GEOLOGY

Department of Earth Sciences

Offered in English.

Faculty

Chair and professor
R.S. James, B.Sc., M.Sc. (McMaster), Ph.D. (Manchester)

Emeritus professors
J.F. Davies, B.Sc., M.Sc. (Manitoba), Ph.D. (Toronto)
D.H. Rousell, B.Sc. (Manitoba), M.Sc. (U.B.C.), Ph.D. (Manitoba)
R.E. Whitehead, B.Sc. (Mt. A.), Ph.D. (U.N.B.)

Professors
A.E. Beswick, B.Sc., Ph.D. (London), D.I.C.
P. Copper, B.A., M.A. (Saskatchewan), Ph.D. (London), D.I.C.
H.L. Gibson, B.Sc. (Queen's), M.Sc., Ph.D. (Carleton)
R.R. Keays, B.Sc. (Queen's), Ph.D. (McMaster)
C.M. Lesher, B.Sc. (Indiana), A.M. (Indiana), Ph.D. (Western Australia) NSERC Chair in Mineral Exploration
D.G.F. Long, B.Sc. (Leicester), M.Sc., Ph.D. (Western)
D.A.B. Pearson, Environmental Earth Science Coordinator, B.Sc. (Durham), Ph.D. (London), D.I.C.

Associate professors
E.A. Gallie, Environmental Earth Science Coordinator, B.Sc. (Queen's), Ph.D. (U.B.C.)
A.M. McDonald, B.Sc. (Toronto), M.Sc., Ph.D. (Carleton)
G.A. Spiers, B.Sc. (Waikato), M.Sc., Ph.D. (Alberta) Chair in Environmental Monitoring

Assistant professors
B. Lafrance, B.Sc. (Montréal), Ph.D. (U.N.B.)
S. Piercey, B.Sc., M.Sc. (Memorial), Ph.D. (U.B.C.)

Affiliate professor
P.C. Thurston, AB (Rutgers), M.Sc. (Bryn Mawr), Ph.D. (Western)
Technologists
W. Desjardins, Dipl. (Cambrian Coll.)
L. Dupuis, B.Sc., M.Sc. (Laurentian)

Adjunct professors
Y. Amelin, M.Sc., Ph.D. (Leningrad)
D. Ames, B.Sc. (Hon.) (Waterloo), M.Sc., Ph.D. (Carleton)
J.A. Ayer, B.Sc., M.Sc. (Carleton), Ph.D. (Ottawa)
P.J. Barnett, B.Sc. (Brock), M.Sc., Ph.D. (Waterloo)
T.C. Barrie, B.Sc. (Michigan), M.Sc. (Texas), Ph.D. (Toronto)
G. Beakhouse, B.Sc., M.Sc. (Manitoba), Ph.D. (McMaster)
A. Cheburkin, B.Sc. (Kiev State), Ph.D. (Ukranian Acad. of Sc.)
M. Easton, B.Sc. (Western), M.Sc. (Hawaii), Ph.D. (Memorial)
C.E.G. Farrow, B.Sc. (Mount Allison), M.Sc. (Acadia), Ph.D. (Carleton)
J.S. Fedorowich, B.Sc., Ph.D. (Saskatchewan)
J.M. Franklin, B.Sc., M.Sc. (Carleton), Ph.D. (Western)
A.G. Galley, B.Sc. (Carleton), M.Sc. (Western), Ph.D. (Carleton)
R.A.F. Grieve, B.Sc. (Aberdeen), M.Sc., Ph.D. (Toronto)
M.D. Hannington, B.Sc., (Queen's), M.Sc., Ph.D. (Toronto)
T.E. Lane, B.A. (Franklin & Marshall Coll.), M.Sc. (Dalhousie), Ph.D. (Memorial)
P.C. Lightfoot, M.Sc. (Toronto), Ph.D. (Open U., Milton Keynes, U.K.)
W.A. Morris, B.Sc. (Leeds), Ph.D. (Open Univ.)
D.C. Peck, B.Sc., M.Sc. (Windsor), Ph.D. (Melbourne)
F. Santaguida, B.Sc. (Hon.), M.Sc. (Waterloo), Ph.D. (Carleton)
G.M. Stott, B.Sc. (McMaster), M.Sc. (Waterloo), Ph.D. (Toronto)
O. Tavchandjan, B.Sc., M.Sc. (d'Aix-Marseille), Ph.D. (U.Q.À.C.)

Admission requirements

Ontario secondary schools

- **1 grade 12 U-level mathematics**
- **2 grade 12 U-level sciences**
- **1 grade 12 U-level English**
- **2 other grade 12 U/M-level courses**

For entry into the Geology program, it is recommended that students include calculus, chemistry and physics in their program at the grade 12/U-level. Students without grade 12/U-level chemistry must take CHMI 1041 before enrolling in the required 1st-year chemistry course.

Students with grade 12/U-level calculus, but with a grade of less than 60%, are strongly advised to take MATH 1912 as a refresher course before proceeding to MATH 1036.

All three grade 12/U-level mathematics courses (i.e. calculus, algebra, and functions and relations) are recommended for students in the Mining Geology Option.

Students with grade 12/U-level geology (or equiv.) may request exemption from GEOL 1006 and 1007. The department chair (or a representative) considers the request and sends a recommendation to the dean of the faculty, normally prior to or during registration.

See "Admissions" for other requirements.

General information

See "Earth Science" for information on the Bachelor of Arts in Earth Science.

See "Environmental Earth Science" for details on this Bachelor of Science program.

The 4-year B.Sc. in Geology is designed for students with a strong background and interest in the physical sciences, chemistry, physics and mathematics whose careers as geologists will be in mineral exploration, the mining industry/government agencies, or the petroleum industry. The program also provides a solid academic base for studies at the master's or Ph.D. level.

The 4-year Mining Geology option prepares students to become professionals with a relatively broad background in geology and a sound appreciation of the basic engineering skills necessary for the minerals industry. Graduates are production-oriented geologists trained to search for and outline the dimensions of mineralized zones, and participate with mining engineers in the exploitation of mineral deposits.

The 3-year B.Sc. in Geology program is addressed to students who intend to work in educational fields, geography, economics, business administration, etc. and may want a broad background in geology. It is not designed for students who wish to become professional geologists.

Students specializing in geology are encouraged to acquire field experience with federal or provincial geological surveys, and mining, oil or exploration companies during the summer months in order to supplement their formal academic training.

Programs

Bachelor of Science in Geology (4-year)

Mandate

The mandate of the B.Sc. in Geology program is to provide a broad, comprehensive, field-based undergraduate degree in Earth sciences that: 1) provides students with a holistic understanding of Earth sciences, 2) teaches students to think critically and to express themselves logically and clearly in both written and oral form, 3) qualifies graduates to become registered professional geologists (PGeo) with the Association of Professional Geologists of Ontario (APGO) or a similar professional regulatory body, and 4) provides the basics in Earth sciences such that a students can continue their education at the M.Sc. or Ph.D. level at any institution, or can be gainfully employed in the government or industrial sectors.

Requirements

120 credits with a minumum of 63 credits of GEOL courses;

6 credits in Chemistry (CHMI 1006/1007 E)

STAT 2246 E MATH 1036

3 credits MATH at any level

3 credits COSC or GEOL 3056 E

6 credits in Physics (PHYS 1006 E or 1206 E and PHYS 1007 E plus 33 credits of electives.

Twelve of the 33 elective credits must be in the social sciences and/or humanities*(students proceeding to the 2nd or higher year levels should consult the Geology Undergraduate Student Advisor before registering in GEOL courses.)

Registration in the Association of Professional Geologists of Ontario (APGO)

The four-year B.Sc. in Geology is constructed to meet the academic requirements for registration as a professional geologist (PGeo) with the Association of Professional Geologists of Ontario (APGO). Students are advised to consult the Department of Earth Sciences Undergraduate Handbook.

1st year

GEOL 1006/7 CHMI 1006/7
PHYS 1007 PHYS 1006 ***or*** 1206
MATH 1036

\+ other MATH course (3 cr)

\+ electives (6 cr) (humanities or social science course recommended)

2nd year

GEOL 2006 GEOL 2126
GEOL 2127 GEOL 2237
GEOL 2306 GEOL 2406

\+ elective in a foundation science** (3 cr)

\+ electives* (12 cr)

** STAT 2246 and 3 credits in computer science (or GEOL 3056) are compulsory and may be taken in any year.*

*** A foundation science elective is a course in biology, chemistry, computer science, mathematics, statistics or physics at the upper-year level. GEOL 2407 qualifies as a BIOL foundation elective. CHMI 2516 or 2526 is strongly recommended for students planning studies in mineral exploration, igneous or metamorphic petrology, geochemistry or mineralogy.*

3rd year

GEOL 3006 GEOL 3206/7
GEOL 3217 GEOL 3306
GEOL 3417 GEOL 3607
GEOL 3306

\+ electives* (6 cr)

4th year

GEOL 4505

\+ 12 credits from:

GEOL 4026 GEOL 4127
GEOL 4206 GEOL 4217
GEOL 4226 GEOL 4307
GEOL 4956 GEOL 4416
GEOL 4607 GEOL 4706

\+ electives* (12 cr)

** Up to 6 credits may be GEOL 4005 or two of the above 3-credit GEOL courses.*

Note: If students choose not to take GEOL 4005 E (Thesis) and still wish to be registered by APGO, they must take 6 credits in geoscience electives from fourth-year GEOL courses or equivalent (see list below). In addition, these students should consult the Department of Earth Sciences Undergraduate Handbook and the Geology Undergraduate Advisor for confirmation of the eligibility of a course as a geoscience elective.*

Recommended science electives

CHMI 2516 E or 2526 E- Physical Chemistry
CHMI 2517 E - Introductory Physical Chemistry II*
CHMI 2316 E - Inorganic Chemistry I*
MATH 1056 E - Discrete Mathematics I
MATH 1057 E - Linear Algebra I
BIOL 1506 E - Biology I
BIOL 1507 E - Biology II
BIOL 3056 E - Mineral Exploitation and the Biosphere
ENGR 1056 E - Applied Mechanics I
ENGR 2097 E - Fluid Mechanics
ENGR 2106 E - Introduction to Mineral Resources Engineering
ENGR 2517 E - Plane Surveying and Photogrammetry
GEOL 3397 E - Introductory Soil Science
GEOL 3417 E - Oceanography

Recommended social science or humanities electives

GEOG 2026 E - Introduction to Quantitative Methods
GEOG 2027 E - Quantitative Methods in Geography
GEOG 2107 E - Geomorphology II*
GEOG 3036 E - Air Photo Interpretation*
GEOG 3037 E - Remote Sensing of the Environment
GEOG 4106 E - Applied Geomorphology*
ANTR 2026 E - Essentials of Archaeology
ANTR 2027 E - The Archaeology of Ontario in a North American Framework
ENGL 1705 E - Introduction to Writing and English Studies
ENGL 2556 E - Principles and Practices of Workplace Communication
PHIL 1115 E - Introductory Philosophy

** Denotes courses eligible for geoscience elective status with the Association of Professional Geologists of Ontario.*

Bachelor of Science in Geology - Mining Geology option (4-year)

Requirements

120 credits (with min. 48 GEOL credits)

1st year

GEOL 1006 GEOL 1007
CHMI 1006 CHMI 1007
MATH 1036 MATH 1037
ENGR 1007 ENGR 1077
PHYS 1007 PHYS 1006 ***or*** 1206

2nd year

GEOL 2006	GEOL 2126
GEOL 2237	GEOL 2127
ENGR 1056	ENGR 2517
STAT 2246	

\+ CHMI 2526 ***or*** ENGR 2036 ***or*** CHMI 2516
\+ electives in social sciences or humanities (6 cr)

3rd year

GEOL 3006	GEOL 3206
GEOL 3207	GEOL 3306
GEOL 3607	ENGR 2076
ENGR 2106	ENGR 2346
GEOL 3806	

\+ elective in social sciences or humanities (3 cr)

4th year

GEOL 4607	ENGR 3387
GEOL courses (9 cr)	

\+ electives in sciences/engineering* (12 cr)
\+ elective** (3 cr)

** It is recommended to combine GEOL courses with courses from the ENGR electives list.*

*** Must be from social sciences or humanities if the 12-credit requirement has not yet been met.*

Engineering electives

ENGR 2356	ENGR 3126
ENGR 3317	ENGR 3376
ENGR 4336	ENGR 4356

Bachelor of Science (general) in Geology (3-year)

RECOMMENDED PROGRAM

90 credits (with min. 36 GEOL credits)

1st year

GEOL 1006/7	CHMI 1006/7
PHYS 1006 ***or*** 1206	
PHYS 1007	

\+ 1000-series MATH courses (6 cr)
\+ electives (6 cr)

2nd year

GEOL 2006	GEOL 2126/7
GEOL 2237	GEOL 2406/7

\+ electives (12 cr)

3rd year

GEOL 3006

\+ 12 credits* from:

GEOL 3206/7	GEOL 3217
GEOL 3306	GEOL 3806

\+ electives (15 cr)

** Courses may be subject to prerequisites.*

Note: Students may include a maximum of 48 credits at the 1000 level in their degree program.

Qualifying year

After completing the 3-year degree, students may choose to pursue a qualifying 4th year. They are required to complete a minimum of 27 credits in geology (courses not taken in previous years; selected from the 4th-year honours program), so that, once they are finished, they will have a total of at least 63 credits in geology (including B.Sc. credits).

Honours Diploma in Geology

This program is intended for students who have already graduated from the general degree and also for geologists who wish to pursue a full year of study at the honours level, to upgrade their academic and professional qualifications. The normal prerequisite is a 3-year B.Sc. degree in geoscience with a minimum 70% average in geology courses. However, mature applicants with industry experience may also be admitted with department approval. Students must achieve at least 70% on all GEOL courses and have their program approved by the department.

GEOL 4505

\+ 12 credits from:

GEOL 4026	GEOL 4127
GEOL 4206	GEOL 4217
GEOL 4226	GEOL 4307
GEOL 4956	GEOL 4416
GEOL 4607	GEOL 4706

\+ electives* (12 cr)

** Up to 6 credits may be GEOL 4005 or two of the above 3-credit GEOL courses.*

Master of Science in Geology

The department offers graduate studies in two principal areas: mineral deposit geology and Precambrian geology. It also offers an applied course work master's option. This is a new modular option initiated in September 1999, designed to facilitate participation by part-time students who are employed in the mining industry. For information, consult the graduate calendar on the departmental web page, or contact the department's graduate secretary.

Liberal Science - Continuations

Students taking a degree in Liberal Science and following a continuation in geology may include up to 9 credits from the following list as part of the geology continuation.

GEOG 2106 E*	GEOG 2107 E
GEOG 3036 E	GEOG 3037 E
GEOG 4106 E	

** Students who have taken GEOL 1006/7 may not take GEOG 2106 for credit.*

Courses for non-geologists

Suitable as electives for Liberal Science or other B.Sc. programs (excluding geology)

GEOL 1021 E	GEOL 1022 E
GEOL 2021 E	GEOL 2406/7 E

Course descriptions

GEOL 1006 E - Introductory Geology I
This course covers the physical geology of the Earth, including the origin of the solar system, Earth structure and Earth physics (seismology, geomagnetism), plate tectonics as the unifying theory in Earth sciences, earthquakes, magma generation, volcanic activity, continental growth, mountain building, geological structures (folds and faults), the rock cycle, sedimentary/metamorphic/igneous rocks, and rock-forming minerals. Laboratory exercises includes earthquakes, plate tectonics and identification of common rocks and rock-forming minerals. A field trip across the Sudbury Basin introduces students to interpreting rocks in the field. *(lec 3, lab 3) cr 3*

GEOL 1007 E - Introductory Geology II
This course builds on concepts introduced in GEOL 1006 E and serves as an introduction to the methods used in reconstructing the geologic history of the Earth and its regions. Topics include: the geologic time scale; dating methods; life, fossils & evolution; sedimentary environments; introduction to stratigraphy & correlation; an overview of major events in Earth history. Laboratory sessions provide an introduction to relative dating, fossils, sedimentary rocks, stratigraphy and geologic maps. *PREREQ: GEOL 1006 E (lec 3, lab 3) cr 3*

GEOL 1021 E - Understanding the Earth I
This course covers the physical geology of the Earth, including the origin of the solar system, Earth structure and Earth physics (seismology, geomagnetism), plate tectonics as the unifying theory in Earth sciences, earthquakes, magma generation, volcanic activity, continental growth, mountain building, geological structures (folds and faults), the rock cycle, sedimentary/metamorphic/igneous rocks and rock-forming minerals. This course has the same lecture content as GEOL 1006 E, but does not have a laboratory component. It is not a credit for geology majors and cannot be taken for credit concurrently with, or subsequent to, GEOL 1006 E. *(lec 3) cr 3*

GEOL 1022 E - Understanding the Earth II
This course builds on concepts introduced in GEOL 1021 and serves as an introduction to the methods used in reconstructing the geologic history of the Earth and its regions. Topics include: the geologic time scale; dating methods; life, fossils and evolution; sedimentary environments; introduction to stratigraphy and correlation; an overview of major events in Earth history. *Geology majors cannot retain credit for this course; students cannot take GEOL 1022 E at the same time as, or after GEOL 1007 E. PREREQ: GEOL 1021 E. (lec 3) cr 3*

GEOL 2006 E - Field Geology I
This course introduces students to the science of field geology. In the 5 weekdays prior to the start of the fall term, students will visit a variety of geological settings in the field where students will be introduced to and learn safety in the field, basic geological observation and data recording, and basic mapping techniques both in plan and section. At each area students will undertake small (outcrop) scale mapping projects. During the fall academic term students will attend seven field trips (Friday afternoons from mid September to late October) led by faculty to examine and document specific geological environments. The final section of the course will be devoted to classroom map exercises (three point, apparent dip, strata thickness and orientation, geological cross sections - 3 hours per week).
PREREQ: GEOL 1006 E, 1007 E. cr 3

GEOL 2021 E - Geology of Earth Resources
This course covers the nature and geological origin of important non-renewable resources in the Earth's crust with special reference to Canadian occurrences of metals, fossil fuels, phosphates and evaporites. This course is directed towards non-science students and is not available for credit in the B.Sc. in Geology.
PREREQ: GEOL 1021/1022 E or equivalent, or permission from the instructor. (lec 3) cr 3

GEOL 2022 E - The Dynamic Earth
This course is a study of the global plate tectonic processes that led to the deformation of the Earth's lithosphere. Topics include the origin of mountain belts and other major regional geologic structures and the formation and growth of the North American continent. This course is directed towards non-science students and is not available for credit in the B.Sc. in Geology or Environmental Earth Science programs.
PREREQ: GEOL 1021/1022 E or equivalent or permission from the instructor. (lec 3) cr 3

GEOL 2126 E - Mineralogy I
An introduction to the crystallography of minerals emphasizing external morphology: symmetry elements, crystallographic axes, crystal systems, Miller indices, simple stereograms and crystal classes. Topics include: the physical and chemical properties of minerals and how these properties are related to internal structure; packing of atoms, radius ratios and atomic coordination; derivation of chemical formulae from chemical analyses; atomic bonds and their relationship to mineral composition and structure; unary and binary phase diagrams. Involves systematic discussion of crystal chemistry and occurrence of main mineral groups. Laboratory work involves hand specimen examination of major mineral groups identification using crystallographic, physical and chemical properties.
PREREQ: GEOL 1006/7. (lec 3, lab 3) cr 3

GEOL 2127 E - Optical Mineralogy
An introduction to the theory and methods of optical crystallography as it relates to the passage of light through isotropic and anisotropic minerals. Emphasis in laboratory exercises is placed on the application of theory to the identification of minerals in thin section using a polarizing microscope. Includes an introduction to the optical mineralogy of the most important minerals in common igneous, metamorphic and sedimentary rocks.
PREREQ: GEOL 2126. (lec 3, lab 3) cr 3

GEOL 2237 E - Sedimentary, Igneous and Metamorphic Rocks
This course examines the classification and recognition of sedimentary, igneous and metamorphic rocks, the nature of their occurrence and processes responsible for their formation. A third of the course is devoted to each of the three major lithotypes. Laboratory exercises and field-oriented assignments will focus on hand specimen material, emphasizing common mineral associations, structures and textures. *PREREQ: GEOL 1006 E or GEOL 1007 E or equivalent. (lec 3, lab 3) cr 3*

GEOL 2406 E - Paleobiology I
A broad overview of the history of life on earth over the past four billion years, outlining the importance of biological input into the making of planet Earth. Topics also include: the use of fossils as keys to geological time, evolution and ancient environments; the origins of life, development of the atmosphere and oceans and evolution of marine and terrestrial ecosystems in the light of plate tectonics; morphology, paleoecology and evolution of important fossil groups, starting with bacteria, algae, vascular plants, and ending with protochordate invertebrates. Laboratory sessions deal with stromatolites, calcareous algae, vascular plants, microfossils and invertebrates (sponges, corals, bryozoans: remaining labs covered in GEOL 2407).
Annual fall field trip to Manitoulin Island. Suitable for students of biology, geography or anthropology. (lec 3, lab 3) cr 3

GEOL 2407 E - Paleobiology II
A continuation of GEOL 2406. The course begins with the origin of the oldest vertebrates about 500 million years ago (Cambrian), the invasion of fresh water habitats by the armoured fishes, and the arrival of the tetrapods (amphibians) on land in the Late Devonian. Also examines the rise of the reptiles during the Carboniferous, mammal-reptiles of the late Paleozoic-Triassic, dinosaur success of the Mesozoic and mass extinctions; origins of flight in reptiles and birds, reptile conquest of the seas in the Mesozoic; arrival of the mammals in the Triassic, radiation and expansion in the Cenozoic. Ends with the evolution of primates and humans. Laboratory sessions deal with invertebrates (covered in GEOL 2406), including brachiopods, molluscs, echinoderms, trilobites-ostracodes, graptoloids, conodonts and trace fossils.
PREREQ: GEOL 2406. (lec 3, lab 3) cr 3

GEOL 3006 E - Field Geology II
This course requires students to create one or more geological maps and a geological report that presents the geological framework for the mapping project(s) and explains the field observations. Structural mapping of polydeformed rocks will be emphasized. Field supervision for the course is normally offered during the first two weeks of May for students finishing their third year of study in an Earth sciences program. Final maps and reports are due on the last day of the field school. This course will provide students with general skills in: 1) orientation and map reading; 2) use of GPS and air photography; 3) traverse and mapping techniques; 4) field structural analysis; and 5) technical report writing. *PREREQ: GEOL 2126 E, 2237 E, 3306 E. cr 3*

GEOL 3056 E - Computer Applications in the Earth Sciences
Deals with the use of computer software packages aimed at compiling geological and environmental earth science field data and producing maps and diagrams of high quality. These may include Field Log, Map Info, AutoCAD, Corel Draw or other programs as they become available. Methods of calibrating digitized maps to geographic coordinates and exporting to other programs for final editing are studied. *Restricted to students of the 4-year Geology or Environmental Earth Science program. (tut 3) cr 3*

GEOL 3206 E - Igneous Petrography
Topics include: the mineralogical, petrographic and chemical characteristics of the major plutonic and volcanic igneous rock associations and their field characteristics; introduction to the theories of magmatic differentiation and their roles in igneous rock diversification; introduction to the interpretation of igneous mineral paragenesis from textural relations and considerations of crystallization behaviour in simple silicate systems. Laboratory exercises include representative examples of diagnostic rock types and rock suites and require an adequate understanding of optical mineralogy. *(lec 3, lab 3) cr 3*

GEOL 3207 E - Metamorphic Petrography
The study of the classification of metamorphic rocks. Topics include: types of metamorphism; zones, index minerals, isograds and relation to metamorphic facies concept; ACF, AKF, AFM projections and use to represent mineral assemblages; metamorphic textures and interpretations; Gibbs and Goldschmidt phase rules (application to experimental and natural mineral equilibria); discussion of major metamorphic facies and environments where these rocks occur. Laboratories present samples and suites of material illustrating lecture material and concepts. *(lec 3, lab 3) cr 3*

GEOL 3217 E - Sedimentary Facies
Examines the identification, origin, architecture and stratigraphy of siliciclastic sedimentary facies developed in terrestrial and marine sedimentary environments in a broad range of climatic settings. Includes discussion of stratigraphic methodology, detailed petrographic analysis of clastic sedimentary rocks, and an introduction to the petrography of carbonate rocks. *PREREQ: GEOL 2127 & 2237. (lec 3, lab 3, field trip) cr 3*

GEOL 3306 E - Structural Geology
The course examines the formation of tectonic structures in rocks. It begins with an introduction to strain and stress. This is followed by an examination of brittle structures, such as faults, cataclasites, fractures and veins, in terms of classification, recognition and modes of origin. During the second half of the course, the development of shear zones, foliations, lineations and folds is discussed with an emphasis on the interrelationships between these structures. Rock flow equations, shear sense indicators in fault zones, and grain-scale plastic deformation processes are other topics covered in the course. Laboratory work comprises stress and strain exercises, stereographic projections, solution of 3D structural problems by descriptive geometry and stereographic projections, map interpretation of deformed areas, and interpretation of the attitude of deformed orebodies from drill hole data. *PREREQ: GEOL 1006/7 E, 2237 E. (lec 3, lab 3) cr 3*

GEOL 3312 E - Introduction to Earth Structures
Introduces students to the major structural features found in deformed rocks and to the physical conditions under which they formed, and how to collect, process and interpret structural data. The course material is divided into two parts, namely text and assignments. *Not available for credit in the B.Sc. specialization in Geology or Environmental Earth Sciences. PREREQ: GEOL 1006 & 1007 or GEOL 1021 & 1022 and GEOL 2021 & 2022. cr 3*

GEOL 3397 E - Introductory Soil Science
An introduction to the formation and classification of soils, including their physical, chemical and biological properties. Also considers environmental issues involving soil. *PREREQ: CHMI 1041 or grade 12/U-level chemistry & GEOL 1007 or dept.'s permission. Cross-listed as BIOL 3397; students cannot take both GEOL & BIOL 3397. (lec 3, lab 3) cr 3*

GEOL 3417 E - Oceanography
Topics include: origin of the ocean-atmosphere system; ocean basins and plate tectonic processes; marine geology, hot spots, deep sea vents; ocean salinity, density, gases, thermal properties, heat budgets, circulation; marine provinces; oceanic ridges, rises and trenches; life in the oceans; evolution of marine communities and marine extinctions; sediment distribution; current systems; ocean resources and their exploitation; environmental concerns. *PREREQ: GEOL 1006 E or 1021 E, GEOL 1007 E or 1022 E.*

GEOL 3607 E - Ore Deposits and their Geological Environment
An introduction to the nature, morphology, geologic setting and classification of the principal types of ore deposits and theories about their genesis. Includes a description of significant Canadian deposits and their geological and tectonic environment as well as notable deposits elsewhere in the world. Emphasis is placed on shield deposits and metallogeny, and attention is given to mineral economics, mining and metallurgical techniques, and relevant environmental issues. Laboratories introduce students to techniques used to understand ore deposits (microscopy, microprobe analysis, study of fluid inclusions and stable isotopes) and focus on specific deposits and their host rocks. *Students cannot take both GEOL 3607 & 4606. PREREQ: GEOL 2127, 2237, 2306 & 2807. (lec 3, lab 3) cr 3*

GEOL 3806 E - Geochemistry
This course provides an introduction to geochemistry and mineralogy of the Earth's crust, the chemical processes that take place at the Earth's surface and the geochemistry of both low- and high-temperature systems. Topics include geochemical variations from core to crust; Goldschmidt's classification of the elements; laws of thermodynamics; solution geochemistry; salts and their ions; weathering and mineral stability diagrams including carbonates, sulphates, sulphides and silicates; electrochemistry and Eh-pH diagrams; soil formation; quantitative calculation of elemental variations during mineral and rock weathering; stable isotopes and their application to paleoclimatology and near-surface earth processes; radiogenic isotopes and their application in geology; major and trace element geochemistry.
PREREQ: GEOL 2126 E, CHMI 1006/1007 E. (lec 3, lab 3) cr 3

GEOL 3811 E - Chemistry of Earth Materials
Provides a quantitative treatment of selective chemical and mineralogical processes important in understanding the chemistry of the Earth. This will include the use of phase diagrams to review the chemical variation from the mantle of the Earth to its crust and the classification of rocks based on its chemistry and mineral assemblages. Metamorphic and metasomatic processes will be considered briefly. Also included will be the application of aqueous chemistry using Eh-pH and activity or concentration diagrams to investigate the processes of weathering of silicate rocks and mineral deposits. This section will also include the formation of clays and soils. The chemistry of the oceans will be dealt with briefly.
Not available for credit in the B.Sc. specialization in Geology or Environmental Earth Sciences. PREREQ: GEOL 1006 & 1007 or GEOL 1021 & 1022. cr 3

GEOL 4005 E - Thesis
A thesis requiring independent research and the guidance of one or more faculty members. The subject is chosen by the student in consultation with the course coordinator and the supervising professor. Students are encouraged to obtain permission of their employer to use material gathered during the summer as a basis for the thesis. The thesis is defended orally and a final draft, suitable for defence, is normally submitted at least two weeks before the end of classes of the 2nd term.
PREREQ: min. 70% average on required courses or permission of the chair. (sem, exp) cr 6

GEOL 4026 E - Field Geology III
Shows how geological and ore-forming problems can be solved by integrating detailed mapping with geochemical and petrographic analysis. Students create one or more geological maps and measured stratigraphic/structural sections in three areas, Noranda, Timmins and Sudbury. These areas illustrate different geological and ore-forming environments and the map areas are selected to illustrate particular geological problems. The 10-day field component begins one week prior to the fall session for students entering the 4th year of an Earth Science program. Subsequent laboratory analysis includes examination of samples, whole rock and trace element geochemical data, and thin sections representative of rock types, alteration and mineralization in each map area. Students produce final maps and a comprehensive geological report summarizing each of the map areas, including interpretations derived from geochemical and petrographic data. *Students cover all extra costs associated with this course. PREREQ: completion of required 3rd-year GEOL courses & enrolment in 4-year Geology program or instructor's permission. (exp) cr 3*

GEOL 4037 E - Applied Remote Sensing
Includes lectures, seminars and projects covering the application of remote sensing to geological, land cover and water quality mapping. Projects are chosen from within these fields where data sets are available and are structured to address issues specific to the particular application, as well as general remote sensing issues such as atmospheric correction, statistical vs. biophysical modelling approaches, and multi data-type integration.
PREREQ: GEOG 3037, a statistics course & GEOL 1007, or dept.'s permission. (lec 3, lab 3) cr 3

GEOL 4127 E - Advanced Mineralogy
An applied course designed to provide students with detailed information on specific minerals and mineral groups along with the analytical techniques used to identify and characterize them. Mineralogical topics to be discussed may include: mineralogy of massive sulphide ore deposits (Fe-Ni-Cu sulfides), phase equilibria of the Fe-Ni-Cu-PGE ternary, Fe-Ti oxides, alteration minerals (chlorite, amphiboles, white micas) and application of their distribution to ore deposit exploration, the distribution, occurrence and synthesis of platinum-group minerals, classification of clay phyllosilicates, crystal chemistry and classification of zeolites, adsorptive and ion exchange properties of clays, mineralogy of orchre and laterite deposits, alteration of primary Fe-Ni-Cu sulfides. Analytical topics to be discussed may include: powder and single-crystal X-ray diffraction, Rietveld analysis of X-ray data, electron-microbeam techniques (scanning electron miscroscopy, wavelength- and energy-dispersive spectrometry), FTIR/Raman spectroscopy, ICP-MS techniques. Students considering this course are strongly recommended to discuss the course content with the appropriate instructor prior to registration.
PREREQ: GEOL 2126 E & 3806 E. (lec 3, lab 3) cr 3

GEOL 4206 E - Igneous Petrology
Topics include: genesis of magmas, magma types, petrographic provinces and their distribution in time and space, relations to tectonic setting; differentiation indices, variation diagrams, distribution trends of major and trace elements; equilibrium and fractional crystallization in selected synthetic systems and their application to natural systems; stability of minerals and mineral assemblages and the phase rule, volatile effects; mineralogy, texture, field relations, associations and petrogenesis of selected areas.
PREREQ: GEOL 3206. (lec 3, sem) cr 3

GEOL 4217 E - Carbonates, Sedimentology
This course will examine the processes and products of deposition in tropical and temperate carbonate producing environments, with emphasis on identification and significance of facies, microfacies, organisms and diagenetic processes and products. The application of carbonate facies analysis and sequence stratigraphy will be considered within the context of petroleum exploration models.
PREREQ: GEOL 2406 E, 3217 E. (lec 3, lab 3, sem) cr 3

GEOL 4226 E - Pleistocene and Glacial Geology
Topics include: continental and alpine glaciation; erosional and depositional features; glacial climates and their origin; ancient glaciations (Huronian, late Precambrian, Ordovician, late Paleozoic); glacio-marine environments; glaciations and floral-faunal changes, extinctions, coeval low latitude environments. Laboratories deal with glacial geomorphology and sediments. Local field trips examine gravel deposit, glacial varvites (clays) and soils. *PREREQ: GEOL 3217 or instructor's permission. (lec 3, lab 3) cr 3*

GEOL 4307 E - Polyphase Metamorphism and Deformation
The course studies the combined metamorphic and structural changes in rocks during orogenesis. The aim of the course is to integrate concepts learned in third year metamorphic and structural courses to better understand the transformation in the structure, texture and mineralogy of rocks after depositions. During the first half of the course, students will be introduced to the concept of vorticity during rock flow, the development of structures in high strain zones of monoclinic and triclinic symmetry, the interpretation of textural relationships between microstructures and metamorphic minerals, and the analysis of porphyroblast-matrix relations. During the second half of the course, students will learn how to analyze the metamorphic and deformation history of rocks, construct petrogenetic grids, calculate metamorphic temperatures and pressures using experimental and thermodynamic data, and interpret pressure-temperature-deformation-time paths. Laboratory work will include petrographic case studies of deformed and metamorphosed suites of rocks from different tectonic environments and a field project within the Sudbury area.
PREREQ: GEOL 3207 E, 3306 E. (lec 3, lab 3) cr 3.

GEOL 4416 E - Global Change: The Geologic Record
Examines the long-term record of global change as reflected in sedimentary rocks, fossil faunas and floras, and low temperature isotope geochemistry. Topics include: major changes in biogeochemical cycling processes through geologic time; lithosphere-ocean-atmosphere interactions; sedimentary suites and fossils as paleoclimatic keys; sedimentary processes related to global change; plate tectonic and mountain building as forcing mechanisms for climatic change; extra-terrestrial forcing.
Designed for senior-level students. (lec 3) cr 3

GEOL 4505 E - Tectonics, Petrogenesis and Metallogenesis
A synthesis course providing an integrated overview of tectonic environments and geodynamic processes and their roles in metallogenesis in Phanerozoic to Precambrian environments. The course will integrate knowledge from the fields of geophysics, structure, tectonics, igneous petrology, volcanology, metamorphic petrology, sedimentology, and metallogenesis of divergent margins, convergent margins, passive margins, large igneous provinces, and Precambrian greenstone belts. The course will also consider how petrogenetic processes and structural styles have varied in orogens representing a variety of crustal levels through Earth history.
PREREQ: GEOL 3206 E, 3207 E, 3217 E, 3306 E, 3607 E, 3806 E. (lec 3) cr 6

GEOL 4607 E - Ore-forming Processes
Examines processes involved in the genesis of magmatic and hydrothermal ore deposits. Emphasis is placed on Ni-Cu-PGE and chromite deposits, the role of sulphur in silicate melts, and contamination and magma mixing. In considering hydrothermal deposits, topics include: the types of hydrothermal fluids involved in mineralizing processes; sulphur and chloride species; the solubility of metals, and alteration and hydrogen metasomatism including techniques to assess chemical gains and losses. Attention is given to porphyry copper, volcanogenic massive sulphides, epithermal and lode-Au deposits. Laboratories involve examination of selected sample suites, problem sets and a project.
PREREQ: GEOL 3206/7, 3307, 3607 & 3807. (lec 3, lab 3) cr 3

GEOL 4706 E - Hydrogeology
An introduction to hydrogeology covering hydrogeologic properties of porous media, flow nets, groundwater resource evaluation, groundwater chemistry, geology of groundwater occurrence, groundwater and the hydrologic cycle, and groundwater contamination.
PREREQ: GEOL 1006/7, CHMI 1006/7 & MATH 1912 or 1036. (lec 3, lab 3) cr 3

GEOL 4956 E - Geophysical Methods
Physics of the Earth, the principles of geophysics, and an introduction to geophysical exploration methods, including gravity, magnetics, seismology, thermal history, and applications in mineral exploration.
PREREQ: GEOL 1006 E and PHYS 1006 or 1206; completion of 2nd year of Geology; MATH 1036 or 1912 recommended. (lec 3, lab 3) cr 3