MODULE A: Geological Principles

1. Geological Time

a. Age of the Earth

James Ussher (1581-1665) - Archbishop of Armagh
- one of earliest and most influential figures in interpretation of geological time
- published a chronology of Earth's history using all dates mentioned in Bible to establish a timeline
-established first day of creation was Oct 22 4004BC, which would make Earth a little over 6000 years old

George Louis De Buffon (1707-1788)
-believed Earth to have been initially hot molten mass
-heated iron spheres (thought was reasonable model for structure of planet) and calculated time they took to cool
-using this method Buffon believed Earth was 75,000 years old

John Joly
-published paper in 1899 in which he estimated Earth's oceans (which he believed to be same age as the planet) to be about 90 million years old
-calculated this by estimating how long it would take for the oceans to reach their current salinity (from an original fresh water state) as salt is added via erosion of minerals in the rocks.

-radioactive decay in minerals is the technique which provided us with the current age of the Earth at 4.6 Billion yrs.

b. Deep Time

Deep time: concept of trying to understand the evolution of the Earth and its biological systems

2. Geological Concepts and Terminology

Mineral: a naturally occurring crystalline solid with a characteristic chemical composition, a highly ordered atomic structure, and specific physical properties

Rock: an aggregate of minerals. Rocks fall into a basic 3-fold classification:
1. Igneous
2. Metamorphic
3. Sedimentary

A. Igneous Rocks

Igneous rocks: (derived from latin "ignis" meaning fire) formed by the cooling of magma or lava. Generally composed of interlocking crystals of varying sizes

-if magma cools within Earth's crust it is referred to as an intrusive igneous rock. As they cool slowly they often develop large crystals

-if magma escapes via volcanic activity and forms a lava the igneous rock is called extrusive igneous rock. These rocks cool quickly, so crystals that form are very small and often invisible to human eye

B. Metamorphic Rocks

Metamorphic rocks: form as a result of the transformation of an existing rock via heat, pressure and/or

the action of fluids.
- commonly occur deep in Earth's crust

C. Sedimentary Rocks

Sedimentary rocks: form in response to particular environmental conditions and as such, provide clues to Earth's past including climate, ancient geography and life forms.

-form via sedimentation of materials at the Earth's surface and within water bodies, commonly in layers called strata or sedimentary beds.

Diagensis: transformation of sediments into a sedimentary rock via a collective variety of chemical, physical and sometimes biological processes.

D. Clastic Sedimentary Rocks

Most sedimentary rocks are produced by the erosion of pre-existing rocks producing fragments or grains that are transported and deposited at various distances from the site of erosion --> these rocks are called clastic sedimentary rocks

-Clastic sedimentary rocks provide a simple tool that can be used to determine the source, origin and length of transport of a particular sediment prior to it becoming a sedimentary rock

-If a sediment is deposited close to rocks from which it originally eroded, it will have a number of characteristics that will uniquely identify it as such:
- large number of coarse/angular grains and clasts (greater than 4mm), higher proportion of unstable minerals and fragments of rocks, exhibit poor sorting (variation in clast/grain sizes)
-sediment with characteristics as described above is called an immature sediment
-mature sediment: undergone extensive transport, fine grained, composed mostly of well-rounded and well-sorted quartz grains

E. Calcium Carbonate

calcium carbonate: precipitated sediments by various creatures including corals and mollusks to form thick deposits of limestone

-microplankton are also calcium carbonate producers, such as cocclithophores. During Createceous, warm shallow oceans covered much of Earth's continents providing perfect conditions for proliferation of cocclithophores and ultimately the generation of vast thicknesses of fine grained limestone

F. Evaporites

Evaporites: intense evaporation of water precipitate sediments in the form of salt crystals

-can form a number of ways including: inland sea or part of ocean with restricted contact to wider ocean (occur in arid areas with limited freshwater input)

3. Stratigraphy

stratigraphy: study of how rock layers are arranged.

a. Principle of Superposition:
-states that in layered strata, the oldest layer will be at the bottom of the exposed strata and the youngest at the top
b. Principle of Original Horizontality: sediments are deposited horizontally, after transformed into rock

possible for strata to become tilted by tectonic movements
c. Principle of lateral Continuity: stratum of sedimentary rock will continue in all directions until it thins, grades into another type of sediment or comes against the edge of the depression into which it is being deposited.
d. Cross-cutting relationships: relationships between stratigraphic units indicated that the Earth was very old.

f. Unconformities: represent periods of non-deposition of sediment or active erosion of strata

Several types of unconformity are recognized:
1. Disconformity: exists where the layers above and below an erosional boundary have the same orientation
2. Nonconformity: develops where sediments are deposited on top of an eroded surface of igneous or metamorphic rocks
3. Paraconformity: strata on either side of unconformity are parallel, there is little apparent erosion
4. angular unconformity: strata is deposited on tilted and eroded layers

h. Relative Dating: working out the history of a geological section

inherent errors with this estimate:
-the rate of accumulation of sediment might not be constant
-period of non-deposition or active erosion may have occurred
-during diagensis, sediments are compressed and compacted so that the vertical extent of sedimentary rocks may not represent the original vertical extent of sediment

i. Uniformitarianism: basis for the understanding of the Earth and the science of modern geology.

Actualism: acknowledges that although most geological processes are very slow, some geological processes can cause changes that are relatively geologically instantaneous

LESSON 2: Sediments and Geological Time

1. Sedimentary Facies

sedimentary environments: areas where sediments are being deposited

a. Near Shore Sedimentary Environment

The coarsest (most dense) portion of the sediment from the river is deposited close to the shoreline where the water is most turbulent. The finer (least dense) material stays in suspension until it settles out of the water where conditions are less turbulent

-beyond the area where all the material from the river has been deposited, calcium carbonate secreting organisms provide the main sediment type: carbonate mud. This accounts for the changing lateral character of the sediments in this environment from coarse sandy material close to shore line passing into mud/clay and ultimately carbonate mud further off shore.

facies: environmentally controlled sediment differences
-refers to all the characteristics that can be used to define a particular sedimentary unit: sediment type (eg. sandstone,mudstone, limestone), presence of any sedimentary structures (ex. ripples, cross bedding), and sometimes fossil content
-facies changes are gradual

b. The temporal - Sea Level Component
over time, the distribution of sedimentary facies is controlled by changes in sea level.

-sea level has changed globally many times and can also change locally.

Scenario 1: No sea Level Change
Rate that sediments are deposited keeps pace with changes in sea level. Facies get built on top of each other, producing a pattern where facies boundaries and the location of the shoreline will not change location over time

Scenario 2: Rising Sea Level - Transgression

Now in sea level between Time 1 and Time 2, the shore line moves back towards the land. A new package of sediment between T1 and T2 has been deposited.

Marine Transgression: facies move towards the land

Sea level continues to rise with the deposition of sediment between T2 and T3. Shoreline and the boundaries between facies continue to move towards the land

diachronous: change in environmental conditions over time as demonstrated by the facies

Vertical pattern of sediments: bottom part of core has near shore sediments while on top has offshore carbonate muds

Scenario 3: Falling Sea Level- Regression

Marine regression: shoreline and facies move away from the land

Vertical pattern of sediments: opposite of that recorded for a marine transgression.
-The core goes from offshore carbonate muds at the bottom to near shore sediments at the top --> means sea level must have been decreasing and a regression occurred.

Walther's Law: Facies that occur in a conformable (ie. demonstrating no unconformities) vertical succession of strata were deposited in laterally adjacent depositional environments. --> adjacent sedimentary environments will end up overlapping one another over time

2. Controls on Sea Level Change

a. Local Sea Level Change

i) Crustal deformation: where tectonic plates collide, the crust is buckled and raised, forming mountains.
Mountain building can also occur where an oceanic plate collides with a continental plate and descends below it (subduction)
Mountain development requires crusts in these areas to move vertically - those areas at the edge of an ocean would record a relative fall in sea level. Even if the overall depth of the ocean was not decreasing, facies in these areas would record a local fall in sea level

ii) Isostatic Redress
-enormous weight of ice sheets caused the surface of the Earth's crust to deform and warp downward, forcing the fluid mantle material below the crust to flow away from the loaded region
-glaciers retreated, removal of the weight from the depressed land led to slow (still ongoing) uplift or rebound of the land and the return flow of mantle material back under the de-glaciated area.
-due to extreme viscosity of the mantle, it will take many thousands of years for the land to reach an equilibrium level

b.) Global or Eustatic Sea Level Change

i) other Glacial Effects:
-during a glacial period, water that would normally be rain is locked up on continents as ice --> record a fall in global sea level.
- when ice melts, corresponding sea level rise

ii) Spreading Ridge Activity:
-divergent plate boundary: sea floor spreads and moves away from both sides of the heated ridge, it cools and subsides, forming a ridge crest.
-average ridge crest ~2500m
-periods of rapid sea floor spreading produce high elevation profiles --> occupy volume in the ocean basin and displace water onto continents
-slower sea floor spreading rates produce lower elevation profiles --> displace less water
-sea level higher during times of accelerated sea floor spreading

iii) Thermal Expansion of Sea Water:
-as water warms, it expands.

LESSON 3: Lithostratigraphy and Biostratigraphy: Correlating Rocks

1. Lithostratigraphy

Lithostratigraphy is the study and classification of strata.
Lithostratigraphic units are arranged from small to large:
-bed: a lithologically distinct layer
-member: a collection of beds with related characteristics
-formation: a collection of lithostratigraphic units that can be recognized and mapped occur a wide area
-group: a collection of related yet distinct formations
-supergroup: a collection of related yet distinct groups

chronostratigraphy: particular geological aged defined for Earth history

-time planes (horizons of sediment deposited at the same time) will be composed of different facies as one moves laterally

biostratigraphy: using fossils as time pieces

2. Biostratigraphy

William Smith (1768-1839) first to use fossils as tools of correlation.
Georges Cuvier used fossils to determine that some animals were extinct

Quenstedt and Oppel: Fossil Ranges

A fossil range is the length of time any fossil exists from the time it evolves to the time it becomes extinct.

e. A Record of Evolution Stored in Sedimentary Rocks

bizones: time interval defined by the occurrence of a particular fossil.

f. The Ideal Zone Fossil

Fossils must be:
1. Rapidly Evolving: the fossil must define a short period of geological time. If long-ranging forms were used, the subdivisions of geological time would be too broad and lack resolution
2. Widespread across different facies and biogeographical provinces: the fossil must occur in as wide an area as possible so correlation between areas separated by great distances can be established. Fossil must not be tied to a particular sedimentary environment or by facies dependent.
3. Relatively Common
4. Easy to Identify

Grapholites are common in marine sediments underlying the open ocean 9oceanic regions that are not close to the bottom or near shore) and are excellent zone fossils.

3. Geochronology and Geological Time Scale
-largest division of time is the Precambrian and Super Eon which itself is subdivided into 3 eons. These eons are subdivided into eras, periods, and even finer time subdivisions.

Presence of abundant fossils during Phanerozoic
-ages on time scale have been calculated using radiometric isotopes

Geochronoligocal "Time" Units	Equivalent Chronostratigraphic "Rock" Units
Super Eon	No Equivalent
Eon	Eonothem
Era	Erathem
Period	System
Epoch	Series
Age	Stage
Chron	Zone (Chronozone)

4. Type Sections
Criteria for Stratotype Bases

Bases fo stratotypes receive the most attention as these define the boundaries of the time slices. Criteria for their selection:

i) Virtually continuous sedimentation so as to record the maximum amount of geological information
ii) few unconformities so any gaps in record are minimized
iii) little structural (folding and faulting) disturbance or metamorphism. Folding and faulting complicate the interpretion of a geological section and metamorphism can remove or seriously degrade the quality of any fossils/isotopic/sedimentological information that was present
iv) rich in fossils to aid in correlation

5. Absolute Dating

Absolute dating uses an understanding of radioactive decay to date rocks.
-during radioactive decay the nucleus of a radioactive atom spontaneously reacts --> results in the production of an atom of a different element and the release of radiation energy

-the sequence of several decay events when daughter products produced in the intermediate stages are radioactive and unstable, called a decay chain.

radiometric techniques will only be valid if it can be demonstrated that the decay took place in a

closed system where there has been no contamination or loss of either parent or daughter material.
-best closed systems are crystals in igneous rocks.
Other limits to the use of radiometric techniques have to be considered in its application:
-weathering can cause leakage of isotopic material
-metamorphism resets the isotopic clock such that nay date obtained from the rock would date from the time of metamorphism and not the original formation of the rock
-apart from a very few exceptional cases, radiometric techniques cannot be used on sedimentary rocks.