UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Basics of Ore Geology, Industrial Minerals and Rocks

2425-3-E3401Q046

Aims

Introduction to mineral resources, from ore minerals to industrial minerals, up to dimension stones and aggregates (sands and gravels). The basic concepts for the description of an ore deposit are provided, both from a geometrical - morphological and genetic point of view (magmatic, hydrothermal, sedimentary, metamorphic and supergenic enrichment deposits), as well as mining prospecting techniques. Finally, the main methods of mining cultivation of quarries and mines, both open cast and underground, are described, as well as the main analytical techniques for the chemical and mineralogical characterization of ore and industrial minerals.

Contents

- **Ore and industrial minerals**, concept of mineral deposit, grade or tenor, tonnage and Clarke (mean crustal tenor).

- **Extraction and processing of metallic and industrial minerals**, mineral processing, related environmental problems (eg AMD - acid mine drainage).

- **Quarries and mines**, national and international legislation. Open and underground mining techniques.

- **Mining with explosives**, both open cast and underground.

- **Evolution of the Earth's crust from the Archean to the Phanerozoic**, main metallogenic events.

- **The main analytical techniques for the chemical and mineralogical characterization of ore and industrial minerals**: optical microscopy in transmitted and reflected light, XRF, ICP-AES, ICP-MS, NAA, SEM, TEM, EDS and WDS microanalysis, XRPD, Raman spectroscopy .

- **Morphology and nature of ore bodies** according to the host rocks: lodes, veins, pipes, mantos, pods, stratiform and stratabound bodies .

- **Textures and microstructures of ore minerals and gangue**, implication for their treatment (ore dressing).

- **Mineral resources and reserves**, geochemical and geophysical mineral prospecting, core drilling, examples.

- **Magmatic deposits**: fractional crystallization, liquation, magmatic assimilation. Examples: massive sulphides in Kambalda komatiites (Australia), chromite and PGE seams in the Bushveld complex (South Africa), massive Fe-Ni-Cu sulphides in Norilsk (Russia), kimberlites, carbonatites, pegmatites, greisen, skarn.

- **Hydrothermal deposits**: key factors in their genesis, study techniques. Porphyry, VMS (volcanogenic massive sulphide), MVT (Mississippi Valley Type), SEDEX (Sedimentary Exhalative), IOCG (Iron Oxide Copper Gold), U deposits.

- **Sedimentary deposits**: placers, BIF (banded Iron Formations), evaporites.

- **Metamorphic deposits**: talc, graphite, Al silicates.

- **Residual deposits** (e.g. Al, Ni) and supergenic enrichment.

- **Dimension stones**: commercial classification, typologies, open pit and underground quarries, main extraction methods, processing of stone materials, environmental impact and relative mitigation.

- **Technical (physical-mechanical) tests** for the characterization of stone materials and aggregates.

Detailed program

Ore minerals & industrial minerals, ore deposits, ore minerals, gangue, tonnage, tenor, tout-vènant, Clarke and concentration Clarke. Tonnage - tenor diagrams. Mineral and metal ore prices, commercial classification. "Critical" metals: REE and PGE. Import and export of raw materials, Italian and Lombard production. Recovery and by-products, mineralogical form of metals, unwanted substances, smelting processes and ore dressing, environmental problems. Regulatory classification of raw materials: I and II category materials, quarries and mines.

Evolution of the Earth's crust, from the Archean to the Phanerozoic eon.

Mining and quarrying with explosives: main types of explosives, deflagrants and detonants, technical characteristics. Fire, electric, electronic and NONEL detonators, boosters. Detonating cord. The use of explosives in open pit mines and quarries, dimension stone quarries and underground excavations.

The main analytical techniques for the chemical and mineralogical characterization of geological materials of economic and industrial interest. Whole-rock geochemical analysis: XRF, ICP-ES, ICP-MS, NAA, merits and limits. Optical microscopy in transmitted and reflected light, modal analysis. Mineralogical analysis: X-ray powder diffraction (XRPD). Scanning electron microscopy (SEM) and transmission electron microscopy (TEM), EDS and WDS microprobe. Overview of Raman spectroscopy.

Nature and morphology of ore bodies. Syngenesis and epigenesis, discordant and concordant ore bodies. Tabular bodies (lodes and veins), tubular bodies (pipes and mantos), disseminations, stockwork, replacement (e.g. skarn), stratiform and stratabound bodies. Main types of host rocks and relationships with ore bodies. Textures and microstructures of ore and gangue minerals, attitude to ore dressing and processing.

Mineral resources and reserves; **mineral prospecting**: geological surveys, remote sensing, geochemistry,

geophysics core drilling, statistical data processing.

Genetic classification of mineral deposits, metallogenesis, inheritance, permanence, transformation, zoning, metallotect, metallogenic epoch and paragenesis. Magmatic deposits: magmatic crystallization (e.g. diamonds in kimberlites, chromites in stratified basic complexes, feldspars in pegmatites), magmatic segregation (fractional crystallization, liquation). Hydrothermal deposits: origin of hydrothermal fluids, ligands, transport, deposition, VMS (volcanic massive sulfide) deposits, SEDEX (sedimentary-exhalative), MVT (Mississippi Valley Type). Uranium deposits. Deposits linked to metamorphic processes. Deposits linked to sedimentary processes BIF (banded iron formations), Cu in sandstones, placers, evaporites. Deposits linked to weathering: laterites, bauxites. Supergene enrichment.

Main ore minerals (associations, ore assemblage, gangue, mining grade): Be, Cr, Cu, Au, Fe, Pb, Zn, Li, Mn, Hg, Mo, Ni, Co, Nb, Ta, PGE (platinum group elements), Ag, Sn, W, Ti, U, V, REE (rare earth elements).

Dimension stones: commercial varieties (marbles, granites and stones), quarry production cycle and environmental problems. Workability of ornamental rocks according to mineralogical and textural characteristics. Main world producers, the Italian extraction basins. Quarries of ornamental stones: preliminary geological investigations, types of quarries with respect to the morphology, open and underground cultivation. Quarrying methods with vertical and horizontal progression. Main quarrying techniques: helicoidal wire, diamond wire, drilling (with and without explosives), chain cutting machine, flame-jet, water-jet, expanding cements. Processing of stone materials: framing, cutting, frame saw, finishing, special processing. Environmental impact: EIA (environmental impact assessment), mitigation measures, environmental recovery.

Technical characterization of stone materials and aggregates. Stone materials for ornamental and structural use: main physical-mechanical tests for the technical characterization of rocks for ornamental and structural use, links with mineralogy and microstructures. Measurement of porosity by Hg intrusion porosimetry (MIP). Aggregates for road use and for concrete: main technical tests for the characterization of aggregates used in concrete or for bituminous conglomerates (e.g. Los Angeles rattle test). Mineralogical characterization, undesired minerals, alkali-silica reactions.

Prerequisites

Basic knowledge in mineralogy, petrography and chemistry.

Teaching form

3 credits of lectures, 2 credit of laboratory (analytical techniques, technical characterization of minerals and rocks), 1 credit of campus abroad teaching (technical visits at quarries, mines and processing plants). Held in Italian.

a) 12 two-hour lectures, in person, Delivered Didactics

b) 15 two-hour lab activities, in person, Interactive Teaching

c) 2 five-hour field activities, in person, Interactive Teaching

In case of health emergencies , lessons will take place in a mixed mode: partial presence (laboratory and campus abroad) and asynchronous recorded lessons.

Textbook and teaching resource

Introduction to ore geology

Course slides (available on e-learning), notes and schemes distributed during the course, recommended books and texts.

Slide del corso (disponibili su e-learning), appunti e dispense distribuiti durante il corso, testi consigliati dal docente.

Neukirchen & Ries (2020) - The World of Mineral Deposits. A Beginner's Guide to Economic Geology. Springer, 371 pp.

Sanz, Tomasa, Jimenez-Franco, Sidki-Rius (2022) - Elements and Mineral Resources. Springer, 411 pp.

Arndt & Ganino (2012) - Metals and Society. An introduction to Economic Geology. Springer, 160 pp.

Brigo & Montanari (2006) - Metalli e minerali industriali. Parametri geominerari ed economici. Aracne editrice, 394 pp.

Evans (1993) - Ore geology and industrial minerals. An introduction (III edition). Blackwell Publishing, 389 pp.

Marjoribanks (2010) - Geological methods in mineral exploration and mining. Second Edition. Springer, 238 pp.

Jackson (2019) - Earth Science for Civil and Environmental Engineers. Cambridge University Press, 458 pp.

Kesler & Simon (2015) - Mineral resources, economics and the environment (II edition). Cambridge University Press, 434 pp.

Primavori (1999) - Pianeta Pietra. Giorgio Zusi Editore, 326 pp.

Analytical techniques

Gualtieri (2018) - Introduzione alle tecniche analitiche strumentali. Applicazioni alla mineralogia e alla scienza dei materiali. Libreriauniversitaria.it Ed., 335 pp.

Mercurio, Langella, Di Maggio & Cappelletti (2019) - Analisi mineralogiche in ambito forense. Aracne editrice, 455 pp.

Mineral exploration

Dentith & Mudge (2014) - Geophysics for the Mineral Exploration Geoscientist. Cambridge University Press, 438 pp.

Moon, Whateley & Evans (2004) - Introduction to Mineral Exploration, II ed. Blackwell publishing, 481 pp.

Semester

II semester

Assessment method

Preliminary written test, consisting of a closed-ended test (10 questions) and 3 simple exercises. Each correct answer, depending on the complexity of the topic, allows 1 to 3 points (maximum total score of 30/30). The correctness of knowledge and the ability to process information are evaluated. The grade of the written exam affects 50% of the final mark.

The subsequent oral examination consists of an interview on the topics covered in class (3 to 4 open-ended questions). Clarity of exposition, use of appropriate language and ability to extend theoretical concepts to real cases are evaluated. The oral exam grade contributes 50% 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