UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Isotope Geochemistry

2526-1-F7402Q039

Aims

The course aims to provide students with a comprehensive overview of isotopic geochemistry and its applications in Earth Sciences, considering both stable isotopes and unstable or radiogenic isotopes. The course, divided into three main modules (traditional stable isotopes, non-traditional stable isotopes, unstable or radiogenic isotopes), will provide the necessary knowledge to correctly interpret isotopic data related to rock materials (e.g., lavas, carbonates, meteorites), waters (marine waters, surface waters, rainwater, deep waters), gases (atmospheric and volcanic) in various geodynamic contexts. At the end of the course, students will have acquired a wealth of knowledge that will allow them to plan and conduct isotopic studies in various sectors of Earth Sciences, such as, for example, volcanology/petrology, hydrogeology, paleontology.

Knowledge and Understanding
The student will complete and strengthen the preparation and comprehension skills acquired through other Geochemistry courses. They will gain in-depth knowledge of isotopic geochemistry processes, enabling them to understand and interpret complex processes such as isotopic fractionation in high- and low-temperature environments, the reconstruction of trophic chains, and the identification of source zones. These skills are acquired through attendance at lectures. The level of learning is assessed via an oral exam after the course.

Ability to Apply Knowledge and Understanding

Thanks to the knowledge acquired, the student will be able to:

- Analyze in detail isotopic fractionation processes;
- Independently carry out study and research activities in the field of isotopic geochemistry;
- Use their theoretical knowledge to identify critical situations and propose possible solutions;
- Independently solve geochemical-environmental problems with the support of isotopic geochemistry.

Autonomy of Judgment
The student will develop the ability to characterize and evaluate the reliability of collected information, the level of uncertainty in data and measurements, and the complexity of available models for problem-solving. This capacity

will allow the student to independently assess problems and formulate solutions even based on limited or incomplete information. Additionally, the student will learn to evaluate the consequences of their choices and proposed solutions on the isotopic context. All these skills are developed through the study and discussion of real cases in class.

Communication Skills
The student will acquire the ability to communicate their evaluations and proposed solutions concisely and effectively, both to a specialized audience (e.g., conferences, colleagues) and to a non-specialist audience (clients, the general public). This latter aspect is crucial for risk management topics, as technical assessments must be clearly conveyed to policymakers who interact with the population. Communication skills are developed through classroom discussions of the studied issues.

Learning Ability
The student will develop the ability to autonomously learn new concepts and theories, mainly by consulting literature in English. The various topics of the course will be addressed using articles published in specialized journals and textbooks in English. The level of learning achieved will be evaluated through the exam.

Contents

- Geochemistry of Traditional Stable Isotopes (C, N, O, H, S): Introduction: Terminology, standards, and mass spectrometry; equilibrium isotopic fractionation and kinetic isotopic fractionation; the hydrosphere; the oceans; biogenic carbonates: oxygen; carbon in low-temperature environments; low-temperature minerals other than carbonates; nitrogen; sulfur; igneous petrology; extraterrestrial materials.

- Geochemistry of Non-Traditional Stable Isotopes: Isotopic fractionation processes of selected elements (Li, B, Mg, Si, Cl, Ca, V, Cr, Fe, Ni, Cu, Zn, Ge, Se, Br, Sr, Mo, Cd, Sn, Sb, Te, Ba, Tl, U).

- Geochemistry of Unstable or Radiogenic Isotopes: Physics and structure of the nucleus; basic concepts of radiogenic isotope geochemistry; decay systems and their applications; isotopes of helium and other rare gases; cosmogenic and fossil isotopes.

Detailed program

Traditional Stable Isotope Geochemistry (C, N, O, H, S)

1. Introduction: Purpose of the discipline, isotopic abundances of elements, characteristics of elements that undergo significant isotopic fractionation, applications in Earth Sciences, isotopic effects (equilibrium and kinetic).
2. Terminology, Standards, and Mass Spectrometry: Isotopes, isotopologues, isotopomers, delta value, fractionation factor ?, values 1000ln?, ?, and ?, reference standards, mass spectrometry of isotopic ratios.
3. Equilibrium Isotopic Fractionation: Theory of stable isotope fractionation factors, relation with temperature, experimental determination of fractionation factors, empirical determination of fractionation factors, other factors controlling isotopic fractionation, multiple isotopic systems, distribution of isotopologues.
4. The Hydrosphere: Natural abundances of water isotopologues, meteoric waters, meteoric water line, evaporation and condensation, factors controlling the isotopic composition of precipitation, groundwater, geothermal systems, basin brines and formation waters, glacial ice.
5. The Oceans: Variations in oxygen isotopes in modern oceans, depth profiles for oxygen and carbon isotopes in modern oceans, stable isotope ratios as productivity indicators, isotopic compositions of ancient

oceans, basalt/seawater interactions, buffering of ocean water oxygen isotopic ratio.

6. Biogenic Carbonates - Oxygen: Phosphoric acid method, paleotemperature scale for oxygen isotopes, factors affecting paleotemperatures estimated through oxygen isotopes, applications of oxygen isotope paleothermometry.
7. Carbon in Low-Temperature Environments: Carbon cycle, carbon reservoirs, isotopic values of carbonates, marine and terrestrial.
8. Low-Temperature Minerals Other Than Carbonates: Phosphates, silica, clay minerals, iron oxides.
9. Nitrogen: Nitrogen cycle, nitrogen isotope fractionation, characteristic nitrogen isotope ratios for different materials (plants, soils, fertilizers, rain, fossil fuels, waters), nitrogen isotope ratios in animals.
10. Sulfur: Analytical techniques, equilibrium fractionation and geothermometry, formation of sulfates and sulfides at low temperature - sedimentary sulfur cycle, secular variations of sulfur isotope ratios, sulfur isotope ratios in terrestrial environments, variations in sulfur isotope oxygen.
11. Igneous Petrology: Isotopes of carbon, oxygen, hydrogen, nitrogen, and sulfur in crust and mantle, emplacement of plutons: crust and hydrosphere interactions, calculating fluid/rock ratios, degassing, assimilation, and fractional crystallization.
12. Extraterrestrial Materials: Classification of meteorites, oxygen isotopes in the solar system, hydrogen, carbon, nitrogen, sulfur, and chlorine isotopes in meteorites.

Non-Traditional Stable Isotope Geochemistry

1. Basic information on non-traditional stable isotopes
2. Applications in igneous petrology.

Radiogenic Isotope Geochemistry

1. Physics and Structure of the Nucleus: Nuclear structure and energy; decay of excited and unstable nuclei (alpha, beta, and gamma decay, electron capture, spontaneous fission).
2. Basic Concepts of Radiogenic Isotope Geochemistry: Radioactive decay equation; geochronology.
3. Decay Systems and Their Applications: Rb-Sr system; Sm-Nd system; Lu-Hf system; Re-Os system; La-Ce system; U-Th-Pb system; U and Th decay series isotopes.
4. Isotopes of Helium and Other Rare Gases: Helium; neon.
5. Cosmogenic and Fossil Isotopes: ^{1}?C; ^{3}?Cl in hydrology; ^{1}?Be in subduction zones; meteorite age by cosmic ray exposure; fossil nuclides.

Prerequisites

Good knowledge of Chemistry and Geochemistry.

Teaching form

The 57 total hours of the course (6 credits), to be completed in person, are divided into 21 hours of lectures (3 credits) and 36 hours of exercises (3 credits). The exercise hours require a minimum mandatory attendance of 75%.

Textbook and teaching resource

powerpoint presentations provided by the professor

Specifically for the Traditional Stable Isotope Module:

Sharp Z, Principles of Stable Isotope Geochemistry, second edition, 2017.

Specifically for the Non-Traditional Stable Isotope Module:

Hoefs J, Stable Isotope Geochemistry, seventh edition, 2015. Springer.

Specifically for the Radiogenic Isotope Module:

White WM, Chapter 8: Radiogenic Isotope Geochemistry. In Geochemistry, second edition, 2020. Wiley-Blackwell.

Semester

Second semester

Assessment method

Oral exam after the end of the course (there are no mid-term tests) consisting of an interview on the topics covered during the course. The exam will consist of a minimum of three questions. Students who attend at least 90% of the classes will be able to choose three topics on which to focus in the oral exam. The following will be evaluated: the degree of knowledge and depth of the various topics, the ability to make connections, the clarity of language, and the use of appropriate technical-scientific language.

Office hours

Appointments to be arranged via email: alessandro.fabbrizio@unimib.it

Sustainable Development Goals