GEOL 30110: Metamporphic Petrology

MODULE COORDINATOR: Prof. Stephen Daly

CREDITS: 5	**MODULE LEVEL**: 3	**SEMESTER**: II

PRE-REQUISITES/PRIOR LEARNING:

Students should be familiar with the use of a petrological microscope and have taken an introductory level course in mineralogy such as GEOL 20120 Investigating Minerals or equivalent offered by home institution.

OVERVIEW OF MODULE:

The first part of the module outlines the field appearance and tectonic settings of metamorphic rocks. It deals with the development of metamorphic textures and the mechanisms by which minerals crystallise in the solid state in response to strain and changing pressure and temperature conditions. It covers the mineral assemblages that develop in metamorphosed basis igneous rocks (metabasites), mudstones and shales (pelites) and limestones (calc-silicates) and the methods used to study them in the field and in the laboratory. Laboratory techniques include petrological (optical) microscopy, scanning electron microscopy, electron probe microanalysis and the use and interpretation of chemographic and pressure-temperature phase diagrams. The second part of the course provides a rigorous introduction to the application of equilibrium thermodynamics to geothermobarometry and discusses the application of Shreinemakers' method in the topological analysis of phase diagrams. Metamorphic reactions and the resultant mineral assemblages are explored in different tectonic settings, e.g. the Barrovian, Buchan and high pressure (blueschist) styles of regional metamorphism, high temperature (granulite-facies) terrains and the metamorphism of the ultramafic mantle rocks in rift zones.

LEARNING OUTCOMES:

On completion of this module students should be able to:

1. Appreciate the role that metamorphic rocks play in recording Earth's memory of past plate tectonic events;
2. Interpret the mineral assemblages and textures in metamorphic rocks;
3. Interpret a variety of chemographic and pressure-temperature phase diagrams;
4. Construct a phase diagram from thermodynamic data and analyse it using Schreinemakers' method;
5. Appreciate the thermodynamic basis for predicting reaction relationships in metamorphic rocks;
6. Critically evaluate the evidence for equilibrium and disequilibrium processes in metamorphic rocks;
7. Deduce aspects of the tectonic history from pressure and temperatures excursions inferred from chemical zoning in metamorphic minerals.

ASSESSMENT:

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

Examination: 50%
(2-hour end of semester written examination covering entire course)

LECTURES:

Lecture 1: Introduction to metamorphic rocks and scope of the module *(Prof. J.S. Daly)*
Physical and chemical controls on metamorphism. Geothermal gradients and heat sources. Textures associated with ductile deformation: foliation and lineation; polyphase deformation (D, F, S terminology), polycyclic events in orogens; field classification of metamorphic rocks.

Lecture 2: Textural analysis *(Prof. J.S. Daly)*
Use of metamorphic textures (relative time of PT and strain, PTtD paths); pre-, syn-, and post-tectonic growth of minerals; how to describe a metamorphic rock. Test for equilibrium, growth sequence, tectonic microstructures, relict textures. Porphyroblast-matrix relationships.

Lecture 3: Regional metamorphism of pelites 1 - Principles *(Prof. J.S. Daly)*
Pelite chemistry and protolith mineralogy. Classification of metamorphic grade using metapelite assemblages. Barrow Zones. Isograds. Dalradian of Glen Esk. Reactions at isograds. Melting and migmatites.

Lecture 4: Nature of foliations *(Prof. J.S. Daly)*
Preferred orientation mechanisms; textural analysis (using pelites as examples).

Lecture 5: Metabasites and facies *(Prof. J.S. Daly)*
Metabasite mineral assemblages; Classification of metamorphic grade based on metabasite assemblages; facies in PT space. Introduction to chemographic analysis; Gibbs Phase Rule; properties of triangular diagrams; ACF diagram. Metabasite mineral assemblages in the ACF diagram.

Lecture 6: Electron probe microanalysis (EPMA) *(Prof. J.S. Daly)*
Energy dispersive (EDS) and wavelength-dispersive spectrometry (WDS), principles and design, qualitative and quantitative analysis, ZAF corrections. Chemical zoning. Detection limits.

Lecture 7: Chemography (mainly pelites) *(Prof. J.S. Daly)*
Reactions defining the Barrow Zone isograds. Methods of identifying reactions: AFM chemography, petrography, (experiments). Metapelite chemography. AFM and AKF diagrams. Gibbs Phase Rule. Chemographic evidence for reactions. Reactions conts. Isochemical nature of metamorphism.

Lecture 8: Carbonates and calc-silicates *(Prof. J.S. Daly)*
Metamorphic mineralogy in the CMS system. Siliceous dolomites. Calc-silicate reactions in the Lepontine Alps. Correlation of calc-silicate zones in New England with pelite mineral zones and facies (based on metabasites). Decarbonation and CO2 release to atmosphere. Beinn an Dubhaich aureole.

Lecture 9: Fluids in metamorphism *(Prof. J.S. Daly)*
Basic fluid physics. Fluid pressure. Critical point for water. Role of fluids in metamorphism. Fluid chemistry. Hydration and dehydration. Retrogression. Metamorphic fluids and mineralization, e.g. Au-bearing quartz veins.

Lecture 10: Contact metamorphism *(Prof. J.S. Daly)*
Contact metamorphic facies. Depth-dependent recognition of thermal effects of igneous intrusions. Post-tectonic, anorogenic and syn-tectonic magmatism. Textures of contact metamorphism. Skiddaw aureole (pelites). Dehydration/hydration in aureoles. Retrogression in the roof zone of plutons (e.g. Skiddaw).

Lecture 11: Geothermobarometry 1 *(Prof. J.S. Daly)*
Basic thermodynamics, Chemical potential, Activity, Clausius-Clapeyron Eqn, Van't Hoff isotherm.

Lecture 12: Geothermobarometry 2 *(Prof. J.S. Daly)*
Practical thermobarometry. Net Transfer Reactions for barometry. Isovalent major element exchange reactions for geothermometry. Case studies from Tyrone Dalradian and lower crustal xenoliths.

Lecture 13: UM rocks *(Prof. J.S. Daly)*
Classification, occurrence, mineralogy of UM rocks. Reactions in the MSH and CMSH systems. Serpentinization of peridotites including the shallow mantle. Prograde metamorphism of serpentinites in the Bergell aureole. Carbonation of UM rocks for CO_2 storage.

Lecture 14: Metamorphism of pelites 2 *(Prof. J.S. Daly)*
Investigation of metapelite reactions; chemical zoning in minerals.

Lecture 15: Migmatites *(Prof. J.S. Daly)*
Field classification, petrogenesis, relationship to S-type granites.

Lecture 16: Granulite facies rocks *(Prof. J.S. Daly)*
Mineralogical and textural features. High T solid solutions, exsolution. Metabasites. Role of water. Dehydration mechanisms. Lower crust. Lower crustal xenoliths.

Lecture 17: Metamorphism & exhumation of blueschists *(Prof. J.S. Daly)*
Variations in metamorphic field gradient, Barrovian, Buchan & Sanbagawa. Paired metamorphic belts. Blueschist assemblages in metabasites and siliciclastics. Franciscan mélange vs coherent blueschist belts (e.g. Achill). Thermal relaxation. Platt's exhumation model. Achill case study.

Lecture 18: Grampian metamorphism in Scotland & Ireland *(Prof. J.S. Daly)*
Evidence for Pre-Cambrian Andean-style subduction and strike-slip tectonics in the Avalon and Monian terranes, then lying on the Gondwana continental margin.

Lecture 18: Caledonian/Acadian Orogeny *(Prof. J.S. Daly)*
Metamorphic field gradient variations, Barrovian, Buchan. Banffshire & Connemara. Barrovian N. Mayo.

PRACTICAL CLASSES

Practical 1: Regional metamorphism of pelites I - the Barrow Zones *(Prof. J.S. Daly)*
This practical illustrates the mineralogy and textures of two regionally metamorphosed pelites from the chlorite (B10) and biotite (AB1) zones. Specific questions are posed for each specimen.

Practical 2: Regional metamorphism of pelites II - the Barrow Zones *(Prof. J.S. Daly)*
This practical illustrates the mineralogy and textures of a staurolite zone regionally metamorphosed pelite emphasising the interpretation of helicitic texture.

Practical 3: Metabasites I *(Prof. J.S. Daly)*
Structural, morphological and geological analysis of a map spanning the margin and center of an active A7 KIL1 amphibolite; plot data on ACF diagram.

Practical 4: Metabasites II *(Prof. J.S. Daly)*
A15 and B9. Metabasite assemblages are illustrated using a granulite from the Adirondack Mountains, New York and an eclogite from Bavaria. Two test questions on protolith and metamorphic grade.

Practical 5: Pelites in contact aureoles *(Prof. J.S. Daly)*
Descriptions of metapelites from the metamorphic aureoles of the Leinster and Skiddaw granites. Sketch mineral assemblage(s) on AFM diagram; as far as possible comment on the textural history.

Practical 6: Thermo puzzles *(Prof. J.S. Daly)*
Thermodynamic drivers of reactions, Al2SiO5 phase diagram.

Practical 7: Composition paragenesis diagrams *(Prof. J.S. Daly)*
Complete Al_2SiO_5 phase diagram using Schreinemakers' method; Phase diagram puzzles.

Practical 8: Pelite mineral assemblages, garnet zoning and thermobarometry *(Prof. J.S. Daly)*
5144/ BKH1 (Grampian S Donegal) AFM diagram, zoning profiles and tectonic inferences.

Practical 9: Slishwood Division *(Prof. J.S. Daly)*
Early (or?pre-) Grampian eclogite facies and later Grampian high-P granulite facies metamorphism.

Practical 10: Blueschists *(Prof. J.S. Daly)*
Isle de Groix (metabasites), Pacheco Pass (metagreywacke).

Practical 11: Grampian N Mayo *(Prof. J.S. Daly)*
SCP16 (post-Grenville metabasite), 4/92-2 (Dalradian pelite)