

Lecture 1:

Q&A's

Explain the meaning of "the Earth as a system" + give an example.

- To view the Earth as a whole, rather than separating into different disciplines like chemistry, physics, biology and geology, we integrate these and investigate their interrelationships with the biosphere, geosphere, atmosphere leading to understanding of the Earth as a system of all of these relationships and connections.
- Example: volcanic eruption + the transport of ash through the atmosphere and the effect of this on climate and weather

Steps of Deductive Reasoning + give an example.

1. Collection of scientific facts (**DATA**)
2. Development of one or more working **hypotheses** to explain
3. Development of observations + experiments to **test** the hypotheses
4. Acceptance, modification, rejection (**a, m, r**)

Example: Global/Climate warming

- Could be due to release of CO₂ into atmosphere by humans or the cyclic nature of Earth's climate

Differences between two methods of scientific inquiry

1. Deductive (Darwinian) = particular event → general conclusion
 2. Inductive (Baconian) = general conclusion → particular event
- Both commonly used in geology and other sciences, leading to general patterns from observation and measurement
 - These patterns lead to hypotheses which are explored and possibly made into theories over time
 - Examples of deductive: extinction of dinosaurs, climate change

Evidence + Observations that support the theory of bolide impact

- Mexico chicxulub crater
- Tektites (glass balls made from crater melting into the Earth) + other anomalies (ash, soot, glass)
- Carbon, Sulfur, Iridium anomalies in the rock record occur at that time

The idea of "the present is the key to the past"

Principle of Uniformitarianism

- Describes the earth processes that operate today are the same as ones that operated throughout geologic time. Helps us to make assumptions and collect data on geologic history

Systems of Earth

1. Atmosphere
2. Biosphere

3. Lithosphere
4. Cryosphere
5. Hydrosphere

Geology as a study

What is Geology?

- Science that pursues understanding of Earth and assumes that the natural world is consistent and predictable
 1. How Geology differs from other sciences
 - Deals with large spatial scales + complex systems
 - Deals with time scales immense compared to human life
 - Geologic evidence is fragmented and incomplete
 2. How and Why things happen explained by:
 - Hypothesis
 - Theory
 - Law
 3. Observations and description are important because:
 - Systems are complex
 - Controlled experiments are not always possible
 - Nature is commonly the laboratory
 - Time scales are vast
 4. Dino extinction was synchronous with Sulfur, Carbon and Iridium anomalies

Lecture 2:

Q&A's

1. Age of the 8 planets

- They were formed at roughly the same time, this is assumed because of their similar orbits
- They were formed by the same planetary nebula

2. Why the moon has more craters than the Earth?

- Moon has little tectonics or weathering to deny craters
- No atmosphere or tectonics on the moon makes the surface not continuously under erosional processes and the plates are regenerative

3. How do Moons form?

1. Impact theory (favoured for the Earth's moon)
 - Impact between 2 objects forms spiralling material that come together to form a satellite
2. Capture
 - Object captured by stronger gravitational pull of the planet

4. Explain planet accretion + how it helped create the solar system

- Accretion = formation of massive object through gravitational attraction
 - It is a process integral to nebular theory where accretion allowed for formation of

the planets from dust and other small objects

5. Differences between Terrestrial and Jovian planets

Terrestrial:

- Atmosphere on all but mercury
- Closer to the sun
- Rocky surfaces
- Few satellites
- Dense metallic cores

Jovian:

- Larger in size
- Gaseous material
- Many satellites
- Presence of rings
- Low density

6. Similarities of orbits between Terrestrial and Jovian planets

- Almost all revolve around the sun in the same direction
- All revolve with the same ecliptic
- Almost all revolve counterclockwise on their axes
- Axes of rotation nearly all perpendicular to ecliptic

7. Why orbiting planets from Earth undergo retrograde motion

What is retrograde motion?

- Backwards motion of a planet, it is opposite of prograde and opposite of what is expected.
 - Earth completes its orbit in shorter amount of time than planets outside of its orbit, so it periodically overtakes them. When this occurs, planet being overtaken will appear to stop and then change its motion
 - As earth proceeds past the planet, it appears to continue with normal prograde motion, but the inner planets appear to continue with retrograde motion because their orbits are faster
 - Analogy: earth is a slow moving car being passed by a faster car but creating the illusion of a change in direction (orbit)

Definitions

- Solar system
 - Consists of our star, sun, the terrestrial and jovian planets, satellites and asteroids
 - It is contained within the milky way galaxy
- Geocentric Perspective
 - Planets following a smaller circular orbit (called epicycles)
- Law of Ellipses
 - Orbit of each planet is an ellipse with sun at one focus of it

- Law of Orbital Harmony
 - For any planet, the square of the orbital period in years is proportional to the cube of the planet's average distance from the sun.
- Law of Equal Areas
 - The line drawn from a planet to the sun sweeps out equal areas in equal time
- IO
 - 1 of 4 of the Galilean satellites
 - Volcanically active
 - Melting from tidal energy
- Solar Nebula Theory
 - Everything in the solar system is approximately the same age
 - Planets revolve around the sun in the same direction and within the same plane
 - Almost all revolve counterclockwise on their axes (venus is clockwise, uranus is tilted)
 - Sun revolves counterclockwise
 - Nearly all planets and the sun's axes of rotation are perpendicular to the ecliptic
 - Planets result from accretion of dust
 - Sun originates from concentration of mass at the centre of it

Problems with this theory:

- Venus rotates clockwise
- Origin of the asteroid belt
- Rotation speed of the sun is too slow given its position at the centre of the disk
- Meteors
 - Glowing fragments of rock inside Earth's atmosphere
- Meteoroid
 - Meteorite before it hits the Earth's surface
- Meteorite
 - Piece of rock from space that hits the Earth's surface
- Fire balls
 - Very bright meteors
- Meteor showers
 - Earth's orbit passes through a belt of cosmic dust and rock
- Asteroid belt
 - Swarm of 100,000 objects (asteroids)
- Comets
 - Body that orbits the sun. Made of ice and rock radiation that generates gases, giving it a long, bright tail

Effects of Impacts on Earth

- Earthquakes
- Dust + ash released into the atmosphere (causing cooling)
- Wildfires (more ash + dust = cooling)
- If the impact is in the ocean, water vapour releases and scatters solar radiation (warming effect)
- Shock produces nitrogen oxides (acid rain)
- If in ocean, possible tsunami

The Planets

- Mercury
 - Fairly dense and small, scarps (broken surface/cracks)
- Venus
 - Earth's "twin" (similar in size)
 - Has runaway greenhouse effect
 - Has evidence of active or previously active tectonics
- Mars
 - Slightly less dense than Earth
 - Volcanoes and tectonics (has biggest volcano in solar system)
 - Has evidence of active or previously active tectonics
- Jupiter
 - Density is dropping
 - Mostly liquid
- Saturn
 - Layered, gaseous
 - Core similar to Earth
 - Sizeable magnetic field
 - Moons: Titan - moon with liquid lakes and atmosphere; enceladus - its moon (icy shoots, methane and ice)
- Uranus + Neptune
 - The "twins"
 - Rocky centre, icy mantle, outer gaseous envelope
 - Uranus rotates like a wheel instead of spinning top

Lecture 3:

Basis of dividing Earth into crust, mantle and core?

- They have significant compositional differences

Basis of dividing Earth into lithosphere, asthenosphere, mesosphere and core?

- Significant mechanical differences

How did Andrija Mohorovicic discover boundary between crust and mantle

- He observed the seismic velocities are slower in the crust than in the mantle (seismic velocities increased at the boundary)

What process causes the P-wave shadow zone

- Refraction (or bending) of P-waves at the liquid core and solid mantle boundary

Reasons temperature increases with depth within the Earth

- Radioactive decay of isotopes U, Th, K emitting heat
- Crystallization of iron at inner core emits heat
- Latent heat from collision of particles during formation of Earth

Why is oldest continental crust so much older than oldest oceanic crust?

- Oceanic crust is more dense + commonly recycled during plate tectonics processes

Difference between primary + secondary waves

- P-waves propagate through all mediums and are faster
- S-waves only propagate through solids and are slower

Why does density increase with depth in the crust?

- Because pressure increases with depth

Why do scientists think magnetic reversals are a potential contributor to extinctions

- Because the weakened magnetic field no longer protects the Earth from cosmic rays + solar winds

What does the s-wave shadow zone tell us about internal structure of Earth?

- That the outer core is liquid

How does geothermal gradient vary with depth within the Earth?

- Steep increase in the crust, gradual increase in mantle + core

Important to know

- Rock is an aggregate of 1 or more minerals
 - Mineral is a natural, inorganic solid

Plate Tectonics

- Centuries of observations have concluded that Earth's makeup is not random
- Pattern recognition: earthquakes occur where mountains rise + volcanoes explode
- 4 concepts
 1. Outer portion of Earth is composed of rigid layers called plates
 2. Plates move slowly
 3. Most large scales geologic activity occurs at plate boundaries
 4. Interior of plates are relatively geologically quiet

What is an Earthquake?

- Vibration of Earth produced by rapid release of energy stored in rock subjected to stress (plates rubbing each other)
 - Energy in form of waves (body + surface waves)
 - Radiates in all direction

Characteristics of Body Waves

- Velocities proportional to density + elasticity

- Velocity increases with depth
- P-waves propagate through everything
- S-waves propagate through solids

How can we “use” Earthquakes

- They allow us to “x-ray” image the Earth

Law of Reflection

- Angle that the wave is incident to on the surface = the angle at which it is reflected

Crust-mantle boundary (Moho)

- Seismic velocities slower in crust than mantle

Crust-mantle boundary (B. Gutenberg)

- P-waves disappear @ 105° from earthquake and reappear at 140° (p-wave shadow zone)

The core

- Seismic waves travel in/out of it
- Characterized by bending P waves
- Existence of liquid layer beneath mantle (proven by S-waves not travelling through the solid core)

Seismic Waves + Earth’s Structure

- Changes in seismic wave velocities = Earth is composed of distinct shell
 - Layers defined by composition and chemistry, mechanics/physics

Chemistry + Composition of layers of Earth

1. Crust - oceanic and continental, solid, strong, rigid
2. Mantle - solid, weak, ductile
3. Core - outer (liquid) and inner (solid)

Physical + Mechanical of layers of Earth

1. Crust + upper mantle = lithosphere
2. Below lithosphere = asthenosphere
3. Below asthenosphere = mesosphere

Earth is layered but...

- Competing pressure + temperature forces complicate things
- Increased depth = increased temperature = melting
- Increased depth = increased pressure = stronger rock

Lithosphere

- Cool + strong, brittle
- Continental + oceanic crust

Asthenosphere

- Partially melted, ductile

Mesosphere

- Strong + hot

Geothermal Gradient

- Varies considerably from place to place
- Temperature change over distance

Heat flow in the crust

- Process called conduction
- Rates of heat flow in crust varies

Mantle Convection

- No large change in temperature with depth in mantle
- Mantle must have effective method of transmitting heat from core outward

Core = Earth's Magnetic Field

- Provide force field from solar wind

For the core to produce magnetic field:

- It is mobile
- It is composed of material that conducts electricity
- Magnetic field has North + South magnetic pole
- Magnetic field allows use of compasses
- Magnetic field occasionally flips

Rock Magnetism + Paleomagnetism

- Use mineral magnetic alignment to determine direction and distance to magnetic pole
- Steeper dip angles indicate rocks formed closer to magnetic pole

Marine Magnetic Anomalies

- Bands of normal + reversed magnetic field signatures

Plate Tectonics

- All evidence leads to this

1. Seafloor spreading

- Seafloor moves away from mid-oceanic ridge due to mantle convection (circulation driven by rising hot material and/or sinking cool material)

Plate Movements + Boundaries

- Divergence = rifting/extension
 - Great East African Rift, Atlantic Basin, Basin + Range
- Convergence = subduction/collision
 - Appalachians, Himalaya, Andes
- Conservation = translation/transformation
 - San Andreas Fault, California

Why do Plates move?

Gravity: old tectonic plates sink at convergent margins + are formed at divergent margins

Mantle Convection = cause or effect of circulation by slab-pull or slab-push

*** Mantle composition is like the moons ***

Lecture 4:

Mafic Rock

- Made of Mg and Fe with small amount of O
- Found in asthenosphere + mesosphere

Things that generate magma

- Increase temperature from radioactive decay within Earth
- Decrease rock pressure to weaken bonds of solid
- Increase frictional heat of tectonic plates
- Increase temperature because of heat stored from production of early Earth

Pyroclastic

Rock containing material generated by explosive fragmentation of magma or previous solid rock during volcanic eruption

Aphanitic rock texture of the igneous rock rhyolite suggests:

That rock was cooled quickly

If basalt from mantle is melted, what would happen?

Magma will cool resulting in crystallization of ultramafic rocks at high temperature followed by felsic rocks crystallized at low temperature

Why does Bowen's reaction series work in theory but not in field?

- Not a closed system (assimilation of wallrock material or magma mixing from other sources)
- Minerals do not remain in contact with magma. They settle to bottom of chamber or get stuck on walls (fractionation)

Porphyritic

- Texture of rock composed of large crystals in a matrix of smaller microscopic crystals
- Slow cooling underground allow large crystal formation followed by quick cooling above ground resulting in small crystals

Mineral Polymorphs = Minerals with/ same chemistry and different structure

- Eg. carbon in diamond + graphite
- Different from solid solution because in solid solution, one atom substituted for another in a compound.
- Same in chemistry but structure is the different

Silicates = Most common class of minerals

- Contain oxygen, calcium, aluminum, silicon, iron, magnesium, potassium
- crust = quartz, mica, potassium feldspar, plagioclase feldspar, amphibole
- Mantle = pyroxene olivene

Physiochemical factors that control formation of igneous rocks

- Temperature and pressure of system
- Abundance of elements available
- Size + charge of atoms to form compounds
- Extrusive + intrusive igneous form

Tectonic Plates = Part of Lithosphere - made of minerals, enriched in elements (Si, Al, K, Na, Ca

- Rocks termed felsic or acid

Asthenosphere + Mesosphere (made of rock enriched in elements)

- Mg and Fe
- Rocks termed ultramafic or ultrabasic

Minerals are building blocks of rock

- Naturally occurring
- Solid
- Definite chemical composition
- Crystal structure

Elements

- Form of matter that cannot be broken down by heating or cooling or chemical reaction
- Atoms bond to form minerals in regular geometric shapes
- Compound = combination of one or more elements

Combination of Elements depend on characteristics of atoms of that elements

1. Relative abundance of available elements (within crust)
2. Temperature and pressure at time of formation
3. Size and charge of atoms + ions

Oxygen = second most abundant element on Earth by weight (most abundant in crust). This is important for forming most minerals

Chemical Bonding

- Ionic
 - Atoms gain or lose electrons to form ions
- Covalent
 - Sharing of electrons to achieve electrical neutrality
- Other
 - a) Metallic - cloud of electrons free to migrate among atoms
 - b) Van der Waal forces - weak electrostatic forces

Igneous Rock

- Magma = molten rock in the ground that contains crystals and gases
- Melt = generally the only liquid portion of the process
- Lava = molten rock containing crystals and gases at Earth's surface

How Magma Forms

- It comes from subduction zones and spreading centres in intraplate volcanism

Factors:

1. Temperature
 - Radioactive decay within Earth
 - Early Earth produced during big bang
 - Frictional heat of tectonic plates
 - Convergent margins
2. Pressure
 - High pressure gives higher temperature to melt solid rock
 - Divergent margins moving away from each other
 - Mantle becomes exposed, pressure drop causes melting
3. Add flux
 - Volatiles reduce melting temperature of solid

Lecture 5:

Black Mudstone use:

- It tells us the environment is anoxic

Chemical Sedimentary rock with large grain size suggests:

- Nothing about the distance of transport

How much CaCO₃ precipitation is expected in Northern Latitudes compared to mid-latitudes

- No CaCO₃ precipitation in northern, and moderate in mid (high in Southern)

3 aspects of grains within clastic Sedimentary rock help define Texture

- Size
- Shape

- Sorting

Weathering of rocks in the desert vs rainforest:

Desert: erosion mostly from wind. Little thermal expansion and contraction

Rainforest: lots of rain, more water, greater weathering and erosion

Small holes + no identifiable writing on limestone grave marker suggests what process has occurred? Why did it occur and how does it affect the environment?

- Chemical weathering ($\text{CaCO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{Ca} + \text{SO}_4 + \text{H}_2\text{O} + \text{CO}_2$)
- Happened because of chemical breakdown. The limestone breaks down easier when exposed to acid rain which releases CO_2 , leading to global warming which is a negative impact on the environment.

Most and Least stable mineral on Earth? How do you know?

- Minerals are most stable at temperature and pressure that they form at
- Higher temperature minerals when exposed to the surface are further from comfort and weather/erode faster
- Quartz is more stable because it is close to its preferred temperature and pressure (comfort zone)

Two Types of Pressures associated with metamorphism?

1. Lithostatic/confining
 - Pushes on rock equally from all directions
 - Rock becomes more dense, no shape change
2. Directed
 - Pressure greatest in one direction
 - Change in shape

What type of rock is coal? How is it formed?

Chemical sedimentary

- Formed by decay, compression and lithification of land plants

What is sedimentary rock?

- It is made of sediments (rock fragments that settle and accumulate after being transported or precipitated)
 1. Detrital/clastic rocks - transported sediment as solid particles
 2. Chemical rocks - sediment that precipitates from solution or extra from water by organisms

Sedimentary Process:

Rock

↓ weathering/erosion

Sediment

↓ transport

Relocation

↓ Deposition + Lithification

Rock

Where does rock come from?

- Liquid magma suspends random atoms in non-crystalline structure (**before minerals form**)
- Atomic vibrations slow bonds and begin to form compounds and eventually crystalline structure (**During magma cooling**)
- **After cooling = igneous rock**
Rock that cooled + crystallized directly from molten material at/near the surface

Volcanic/Extrusive = at the surface

- Erupt and flow
- Cooling times range from seconds to years
- Basalt = archetype

Plutonic/Intrusive = at the subsurface

- Intrude within the crust
- Form huge masses that cool over a million years
- Granite = archetype

Characteristics of Magma

Composed of:

- 1) Liquids (melt)
- 2) Solids (crystals)
- 3) Gases (volatiles)
 - Cooling results in systematic crystallization pattern
 - Silicate minerals crystallize in predictable order

Bowen's Reaction Series

- Explains diversity of igneous rock that appear to have evolved from basalt
 - As they cool, different minerals achieve saturations at different temperatures
 - Crystallization of minerals changes chemical composition of magma
- a) Discontinuous - specific sequence of crystallization, goes from simple → complex
 - b) Continuous - Na ions replace Ca in crystal, causes little structural change

Assumptions:

- Closed system
- Early minerals remain in contact with magma

- Full range of igneous rocks could be produced from same mafic magma

****Silicates are dominant in igneous rock****

Magma Compositions (other than Plutonic and Volcanic)

1. Intermediate - relative to granite, associated with explosive volcanic activity
2. Ultramafic - rare and composed of olivine and pyroxene

Igneous Textures

- These describe overall appearance based on size, shape, sorting
1. Phaneritic - coarse grained
 2. Aphanitic - fine grained
 3. Porphyritic - large AND small crystals
 4. Glassy - no crystals visible
 5. Pyroclastic - fragments ejected during violent volcanic eruption
 6. Pegmatitic - exceptionally coarse grained

Weathering

- Physical and chemical changes to rock

Factors:

1. Parent rock
2. Climate
3. Soil
4. Time

Clastic Sedimentary Rocks

- Clay
- Quarts
- Feldspars
- Micas

Classifying Sedimentary Rocks

- Texture (reflects the process)
1. Grain size
 2. Grain sorting
 3. Grain shape

**** Transportation + Deposition lead to characteristic rock textures ****

Mudstone

Clay to silt-sized particles in thin layers

Sandstone

Sand sized particles, mostly quartz

- Conglomerate = rounded gravels
- Breccia = angular particles

Chemical Sedimentary Rocks

- Precipitated material that was once solution
- Precipitation occurs by: inorganic and organic processes

** Limestone (CaCO_3) = 10-15% of sedimentary rocks

Factors Controlling CaCO_3 Precipitation

- solubility of CaCO_3
- Cold water has more CO_2 , as water warms, it precipitates
- Also affected by agitation of water, photosynthesis and water depth

Common Chemical Sedimentary Rocks

1. Chert - microcrystalline quartz
2. Evaporites - evaporation triggers deposition of inorganic chemical precipitates
3. Coal - decay + compression of land plants; inorganic material accumulated in swamps (anoxic environments)
Peat → Lignite → Bituminous Coal → Anthracite

Economic Considerations of Sedimentary Rocks

- Coal
- Petroleum
- Sources of Fe, Al, Mn
- Phosphates → fertilizers
- Evaporites - salt, gypsum

Scientific Considerations of Sedimentary Rocks

- Fossils
- Geologic history

Metamorphism

- Temperature, pressure, chemical reactions alter mineral content of pre-existing rock
- Metamorphic rock produced from : igneous, sedimentary and other metamorphic rocks

Controls of Metamorphism

1. Temperature - not absolute, but a change in it
2. Pressure - lithostatic and directed
3. Fluid activity - H_2O and CO_2 , increases potential for reaction

These control the process of metamorphism, but **protolith** controls **composition**

** example of metamorphic rock = sandy limestone **

Metamorphic Environments are @ Plate Boundaries

1. Regional metamorphism

- a) Burial - Temperature and Pressure within sedimentary basins
- b) Dynamothermal - occurs in response to temperature and pressure changes induced by tectonics
- 2. Contact Metamorphism
 - Response to temperature change produced by intrusion of magma to the cooler rocks
 - Local in scale
- 3. Hydrothermal Metamorphism
 - Chemical alteration caused when hot, ion-rich fluids circulate through fissures and cracks that develop in rock
 - Ocean crust is metamorphosed

Classification of Metamorphic Rocks

- Reflected in **texture**, determined by grain size, sorting, and shape (mineralogy)
 1. Foliated rock - size of crystals, nature of foliation
 2. Granoblastic rock - non-foliated, classified based on composition, crystals grow in interlocking equant shapes
 3. Porphyroblasts - occur in both foliated and granoblastic rocks
 4. Hornfels - high temperature contact, uniform grain size
 5. Marble - temperature and pressure acting on limestone or dolostone
 6. Quartzite - hard, non-foliated, derived from quartz-rich sandstone, big and preserved bedding
 7. Slate - foliated rock formed from low temperature and pressure, fine-grained
 8. Phyllite - higher temperature and pressure than slate, glossy and sheen look
 9. Schist - intensely metamorphosed with platy crystals, light and dark bands
 10. Gneiss - coarse-grained rock with high temperature and pressure, light and dark bands that are very segregated
 11. Migmatite - very high temperature, where rock begins to melt. It is deformed and contorted

Foliation = very common textural feature

Lecture 6

Some important random notes:

New crust is added to the Earth @ spreading centres, but Earth does not expand

- Crust is consumed elsewhere @ convergent plate boundaries + subduction zones
- In divergent plate boundaries, they split bilaterally

Shield Volcanoes

- Made of mafic rocks
- Results from effusive eruptions near or from the main vent
- Little pyroclastic material
- Slope angles are gentle
- Large in size
- Example: mauna loa or olympus mons

Stratovolcano (AKA composite cone)

- felsic rock (layered lava + pyroclastic flows)
- Results from layered pyroclastic eruptions and very viscous lava flows
- Produces nuee ardente
- Most violent eruption
- large , classic shaped volcano
- Most are adjacent to the pacific ocean
- Example: mt. vesuvius, mt. st. helens

Pyroclastic Volcano (AKA cinder cone)

- Made of tephra and loose pyroclastic material
- Small, steep sided
- Example: sunset crater, paricutin volcano

↓ Gas + ↑ Si + ↓ Temp = ↑ viscosity = felsic, explosive because of ↑ pressure

↑ Gas + ↓ Si + ↑ Temp = ↓ viscosity = mafic, non-explosive because pressure escapes

Hotspots

- Felsic because the continental crust is melting

Melt

- Has low viscosity and is therefore formed from ↑ Gas + ↑ Temp and ↓ Pressure
- Magma and lava are the opposite

Indicators of Volcanic Eruptions

- ↑ seismic activity
- Change in groundwater levels + chemistry
- Surface doming
- Change in animal behaviour

Chain of Volcanoes

- Made from movement of plates over a hotspot

Fastest → Slowest

Pyroclastic → Pahohoe → Aa → Pillow

Green = non-effusive

Igneous Activity + Plate Tectonics

- Global distribution not random, it is related to tectonic plate boundaries (found in oceanic basins)
- Active volcanoes correlate with earthquakes
- Volcanoes produce igneous rock

** Volcanoes are classified according to shape, composition of magma and eruption style **

Nature of Volcanic Eruption

Factors determining explosiveness of a volcanic eruption:

- Composition of magma (Lots of Si = ↑ velocity)
- Temperature of magma (low temperature = ↑ velocity)
- Gases in magma (low gas = ↑ velocity)

** viscosity affects the nature of an eruption, low viscosity = non-explosive, high = explosive **

1. Magma - molten rock containing crystals and gases within the earth
2. Melt - the only liquid portion of eruption process
3. Lava - molten rock containing crystals and gases at surface of the earth
4. Felsic rock - Si rich, viscous
5. Mafic rock - Si poor, fluid like

Effusive (non-explosive) Volcanoes

Materials extruded:

- Pahoehoe (twisted, ropey texture)
- Aa lava (rough, blocky, jagged texture)
- Pillow (underwater lava)
- Lava domes (masses of congealed lava associated with explosive but have gas poor eruptions)

Explosive Volcanoes

Materials extruded:

- Pyroclastics = fire fragments of tephra, ash, dust, fine and glassy cinders, pumice
- Eruption column = cloud of gas and tephra
- Lateral blast = lots of pressure, magma and gas direct themselves sideways
- Pyroclastic flows and surges = mix of hot gas and rock that becomes avalanche like, generally in valleys and originate from a lava dome collapse
- Nuee ardente = pyroclastic flow, fast, hot gases, ash and other debris

Eruption Types

1. Hawaiian - low viscosity, little pyroclastic material, effusive
2. Strombolian - blast of lava (bombs and tephra), low elevation columns and pyroclastic flows mildly explosive
3. Vulcanian - highly viscous magma, sustained explosions, columns high and collapse to produce pyroclastic flows, very explosive
4. Pelean - collapse of lava dome producing nuee ardente, violently explosive
5. Plinian - sustained ejection, eruption column up to 45km, ash cloud can circle Earth for days, violently explosive
6. Phreatic - results from mix of magma and shallow groundwater, becomes steam and explosively erupts, no new magma reaches the surface

Volcanic Landforms

1. Volcanic cone - hill or mountain
2. Vent - surface source of eruption
3. Volcanic crater (caldera) - depression surrounding vent (crater=small, caldera=large)
4. Fissures - flood lava / basalt
5. Volcanic pipes and necks - short conduits connecting magma chamber to the surface
6. Lava tube - metro system for lava

Fumaroles

- Vent where gases emerge at surface of the Earth

Hot Springs

- Hot water comes to surface (along a fault)

Geysers

- Results from hot spring plumbing system allowing accumulation of steam, increasing pressure, steam will move rapidly towards surface, causing eruption of hot water

Volcanic Eruptions

Primary Effects

- Lava flows - not explosive, slow moving, threatening to buildings
- Eruptions and pyroclastic flows - fast, hot, potentially widespread, most dangerous
- Gas emissions - HCl, H₂S, HF and CO₂

Secondary Effects

- Lahar - unconsolidated tephra + water makes mudflow which is rapid downslope movement of material, may occur during eruption or years later
- Debris avalanches/flows - do not necessarily accompany eruptions, relatively unconsolidated volcanic material which flows downslope from gravity
- Tsunamis - flows, avalanches, landslides, caldera collapse entering body of H₂O
- Flooding - flows can block or re-route rivers
- Atmosphere effects - solid + gas particles released causing reflection of solar radiation
- Acid rain
- Geothermal energy
- Metallic ore deposits
- Outgassing of Earth
- Fertile soil

Volcanic Activity

1. Active - shown eruptive activity within recorded history
2. Extinct - shown no signs of recent or historic activity
3. Dormant - "sleeping" - this is something in between the other 2

Long Term Forecasting

- Knowledge of geologic + eruption history of region

Short Term Forecasting

- Seismic monitoring and exploration (earthquakes preceding eruptions as magma intrudes and moves within the volcano)
- Volcanic tremor - rhythmic shaking
- Ground deformation
- Tilt metres
- Changes in heat flow
- Changes in magnetic field
- Changes in electrical resistivity
- Changes in the groundwater system
- Changes in gas composition

Lecture 8

Strain vs. Stress

- Strain is a deformation of rock and stress is the force that causes it

Joints vs Fractures

- Joints are faults that have had no movement occur and fractures are faults that have had movement occur
- Multiple parallel joints = joint sets

(L) and (R) waves

L waves - love waves, move in side-to-side waves and is not as damaging as r-waves

R waves - Rayleigh waves that move like ocean waves and are more destructive.

Both are types of surface waves

Earthquakes

- Occur at 100 km depth because deeper than that, rocks are ductile instead of brittle, so they cannot rupture, only flow. Rock rupture is what causes the earthquake to occur

Deformation

1. Ductile: \uparrow pressure \uparrow temperature \rightarrow flows and folds
2. Brittle: \downarrow pressure \downarrow temperature \rightarrow ruptures and faults

Faulting

1. Normal - hanging wall drops, thins the crust (Divergent Margins)
2. Reverse faulting - upwards hanging wall (Divergent Margins)
3. Strike/slip - hanging wall and footwall slide past each other right lateral or left lateral (Transform Margins)
4. Thrust - hanging wall moves up with respect to footwall, movement is parallel to the dip of the fault plane, causes duplication of rock and thickening (Convergent Margins)
5. Elastic rebounds - rocks bend and store elastic energy, there will be a buildup of strain until release of energy which causes earthquakes (Ductile Deformation)

** source of earthquakes = hypocentre and the location on the surface above the hypocentre = epicentre **

Boundaries

1. Transform Plate Boundary - no loss or gain of crust
2. Divergent Plate Boundary - crust is stretched and thinned
3. Convergent Plate Boundary - depends on the type but is crustal thickening

All Evidence leads to the Theory of PLATE TECTONICS

- Ideas explained motion of lithosphere through subduction and seafloor spreading, generating continents and oceanic basins
 - Tectonic plates are made of rigid, brittle lithosphere
 - They float upon the ductile asthenosphere
 - Plates interact at the boundaries (relative plate motion)
 - They move apart at divergent boundaries
 - Slide past each other at transform boundaries
 - Move together at convergent boundaries

gravity = driving force of tectonics (like a conveyor belt, plates are recycled at the mantle)

Mantle Convection

- May be cause or effect of circulation set up by :
 - Slab-pull : pulling of crust into mantle by down-going slab during subduction
 - Slab-push : pushing of crust resulting from elevated position of oceanic ridge system, causing crust to slide down flanks of the ridge

Divergent/Constructive Margins ←..→

- Plates move away from each other
- Occur within oceans or within continent but always create basins
- Marked by faults, volcanoes and uplift
 - Crust is stretched and thinned
 - Normal faults mark rift zones
 - Decompression causes melting
 - Hot rocks are thermally buoyant

Types of Convergent Margins

1. Ocean-ocean convergence : marked by deep ocean trench and volcanic island arc (subduction zone)
2. Ocean-continent convergence : marked by ocean trench, volcanic arc, mountain belt, moderate thermal heating, voluminous igneous activity, moderate crustal shortening
3. Continent-continent convergence : marked by mountain belts and thrust faults, thermal heating, igneous activity, extreme crustal shortening

** not all rocks fault/break **

Folds

- Wave like undulations in rock layers
- Mm-km scale fractures
- The result of horizontal or lateral compressional forces
 1. Dome = upwarped displacement of rock
 2. Basin = downwarped displacement of rock

What is an Earthquake?

- Vibration of Earth by rapid release of energy in rock subjected to stress
- It is produced by movement of rock bodies past each other, the stress of this must exceed the strength of the rocks in a brittle manner (where cohesion is lost)
- Loci of earthquake movements are faults (ie. brittle deformation zones)
- Faults come at all scales and so do earthquakes

Fault creep - slow migration of crust along fault plane (weak vibrations)

Seismology

- Study of earthquake wakes
- Done by seismographs/seismometers
- Records are seismograms

Types of seismic waves : P-waves, S-waves, First surface waves

Body Waves

- P waves
- S waves

Surface Waves

- Rayleigh waves
- Love waves

Measuring Earthquake Size

1. Intensity
 - Measure of the degree of earthquakes shaking at a given location based on damage
2. Magnitude
 - Estimates the amount of energy released at the source of the earthquake

Scales

- Richter
 - Based on amplitude of largest seismic wave 100km from epicentre
 - Less than 2.0 is not felt
- Movement Magnitude Scale
 - Gauges the earthquakes total energy (using fault rupture length, fault rupture depth, amount of slip along the rupture, and strength of rock)

Earthquake Destruction

Damage Attributable to earthquakes

- Intensity and duration of vibrations
- Nature of the material that the structure is on
- Designs of the structure

Destruction from Earthquakes

- Ground movement and fire (building collapse)
- Floods and landslides (dam break + river course change)
- Liquefaction : unconsolidated materials saturated with water converts into a mobile fluid
- Seiches : rhythmic sloshing of water in lakes, reservoirs and enclosed basins, waves can weaken reservoir walls and cause destruction
- Tsunamis : high speeds in ocean, can be very destructive

Rock Behaviours

1. Elastically : if deformed, material return to original shape after the stress is removed, if the stress exceeds the elastic limit, it will deform permanently
2. Plastically : caused by ductile deformation
3. Fracturing / rupture : caused by brittle deformation

Earthquake Predictions

- Rocks under stress expand in volume (dilate) which physically changes the crust

Short Term Predictions (unreliable)

- Swarms of foreshocks
- tilt/bulge of crust or land surface
- Changes in seismic wave velocity
- Changes in radon and ground water level and chemistry
- Strain monitors
- Paleoseismology

Long Term Predictions (reliable)

- Seismic gaps
- Strain monitors and ground deformation

Lecture 10:

Metals in Canada

- Gold, copper, iron

Most Common way that ore minerals are precipitated

- Through fluids

Alloy

- Compound synthesized by mixing metals together

** igneous, sedimentary AND metamorphic rocks are all associated with metallic mineral deposits **

Essential Requirements of making ore deposits

Source → Transport → Trap

**water in hydrothermal fluids originate from seawater, rainwaters and magmas **

Latente deposits concentrate elements by leaching out other elements through deep weathering of parent rock

Porphyry deposits are associated with root zones of volcanoes

Placer deposits of heavy metals are formed by heavy metals being mechanically transported and concentrated by rivers

Volcanogenic massive sulphide deposits associated with black smoker and form from hydrothermal vents on the seafloor

Diamonds form under cold and old lithosphere

Hazards of Fracking

- Earthquakes
- Contamination of water wells
- Escape of methane from gas wells
- Destruction of landscape
- Can lead to micro-earthquakes because it has increased pressure injection of fluid to depths to fracture the rock. These fluids can lower the effective normal stress along pre-existing fractures or faults

Acid Mine Drainage

- Oxidation and hydrolysis of sulfide minerals that exist with ore minerals

What are Minerals/Rock used for?

- Display
- Battery

- Speakers and vibration
- Electronics and circuitry
- Example: copper used for wire, bismuth used for replacement of lead

Ore Minerals

- Most are sulfides
- Some are oxides
- Rarely occur alone (mixed with other non-valuable minerals)

Origins of Mineral Deposits

- Minerals become concentrated in 5 ways
 1. Concentration by hot, aqueous solutions forms hydrothermal mineral deposits
 2. Concentration by magmatic processes forms magmatic mineral deposits
 3. Concentration by precipitation forms sedimentary mineral deposits
 4. Concentration by precipitation forms sedimentary mineral deposits
 5. Concentration by flowing surface water forms placers
 6. Concentration by weather processes forms residual/supergene mineral deposits

Where are they found

- Variety of plate tectonic settings depending on where these processes operate

Metallic Mineral Deposits

- Magmatic Ore Deposits
 - Some of the most important accumulations of metals are associated with magma that forms igneous rock
 1. Fractional Crystallization/Magmatic Differentiation : heavy minerals that crystallize early settle and concentrate on the bottom of the magma chamber
 2. Immiscibility : segregation of metal-rich liquid from crystallizing magma
 3. Pegmatites : melt remaining in last stages of crystallization of granitic magma is rich in volatiles and rare elements

Deposits associated with Metamorphism

- Called skarns

Hydrothermal Ore Deposits

Associated with igneous activity

1. Veins : concentrated in areas of intense faulting (eg. calcite & quartz)
2. Disseminated : metals are distributed throughout the rock body, rather than concentrated in veins
3. VMS : lenses of sulfides that accumulate on seafloor from hydrothermal vents

One associated with sediments

1. Mississippi valley type deposits

2. Unconformity associated uranium

Sedimentary Ore Deposits

- Dissolved iron to accumulate in ocean basins, eventually photosynthesizing bacteria generated enough oxygen to precipitate iron oxide minerals

Sedimentary hosted deposits

- Placer deposits : formed when heavy metals are mechanically concentrated by currents in rivers

Deposits associated with Weathering

- Residual enrichment
- Laterite forms by deep weathering of parent rock and leaching out elements like silica
- Supergene enrichment occurs when soluble minerals are dissolved near the surface and reprecipitated at depth near water table
- Formed in acid climates

Non-Metallic Resources

Eg. diamond, quartz, sulfur

**** when rock breaks, the bigger rock is the parent rock ****

Fossil Fuels

1. Coals : decay and compression of land plants rich in resins, waxes and lignins, widespread distribution
2. Oil + Gas : formed from remains of marine plants and animals, rich in proteins, lipids and carbohydrates. Oil traps = anticlinal, stratigraphic, fault trap, salt dome trap
3. Tar + Oil Sands : viscous + immature oil that cannot be pumped, found in unconsolidated material, extraction can be polluting
4. Oil + Gas Shale : contains kerogen, exploitation energy intensive, impacts from fracking. Shale gas positives - less environmental impact, less water consumption, lower greenhouse gas emissions. Shale gas negatives - more environmental impact, domestic water contamination
5. Gas Hydrates : new resource, clathrate structure where methane is enclosed in a water molecule cage, potential source of clean energy

Impacts: large injection of methane into atmosphere, large amount of carbon released in shore, large amount of carbon released in short period of time

Exam 3 Review Material:

Definitions

- Flood stage
 - Refers to the height of a river above a locally defined elevation is the stage at

- which the river will overflow its banks
- Meandering Channel
 - Water course such as stream, river that meanders (bends, loops, turns) rather than going straight
 - Stream channel of lower/more regular discharge, lower slopes, cohesive banks, slower more regular channel migration and abundant fine sediment (**straight**)
 - Rapid and irregular discharge, higher slopes, erodible bank, rapid channel migration, abundant coarse sediment (**braided**)
- Lag Time
 - Time between when most of the rainfall occurs and a flood is produced
- Base level
 - Lowest levels to which a river can erode
- Drainage divide
 - Separates each drainage basin from other basins
- Stream discharge
 - Amount of water passing any point on a stream (volume/time)
- Karst
 - Landscape underlying with limestone that's been eroded by many factors (ie. dissolution, producing ridges, fissures, sinkholes)
- Runoff
 - Controlled by soil type, thickness, original water content and precipitation
 - Water that flows over land instead of being absorbed into groundwater and evaporating
- Unconformity
 - A gap or break in rock record produced by erosion and/or non-deposition of rock units
 - a) Angular - tilted/folded rocks overlaid by flat lying rocks
 - b) Disconformity - strata on either side of unconformity are parallel but ages differ
 - c) Nonconformity - metamorphic or igneous rock in contact with sedimentary strata
- Floodplain
 - Flat area in valley level with top of channel. Portion of the valley that can be flooded
- Valley
 - Sloping area around a stream
- Channel
 - Bottom of valley, where water flows

- Residence Time
 - volume/flux per time
- Base level
 - Movement of water between the ocean (hydrosphere), air (atmosphere), and land (lithosphere)
- 100 year flood
 - A flood event that has a 1% probability of occurring in any given year, calculated by $P_e = m/n+1$ inverse
- Levee
 - Increases cross-sectional area. Is an Earth embankment constructed parallel to a river
- Subsidence
 - Ground surface gently sags or catastrophically drops as voids in rocks close
- Isotope
 - New form of an element; same number protons, different number neutrons through emission of subatomic particles, helps in numerical dating
- Quick Clay
 - Most mobile of all deposits. Fine rock flour scoured by glaciers, deposited in seas + later exposed above water
- Principles of Cross-Cutting Relationships
 - Intrusive (igneous) formation, must be younger than the rock it cuts across
- Principle of Superposition
 - Most sediments settle from water/wind
 - Young rock material (sediment) is deposited on top of older, earlier deposits
- Principle of Horizontality
 - Layers of sediment and lava generally deposited in a horizontal position
- Principle of Fossil Succession
 - Fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content
 - Short lived widespread organisms = index fossils
- Principle of Uniformitarianism
 - Present is key to the past
 - Same processes act throughout time but possibly at different rates
- Principles of Radioactive Dating ASSUMPTIONS

- Rates of decay have been measured and do not vary through time
- Assumed closed system (initial material has only parent material, no loss of daughter after mineral forms)
- Radiometric clock in minerals starts when daughter product begins to be trapped (usually controlled thermally)

Define the 5 Factors of Slope Failures

1. Slope angle/slope support
 - Increased by downcutting of landscape by rivers or waves
2. Slope composition
 - Weathered fractured rock, high clay concentration, or unconsolidated materials unstable
3. Vegetation
 - Presence of vegetation anchors unconsolidated material
4. Weight
 - Water overlying sediment
5. Water
 - Little amounts holds unconsolidated material together
 - Large amounts and reduces friction between grains and acts by buoying up weight of slope material

Difference between creep + solifluction

Solifluction - permafrost regions of steep slopes, sun thaws top layer of soil and it flows slowly over frozen subsoil

Creep - slowest, most widespread form of slope failure that is almost imperceptible downhill movement of soil and uppermost bedrock layers and swelling and shrinking of soil in response to freezing and expanding, absorption, heating of water. The soil expands perpendicular to ground surface, shrinks downward response to gravity

Difference between rock flow and rock slide and rock fall

Rock slide - the rocks slide down a slope (large rocks in water)

Rock fall - the rock free-fall from a mountain

Rock flow - water, sediments and parts of rock flow down mountain

Define 4 types of subsidence

1. Rock dissolution : caves occur in limestone
2. Mine Collapse : coal, salt, metallic ore. Can create voids that collapse and cause earth's surface to subside
3. Fluid withdrawal : water removed, loose sand attains tighter packing due to weight of overburden
4. Sediment compaction : delta = loose pile of water, saturated sand + mud at the end of river and starts to compact and sink

Benefits of Flooding

- Flood storage and erosion control
- Water quality + maintenance

- Groundwater recharge
- Biological productivity
- Habitat for fish and wildlife
- Recreational activities (economical base)

Lecture 11

Relative Dating

- Compares 2 or more entities to determine which is older

Numerical Dating (AKA absolute age)

- Specifying the actual # of years that have passed since an event

Correlation

- Matching of rocks of similar ages in different regions
 - a) Lithostratigraphic - matching continuous rock sequences
 - b) Chronostratigraphic - matching rocks of same age (fossils using biostratigraphy)

Conformable Sequences

- Layers of rock deposited without interruption

**** numerical dating relies on radioactive isotope decay****

Radioactivity

- Spontaneous decay in atomic nuclei

Isotopes

- a) Parent - unstable radioactive isotope
- b) Daughter - isotope resulting from decay of a parent
- c) Half-life - defined by decay constant for each isotope

Types of Decay

- a) Alpha emission - nucleus decays alpha particle, mass number reduced by 4, atomic number reduced by 2
- b) Beta emission - originate from breakdown of neutron in nucleus, increases protons and atomic number
- c) Electron capture - nucleus steals electron from atoms orbit cloud, creates neutron, decreases atomic number

Radiogenic Dating

- Percentage of radioactive atoms that decay during are half-life is always the same, but number of atoms decaying decreases

Eon - greatest expanse of time

Era - subdivision of Eon

Period - subdivision of Era

Epoch - subdivision of Period

Mitigation of Mass Movements

- a) Rotational + Translational landslides - unloading head, reinforcing body and supporting toe. Holding rocks in place with wire mesh nets to catch fallen rocks
- b) Flows of Earth or Snow - steering flow by building walls + digging channels, removing rock and decreasing slope angle
- c) Rock Falls - avalanche tunnels or fences
- d) Avalanches - boom

Hydrologic Cycle

- Movements of water between oceans, air and land

Evaporation → Precipitation → infiltration (controlled by soil type) →
evapotranspiration → runoff (controlled by soil type)

Aquifer - geologic unit stores and transmits water. Controlled by porosity

- a) Unconfined : has ground surface as an upper bound bound that interacts with surface water and streams
- b) Confined : has confining unit of low conductivity as upper and lower bound

****anything that cools slower gives air bubbles time to escape and therefore is less porous, Anything that cools quickly will trap air bubbles and therefore be more porous****

Water table - zone between saturated and unsaturated soil

Stream Systems

- Stream
 - Body of water that carries rock and dissolved ions flowing downslope along a defined path (channel)
 - Major source of water and transportation

Geometry + Dynamics of Stream Channels

- Factors
 1. Cross-sectional shape : varies with position in the stream and discharge
 2. Long profile of channel : a plot of elevation vs distance
 3. Velocity of water : dependent on position, irregularities of steam channel and gradient
 4. Discharge of stream : water passing at any given time
 5. Load of stream - rock particles + dissolved ions carried by it
 - a) Suspended
 - b) Bed
 - c) Dissolved

Triggers of Mass Movements

- Slope losing strength through events and near failures
- Underlying causes push slope to brink of failure
- Heavy rain, earthquakes, volcanoes thawing of frozen ground humans

Internal Causes of Slope Failure

- a) Ancient slip surfaces : sliding creates a smooth, slick layer of ground-up materials that can easily slide over and over again, especially where wet
- b) Exposed bedding : layers at flatter angle than hillside = bedding allows slippage
Layers at steeper angle = difficult to slip
- c) Structures within rocks : not cemented together, clay layers, fractures
- d) Exfoliation: Decreases in composition/cohesion, Rocks buried compress into smaller volumes, Rocks uplifted to surface expand in volume, fracture and increase porosity reduces strength of rock, increases opening for water to weaken rock
- e) Water : weakens earth materials by its weight filling pore spaces of sedimentary rock

Classification of Mass Movements

- Creep
- Solifluction
- Earthflow : rock layers tilt seaward, contain clay, and ocean waves erode toe and keep ancient earthflow moving
- Slides: movement of block above failure surface
 - a) Rotational slides : move downward and outward above curved slip surface
 - b) Translational slides : move on planar slip surface, move on downward inclined surface
- Long runout debris flows (sturzstroms) : massive rock falls that convert into fluid rapid debris this travels far, movement of highly fluidized rock flows
- Avalanches
 - a) Snow : behave like earth mass movements but made of snow
 - b) Loose powder : low cohesion with 95% volume as pore space
 - c) Slab : slabs of snow that break free from the base, turning to flows on the way back

Graded Streams

- Equilibrium state when channel geometry and hydraulic parameters enable the stream to transport its load with neither deposition nor erosion

Channel Patterns

- Each stream drains a certain area called a drainage basin

Drainage patterns

- a) Dendritic
- b) Radial
- c) Rectangular
- d) Trellis

Stream Deposits

- Sudden decreases in velocity can result in sediment deposition by streams

- a) Floodplain
- b) Levee
- c) Delta - stream enters standing body of water
- d) Terrace
- e) Alluvial fan - steep mountain stream enters flat valley

Floods Occur:

- When discharge of stream becomes too high, the stream widens its channel by overtapping its banks and flooding low-lying areas surrounding the stream (floodplains)
- a) Precipitation
- b) Coastal flooding
- c) Dam and levee failures

Hazards of Floods

Primary

- a) High water velocity
 - Transport larger rocks, autos, houses, bridges
 - Carry away humans and animals
 - More erosion
 - Water damage, loss of crops
 - Concentrates garbage, debris and pollutants

Secondary

- a) Disruption of services
- b) Water and sanitation
- c) Gas and electrical
- d) Public transportation

Tertiary

- a) River relocation
- b) Destruction of habitats
- c) Erosion or deposition of sediment for farmland
- d) Job loss from disruption of services
- e) Insurance rates increase

Flood Predicting

- a) Statistics - determine probability and frequency of increased discharges
- b) Mapping + Modelling of Landscape - determine extent of future floods from past ones
- c) Monitor rainfall and snowmelt (short term)

Flood Prevention

- a) Channelization : increases cross sectional area, straightens channels

- b) Levees, dikes, flood walls : increases cross sectional area
- c) Dams : increases cross sectional area
- d) Retention ponds + Floodways : increases cross sectional area

Urbanization and flooding

- Storm sewers
- Pavement (reduces infiltration and increases discharge)

Regulatory Approach

- Zoning
- Building codes
- Mortgage limitation
- Flood buyout program

Groundwater Lecture

What Percentage of Earth's inventory of liquid freshwater is made up by groundwater?

97%

Geotechnical issues in hydrogeology represent:

Stability of dams

** groundwater classically includes free water below the water table but a broader definition includes water in unsaturated soils **

Aquitards and Aquicludes are increasingly relied upon as barriers to protect groundwater and surface water resources from which of the following

Shale fracking, sanitary landfill leachates, buried nuclear waste in geological repository

Where would you drill a well for groundwater resources, in a clay-rich formation with 45% porosity or in a fractured granite with only 2% porosity?

Fractured granite because it has less water in storage, but high permeability in the fractures and so makes a better aquifer.

** a pressure surface or "potential" surface for a confined aquifer is the equivalent of a water table in an unconfined aquifer **

What is the Darcy Flux, q , for groundwater in an aquifer and what is the equation?

Darcy flux is the discharge, Q , in m^3/s , normalized to a cross sectional area, m^2

Equation: $q=K \times dh/dl$ where K is the hydraulic conductivity (m/s) and dh/dl is the hydraulic gradient

What are some major sources of nitrate contamination in groundwater?

Septic fields, agriculture, blasting residues from mining, landfill leachate leakage

Surface feature found where the water table intersects the land surface?

A spring or seepage face

What type of rock is karst typically found in?

Limestone

What type of rock commonly has sinkholes?

Limestone with karst

The gradient term in Darcy's equation for groundwater flow is determined by:

Different in hydraulic head, over some distance along groundwater flow

What are a few of the major cations and anions (minerals) in groundwater?

Ca, Mg, Na, K, HCO₃, SO₄, Cl

What are the three phases that comprise the unsaturated zone:

Mineral solids, liquid, water, and gas

** The water table is the surface where the water pressure is zero whereas water in the saturated capillary fringe has negative water pressure **

A flowing artesian well is:

A well completed in a confined aquifer where the potential surface is above the ground surface.

** groundwater can not flow only from high elevation to low elevation **

** groundwater can only flow through connected porosity in an aquifer **

** groundwater flow velocities of tens of meters per year are NOT unheard of **

** connected porosity is a feature of sand and gravel aquifers and of fractured rock aquifers **

An aquifer with hydraulic gradient of 10^{-2} and a hydraulic conductivity, $K=10^{-4}$ m/s will have a specific discharge, q , of:

10^{-6} m/s

** used darcy's flux ($q=K \times dh/dl$) for this **

Populations reliant on groundwater for domestic use:

25-40% in Canada , 70% of that is in the maritimes

Groundwater resources

- Drinking water
- Irrigation
- Industry

Groundwater contamination

- Agriculture
- Waste water
- Industrial spills
- Energy development
- Fuels and solvents
- Bacteria and viruses
- Nutrients (ie. nitrogen)

Groundwater geotechnical

- Dams and reservoirs
- Building foundations
- Landslides and mudflows

Groundwater?

- Subsurface water found in pores and fractures in geological media
- classically it is defined as water below the water table
- Broader definition: water in unsaturated soils and sediments
- Moves from a driving force or gradient, the flow is proportional to the force or gradient.
The movement is also proportional to the permeability of the aquifer

Found in:

1. Aquifer : a saturated geologic unit that readily transmits significant amounts of water (GW flows through these)
2. Aquitard : a saturated geologic unit that poorly transmits water in low quantities that are insufficient for a well. These are a barrier to contaminants of GW
3. Aquiclude : a saturated geologic unit incapable of transmitting significant amounts of water

Porosity and Permeability in order :

Clay is most porous, then sand, then fractured granite, then unfractured granite.

Sand is most permeable, then fractured granite, then clay, then unfractured granite

Rock Aquifers

- Made of basalt from cooled pahoehoe and Aa lava
- Limestone karst feeds salmon streams
- Sandstone becomes stained by GW flow and mineral oxidation
- Fractured granite has fractures where GW discharge sustains vegetation

Features of Karst

- Sinkholes
- Cenotes

Distribution of GW

1. Unsaturated zone : voids filled by water and air through infiltration and percolation. The water is under suction from capillary forces, and it cannot be pumped by wells
2. Zone of saturation : all voids in soil, sediment and rock are only filled with water, water is

- under positive pressure and can be extracted by wells
3. Water table : upper limit of the zone of saturation, surface of the water level in the ground

Unconfined (Phreatic) Aquifer

- Connected to atmosphere
- Unsaturated zone : Water table defines the groundwater pressure
- Saturated zone: Direct recharge occurs along its length

Confined (Artesian) Aquifer

- Bound above by a low-permeability formation (aquitard)
- Fully saturated with no unsaturated zone
- Potential surface defines the GW pressure

Springs

- Where the aquifer outcrops or intersects with the land surface

Qanats

- Ancient water resource technology to tap the water table

Darcy's Law

- Determines groundwater flow DISCHARGE
- $Q = -K (dh/dl)A \text{ m}^3/\text{s}$
- Can allow groundwater flow uphill or downhill

Darcy Flux

- Groundwater flow flux

$$Q/A = q = -K (dh/dl) \text{ m/s}$$

- Linear velocity for groundwater flow

$$V = q/n = -K/n (dh/dl) \text{ m/s}$$

Groundwater Movement

1. Gaining streams : gain water from the inflow of groundwater through the streambed
2. Losing streams : lose water to the groundwater system by outflow through the streambed

Overpumping of Groundwater

- This can cause neighbouring wells to dry up
 1. Drawdown - lowering of water table
 2. Cone of depression in the water table

Coastal Plain Groundwaters

- Exploited groundwaters for irrigation of wheat and other crops

Geothermal GW

- Recharged at high elevation by meteoric waters, seen by isotopes
- Circulation is driven by topography, providing a gradient.

Geothermal Energy

- Wells completed deep in geothermal reservoirs allow the superheated GW to flash to steam and produce energy (can drive turbines etc)

Glaciers Lecture

Name 2 largest continental ice sheets on Earth and two ice caps in the Canadian Arctic

1. Greenland Ice sheet
2. East Antarctic Ice Sheet
 - Barnes, Penny, Devon, Agassiz

Largest Pleistocene ice sheet in North America

- Laurentide Ice Sheet

Continental ice sheet move by:

- Strain in response to the downward stress of its own weight

** Ice streams act to coalesce ice flow along narrow channels to the coast **

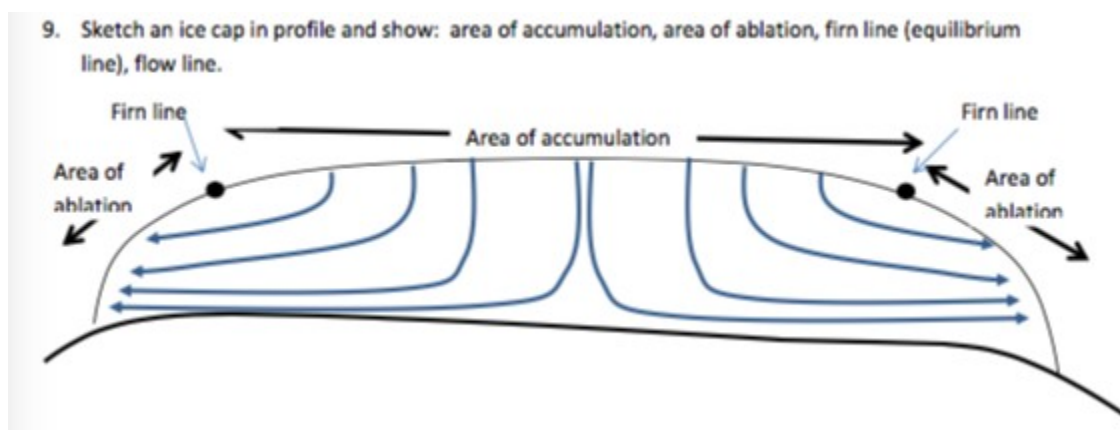
** Ice patches are ice accumulations that never gained enough mass to flow like a glacier **

** ice in North polar region is sea ice **

Ice Shelf

- Is floating glacier ice
- Is fed by ice streams
- Is a rapid mechanism for glacier ablation
- Is grounded on the continental margin at some depth below sea level

** The Greenland ice sheet has most of its surface area situated above the equilibrium line **



Two major types of Glacier ablation?

- Melting and calving

Two dominant parameters that control glacier ice flow by stress and strain are:

- Slope of the upper surface
- Thickness

** ice shelf instability caused by sea level rise leads to accelerated flow of ice, more ice loss, greater sea level rise and inland migration of the grounding line. This results in positive feedback that can result in rapid collapse of ice sheets. **

Glacier Erosion types

- Abrasion
- Quarrying
- Polishing

Main Sediments in the following deposits, good aquifer or aquitard?

1. Esker : sand and gravel = aquifer
2. Marine mud : clay and silt = aquitard
3. Till : clay, silt, sand, gravel = aquitard
4. Glacial outwash : sand and gravel = aquifer

** Moraine glacial sedimentary feature best delineates the maximum extent of an ice sheet margin **

** Pleistocene is characterized by at least 10 distinct glaciations **

Laurentide Ice Sheet

- Reached thickness greater than 3km
- Had 2 spreading centers (Keewatin and Northern Quebec)
- Eroded the great lakes basin
- Built up terminal moraines in the northeastern states

Types of Glaciers

1. Ice sheets - have continental scale (eg. greenland, antarctic)
2. Ice caps - small ice sheet (eg. baffin island, penny, barnes ice cap)
3. Mountain glaciers - coalesced sheet of alpine glaciers
4. Valley - over 100km long in alaska. Discharge of ice from ice sheets, ice caps and mountain glaciers into low elevation creates them
5. Alpine - high alpine in cirques

Antarctic's Ice Sheets

- Covered around 98% of the continent
- Largest single ice mass on Earth
- East ice sheet rest on major land mass

- West ice sheet is partially below sea level

Greenland Ice Sheet

- Around 80% of the surface of Greenland
- It's ablation is by surface melting and runoff

Snow - Firn - Ice Transition

- **Recrystallization** of snow by ice vapour
- **Firn** (last years snow) survives a melt season
- **Occlusion** of porosity to non-connected air bubbles
- **Metamorphism** - flow of ice deforms bedding, adds textures

Glacier Budget

Accumulation - Ablation = Budget

Steady state means budget = 0

Calving

- Loss of ice directly into seawater (forming icebergs)

Glacier Movement

- stress/strain (Glen Flow Law - velocity = original volume - new volume / original volume)
- Basal creep
- Basal sliding (needs a wet base)
- Surging
- Streaming

** glacial outwash = sorted deposits from glacier

** glacial till = unsorted deposits from glacier

Marine Mud, quick clays

- Clay size sediments
- Leda sensitive clay
- Marine

Esker

- Subglacial river bed
- Sinusoidal over short distances, but have lengths of many km's to track direction of retreat
- Are a product of meltwater drainage plumbing at the ablating margin of the ice sheet

Economic value of glacial sediments:

- Aggregate industry for roads and concrete
- Champlain sea sediments are rich in soils for crops

Glaciers through geological time

1. Snowball earth - glaciers grew on land and sea. Terminated by influx of nutrients and life forms
2. Ediacaran period - multicellular animals

** ice cores - paleotemperature and paleo-air bubbles **

Key Words and what they mean/are

1. Ablation - process that removes snow, ice or water from glacier
2. Abrasion - the mechanical scraping of a rock surface by friction between rocks and moving particles during their transport by wind, glacier, waves, gravity, running water or erosion
3. Aggregate - sand, gravel or crushed rock that has been mined for use as a building material in the construction industry
4. Cirque - an amphitheatre-like valley formed by glacial erosion.
5. Drumlin - elongated hill believed to have been formed by the streamlined movement of glacial ice sheets across rock debris, or till
6. Moraine - accumulation of rock debris (till) carried or deposited by a glacier.
7. Firn Line - the minimum elevation of firn lying on a glacier surface
8. Pleistocene - aka the ice age
9. Occlusion - linear furrows generated from fault movement
10. Furrow - long narrow trench made in the ground

Oceans, Earth System and Climate Lecture

What Geological periods experienced a major glacial period?

- Neoproterozoic
- End of ordovician
- End of permian
- Jurassic / cretaceous transition
- Quaternary

Ediacaran Period

- A time where an expansion of animal life living off chemicals in the ocean occurred

the effect of volcanism on climate is cooling due to increased reflection of incoming solar radiation by aerosols

Tertiary Climatic Decline

- Preceded the pleistocene glacial period

High energy cosmic radiation causes ionization of gases in the atmosphere which creates cloud forming nuclei that condense water vapour to form clouds. This process:

- Leads to climate cooling
- Can be attenuated by increased solar activity, leading to climate warming
- Seems to affect modern climate as well as climate over geological time

Milankovitch identified three processes in Earth's rotation and orbit that he determined follow regular cycles. These change in the distribution of solar insolation through the seasons and over high latitudes. Describe each of these processes:

1. Eccentricity - earth's orbit evolves from a near circle to an ellipse with a period of 96ka and 400 ka
2. Obliquity - earth's axis of rotation is on an angle with respect to our orbital plane, which gives rise to the 4 seasons. This angle changes between 22 degrees and 24.5 degrees every 41ka.
3. Precession - the axis of rotation is wobbling, with a full rotation about every 20ka. This changes the point on the elliptical orbit when the seasons occur, such that summer can occur in the northern hemisphere when the Earth is at its closest point to the sun in its annual orbit or it can occur when the earth is at its furthest point in the annual orbit.

Incoming Shortwave Solar Radiation at the top of the atmosphere is:

- 48% absorbed by land and oceans
- 23% absorbed in the atmosphere
- 29% reflected by cloud and ice
- 70% converted to heat by the planet

Principle Greenhouse Gas

- Water vapour

Periods of Climate Warming and cooling during Holocene

1. Little ice age - between 1400 and 1800 AD
2. Medieval warm period around 1000 AD
3. The early holocene optimum between 8ka and 6ka
4. The roman climate optimum about 2000 years ago
5. The mid holocene climate optimum from about 5ka and 4ka

Wavelength bands

1. Shortwave (visible) electromagnetic radiation - 400 to 800 nm
2. Longwave (infrared) electromagnetic radiation - 1 to 100 micrometers
3. Radiation from earth - 10 um (5-20)
4. Principle absorption spectrum for water vapour - 5 to 8 um and greater than 15 um
5. Principle absorption spectrum for CO₂ - 15 to 18 um

** oceans attenuate incoming shortwave radiation by absorption in the photic zone to a depth of about 100-200 micrometres **

El Nino Event

- Warm waters in the western equatorial pacific migrate eastward and pool off shore of the western South American coastline when upwelling of deep ocean currents in the eastern Pacific shut down. This is related to the position of the thermocline which normally rises to the surface in the eastern Pacific during venting, but is deeper during an El Nino event that shuts off venting, allowing the warm waters to migrate east.

Modern Sea Level Rise is:

About $\frac{2}{3}$ added water and $\frac{1}{3}$ thermal expansion of oceans. And about 3.3 mm per year.

Climate Through Geological Time

- Shows many periods of glaciation
- Last glacial maximum was the peak of glaciation during the pleistocene ice age
- Lack of glaciation in southern hemisphere except for antarctica. This is because of the increased heat near the equator

Climate and Earth's radiative budget

- This is complicated and represents how the Earth cools as radiating black body simplifies critical components which affects surface temperature (ie. oceans cooled by evaporation whose latent heat is carried to the troposphere by rising warm air, it cools as it rises and condenses in the upper troposphere and then radiated back to space)

Oceans and Heat Transport

1. Continental shelves
2. Abyssal plains
3. Spreading ridges
4. Sea mounts and ridges

**photic / epipelagic zone - limit of photosynthesis, light penetration variable and limited by organic in water column

**mesopelagic zone - no primary production, life supported by rain of organic debris from the photic zone

Thermohaline Circulation

- Temperature of surface waters increases surface evaporation, which increases density and decreases temperature.
- Evaporation increases salinity, which affects seawater density
- Deep ocean water : formed by higher altitudes and increased density
- This deep water returns from upwelling currents to coastal areas to complete the circulation

** solar activity is a short term climate change - shown by Bond cycles/events **

**heliomagentosphere and geomagnetosphere attenuate the galactic cosmic ray flux **

