UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Geochronology and Geochemistry of The Solid Earth

2627-1-F7402Q038

Aims

O1 – Knowledge and understanding

1. Understand the fundamental principles of geochronology and the role of absolute and relative dating in reconstructing the evolution of geological processes over different timescales.
2. Understand the principles of natural radioactivity, radioactive decay, decay constants, decay chains, secular equilibrium, and the concept of a closed isotopic system.
3. Understand the main radiometric dating methods, with particular reference to the K-Ar, Ar-Ar, Rb-Sr, U-Th-Pb, radiocarbon, cosmogenic nuclide, thermoluminescence and fission-track systems.
4. Understand the geological meaning of ages obtained from different geochronometers, distinguishing between crystallization, cooling, metamorphic, alteration, surface exposure, burial and eruption ages.
5. Understand the role of closure temperatures, isotopic diffusion, loss or gain of radiogenic isotopes, alteration and contamination in the correct interpretation of geochronological data.
6. Understand the fundamental principles of solid Earth geochemistry, with particular reference to the origin, behaviour and cycle of volatiles in the Earth's interior.
7. Understand the use of geochemical and isotopic tracers of fluids, including stable isotopes, radiogenic isotopes and noble gases, to reconstruct the origin of magmatic, hydrothermal, crustal and mantle-derived fluids.
8. Understand the relationships among fluid geochemical composition, Earth geodynamics, magmatic and volcanic degassing, submarine and subaerial volcanism, and the impact of volatiles on the atmosphere-hydrosphere system and on Earth's climate.
9. Understand the basics of the main techniques for sampling rocks and fluids, laboratory and field analytical methodologies, and methods for acquiring, visualizing and processing geochronological and geochemical data.

O2 – Ability to apply knowledge and understanding

1. Be able to apply the principles of radioactive decay and radiogenic isotopic growth to the understanding of the main absolute dating methods.

2. Be able to choose the most appropriate geochronological method according to the geological problem, taking into account the expected age, the available material, the datable mineral, the closure temperature and the geological meaning of the age obtained.
3. Be able to interpret geochronological data derived from methods such as K-Ar, Ar-Ar, Rb-Sr, U-Th-Pb, radiocarbon, cosmogenic nuclides, thermoluminescence and fission tracks.
4. Be able to recognize and interpret fundamental geochronological diagrams, such as isochrons, concordia-discordia diagrams, Ar-Ar age spectra, plateau ages, inverse isochrons, isotopic evolution diagrams and exposure/burial diagrams for cosmogenic nuclides.
5. Be able to evaluate the meaning of analytical and interpretative parameters such as initial isotopic ratio, Ar loss, atmospheric correction, J factor in the Ar-Ar method, analytical uncertainty and data dispersion.
6. Be able to apply the concepts of fluid isotope geochemistry to the interpretation of the origin of volatile species in magmatic, hydrothermal, crustal and mantle-derived systems.
7. Be able to use isotopic ratios and chemical compositions of fluids to distinguish mantle, crustal, atmospheric, sedimentary, organic and hydrothermal contributions.
8. Be able to relate fluid geochemical data to magmatic degassing processes, volcanic dynamics, water-rock interaction, subduction, volatile recycling and gas transfer toward the atmosphere and hydrosphere.
9. Be able to apply basic procedures for visualizing and processing geochronological and geochemical data through graphs, isotopic diagrams, binary diagrams, ternary diagrams, regressions and simple mixing models.
10. Be able to correctly design, at a basic level, a sampling strategy for rocks and fluids aimed at geochronological and geochemical investigations.

O3 – Autonomy of judgement

1. Be able to critically evaluate which dating method is most suitable for addressing a specific geological problem, taking into account the context, the available material and the timescale of the process being investigated.
2. Be able to distinguish between apparent ages and geologically meaningful ages.
3. Be able to assess the reliability of geochronological data on the basis of sample quality, mineralogy, preservation state, consistency of isotopic data, analytical uncertainties and statistical regression criteria.
4. Be able to recognize the main interpretative issues of geochronological methods.
5. Be able to critically evaluate the origin of a natural fluid on the basis of chemical and isotopic data, distinguishing between mantle, crustal, sedimentary, atmospheric, biogenic and hydrothermal contributions.
6. Be able to distinguish between a simple compositional description of fluids and a process-based interpretation, recognizing the geological meaning of isotopic ratios, relative abundances, elemental ratios and geochemical anomalies.
7. Be able to formulate coherent interpretations by integrating geochronological data, geochemical data, and petrological, volcanological, structural and geodynamic contexts.
8. Be able to recognize the limitations of the available data and evaluate when additional analyses, mineralogical checks, petrographic verification, analytical replicates or multi-method approaches are required.

O4 – Communication skills

1. Be able to describe, using appropriate terminology, the fundamental principles of geochronology, natural radioactivity, unstable isotopic systems and the main dating methods.
2. Be able to clearly explain the geological meaning of radiometric and relative ages.
3. Be able to illustrate how the main geochronological methods work, including datable materials, minerals used, analytical techniques, sampling, sample treatment, data processing and interpretative limitations.
4. Be able to describe and interpret geochronological and isotopic diagrams, such as isochrons, concordia-discordia diagrams, Ar-Ar spectra, Pb-Pb diagrams, isotopic evolution diagrams and fluid mixing diagrams.
5. Be able to communicate the interpretation of geochronological or geochemical data in an organized and scientifically correct way, linking the analytical method, numerical result, uncertainty and geological meaning.
6. Be able to correctly use the specific terminology of fluid geochemistry and solid Earth geochemistry, with

particular reference to volatiles, degassing, isotopic tracers, mantle-derived fluids, crustal fluids and geodynamic recycling.
7. Be able to present, orally and in writing, the results of simple geochronological and geochemical data processing, arguing the interpretative choices and recognizing the main uncertainties.

O5 – Learning skills

1. Be able to use the acquired knowledge to independently approach the study of geological processes that require an absolute or relative temporal framework.
2. Be able to independently explore the main geochronological methods and their applications to magmatic, metamorphic, sedimentary, volcanological, geomorphological and tectonic processes.
3. Be able to integrate knowledge of geochemistry, mineralogy, petrography, volcanology, structural geology, geodynamics and the physics of radioactive decay to interpret isotopic and geochronological data.
4. Be able to independently explore topics in solid Earth geochemistry, fluid geochemistry, noble gas geochemistry, terrestrial degassing, volatile recycling and the interaction between the Earth's interior, atmosphere and hydrosphere.
5. Be able to use textbooks, lecture notes, analytical data, diagrams, databases and scientific literature to consolidate and update their knowledge of geochronological and geochemical methods.
6. Be able to transfer the theoretical, analytical and interpretative knowledge acquired during the course to subsequent applications related to natural, environmental, volcanological, geodynamic and climatic processes.
7. Be able to develop a critical and multi-method approach, recognizing that reconstructing the temporal and geochemical evolution of natural systems often requires the integration of multiple geochronometers, multiple isotopic tracers and multiple lines of geological evidence.

Contents

Recall of nucleosynthesis, origin and evolution of the Earth, atomic structure and definition of unstable isotope. Concept of radioactive decay, decay mechanisms, radiometric methods of absolute dating on long and short time scales. Dating through cosmogenic nuclides. Non-radiometric dating methods. Radiogenic isotopes.
Basic concepts of fluid geochemistry. Stable isotopes and isotopes of noble gases. Composition of volatiles in mantle, magma and volcanic/hydrothermal systems. Solubility of volatiles in silicate melts. Magmatic degassing. Compositional variations in relation to geodynamics. Impact of degassing on marine/ocean and atmospheric ecosystems, climate implications. Cycle of volatiles in the mantle.
Main fluid/rock sampling techniques, practical field experience, and analytical methodologies. Acquisition, visualization and processing of geochemical data.

Detailed program

Presentation of the course. Recall on atomic structure, definition of stable, unstable and radiogenic isotope. Notes on nucleosynthesis, formation and evolution of the Earth, geochemical affinity of the elements, geochemical spheres. Recalls on major and trace elements.
Concept of radioactive decay, main decay mechanisms, general equation of radioactive decay. Rb-Sr, Sm-Nd, U-Th-Pb, K-Ar and ^{3}?Ar-??Ar method. Dating through radiocarbon (^{1}?C) and other cosmogenic nuclides (e.g. ^{3}He, ^{3}H). Non-radiometric dating methods based on the regular accumulation of sediments, ice or biological material (e.g. varve dating and dendrochronology) over time, and relative dating based on age equivalence. Recall on stable isotopes, radiogenic isotopes and isotopes of noble gases. Stable isotopes (delta^{13}C, delta^{1}?O, deltaD) as geochronometers and paleoclimatic reconstruction methods.
Composition of mantle/magmatic/volcanic volatiles (H?O, CO?, S, noble gases, halogens) and compositional

variations in relation to geodynamics. Solubility of volatiles in silicate melts and distribution of species among the coexisting phases. Magmatic degassing: definition, typology and main models used. Processes of fractionation, contamination and mixing between gases of different origins. Volcanism and degassing in underwater environments; impact on marine/ocean and atmospheric ecosystems, climate change. General implications on the volatile cycle in relation to geodynamics.
Principles of mass spectrometry. Methods of acquisition, visualization and processing of geochemical data. Visit to the DISAT noble gas isotopes laboratory.
Excursion to verify in the field the concepts acquired during the course, practical experience of sampling fluids/rocks for subsequent geochemical analyzes and field measurements (target Canary Islands).

Prerequisites

Students must have taken the Safety course to attend field work.
The “Introduction to Volcanology” course (active since 2024-2025) foreseen as an elective subject in the three-year course is recommended.

Teaching form

Total hours: 52
14 two-hour lectures, in person, Delivered Didactics
4 six-hour field activities, in person, Interactive Teaching

Textbook and teaching resource

Slides provided during the lessons, scientific publications
BOOKS
Walker M., Quaternary Dating Methods, Wiley
W.M. White, Geochemistry
McSween H.Y., Richardson S.M. Jr., Uhle M.E., Geochemistry (Pathways and Processes)
J. Hoefs, Stable isotope Geochemistry
Porcelli, D., Ballentine, C.J. and Wieler, R. (2002). An introduction to noble gas geochemistry and cosmochemistry. Reviews in Mineralogy and Geochemistry, 47: 1-18.

FURTHER INSIGHTS
A. Longinelli, S. Deganello, Introduzione alla Geochimica
Faure G. (1998), Principles and Applications of Geochemistry
Ozima M. & Podosek F.A. (2002), Noble Gas Geochemistry, Cambridge University
Burnard P., The Noble Gases as geochemical tracers, Springer
C.J. Allègre, Isotope Geology

Semester

First semester

Assessment method

The assessment of learning consists of a final evaluation divided into two components:

- an individual oral examination on the topics covered during the course, accounting for 70% of the final grade;
- a report and/or presentation related to the field excursion or practical activity included in the course, accounting for 30% of the final grade.
  There are no written mid-term tests or final written examinations. During the course, exercises, guided discussions, diagram analyses, case studies or practical activities may be proposed to support preparation for the exam; however, these activities do not constitute mid-term assessments with an independent grade expressed out of thirty. Both components of the assessment contribute to the final grade, which is expressed out of thirty.

Oral examination
The oral examination consists of an individual interview on the topics covered during the course and on the contents of the field excursion report. The examination consists of no fewer than three open questions and begins with a discussion of the evaluation of the field excursion report. The first question may concern a topic of the programme chosen by the student, in order to allow an initial autonomous and structured presentation of a topic considered particularly significant. The following questions are aimed at assessing the student's overall preparation on the main course contents, with reference to both the geochronology part and the solid Earth and fluid geochemistry part. The oral examination may also include the discussion of diagrams, schemes, isotopic data or interpretative case studies, such as:

- isochrons and isotopic evolution diagrams;
- concordia-discordia diagrams;
- Ar-Ar age spectra and plateau ages;
- isotopic and geochemical diagrams applied to the origin of natural fluids;
- simple schemes of sampling, analytical treatment and data interpretation.
  The oral examination is aimed at assessing knowledge of the course topics, understanding of the geological significance of the processes studied, the ability to connect different topics, clarity of presentation and the correct use of the scientific terminology specific to the discipline. The oral examination is graded out of thirty and contributes 70% to the final grade.

Report and/or presentation on the field excursion or practical activity
The report and/or presentation related to the field excursion or practical activity is intended to assess what has been learned during the excursion and/or the student's ability to apply the knowledge acquired during the course to a real geological context or to a case study discussed during the course. The report and/or presentation is submitted a few days before the exam session and is graded out of thirty, contributing 30% to the final grade.

The final grade is expressed out of thirty and is obtained, indicatively, as the weighted average between:

- 70% oral examination;
- 30% report/presentation on the field excursion or practical activity

Office hours

To make an appointment, please write to andrealuca.rizzo@unimib.it

Sustainable Development Goals