MSc in Earth and Planetary Science, Environment

Speciality:
Mineral Materials / International

MSc in Advanced Clay Science

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A network of professionals, teachers and researchers

To help you build your future

Poitiers University, Grenoble Alpes University, Nantes University, Lorraine University, Haute Alsace University, UPMC Paris, Clermont Ferrand BP University, Franche Comté University, ENS Paris, Limoges University, Lille 1 University, Technical University of Crete, Le Louvre Paris, French Geological Survey, AREVA, TOTAL, IFSTTAR, Massachusetts Institute of Technology, Federal University of Rio Negro, Tel Hai College, Federal University of Rio Grande do Sul...
A multidisciplinary master's degree for ... a wide range of opportunities
Expertise in many analytical tools for mineral and geomaterials characterization
Two periods of internship in privates companies or academic laboratories (in France or abroad)
Linked to the industrial demand (TOTAL, AREVA, LAFARGE HOLCIM, IMERYS, IFSTTAR, IPSEN, INRA, LA MANCHA, ERM...), associated with a wide range of private and academic laboratories
An international training course
A national and international recognition

Labellisation Erasmus Mundus (2010-2015)

Student awardees at the last Euroclay meeting (Edinburgh 2015), from left to right: Liva Dzene, Carmen Ciotonea, Fabien Baron, Valentin Robin. (photo K Murphy - S Hillier)
Opportunities

- Analysis / Research / Development laboratories – Scientific instrumentation
- Mineralogist
- Geologist, mining geologist, exploitation of mineral/energetic resources (deposits, quarries), remediation
- Material Engineer (industrial minerals, ceramics, cement, geopolymers, eco-materials and nanomaterials)
- Geotechnical Engineer
- Soil expert, polluted sites and soils
- Geoarcheologist
- Protection of natural and cultural heritage
- Researcher / lecturer
- Scientific journalism

Position - 6 months after graduation

- Research and development: 62%
- Assistant lecturer: 14%
- Job area related to the program (private): 10%
- Job area related to the program (academic): 6%
- Job area not related to the program: 2%
- Research for job-PhD: 2%
- Complementary training: 2%
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Programme
First Year
PROGRAMME
Rocks or geomaterials are composed of minerals whose organization is intimately linked to a network of pores that stores fluids such as water, gases and organic pollutants. Understanding the organization of solids and pores is therefore essential in order to control and predict the distribution, macroscopic transfer and quantities of stored fluids. This organization also controls the mechanical and geotechnical properties of soils. The knowledge of associated physical phenomena as well as the measurement in the laboratory of mechanical and transfer properties will therefore be an asset in geosciences to address applied and environmental issues.

**Objectives**

The objective of this module will be to understand and how to manipulate the physical laws involved in rocks, soils and geomaterials in order to measure and predict the transfer of fluids/pollutants and their mechanical characteristics.
Content

- Soil and rock physics: composition, porous network, state of water.
- Methods of characterization of porous networks (size, pore morphology, classification) and water distribution in rocks/soils.
- Physical phenomena controlling the distribution of water and organic pollutants in saturated and unsaturated environments.
- Introduction to 2D/3D imaging concepts of solid skeletons and porous networks
- Soil description, identification and geotechnical classification of soils: soil condition; properties of soil components; characterization tests and geotechnical classification of soils.
- Flow and diffusion in porous media
- Practical work: Atterberg limits, Methylen blue test, sand equivalent, granulometric analysis, PROCTOR test, permeability, water and gas adsorption isotherms, mercury porosimetry, processing and evaluation of 1D/2D/3D image data.

Prerequisites

Basics in Mathematics and Physics

Knowledge/skills acquired

- Ability to characterize and classify a soil from a geotechnical point of view
- Understand and know how to predict qualitatively the properties of water and phase pollutants in soils and their distribution
- Ability to link the organization of the solid skeleton and the porous network of soils/rocks to their physical properties.
- Understand the physical mechanisms governing the flow and diffusive transport of water and pollutants in soils and rocks.

Assessment

Continuous assessment (practical work reports)

Head of the training unit:

Dimitri Prêt, dimitri.pret@univ-poitiers.fr

Main contributors

Dimitri Prêt, Poitiers University (IC2MP Institute)
Richard Giot, Poitiers University (IC2MP Institute)
This unit is devoted to give basic tools of thermodynamic in order to predict chemical reactions between a given fluid and minerals and/or natural rocks. We focus on dissolution/precipitation reactions due to their strong influence on the transfer properties of rocks and aquifers. Redox interactions are also discussed in this unit.

**Objectives**

In the context of dissolution/precipitation interactions, the first objective will be to predict the saturation state of a natural water with respect to a mineral, especially by considering the salinity of the geological fluid. Then, these notions will be applied to rocks in order to predict the stability of the minerals presented inside with respect to a given fluid. One of the main objectives is the construction of activity diagrams generally used to predict fluid/rocks interactions at equilibrium (mineral solubility versus pH, T or salinity; Korjinski diagram; Eh/pH graphics).
Content

• Chemical composition of natural waters (water facies, charge balance, graphic representation of hydrochemical analyses)
• Basics of thermodynamics applied to chemistry of natural waters
• Saturation state of a given water (dissolution/precipitation equilibrium) and aqueous speciation calculations
• Mineral stability versus chemical composition of water
• Construction and interpretation of activity diagram: prediction of the chemical composition of a water at equilibrium with a rock
• Eh/pH diagram: application to retreatment of mine wastes and/or polluted waters
• Practical works: (i) dosage of major cations in natural waters, (ii) speciation calculation of sea water with hydro-chemical software (iii), assessment of solubility of a mineral versus pH and solubility product from an experimental point of view.

Prerequisites

• Mineral definition – Main terrestrial rocks minerals
• Main ions in natural waters

Knowledge/skills acquired

• Calculation of the charge balance of a given water
• Calculation of the saturation state of a given water with respect to minerals and prediction of its aggressiveness with respect to a mineralogical assemblage
• Knowledge of the difference between aqueous species and dissolved elements
• Know « how to construct » activity diagrams
• Basic measurements in spectrophotometry

Assessment

Continuous assessment
Practical work report (2)

Head of the training unit
Emmanuel Tertre, emmanuel.tertre@univ-poitiers.fr

Bibliography


Main contributors
Emmanuel Tertre, Poitiers University (IC2MP Institute)
Aude Naveau, Poitiers University (IC2MP Institute)
This course unit presents the main rock weathering processes and soil formation and evolution. It also presents the major soil types of the world in relation with weathering processes and macroclimate. It will be focused on:

- Supergene or meteoric rock weathering mechanisms: definition of the key factors controlling biogeochemical weathering processes.
- Relationships between rock weathering, clay formation and porosity development.
- Presentation of pedogenesis mechanisms, neoformed minerals, associated soil types and spatial distribution at the earth surface.
- Presentation of soil variability at different scales.
- Introduction to soil sustainability.

Objectives
The objectives of this course unit are to describe the main rock weathering and soil formation mechanisms and the factors that control these processes. Rock weathering mechanisms depend on geology, climate and topography. Knowledge of soil formation processes is important as it plays a key role on physical (water transfer) and chemical (cation exchange capacity, interactions with pollutants) properties that must be taken into account for environmental monitoring.
Content

•Basics of rock weathering and pedogenesis processes: disequilibrium between rock formation conditions and conditions prevailing in soils.
•Factors of soil formation: climate, mineral parent material, living organisms and organic matter, relief, time
•Physical disaggregation and biogeochemical weathering
•Primary mineral weathering mechanisms: heritage, transformation, neoformation
•Transformation of rock into a porous and friable material: porosity development
•The main principles of pedogenesis: hydrolysis, acidolysis, complexation, decarbonation, brunification, leaching
•Mineralogy of the soils associated to the main processes of pedogenesis (tropical soils – soils from temperate regions).
•Transfers of matter in soils: development of profiles
•The major types of soil horizons
•The major soils of the world
•Duration of pedogenesis and durability/sustainability of soils.

Prerequisites

•Basic knowledge in soils science and geology.

Knowledge/skills acquired

•Ability to describe the processes of formation and evolution of soils related to their environment (climate, geology, and geomorphology)
•Ability to describe the processes of formation of the major soils of the world
•Ability to propose a reasoning for identifying the mechanisms involved in the formation of a soil from a complete analysis report.
Bibliography


Assessment

Final exam
Continuous assessment

Head of the training unit

Laurent Caner, laurent.caner@univ-poitiers.fr

Main contributors

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Tales Tiecher, Federal University of Rio Grande do Sul (Brazil)
Course unit: **Programming and data analyses**

Semester 1 - ECTS credits: 3 (25h including 6h lectures, 19h practical) - In order to develop the required competences, students must complete a programming project. From a given dataset, students will have to 1/ organize the data, 2/ manipulate it using filtering, combining and other techniques, and 3/ represent data graphically, those allowing data analysis - Teaching language: English

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Treat and analyze data coming from the different other master course units is possible only by the efficient assimilation and using of programming tools. These tools should answer to the following requirements: accessibility (free ware should be prioritized), simplicity of handling, and applicability to complex data. The study of many complementary tools is necessary to manipulate different digitized objects: spectra, images, files coming from simulations. More broadly, knowledge of programming tools is a common pre requirement for facilitating student integration in the professional world

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**Objectives**

The objective of this course unit is to provide the student with programming skills in different languages/codes and a better vision of grammatical variations in addition to universal programming methods.
Content

• Toolbox 1: Visual Basic under Microsoft Excel. Introduction to variables, loops, tests.
• Toolbox 2: ImageJ, basic notions on image processing and analysis, programming language java.
• Toolbox 3: Codeblock C++, input/output of text files
• Toolbox 4: GNU Octave. Scientific plots and calculations.

Prerequisites

• All necessary training will be included in the course unit.

Knowledge/skills acquired

For simple programming tasks, the student should be self-sufficient at the end of the course. These acquired tasks will be the followings:

• Files manipulations including conversion and analysis of raw data and data filtering.
• Simulations of simple phenomena: scientific calculation, plotting and data analysis.

Assessment

Continuous assessment

Head of the training unit

Paul Sardini, paul.sardini@univ-poitiers.fr

Main contributors

Paul Sardini, Poitiers University (IC2MP Institute)
Baptiste Dazas, Poitiers University (IC2MP Institute)
Course unit: Minerals/Materials characterization techniques – Part 1

Semester 1 - ECTS credits: 6 (50h including 24h lectures, 19h tutorials, 7h practical) - Teaching language: English

Based on examples and applications to clays and other minerals, we will see how to use a wide range of techniques dedicated to solid characterization (spectroscopy, diffraction) to better analyze, understand and model mineral structures. The module will mainly rely on the study of the structures and crystal chemistry of lamellar materials and more specifically clays. The great chemical and structural diversity of these minerals makes them complex subjects of study, thus allowing us to understand the analysis capabilities and limitations of the different instruments with a complex natural material.

Objectives

This module, in two parts, is intended for all students who, in their professional life, will be confronted with scientific instrumentation and/or the characterization of natural/synthetic material using physical methods.

The first part of this module will focus on the theoretical bases as well as crystal-chemical solid analysis techniques.
Content

1) **Introduction to crystal-chemistry:**

This first course will introduce the context as well as the goal of the module for students. Basics of coordination chemistry and solid chemistry will be introduced. These bases will be applied to minerals and more specifically to the crystal chemistry of clays. These lectures will ultimately allow us to understand the use of the different techniques applied to clay minerals.

- General crystal-chemistry reminder (Bounds, Coordination)
- Phyllosilicates crystal-chemistry (basics) and other lamellar minerals
- Structure and chemistry of clay minerals (phyllosilicates).

2) **Physics of radiation/material interactions:**

To achieve an advanced level of analysis and experimental data understanding, it is important to grasp the physical principle of interactions between radiation and solid matter. These interactions are the basis of all the solid analysis techniques that will be addressed in the module. The fundamental principles of these interactions between radiation (electromagnetic or particles) and solid matter must therefore be understood by the student and will serve as a theoretical basis for the rest of the course.

- Physical basis of the radiation/material interaction
- Illustration of the first crystal-chemical studies through analysis of samples by X-ray Fluorescence
- The results of chemical analyses by X-ray fluorescence will be supplemented by the information provided by the Thermal Analysis: TGA-DTA for species not easily detected by the first techniques (H$_2$O, OH, CO$_3^{2-}$...).
3) **Crystallography – Diffraction Basics:**

X-ray diffraction is one of the most popular techniques for solid characterization. It allows the identification of the (known) crystalline species present in a sample as well as their quantification. It also allows the determination of unknown structures or the fine characterization of crystal-chemistry properties of natural or synthetic crystalline materials. Diffraction requires basic crystallographic knowledge to be correctly interpreted.

Theoretical basis of crystallography:
- First principles: Symmetries, Space groups.

Theoretical basis of diffraction (X-rays) and usual applications (phase identification):
- Crystalline networks, reciprocal networks, indexes.
- Theory of diffraction (structure factor, form factor)
- Interpretation of diffractograms (data reading, phase identification)
- Parameters affecting diffraction
- Specifications of lamellar materials

4) **Infrared spectroscopy:**

This part of the module is designed to train students in the use, analysis and understanding of infrared spectra. This crystal-chemical characterization technique is based on radiation/material interaction. The courses will also address the interactions between mineral and organic matter.

- Theoretical basis specific to infrared spectroscopy
- Spectrum acquisition
- Analysis of experimental data and interpretations.
- Crystal-chemistry of mineral materials.
Prerequisites

• Bases of mineralogy
• Basics in Mathematics, Chemistry and Physics (general science course)

Knowledge/skills acquired

• Solid knowledge of the crystalline structures and crystal-chemistry of lamellar mineral materials.
• Complete vision of the analysis of a mineral through different techniques (diffraction, spectroscopy).
• Ability to manage the entire chain of analysis, from sample preparation and data acquisition to final analysis and understanding radiation/material interactions.
• Ability to process a signal (XRD, FTIR...).
• Ability to extract the relevant crystal-chemical information while being aware of the limitations of their analyses.

Assessment

Final exam
Continuous assessment

Head of the training unit

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Bruno Lanson : bruno.lanson@univ-grenoble-alpes.fr

Main contributors

Alexandre Simionovici, Grenoble Alpes University (ISTerre Institute)
Baptiste Dazas, Poitiers University (IC2MP Institute)
Karine Vigier, Poitiers University (IC2MP Institute)
Anne Claire Gaillot, Nantes University (IMN institute)
Electron microscopy is an essential tool for the microstructural study of geomaterials up to atomic scale. This course will provide the basis for the theoretical and practical aspects of scanning and transmission electron microscopy. Emphasis will be placed on both imaging and electron diffraction techniques and spatially-resolved chemical analysis.

**Objectives**

The objective of this course is to understand the physics, advantages and limitations of electron microscopy in order to master the characterization of geomaterials at different scales.
Content
• From the photonic microscope to the electron microscope
• Fundamental aspects of electron-matter interaction and X-ray matter interaction
• Instrumentation: transmission and scanning electron microscopes (and notions of sample preparation)
• Electron diffraction
• The origins of contrast in transmission electron microscopy
• Conventional microscopy (bright/dark field)
• Scanning transmission electron microscopy (atomic number contrast, atomic resolution)
• Analytical transmission electron microscopy and recent developments (STEM-EELS/EDS)
• Scanning electron microscopy in secondary electron mode (topography) and backscattered electron microscopy (atomic number contrast)
• Chemical analysis (EDS)
• Practical work: Imaging method in STEM-HAADF mode (atomic number contrast) and SEM/EDS, chemical analysis processing.

Prerequisites
Bases of crystallography

Knowledge/skills acquired
• Knowledge of the current imaging and spectroscopy methods used in electron microscopy to characterize the microstructure of geomaterials at different scales, their advantages and limitations.
• Knowledge of the chemical composition analyses of geomaterial components.

Assessment
Continuous examination

Head of the training unit
Marie Laure David, marie.laure.david@univ-poitiers.fr

Main contributors
Marie Laure David, Poitiers University (PPRIME Institute)
Dimitri Prêt, Poitiers University (IC2MP Institute)
Course unit: **English**

Semester 1 - ECTS credits: 3 (25h including 25h tutorials) - Teaching language: English

English for specialists in Mineral Material science

**Content**
- Continuing work on grammar and linguistic structures, in class and autonomously
- Oral presentation of subject relevant to discipline
- Oral comprehension using video documents in the language laboratory
- Oral interaction work in class.

**Prerequisites**
- Minimum required level of English: Level B1+

**Knowledge/skills acquired**
- Practical communication, comprehension and expression

**Objectives**
Development of comprehension and expression skills to enable students to follow lectures and reading in English in their specialty.

**Assessment**
Continuous examination

**Head of the training unit and contributor**
Andrew King, andrew.king@univ-poitiers.fr
This unit is devoted to practice of hydrogeochemical software (such as JCHESS or Phreeqc), in order to respond to problems relative to the speciation of chemical elements in waters and in minerals/rocks. Some codes coupling chemical reactions to transport processes will be also used in order to simulate environmental issues. This unit will illustrate the bases introduced in the lectures devoted to « fluid/rocks interactions »

**Objectives**

The main objective of this course unit, which will illustrate the bases of fluid/rock interactions, is to use one (or more) hydrogeochemical softwares (ex: JCHESS, Phreeqc...) in order to simulate chemical reactions which can occur in natural media and which can be sometimes very complex. Using computer code will allow students to resolve numerically complex speciation problematics.
Content

• Description of the main tools and models included in geochemical codes (JChess, Phreeqc, Minteq, ...)
• Applications to prediction of the chemical composition of a given water in contact with a rock with a known paragenesis:
  Speciation simulation for different facies
  Plotting and interpretation of activity diagram
• Applications to the prediction of the behavior of a micro-pollutant:
  Simulation for a mixing of effluent and natural water

Prerequisites

• Basics of chemical equilibria
• Mineralogical composition of the main terrestrial rocks
• Main ions of a natural water

Knowledge/skills acquired

• Ability to use geochemical code to simulate the chemical composition of a water in equilibrium with a mineralogical assemblage
• Ability to use geochemical code to simulate aqueous speciation of an element from the chemical composition of a water measured in laboratory
• Ability to construct and interpret activity diagram with a numerical code
  Ability to choose the pertinent variables to predict the behavior of a dissolved element in different natural media

Bibliography


Assessment

Continuous assessment

Head of the training unit:

Emmanuel Tertre (emmanuel.tertre@univ-poitiers.fr)

Main contributors

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Aude Naveau, Poitiers University (IC2MP Institute)
Michael Descostes, AREVA
This unit is devoted to give the basis of chemical and physical properties of fine minerals and organic particles diluted in water. We will focus more on adsorption of solute on mineral colloid especially by taking into account their surface charge, and on their coagulation/flocculation properties.

**Objectives**

One of the objectives is to know the main experimental techniques used to obtain the surface site density and associated charge of colloids (fine particles). Another objective is to be able to know how to obtain an adsorption isotherm of a solute on a colloid particle and to interpret it. Finally, an important objective is also be able to predict the colloidal stability (or flocculation) of a system composed of fine particles diluted in water.
Content

• Colloid definition
• Functional groups and associated charge of colloids – Specific case of clay minerals
• Electrical double layer – associated model; electrophoretic mobility
• Examples of thermodynamic models describing solute adsorption onto mineral surfaces
• Coagulation/flocculation and colloidal stability
• Implication of colloidal stability in engineering

Prerequisites

• Mineral definition – Knowledge of the structure of the main phyllosilicates
• Knowledge of the main ions located in natural waters
• Knowledge of the definitions of specific surface area and material porosity

Assessment

Final exam
Continuous assessment

Head of the training unit:

Emmanuel Tertre (emmanuel.tertre@univ-poitiers.fr)

Main contributors

Emmanuel Tertre, Poitiers University (IC2MP Institute)
Fabien Thomas, CNRS, Université de Lorraine, LIEC
Based on examples and applications to clays and other minerals, we will see how to use a wide range of techniques dedicated to solid characterization (spectroscopy, diffraction) to better analyze, understand and model mineral structures. The module will mainly rely on the study of the structures and crystal chemistry of lamellar materials and more specifically clays. The great chemical and structural diversity of these minerals makes them complex subjects of study, thus allowing us to understand the analysis capabilities and limitations of the different instruments with a complex natural material.

**Objectives**

This module, in two parts, is intended for all students who, in their professional life, will be confronted with scientific instrumentation and/or the characterization of natural/synthetic material using physical methods.

The second part of this module is intended to allow a thorough interpretation of spectroscopic and diffraction signals. Detailed and quantitative information on the properties and structures of minerals/materials is thus possible.
Content

1) **Diffraction:**
After being introduced to the basics of diffraction in the first part of the module, students will learn about the advanced possibilities of X-ray diffraction. This part of the module will thus address the physical and analytical details of diffraction through modelling approaches. In this way, structural and quantitative information can be extracted from minerals/materials.

- Application of X-ray diffraction to the identification of clay minerals (phyllosilicates)
- Specificities of lamellar materials and clay minerals with respect to X-ray diffraction (isomorphic substitutions, order-disorder, structural defects, stacking faults, interstratification)
- Quantitative mineralogical analysis of natural samples containing disordered phases (Rietveld modelling)
- Structural defects taken into account during structural characterization of lamellar materials (modelling of experimental diffractograms).

2) **Spectroscopic techniques and additional mineral information:**
In order to obtain a range of spectroscopic techniques for solid analysis, the module also covers the basics of complementary techniques:

Introduction to X-ray absorption spectroscopy to obtain information on the local order around a specific element (usually a transition metal).

Introduction to Nuclear Magnetic Resonance. Such technique allows to obtain information on the order around specific atoms (H, Na, Al for solid NMR) and complementary atoms. On the other hand, the possibility to probe H becomes interesting for interactions between mineral and organic matter. The NMR teaching will be complemented by a mineral/infra-red interaction component, providing a comprehensive and coherent view of the OM studies.

3) **Electronic Paramagnetic Resonance**
Electron paramagnetic resonance spectroscopy is a sensitive and non-destructive method concerning species with unpaired electrons.
Analyzed species include cations of transition elements, point radiation-induced defects, organic free radicals.
Main applications will be done on clay minerals (distinction of conditions of formation, reconstruction of past migrations of radioelements, dating).
Prerequisites

• Bases of mineralogy
• Basics in mathematics, chemistry and physics (general science course)

Knowledge/skills acquired

• Solid knowledge of the crystalline structures and crystal-chemistry of lamellar mineral materials.
• Complete vision of the analysis of a mineral through different techniques (diffraction, spectroscopy).
• Ability to manage the entire chain of analysis, from sample preparation and data acquisition to final analysis and understanding radiation/material interactions.
• Ability to process a signal (XRD, FTIR...).
• Ability to extract the relevant crystal-chemical information while being aware of the limitations of their analyses.

Assessment

Final exam
Continuous assessment

Head of the training unit

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Main contributors

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Thierry Allard, CNRS, IMPMC Paris
Baptiste Dazas, Poitiers University (IC2MP Institute)
Alexandre Simionovici, Grenoble Alpes University (ISTerre Institute)
Course unit: **Soil science – current research and development on soils components**

Semester 2 - ECTS credits: 3 (25h including 10h lectures, 6h tutorials, 9h methodological workshop) - Seminars (3h)
Teaching language: English

This course concerns the study of soil mineralogy and the key role played by minerals in the current worldwide challenges in soil science research. The first part of the teaching is focused on the methodology for the identification of soil minerals. The second part addresses the role of soil minerals through three worldwide challenges in soil science: feeding resources, carbon sequestration and the migration of contaminants.

Practical skills developed in the research laboratory focus on the main steps leading to the identification of soil minerals: sample preparation, data recording and interpretation of the data.

**Objectives**

One of the objectives of this course unit is to introduce the key role of mineralogy in the main current challenges in soil science research (feeding resources, carbon sequestration and the migration of contaminants). The second objective is to train the student to implement and optimize methodologies for the characterization of soil minerals.
Content

• General introduction on soil mineralogy
• Advanced method for the identification of soil minerals based on the X-ray diffraction profile modelling approach.
• Identification and role of soil minerals in the context of agricultural and forest soils.
• Role of mineralogy for the soil carbon sequestration.
• Role of mineralogy for the migration of contaminants.

Prerequisites

• Course unit: Soil science – Soil formation processes
• Course unit: Minerals/Materials characterization techniques

Knowledge/skills acquired

• Implementation and optimization of methodologies at the laboratory for the characterization of soil minerals.
• Expertise concerning the identification of soil minerals and their role for soil carbon sequestration, feeding resources and migration of contaminants.

Bibliography


Assessment

Final exam
Continuous assessment (report on practical activity/methodological workshop)

Head of the training unit

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Main contributors

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Laurent Caner, Poitiers University (IC2MP Institute)
Pierre Barré, ENS Paris (Geology lab)
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The sub-surface geological systems of the continents (diagenetic and hydrothermal series) are complex. These systems can be extremely dynamic over time and in space, in response to changes in environmental conditions (temperature, fluid composition, tectonic activity, etc.). In the case of sub-surface rocks, alteration due to circulation of crustal fluids linked to sediment burial, tectono-magmatic/metamorphic activity causes extensive changes in the mineralogical composition and texture of the rocks. These changes are at the origin of the formation of the main deposits that constitute the resources of metallic raw materials, minerals and fossil or renewable energy necessary for the economic development of our societies (hydrocarbons, uranium, geothermal reservoirs...).

Objectives

In each geological system considered, interventions will focus on the use of the properties of altered/transformed rocks and clay minerals as markers for the evolution of fluid/rock interaction conditions. Clay minerals are particularly reactive and important actors of fluid-rock interactions. They have the ability to archive the history of geological formations in reaction mineral sequences or the intrinsic properties of crystals. They will be therefore used as potential markers of the chemical and physical conditions essential for understanding the functioning of natural systems.
Content
• Several sub-surface geological environments will be addressed
• Ocean domains and underwater hydrothermalism
• Geothermal fields and continental hydrothermalism
• Sedimentary basins and the silicoclastic diagenesis
• This module includes sampling (field work and/or lab) and integrated laboratory study of natural samples (use of different petrography-mineralogy tools). This work is carried out on samples from environments described in the module with a problematic applied to the natural resources and energy sectors.

Prerequisites
• Basic knowledge of petrology/mineralogy.
• Minerals/Materials characterization course units of semester 1 and 2

Knowledge/skills acquired
• Up-to-date basics on the petrology of alterations and mineralogy of clays in the sub-surface context
• Ability to conduct representative and relevant sampling
• Implementation of the techniques studied during semesters 1 and 2: sample preparation, analysis and interpretation in terms of paleo conditions.
• Ability to format results

Assessment
Final exam
Continuous assessment (report on practical activity/methodological workshop)

Head of the training unit
Patricia Patrier, patricia.patrier@univ-poitiers.fr

Main contributors
Patricia Patrier, Poitiers University (IC2MP Institute)
Martine Buatier, Franche Comté University (Chrono Environnement lab.)
Jean Pierre Girard, TOTAL Company
Claire Fialips, TOTAL Company
Abder EL Albani, Poitiers University (IC2MP Institute)
The module prepares the student for scientific communication (written and oral) and in particular for writing and defending a project and/or an internship dissertation. It is based on analyses of scientific documents, presentations of reports, and the production of a poster.

**Objectives**

The aim is to provide the student with communication tools and approaches that will be necessary during the training period (during periods of internship in a company/laboratory or for the projects he/she will have to carry out) as well as during his/her professional career.
Content

• Decryption of scientific articles to identify the steps to follow when writing articles.
• Creation of posters
• Oral presentations and self-assessment procedures
• Individual or collective drafting of scientific documents (in particular internship project document) and their presentation to the jury.
• The student may be asked to present these works during open days or scientific days.

Prerequisites

• Bases in geology and mineralogy.

Knowledge/skills acquired

• Mastery of traditional office automation tools for writing and presenting data
• Ability to manage time in an oral presentation
• Ability to collect, critically evaluate, synthesize and report on a particular subject according to a particular standard (bibliographic synthesis...)
• Ability to format results and communicate through various media (oral presentations, writing reports, posters, etc.).
• Ability to present/write a research project according to the standards requested by the company.
• Awareness of plagiarism regulations.

Assessment

Oral presentation (internship activity)
Internship report

Head of the training unit

Abder El Albani, abder.albani@univ-poitiers.fr

Main contributors

Abder El Albani, Poitiers University (IC2MP Institute)
Course unit: **English**

Semester 2 - ECTS credits: 3 (25h including 25h tutorials) - Teaching language: English

**English for specialists in Mineral Material science**

**Content**
Continuing work on grammar and linguistic structures, in class and autonomously, texts relevant to discipline (comprehension and expression), oral comprehension using video documents in the language laboratory, production of film on chosen subject relevant to discipline and continuing oral interaction work in class...

**Prerequisites**
Minimum required level of English: Level B1+

**Knowledge/skills acquired**
Practical communication, comprehension and expression

**Objectives**
Continuing development of comprehension and expression skills with additional emphasis on specialised technical vocabulary relevant to discipline.

**Assessment**
Continuous examination

**Head of the training unit and contributor**
Andrew King, andrew.king@univ-poitiers.fr
Minimum 1 month internship (up to 4 months) in university or industrial laboratories. This internship is a key element of the training because it allows a complete immersion in a professional environment (academic laboratory and/or company).

**Objectives**

The objective of this module is to develop:

- Organizational skills (working independently, conducting information research, implementing and carrying out a project)
- Relational skills (integration into a professional environment)
- General scientific skills (implementation of a scientific approach)
- Specific disciplinary skills

The student will have to be able to use information and communication technologies, to prepare adapted communication materials, to speak in public, to present the major scientific points of his or her work.
Examples of internships:

**Environment - soil**

- Environmental impact of the Torkuduk mine (Kazakhstan) - Uranium recovered by in-situ recovery (AREVA)
- Study of basalt weathering in Southern Brazil (IC2MP)
- Development of mesoporous organo-siliceous compounds for trapping organic pollutants in aqueous phase (Univ. Aveiro)
- Use of HDL in decontamination (Charles Gerhardt Institute, Montpellier)
- Effects of environmental parameters on phosphate adsorption by kaolinite (Eco&Sols, Montpellier - INRA)
- Assessment of the bioremediation potential of aquifers exploited by acid ISR (AREVA)
- Beidellite sorption properties with respect to inorganic elements (Na⁺, Ca²⁺, Mg²⁺, K⁺) (IC2MP)
- Establishment of a database on soil characteristics in the Paris basin (Geolia)

**Exploration/Exploitation mining and energy**

- Petrography and sedimentology of the Francevillian Basin - Gabon (Univ. Poitiers)
- Hydrocarbon migration in Los Chihuidos Formation, Neuquen Basin, Argentina. (Univ. Poitiers - Univ. Comahue)
- Hydrothermal alteration associated with the epithermal deposit at Ag de Navidad (Argentina) - (IC2MP Univ. Poitiers - Univ. Rio Negro Argentina)
- Use of portable IR spectrometry for high energy geothermal exploration (Guadeloupe) (BRGM)
- Spectral analysis of iron oxides and associated clay minerals and their application to iron deposits (CSIRO - Australia)
- Evolution of depositional setting and diagenetic grade over Precambrian/Cambrian : Podolia basin (Ukraine) – (IC2MP)
- Crystal-chemistry and typology of chlorite coatings in sandstone reservoirs: relation with deposit facies and early diagenesis (TOTAL)
Civil Engineering

• Limits of use of clay sands in bituminous binders: physico-chemical study (IFSTTAR)
• Handling of dust during excavation and construction phases, impact on water consumption (IFSTTAR)
• Spatial distribution of drying slots in marsh soils: tomography coupling - electrical resistivity (IC2MP, Univ. Poitiers)
• Development of a method for a field diagnosis on the swelling behaviour of clays (BRGM)
• Mineralogical control of the petrophysical properties of clayey rocks: Study of the Montiers-Sur-Saulx site (ANDRA)
• Simple compressive strength of concrete specimens with variable bentonite content (IFSTTAR)

Geomaterials, nanomaterials

• Behaviour of clayey materials subjected to helium implantation (PPRIME)
• Elaboration of heterostructures based on assemblies between LDH and sepiolite : development of functional materials for environmental applications (Univ Clermont Ferrand)
• The rheological and organophylic properties of an Uruguayan bentonite. (Tech. Univ. of Crete)
• Extraction of aluminum by acid treatment of kaolin. (Tech. Univ. of Crete)
• Textured ceramics based on phyllosilicates: formulation, processes, properties (ENSCI Limoges)
• Study of Manganese speciation in an industrial process involving Montmorillonite clays (IPSEN)

Geoarcheology

• Physico-chemical characterization of plaster coatings and wall flakes for buildings of the Iron Age in western Gaul (Saint-Georges-les-Bailleul; Paule; Quimper; Prat, site of Pouilladou...) (IC2MP-HeRMA lab., Univ. Poitiers)
• Analysis of the degradation of green marble: Raman mapping of the serpentine structure (CICRP - CINaM Marseille)
• The evolution of bacteria and organic molecules during a fossilization context (UPMC-Paris)

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Second year

PROGRAMME
The analysis of the rock microstructure (organization of minerals and pores) is pivotal for understanding their geological history and physical properties (fluid transfer and mechanical behavior). To solve this, imaging techniques are subject to intense developments and widely applied both for academic researches and industrials applications. The obtained data feed realistic modelling approaches of macroscopic physical properties of rocks.

**Objectives**

The aim is to understand the physics, the advantages and limitations of the different methods available for characterizing the microstructure in order to be able to combine them in a multiscale approach and feed realistic modelling of rock properties.
Content

• Advanced gas adsorption methods for pore network and reactive surface analyses.
• Preparation methods for microscopy
• 2D/3D imaging techniques of the solid skeleton and pore network at different scales: quantitative mapping of minerals and porosity from core scale down to the crystal scale
• Practices: acquisition and advanced treatment of gas adsorption isotherms and imaging data (chemical mapping, X-ray tomography, 2D and 3D high resolution scanning electron microscopy, autoradiograph).

Prerequisites

• Unit formula calculations, beam/matter interactions, excel, clay crystal-chemistry.

Knowledge/skills acquired

• Being able to analyse the organization of materials by using cutting-edge imaging technics at different scales and accounting for their limitations and advantages.
• Being able to analyze the pore network by classical bulk methods, taking account of the assumptions applied.

Assessment

Practical activity report

Head of the training unit

Prêt Dimitri, dimitri.pret@univ-poitiers.fr

Main contributors

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Isabelle Gener Batonneau, Poitiers University (IC2MP Institute)
Fabien Thomas, CNRS, LIEC Nancy
Industrial minerals and geomaterials (kaolin, quartz, talc, feldspar, clay, lime...) are natural raw materials essential for the manufacture of products of everyday life (buildings, vehicles, computers, medicines, paper, paint, plastic, glass, cosmetics, etc.). They therefore represent major economic issues, and a need to know the structure and physico-chemical properties of these materials, thus conditioning their use and their economic interest.

**Objectives**

The objective of the course unit is to provide the students with fundamental on industrial clays and on uses and reactivity of clay based material (including reuses and recycling).

**Content**

(i) The principal aspects of industrial clays. The students receive a brief introduction in clay mineral structures followed by presentation of the main physical properties of clays valued by the industry (cation exchange capacity, plasticity, viscosity, colour, particle size distribution, reactions with organic and inorganic molecules). The main types of industrial clays are presented (bentonites, kaolins, palygorskite and sepiolite, vermiculite, common clays and shales). For each type of industrial clay the geological, mineralogical and geochemical characteristics are presented followed by techniques for their characterization and by assessment routes. Typical examples will be presented. The students perform an evaluation of characteristic industrial clays in the laboratory (bentonite, kaolin) and prepare their own reports. Finally each student presents a seminar on a specific topic related to industrial clays.
(ii) The uses and reactivity of these clay or clay-based geomaterials for various applications related to building materials and civil engineering. The students will discover various routes such as cements/concretes, geopolymers, composite materials, and soil stabilization. The rheology of geomaterials will also be seen because of its importance in knowledge phenomena and their use. The students perform practical materials-making applications that they will characterize from beginning to end. Finally, in accordance with the circular economy the reuse and recycling of geomaterials will be introduced. The module also provides a realistic idea of the research and development sector in this area.

**Prerequisites**
Bases of mineralogy and characterization of clays.

**Knowledge/skills acquired**
- To become familiar with the industrial clays and their properties
- To be able to characterize and evaluate industrial clay deposits for the most important industrial applications
- To become familiar with geomaterials and the reactivity of clays during mixed reactions

**Assessment**
Final exam
Continuous assessment

**Head of the training unit**
Emmanuel Joussein, emmanuel.joussein@unilim.fr

**Main contributors**
- Emmanuel Joussein, University of Limoges (PEREINE- GRESE)
- George Christidis, Technical University of Crete, School of Mineral Resources Engineering
- Dimitri Deneele, CNRS, IMN Nantes
- Sébastien Jarny, Poitiers University (PPRIME Institute)
- Gisèle Lecomte, Limoges University (SPCTS)
The course unit “clays in cultural heritage” proposes to present an overview of conservation issues on built heritage as well as cultural heritage in museum dealing with clay mineral.

Clay minerals are present in sedimentary or metamorphic stones but also in an extremely wide and varied raw earth heritage. Color is also one of the most important properties of objects, in archaeology and art history. Among the traditional inorganic pigments, iron oxides and earth are considered for their archaeological evidence and their uses (medicinal, religious, decorative purposes...).

**Objectives**

- How is identified this heritage, and what are its conditions of conservation? To answer these questions, we propose to contextualize clay minerals within the porous material, and show how clay minerals can be a source of strength and a weakness for objects and buildings.
**Content**

This course is the opportunity to show:
- Impacts of hydric and hygric deformations that can cause heavy damages on buildings (flaking, cracking of withdrawal, etc...).
- A multiscale approach of material from capillary cohesion between clays and grains to build buildings for millennia.
- The know-how of clays and ceramics: origin of the raw material, evolution of ceramic techniques through the ages: multi-scaled analytical protocols illustrated with examples from the most famous ceramic productions.
- Unfired clays artifacts and their conservation challenge: Mesopotamian clay tablets, a complex researches involving interdisciplinary teams.
- Applied research on causes of degradation in buildings, and the ways to conserve and restore this extremely rich heritage: a conservation approach different from the museum conservation.
- Clays and their specific properties used for conservation purposes of object and building (cleaning, desalination...).
- Pigments: Chemical composition, structural and chromatic properties, stability and also both natural origin and synthetic production from the modern times will be presented.

**Knowledge/skills acquired**

- Ability to understand a multiscale approach
- Ability to understand issue between conservation and innovating researches

**Assessment**

Final exam
Continuous assessment

**Head of the training unit**

Anne Bouquillon, anne.bouquillon@culture.gouv.fr

**Main contributors**

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Anne Solenn Leho, C2RMF, Le Louvre Paris
Ann Bourgès, Laboratoire de recherche des monuments historiques, Champs-sur-Marne
Anne Liegey
The capacity to properly address the worldwide incidence of infectious diseases lies in the ability to detect, prevent and effectively treat these infections. Therefore, identifying and analyzing inhibitory agents are worthwhile endeavors in an era when few new classes of effective antimicrobials have been developed. The use of geological nanomaterials to heal skin or other infections has been evident since the earliest recorded history, and specific clay minerals may prove valuable in the treatment of bacterial diseases, including infections for which there are no effective antibiotics.

Overuse of antibiotics in healthcare is a major concern because of the consequential proliferation of antimicrobial resistance. Recent research studies highlight the effective inactivation of antibiotic resistant microorganisms using appropriate clays, as an alternative approach towards public health protection and elimination of infectious diseases.
Objectives
The aim is to understand the physics, the advantages and limitations of the The objectives of the course unit is to introduce environmental microbiology and the behavior/response of microorganisms to biocidal factors. This introduction includes i) the composition of microbial cell and the main groups of microorganisms involved with public health issues, and which may be found in the environment; ii) antimicrobial properties of clays in relation to the different mechanisms of resistance which may be induced in microbial cells; iii) evolution of microorganisms in terms of the development of resistance under environmental stressed conditions and its overall impact for public health.

Content
• Introduction to environmental microbiology – major microbial groups important for public health
• Microbial nutrition/growth
• Antibiotic resistant bacteria – microorganisms and metal pollutants
• Clays VS microorganisms – microbial terminology (bacteriostatic & bactericidal agents)
• Healing clays
• Testing antibacterial properties of clays
• Antibacterial components present in therapeutic muds – mode of action
• Antibacterial activities of clay minerals against antibiotic-susceptible and antibiotic-resistant bacterial pathogens
• Clay polymer nanocomposites (CPNs) for the removal of microorganisms
• Advanced oxidation processes for environmental applications

Prerequisite
• Basic knowledge in clay mineralogy and characterization techniques.

Knowledge/skills acquired
Students will be introduced to the beneficial effects of clays in terms of their use as antimicrobial agents, against virulent pathogens that are considered threats to public health. They will be familiarized with the applications of environmental microbiology and methods used for the evaluation of microbial resistance in the presence of biocidal factors.
Bibliography

Assessment

Final exam
Literature review
Seminar projects

Head of the training unit
Danae Venieri, danae.venieri@enveng.tuc.gr

Main contributors
• Danae Venieri, Technical University of Crete (Environmental Microbiology Lab.)
• Iosifina Gounaki, Technical University of Crete (Environmental Microbiology Lab./Technical lab. staff)
Semester 3 - ECTS credits: 6 (50h including 21.5h lecture, 20.5h tutorials, 8h practical) - Teaching language: English

Course unit: **Functionalized layered materials and minerals**

Objectives

The objective of this course unit is to provide the student with the necessary basis of modified clays, layered double hydroxides and nanocomposites and skills in the synthesis and modification of these materials as well as in characterization (structural/property relationships, advanced characterization methods).

In order to meet environmental and societal challenges, the use of abundant and inexpensive natural or synthetic minerals and materials is particularly important. The modification/functionlization of the clays and Layered Double Hydroxides and the understanding of the structure-property relations allow to increase their fields of application, which can thus be aimed at catalysis, health, environmental remediation, energy storage or conversion and the development of mineral fillers as polymer additives (nanocomposites).
### Content

Modified clays
- Modifications of clays by ion exchange and grafting
- Modifications of clays by direct synthesis
- Thermal behavior

Modified LDH and LDH
- Direct synthesis and morphology of LDH
- Hybrid LDH and LDH structures and microstructures
- Green Rust: Formation, structure, reactivity and environmental impact

Nanocomposites Clay and functional materials
- Nanocomposites: Polymer-clay and clay-nanoparticles
- New developments in research

LDH Nanocomposites and Functional LDH Materials
- Properties, functionalization and application of LDH
- Practical work: Synthesis of LDH in soft chemistry

### Prerequisites

- Mineral/material characterization techniques.

### Knowledge/skills acquired

- Perform/know the methods of synthesis and modification of lamellar and mineral materials.
- Predict or implement an approach to predict the structure/property relationships of materials and minerals.
- Implement advanced characterization methods.

### Assessment

Final exam
Continuous assessment

### Head of the training unit

Brian Grégoire, brian.gregoire@univ-poitiers.fr

### Main contributors

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Modelling (numerical simulation) is an approach used increasingly in all scientific branches, including material science, chemistry, biology and physics. Its ascent, since the 1980s, goes hand in hand with the ever-increasing computational power, as well as improvements in the simulation algorithms used. Within a given model of a system, modelling allows measuring physical quantities that are inaccessible experimentally, either because of low signal intensities or due to extreme conditions, such as high temperatures and pressures. Modelling can now be considered as part of the standard set of tools to study mineral materials.

Objectives

The objectives of this course unit is to introduce the principal methods used to simulate structure and dynamics in minerals (Monte Carlo, Molecular Dynamics). This introduction is supported by numerous examples on clay materials (about half of the module is practical work) where the student encounters basics of programming, the general structure of a simulation code, and is shown how to exploit simulation results to arrive at meaningful physical quantities.
Content

After a reminder of the main concepts of statistical thermodynamics necessary to understand atomic-level simulations (thermodynamic ensembles, ensemble averages etc.), the two main methods of atomic-scale modelling are introduced: Monte Carlo and Molecular Dynamics. We show several recent examples of simulations on clays, highlighting the physical quantities they allow us to calculate. We finish by showing the multiple points of comparison of simulated data with experimental results, mainly by scattering techniques (X-ray and neutron scattering), and highlight the additional information simulations bring into the description of clays.

Prerequisites

Mathematical operations - including basics of integration and differentiation, basics of probability, basics of thermodynamics (1st and 2nd law, state functions), basics of atomic structures and crystallography.

Knowledge/skills acquired

• Main concepts of statistical thermodynamics and the principles of the two main methods of molecular modelling – Monte Carlo and Molecular Dynamics
• Basics of programming and general structure of a simulation code
• Simulation results exploitation to arrive at meaningful physical quantities.

Assessment

Final exam
Continuous assessment

Head of the training unit

Natalie Malikova, natalie.malikova@upmc.fr

Main contributors

Benjamin Rotenberg, CNRS, PHENIX lab. Paris
Virginie Marry, UPMC University Paris (PHENIX lab.)
Natalie Malikova, CNRS, PHENIX lab. Paris
Roland Pellenq, Massachusetts Institute of Technology (MIT)
Course unit: *Organization of clay suspensions*

Semester 3 - ECTS credits: 3 (25h including 9h lectures, 7h tutorials, 9h practical)
Teaching language: English

This unit will present the different possible structures of colloidal systems (in water saturated conditions) and will try to make the link with rheological properties. Concepts concerning electrostatic interactions (type, condition and range), auto-organization and phase transitions will be introduced in general and illustrated in the cases of clayey dispersions. The structural and mechanical behavior will be analyzed by using tools as small-angle X-ray scattering and rheology in saturated conditions. The analysis of data will familiarize students with experimental approaches, especially on the type of information which can be obtained.

**Objectives**

The main objective of this unit will be to give basics of physico-chemistry and tools in order to determine/predict the structure of colloidal dispersions in relation with the physico-chemical parameters of the media (salinity, solid/solution ratio...) and intrinsic properties of the fine particles chosen (size, morphology, surface charge...). The different concepts will be illustrated by giving examples issued from everyday life and scientific literature.
Content

- Colloidal stability (DLVO theory, repulsive and attractive forces)
- Structural organization of repulsive colloidal systems in water saturated conditions (using data from small-angle X-ray scattering)
- Liquid crystal - phase transition
- Relation between structure of colloidal system and rheological properties

Prerequisites

**Knowledge of:**
- Electrical double layer
- Mechanical properties and rheological models

**Knowledge/skills acquired**

- Predict the colloidal behavior of a colloidal dispersion (stability versus aggregation)
- Comment a phase diagram salinity/solid-solution ratio for a colloidal system
- Know the structural parameters of a colloidal system which can be obtained from the analysis of small-angle X-ray scattering data.
- Make the link between mechanical properties obtained at the macroscopic scale and colloidal organization obtained at the meso and microscopic scales.

Assessment

Final exam
Continuous assessment

Head of the training unit

Erwan Paineau, erwan-nicolas.paineau@u-psud.fr

Main contributors

Erwan Paineau, Paris Sud University (LPS Lab.)
Emmanuel Tertre, Poitiers University (IC2MP Institute)
English for specialists in Mineral Material science

Content
Texts relevant to discipline and professional life (comprehension and expression), oral presentation of completed internship using appropriate linguistic structures and vocabulary, preparation of CV and oral presentation of individual as a candidate detailing education, professional experience and personal elements. Familiarization with TOEIC (reading and listening)

Prerequisites
Minimum required level of English: Level B2+

Knowledge/skills acquired
Practical communication, comprehension and expression

Objectives
Development of language skills relevant to professional life, development of comprehension and expression skills with emphasis on specialised technical vocabulary relevant to discipline...

Assessment
Continuous examination

Head of the training unit and contributor
Andrew King, andrew.king@univ-poitiers.fr
This module is an introduction to civil engineering and geotechnical activities related to the presence of clayey geomaterials (soils, rocks, backfill materials). It is devoted to the description of the macroscopic (mechanical and rheological) and microscopic behavior of clays in soils or rocks.

**Objectives**

This module aims to make students aware of the potential of clays and the problems they generate. Indeed, although clays are remarkable materials because of their properties (e.g. rheological properties that make them good drilling muds, low permeability that allows them to ensure the tightness of structures), they are nevertheless at the origin of many problems in civil engineering. Their detection in a ground intended to receive a pavement or a building requires the implementation of specific measures (e.g. adapting the dimensioning of the structure, reinforcing the foundations or the structure, treating the ground). In contrast, clay swelling properties (responsible for disorders underneath buildings in times of drought) are used to ensure the sealing of the structure to waste storage.
Content

Introduction to the mechanics of clay geomaterials
The course covers the main characterizations of the mechanical behavior of clay geomaterials:
- Physical characterization (densities, void index, porosity, granulometry ...)
- (Hydro) mechanical characterization: Terzaghi principle, Biot parameters.
- Consolidation of clay soils: role of interstitial water, oedometric test.
The influence of mineralogy and clay structure on the mechanical response is also introduced.

At the end of the course, students, in groups of two or three, conduct a geotechnical project. This project deals with the computation of the settlements of a petroleum tank carried out on a compressible clay soil.

Shrinkage and swelling of soils under foundation
The course presents a global approach of shrinkage-swelling phenomenon (geotechnical hazard) or how to take into account the presence of swelling clays in soil under a construction. The microscopic properties of clays are revised (classification, microstructure, ability to swell...) and how it can help geotechnicians to characterize the in situ soil sensitivity to shrinkage and swelling. Climatic factors and geological, hydrological and topographic context related to the site have to be considered too. The map and risk prevention plans have to be consulted and on-site recognition and laboratory tests applied. Finally, the factors that can trigger or aggravate the swelling-shrinkage phenomena as well as the different ways to prevent damages by acting on construction or on soil are presented.

Clay soil treatment and durability: earthwork and surface waste storage
The course covers the various aspects of techniques related to clay materials implementation in the field. This module aims at raising students’ awareness on: the different phases of earthworks projects and at emphasizing the importance of the choice of materials; the opportunity to take benefit of the physical and chemical properties of clays for engineered barriers; the various techniques of soil treatments to reinforce the durability of the performance of waste materials.

At the end of the course, the students, in groups of two or three, carry out a project around issues related to earthworks and in particular on the soil-atmosphere interaction.


**Tunnel and underground structures in clayey rocks**

The behavior of underground structures in clay rocks has been studied for many years, particularly in the context of radioactive waste disposal projects. This course takes stock of the knowledge acquired in the field and presents the problems related to digging tunnels and underground structures in clay rock masses. Particular emphasis is placed on sizing, excavation and support methods in clayey rocks. The course is illustrated by real cases to highlight the specificities of these materials, including the development of the damaged zone, and the adaptations they require in different methods of digging and support.

**Introduction to (natural or synthetic) clays, cement, plaster and ceramic pastes rheology**

This course is an introduction to geomaterials rheometry and their application in the field of civil engineering with a practical session on materials. The first part presents the theoretical bases of rheology by presenting the behavior laws used with geomaterials, with some results illustrating the theory. Then a presentation of the measurement tools used both in situ and in laboratory is made with particular emphasis on the different geometries of laboratory rheometers. The assumptions related to their use are detailed from a theoretical and practical point of view as well as the advantages and disadvantages inherent to each geometry. At the end of the course, a project is proposed to the students in the form of measurements (Practical session) and analysis (in autonomy) of results on clay suspensions. They analyze their experimental curves with free software that they can download legally and by using scientific reference articles distributed for this purpose.

**Prerequisites**

Education in Earth sciences, Physics (material), Physical chemistry.

**Knowledge/skills acquired**

- Basics of soil and rock mechanics, rheology of pastes and suspensions.
- Geotechnical description of a soil or rock (geotechnical identification).
- Microstructural description of a clayey soil (mineralogy and microstructure)
- Introduction to the problems generated by clays in civil engineering
- Basics of soil treatment in earthworks
Assessment

Final exam
Continuous assessment

Head of the training unit

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Main contributors

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Richard Giot, Poitiers University (IC2MP Institute)
Andry Razakamanantsoa, IFSTTAR/GERS/GMG (French Institute for Transport, Development and Networks Science and Technology)
Master thesis internship

Semester 4 - ECTS credits: 27

Objectives

The objective of this module is to develop:

• Organizational skills (working independently, conducting information research, implementing and carrying out a project)
• Relational skills (integration into a professional environment)
• General scientific skills (implementation a scientific approach)
• Specific disciplinary skills

Minimum 5 months internship (up to 6 months) in university or industrial laboratories. This internship is a key element of the training because it allows a complete immersion in a professional environment (academic laboratory and/or company).

Student will have to apply all the knowledge/skills acquired during the first 3 semesters to deal with a real scientific or technical problem.

The student will have to use information and communication technologies, to prepare adapted communication materials, to speak in public, to present the major scientific points of his or her work, to lead a scientific debate on the topic addressed during the internship and to propose extensions to his/her work.
Examples of internships:

Environment - soil

• Characterization of transported and/or precipitated solids in mine effluents (AREVA)
• Importance of clay minerals for trapping metallic elements in the lagoon of New Caledonia (Program CNRT-ADIIP / Univ. Aix Marseille)
• Mineralogical evolution induced by plant activity and K consumption (ISTerre, Grenoble)
• Study of the formulation of fertilizers containing lamellar materials to ensure the growth of plants by controlled release of amino-acids (IS2M)
• Characterization of the heterogeneities of the Uyuk reservoir, interpretation of their distribution in the context of rehabilitation of an in situ recovery operation of an uranium deposit. (AREVA)
• Selective capture of phosphate from wastewaters for improved quality of the P product using LDH recyclable materials (Univ Clermont Ferrand)
• Study and monitoring of soil evolution in Marais Poitevin area (IC2MP)
• Environmental tracing of an old Cu-Sn mine in proximity of Bois Noirs Limouzat site (AREVA)
• Nanoscale organo-mineral interactions in soils, nanoSIMS approach (CEREGE)

Exploration/Exploitation mining and energy

• Characterization of clay minerals identified in the Gold Mine of Mont Ity gold (Ivory Coast), prospecting assistance (LA MANCHA)
• Garnierite and nickel serpentine characterization — implication for Solsa project (BRGM)
• Contribution of clayey sediments to the understanding of the functioning of the turbidite from the Quaternary system of Ogooué (Gabon) (IC2MP)
• Crystal chemical and mineralogical evolutions of clay minerals in the Vaca Muerta formation: impact on the Vclay (TOTAL)
• Characterization of clays and crystal-chemistry of smectites in uranium mines exploited by ISR (AREVA)
• Combining multisensors for iron ores characterization (CSIRO)
• Quantification of coffinite by visible spectrometry — SWIR (AREVA)
• Study of disequilibrium of 238U and 232Th disintegration chains by mapping approach (AREVA)
Civil Engineering

• Study of the chemical and microstructural evolution of cement material at 70°C interacting with a clayey rock in a context of radioactive waste storage (IRSN)
• Potential impact of La Peyratte granite mineralogy on its use in road techniques (COLAS)
• Monitoring of hydromechanical deformation induced by removing the support of an underground gallery excavated in clay rocks (IC2MP)
• Co-valorization of materials applied to dredged sediments (IFSTTAR)
• Sustainability and implementation of soil mixing material (IFSTTAR)
• Influence of cement additives on cement hydration (IMN)

Geomaterials, nanomaterials

• Effect of clays on cement hydration (IFSTTAR-IMN-LAFARGE)
• Characterization of kaolinite properties in the Rio Capim region (North Brazil). (UFRGS)
• Processes for improving low quality kaolin. (Tech. Univ. of Crete)
• Impact of alumino-silicate source on geopolymer formation - (IFSTTAR)
• Bacterial Reduction of Synthetic Nontronites (Univ. Ottawa)
• Study of Velay clays (Univ Clermont Ferrand)
• Consolidation of clay materials: process – microstructure – properties (ENSCIL)
• Study of encapsulation of dyes in lamellar materials (IS2M)
• Phosphate removal from water using yttrium and aluminum modified clays (Tel Hai College)
• Surface properties of Fe-doped imogolite nanotubes (UPS)
• Formaldehyde oxidation over bulk and supported mesoporous transition metal oxides (UCCS)
• Impact of alumino-silicate sources on geopolymer formulation (IMN/IFSTTAR)
• Synthesis and characterization of oxide nanoclusters supported onto reduced graphene oxide substrate (IC2MP)
• Liquid-crystalline phases behavior of inorganic metal-oxide imogolite nanotubes (UPS)
• Kaolinite intercalated by urea : ceramic applications (ENSCIL)

Geoarcheology

• Determination of the origin of the rocks constituting the historical monuments of Poitiers. (ERM Poitiers)
Graduation ceremony