

GEOL 20110: Global Environmental Change

MODULE COORDINATOR: Assoc. Prof. Patrick Orr

CREDITS: 5

MODULE LEVEL: 2

SEMESTER: I and II

PRE-REQUISITES/PRIOR LEARNING:

This module is offered in both Semester I and Semester II. It is taught entirely online and tested by three MCQ tests/examinations. A previous level one Earth Sciences module (GEOL10060) would be advantageous but is not essential.

OVERVIEW OF MODULE:

Earth History: the geological record of global environmental change.

The Earth is currently experiencing an episode of rapid climate change that most authorities consider to be the result of human activities. This change poses a challenge, even threat, to the functioning of Earth's ecosystems.

We can monitor on-going environmental change on local through to global scales using various instruments. We can make predictions as the future condition of the Earth System (for example via computer modelling).

There is another relevant dataset which this module introduces you to Environmental change over time is a natural phenomenon - part of the normal functioning of the Earth System. The geological record is thus an archive that records the causes and effects of such changes, - both in the relatively recent past (hundreds to thousands of years), and in deep time (tens to hundreds of millions of years).

This module therefore focuses on how the geological record captures and informs on global environmental change through time. It investigates how Earth Scientists reconstruct past environments and climates, and demonstrates, using selected case studies, what drives climate change and how ecosystems respond to these forcing factors.

There are four parts:

- (a) an introduction to the geological timescale and the stratigraphy of sedimentary successions; these concepts underpin how we 'read' the geological record;
- (b) a review of the principal sedimentary rock types that are sensitive environmental indicators; it is these that allow us to translate from 'observing rocks' to understanding ancient environments;
- (c) a review of the large scale global processes that shape climate now and would have done so in the geological past;
- (d) an introduction, using selected datasets, to the varied ways in which the chemistry and biology of fauna and flora serve as environmental proxies - and indirectly record fluctuations over time in key environmental parameters such as temperature, aridity, salinity and solar radiation.

The module assumes no previous knowledge of these topics, and its content is relevant to those interested in the geological, archaeological, environmental, geographical or biological sciences. It is, however, a Level 2 module so topics are investigated in reasonable depth; the module extends beyond a general introduction to each topic considered.

This is an on-line module (i.e. there are no scheduled classes). The workload is in three parts (A-C), each examined separately. Each part comprises a series of lectures and independent exercises, presented using a combination of on-line and practical resources. Students complete this workload and supplementary reading in their own time over the course of the semester. The course presenter will be available at scheduled periods throughout the semester to assist.

LEARNING OUTCOMES:

Upon successful completion of the module, students will have an understanding of:

1. the concept of the geological timescale and the basic principles of, and terminology associated with, the stratigraphy of sedimentary successions;
2. how different sediments, for example fossil soils, evaporates and limestones and their textures can be diagnostic of particular environmental settings;
3. how changes in sedimentary successions over time occur in response to phenomena such as plate

- tectonics, changes in sea level, and astronomical forcing of climate;
4. the extremely varied ways in which sedimentological, chemical and biological data (proxies) are used by earth and environmental scientists to reconstruct ancient environments and climates.

ASSESSMENT:

Multiple Choice Questionnaire: 30%
(MCQ mid-term exam on first part of course)

Multiple Choice Questionnaire: 30%
(MCQ mid-term exam on second part of course)

Multiple Choice Questionnaire: 40%
(1-hour MCQ end of semester exam on final part of course)

PART A: Reading the Geological Record

11 online lectures and 1 online practical exercise. At the end of the section, students should have an understanding of:

(a) the challenges Earth Scientists face in reconstructing the geological history of a single succession (e.g. a core or cliff-face), and, especially, linking between sections/localities to expand a study over longer temporal successions and wider geographic areas.

(b) the techniques used to reconstruct the stratigraphy of a single succession, based around a series of principles. Rocks require names and ages: the physical units must be defined (using a lithostratigraphical classification) and their relative age (chronostratigraphy, including event stratigraphy and biostratigraphy) or absolute age (geochronology) identified

(c) Layer cake stratigraphies are rare. At any given time, sedimentary environments and thus rock types will change laterally. Over time, sedimentary environments and thus the stratigraphical successions they generate are dynamic; i.e. they change in response to forcing factors, often sea level change. A rock unit identified on the basis of its physical properties need not be the same age everywhere it occurs. This poses a particular challenge. A change upwards in what rocks are present in a single succession is likely to correspond to a change in environment; in a continuous undeformed succession this will originate as laterally equivalent environments replace each other (Walther's Law).

(d) There are three principal types of sedimentary rock (clastic, carbonate, and evaporate). There are (very many) different lithologies possible within each, especially the first two. Having said that, many attributes of each rock type can be described, and the rock classified, using a limited number of descriptive terms: its petrology, color and any sedimentary structures that are present. This is the first step in building an environmental interpretation.

The key concepts and terms students should become familiar with are:

Law of Superposition; Principle of original horizontality; unconformity (angular unconformity, disconformity, non-conformity); Principle of original lateral continuity; Cross-cutting relationships and how these establish the relative timing of events; Principle of Uniformitarianism; Principle of inclusions;

Lithostratigraphy inc. terminology (group formation member bed). Note lithofacies is not a lithostratigraphical term.

How a diachronous unit forms. Walther's Law of vertical and lateral lithofacies (transgression regression progradational retrogradational aggradational) Eustatic and relative sea level.

Chronostratigraphy (erathem system series stage): (1) biostratigraphy: index fossils and biozones (taxon range, concurrent range and interval); (2) event stratigraphy (a) bolide impact as a case study (Ir, boundary clay) (b) ash layers: Oruanui eruption: tephrostratigraphy.

Dangers of assuming constant depositional rate: Geochronology (era period epoch age) Radiometric dating: half-life ^{14}C as an example.

Clastic sedimentary rocks: Udden Wentworth grain-size scale; ternary diagrams (Gravel:sand:mud and QFL)

Grain shape grain sorting; roundness and sphericity

Conglomerates (rounded clasts) and breccias (angular clasts): clast-supported matrix-supported monomictic oligomictic polymictic

Compositional and textural maturity

Carbonates: Dunham's carbonate rock texture classification

Volcaniclastic deposits

Evaporates (gypsum and halite)

Color red (ferric iron); green (reducing conditions (ferrous iron)); black (organic rich: sapropels oil shales)

Transgressive anoxia in basins; Ocean Anoxic Events

Sedimentary structures produced during transport: stratification (bedding/lamination): horizontal/cross(planar/trough). Current and wave ripples. Herringbone cross stratification. Aeolian processes. Debris flows. Turbidity Currents. Normal and reverse grading (of a bed) Fining-up and coarsening-up of a succession

Examples of sedimentary structures as way-up indicators: flute marks, groove marks, obstacle scours; erosively-based beds normal grading: trough cross bedding mudcracks; footprints; geopetal structures

PART B: Reconstructing Depositional Environments

9 online lectures and 1 online practical exercise. At the end of the section, students should have an understanding that:

(a) There are individual lithologies that are diagnostic of specific depositional environments and thus a particular set of environmental conditions. Examples include coal, calcrete, bauxite, laterite. Students should understand how each forms and what their environmental significance is.

(b) Facies and, especially, facies associations are what is most widely used to define a specific depositional setting.

(c) Using generalised models students will become familiar with the facies association and key indicators typical of each of the following environments

(1) Glacial environments (till, loess, dropstones, ice rafted debris (IRD))

Heinrich events, and the significance of the following minerals: glendonite, ikaite.

Case Study: the Spetchy Kopf –Rockwell Diamictite: what criteria identify this as a glacial till, and why is it significant?

(2) Desert environments: various facies deposited in:

(i) alluvial fans (screes and debris flows)

(ii) alluvial plains (debris flows, wadis)

(iii) lake settings (facies extremely variable, often related to persistence of the lake: ephemeral lakes often comprise interbedded mudstones and evaporates; persistent lakes may have continuous sedimentary sequences that are important archives of environmental changes)

(iv) aeolian dune fields: note characteristic texture of aeolian sands (including distinctive appearance in thin section) and how this originates.

Why the Atacama Desert formed (role of orographic effects; ocean currents) latitudinal distribution of arid warm deserts.

Case study: Sediment Core 658C: wind-blown terrigenous sediment sourced from the Sahara desert is deposited in marine sediments offshore Africa. How the flux (fluctuations over time in amount) of wind-blown sand allow two episodes of environmental change to be identified: the African Humid Period; the Younger Dryas.

(3) Lacustrine environments.

Students should be aware of the following:

That these are very important archives of environmental change;

Data sources can be both physical records (i.e. the sediments) or biological (how organisms respond to environmental change).

Data incorporated into the lake sediments can be allochthonous or autochthonous.

Lake levels (and thus environmental conditions) respond to various forcing factors, of which insolation is a response to variations in precipitation versus evaporation over watershed.

Evaporite minerals (the sequence in which they evaporate –calcium carbonate, then gypsum, then halite) are a strong signal that $P < E$

Facies and Facies Associations are extremely variable depending on lake type, but deeper water facies that are finely laminated often offer continuous sedimentary records with high temporal resolution

Varves are laminated sediments in which an annual signal is preserved: multiple laminae may correspond to a single year as sediment flux and communities of organisms (e.g. diatoms) living in lake can change within a year (often seasonally). Varves offer extremely high resolution temporal analysis.

Case Study: onset of Younger Dryas event as revealed in varved sequence from Lake Meerfelder Maar, Germany. Students should be aware of: (a) the structure of the two different varved sequences (Allerød and Younger Dryas varves), (b) how each type of varve formed, and what environmental conditions each represents. (c) the timing implied for how rapidly the Younger Dryas episode began (note that this based on the fact that the varves are annual records).

(4) Marine environments.

These are broadly divided into nearshore/shallow marine and deep-marine settings.

(4a) Nearshore/shallow marine settings:

are important in tracking the position of the coastline; i.e. how this might change over time in response to sea level changes (transgressions and regressions).

Include beaches and deltas.

Beaches are extremely variable in their structure, and generalised facies models are difficult to erect. Certain sedimentary structures can, however, be diagnostic of these near-shore settings.

Deltas are complex structures, but the facies association will typically include facies deposited under either marine (e.g. pro-delta deposits) or not fully marine (freshwater or brackish-water) conditions (delta channels) plus terrestrial surfaces (latter often evident as rooted horizons that can be associated with coals).

Case Study: Holocene history of the Po Plain. A superb example of how the stratigraphy and sedimentology can be integrated to model the changes in relative sea level that occurred in response to a transgression then regression. Definition of facies, and the facies association; the identification of isochrons, absolute ages for the sequence determined via radiocarbon dates. Many of the principles in this are also explored in Practical Exercises 1 and 2.

(4b) Deep-marine settings:

An extremely important archive of environmental change as low rates of continuous sedimentation imply good temporal resolution, continuity over extended time intervals

Typically accessed by ocean drilling and recovery of cores of pelagic sediments

Focus is on marine biogenic sediments (30% + skeletons of microscopic organisms)

The spatial distribution of biogenic sediments, and in particular the control on distribution with depth as a result of the CCD

Roles of production dissolution and dilution in formation of marine biogenic sediments

Chalk and epeiric seas

The ecology, mineralogy and biology of the 4 principal types of microfossils contributing to pelagic biogenic sediments: coccolithophores, foraminifera, diatoms, radiolaria.

The key concepts and terms students should become familiar with are:

Lithology, facies, facies association, graphic log,

Coal (grade rank, sequence of formation)

Palaeosols: calcrete (rhizoconcretions, glaebules, layer) bauxite, laterite (Interbasaltic Formation: lithomarge, laterite, iron-rich crust) Great Dirt Bed

Glacial deposits: basal till, meltout till, striated clasts, loess (including grain properties), dropstones, IRD, Heinrich events and their causes, glendonite, ikaite, Speckty Kopf-Rockwell diamictite and its facies association

Desert Environments: Atacama Desert, orographic effects, Humboldt current, aeolian sands, wadis, debris flows, African Humid Period, Younger Dryas

Lacustrine deposits: Varves, diatoms, Sandwich Fish Bed, Younger Dryas and Allerød Varves

Autochthonous versus allochthonous

Insolation

Forcing factors, including P-E

Biogenic sediment/deposit; carbonate ooze, siliceous ooze, pelagic sediment, chalk, epeiric sea, Western Interior Seaway, Coccoliths, coccolithophores, phytoplankton, zooplankton, foraminifer, test, diatom, frustule, epifaunal, infaunal, planktonic, autotroph

PART C: What drives environmental change? An introduction to absolute dating Environmental Proxies

11 online lectures. Part C is split into two sections.

Section 1 Drivers of Environmental Change

Identifying what happened at the Permian – Triassic boundary prompts us to think about why it happened – i.e. what caused this pronounced environmental shift? To consider that we would first need to discuss what the possible drivers of environmental change are. We will do this in the first part of Part C. The following are the key points and learning outcomes for this part. This is followed by a list of the key words for which students would be expected to be able to provide definitions and explanations.

At the end of this section students should be aware of the following:

(a) environmental change occurs across various spatial and temporal scales, and is a natural phenomenon in the Earth System

(b) anthropogenic causes are widely recognised as a major part of the relatively recent, global scale, perturbations the Earth System is currently experiencing

(c) significant human modification of the environment occurred after the onset of agriculture and, more recently, industrialisation

(d) the drivers responsible for environmental change are individually complex and interact: they include +ve and -ve feedbacks

(e) the principal drivers of environmental change are as follows: (key terms and concepts are in brackets)

(1) atmospheric composition (not constant over time (biological driver); greenhouse gases (water vapour CO₂ CH₄ NO₂) particularly important)

(2) atmospheric and surface reflectivity (albedo; latitudinal variation in solar inputs and outputs; continental distribution)

(3) ocean-atmosphere heat exchange (thermohaline circulation: 'ocean conveyor belt')

(4) aerosols: note importance of emissions from volcanoes

(5) rock cycle: on geological time scales this regulates CO₂ in atmosphere

(6) Earth-Sun geometry (astronomical forcing of climate)

(7) variation in solar output (solar luminosity: insolation: TSI)

Case Study: Little Ice Age. Potential causes (a) solar phenomena – in particular a decline in sunspot activity; (b) anthropogenic factors (Black Death); (c) increase in volcanic activity

(8) plate tectonics

Students should be able to define the following terms:

albedo (perfect absorber = 0; perfect reflector = 1); ice-albedo feedback; red beds/hematite; photoautotrophs; significance of detrital pyrite; N₂ and O₂ content of present day atmosphere; role of greenhouse gases (water vapour CO₂ CH₄ NO₂); thermohaline; NADW; aerosol; eccentricity (100,000 years; perihelion; aphelion); obliquity (41,000 years); precession (19-23,000 years); solar luminosity (today =1); insolation; TSI; Maunder Minimum; Little Ice Age (14th/16th-mid 19th centuries); convergent divergent and transform boundaries; continental crust, oceanic crust and mantle; lithosphere and asthenosphere; ridge push + slab pull; oceanic- continental or Andean-type subduction; oceanic-oceanic or island-arc subduction; rain shadows; adiabatic cooling; orographic effects; eustasy; epicontinental seas; clathrates; LIPS; CAMP; Urey reaction

Section 2 Environmental proxies and an introduction to dating techniques

The second part of Part C includes a brief introduction to how absolute ages are calculated. We will use two techniques that are widely used for the study of geologically young deposits: (a) dendrochronology and (b) radiocarbon dating. These methods are prioritised as both are often used in archaeological contexts. In addition radiocarbon dating is often used to calculate the age of relatively young sedimentary sequences – up to a few tens of thousands of years old. Successions of this age are especially relevant to establishing baselines in successions against which the scale of on-going environmental change as a result of anthropogenic change can be established. Note this course provides only a general introduction to the principles of radiocarbon dating. We will not cover the various factors that complicate the use of the radioactive decay of carbon-14, and which, if not accounted for, can result in erroneous results.

In the course we have concentrated on how the lithologies and lithofacies in sedimentary successions allow us to reconstruct ancient environments and how changes in these through time reveal what environmental change has occurred. Study of the sediments is almost always undertaken, hence the emphasis we have placed on it in this course.

Analysis of the sediments can be supplemented by study of how specific environmental proxies change over time. An environmental proxy is a measure of some variable that indirectly informs on environmental conditions. For example, changes over time (for example -depth in a core) in the relative abundance of different types of pollen could imply different climatic conditions i.e. relatively warmer or relatively colder. In the example below, mineralogy, the concentration of charcoal, and pollen are used as environmental proxies. . Note the use of radiocarbon dates to determine the age of the sequence at different depths. The minerals present include struvite, (magnesium ammonium phosphate). This unusual mineral probably originates from guano (animal excrement). It occurs episodically at various levels in the succession and may result from repeated visits of large numbers of waterfowl to Kettle Lake when other lakes in the region were dry. The pollen is from grasses (known by the family name Poaceae, in green) and weedy annuals (Ambrosia-type, in red). Microfossils such as pollen are commonly used in such studies as their small size means large numbers can often be recovered from even small sample volumes: note the small size (20µm diameter) of the grass pollen in this image. A µm is 0.001 (1,000th) of a mm.

In this study of Kettle Lake, the coincidence of changes in mineral composition, charcoal abundance and pollen types are used to define relatively dry and humid episodes over the past 7700 years. Data such as this allows a qualitative interpretation – “relatively dryer” – “more humid” etc. It is, however, often possible to derive quantitative information about past climates from environmental proxies. For example, for many biological proxies the absolute changes in a variable e.g. temperature, can be calculated on the basis of the environmental tolerance of living examples of the proxy being used. Often if the same taxon is not available a method known as the Nearest Living Relative (NLR) can be used; just as the name suggest a closely related taxon is substituted. The NLR method assumes the fossil had the same environmental tolerances as its NLR and that these have stayed constant over time.

There are a bewildering number of environmental proxies available to the Earth Scientist and this course can only be a brief introduction. We use two case studies (one from the west African Sahel and one from Elk Lake Minnesota) to illustrate the general concepts.

At the end of this section students should be aware of the following:

- (a) what is meant by the concept of an environmental proxy
- (b) the key features of foraminifera
- (c) Case Study: what (a) the abundance, and (b) the relative proportion of left and right coiling forms, of the foraminifer *Neoglobobulimina papyrifera* reveals about modern environments;
- (d) contexts in which annual or sub-annual temporal resolution can be preserved including (a) tree rings; (b) varved sediments.
- (e) the environmental conditions within lakes that favour preservation of laminated sediments (lacustrine deposits, especially laminated sediments, are one of the most widely used records of relatively recent environmental change (past few hundreds to thousands of years))
- (f) the importance of 'translating' a relative age into an absolute age (especially as it cannot be assumed that depositional rate is a constant in any sedimentary succession)
- (g) dendrochronology using the Bridging Technique to establish a chronology
- (h) radiocarbon dating – one of the most widely used methods to date sequences < a few tens of thousands of years old
- (i) the various sources of materials that can be used as environmental proxies including (a) oral pictorial and written records; (b) lithological (c) geochemical and (d) biological sources.

Case Study 1. Fluctuations in wind-blown dust from the west African Sahel during the Holocene as a proxy for climate changes. This tracks a single variable (dust content in the sediments) through time to identify phases of greater aridity in which higher levels of supply of dust to lake;

Case Study 2. The environmental history of Elk Lake, northwestern Minnesota. This uses a multidisciplinary approach where lithology (varve thickness and quartz content), chemistry of the sediments, pollen and diatom content are integrated to produce a model with 3 distinct episodes over past 10,000 years. Drought (on various timescales) occurs when Pacific airmass (dry) dominates weather systems. Two forested episodes (different trees) are separated by a grassland phase with prairie vegetation: note how combination of proxies signal for this.

Students should be able to define the following terms:

struvite, (magnesium ammonium phosphate); guano (animal excrement) grasses (Family Poaceae) Nearest Living Relative (NLR); foraminifera; testate; protozoa.

dendrochronology (phloem, cambium, xylem, heartwood, pith, early wood, latewood, false ring); bridging technique.

varved sediments in lakes: epilimnion; hypolimnion; thermal stratification; monimolimnion; holomictic; meromictic

Radiocarbon dating: ^{14}C ^{14}N , half-life (5370 years)

Maunder Minimum c. 1650-1700AD

Case Study 1. Fluctuations in wind-blown dust from the west African Sahel during the Holocene as a proxy for climate changes. Lake Chad; Paleolake Chad, Bodélé Depression ODP Site 658C, data from Jikariya Oasis and Kajemarum Oasis identify 3 phases.

Case Study 2. The environmental history of Elk Lake, northwestern Minnesota. Gulf of Mexico (wet) Arctic (cold dry) and Pacific (dry) airmasses interact; autochthonous and allochthonous sedimentary components; varve thickness (silt and clay); Aulacoseria; Plagioclase feldspar (content revealed by Na signal); pollen – esp. sagebrush; 3 environmental phases in past 10,000 years.