Content (10 credit points): Ore deposits, especially when mined and processed, are a potential environmental hazard. Exposure of fresh rock surfaces during mining, as well as the produced crushed and milled waste, will be subject to weathering processes, causing large-scale environmental damage if not sufficiently managed. Sulphide-bearing mineralization, in particular, is readily oxidized at surface, and has the potential to produce acid rock drainage (ARD), as well as release of heavy metals. Significant contamination of surface and groundwater may readily result from these two processes. In addition to the contamination threat, there is also a geotechnical threat to the environment; tailings dams, and waste rock piles may fail if poorly designed, mismanaged or subject to physical/geochemical weathering. Field trips and laboratory exercises are very important part of this course.

Goals: The potential environmental threat of a mine (or an unmined mineral/ore deposit) can only be understood and managed through specific knowledge of mineralogy and geochemistry, hydrogeology, and geotechnical engineering. The course will therefore provide students with the basic knowledge required to evaluate the potential environmental hazard of a given property from a regulatory perspective and to understand the environmental aspects of the existing or planned operation.

Previous course requirements/restrictions: Basic knowledge of geology including mineralogy, plus chemistry and mathematics.

This course builds on: GEO 1011, GEL 2110, KJM 1000, GEO4910.

Teaching format and regularity: This intensive course will run once a year over a period of two weeks in the spring semester containing lectures and seminars (case studies / laboratory work) and fieldwork (one 3-4 day field trip). The course will provide the student with a basic understanding of both the practical and technical aspects of mine waste management. Emphasis will be placed on practical real-life examples. Language: English or Norwegian depending on students enrolled.

The course is broken down into the following 7 elements (10 credits total):

1. Environmental geochemistry of ore deposits and mining activities, process review and introduction (10%)
2. Geochemistry and hydrogeology of tailings and waste rocks (25%)
3. Pit-lake hydrogeology and geochemistry (5%)
4. Mine water management (10%)
5. Geotechnical aspects of mine waste (15%)
6. Mining regulation, mine waste management, reclamation/remediation/mitigation (25%)
7. Risk Assessment (10%)

The course requires a solid background in geology, mineralogy, geochemistry, and ore geology.

Exams: Oral, plus graded calculation exercises, laboratory exercises, and field report.

Course description:

1. Environmental geochemistry of ore deposits and mining activities

A major environmental issue of mining activities is related to mineral reactions, metal release, and metal transport. The students should know the basic concepts of these geochemical processes and there will be only a brief review together with an introduction to the more specific geochemical
processes, that are likely to occur in un-mined material or that are currently taking place within mined materials.

**Overview**

Geological, geochemical and environmental aspects of mine material will be assessed through classroom instruction, laboratory exercise and a field trip. Geochemical parameters will be used to assess mine waste “hazards”. Included in the assessment will be the determination of mineralogical (ore and gangue mineralogy), lithological, and alteration characteristics of the *in situ* resource, wall-rocks, mined material, tailings/waste, surface and groundwater.

Topics covered include: mine waste management, mine water geochemistry, acid/neutral rock drainage, waste rock weathering, ARD prediction methods, remediation/reclamation and the use of geochemical modelling for ARD and leaching within mine material.

### 2. Geochemistry and hydrogeology of tailings and mine wastes

The extractive mining industry produces enormous quantities of tailings and waste rocks. These quantities are increasing as lower and lower grades are mined. The environmental affect of this waste material can be enormous, yet manageable, and to the untrained eye, can appear much worse, than it really is. In light of changing regulations in Europe, much effort has been placed to improve understanding of the physical and chemical processes taking place within these materials.

**Overview**

We will discuss geochemical weathering of waste rocks under different conditions and with different material components, and how this may affect the stability of a waste rock pile and the surrounding environment. These discussions cover matrix-macro flow, weathering reaction rates, water gas mineral interactions climate, etc. We will discuss element transport and cycling in tailings, bacteriological affects on mineral dissolutions and formation, oxygen transport, and sulphide oxidation rates.

Topics covered include: mineral reaction rates, geochemical weathering rates, mineral solubility and metal transport, mineral reaction processes, microbial effects on mineral stabilities, sampling and instrumentation, ARD prediction methods, oxidation front movement, infiltration rates, element cycling, matrix-macro flow hydrology, cover design criteria, matrix macro flow geochemistry, and waste rock mixing.

### 3. Pit lake hydrogeology and geochemistry

Following mine closure, open pit mining activities leave behind large pits that, in many cases, will be partly or fully filled with water (Mine Pit lakes). These pit lakes may, in the near or distant future, have a water chemistry that will impact wildlife and groundwater resources. This course element focuses on the hydrogeology and geochemical processes affecting pit lake water formation.

**Overview**

We will discuss the formation of pit lakes from hydrological and geochemical perspectives. This includes groundwater flow and open discharge evaluation and modelling. Geochemical aspects include wall rock interaction and weathering and groundwater reactive transport. Pit lake stratigraphy and its effect on geochemical cycles will also be discussed. Methods for predicting future pit lake geochemistry and ways to alter the predicted future pit chemistry will be emphasized.

Topics covered include: pit lake development, shrinking core model, temperature variations, geochemical prediction methods, natural lake chemistry, microbial effects, water discharge regimes,
element cycling, layering and overturn effects, redox driven cycles, mineral solubility and metal transport within pit-lakes, remediation options, wall-rock weathering.

4. Mine-water management
Usage of water in the mining and industrial sectors produces high concentrations of wastes and effluents. Some mining activities produce wastes that act as sources of water quality degradation and acid mine drainage.

Overview
We will discuss solutions focussing on the minimization of waste and maximization of water re-use within the framework of appropriate, innovative and integrated solutions for application in the mining sector.

5. Geotechnical aspects of mine waste
Proper design and operation of tailings and waste rocks facilities is very important to avoid massive failures. This course segment will introduce students to the geotechnical aspects of selecting, designing and operating tailings and waste rock facilities.

Overview
Proper design of a new tailings dump, or evaluation of an existing depository, starts with physical and chemical characterization. We will review materials characterization, the weathering processes that potentially take place within waste material, and how to select the proper site for this material. We will then discuss impoundment options and deposition methods based on climate, type of waste material, surface hydrology management, and regulatory framework. Dam failure is a major threat to the surrounding environment. The course will, therefore, include how to perform proper risk assessment.

Topics covered include: waste characterization, surface hydrology, environmental impact liners, physical and geochemical weathering, monitoring, site selection, stability analysis, impoundment options and design consideration, risk assessment, methods of tailings deposition closure, earth embankment.

6. Mining regulation, mine-waste management, and mitigation/reclamation/remediation of mine sites
The mining industry places increasing emphasis on finding solutions to mine waste management issues that are both environmentally sound and cost-effective. Long-term, environmentally acceptable approaches are needed to meet increasingly stringent regulatory requirements and public concerns, and to reduce liability for environmental contamination that may result from mining.

Overview
We will discuss various scientifically sound and sustainable options for mine waste disposal, management and rehabilitation, including acidic drainage: prediction, prevention and treatment water quality issues, lime treatment, and sludge disposal technologies, metal recovery from acid mine drainage and mine waste, the benefits and risks of marine tailings disposal, and other practical aspects of mine decommissioning.

7. Risk assessment
Recent releases of tailing effluents and solids from containment facilities around the world have heightened awareness for mine operators and the general public of the risks associated with tailing
containment. Risks need to be considered as a day to day parameter of mining and land management activity.

Overview
We will focus on the principles and theory of risk assessment, risk and crisis management, and risk evaluation and objective, comparative studies of risk in a mining context, risk-based decision making, risk-based evaluation of feasibility of projects and the development of risk mitigation and crisis management plans.

Examination requirements (individual learning): The following textbook plus lecture notes provided by the course instructors:

[or an updated version, in preparation].

Instructors:
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