is the origin of the magnetic field? How, where and why do earthquakes occur, and how can the risks be diminished?

- **Mineralogy and Geochemistry:** The Major in Mineralogy and Geochemistry provides students with in-depth knowledge of the structure and properties of earth materials such as rock, minerals and fluids. They learn to determine which properties exert an impact on geological processes such as magneticity, orogeny, the generation of energy and mineral resources.

- **Engineering Geology:** The Major in Engineering Geology addresses the dynamics between people, built structures, and geology. Students gain experience and expertise at representing local geology on-site in the form of comprehensive geotechnical or hydrogeological models, and in conducting specific site investigations.

The **Joint Master in Applied Geophysics** is a study programme offered by the ETH Zurich in collaboration with the TU Delft and the RWTH Aachen, with students attending courses at all three institutions. The programme includes the exploration and extraction of raw materials, geothermal energy, and environmental and engineering geophysics.

The **Master in Atmospheric and Climate Science** is offered in conjunction with the Environmental Sciences Department. The teaching modules are as follows: weather systems and atmospheric dynamics, climate processes and climate dynamics, atmospheric components and cycles, climate history and paleoclimatology, hydrology and water cycles.

Doctoral Programme

The doctoral degree is awarded for largely independent research at the forefront of global findings in the geosciences. The PhD degree is a prerequisite for an academic profession, and the successful candidate often chooses a career in industry, public administration or in planning and consulting. While completing the degree requirements and working on the thesis, the doctoral student is engaged for a three- to four-year maximum period as an assistant in the research group.

Studies in Earth Sciences, particularly at the master and doctoral level, can be pursued in combination with scientific studies at other universities such as the University of Zurich, or member institutions of the European IDEA League: RWTH Aachen, TU Delft, Imperial College London and TU Paris. In addition, an active research and teaching exchange exists between the Department of Earth Sciences and leading research universities in North America such as the Massachusetts Institute of Technology (MIT) in Boston and Asian Ivy League universities like TIT in Tokyo and Singapore.

Professional Outlook

On pages 8 and 9 under "Careers" some of the many attractive career opportunities are listed that are open to graduates of our programs.

ERFA – THE GEOSCIENCES ASSOCIATION

Better known by its German designation, erfa (erdwissenschaftlicher Fachverein), the geosciences association represents the interests of students in the Department of Earth Sciences, and acts as a link between the administration and the students. Erfa functions in friendly collaboration with the professional associations of other departments, the ETH and the Student Union, VSETH. This not only gives erfa a direct connection to all events and occurrences, it also allows the organization to be the voice of the students in matters that concern the future of the ETH and the Department of Earth Sciences.

When students are confronted with problems or uncertainties relating to their studies, the first place to turn is erfa. The organization advocates on behalf of students and offers individual guidance, directing students to the appropriate next step in finding a solution.

Erfa is also instrumental in providing balance to university life, by organizing social events to help students get acquainted with one another and to inject some fresh wind, at least temporarily, into the stresses of academic life. The wide range of opportunities offered include geological excursions lasting several days, social events and parties at the ETH, as well as student functions to help freshmen and visiting students to find their way, have fun, and become integrated in the earth science community. One example of such an event is the "erfa Trophy" which takes place every year at the beginning of the fall semester. The various teams are given tasks to perform in the realm of sports, geography or arts and crafts, with the aim of scoring the most points possible and earning a spot on the podium. In addition, every year erfa invites professionals from the many-faceted field of geosciences to come and report in detail on various aspects of their chosen career. This gives students the opportunity to discern, early on in their studies, the many options open to them in terms of career direction once a degree is awarded.

In addition, erfa serves as an intermediary for work placements and doctoral study positions, and provides information on a variety of part-time jobs and other earning opportunities.

ERDWISSENSCHAFTLICHER FACHVEREIN ETH
erfa
EST. 2001

CAREERS

Sarah Signorelli
Dr. sc. ETH Zurich, Project Leader at Geowatt AG

Christian Frei
Geologist at the geological office Dr Heinrich Jäckli AG, Zurich

Why I studied Earth and Climate Sciences

I always wanted to know how the earth system works. A teacher invited me to the Earth and Climate Sciences study programme at ETH Zurich. I then visted the department on a "Maturandentag", where I was impressed by the wide variety of basic education, covering a diverse range of subjects in earth sciences. During my studies I quickly realised that I wanted to specialise in the area of geothermal energy.

What I do today

I design geothermal facilities for the heating and cooling of buildings, e. g. the Science City campus at ETH. I am the link between underground and building services. I simulate the configuration and the depth of ground source heat pumps and provide the requirements for sustainable management. I organise and check every subsection, from the borehole to the entry into the heating system. I enjoy collaborating with the people who are responsible for the system construction. I also like the fact that at the end of a project we can hand over a finished product to our clients.

What my future plans are

Since I have children now I work part time. Nevertheless, because we work in teams, it is possible for me to oversee large-scale projects. But there is only limited scope for a career in a classic sense, because we are a small company with a flat hierarchy. In fact, I hope that, in the future, I will be able to work out solutions for a sustainable usage of the earth's natural heat resources. In due time, I may attend a further education programme in the field of building services engineering.

Why I studied Earth and Climate Sciences

During Christmas 1999, I witnessed hurricane Lothar swirling spray from lake Zurich into the air. I was fascinated and wanted to learn more about how nature works. I wanted to have a job which would enable me to work both indoors and outdoors and which offers a varied daily working routine. The possibility of such a future job seemed within grasp by studying Earth and Climate Sciences.

What I do today

I am a geologist with a geological offfice in Zurich. My tasks range from the investigation of existing waste deposits to examination of the underground, the creation of special geological maps, and introducing measures for protecting drinking water. For these purposes, I am often in the field visiting construction sites in addition to working in the office. I also take part in meetings with administrative offices and clients, where we often act as mediators. Our everyday work is extremely diverse. Today for example, I mapped a borehole core while it was raining heavily. Afterwards I had a meeting on contaminated loads in the underground. Back in my dry office, I worked on a map which shows the past occurence of dinosaurs.

What my future plans are

My goal in the future is to work on as many diverse projects as possible. The variety is enormous. In particular I want to gain a better insight into geothermal energy and natural hazards. This will enable me to manage larger interdisciplinary projects in the future.

Michael Ruppen
Engineering geologist at OSPAG – Odilo Schmid & Partner AG

Paola Ardia
Dr. sc. ETH Zurich, Project Manager for Mineral Resources, ZAR Development Center for Sustainable Management of Recyclable Waste and Resources, Hinwil

Why I studied engineering geology

Students who study engineering geology gain a broad education as well as specific knowledge in applied geology. I liked the curriculum because it has a close connection to practice. During numerous excursions and field courses we were able to convert theory into practice, so that we were well prepared for our future everyday work.

What I do today

After graduation I went back to the Valais where I've since worked as a engineering geologist for Odilo Schmid & Partner AG. As either executive officer or project leader I provide expert reports on underground, project work on various mandates in road and mitigation construction, prepare hazard maps, work on the segregation and protection of springs and organise field tests. In my job it is essential to have a good working knowledge of GIS and CAD software programmes.

What my future plans are

After having worked one year for Odilo Schmid & Partner AG I had the opportunity to become a shareholder in the company. This was path-breaking for my career as a partner in a team of three geologists. I think it is important to always engage in continuing education – in a professional as well as in a private capacity. We shall see what the future brings.

Why I studied Earth and Climate Sciences

Since I can recall I have been fascinated by natural phenomena and the impact they have on our Earth. Just by chance I once took a class on volcanology which explained how volcanic explosions happen. I remember – as if it were yesterday – a picture in a book that illustrated the physical and rheological properties of the basic materials that combine to trigger a spectacular volcanic eruption. By studying Earth and Climate Sciences I found out the answers to many of my questions, and what is more, I discovered a world of breathtaking beauty – the world we live in.

What I like most about my job

My current position provides me with very interesting tasks, and it enables, well, forces me to approach the individual problems from various perspectives. The earth sciences too, force one to take a broad, multidisciplinary view of a situation, to be attentive and to go through life with eyes wide open. The study programme prepares one to pick up on even the slightest nuance, and it has led me to a career that offers new challenges, every day.

What my future plans are

Each day offers me the opportunity to learn something new, and to work together with people from industry, academia, and public administration. I plan to continue to be professionally active in the field of energy and sustainable resource management.

Sarah Signorelli's work includes construction supervision on the site.

The lead content of a soil sample is determined using a mobile x-ray fluorescence device.

Complex excavation safety – reinforced and prestressed shotcrete wall.

At the cutting table, checking for the density separation of the metallic fraction.

STRUCTURAL GEOLOGY AND TECTONICS

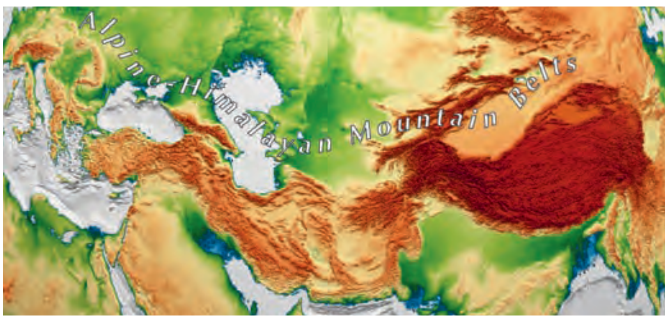
Students examining folded rocks from a shear zone on Syros Island in Greece.

(SGT) group led by Professor Whitney Behr focuses on the rapidly deforming zones that define Earth's tectonic plate boundaries and generate many of the planet's geohazards. The SGT group is interested in the rates and directions in which faults and shear zones move; their geometries, widths and mechanical behaviors at depth; and the processes that shape them over geologic time. This research has broad implications:

- Over human timescales, for example, quantifying fault slip rates in active tectonic environments is critical to assessing seismic risk to human life and property.
- Observations of the deep roots of faults provide clues as to how they are loaded from below and how they might interact with each other during decadal- to thousand-year seismic cycles.
- Over million-year timescales, understanding the mechanical properties and geometries of shear zones helps us to constrain the forces that govern Earth's most prominent topography: e. g. its mountain belts, continental and oceanic rift zones, and oceanic basins and trenches.

To address these topics, SGT group members employ a range of tools and techniques that include field observations, analytical measurements, laboratory experiments, and numerical models. The group members frequently forge collaborations and synthesize datasets that cross disciplines, including structural geology, petrology and geochemistry, experimental rock mechanics, surface processes, seismology, and geodynamics.

Some specific themes of the SGT group's active research include:



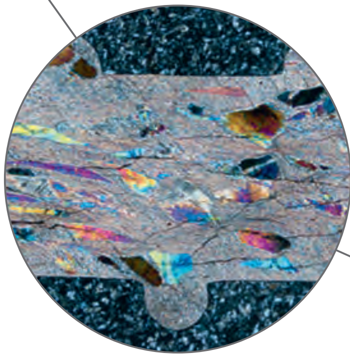
Alpine-Himalayan mountain belt colored by topographic relief.

Active tectonics and the earthquake cycle

A question that is fundamental to understanding earthquake hazard is determining whether faults move steadily or in "fits and spurts" over time. The answer to this question is important because it tells us whether earthquake activity on individual faults is sensitive to local perturbations such as activity on nearby faults, climatically-induced changes in fault loading, or interactions with crustal or mantle deformation at the base of faults. To answer this question, we measure both the offset and the age of offset geomorphic features that are preserved along crustal fault zones.

Localization of Strain in the Ductile Lithosphere

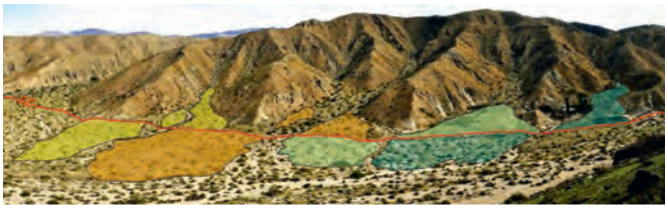
Another critical aspect of understanding faults, is determining what they become at depth below the upper crustal seismogenic layer. For example, whether they retain their identities as localised zones all the way through the lithosphere, or whether instead they sole into distributed ductile deformation at some depth within the lithosphere. One of the ways that we can look at this problem is by studying crust and mantle rocks that are brought to the surface by volcanic or tectonic processes. We can also examine this problem through rock deformation experiments by reproducing the high pressure, high temperature, and high strain conditions of Earth's lithosphere in the lab.



Example of rock deformation experiment conducted on the mantle mineral olivine.

The Role of Heterogeneities in Fault Zones

A burst of new instrumentation and monitoring of active fault zones demonstrates that fault seismic behavior is quite varied – faults can slip in fast earthquakes, slow earthquakes, in tiny bursts called "tectonic tremor", or a-seismically. Explanations for this spectrum of fault slip behaviour require significant heterogeneity in rock types along fault zones. The SGT group uses a variety of field, microstructural and experimental observations to track the types of heterogeneities that characterise faults where these types of unique seismic behaviours are recorded.



Offset geomorphic features along the San Andreas Fault in Southern California.

Underground Rock Laboratories

The SGT Group also participates in projects related to renewable energy promoted at the Swiss Underground Rock Laboratories (e.g., Bedretto Lab). The research focuses on fluid-rock coupled processes at various scales connected to the deep geo-energy reservoir engineering. By experimental research and field study, the SGT group characterizes the potential target volume for geothermal energy production. The structural geology and tectonics group is also active in the field of climate change and reduction of CO_2 emissions, through investigations on caprock and reservoir formations, beneficiary for safe Carbon Storage.

Whitney Behr

CLIMATE GEOLOGY

Climate Geologists study how the earth's climate system has responded in the past to different levels of atmospheric CO_2, solar energy, and frequency of volcanic events. We obtain climate information from stalagmites and microfossils from ocean and lake sediments. These records elucidate how the earth's climate system works, and better predict the climate response to anthropogenic changes.

How easy is it to melt the Greenland and Northern Hemisphere ice sheets?

The Greenland ice sheet melted back to less than half its current size, around 125 000 years ago. Consequently, sea levels were at least 5 meters higher than now. We are investigating how changes in solar energy, greenhouse gases, and ocean currents contributed to melt the Greenland and northern hemisphere ice sheets.

We study indicators of climate in stalagmites that grew in caves of northwest Spain throughout the last several hundreds of thousands of years. Each year, rainwater infiltrating into the cave lays down a thin layer of mineral on the stalagmite. We carefully sample these layers and analyze their elemental and isotopic composition. From this we can learn about the size of large ice sheets, the temperature, and amount of rainfall during the time each layer was deposited. Stalagmites are unique among climate archives for this time period because they can be independently dated radiometrically. By knowing the exact age, we can precisely compare the climate with calculations of how the solar energy changed in different seasons due to slow cyclical changes in the earth's orbit around the sun.

We can also investigate how the melting of the ice sheets affects the ocean currents in the North Atlantic, which in turn influence climate. Since the Greenland ice sheet may be vulnerable to anthropogenic warming, these results help predict future climate.

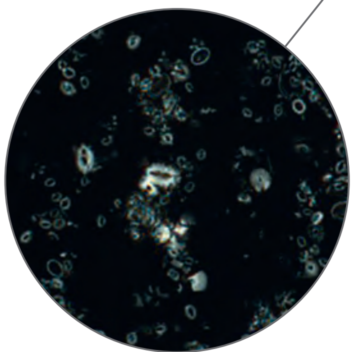
How sensitive is earth's climate to atmospheric CO_2?

Tree pollen around Antarctica and records of 26 degree oceans off New Zealand, suggest that earth was much warmer than present 50 million years ago. Then about 33 million years ago, the Antarctic Ice sheet, with ten times more ice than Greenland, grew and expanded out to the coast of Antarctica. Changing levels of atmospheric CO_2 are often invoked to explain these changes. But how high was CO_2 when Antarctica was ice free and covered with coastal forests? What was the critical CO_2 level when the Antarctic ice sheet formed?

And at what CO_2 level has significant meltback occurred? More generally, how sensitive is the earth's climate to atmospheric CO_2 levels?

To answer these questions, we are working to develop better ways to estimate atmospheric CO_2 levels in the distant past.

Marine algae need CO_2 for photosynthesis, and the isotopic composition of organic and mineral fossils they produce can reveal the level of CO_2 limitation they experienced. We use the fossils of microscopic algae that accumulate in sediments at the bottom of the ocean. Cores of sediments taken from hundreds of meters below the sea floor allow us to sample and analyze these fossils. Our work so far has revealed a previously undetected CO_2 decline accounting for a strong cooling between 10 and 6 million years ago.



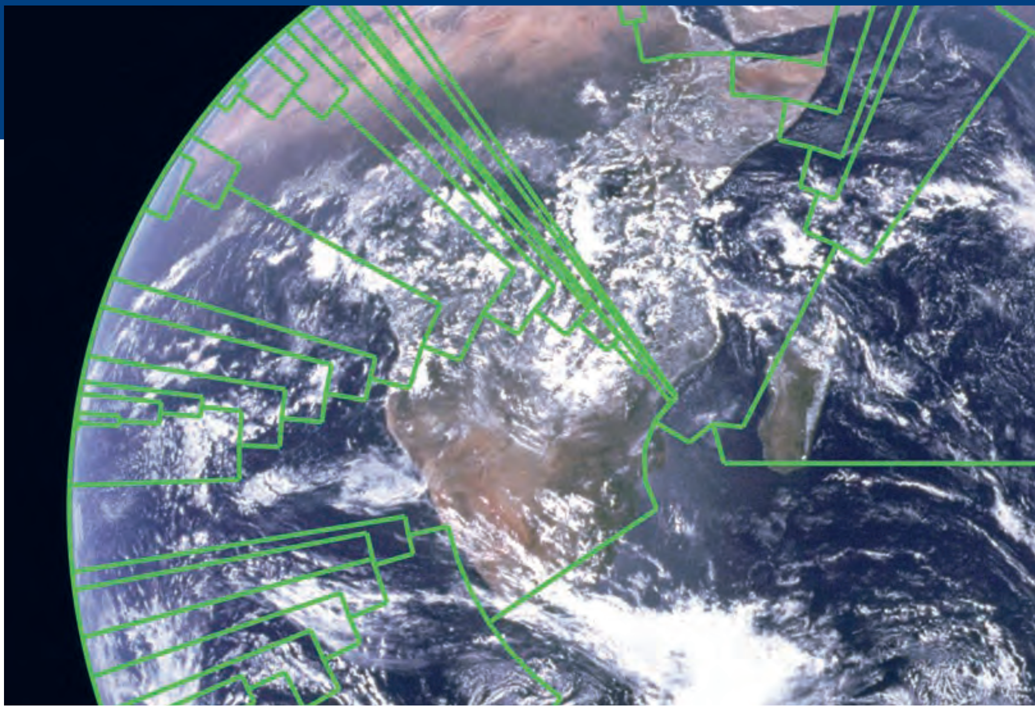
Heather Stoll

The size and shape of the fossils themselves also reveal adaptations to CO_2. We use high resolution microscopy with digital cameras to see measure changes in the size and the thickness of the calcite mineral shells that covered the algae. With new methods we try to reconstruct the global ocean temperatures during periods of high CO_2 concentration. To better understand how marine algae record CO_2 conditions and adapt to changing levels of CO_2, we grow marine algae in an experimental growth chamber under different levels of CO_2, light, and nutrients.

How hot was it on the mainland of America 50 million years ago?

The estimation of past temperatures is one of the fundamental goals of paleoclimate research. We are working to improve the measurement precision and calibration of a widely applicable "paleothermometer".

GEOBIOLOGY



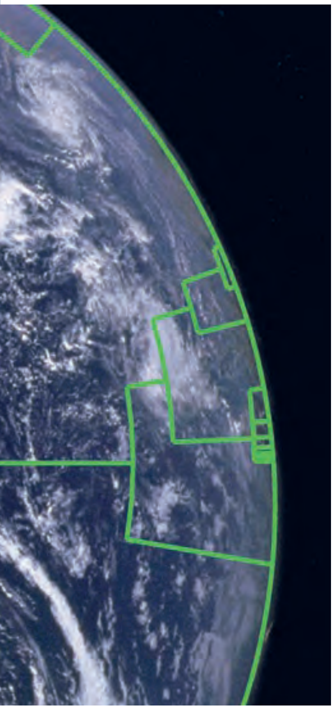
The history of Earth is intricately tied to the origin and evolution of life. Our planet is imprinted with signatures of life and the biologic diversity we see today is the product of over 3.5 billion years of co-evolution with our planet. The Geobiology Group led by Prof. Cara Magnabosco studies the interactions between life and the environment to better understand the history of Earth's surface, atmosphere and biosphere and how these interactions may change in the future.

Life on a changing planet

Our planet has experienced a wide range of redox and climatic changes and the biological diversity we directly observe on Earth is either living or preserved within the geologic record as fossils. However, we now understand that not all life can be accurately traced through the fossil record and that the diversity on our planet is far greater than previously understood. These preservation and observation anomalies are especially apparent within Bacteria and Archaea, organisms that represent the oldest known cellular life forms and drive the biogeochemical cycles that connect the living and non-living components of Earth. The genomes of contemporary microorganisms are the product of over 3.5 billion years of co-evolution with our planet and, thus, encode information about our changing planet. Using methods inspired by systems biology, phylogenetics, and data science, the Geobiology Group accesses and studies this "genetic record" to infer past environmental conditions and predict how microbial populations will respond to changing environments.

At the same time, advances in genomics are revealing that the diversity of life on our planet is far greater than previously understood. Recent sequencing efforts have estimated that <1% of bacterial and archaeal species have been cultivated and that the phylogenetic and metabolic diversity of these organisms has been grossly underestimated. Prof. Magnabosco and her team study the contribution of this "uncultivated majority" to global biogeochemical cycles around the world.

Previously barren landscapes are "greening" as a result of longer snow-free periods and increases in plant growth. The Geobiology Group is studying why alien species like Achillea millefolium are succeeding in some parts of the Arctic and not others



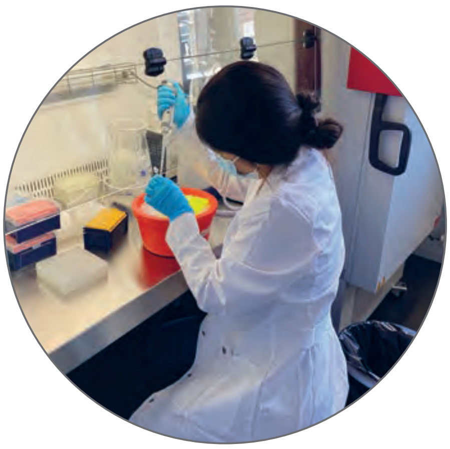
Sampling a deep borehole in the Bedretto Underground Laboratory for Geosciences and Geoenergies

Are other planets habitable?

A habitable planet is capable of sustaining life for extended periods of time and, while the Earth is habitable, not all of Earth's environments are inhabited. This simple observation provides important insights regarding the environmental conditions in which life can exist and the types of biosignatures that can be detected. The Geobiology Group studies environments that encapsulate a transition between "living" and 'non-living" and the biogeochemical impact of life at these physical-chemical limits. A long-standing interest within our group is the study of life at the thermodynamic limit — the point at which there is barely enough energy to survive. Earth's subsurface is an important example of these "extreme environments" as subsurface environments on other planets within the solar system are more likely to be habitable than their corresponding surface environments. The Geobiology Group accesses subsurface environments through deep boreholes, mines and underground laboratories to collect physical, chemical and biological data to study how life survives and manipulates its surrounding environment. By understanding the diversity and limits of life on Earth, we hope to gain new insights about which biosignatures to look for and the instrumental sensitivity needed to detect life on other planetary bodies.

Cara Magnabosco

How long can life survive after isolation from the surface?

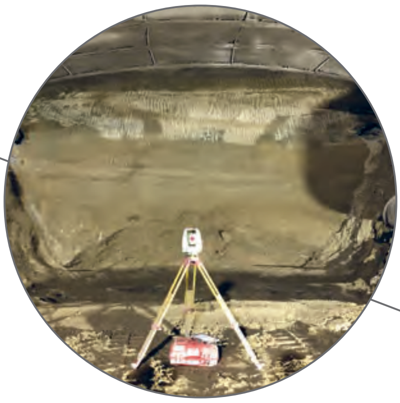


Preparing a sample for DNA sequencing

ENGINEERING GEOLOGY

Debris flow deposits in the Alps

Engineering geology is the application of earth science knowledge to the design and management of engineering systems. This can include, for example, understanding and managing the risk posed by natural hazards, as well as geological aspects associated with the construction of underground excavations. Increased development pressures in marginal areas, increased demand for natural resources, and climate change require innovative advances to safely and sustainably manage these systems. This has been recently manifested by increasing consequences caused by natural disasters, as well as a societal emphasis on finding innovative solutions to challenges posed by a changing climate.



Convergence measurements in an underground excavation.

Forecasting the effect of these uncertain future scenarios on engineering geology systems requires new fundamental insights into their mechanistic behaviour, and transfer of the insights into tools that can be useful to practitioners. The Chair of Engineering Geology combines process understanding with powerful new technological breakthroughs in order to make progress on both of these aspects. We approach this by answering the questions below:

How can we leverage new technological breakthroughs to measure field-scale processes?

Every year thousands of people are killed and billions of dollars of damages are caused by landslides. These events are controlled by the interaction of complex environmental and geological factors, such as rock slope destabilization by glacial retreat. The Chair of Engineering Geology leverages recent advances in environmental sensing and robotics, such as autonomous vehicle technology, to measure landslide processes at the field scale, in order to understand landslide motion and untangle its complex relationship to environmental forcing. We operate a number of field sites in multiple countries, and use the data as a foundation for making new insights into these processes.

How can we study the behaviour of soil and rock at the laboratory scale?

Engineering geology systems are controlled by complex mechanisms. This includes, for example, fracture propagation due to thermo-hydro-mechanical coupled processes. Laboratory

CT scan showing induced fractures (yellow) and pore structure (red) produced during a lab experiment.

analysis provides the opportunity to further our understanding of these mechanisms. We are currently developing new laboratory methods for studying phenomenon such as the failure behaviour of jointed rock, and landslide kinematics. The group uses state-of-the-art laboratory facilities, and performs many experiments related to the behaviour of rock and soil.

How can state-of-the-art computing techniques be used to simulate complex geological processes?

Many phenomenon that are prominent in engineering geology, such as grain scale response to temperature fluctuations and sediment transfer processes in large alpine catchments can only be studied using advanced numerical models. These models provide a method to upscale laboratory findings to the field scale, and to generate probabilistic forecasts of the future behaviour of engineering geology systems. We develop and apply advanced numerical models to study these phenomena. We place a special emphasis on developing models that can account for the complexity observed in our in-situ data and laboratory experiments.

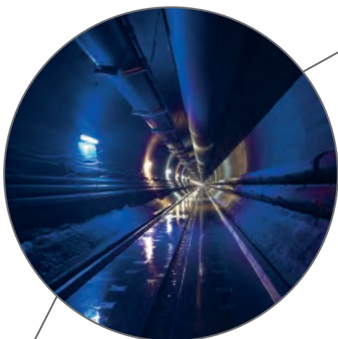
Field monitoring in the Illgraben, Switzerland.

Jordan Aaron

How can our new fundamental insights be translated into tools useful for practitioners?

The Chair of Engineering Geology emphasizes translating the fundamental insights we gain from our field, laboratory and numerical analysis into tools that can be used by practitioners and regulators. This can include, for example, using the numerical models we have developed to forecast landslide motion, or using the new measurement techniques we have pioneered to assess debris flow volumes to design mitigation measures. By emphasizing the transfer of research results into practice, we ensure that our research remains relevant to solving societal challenges.

Debris flow front documented in the Illgraben, Valais.



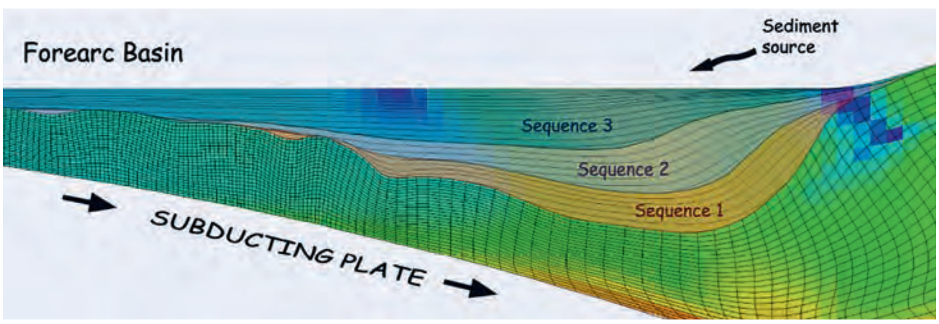
Excursion to a tunnel.

EARTH SURFACE DYNAMICS

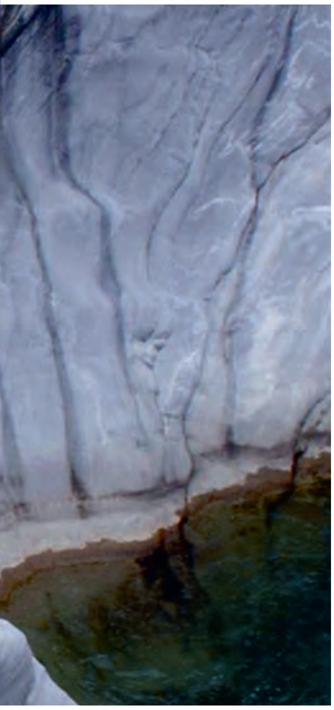
Marble Gorge in Taiwan.

Sean Willett and the Earth Surface Dynamics (ESD) group study the diverse processes that act together to create the morphology and surface geology of Earth. The focus of the group is on tectonic processes that deform the near-surface of Earth and surface erosion processes that sculpt the surface, creating landforms and sediment. Mountain systems are the best example of this linked system, with mountain-building processes occurring where continents collide, raising high mountains that erode strongly under the influence of harsh climate conditions. This produces sediments that are deposited around mountain belts in orogenic basins which preserve the archive of a mountain belt history. The processes of continental collision, tectonic mountain building, erosion, sediment production and transport are all of interest to the Earth Surface Dynamics group.

The ESD group employs a variety of techniques to study this system. These include modelling, fieldwork, and geochemical analyses. Computer modelling of tectonic and geomorphic processes play an important role in this research. By making models of the tectonic processes that create topography and the erosional processes that destroy it, the researchers can learn much about how the landscape evolves. Complex computer codes allow simulation of lithosphere deformation, surface processes and climate influences on the landscape. Fieldwork is also an important component of their research. By studying landforms, we learn more about the river, wind and glacial processes that form them. By studying the sediments around mountain belts, we can learn more about how the mountains formed and eroded as well as something of the formation of the basins in which the sediments are found.



Numerical model of a sedimentary basin.



A number of analytical techniques are important to sediment analysis. In particular, the measurement of cooling ages using a variety of geochemical techniques to determine when and where the sediments originated during erosion. Wilfried Winkler has specialised in this sedimentary research.

Young deposits in the mountains of Taiwan.

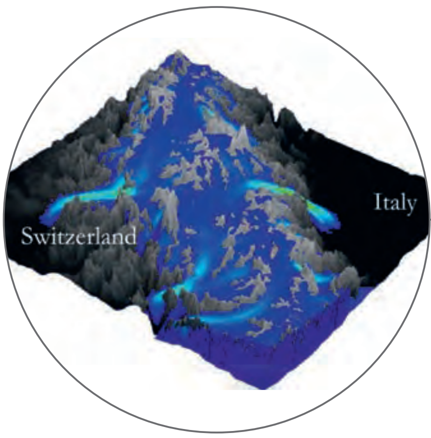
The geochemical analysis of minerals in sediments can help determine the origin of the sediment. The age of the sediment is determined using low temperature methods like fission-track dating. New techniques such as exposure dating with isotopes formed by cosmic ray exposure are also useful for dating geomorphic surfaces and the group works with the ETH physics department to apply these methods in research.

Students doing field work in Italy.

Recent field projects have focused mostly on young mountain belts. Sean Willett and his colleagues have done much work on the island of Taiwan, where some of the earth's most rapid mountain building is occurring. This locality is also interesting because of the massive erosion and sediment transport that occurs in response to the frequent typhoons that hit the region. In addition, the area is seismically very active. Other active or recently active mountain belts that have received attention include New Zealand, the Himalayas, Alaska, Iran, the Pyrenees, the Apennines and of course, the Alps.

Sean Willet

Some of the specific research problems in which the ESD group has been involved more recently include the modelling of ice caps and glaciers in alpine-scale erosion and the reconstruction of the topography of the Alps over the last ten million years.



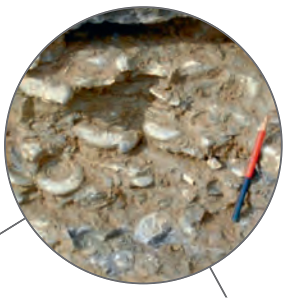
Ice-cap modelling of the Alps.

PALEONTOLOGY

Paleontology deals with the evolution of life on our planet and is at the interface between earth and life sciences. This is the field of Hugo Bucher and Marcelo Sánchez. The biological consequences of past global environmental changes on the surface of the earth are at the core of Hugo Bucher's research group. The study of past extinctions and recoveries is of prime importance for comparison with the ongoing biodiversity crisis of anthropogenic origin. The physical and chemical changes of the ocean and atmosphere, combined with the fluctuations of sea level were crucial parameters in past biodiversity crises. High resolution paleontological and paleoenvironmental data are obtained from the field and analysed in the laboratory. This data mainly covers the biggest mass extinction in the history of the earth at the end of the Permian about 251 million years ago.

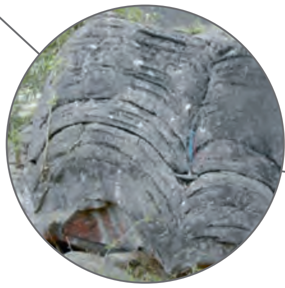
Field research is conducted in many different parts of the world (from NE Greenland to South China). Bucher and his team work together with experts in geochronology and geochemistry; Urs Schaltegger from the University of Geneva, and Stefano Bernasconi from ETH Zurich. Numerical simulations are used to test the impact of abiotic factors on the diversity dynamics of clades in time and space.

The reactions of marine organisms to abiotic stresses such as high pCO_2, pH, T°C are analysed by means of ammonites and other mollusks. Experiments with living gastropods and numerical modelling provide information on morphogenesis, i.e. how a biological shape is being built. Understanding the mechanisms of growth is of paramount importance for phylogenetic analysis. The phylogenetic significance of morphology is addressed by means of living forms, using computer tomography to extract 3D-data sets of the entire succession of developmental stages throughout growth.



Ammonoids from the early Triassic in South China.

Extracting large samples of sediments with fossils from the Pliocene rocks of Venezuela.



"Disaster forms": basalt microbial limestone from the Early Triassic in South China.

Basal Phylloceratites from the early Triassic in Northeastern Greenland.

Evolutionary morphological change is largely driven by changes in development mechanisms, the subject of investigation in Marcelo Sanchez' team. The rich fossil record of mammals, reptiles and amphibians and their living counterparts offers opportunities to study patterns of evolution in the skeleton, a fundamental aspect of the anatomy in land vertebrates, as it is most often preserved in fossils. Bone is a dynamic, living tissue. It supports and protects the soft tissues and stores important minerals.

The structure of the bone depends on the physiology and reveals much about the evolutionary history. In Sanchez' laboratory, the development of bone microstructure and the timing of bone development in various extinct and living groups is studied and compared in an evolutionary context, focusing on the integration of paleontological and embryological knowledge.

The studies use diverse techniques to document and compare anatomical features, including dissections, computer tomography scans, immunochemistry and diverse molecular biology techniques. The laboratory is well equipped for morphometric studies of small objects such as fossil teeth and embryos.

Fieldwork is also an essential aspect of the studies, as it is the only way to discover and describe the biological diversity of extinct specimens. This fieldwork is largely concentrated in the Caribbean region of South America, but diverse.

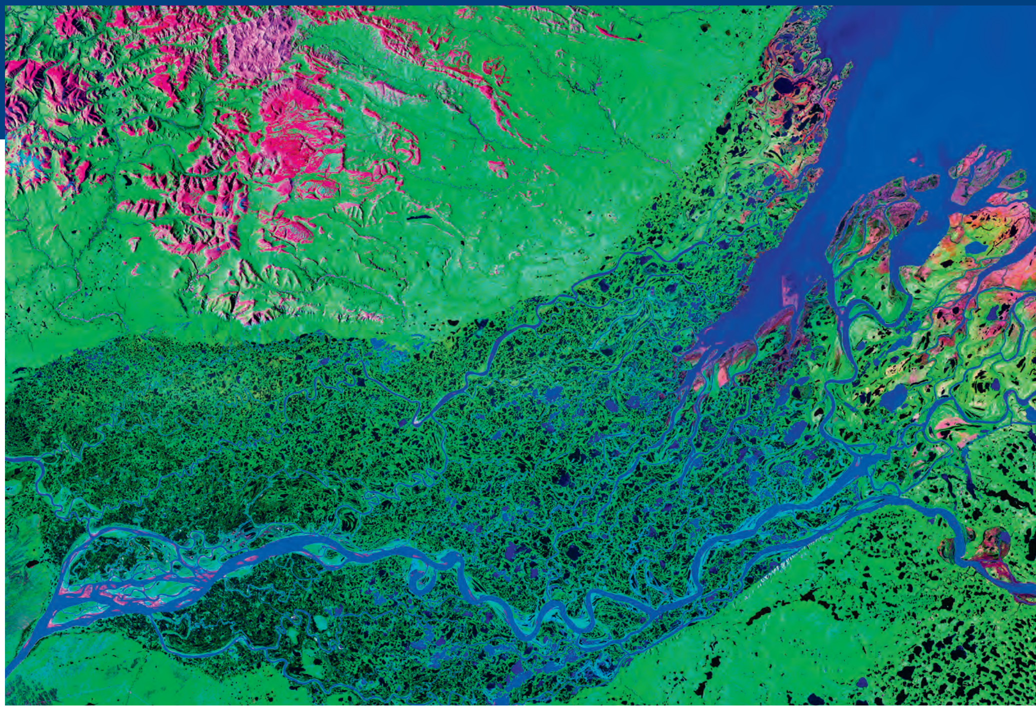
Hugo Bucher

Marcelo Sánchez

Base camp in Northeastern Greenland.

Sample transport in Northeastern Greenland.

BIOGEOSCIENCE



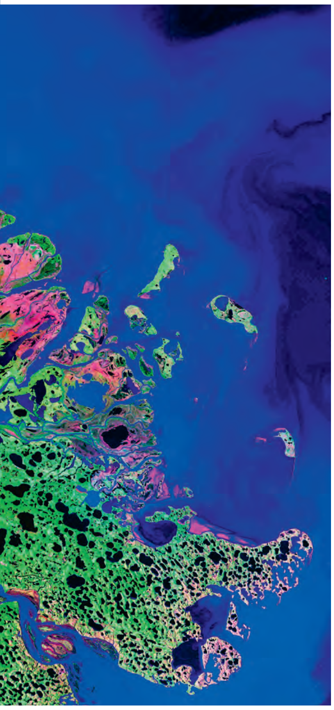
A false-colour satellite image of the Mackenzie Delta, Northwest Territories, Canada.

The focus of the research programme of Tim Eglinton and the Biogeoscience group is to investigate the workings of the global organic carbon cycle, and to understand how climate and anthropogenic activity influences, and is influenced by, this cycle. A particular emphasis is on the processes that give rise to the accumulation of organic matter in ocean sediments, and on deciphering the record of past Earth and ecosystem changes embedded in these sedimentary archives.

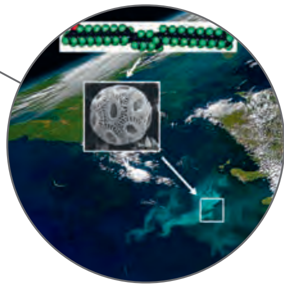
Life on Earth builds diverse biomolecules, many of which have complex, exquisitely ornate chemical structures. The latter are designed to perform a wide range of biological functions: from encoding and propagating genetic information, to orchestrating specific cellular processes, through to maintaining the structural integrity of the organism. Of the plethora of biomolecules synthesised, most are rapidly recycled to carbon dioxide on the death of the organism. However, those that persist in the environment can be used to explore the carbon cycle and provide a lasting record of how it has operated in the past. Eglinton and his colleagues exploit these "legacy molecules" to trace organic matter produced by both terrestrial and aquatic organisms from biological source to sedimentary sink. Recent analytical advances in molecular characterisation techniques that probe the distribution and stable isotopic composition of these legacy compounds afford information not only on the biological source but also the environmental conditions experienced by the precursor organisms.

Lifting the sediment trap.

Although much has been learned about the types of information embedded in these molecular signatures, this rich archive remains only partially deciphered. Moreover, we have only a limited understanding of the mechanisms and timescales involved in organic matter cycling in the environment. This latter question lies at the core of the Biogeoscience group's research activities. In order to address this question, they use a key attribute of organic matter – its radiocarbon age. Eglinton has pioneered methods for radiocarbon dating at the molecular level and uses this information as a "clock" to explore the timeframe over which specific pools of carbon move within and between different Earth surface reservoirs. This information is used in tandem with other molecular and isotopic attributes to examine carbon cycling in contemporary and late Quaternary terrestrial and oceanic environments,



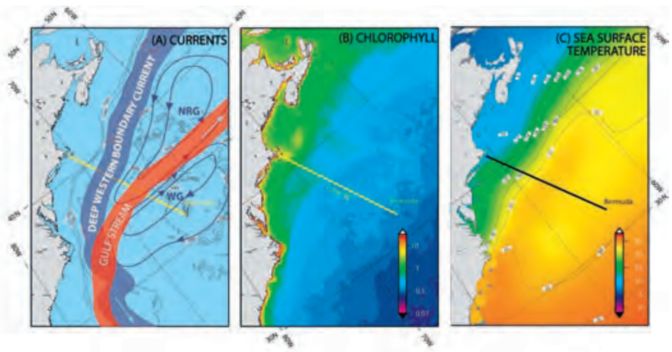
and to infer past changes in organic matter cycling deeper in the geologic record.



Satellite image of a phytoplankton bloom off Newfoundland in the Northwest Atlantic Ocean.

The Biogeoscience group examines processes leading to the mobilisation, transport, and burial of organic matter over a wide range of spatial and temporal scales. Specific areas of current emphasis are carbon cycling in large river systems, at the land-ocean interface, and the dispersal and burial of organic matter on continental margins. Particular effort is focused on carbon cycling in the Arctic where both terrestrial and marine systems are poised to experience dramatic changes in the face of a warming climate. For example, as part of a multi-institutional research programme on fluvial systems, carbon transport and discharge by the Mackenzie River is being investigated. The response of the Arctic Ocean's biological pump – the vertical export of carbon produced by marine primary production from surface waters – to changing sea ice and nutrient conditions is also being investigated. These observations are placed in the context of organic matter transport through the water column and to the sea floor in different regions of the world's oceans.

Taking samples from a lake in the Mackenzie Delta.



Fluctuations in chlorophyll, surface temperature, and the deep currents in the northwest Atlantic.

Top of a sediment core from the Black Sea.

Research programmes within the Biogeoscience group involve in-depth investigations of specific environmental systems, coupled with extensive surveys spanning large environmental gradients, and sustained observations of critically important processes. They also involve close collaboration with other groups in the Department of Earth Sciences, as well as with the other ETH departments and with institutions that add complementary expertise and perspectives. By developing and applying techniques that enable large-scale molecular and isotopic surveys and yield new compositional information, Eglinton and his colleagues seek to develop a more quantitative and mechanistic understanding of the dynamics of the carbon cycle, its relationship to physical, biological and environmental controls, as well as how it functioned in the geologic past.

Timothy Eglinton

SURFACE EARTH EVOLUTION

Sampling in the Southern Alps, New Zealand, to constrain how landslides impact rock weathering rates.

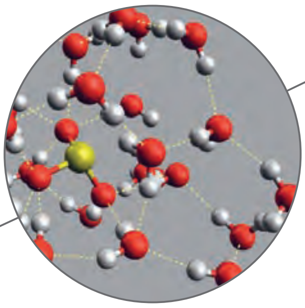
The Surface Earth Evolution group studies how geologic, climatic, and biologic factors regulate the chemical composition of the oceans and atmosphere throughout Earth's history. We are a multi-disciplinary group dedicated to understanding how Earth's biogeochemical cycles evolve through time. Our work incorporates three central pillars that span several spatial and temporal scales:

Laboratory experiments and novel stable-isotope development

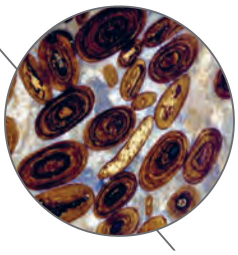
Much of what we know about past environments comes from proxy records, but our collective understanding of what controls these proxies is often incomplete. "Laboratory calibrations" are therefore crucial to confidently reconstruct the geologic past. Our group uses a combination of quantum chemical calculations, high-precision mass spectrometry, and laboratory incubation experiments to constrain how isotope signals – primarily those of carbon, oxygen, and sulfur – reflect various geologic and biologic processes. We are particularly interested in the interactions between mineral surfaces and their surrounding environment. For example, this includes understanding how short-lived reactive oxygen species drive redox reactions on pyrite grains, a process with implications ranging from the origin of life to modern oxygen and carbon dioxide budgets.

Field work in modern analog systems

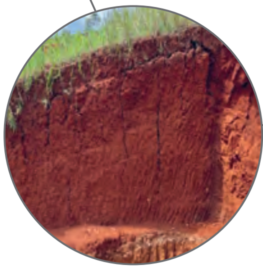
We measure modern systems to gain "real-world" mechanistic insight into the biogeochemical factors that govern various isotope proxies and to understand how changes in these governing factors are recorded in geologic archives. This work is often focused on redox and weathering gradients in



Computational chemistry output used to theoretically predict oxygen-isotope fractionation factors.



Hematite ooids provide a rich archive for reconstructing the chemical composition of near-shore seawater in the geologic past.



Deeply weathered soils from the Congo Basin. The oxygen isotope composition of soil clays and iron oxides records past weathering conditions.

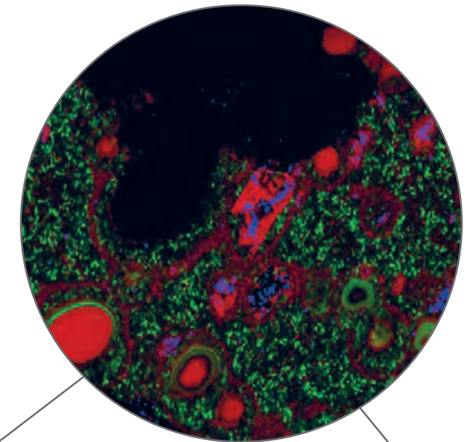
terrestrial landscapes – for example, groundwater and deep soil formation in the Congo River basin – and includes exotic systems such as acid-mine drainage that may be analogs for weathering environments deep in Earth's past. By strategically utilising natural gradients, we aim to isolate and constrain how geochemical processes such as rock weathering respond to forcings such as temperature, hydrology, and erosion rate.

Earth-history reconstructions

Using the insights gained from the laboratory and modern field settings, we apply these novel isotope proxies to geologic archives to reconstruct how and why climate, weathering, and the chemical compositions of the oceans and atmosphere have evolved throughout Earth's history. This often involves working in close collaboration with field geologists. Previous reconstructions include quantifying the severity of Neoproterozoic "snowball" Earth events using oxygen-isotope signals recorded in Mackenzie Mountain ironstone formations and discerning the ecological drivers of Mesozoic ocean anoxic events using molecular and carbon-isotope signals in marine sediments. Ongoing work is focused on understanding weathering responses in hyperthermal climates such as the Paleocene Eocene Thermal Maximum and on reconstructing marine dissolved organic carbon concentrations since the Neoproterozoic.

Jordon Hemingway

Weathering and biogeochemical cycles in the high Alps can be traced using the chemical composition Alpine lakes such as the Jöriseen shown here.



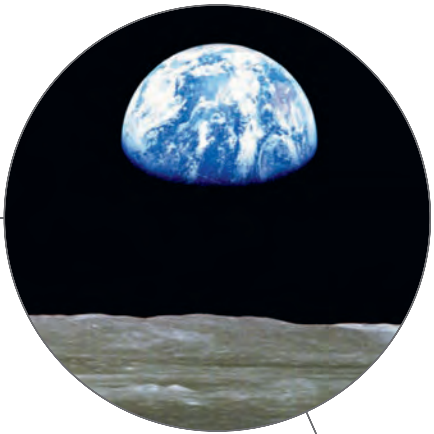
An elemental map showing iron-rich ooids (red) used to reconstruct the ocean's oxygen-isotope composition in the geologic past.

PLANETARY GEOCHEMISTRY

Haleakala volcano on the island of Maui, Hawaii. Samples from such volcanoes provide valuable information about Earth's interior.

Maria Schönbächler's group studies the origin and evolution of our solar system and our planet Earth. Their research focuses on processes, which occurred before, during and after the formation of the Earth. It includes the Earth's earliest evolutional stages, such as the formation of the core, the creation of the Moon and the development of the first continents.

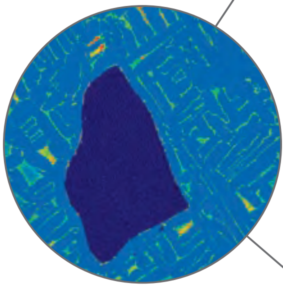
These topics are mainly pursued using isotope geochemistry, which allows the researchers to investigate a large number of geological processes by comparing the abundance of isotopes in various samples. Isotopes are atoms of an element with varying numbers of neutrons in the atomic nucleus and this leads to different masses. The isotope abundances can be determined with mass spectrometers. Some isotopes are radioactive and decay over time into isotopes of a different element. This radioactive decay can be used as a clock to determine the age of a rock or to date geological processes such as the formation of the earth's core. In addition to radioactive decay, various other chemical and physical processes also induce subtle changes in the abundance of stable isotopes of an element, and these aid to deepen our understanding of the origin and evolution of the Earth.



The Earth rising over the Moon. This photo was taken during an Apollo mission to the Moon. Samples returned from the Moon provide important clues on how the Moon formed and on the early history of the Earth. (Photo: NASA)

Prerequisites for successful research in isotope geochemistry are highly sensitive state-of-the-art mass spectrometers and ultra-modern clean-room laboratories. The isotope geochemistry laboratory at ETH Zurich is one of the bestequipped labs of its type worldwide and is used for the analysis of stable and radioactive isotopes and noble gases. It is operated in cooperation with the Earth Surface Geochemistry group. Novel methods of isotope analysis and new types of equipment are also developed here.

By analyzing the composition of meteorites, as well as terrestrial and lunar samples, Maria Schönbächler's group researches the formation of the earth and the solar system from the so-called solar nebula. This is a disk consisting of dust and gas, which rotated around the newly formed sun and from which the planets and asteroids were built.



Inclusions of sulfides in the Cape York iron meteorite. The dark color indicates the low nickel concentration in the sulfide (approx. 3 cm long) compared to the surrounding metal, light blue / green in color.

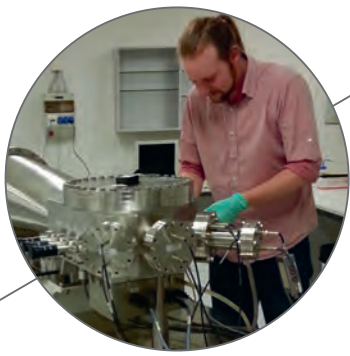
The Ste. Marguerite meteorite is an ordinary chondrite. On the left, dark fusion crust is visible, which formed through heating in the atmosphere during its descent.

Primary research focus of the group:

- To determine the origin of the initial material, which makes up the planets including the Earth. The group applies high-precision isotope measurements of elements such as zirconium and titanium and demonstrated that meteorites, which originate from asteroids, are not direct remnants of the Earth's building blocks.
- To refine the chronology of events in the first million years of our solar system using radioactive isotopes.
- To better understand the physical and chemical conditions under which the earth and other celestial bodies were formed. This includes, for example, how the earth's core and the metallic cores of aste roids formed and evolved. By analyzing iron meteorites, which sample metallic cores of asteroids, the research group was able to show that these cores had solidified within the first few million years of our solar system.
- To determine the origin of volatile elements in the earth and their history in the early solar system based on noble gases and short-lived radioactive isotopes. This research revealed that the Earth was very dry in the beginning, and that volatile elements arrived on Earth slightly later, while the formation of the Earth's core was still underway.
- To track the formation of the Earth's Moon and the first continents early in the Earth's history.
- To develop the cutting-edge methods in isotope geochemistry needed to resolve important questions in the earth sciences.

Maria Schönbächler

In the clean laboratory.



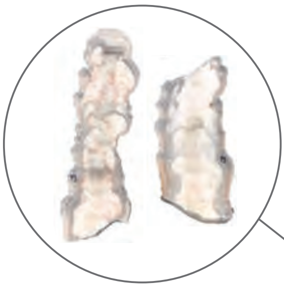
Working at the mass spectrometer.

EARTH SURFACE GEOCHEMISTRY

The Ganges-Brahmaputra delta from satellites. (NASA)

The Earth Surface Geochemistry group exploits the record of the chemistry of the past earth held in sediments and rocks to decipher the evolution of conditions at the surface of the planet. We also investigate the key components of chemical cycles on the modern earth by studying the chemistry of soils, rivers, lakes and the oceans. The big research questions we are interested in include:

- Large-scale geochemical cycles at the surface of the earth, including that of carbon and oxygen
- The controls on major changes in the chemistry of the oceans through time, including levels of dissolved oxygen
- The interactions between these major geochemical cycles and Earth's climate
- The feedbacks between the surface environment of the earth and its biosphere



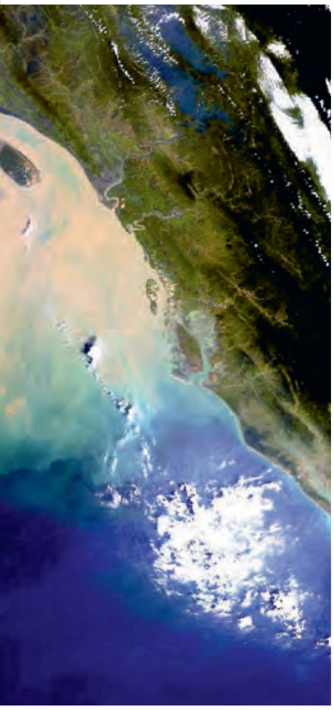
A stalagmite from Yemen, formed in a cave approx. 1300 to 10 400 years ago.

Geochemistry begins in the field, and over the past decade the group has collected soil, river and seawater samples from all over the world. This fieldwork has included: soil sampling in Switzerland, USA and the UK; work on large river systems such as the Amazon in Brazil, the Ganges- Brahmaputra in India and Bangladesh, the Yangtze in China, the Nile in Sudan and Egypt, remote Arctic rivers in northern Sweden; involvement in major international ocean sampling campaigns that have returned samples of seawater from remote parts of the Pacific, Indian and Atlantic Oceans as well as the Southern Ocean around Antarctica. We have also been involved in field campaigns in Italy, Libya, USA, South Africa and Australia to understand and collect sedimentary rocks that provide our record of chemical processes on the past Earth.

One of our main tools in the group is isotope geochemistry, which uses small variations in the abundances of different isotopes of a given element to understand the key physicochemical processes operating in surface Earth environments. For example, tiny variations in the isotopic composition of trace metals in seawater can tell us about how oceanic plankton cycle these metals through their bodies into and out of the dissolved phase in the oceans. We also use these variations as tracers of mass transfer around the modern and past Earth. For example, we have used isotope geochemistry to trace water movement down river systems through the Sahara, river systems that are now long-gone but may once have allowed early modern humans to migrate "Out of Africa".

Taking samples of sedimentary rock at Gubbio, Italy: the dark layer preserves evidence of a time when large parts of the oceans appear to have become "anoxic" – i. e. become devoid of oxygen.

Sediment sampling in Golfo Dulce, Costa Rica, a semi-isolated embayment whose water periodically becomes devoid of oxygen today.



The use of isotope geochemistry to do all this requires sophisticated laboratories and instruments. We are lucky at ETH Zurich to have one of the best facilities for this purpose worldwide, attracting a wide variety of researchers, young and old, from around the world.

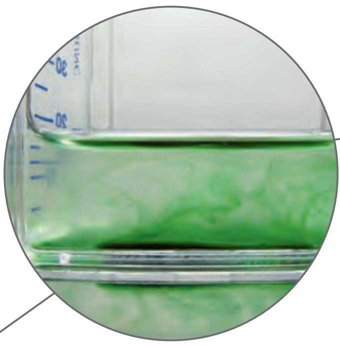
In addition to the chemical and isotopic analysis of soils, water and rocks, we use a variety of experimental approaches to understand the results. For example, we are engaged in the culturing of phytoplankton – in other words, the growth of photosynthesising plankton in controlled conditions in the laboratory in order to study the way they impact the chemistry of their surroundings. We also do experiments that do not involve life, such as the way in which different mineral components of soils, or the particulate phase of rivers, take up metals from the dissolved pool in soil solutions of river water. We use these experiments as micro-scale analogues of nature, in order to better understand chemical and isotopic data from field studies, where the main controlling processes are often less clear.

Derek Vance

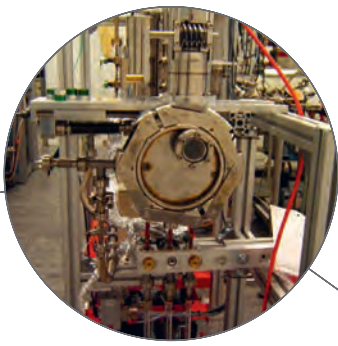
Finally, we use the field data as well as the understanding obtained from experiments in quantitative models of the earth. For example, we can quantitatively assess the degree to which mass transfer from the continents to the oceans via rivers (and ultimately chemical weathering of the continents) determines ocean chemistry, now and in the past. We can quantitatively simulate the degree to which ocean biology, as opposed to abiotic processes, control geographic and temporal variations in the pool of trace metals and other plant nutrients dissolved in seawater.

Taking samples from the Kalix River, within the Arctic Circle in northern Sweden.

Some of the oldest rocks in the world can be found in Barberton, South Africa. They contain information on the oceans, and the life that perhaps once thrived there.



A cyanobacteria culture, bred in a laboratory.



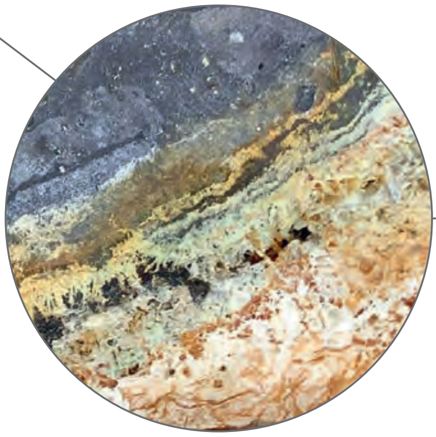
An analysis device which can determine the original temperature in caves: it measures the concentration of noble gas in the water of inclusions found in stalagmites.

MINERAL RESOURCE SYSTEMS AND ORE FLUIDS

Copper-gold mine, Bulgaria.

Where do the metals that we use come from?
What is not grown, is extracted from geological deposits. Buildings, infrastructure, and the majority of objects we use in our daily lives are made of materials extracted from thousands of mines and quarries around the planet. While a simple spoon, for example, is made of iron, chromium and nickel, cell phones and electric cars require up to seventy different elements for their fabrication. Over a lifetime, each European individual will consume about 50 tons of metals and 500 tons of construction and industrial minerals (e. g. sand, limestone, gypsum, kaolin, salt, phosphate, etc.). These figures highlight the geological, environmental, industrial and societal challenges posed in relation to the extraction and supply of mineral resources around the world.

Mineral resources in times of climate change
The urgent move towards a low-carbon energy production and economy will trigger an unprecedented demand for metals and building minerals. The construction of renewable energy production facilities alone (e. g. solar and wind), requires about ten times more raw material than hydrocarbon and nuclear power plants to deliver the same amount of energy. Similarly, the use and storage of this green energy call upon metal-hungry technologies, such as batteries and electric cars. While improvements in recycling efficiency needs to carry part of that burden, the majority of the demand will need to be satisfied through primary extraction from mineral deposits. This challenge will require expertise and creativity from all sides of the society, among which Earth scientists have a large role to play.



Hydrothermally altered rock with copper and gold mineralization (width of the picture is about 15 cm).

Geological field mapping in a mineralized magmatic-hydrothermal system in the USA (left) and Greece (right).

How do mineral deposits form?

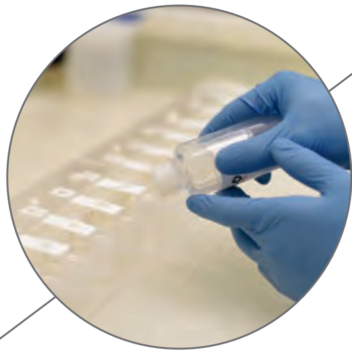
This is the main question with which the group of Mineral Resource Systems led by Prof. Cyril Chelle-Michou is concerned. The study of mineral resources involves a cross-disciplinary approach, where data and concepts, embracing a broad range of fields need to be put together to unravel the processes that have shaped our planet, and generated the natural resources on which our society relies. This systemoriented research is located at the crossroad of many Earth Science disciplines including field geology, economic geology, geochronology, igneous and experimental petrology, geochemistry, tectonics, geothermal research, and numerical modelling.

Most mineral resources that we find close to the surface today formed millions of years ago, deep in the Earth crust, in response to the transport of heat and metals by fluids and magma. The Mineral Resource Systems group studies well-exposed minerals systems in Europe, north America and the Andes of south America. There, scientists and students map the geology and collect rock samples that preserve precious information about the processes that have formed those mineral deposits. This information is subsequently unlocked in the state-of-the-art laboratories located at ETH Zurich and the relevant processes are modelled using computer simulations.

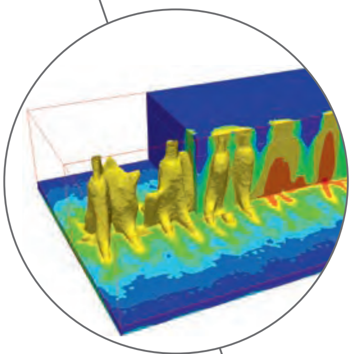
This research is carried out in collaboration with mining companies, utilising deep exploration drill holes and active mines, which provide excellent three-dimensional archives of mineralizing systems. In return, uncovering the processes that control the formation and size of mineral deposits helps the industry in finding new deposits to fuel our metal-demanding society. The knowledge gained, provides the basis for reducing economic risks by localising more deeply located resources – these are more difficult to find, but commonly more environmentally friendly to mine.

Cyril Chelle-Michou

Thomas Driesner



High-precision U–Pb dating is an essential tool to constrain the timing and rate of geological processes involved in the formation of mineral deposits. U and Pb are separated for their host mineral (for example a zircon; see electron microscope cathodoluminescence image in the inset) in the clean lab and analysed by mass spectrometry.



Numerical simulation of hot fluid ascending through fractured rock at mid-ocean ridges (1×3×4 km sized model). The hot fluids vent as "black smokers" but can also form large mineral deposits just below the ocean floor. Such simulation considerably helps to understand the complexe thermodynamic and mechanical feedbacks occuring during fluid flow.

VOLCANOLOGY AND MAGMATIC PETROLOGY

Mt Bromo, within the Tengger caldera, erupting in the foreground, with Mt Semeru, the tallest active volcano in Indonesia, in the background

The themes of volcanology and magmatic petrology focus on processes that involve magmas from source to surface. Volcanic systems, planetary differentiation, and the evolution of Earth's crust are the primary objects of study, with the goal of gaining sharper insight into how magmas are generated, and how they move. While volcanic eruptions on our increasingly overpopulated planet can lead to unparalleled devastation, magmas also provide benefits, for example in the form of hydrothermal energy and mineral resources. The Volcanology and Magmatic Petrology group is led by Olivier Bachmann.

Car driving in front of a pyroclastic flow coming down from Mt Pinatubo, in June 1991, during the second largest explosive eruption of the 20th century.

The research scientists investigate magmatic rock from different regions of the world, as well as samples from Mars, using a variety of techniques, which include field geology, textural analysis, and geochemistry (both on bulk-rock and minerals, including trace elements, and isotopes). The group is also active in the area of geochronology and geophysics/ physical modelling of magmatic processes, and tries to merge all these techniques, which traditionally have rarely been combined in the earth sciences. Although this multidisciplinary approach poses many challenges, it also represents a promising way to address such complex questions as the behaviors of volcanoes, construction of the continental crust, and formation of magmatically-derived ore deposits or atmospheres on different planets.

What happens in magmas reservoirs in the Earth's crust?

Olivier Bachmann focuses particularly on the dynamics and differentiation of magma reservoirs in the Earth's crust, combining volcanic and plutonic rock to unravel magmatic processes from deep to shallow. The samples gathered from across the globe contain information from many different tectonic environments and eras. His group makes use of as many tools as possible in order to draw a coherent picture of these processes. Currently the scientists are concentrating

Eruption of Etna, Sicily, Italy, 2006. (Photo: M. Fulle)

on establishing a clearer link between volcanic and plutonic rock, seeking out geochemical and textural similarities from field samples to demonstrate a connection between the two classes of rock. Beyond this, the team has developed physical models of melt material extraction from large magmatic reservoirs in Earth's crust en-route toward the surface. These models are being tested at field locations around the world.

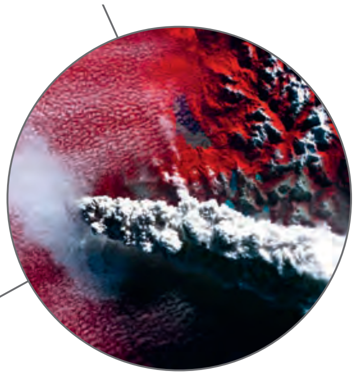
Central cone of the Aso Caldera, one of the most active supervolcanoes in Japan. (Photo: Olivier Bachmann)

Why, when and how do volcanoes erupt?

An additional focus is the investigation of so-called eruptive dynamics, the processes involved in the eruption of volcanoes, in particular the transition from effusive lava flow to the explosive emission of magma. While undoubtedly a stunning sight, lava flows pose only a high risk to the immediate vicinity of the volcanic cone, only. Explosive eruptions, by contrast, affect regions up to thousands of kilometers away and exert a significant impact on climate, with its consequences on the global economy. Hence, better understanding this effusive-explosive transition will allow a better assessment of the hazards posed by active volcanoes and an optimization of the measures taken by society to deal with this threat. In conjunction with earth scientists around the world, Olivier Bachmann and his team are also very involved in related areas such as the geophysical imaging of magmatic plumbing systems for active volcanoes and in gaining a more comprehensive knowledge of volcanic degassing processes during and in between eruptions, with clear impacts of the chemistry of atmospheres on Earth, and beyond (e.g., exoplanets).

Olivier Bachmann

Volcanic cloud diverted by the wind, Puyehue volcano, 2011. (Photo: NASA)



Horses escaping from an ash cloud, Eyjafjallajökull volcano, Iceland, on April 17, 2010. (Photo: National Geographic)

HIGH PRESSURE GEOLOGY

Melt infiltration zone within mantle rock, Kohistan.

High-pressure geology simulates physical and chemical conditions as present in the interior of the Earth, the moon and other planets in order to understand their formation and evolution. Max Schmidt, James Connolly and Peter Ulmer's research group uses experiments as well as field-based studies to investigate deep regions ranging from the formation of the metallic Earth core to volcanism at the Earth's surface. The research team developed state-of-the-art high-pressure equipment capable of applying temperatures up to 2500 °C and pressures corresponding to 1200 km depth to small samples. Most of this equipment was designed by the scientific team and engineered and built by their own workshops.

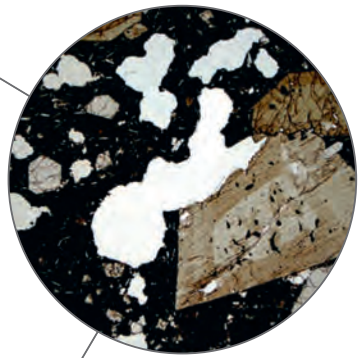
A special high-pressure centrifuge has been constructed at ETH and is employed, for example, to determine the segregation velocity of metal and silicate liquids during the accretion of the earth. The partitioning of elements between liquids and also crystals provides crucial information on depth and temperature conditions during the formation of the earth's metallic core and silicate mantle. Merely 1.5 per cent of Earth's mass is directly accessible through rock samples; the remaining 98.5 per cent are beyond direct observation, but is responsible for the dynamics and surface structure of our planet: the proportion of land to ocean mass is governed by processes operating within Earth´s mantle – leading to the so-called igneous cycles which generally operate at depths between 20 and 200 km and over time periods of hundreds to millions of years.

The world-wide unique centrifuge that exerts 3000-times Earth's gravitational acceleration on molten rock samples at pressures corresponding to a depth of 100 km.

The group's principle research targets are: the earth's crust which resides over the earth's mantle and extends to depths of 15 to 40 km, the chemical evolution of magmas and, the subsequent growth of the crust which evolves over billions of years. Studies of the upper crust (3 to 15 km) encompass the emplacement of magmas, their chemical and thermal interaction with country rocks as well as their evolution over time. This research combines experimental and field-related studies, which take place in the Adamello and Bergell areas (N. Italy), the Sierra Nevada (USA) or Mongolia.

The continents, which we inhabit, form at the distinct locations where tectonic plates collide and one plate slides below the other – the so-called subduction zones. Minerals in subsiding plates transport volatile components, principally water and carbon dioxide, from Earth's surface to depths where the breakdown of these minerals leads to liberation of water and carbon dioxide and to the partial melting of Earth's mantle. This occurs at depths between 40 and 660 km. In turn, these

partially melted magmas ascend toward the surface thereby closing the deep earth material cycle. In order to identify and quantify the building blocks of the water and carbon dioxide cycles within Earth, our research group employs high-pressure experiments and thermodynamic modelling.



Photomicrograph of lava composed of crystals, vapour bubbles (white) and glass (black).

Mathematical computer models of the mechanics of molten rocks provide us with an understanding of the extraction of magmas under the mid-ocean ridge (for instance the magma which flows out of the MOR today was formed during the time of the pharaohs), and allows us to determine the ascention pathway and velocity of fluids and magmas in subduction zones. Another focus of our research is the analysis of mineral stabilities. These stabilities are calculated and predicted by theoretical thermodynamic models that use data from experiments conducted at known pressure and temperature.

The mechanical behaviour and elastic properties of magmas that control the occurrence and mode of volcanism are also investigated experimentally. Natural magmas are complex mixtures of a silicate or carbonate liquid (i. e. molten rock), crystals and vapour bubbles. These mixtures, depending on the ascent and cooling path, flow either quietly out as lava flows from a vent, or explosively, in a violent eruption that destroys the volcanic edifice. In the East African Rift Valley rare carbonatite magmas are directly discharged at the surface. These unusual igneous rocks are studied, after direct sampling of fluid lava, by mineralogical and chemical analysis of associated volcanic ashes; by experimental simulation of shallow magma reservoir processes; and by partial melting of carbonate-bearing sedimentary compositions in the laboratory which simulate depths of 100 – 700 km.

Max Schmidt

Karakorum-Excursion, North Pakistan.

In addition the research group maintains an extensive pool of analytical instruments to characterise the mineralogy and chemical compositions of natural and experi¬mentally produced (rock) samples. This equipment is also utilised to address questions raised in applied industry and solid-state chemistry. Ultimately, glass, cement, ceramics and slag from steel-making or from wasteburning furnaces are synthetic equivalents of natural liquids and highpressure rocks.

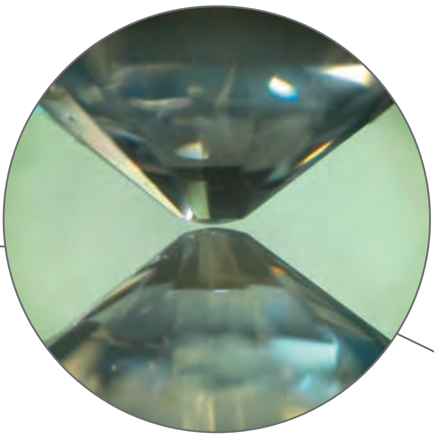
Striking rock layers of the mountain range.

EXPERIMENTAL MINERAL PHYSICS

Earth in full view from Apollo 17. (Photo: NASA)

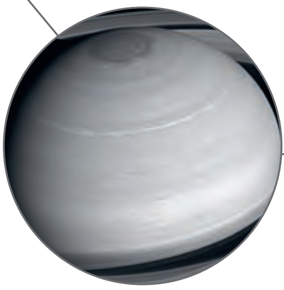
What is inside the Earth?

Although human beings now grasp the inconceivably distant light in the universe about ten billion light-years away by telescope, the world of Earth's deep interior below us which has a depth of only less than ten thousand kilometres is still veiled in a shroud of mystery. The Earth is believed to consist of several layers primarily divided into two components. One with rocky and the other with metallic phases. However, we cannot yet answer the question about what each component is exactly made of. The distance to the center of the Earth is approx. 6400 km from the surface. over this distance both temperature and pressure drastically increase with depth reaching thousands of kelvin (K) in temperature and hundreds of gigapascals (GPa) in pressure.It is not too much to say that extremely high-pressure and high-temperature conditions have prevented us from revealing the true nature of the material at the center of the Earth. As it is impossible to directly sample deep Earth materials by digging the Earth at least below tens of kilometres from the surface, which is far below the depth of the center of the Earth.



Closeup view of the diamond anvil cell apparatus. The culet size at the tip of each diamond where the sample is loaded is 20 µm. (Photo: Motohiko Murakami)

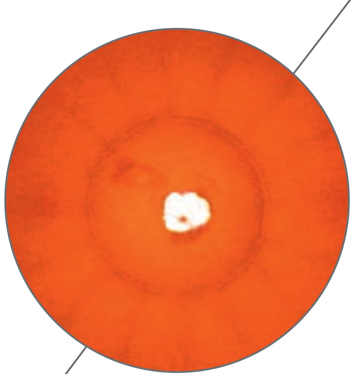
In order to overcome this obstacle, our group applies a high-pressure and high-temperature experimental approach mainly using a laser-heated diamond anvil cell technique, which reproduces the condition of the deep Earth in the laboratory. Diamond is known as one of the most hardest natural materials with high transparency over a wide range of wavelengths. Through this very "hard" and "transparent" window, combined laser heating and various spectroscopic techniques can directly observe the simulated deep Earth under extreme pressure and temperature conditions from which we extract important scientific insights. With this approach, our group is trying to clarify and determine such things as the density, crystal structure, elasticity and chemistry of the deep Earth's materials. These are essential pieces of the jigsaw puzzle we need to eventually reproduce a complete picture of the Earth's interior.



The view of Saturn observed from Cassini-Huygens mission. (Photo: NASA / JPL-Caltech / Space Science Institute)

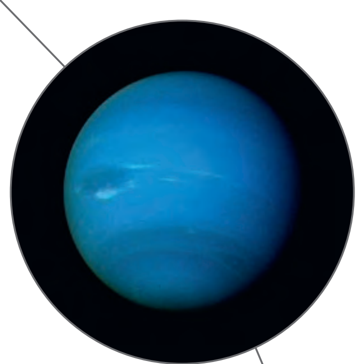
Describing the precise view of the "current" Earth is still not enough to answer fundamental questions about the evolution of the Earth's interior throughout the Earth's history for the last ~4 billion years. It has been thought that the extensive melting of the proto-Earth and the formation of a deep magma ocean facilitated drastic chemical differentiation. We believe that one of the most important keys to resolve this issue is to understand the dynamics and differentiation processes of the deep magma ocean present during the early Earth. To understand this, our group is experimentally simulating the formation process of the Earth from a totally molten state in the laboratory. From the viewpoint of comparative planetology, it is very important to examine whether the Earth is a unique planet in terms of formation processes, structure and composition. Ultrahigh-pressure experimental techniques can be also applied for the exploration of the internal structures of the other planets in the solar system and also the exoplanets, which would offer a broader insight to the planetary sciences.

Pressure plays an important role in changing the physical properties of the materials, and some interesting and unexpected physical properties sometimes emerge under extreme pressures. Synthesis of the new materials with technologically useful features thus would be a fruitful byproduct from our ultrahigh-pressure experimental research. This has great potential in building a bridge between scientific research and real life.

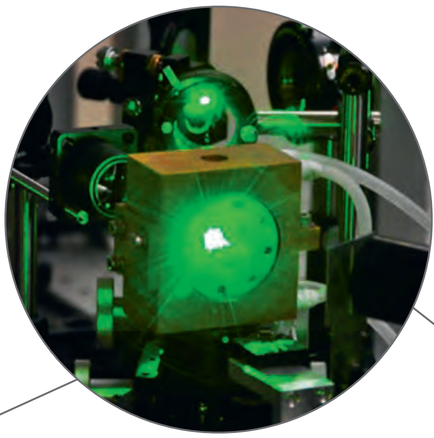


Microscopic view of the sample pressure of 172 GPa inside the diamond anvil cell. Outer ring indicates the culet face of the diamond anvil with 150 µm diameter, and the inner ring shows the pressurized sample ($MgSiO_3$ post-perovskite). (Photo: Motohiko Murakami)

Motohiko Murakami



The view of Jupiter observed from Voyager 1 mission. (Photo: NASA)



Diamond anvil cell during spectroscopic measurement. (Photo: John Hernlund)

EXPERIMENTAL PLANETOLOGY

An artist's impression of the Earth as it was 4.5 billion years ago (left) and its in more clement present-state (right). Credit: Tobias Stierli/PlanetS.

Our group seeks to understand how planets form and evolve, both in our Solar System and beyond.

Although the existence of the four terrestrial planets, Mercury, Venus, Earth and Mars, has been recognised since antiquity, the discovery of the first exoplanet in 1995 led to a revolution of thought in how planets form. Coming to terms with the fact that our solar system is not the only one in the universe means that we find ourselves in a unique position to compare the nature and make-up of the four rocky planets to the ever-growing panorama of exoplanets.

How representative are our planets of those around other stars? Is the nature of our Solar System, and therefore the emergence of life within it, an anomaly? Can we identify the ingredients needed for Earth-like planets capable of supporting life? These are some of the questions that Paolo Sossi and his Experimental Planetology group at ETH Zurich seek to answer.

To do so, the group is at the forefront of developing novel experimental, spectroscopic and numerical techniques. When coupled with ongoing observations of the physical and chemi-

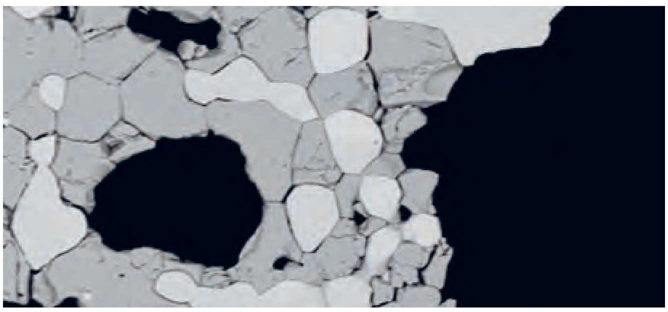
What do planets outside our solar system, or exoplanets, look like? A variety of possibilities are shown in this illustration. Scientists discovered the first exoplanets in the 1990s. As of 2022, the tally stands at just over 5,000 confirmed exoplanets. Credits: NASA/JPL-Caltech

cal properties of rocky planets, both in our own Solar System and beyond, we can hope to provide answers to these questions. Paolo and his team aim to simulate, through experiment, the high temperature conditions that were likely present during the birth of our planet, and of rocky planets more widely.

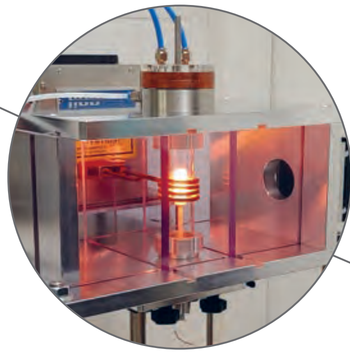
To reach these temperatures, miniature planets and their atmospheres are simulated in the laboratory. The group uses cutting-edge equipment, from mass spectrometers that are able to detect, in-situ, gas species evaporating from molten rock, to visible- and infrared spectroscopy that examines the vibrational properties of solids, liquids and gases relevant to the formation of planets. These data are used to calibrate and ground-truth astrophysical observations of planetary atmospheres and their surfaces coming from next-generation telescopes. This is achieved by extracting fundamental physical and thermodynamic properties from the measurements, and incorporating them into numerical models to provide quantitative descriptions of the composition, structure and dynamics of planetary bodies.

Paolo Sossi

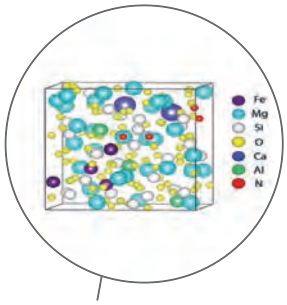
As both experiments and observations become increasingly precise and more numerous, statistical models of planet formation and evolution will be needed to place these data into a more general context which is a key objective of the group. Understanding the life-cycle of a planet in the broadest sense enables predictions to be made on their occurrence, prevalence and, in future, the likelihood of the emergence of life on other worlds.



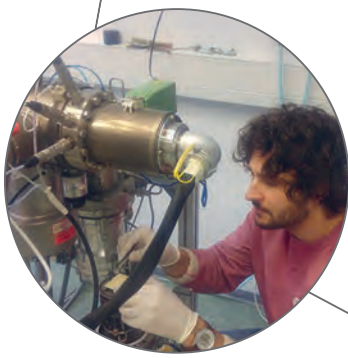
Back-scattered electron image of an experimental sample with Fe and FeS - minerals thought to condense from cooling of the solar nebula. Credit: L. Bischof.



Custom-built furnace for simulating the early stages of planet formation under vacuum conditions.



Snapshot of an ab-initio molecular dynamics simulation of liquid with the composition of Earth's mantle at 4000 K and 62 GPa. Credit: D. Huang.

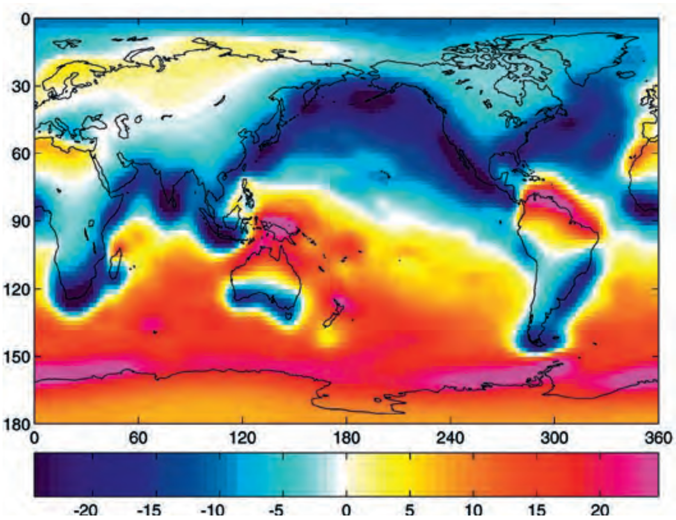


Preparing a sample for mass spectrometric analysis of vapour produced from evaporation of rocky material.

EARTH AND PLANETARY MAGNETISM

The magnetic compass relies on the earth's magnetic field to determine the cardinal points.

The Earth is surrounded by a magnetic field that protects us against extraterrestrial radiation. The field originates in Earth's interior: surrounding an inner core of solid iron lies an outer core of molten iron and light elements such as oxygen, silicon and sulphur. As a result of temperature differences in the outer core the fluid is in constant motion, and convection currents arise. These cause electrical currents, which in turn are the origin of magnetic fields. The generation of the magnetic field from convection currents is known as the "dynamo effect". Andrew Jackson and the EPM group are working on models to clarify these invisible processes and so to understand the mechanisms that lead to the convection currents and the dynamo effect.



The geomagnetic storm of 5 November 2001. The magnetic flux density on the Earth's surface is shown, illustrating the strong influence of the difference in electrical conductivity between the land and the sea.

Based on measurements of the magnetic field on Earth's surface and with the aid of orbiting satellites, the appearance of the magnetic field at the surface of the liquid outer core can be deduced. To simulate the physical conditions that underlie convection currents, complex calculations must be carried out. For this purpose the research group makes use of the Swiss National Supercomputing Centre (CSCS) in Lugano, Ticino. The results will help us to clarify the origin of the earth's magnetic field, which has existed for billions of years. It may also be possible to acquire a better understanding of why the magnetic field reverses polarity from time to time – the most recent occurrence being 780 000 years ago. The simulations could also be useful in astronomy and allow conclusions about the magnetic activity of other planets in the solar system.

The group is a participant of the SWARM mission of the European Space Agency (ESA), within its frame three satellites have been placed simultaneously in orbit from a single rocket launch. The three identical satellites will measure the Earth's magnetic field with a hitherto unachievable precision. They will circle the earth in polar orbits, two next to each other at

Rock drilling in the field.

an altitude of 450 km and the third at an altitude of 530 km. Together they will record the strength, direction and changes with time of the earth's magnetic field. The high-precision measurements will also reveal small electrical currents in the earth's mantle, which surrounds the core, and provide information about the electrical conductivity of the mantle. These electrical currents are induced by rapid changes in the external magnetic field caused by the solar wind. Possible variations in conductivity that may also be detected could answer questions about the temperature and the presence of water in Earth's mantle.

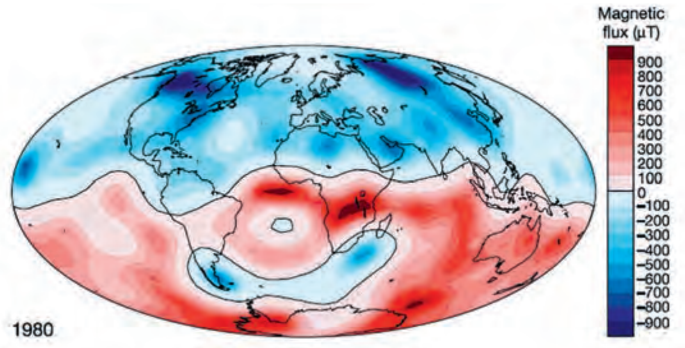


Illustration of the flux of the magnetic field on the surface of the earth's core (at a depth of 2900 km) in 1980.

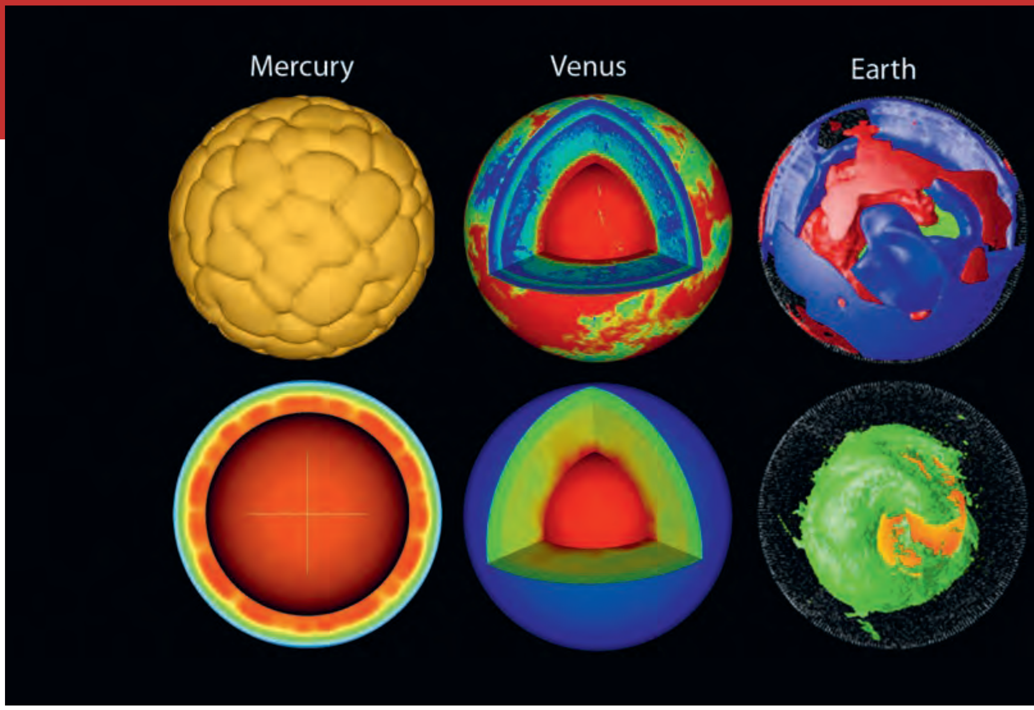
In addition to the magnetic fields of the earth and planets, the EPM group also researches the magnetic properties of natural materials. They measure, for example, the magnetism of minerals and lake sediments that have been recovered from drill cores. The results deliver information about the composition of the environment. In addition, human tissue is the subject of magnetic research in the group: the magnetic composition is being studied for indicators related to certain neurological illnesses such as Alzheimer's disease.

Magnetic-field-free laboratory.

Andrew Jackson

Andrew Jackson's group is also developing new techniques, based on magnetic principles, to study the deformation of rocks. Most experiments are carried out in the Laboratory for Natural Magnetism, a building constructed so as to be almost free of magnetic fields, located on the edge of the city.

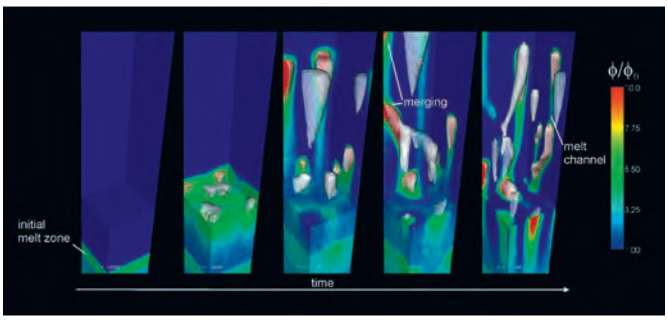
GEOPHYSICAL FLUID DYNAMICS



Numerical simulation of the interiors of Mercury, Venus, Earth and Mars over billions of years.

Long-term geological and planetary processes are in most cases too slow and occur too deep inside a planet for their dynamics to be directly observed. Therefore geophysicists investigate the fluid dynamics of the different kinds of flow and deformation processes in the earth and terrestrial planets using numerical models. This research includes the computation of two and three-dimensional simulations as well as the analysis of the results and their comparison to observational data, from field work or from the laboratory. Not only is earth deformation studied, but also the geochemical and mineralogical evolution of the planet over periods of up to billions of years.

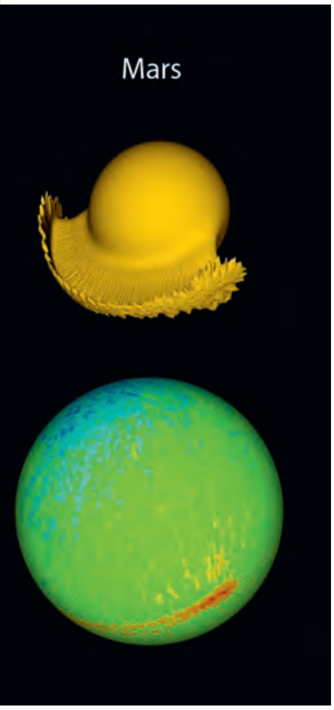
Paul Tackley's group specialises in the development of such numerical models. For this purpose it is a partner owner of ETH's high-performance clusters Euler and Brutus, a powerful computer consisting of thousands of processors. The use of such a cluster is necessary to perform highresolution, three-dimensional numerical simulations.

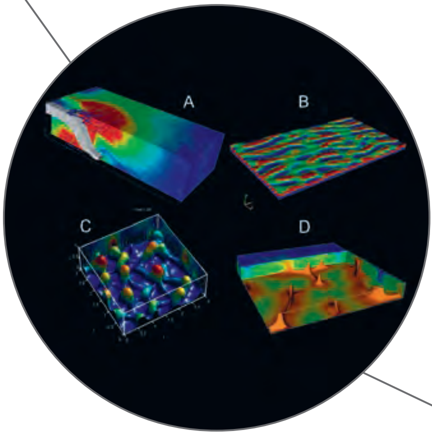


Numerical simulation of magma migration in partially molten rock.

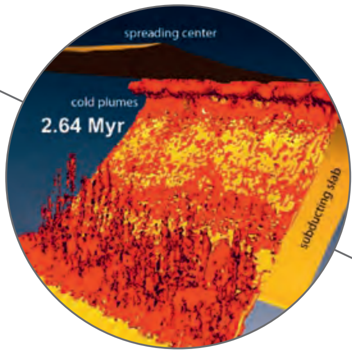
The group works in different teams. One dedicates itself mainly to the dynamics of the earth's crust and uppermost mantle. These researchers examine the processes that occur in this lithospheric region of the earth. They develop realistic two and three-dimensional models of rock deformation and heat transport that include mineralogical phase transitions, in order to model so-called subduction, in which one tectonic plate drops under another, the collision of continents, which builds mountains, and processes at mid-ocean ridge spreading centres.

How did the Alps or the Himalayas develop? How does a volcanic island chain develop? What happens at a mid-ocean ridge? Modellers can answer such questions using realistic simulations, which can be validated by geological, geochemical and geophysical observations.





Computer simulations of various geodynamic processes. A) Subduction, B) Folding, C) Salt tectonics, D) Convection.



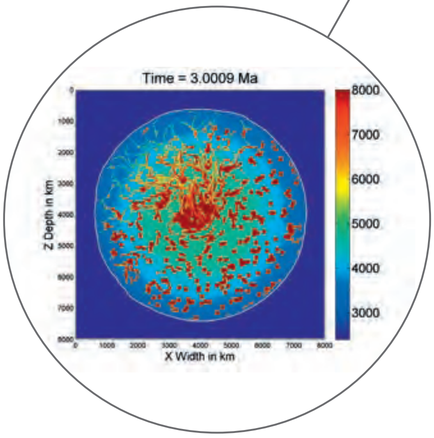
Cold upwelling plumes above a subducting plate.

Another team dedicates itself to the dynamics of the earth's mantle. Motions in the earth's mantle occur through large-scale currents transporting heat, forming so-called convection cells. These researchers perform numerical experiments to explore the influence of different physical complexities on the dynamics of convection. Current research topics include the influence of continents on the flow behaviour of the mantle, the role of mineralogical phase transitions as well as the influence of chemical variations on thermal convection. Various geophysical observations, like seismic data and gravity measurements, are integrated into the geodynamic models.

Paul Tackley

Taras Gerya

The processes that led from a nebula of gas and dust to the planets in our current solar system are not yet completely understood. Most traces of this emergence have been erased, so one must rely on numerical simulations and laboratory experiments. A further team dedicates itself to this research. It is particularly challenging, because of the many overlapping processes involved in the formation of the planets. Fortunately the terrestrial planets Mercury, Venus and Mars as well as asteroids supply valuable data that help to constrain these processes. Using models of planetary interiors, the early evolution of solar system bodies can be reconstructed. Researchers simulate the formation of the iron core as well as the evolution of the magma ocean that once covered the young earth. For these investigations, the group collaborates with researchers in astronomy and geochemistry, whose measurements give valuable information that constraints the geophysical models.



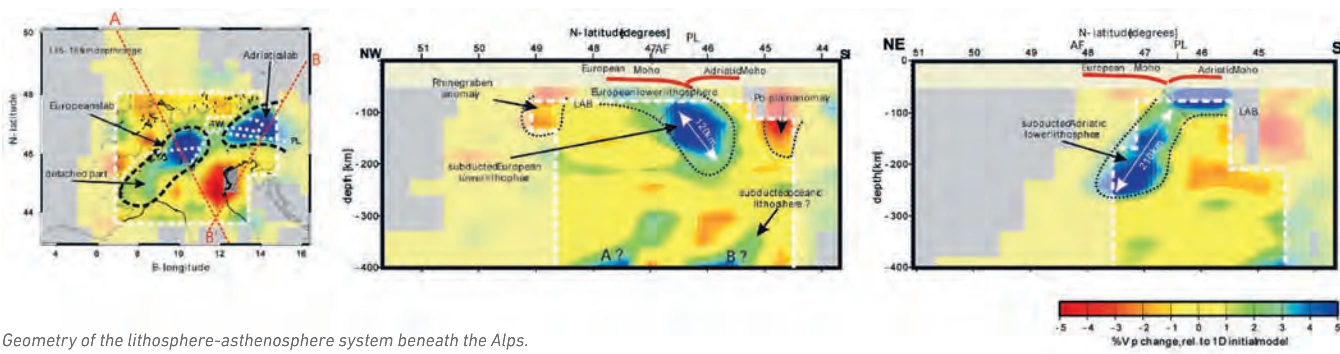
Computer simulation of the formation of Earth's core through the sinking of iron diapirs.

As with Earth, the terrestrial planets Venus, Mars and Mercury also experience thermal circulation, so-called mantle convection, in their interiors. Similar techniques as used for the studying the earth's mantle are applied to understand these other planets. Different convection patterns produce different behaviour in the tectonics, topography and the gravity field of these bodies, which can be compared with direct measurements from past and current space missions, and thus verified.

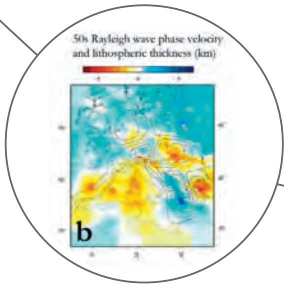
SEISMOLOGY AND GEODYNAMICS

Seismology is the study of the composition, structure, and state of Earth's interior. It encompasses investigating the genesis of earthquakes and the processes of earthquake wave propagation within and along the surface of the earth. The lithosphere, the solid outer shell of Earth, including the crust – the outermost layer on which we live – makes up the approx. 100 km-thick skin of our planet. Beneath this is viscous, semi-fluid material, the mantle. The inside of the earth is actually a rotating hot drop of sticky fluid held together by its own gravitational force and enclosed with in a thin rocky crust. The slowly flowing parts of the deep earth produce a continuous reshaping and movement of this lithospheric skin, causing it to be broken up into different plates. Movement of material within the mantle is the driving force that ultimately causes earthquakes as the plates separate, collide, and slide against each other. This is also the origin of volcanoes and mountain ranges. Geodynamics and plate tectonics seek to describe and understand all these processes.

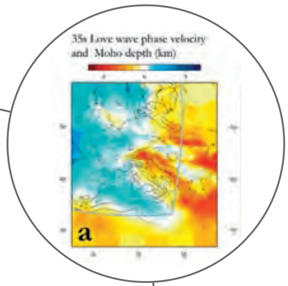
The research group Seismology and Geodynamics (SEG), led by Domenico Giardini and Eduard Kissling, uses seismic waves of all kinds and wavelengths to image, with the help of seismic tomography, the three-dimensional structure of the inner parts of the earth. This relatively young research method has already proved to be by far the most important geophysical method for imaging and understanding the structure of Earth's interior. An important research focus is to improve and extend this method. Recently, the group succeeded in combining refraction and reflection seismic results – recording waves from man-made explosions – with teleseismic data – records of natural earthquake waves – to produce even more precise tomographic images of the deep subsurface. Inputting different wave types together significantly increases the resolution of the tomographic images. In this way, it has become possible to "see" the topography of the boundary between the lithosphere and the underlying viscous asthenosphere beneath the Alps. Another focus of research is the further development of surface wave tomography combined with body wave tomography. Here, research today focuses on the geometry of the secondary (S)



Geometry of the lithosphere-asthenosphere system beneath the Alps.

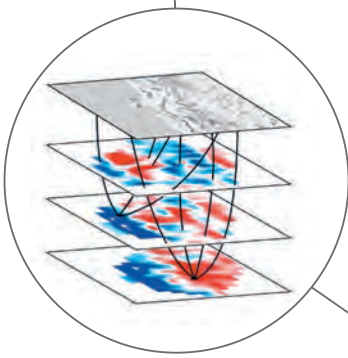


Regional high-resolution surface wave tomography suitable for the detection of the S-wave structure of the lithosphere-asthenosphere system in Europe.



waves that are produced by earthquakes. Since these S-waves depend on the state of fluidity of the medium through which they travel, they are crucial factors in improving our understanding of the flow properties, the rheology of the lithosphere and Earth's mantle.

The SEG group also combines measurements from field experiments with theoretical-methodical research. Another research area is the investigation of orogens, the "crunch zone" where two tectonic plates collide, and subduction zones. The three-dimensional depth structure of the larger alpine area is, due in large part to decades of research conducted by the Institute of Geophysics at ETH Zurich, by far the best known "root zone" of a mountain chain worldwide. Besides investigating the different rheological behaviour of the upper and lower crust and the mantle lithosphere, the SEG group also studies the driving forces that today account for the continued uplift of the Alps. This research is carried out in close collaboration with other groups including Geophysical Fluid Dynamics, Structural Geology, and Tectonics.



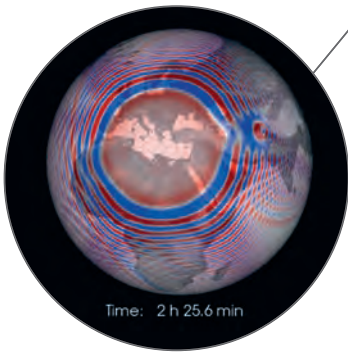
Principle of seismic tomography with local earthquake sources.

Domenico Giardini

The combination of primary (P) and secondary (S) wave tomography is the best method to capture and image the three-dimensional structure of subduction zones. The SEG group combines these methods with fluid dynamic and petrophysical modelling. In this way, one can investigate the formation and migration of magma and fluids that are of great importance in the evolution of continental crust.

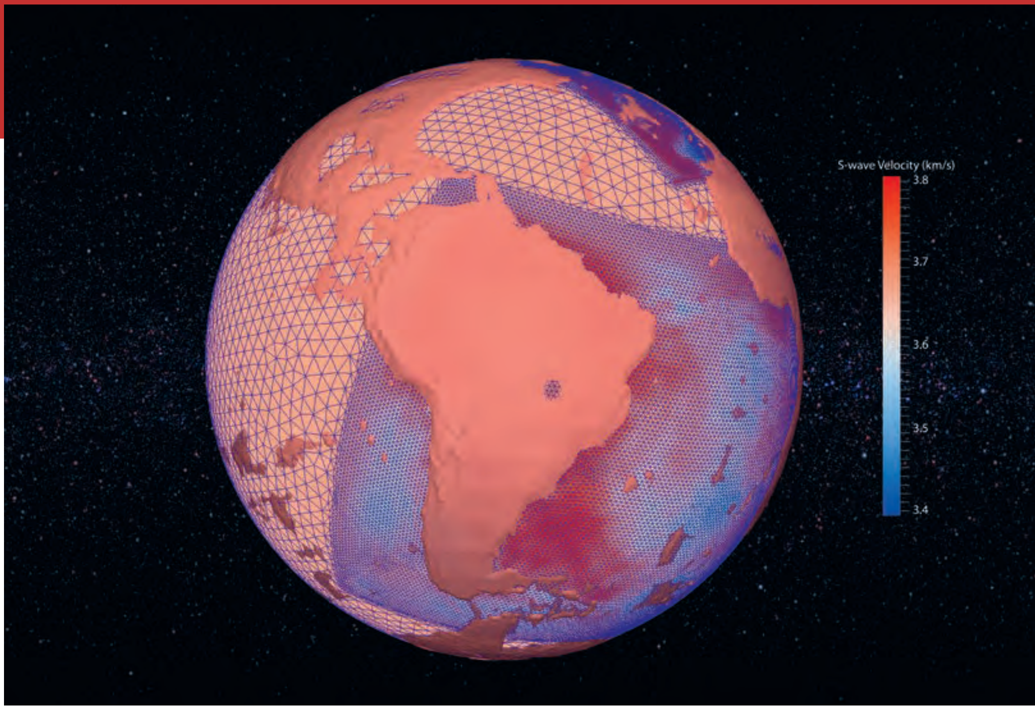
A further focus of research is the investigation and modelling of earthquake source dynamics and waveforms in complex media. With the help of geodetic and seismic methods, these model calculations can be compared with measured regional crustal deformation. This enables one to study the deformation in the lithosphere built up through plate tectonic stresses and dissipated in deformation processes other than earthquakes.

The development of better broadband seismometers is an important prerequisite for the success of modern seismology. Seismometers are essential instruments for investigating the inner composition of planets and their moons. However, implementation in planetary probes places high requirements on the instruments; they must be mechanically exceptionally robust and also be able to withstand large temperature variations. In collaboration with international agencies, such as ESA (European Space Administration), NASA (National Aeronautics and Space Administration), and JAXA (Japan Aerospace Exploration Agency), the SEG team is developing the electronics for lightweight and sturdy seismometers that can be used for planetary missions.



Simulated earthquake near Crete: the white rings illustrate the propagation of earthquake waves around the globe.

SEISMOLOGY AND WAVE PHYSICS



Model of the earth made up of millions of small tetrahedra, with topography (raised) and shear-wave velocity at 100 km depth.

The solid earth is in a constant state of oscillation. This is caused by various phenomena such as ocean waves, atmospheric turbulences or earthquakes which set off seismic waves. They pass through the earth at speeds of more than 10 km per second at times, collecting data about the Earth's inner structure – just as an X-ray passes through the human body, gathering information.

Andreas Fichtner's research group makes use of recordings of seismic waves, GPS data on deformations of the earth's surface, and data on the earth's gravitational field as a means of better understanding the structure and evolution of the earth and the characteristics of large earthquakes. The most important tools are computer simulations of seismic wave propagation and of earthquake processes in geologically active regions of the world. These simulations take advantage of modern supercomputers such as Monte Rosa and Piz Daint at the Swiss National Supercomputing Centre (CSCS) in Lugano. With the aid of graphics devices originally developed for use in image processing for video games, the state-of-the-art CSCS supercomputers are able to calculate seismic waves and earthquakes with a degree of precision that would take a conventional desktop computer more than 100 million years to achieve.

"Piz Daint", the high-performance supercomputer at the CSCS, processes vast amounts of data and enables simulations to be performed at an unprecedented degree of precision.

This combination of modern mathematical methods of computer simulation, along with the availability of high-performance computers at the CSCS, make it possible to study the structure and dynamics of the earth with unprecedented accuracy. Enormous amounts of data can be exploited, which a standard computer would not be able to process, let alone store.

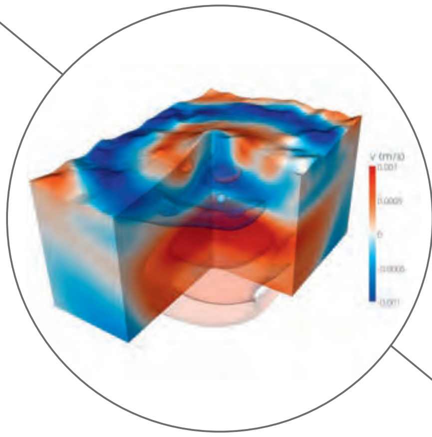
Thanks to these highly specialized resources, this group's research results can produce an extremely detailed picture of convective movements deep within the earth's interior (up to several hundred km depth) and how these movements relate to the processes taking place at the earth's surface such as volcanic activity, mountain building, earthquake activity and the formation of hydrocarbon reservoirs and ore deposits. Most recent study results demonstrate, for example, the man-

ner in which hot and less dense rock from more than 1000 km beneath the earth's surface under Great Britain is transported, as within a narrow conduit, toward Iceland where it is then ejected in volcanic eruptions. In a similar way it has also been possible to prove the existence of an extensive zone of weakness at a depth of 50 – 100 km beneath eastern Turkey, which is responsible for the formation of the North Anatolian Fault Zone along which major earthquakes regularly occur.

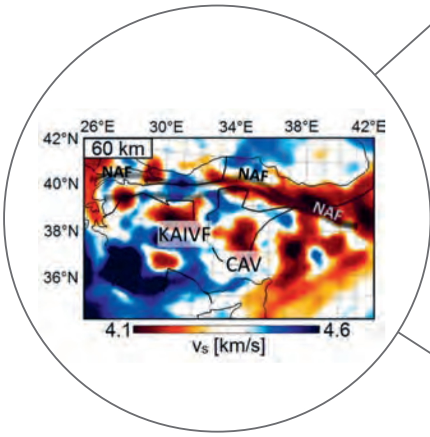
Detailed information about the 3D Earth structure is used in order to better grasp the evolution and dynamics of the earth and to study the rupture processes involved in earthquakes. If the inner structure of the earth is sufficiently well understood, then explanations can be provided for how rock breaks when subjected to high pressure and how the resulting rupture spreads.

In collaboration with researchers from the Australia National University in Canberra, Fichtner's group has developed methods to determine characteristics of large earthquakes such as depth and direction of rupture in close to "real time". Once these are known, they can and should be used to make more reliable forecasts of tsunami occurrence in South Pacific regions.

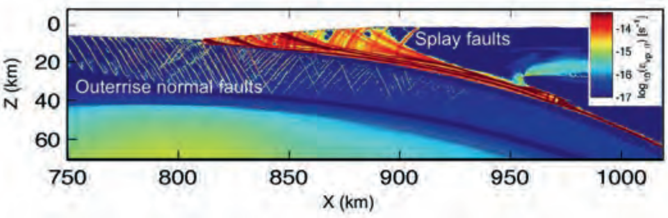
Striving to further improve the spatial resolution of 3D Earth models, the group is currently working on the calculation of a new, comprehensive seismic data set based on seismic noise, with the support of ORFEUS, the European Data Center, and IT specialists from CSCS. Seismic noise is caused, for the most part, by ocean waves, and it is only thanks to the intensive computer processing performed by the group that the data obtained can be used. The new data set is applied to explore the 3D structure and to learn more about the interaction between the oceans and solid Earth.



Propagation of seismic waves through a model of Mount St. Helens.



Shear-wave velocity at 60 km depth beneath Anatolia. Low-velocity bands under the volcanic provinces (Kirka-Avyon-Isparta Volcanic Field / KAIVF), the Central Anatolian Volcanic Field (CAV) and the signature of the North Anatolian Fault (NAF) along which major earthquakes regularly occur.



Numerical model of a subduction zone along which (approaching from the left) a tectonic plate submerges beneath a continent (right). Red-shaded regions represent fault zones that are responsible for a high rate of volcanic activity.

Andreas Fichtner

Interdisciplinary cooperation is key to the work of this group, which functions as a link between various branches of the natural sciences, ranging from mathematics and physics to information technology and seismology, geodynamics, tectonics and geology.

EXPLORATION AND ENVIRONMENTAL GEOPHYSICS

Ground penetrating radar measurements in the Swiss Alps.

Exploration and environmental geophysics is concerned with the development and application of geophysical methods for investigating the shallow sub-surface of Earth. The focus is on the part of the earth's crust that can be accessed from the surface via drilling, i.e. the upper 10–15 km, and especially the upper few kilometers. This region is of critical importance to many highly relevant societal issues such as hydrocarbon and mineral resources, groundwater, hazard assessment, etc.

The scientists in the Exploration and Environmental Geophysics (EEG) group led by Prof. Johan Robertsson apply a wide range of geophysical techniques including seismic methods, ground penetrating radar, geoelectric and IP methods, electromagnetic induction and magnetic methods. Geophysical measurement techniques can be compared to modern medical imaging techniques such as the use of radiology prior to the advent of surgery in medicine. The earth's sub-surface is investigated and characterized non-invasively and remotely, because direct access to the sub-surface can be extremely costly or even impossible. Moreover, geophysical exploration can provide almost continuous sampling of the subsurface and enables more intelligent and effective drilling programs to be conducted. Several aspects make the problem of characterizing the earth's sub-surface more challenging than the medical imaging equivalent. In particular, the large variations of the physical subsurface properties, combined with the limited site access by which the target regions can be viewed (c.f. 360 degree coverage in medical CT and NMR imaging), represent a daunting challenge.

The EEG group is particularly well known for its application of a broad range of methodologies and the rich spectrum of research topics, ranging from the development of modern theoretical approaches to innovative applications. The group benefits from the close collaboration between its members specializing in both theoretical and experimental aspects of their scientific field. Most of the projects are focused on solving a practical geological problem (elaborated below), such as improved oil and gas exploration capability, groundwater search, environmental monitoring, assessing potential nuclear waste repositories, and investigating deep geothermal energy sites.

The group has close collaborations within a network of top international universities and industry partners. An example of this collaboration is the IDEA League Joint Master's Programme in Applied Geophysics of which the EEG is a core partner along with the TU Delft and the RWTH Aachen. In addition, the EEG group benefits from close cooperation with leading researchers in the exploration and energy sectors.

The following is a selection of key research topics, where the EEG group is currently active:

Advanced seismic processing and imaging algorithms

Exploration and development of hydrocarbon resources require sophisticated 3D subsurface mapping capability. EEG is involved in developing enhanced techniques for deghosting of marine seismic data, autofocusing techniques for improved resolution, and superior vector migration / elastic full waveform inversion schemes for detailed structural imaging and rock physics quantification.

Characterisation of geothermal systems

Geothermal energy is gaining in popularity and importance as a viable renewable energy source, especially in Switzerland.

This is driven by field experimentation and numerical simulation, the use of geophysical techniques for describing a variety of geothermal reservoirs which are being developed in the group.

Geophysical measurement campaign in Botswana (Africa).

Permafrost

As a result of global warming, permafrost is melting in many locations around the world, thereby potentially triggering hazardous landslides. In collaboration with other ETH institutes, a number of rock glaciers in the Alps are being studied using various geophysical methods, in particular radar.

Seismic measurements on an alpine glacier.

Monitoring of radioactive waste

Scientists from the EEG group investigate possibilities for monitoring radioactive waste storage sites. The latest and most advanced imaging technologies, such as seismic waveform inversion, are used in order to detect subtle changes within the repositories and their surroundings.

CARNEVAL industrial consortium

The CARNEVAL industrial consortium investigates near-surface structures that can have a profound impact on seismic measurements of the earth's deeper subsurface. Techniques and methodologies are developed to suppress the impact of near-surface layers on exploration-seismic data. The focus lies on the characterization of the near-surface zone, the improvement of different geophysical measurement methods and the joint processing, inversion, and interpretation of such data.

Ship with probes collecting marine seismic data.

Full waveform modelling and inversion of seismic data

Modern seismic data acquisition systems are capable of simultaneously recording several hundred thousand sensor channels such that the seismic wave field arriving at the earth's surface is characterized with unprecedented density and fidelity. The EEG group often works with data realistically simulated from complex Earth models using waves arriving simultaneously in a 3D manner from various directions in space. These datasets provide the basis for developing new imaging and charaterisation techniques, thereby fully accounting for the physics of wave interaction within the complex sub-surface.

Johan Robertsson

High Performance Computer facility at ETH.

Wave propagation laboratory

The new hybrid Wavelab under development will enable the study of seismic waves utilising media in a completely new way; the physical experiment will be fully immersed within a numerical simulation. Potential applications include focusing and time-reversal experimentation, the study of non-linear effects and experimentation on media in which the propagation of seismic waves is not fully understood.

Hansruedi Maurer

GEOTHERMAL ENERGY AND GEOFLUIDS

Laboratory of the Geothermal Energy and Geofluids Group, where reactive flow experiments and visualisations of multi-phase flows in 3D-printed porous media are carried out..

Martin Saar holds the chair of the Geothermal Energy and Geofluids (GEG) Group, which is endowed by the Werner Siemens Foundation. The group investigates fluid and energy transfer in the earth's crust. To conduct this research, we develop and employ computer simulations, perform laboratory experiments, and make field investigations. The goal of this research is both to gain fundamental scientific insights into how fluid and energy transfer operates in the crust and to address some of society's most pressing challenges regarding energy and geofluid (e. g., water) supply as well as global climate change. Research examples include:

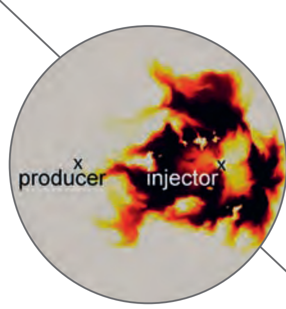
- Water- and CO_2-based geothermal energy:
  - exploration (finding resources)
  - extraction (from reservoirs)
  - conversion:
    - of heat for district heating and industrial processes
    - of enthalpy (heat and pressure energy) to electricity
- Enhanced Geothermal Systems (EGS) development and operation
- Geologic CO_2 sequestration to mitigate global climate change
- Heat energy extraction during enhanced oil recovery
- Electric-grid-scale, geothermal-reservoir-based energy storage
- Groundwater and solute (e. g., tracer, contaminant) flow and freshwater supply

This research is tightly connected to several geoscience, and other scientific and engineering fields such as hydrogeology, engineering geology, geophysics, geochemistry, fluid dynamics, exploration geophysics, computer science, and mathematics as well as mechanical, chemical, and petroleum engineering.

The following are specific examples of the work we do:

Geoelectric methods for geothermal system exploration
We are developing new surface and cross-borehole electromagnetic measurements. We use these methods for exploration of geothermal resources and to investigate permeability modifications due to hydraulic stimulation during Enhanced Geothermal System (EGS) development.

Permeability and heat transfer enhancement of geothermal reservoirs
The GEG Group is co-leading the Deep Underground Geothermal (DUG) Lab field experiment at the NAGRA underground laboratory at the Grimsel Pass in Switzerland. At this site, hydraulic stimulation of a rock mass is investigated to test if it is possible to generate permeability with negligible seismicity. This would result in an efficient geothermal heat exchanger so that EGS may be possible in Switzerland and elsewhere. The GEG Group's involvement here is to study the change in permeability and heat exchange efficiency prior to and after hydraulic stimulation. This project is conducted together with the Swiss Competence Centre on Energy Research – Supply of Electricity (SCCER-SoE).



Simulation of the injection of a fluid into a crack with MOOSE.

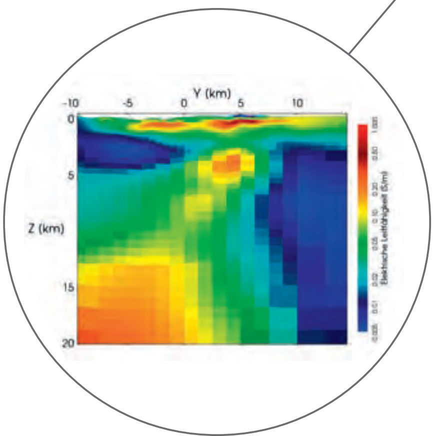
Combining field, lab, and computer investigations

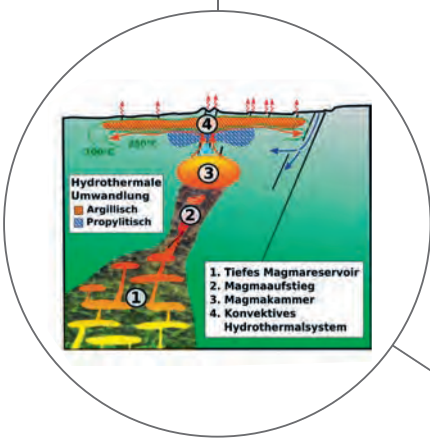
In this example, we take rock cores from geothermal or CO_2 sequestration drill sites and conduct reactive flow-through experiments in the lab, during which CO_2-saturated water percolates through the core and reacts with the minerals. Before- and after-experiment 3D images are taken to visualize dissolution / precipitation of minerals. These 3D images are used as input data for our reactive fluid flow simulator to determine the permeability field evolution due to these fluid-mineral reactions. This information can be used to numerically upscale the results to geothermal or CO_2-sequestration reservoir scales. This numerical upscaling step is critical to answer questions concerning long-term permeability changes, CO_2 leakage potential, or thermal breakthrough timescales during geologic CO_2 storage or CO_2-based geothermal energy extraction operations. This work has significant implications for society in the areas of climate change mitigation and renewable energy supply.

A high-efficiency, CO_2-sequestering geothermal power plant

The GEG group has developed a new method to generate electricity that has not only a neutral but a negative carbon footprint. During this CO_2-Plume Geothermal (CPG) system approach, CO_2, captured at fossil-fuelled power plants, chemical facilities, cement manufacturers, and biofuel refineries, is injected underground for permanent storage to reduce global climate change. However, a small portion of the then geothermally heated CO_2 is piped back to the surface for high-efficiency, baseload electricity generation and then reinjected into the geothermal CO_2-storage reservoir so that no CO_2 is released to the atmosphere. Using CO_2 instead of water to extract geothermal energy allows much lower resource temperatures and lower reservoir depths and permeabilities to be utilized to produce power, while avoiding the need to hydrofracture the subsurface – all of which is of particular importance to Switzerland and useful worldwide.

To learn more about the Geothermal Energy and Geofluids (GEG) Group, please take a look at our web site: **GEG.ethz.ch**





Subsurface model of the electrical conductivity of a geothermal field in the East African Rift. The model was generated by 3D inversion of magnetotelluric data and clearly shows the typical structure of a volcanic high-enthalpy geothermal system. The study is the result of a collaboration between GEG Group (Samrock, Saar), EPM Group (Grayver) and the Icelandic geothermal company Reykjavik Geothermal.

Martin Saar

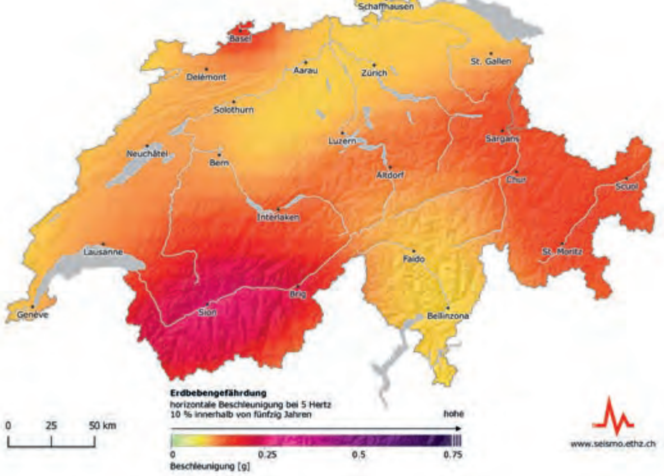
Xiang-Zhao Kong

SWISS SEISMOLOGICAL SERVICE

The observation, causes and impacts of earthquakes are the core focus of the research activities of the professorship for seismology and the Swiss Seismological Service (SED) at the ETH Zurich. Earthquakes pose a serious hazard even in Switzerland and they have the greatest damage potential of all natural hazards. At the same time, seismic waves carry a wealth of information about the structure of our planet. Professor Stefan Wiemer leads the Seismology research group at the ETH since June 2013, and is also Director of the SED, the federal agency responsible for monitoring earthquakes in Switzerland.

The Swiss Seismological Service

The SED monitors the seismic activity in Switzerland and close-border regions, and assesses Switzerland's seismic hazard. In 1878 the Earthquake Commission was established by Switzerland, even before Japan and Italy created similar official bodies. In its present form as an external department of the ETH Zurich, the SED exists since 2009 and employs about 60 scientists, technicians, doctoral candidates and administrative staff. A major part of the research activities is financed by third-party funding. The group conducts research in the framework of a wide and varied range of European and international projects in collaboration with other institutions, which ensures a lively professional exchange well beyond national borders. Although the main emphasis is placed on topics relevant for Switzerland, the SED also participates in projects abroad. As an example, currently a network of more than 30 stations in Bhutan, and several stations in Greenland, are being operated by the SED.



Earthquakes in Switzerland

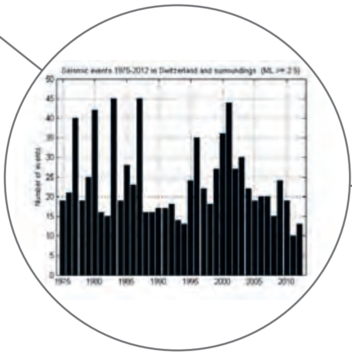
Two earthquakes per day are registered on average in Switzerland and in the adjoining regions, which translates to between 500 and 800 events per year. Of these, approximately 10 are strong enough (magnitude of approx. 2.5 and above) to be felt by the general population. Compared to other European countries, Switzerland exhibits a moderate seismic hazard, though regional differences exist. More earthquakes than in other regions are registered in the Valais, Basel, the St. Gall Rhine Valley, central areas of the Grisons, in Engadine and in Central Switzerland. A strong earthquake with a magnitude of about 6 must be expected on average every 60 to 100 years. The last such event occurred in 1946 near Sierre in the Valais. Such an earthquake, however, can happen again in Switzerland anytime, anywhere.

Earthquake Monitoring and Warning

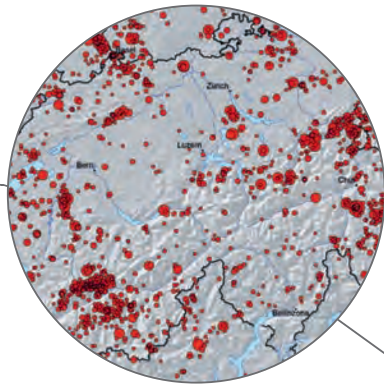
Since 1975 the SED monitors seismic activity in Switzerland with a network of stations equipped with real-time telemetry and centralized data acquisition. The broadband network similar to its present configuration exists since the mid-1990s.

The highly sensitive seismometers record even the slightest shaking, and are able to register vibrations along a broad range of frequencies. These special features allow the group to not only monitor earthquakes on a global and regional level, but also to study the evolution of the earth and the formation of the Alps, to investigate micro-earthquakes, like those occurring during geothermal activities, and to determine geotechnical characteristics of the subsurface.

The data of the more than 150 broadband and strong motion seismometers are transmitted continually and in real time to the central data center in Zurich. In addition, the SED maintains a pool of mobile stations in collaboration with the Seismology and Geodynamics group (SEG) under Prof. Domenico Giardini for conducting short-term measurement campaigns and field experiments.



Earthquakes in Switzerland between 1975 and 2012 with a magnitude of 2.5 or more.



Earthquakes in Switzerland between 1975 and 2012.

An alert system, maintained and constantly being improved by a team of scientists, technicians and programmers, is now capable of detecting earthquakes and determining their location in less than 30 seconds. In case of an earthquake, the SED informs the public, authorities and media concerning the magnitude, location and possible impacts of an earthquake. In addition, the 24/7 SED oncall service provides information about earthquake to all interested parties.

There is a need for research into how to further improve such alert systems, in particular regarding early warning systems: electromagnetic waves, as they are used in communications, propagate much faster than seismic waves. Based on this fact, it is currently possible to issue a warning to areas at some distance from the epicenter of the earthquake a few seconds before the strongest shaking, provided the earthquake is detected soon enough. The SED pursues research that aims to optimize this type of early warning system, and investigates whether the magnitude of an earthquake can be determined reliably based on the seismogram output transmitted in the first few seconds of an event.

Stefan Wiemer

Strong-motion measuring station near Buchs, Buchserberg.

Hazard and Risk

The data collected by the seismic network is useful not only for earthquake detection and alert, it also aids in the assessment of hazard and risk. Seismic hazard is a term that describes the probability with which a particular ground acceleration will occur within a defined time frame at a certain location. In order to determine the seismic hazard, seismologists analyse the local earthquake history as well as regional tectonic and geological data. They evaluate historical accounts of earthquake damage and develop models of wave propagation. One of the core tasks of the SED is to issue and regularly update the seismic hazard assessment for Switzerland. At the same time the group conducts intensive investigations aimed at improving the key information used to assess earthquake hazard in order to minimize the damage caused by future earthquakes. Due to the crucial importance of the subsurface in the determination of the seismic hazard at a specific location, the SED develops and validates new methodologies to improve the knowledge of its properties.

Florian Haslinger

Swiss Seismic Network (as of 2013).

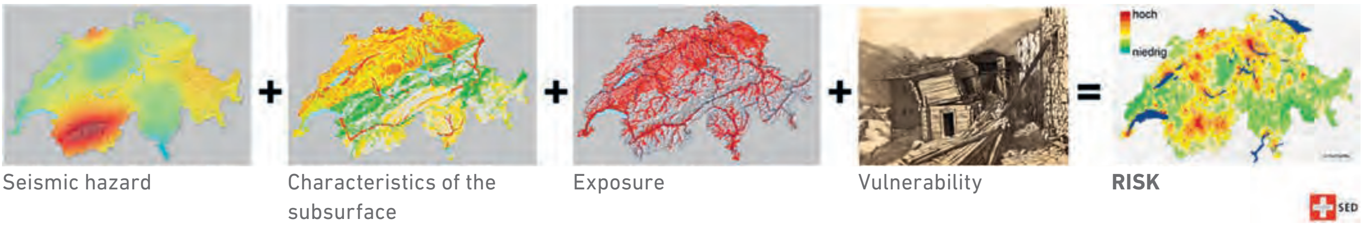
John Clinton

Donat Faeh

SED staff, Spring 2013.

With its scientific collaboration in the Nuclear-Test-Ban Treaty, the SED also contributes to risk mitigation related to nuclear activities. At the Conference on Disarmament held in 1996, the UN negotiated a comprehensive ban on nuclear arms that included a worldwide seismic network as a core element of a global monitoring system. The SED supplies the responsible international organization in Vienna with relevant data and notifies the national agencies of the latest developments in this field.

The research group is also active in the monitoring of rockslides, glacioseismology, statistical seismology, induced seismicity, engineering seismology and seismotectonics.

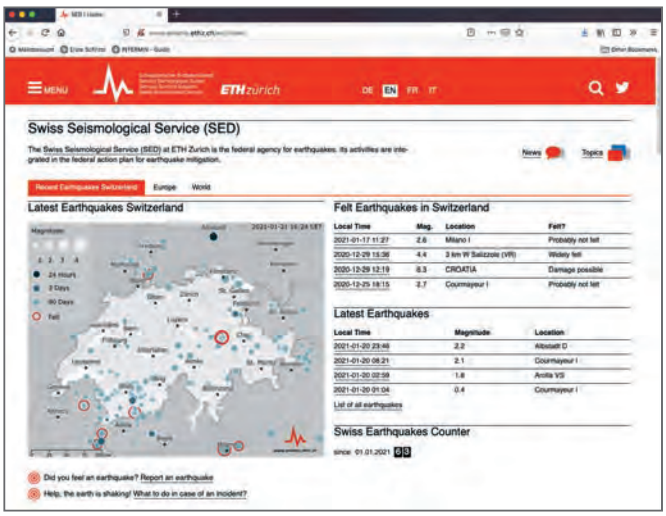


The four earthquake risk factors.

Public Relations and Education

Knowledge acquired by the SED is passed on not only to students, but also to the public, the media, and various authorities. The goal of the SED's wide-ranging media and public relations effort is to increase the public awareness in Switzerland of earthquakes and their associated hazard, and to enhance the understanding by providing clear and comprehensive information.

Follow us on our twitter account **@seismoCH_E**, through which we inform about every earthquake in Switzerland with magnitude 2.5 or greater.



Website of the Swiss Seismology Service: www.seismo.ethz.ch

GEORESOURCES SWITZERLAND GROUP

The Georesources Switzerland Group is part of the Department of Earth Sciences at ETH Zurich and conducts applied research in close collaboration with the Swiss Geological Survey (part of the Federal Office of Topography swisstopo) as well as with different industry partners. Main research focus are geological resources. The group is led by Stefan Heuberger and comprises 6–7 geoscientists.

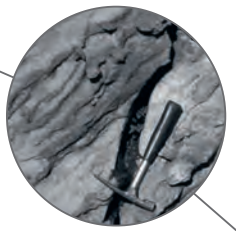
We collect and compile fundamental geological data and data related to the use of the geological resources of Switzerland. Focus areas are the today most important and extracted mineral resources (gravel, sand, clay, limestone, salt, gypsum, natural stone), energy resources from the deep underground (deep geothermal energy, hydrocarbons), secondary mineral resources and geological questions related to the use of georesources and the underground in general. To this end, we compile and harmonise existing geological data like geological maps, borehole data, heat flow and seismic data and integrate these datasets into newly developed databases and 3D models. For calibration issues, we do field work (e.g. geological mapping, detailed outcrop analyses in quarries), lab analyses (e.g. XRF, drillcore analyses, sieve analyses) and apply remote sensing and digital mapping techniques.

**The group was founded in July 2018 and was formed after the dissolution of the Swiss Geotechnical Commission (SGTK).*

Products of our applied research are geological resources maps and (online) databases, geological 3D models (ranging from the scale of a single gravel body up to the entire Swiss Molasse Basin) and comprehensive thematic reports on the different resources types. Our group maintains an own specialised library and has extensive collections of the utilisable rocks of Switzerland including corresponding map datasets. Based on our comprehensive databases and archives on occurrences and extraction sites of geological raw materials as well as on production output, we continuously publish data on freely accessible web-based services (our own Resources Information System RIS on **map.georessourcen.ethz.ch** and the one by swisstopo on **map.geo.admin.ch**).

We also contribute to the department's teaching program in lectures (e.g. Integrierte Erdsysteme III "Georessourcen & Geoenergie"), field courses, excursions and in the supervision of BSc, MSc and PhD theses.

Quarrying limestones and marls in Switzerland.



Stefan Heuberger

CONTINUING EDUCATION

CERTIFICATE OF ADVANCED STUDIES IN APPLIED EARTH SCIENCES (CAS ERDW)

Graduates in earth sciences work in a broad, continuously changing occupational field and continuing education becomes an essential part of life-long learning processes.

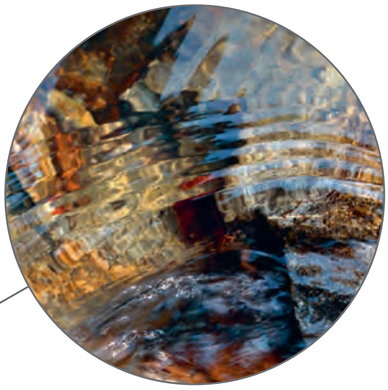
The Department of Earth Sciences offers advanced training courses in applied Earth sciences within the framework of a Certificate of Advanced Studies (CAS). This modular continuing education program is extra-occupational and allows the participants to gain up-to-date theoretical knowledge and state-of-the- art methods based on interdisciplinary approaches.

The CAS in Applied Earth Sciences provides the opportunity for continued transfer of knowledge from academia to practice. Next to this knowledge transfer the continuing education courses promote the exchange of knowledge and experience between practitioners and facilitate network-building.

Three main topics are covered within the framework of the CAS in Applies Earth Sciences: (1) understanding the behaviour of geological materials in soil- and rock engineering, (2) the use of natural resources in particular geothermal energy and the protection of groundwater and (3) risk-management and analysis of natural hazards. For each of the three main topics two four-day modules and an additional project module are offered, together comprising six credits. Every module is open to further education course participants. The content of the modules is coordinated by chairs of the Earth Science Department and implemented together with contributors from other departments and industry.

www.cas-erdw.ethz.ch

Heike Willenberg



FOCUS TERRA

THE EARTH & SCIENCE DISCOVERY CENTER OF ETH ZURICH

*focus*Terra invites both experts and the public to make a fascinating journey from the interior of the earth to the highest alpine peaks. The centre acts as a bridge between research and the public; explaining current topics in earth science in an expansive yet easy to understand manner. *focus*Terra displays exhibits and provides information about the function and importance of natural resources, the origin and evolution of the earth and its forces as well as the formation of extraterrestrial planets.

Ulrike Kastrup

Gillian Grün

Kerstin Bircher

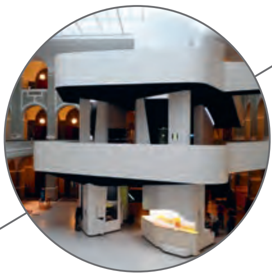
The information and research centre encourages visitors to discover the Earth in an individual way: Experience a model of the earth's dynamo which replicates the magnetic field of the earth which protects us from the dangerous solar winds; or experience an earthquake safely within the earthquake simulation room. You can even view earthquake signals in real-time and see if an earthquake has occurred in the last twelve hours at the earthquake monitor display of the Swiss Seismological Service. Interact with the large rotating Omni-globe which demonstrates just how millions of years of continual movement of the continents has led to our Earth today.

Aesthetic highlights are the precious gems and the spectacular smokey quartz crystal group recovered from the Central Alps and the beautiful crystals on display from the earth science collection of the ETH Zurich. Furthermore, fossils illustrate the geological development of the plant world. And, a three dimensional model allows visitors to discover the development of the local landscape around the city of Zurich which has occurred over the past twelve million years.

Finally visitors can explore the depths of the ocean where bizarre landscapes are created from hot sources originating from the ocean floor. Areas abounding with extraordinary animal life – areas which could possibly be the place where life began.

Temporary exhibits, guided tours and numerous events regularly supplement the permanent exhibit. *focus*Terra communicates scientist's exuberance about research as well as deep understanding of the Earth and aims to encourage visitors to treat the earth in a responsible manner. *focus*Terra is especially suitable for school class trips. Classes can choose to focus on a variety of exhibit themes to complement their classroom studies. Entrance to the exhibits, events and the guided tours held on Sundays are free to visitors. *focus*Terra is jointly operated by the ETH Library and the Department of Earth Science.

Detail information: **www.focusterra.ethz.ch**



The exhibition tower of focusTerra in the atrium of the Earth Sciences building of the ETH Zurich. (Image: Susanna Bruell)

Experience an earthquake in the earthquake simulator. (Image: Peter Rüegg, HK)

The large crystal group from Tiefengletscher in canton Uri, salvaged in 1946 by Peter Indergand sen. (Image: Susanna Bruell)

Where was India located millions of years ago? See on our mini-planet how the continents move around the globe. (Image: Brunecký)

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