UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Raw Materials, Industry and Sustainability

2627-2-F7402Q011

Aims

The course aims to deepen the basic knowledge acquired in the three-year Degree in the field of ore geology - applied mineralogy. The evolution of the Earth's crust from the Archean to the Phanerozoic Eon will be treated in detail, especially the metallogenic phenomena. Particular attention will be dedicated to hydrothermal phenomena and to the various types of related deposits. "Critical" metals for the industry: PGE (Platinum Group Elements), REE (Rare Earth Elements), Sb, Be, Co, Ga, Ge, In, Li, Mg, Nb, Re, Ta and W; for each one the basic knowledge of mineralogy, ore deposits, industrial uses and related environmental issues will be provided. The sector of ceramic materials, glass, inorganic binders (lime and cement) and refractories will be examined in depth, from raw materials, technical characterization up to industrial processes. Finally, asbestos and other mineral fibres will be characterized, from the mineralogical to the industrial aspects, to the hygienic and analytical problems (air, soil, earth and excavation rocks, ACMs).

Knowledge and ability to understand
Basic and in-depth knowledge of the characteristics of mineral deposits in relation to geological time (Archean, Proterozoic and Phanerozoic). Genetic aspects, with emphasis on hydrothermal processes. Critical and strategic raw materials, characteristics of deposits, industrial, economic and environmental aspects. Mineral fibers and dust, in natural and anthropogenic environment, with related mitigation measures. Industrial and environmental aspects in the production of binders (e.g., lime, cement), glass, ceramics and refractories.

Applied knowledge and understanding
The student will be able to apply theoretical knowledge to analyze and interpret experimental data for research and characterization of mineral deposits, evaluation of environmental aspects, industrial processes and risk mitigation.

Autonomy of judgment
Upon completion of the course, the student will be able to critically evaluate theoretical models and experimental results concerning the characteristics and properties of critical (and non-critical) raw materials, industrial and environmental aspects. He/she will also be able to select the most appropriate analytical techniques for materials characterization and environmental impact assessment.

Communication Skills
The student will acquire technical language appropriate to the description of mineral deposits and related genetic processes and will be able to effectively communicate complex concepts related to mining, industrial and environmental processes. During the course, he/she will also be encouraged to experience scientific communication in English, with reading of selected scientific articles and interpretation of experimental data from laboratory analysis.

Ability to learn
The course aims to provide students with a sound and flexible scientific method, enabling them to deal independently and critically with the study of mineral deposits and geological materials of industrial interest. The skills acquired will also be transferable to other scientific/technical and professional fields, such as mineral deposit exploration, technical characterization of materials, and interpretation of environmental data.

Contents

1) **Basic concepts in the field of ore geology**: ore & industrial minerals, tenor, tonnage, Clarke, morphology of mineral bodies, ore textures and processing, main magmatic, hydrothermal, metamorphic, sedimentary, residual and super-gene enrichment ore deposits.

2) **Evolution of the Earth's crust and metallogenic events of the Archean**: greenstone belts, komatiites and massive sulphide Fe-Ni-Cu-PGE deposits, Algoma-type BIF, TTG granites, Au-U deposits.

3) **Evolution of the Earth's crust and metallogenic events of the Proterozoic**: mafic-ultramafic layered intrusions (e.g. Bushveld Complex), Cr-V-PGE mineralizations, carbonatites, kimberlites, SEDEX deposits.

4) **Evolution of the Earth’s crust and metallogenic events of the Phanerozoic**: Cu-Mo-Au-Sn porphyry, MVT (Mississippi Valley Type), VMS (Volcanogenic Massive Sulphide), placer, orogenic mesothermal lodes, laterites, supergenic enrichment.

5) **Hydrothermal processes**: origin of fluids, sources of metals, mechanisms of circulation of fluids, chloride-dominant and sulphide-dominant complexing, deposition mechanisms, study techniques (e.g. fluid inclusions).

6) **"Critical" metals"**: REE, PGE, Sb, Be, Co, Ga, Ge, In, Li, Mg, Nb, Re, Ta and W. Chemical and physical properties, mineralogy, mineral deposits, industrial applications, environmental issues, substitutions.

7) **Silicatic ceramic materials and “special” ceramics, glass, binders (lime and cement), refractories**. Raw materials and their mineralogical and chemical characterization, industrial processes.

8) **Asbestos and other mineral fibres**: mineralogy, ore deposits, industrial uses, environmental problems, pathologies related to exposure to asbestos fibers, analytical techniques for the study and quantification in air and in massive materials (asbestos containing materials - ACMs, soils, earth and rocks from excavation), MMVF (man-made vitreous fibers).

9) **Examples of industrial applications**: recovery of raw materials from mining and quarrying waste; REE minerals in granite and gneiss waste (e.g. granites, orthogneiss); characterisation of raw materials for the industrial production of lime and cement; technical characterisation of ceramic products and identification of the causes of degradation; study of alternative industrial materials (e.g. chromite for refractories); advanced applications of mining waste.

Detailed program

Basic concepts, ore & industrial minerals, ore deposits

Introduction, ore & industrial minerals, tenor and tonnage, cut-off. Syngenesis and epigenesis, lodes, veins, pipes, mantos, pods, stratiform and stratabound ore bodies. Magmatic deposits, fractional crystallization and liquation. Hydrothermal deposits, key factors in their genesis. Sedimentary, chemical, residual deposits, supergene enrichment. Metamorphic deposits.

Archean tectonics and ore deposits

High grade gneiss-granulites terranes and greenstone belts, stratigraphy of greenstone belts. Komatiitic lavas and Fe-Ni-Cu-PGE massive sulphide deposits. Evolution of the atmosphere, cyanobacteria, development of life in the Archean. Orogenic phenomena and TTG-suite granite intrusions, related ore deposits.

Proterozoic tectonics and ore deposits

Main tectonic events in the Proterozoic: growth of the continental crust, anorogenic magmatism, intracontinental rifting, ensialic orogenic belts, mobile belts. Layered mafic-ultramafic complexes: the example of the Bushveld Complex. Irvine model: crystallization of chromite by contamination of crustal rocks and by mixing of an evolved magma with a primitive magma. Carbonatites, REE, Nb, Ti ore deposits. Kimberlites and diamonds, genesis of kimberlitic magmas. The diamond in the industrial and gemological market. Banded Iron Formations, GOE (Great Oxidation Event), BIF mineralogy and nomenclature.

Phanerozoic tectonics and ore deposits

Oceanic crust, Wilson cycles, relationships with ore deposits. Ophiolites and podiform chromites. MVT (Mississippi Valley Type) deposits, porphyry, VMS (volcanogenic massive sulphide), mesothermal orogenic lodes, laterites, supergene enrichment.

Hydrothermal processes

Origin of fluids: magmatic, metamorphic, meteoric, mixed waters. Metal sources and mechanisms for the circulation of fluids (thermally-driven, gravity-driven, fault-dilatancy-driven, orogeny-driven). Chloride-dominant and sulphide-dominant complexing, soft and hard metals and ligands. Deposition mechanisms: changes in pH, Eh, T, P, reactive rocks, boiling, mixing, hydraulic breccias. pH - Eh diagrams, fluid inclusions, geothermometers and geobarometers on sulphides, stable isotopes. Hydrothermal alteration, wall rock-alteration, porphyry, epithermal, mesothermal and hypothermal deposits.

REE: deposits, industrial applications, environmental issues

REE: geochemistry and mineralogy. Ore deposits: primary and secondary, carbonatites, alkaline magmatic rocks, placers, laterites. Industrial REE applications and environmental issues. World market for REEs, perspectives, substitutions, recycling.

Critical metals

Critical metals, industrial applications, global market, recycling. **Antimony, Beryllium, Cobalt, Gallium, Germanium, Indium, Lithium, Magnesium**, **PGM - Platinum Group Metals, Rhenium, Niobium, Tantalum** and **Tungsten.** For each metal: chemical and physical properties, mineralogy, main ore deposits, ore dressing and treatment, industrial applications, environmental issues, resources and reserves, prices, outlook and alternative materials.

Ceramic materials, glass, binders (lime and cement), refractories

Silicate ceramics and “special” ceramic, glass, inorganic binders (lime and cement) and refractories. Raw materials and their chemical and mineralogical characterization, industrial processes, technical properties and commercial varieties, critical issues and innovative approaches.

Asbestos and other mineral fibres

Introduction to asbestos and other mineral fibres: mineralogy, serpentine and amphibole asbestos, concept of asbestiform crystal habit, world production and distribution of mineral deposits. Asbestos: technical properties of chrysotile and amphibole asbestos. NOA: naturally occurring asbestos. Asbestos containing materials (ACMs), friable and compact. Main techniques of removal of ACM, landfill, inertization, encapsulation, confinement. Main pathologies related to professional and occasional exposure to asbestos. Determination of the asbestos content in bulk samples and in airborne dust, analytical criticalities. MMVF (Man-made Vitreous Fibers).

Prerequisites

Basic knowledge of mineralogy, petrography, chemistry and ore geology.

Teaching form

3 CFU of lectures, 2.5 CFU of laboratory work, 2 CFU of practical sessions, 0.5 CFU of campus abroad teaching (a one-day educational field trip), in Italian or English (if there are international students).

a) 11 face-to-face lectures, each lasting 2 hours: Lectures

b) 15 face-to-face laboratory sessions, each lasting 2 hours: Interactive Teaching

c) One 6-hour field trip (campus abroad), face-to-face: Interactive Teaching.

d) 12 in-person classroom exercises, each lasting 2 hours. Practical examples of industrial case studies, analysis and solutions to industrial and environmental issues.

In the event of a health emergency, lessons will be delivered in a blended format: partial in-person attendance (laboratory sessions and campus abroad) and asynchronous pre-recorded video lessons.

Textbook and teaching resource

Course slides (available on e-learning), notes distributed during the course. Texts recommended by the teacher.

Ore geology - introduction

Pirajno (2009) - Hydrothermal processes and mineral systems. Springer, 1250 pp.

Ridley (2013) - Ore deposit geology. Cambridge University Press, 398 pp.

Robb (2021) - Introduction to ore forming processes., 2nd edition. Blackwell Publishing, 456 pp.

Kogel, Trivedi, Barker & Krukowski (2006) - Industrial minerals and rocks. Commodities, markets and uses (VII edition). Society for Mining, Metallurgy and Exploration, Inc. (SME), 1548 pp.

Boudreau (2019) - Hydromagmatic Processes and Platinum-Group Element Deposits in Layered Intrusions. Cambridge University Press, 275 pp.

Primavori (1999) - Planet Stone. Giorgio Zusi editore, 336 pp.

Critical metals & raw materials

Gunn (2014) - Critical metals handbook. AGU Wiley, 439 pp.

Characterization of ore & industrial minerals

Christidis (2011) - Advances in the characterization of industrial minerals. EMU notes in Mineralogy, Vol. 9, The Mineralogical Society of Great Britain and Ireland, 485 pp.

Asbestos and other mineral fibres

Gualtieri (2017) - Mineral fibres: crystal chemistry, chemical-physical properties, biological interaction and toxicity. EMU notes in Mineralogy, Vol. 18, The Mineralogical Society of Great Britain and Ireland, 536 pp.

Ceramics, inorganic binders, glass and refractories

Carter & Norton (2007) – Ceramic Materials: science and Engineering. Springer, 716 pp.

Askeland, Fulay & Wright (2010) – The Science and Engineering of Materials – VI Edition. Cengage Learning, 921 pp.

Schroeder (2018) - Clays in the Critical Zone. Cambridge University Press, 246 pp.

Semester

I semester (October - January)

Assessment method

Preliminary written test lasting 15 minutes, closed-ended test (15 questions, 2 points for each correct answer). Correctness of answers is evaluated. The preliminary test affects 20% of the final mark.

Subsequent written test (duration 2 hours) with about 10 open-ended questions (2 to 4 points for each correct and complete answer, depending on the complexity of the topic). Correctness of knowledge, expository and synthesis skills are assessed. This written test affects 40% of the final mark.

Final oral exam (duration 20-30 minutes), interview on topics covered in class: 3 to 4 open-ended questions. Correctness of knowledge, clarity of exposition, appropriate language, as well as the ability to extend theoretical knowledge to real cases are evaluated. The oral examination contributes 40% to the final mark.

Office hours

Monday from 10:30 to 12:30 AM, or by appointment (building U4, I floor, room 1027).

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE | RESPONSIBLE CONSUMPTION AND PRODUCTION