GEOL 40280: Igneous, Metamorphic and Ore Geology

MODULE COORDINATOR: Assoc. Prof. Julian Menuge

ADDITIONAL LECTURERS: Prof. Stephen Daly
Prof. Frank McDermott

CREDITS: 10	**MODULE LEVEL**: 4	**SEMESTER**: I

PRE-REQUISITES/PRIOR LEARNING:

This module is suitable for students who have taken intermediate courses in igneous and metamorphic petrology (for example UCD modules GEOL30240 Igneous Petrology and GEOL30110 Metamorphic Petrology) and an introductory course in ore deposit geology. A good working knowledge of transmitted polarized light microscopy is essential, but no prior knowledge of reflected light microscopy is required.

OVERVIEW OF MODULE:

The module examines:

1. The causes of magma generation, magma evolution and igneous rock formation in a variety of both modern plate tectonic settings and ancient, less well-understood, tectonic settings.
2. Metamorphsim associated with the crustal evolution and tectonics of Laurentia-Baltica from Archaean to Palaeozoic; metamorphism associated with the Grampian Orogeny; geochronology of metamorphic processes; geothermobarometry and relative thermobarometry; mixed fluid equilibria; eclogites; granulites and thermal aureoles.
3. Major types of metallic mineral deposit and the processes by which they formed, though study of well-researched examples and a one-day visit to a working mine.

LEARNING OUTCOMES:

On completion of this module students should be able to:

1. Critically evaluate, both orally in seminars and in written work, research articles on a variety of topics in igneous petrology and ore geology;
2. Plot, manipulate and carry out calculations on geochemical and isotope data and draw conclusions about the origin and evolution of magmas;
3. Make detailed petrographic descriptions of igneous rocks and from these descriptions draw conclusions on the origin, evolution and crystallization of these rocks;
4. Make detailed petrographic descriptions of mineralized rocks and from these descriptions draw conclusions on the mineralizing processes involved.
5. Students achieving an honours standard in this course will be familiar with current issues in metamorphic petrology through the relevant literature, will achieve competence in the petrographic analysis of metamorphic assemblages, in thermobarometry and metamorphic geochronology. These problem-solving skills will serve as the basis for future career development and will immediately place students in a position to be selected for interview for PhD research positions in petrology.

ASSESSMENT:

Continuous Assessment: 50%
(Continuous assessment of practical and seminar work, including practical exam)

Examination: 50%
(3-hour end of semester written examination)

IGNEOUS PETROLOGY:

9 x 4 hour sessions including lectures, seminars and practical work.

Session 1: Komatiites. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on petrogenesis including the question of magma water content, tectonic setting and conditions of crystallization; practical on description and interpretation of komatiites in thin section from Munro Township, Ontario.

Session 2: Anorthosite-mangerite-charnockite-granite(AMCG) magmatism. *(Assoc. Prof. J.F. Menuge)*
Silicate composition of crust and mantle; The SiO_4 tetrahedron, silicate polymerization and silicate classification, with examples of each class; Goldschmidt's rules, chemical substitution and solid solution; examples of silicate solid solutions; relationships between silicate properties and silicate classification.

Session 3: Lunar igneous petrology. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on the sources of information on lunar igneous petrology, the origin of the Moon, its early differentiation and mechanisms generating the maria basalts; practical based on description and textural interpretation of NASA lunar thin sections.

Session 4: Carbonatite magmatism. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on active volcanism at Oldoinyo Lengai, the relationships between carbonatite and alkaline silicate magmatism, the processes of carbonatite magma formation and the origin of mantle carbonate; practical based on description and interpretation of thin sections of rocks form the Palabora Complex, South Africa.

Session 5: Mid-ocean ridge basalts. *(Prof. P.F. McDermott)*
Mantle melting at constructive plate margins. Mantle upwelling, melting columns sampling of heterogeneities. Influence of spreading rates, lithosphere thickness and regional temperature anomalies. Mechanisms of magma differentiation. Magmatic products and thermal/thickness evolution of oceanic crust. Insights from very slow spreading centres (SWIR and Gakkel). Workshop/debate on the petrological significance of global correlations in the major element composition of mid-ocean ridge basalts (Klein and Langmuir versus Niu and O'Hara).

Session 6: Destructive plate margin. *(Prof. P.F. McDermott)*
Subduction of oceanic crust and dehydration reactions. Fate of subducted slabs and sediments. Temperature profile through a subduction zone. Influence of volatiles on mantle solidus. Volatile transport into mantle wedge. Rates of wedge convection, replenishment and depletion. Magmatic products and their distinctive geochemistry. Data analysis practical using Excel to do basic calculations and plot data. Interpretation of trace element ratio vs. isotope ratio correlations.

Session 7: U-series disequilibria. *(Prof. P.F. McDermott)*
U-series disequilibria. Introduction to the systematics of U-series. U-series constraints on mantle melting, timescales of magma transport and fluid/magma interactions. Data analysis practical with emphasis on U-series data. Introduction to the use of the U-series nuclides in deciphering partial melting processes, effect of slab-derived fluids and timescales of magma generation and ascent. Mineral isochrones in the U-series system.

Session 8: Intra-plate magmatism. *(Prof. P.F. McDermott)*
Oceanic intra-plate magmatism. Ocean island basalts, their petrology and geochemistry. Initiation and evolution of mantle plumes. Asthenospheric and lithospheric contributions to magmatism. The nature and causes of mantle heterogeneity. Geophysical and geochemical evidence for heterogeneity on a range of scales. Preservation of heterogeneities. Links between ocean island magmatism and flood basalt provinces. Student presentations on recent review papers on the geophysical and geochemical constraints on the nature of the Earth's mantle. Models for mantle structure and convection.

Session 9: Granites and alkalic rocks. *(Prof. P.F. McDermott)*
Recent research on granites. Crustal melting vs. mantle inputs. How do granitic melts segregate and migrate? Practical on alkalic lavas from Italy and on a phonolite from Cornwall. Objective of the practical is to review mineralogy of silica-undersaturated rocks and revise optical properties of feldspathoid minerals.

ORE PETROLOGY:

6 x 4 hour sessions, including lectures, seminars, lab work and a one-day field class.

Session 1: The Navan Zn-Pb ore deposit, Co. Meath. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on the geological setting of the Navan deposit, the origin of fluid and dissolved materials, the role of faults, processes of ore precipitation and the timing of mineralization; practical introduces reflected light microscopy, followed by description and interpretation of Navan Zn-Pb ore in polished thin section.

Session 2: Stratiform sediment-hosted base metal deposits. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on the role of redox reactions, timing of mineralization relative to deposition, diagenesis and faulting in both the Kupferschiefer and the Central African Copperbelt; practical on description and interpretation of Cu sulphide ore from Chibuluma, Zambian Copperbelt in polished thin section.

Session 3: Porphyry ore deposits. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on the relationship of mineralization to host intrusions, chemical partitioning between magmas and hydrothermal fluids, the relationship between hydrothermal alteration and mineralization, and processes leading to ore deposition; practical on description and interpretation of Los Pelambres porphyry copper ore, Argentina in polished thin section.

Session 4: Iron oxide apatite (IOA) and iron oxide-copper-gold (IOCG) ore deposits. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on arguments for hydrothermal vs magmatic Fe oxide ores, models for origin of fluids and dissolved constituents in IOCG deposits, age relationships relative to host igneous rocks and the tectonic settings of IOCG mineralization; practical on description and interpretation of Fe oxide-P-REE ores of Pea Ridge, southeast Missouri in ordinary and polished thin section.

Session 5: Magmatic Ni-Cu-Co-PGE ores. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on magmatic processes leading to sulphide mineralization in the Sudbury and Noril'sk District intrusions, including sulphide liquid PGE enrichment and sulphide enrichment processes; practical on description and interpretation of Ni-Cu ores of Sudbury, Ontario in polished thin section.

Session 6: Bushveld PGE-Cr-Fe ore deposits. *(Assoc. Prof. J.F. Menuge)*
Lecture and seminar focusing on input to, and output from, the Bushveld magma chamber, and magmatic and hydrothermal processes leading to chromite, magnetite and platinum group element enrichments; practical on description and interpretation of Merensky Reef pegmatoid in ordinary and polished thin section.

Field Class: Boliden Tara Mines. *(Assoc. Prof. J.F. Menuge)*
This one-day class is led by Tara Mines geological and mineral processing staff, accompanied by Assoc. Prof. Julian Menuge, and consists of:

1. An introductory lecture on the discovery of the deposit, its geological setting and an overview of the mine.
2. A visit to several underground localities that illustrate types of ore and host rocks, as well as some of the mining practices.
3. A visit to the mill, to see the various crushing, grinding, flotation and other processes involved in producing zinc and lead concentrates for export.
4. Brief examination of drill core recently extracted during mineral exploration in and around the mine.

METAMORPHIC PETROLOGY:

9 x 4 hour sessions including lectures, seminars and lab work.

Session 1: Metapelite mineral zones and arguments for and against isochemical metamorphism. *(Prof. J.S. Daly)*
Practical work on metapelites from Glen Esk, Scotland the type area of Barrovian metamorphism and metapelite thermobarometry from the Tyrone Central Inlier, Ireland.

Sessions 2-4: Controls on the mineralogy and texture of metabasites. *(Prof. J.S. Daly)*
Three sessions based on case studies that focus on (a), autometamorphism associated with fluid flow during sill emplacement, (b), interplay between ductile deformation, mineral assemblages and isotopic equilibrium and (c) variations in PT conditions. These sessions involve practical work on metabasites from the Caledonian orogenic belt in Donegal, Ireland and from several localities in the Sveconorwegian belt in SW Sweden. Following the three sessions, the students write a short paper on their own petrographic observations and on the literature.

Session 5: Mixed Fluid Equilibria. *(Prof. J.S. Daly)*
Seminar focusing on chemistry of metamorphic fluids, contact metamorphism of impure limestones and the distinction between closed and open systems and the potential economic significance of the latter in exploration for epithermal metal deposits.

Session 6: Thermobarometry and interpretation of PT paths in granulite-facies rocks.
(Prof. J.S. Daly)
Includes discussion on the limitations of thermobarometry in ultra-high temperature rocks, interpretation of reaction textures and the proposed dehydration mechanisms operating during granulite-facies metamorphism. Examples are discussed from the Lapland Kola Orogen, Russia and from the Grampian belt in NW Ireland. Practical work on granulite-facies rocks from the Sharyzhalgay Complex, Russia and the Svecofennian Orogen.

Session 7: Eclogite facies rocks. *(Prof. J.S. Daly)*
Mineral assemblages in eclogite and other bulk compositions, extreme (ultra-high pressure) metamorphism in orogenic belts and the role of eclogite xenoliths in ground-truthing seismic and thermal models of the mantle. Practical work on Blueschist-facies rocks from the early Caledonian (Grampian) orogen from western Ireland.

Session 8: Thermal controls on and thermal modelling of regional metamorphism. *(Prof. J.S. Daly)*
Seminar discussing the relative importance of radioactive heat production and viscous (frictional) heating and the roles of conductive and advective heat transfer in orogenic belts.

Session 9: Geochronology of metamorphic processes. *(Prof. J.S. Daly)*
Seminar on distinction between crystallization and "cooling" ages. Concept of closure. Practicalities of dating mineral separates using isochrons (Rb-Sr, Sm-Nd and Lu-Hf) vs in situ methods (U-Pb). Examples from the Caledonian orogen in Norway, Scotland and Ireland.