DOC - Lecture notes 1-7

Our Dynamic Planet Earth (Carleton University)

Lecture 1: 3 sept

Early Views Of universe

- Geocentric Model - Aristotle and Ptolemy (earth in middle)
- Heliocentric Model - Copernicus (sun in middle)

Big Bang Theory
- Formation of the universe began with an explosion Called the big bang 13.8 Ga (billion years) ago

Time
- - big band -> early inflationary epoch -> early nebulae form -> First galaxies form -> as universe expands distance between galaxies increases -> present

- early universe smaller, hotter, more dense
- Eventually planets, starts, and galaxies formed as material condensed due to gravitational attraction
- Stars form and collapse many times
- Within stars, fusion -> heavier elements (up to 56Fe)
- Stars die (explode) -> supernovas
- Heavier elements are formed (>Fe) which scatter and are incorporated as dust into gas clouds (nebulae)
- Black holes, planets, life

Formation of our solar system
- **Formed 5.5 -4.6 Ga**

Nebula -> Protoplanetary disk -> Rings of planetesimals -> the eight planets

The Nebular Theory

A Nebula is composed mainly of hydrogen and helium atoms plus heavier elements formed from supernovae. The nebula rotates and contracts under the influence of gravity
Rapidly rotating nebula flattens; central material compressed and heated until nuclear fusion begins . **Proto-sun**(in the middle)
- nebula cools and condenses
- Denser (refractory) material collects in the interior of the disk while less dense (Volatile) material collects in the outer rings.
- Gravitational attraction leads to formation fo planetesimals
- Planetesimals collide (accretion) to form terrestrial planets
- Continued accretion leads to multiple planets forming
- Solar winds dissipate remaining gaseous nebula

Lecture 2

- Our solar system
  - Terrestrial-planets (close to sun, mercury, venus, earth, mars)

- Giant (Jovian) Planets (jupiter, saturn, uranus, (portion of orbital plane of planets), Neptune)

Evidence for the nebular theory

- Imagery, solar abundance, meteorites, bulk earth composition

Orion- star factory

- Located 1,500 light-years away.
- closest massive star-formation factory
- contains more than 1000 young stars

Meteorites

- leftovers from formation of solar system
- Different types of meteorites
    - Chondrite
    - Stony
    - Iron
    - Stony Iron

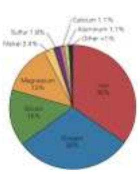
Chondrites - original solar system composition and the building blocks for planet earth

Stony Meteorites (Achondrites) GRO 95535,0- just like earth rocks

Iron Meteorites

Stony-Iron Meteorite

Chemical composition of the earth



Further evolution of the earth
- After accretion, the early earth if entirely melted from collision, pressure heating and radioactive decay

Differentiation of the earth

- Earth formed at 4,56 Ga
- Through time, differentiation results in a layered earth
- Dense elements sink to the centre and less dense elements float to the surface

Structure of earth
- Crust -> upper mantle -> lower mantle -> outer core -> inner core

How are elements heavier than Iron (Fe) created?
1. Fusion in stars
2. Fission in stars
3. supernovae

What do meteorites tell us about earth
- 10% of meteorites are mainly iron
- Therefore part of the earth is likely to be iron
- Iron is very dense
- Iron provides
    - metal needed for magnetic field
    - density to balance total density
- majority of meteorites chondritic, earth must have some rocks that are similar (i.e mantle)

Moon Formation

- did moon form by accretion like earth?
- Each density = 5.5 g/cm3
- Moon density = 3.3 g/cm3

Different model for origin of the moon is required

The moon
- highlands: anorthosite (feldspar), 4.5 Ga, cratered
- Maria: younger impact basins, filled by lava flows: 3.8-3.2 Ga
- Lunar surface: covered by regolith (debris from impacts)

Early Earth
- after moon formation earth totally molten
- Unstable surface and crust due loss of heat
- Earth continues to cool today

What process caused the formation of the earth's core?
1. Homogenization

2. Differentiation
3. Accumulation

Geochronology
Chapter 12

The Geologic time scale was developed in the 19th century using relative dating techniques
Numerical dating did not occur until early in the 20th century using radiometric dating techniques also known as geochronology

- used radioactive isotopes that undergo radioactive decay

Isotope- each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass but not in chemical properties; in particular, a radioactive form of an element.

Unstable Isotope- what makes an **isotope unstable** is the large nucleus. If a nucleus becomes larger enough from the number of neutrons, since the neutron count is what makes **isotopes**, it will be **unstable** and will try to 'shed' its neutrons and/or protons in order to achieve stability

- Carbon 14 isotope is unstable and undergoes radioactive decay

Parent and Daughters Isotope
-Atoms of a **parent** radioactive **isotope** randomly decay into a **daughter isotope**. ... Later it was found that half of the **parent** atoms occurring in a sample at any time will decay into **daughter** atoms in a characteristic time called the half-life.

What is half-life

- Radioactive decay proceeds at a known rate therefore scientists can measure how long it takes for 1/2 of a group of parent isotopes to decay to daughters

Isotopes used in Geochronology

Dating rocks by dating minerals

Applying Radiometric dating

- radiometric clock starts when a mineral reaches its **closure temperature**

- What assumptions made when utilizing the method of radiometric dating?
    - closed systems
        - no addition of parent or daughter
        - no loss of parents or daughter
    - Radiometric clocks starts upon crystallization
    - Decay rate/constant is accurately known

Lecture 3 Geochronology, Earth and Minerals

Earth Has 2 different physiographic features: Oceans 71%, continents 29%

Two types of crusts

- Oceanis crust
- Continental crust
    - mountains thicken crust, stretching thins crust

Assembling a Continent

- Orogens: Growth by addition of continental masses along margins of cartons
    - Cratons - stable interior core of continental landmass

Earth's Atmosphere:

- first atmosphere H, He; swept away by solar wind
- second atmosphere formed by volcanism - H20, CH_4, CO_2, NH_3, H, SO_2
- earth cools enough that condensed H_2O pools, forms lakes, oceans - removes H2)
- O

Lecture 4

Forming Minerals

1. Crystallize from.a melt
2. Precipitate from a solution
3. Solid-state diffusion
4. Biomineralization (ex. Magnetospirillum gryphiswaldense)
5. From a vapour -fumarolic mineralization (from volcanic gasses, hydrogen sulphide)

9 minerals that play a role in all the rocks on earth

Silicate Mineralogy

- silicates are dominant fork forming minerals, **most common mineral**
- Oxygen is the only common anion
- Si forms a strong 50% ionic 50% covalent bond with oxygen
- $(SiO_4)^{4-}$ is the dominant unit …
- **Silicate tetrahedron** is the basis for all silicates
    - form different types of bonds with this formation

Mineral properties

- **Main properties used for all minerals:**
    - **Lustre, hardness, cleavage, fracture, colour, streak, twinning, habit, density**

Lustre: way mineral surface reflects light

Two subdivisions

- metallic - looks like metal (grey look)/ non metallic (different colours) - silky, Vitreous (glassy), shiny, pearly, earthy(dull)

Hardness: scratching resistance of a mineral. Derives from the strength of atomic bonds.

Cleavage: tendency to break along planes of weaker atomic bonds. Described by the number of planes and their angles.

Fracture: irregular breakage, no planar weakness. Conchoidal fracture: when minerals break they are in cone form, how glass breaks/looks like

Colour: it is deceiving, use it with other properties. Colour not diagnostic for silicate, carbonate or phosphates. There are exceptions which are Sulfur (yellow) and Olivine(olive colour). Sulphides are generally identified by their colour or colour of powder.

Streak: colour of powder. Non-metallic minerals: white. Metallic minerals: varies, but diagnostic. You rub against against plate to get streak.

Twinning:

Habit: crystal form. **Caution**: perfect habits are often rare. Most of the time is ugly. Not generally useful

Density:

Special properties Properties

Magnetism: - effervescence (fizzing) - caused by reaction with dilute acid. ex. Calcite, good way
to tell difference between calcite and quartz
- taste
- smell

What is a rock?
- a coherent, naturally occurring solid, consisting of an aggregate of minerals, or much less commonly, a mass of glass.
- igneous, sedimentary, metamorphic rocks are types of rocks

The rock cycle: cycle between these three rock types
- **igneous** - crystallizing from melting ex. Volcano
- **Sedimentary** - break down all other rocks and depositing them somewhere
- **Metamorphic** - solid rock changing from increased temperature/pressure

Character of. Rock is Determined by:
- **Its mineralogy** (mineral assemblage,)
  - relative proportion of a rocks constituent minerals, a rocks mineralogy reflects its chemical Composition
- **Its texture**
  - size, shape, arrangement s of a rocks constituent minerals

Igneous Rocks

- **Mafic** (magnisium and iron rich, silica), **intermediate** (between Mafic, felsic), **felsic** (feltsphar, aluminum)
- **Texture: interlockin**g texture by minerals
  - I**ntrusive rocks** (cool and solify, slowly, within earth so crystals grow big)
  - **Extrusive rocks** (cool and solidify quickly, at surface of earth so crystals small)
    - Some cool quickly causing no crystallization causing texture like glass ex. Obsidian

Sedimentary Rocks

Formed by:
1. Weathering and erosion
2. Transport (ice, water, wind)
3. Deposition
4. Lithification (conversion to rock)

ex of sed rocks: shale, sandstone, limestone

Texture: individual sand grain, grain of sand going through lithification to turn to rock, the glue is water.

Metamorphic Rocks

- Metamorphism refers to change in a rock (igneous, sedimentary or metamorphic) resulting from increased pressure and temperature
- Changes in **mineral assemblage** and **texture**
  - minerals change arrangement to make new texture
    Ex. Foliation (folding, alignment of minerals)

Where do rocks form

Happens on surface and in crust
Sedimentary rocks form on surface
Metamorphic and Igneous in crust
By volume: 8% for sedimentary and rest igneous and meta
By area: mostly sedimentary 75% but not thick and small amount igneous and meta.

The Mantle:

- see rocks made of **Olivine** and **Pyroxene** and some times encased in **basalt**
  - see rocks like gardene

Q: **What are most abundant in crust**

- oxygen and silicon

Lecture 5

Igneous Processes

How magma forms
Why rocks smelt (pressure, (p) texture (t), composition (x))
Where rocks melt
- hot spots
-divergent plate boundaries (spreading ridges)
- convergent plate boundaries (subduction zones and organic belts)

How magma Behaves
- they change

Intrusive: below crust, course grain
Extrusive: everything that comes out of crust, fine grained or glassy

Magma and lava are the same, but when magma comes out of crust it is lava

Magma composition
- **liquid** consisting of Is, O, Ca, Fe, Mg, K, Na, and minor amounts of other elements
- **Dissolved gasses** CO_2, H_2O, H_2S, SO_2, Ar, typically 1-10% with an average of.2-4 wt %
- **Solidified minerals** (crystals) carried by liquid

When you look at rocks you need the **texture** and **mineralogy (**chemistry)

Why Rocks Melt?
Changes in **pressure**
Changes in **temperature**
Changes in **composition**

Divergent (spreading ridges)
-**Decompression melting** due to upwelling
Hot sports
- **decompression melting** due to upwelling
Convergent boundaries
-subduction zones addition of **volatiles(gasses, fluid -composition)** to the mantle
- organic belts increase in **temperature** due to burial/crustal thickening

Decompression Melting
Bars- measurement of pressure
- **Geotherm (line)**
  - temperature beneath normal curst
- **Geothermal gradient**
  - rate of increase in temperature
- **Solidus (line)**
  - solid rock, no melt, line to the left is solid
- **liquidus (line)**
  - temperature where eveything to right is liquid

Between these two lines is (magma), partial melt
When part of mantle goes over solidus there will be partial melt, then when reaches surface melting completely, leaving solid behind. Melting the rock but cooking it because of pressure.

- **this is happening in Mantle, starts as mantle plum**
- **When curst pulls, mantle fills space, causing pressure to decrease causing melting called mathic melt**

Hotspot Volcanoes

- located in the interior of plies rather than along plate boundaries
- Result of mantle plumes
- Decrease in pressure due to upwelling

Lecture 7

- Behaviour of volcanoes is dependant on composition

- Form vesicles as magma is coming up
- Creating vesicles as magma hits air

Most melt a subduction zone is generated by:

- heat transfer melting of the subjecting plate
- **Addition of volatiles into the asthenosphere (A)**
- Decompression melting of the asthenosphere

Sedimentary

What is the name given to an igneous intrusion that cuts vertically through layers of rock?
A. Dike

Formations:
Weathering:

- process by which rocks are broken down at the earths surface to form sediment
- **Physical (mechanical) weathering**: breakdown of rock produced by physical processes that do no not alter its chemical composition
  - forms clast or detritus of variable sizes (boulders >256mm, cobbles 64-256mm, pebbles 2-64mm)
  - water pounding, impacts from rocks. ice(sun?), animals, vegetation
  - big pill of material at the bottom of slope is called **til**
  - burrowing creatures, animal attacks
  - physical action of roots, root wedging
  - pounding by force (water), rivers, glaciers, waves
- **Chemical weathering**: breakdown of rock produced by chemical reaction
  - forms ions in solution
  - acid rain, dissolving, oxidation, enzymes, hydrolysis (both of D/H), hydration
  - dissolve power of water is strong, **Co2 (in air) + H2O -> H2CO3) Carbonic acid**/ not

harmful, limestone will be affected by slightly acid rain
- carbonate minerals (calcite, dolomite) prone to dissolution, produce caves and sink holes

- **Erosion**: combination of processes that separate soil and rock from its substrate and move them away

Lecture 8

Sedimentary Rocks

1. Clastic or detrital
2. Chemical or biochemical
3. Organic

Clastic Sedimentary Rocks

- weathering, erosion, transportation
- Indicated by size, roundness
- Determined by energy
- **course - medium grained - fine grained**

Lithification
- turn sediment into rock
- Do it through compaction, cementation(gluing)
- From compaction and he rocks get close to each other, causing pressure, causing area to heat up, then precipitation in the rocks causing minerals **(silica SIO2, calcite, hematite) that will become cement (cementation), these are what hold the rocks together**
- Strength of rock is determined by how hard the lithification happened and what ion (silica the hardest)

Character of a rock is determined by:
-texture
-mineralogy, composition
- weathering and erosion takes part in process

Classifying clastic sedimentary rocks
- Clast **size** is primary textural feature for classification
- **Course (>2mm)** -makes conglomerate - sub-angular -rounded pebbles/ Breccia - angular pebbles
- **Medium (1/16 to 2mm)** - makes sandstone - massive, fine-grained, round
- **Fine (<1/16mm)** -makes mudstone - siltstone/ claystone, breaks easily
- **Very fine (<1/256mm)** - makes - shale
- **Our tongues is a good indicator to tell roughness of rocks ex. Clayton which is rough and shale which is smooth**
- Lithic fragment are rocks that are not quartz and feldspar.

- 90% of quartz are quartz arenite
- **Grain size** - Closer to source you will find course grain, farther will be fine
- The **roundness** of a rock determines length, rougher closer, rounder farther
- **Sorting** of size will tell length of travel
- **Maturity** - if its uniform, roundness will tell length of travel

Chemical Sedimentary Rocks
- formed from precipitation of materials from solution
- Makes Clert (SiO2), limestone/calcite CaCo3, dolomite (dolostone), CaMg(CO3)2
- **Evaporites:** minerals precipitated from solution-concentrated by evaporation - Gypsum/halite

Chemical (Biochemical) Sedimentary rocks
- shells and shell debris deprived from living organisms, coquina, chalk

Organic Sedimentary rocks
- **D**eprived from organic material (flora/fauna)
- Swamps are best places to accumulate rocks
- Extract water, need heat and pressure and time
- Makes Cole in the end

Sedimentary structures
- **Bedding:** what gives it the layered look, lamentations are beds <1cm thick (thin beds)
- **Ripples:** produced by water/air because on one constant current (one direction) that cause **asymmetric ripples**. Back and forth motion (two direction) cause **symmetric ripples**
  Cross Bedding in asymmetric ripples: the top of bed is up, tells which way sedimentary is Younger, can tell current travel, cross bedding is within bedding, erosion of surface, are Angular
- **Mudcracks:** mud dries and cracks up
- **Graded Bedding**: bedding that has size gradient from bottom to top causes by turbulence like earthquake, heavier stuff on bottom , finer stuff on top
- **Bioturbation**: disruption of bed by biological activity (animals digging)
- **Body Fossils**: first kind, pieces of body that has been fossilized or shell
- **Trace Fossil**: second kind, evidence that organized was there, by footprint, like cavity

Stratigraphic formation
- like to group (beds) sedimentary rocks that have similar characteristics ex, Nepean formation, kaibab limestone, hermit shale, supai group,

Why are sed rocks useful?
- characteristics such as grain size, rounding, sorting, composition, can yield information about transport distance, transport medium, and depositional environment.
- **Depositional environment**: description of an area that tells what type of rock would be there (check slide)

Sedimentary environment

- the present is the key to the past

Lecture 9

Metamorphic Rocks
- Metamorphism involved recrystallization, growth of new minerals and texture change due to chawed in temperature, pressure, and reaction with hot fluids
- Happening mostly in solid form
- **Changes in temperature**: T gradients because of heat flow
- **Changes in pressure**: confining pressure (overlying burden) vs. Differential stress (from squeezing such as in plate movements).
- **Changes in Composition**: Fluids react with minerals and carry in/out elements (metasomatism)
- **Agents of metamorphism (temperature/pressure/composition), work together**

Character of A rock determined by: mineralogy/ texture

How do you know a rock is a metamorphic Rock?
- metamorphic texture (**foliation (**layers in one direction))
- Metamorphic minerals
- Mineral assemblage (all together)

To tell difference between Igneous and metamorphic is foliation, Igneous don't have foliation
Recrystallization: Changing shape and size of **protolith** (original/ parent rock) grains without changing the size minerals composition ex. Sandstone
Pressure Solution: deformation can lead to crystals (grains) partly dissolving. **Stylolites** are lines formed in metamorphic rock which are other minerals, low temperature
Plastic (ductile) deformation: recrystallization accompanied by differential stress allows minerals flow and deform, temperature over 300, destroy any fossils and any other grains
Neocrystallization: growth of new minerals that differ from the **protolith.**
Index Minerals: form under specific P-T conditions and thus can help determine P and T of metamorphism of rock

Differential Stress
- **Confining Pressure**: acts equally in all directions.
- **Lithostatic Pressure**: pressure of overlying rock **PL=p(density)** x **g(gravity)** x **h(height of grow overburden)**
- **Normal stress:** directed perpendicular to a surface; compression vs. Tension
- **Shear Stress**: sideways motion, breaks rocks

All the stress will affect grain shape, ex elongate, platy

Metamorphic Textures
- **Foliated:** preferred mineral orientation or alignment
- **Non-Foliated**

Metamorphosing Mudstone (Shale) (Foliation)

- used this rock as an example because we have a lot of it
- **Slaty cleavage**: fine grained foliation planes along which the trick can break; little to no new mineral growth, just well developed mineral alignment
- **Phyllitic Foliation**: foliation planes defined by slightly larger than clay sized platy minerals (micas)
- **Schistose (Schists) Foliation:** foliation planes defined by large platy minerals (mica) or long prismatic minerals, index minerals often present
- **Gneissic Foliation:** foliation planes defined by large platy minerals (mica) or long prismatic minerals; index minerals often present. **Banding** defined by alternative layers of different composition (often notable colour difference between bands)
- **Migmatite (starting to melt rock)**
- **All these formations due to increase in temperature and pressure**

Types of Metamorphism
- **Regional Metamorphism:** large belts of crust at high p and high t, bigger area, and makes more metamorphic rocks
  - With Depth: temperature varies much; pressure varies little
- **Contact Metamorphism:** small area adjacent to magmatic intrusion, heat up rocks around magma called **contact aureole/ metamorphic aureole,** as we move away from heat we go from high to low grade
- **Dynamic Metamorphism**: along fault zones; shallow and deep (mylonites), shearing rocks, making tiny gains in zone
- **Hydrothermal Metamorphism:** waters heated by intrusion from below, hot fluid interact with rocks, important process responsible for many mineral deposits

Metamorphism and Plant Tectonics

How do metamorphic rocks end up at surface of the earth?
- Exhumation
- Crust thickens and gravity pulls the mountain, causing heat and rocks melting, and erosion, so rocks from 30 km in ground comes to surface.

Lecture 11

Pyroclastic flow: deposits rocks

Lahar: ashe mixed with water from glacier or snow, to make like hot mud or cement

Lava domes:

Earthquakes/landslides
- This type of earthquake is from magma coming up to surface causing breaking

Rhyolitic Volcanism
- high SiO_2, high viscosity =, high gas content
- Large calderas, large tuff deposits, hydrothermal activity

- Melting of felsic continental crust causing volcanoes (yellowstone)

Caldera Formation
- large eruption of volcano
- Then collapsed on itself

Continental Hotspot Magmatism
- hotter magma at the base of the crust
- mafic rocks are hotter than felsic rocks
- Basaltic magmas intruding continental crust (felsic) will drive partial melting
- Fractional crystallization

Columbia River Basalts and Snake River plain/ Yellowstone hotspot track
- hotspot are made of felsic
- Erupts ever 600000
- The grey area are basaltic eruption (snake river)
- Another grey is the very first eruption (columbia river basalt)
  - very flat, lots of minerals
- When crust moves over a mantle plum, tracks are made which are sections of basalt magma
  - plums are being drag causing martial melt in nearby areas
- Small hydrothermal explosions-> strong earthquakes-> lava flows-> caldera forming eruptions (the destruction gets bigger with each one)

\- **Geothermal features - Geysers:** form when water is superheated by magma at depths. Water seeps into ground (500-600), the ground surrounding water is very hot causing water to be less dense and comes up into hot springs (straight up) and steam (not straight up). Causing solubility of rocks to increase. The white stuff not water but calcite being precipitated and deposited

- **Tuff:** product of explosive volcanisms

Impacts of Ash for North America if Yellowstone erupts
- Few mm's transportation issues, electrical systems impacted, respiratory impacts
- In midwest where cm's of ash would impact agriculture, livestock, water distribution and building integrity locally
- Thick deposits would disrupt water and sewer, building integrity and strongly impact agriculture transportation
- Air transportation and electronic communications shut down in North America (at minimum)
- Global climate impact

- **sizemic rays** are like x-rays but for detective earthquakes
  - hot rocks slow it down, cold rocks speed it up

Immediate impact
- hot ejecta
- Pyroclastic flows (vesuvius, pinatubo)

Short-term impacts

- large impact to surrounding natural environments (tephra, blast, lahar, lava flows)
- Particles in ejecta block sunlights
- Chemical in ejecta effect balance in atmosphere
- Particulate matter (ash) remaining in the air (breathing hazard), transportation

Long-term impacts

- large-scale climate change linked to volcanism and plate tectonics- possible cause of mass Extinctions