EESA06 Textbook Notes

Chapter 1: Introduction to Physical Geology and the Environment
What is Geology?
Geology – the study of earth
Moving Continents
1.1 William Smith – Father of English Geology, first to publish a geological map
1.2 William Logan – first to systematically describe the geology of Canada (Candian)
- Cross-section – a hypothetical vertical slice thru the land

1.3 Alfred Wegener – theory of continental drift in 1912 "The Origin of Continents and Oceans"
- Pangea – continents has previously been clustered together in a large land mass

1.4 J. Tuzo Wilson – plate tectonics theory in the early 1970s (Canadian)
- Transform faults – large-scale faults that offset the crust laterally but neither created nor destroyed material, now recognized as a major plate boundary type
- Hot spots – active volcanoes, young volcanic islands stuck in the middle of the oceans
- Volcanic islands chains (ex: Hawaiian Islands) resulted from a moving plate drifting over a stationary magma plume in the mantle – support for plate tectonic theory

Time and Geology
Deep time – vastly greater amounts of time (more than hours, years)
Mid-ocean ridge – a giant mountain range that lies under the ocean
Earth is estimated to be at least 4.55 Ga years old

What do Geoscientists Do?
1.5 Exploration Geologists – looking for gold, diamonds and other metals
Geoscientists – expand the scope and responsibilities of modern geologist into additional scientific fields
- Geochemists – working in a ordered environment of the laboratory and use high-technology equipment to analyze the chemistry of rocks or minerals
- Mineralogists – study minerals

1.6 Petrologists – study the makeup of rocks and how they form
- Geophysicists – using high-tech equipment in the field, using boats, planes, or satellites to learn more of the nature of the physical conditions on or under the Earth's surface
- Petroleum/coal geologists – search for oil and gas and coal
- Seismologists – study how to measure and mitigate earthquake activity
- Paleontologist – studies the fossilized remains of ancient organisms
- Glacial Geologists – study landforms and sediments left behind by ice sheets (glaciers)
- Hydro-geologists – study and protect sediments that contain and transmit water

1.7 Environmental Geoscientists – finding and managing drinking water, dealing with a wide range of wastes ranging from radioactive waste to household (municipal) waste
1.8 Engineering Geologists – work with the challenges of engineering structures that form part of the human landscape, landscape stability problems.
1.9 Geomatician – collect, organize, analyze and create images from any spatial and geographical data available in digital form

What is the Scientific Method?
Scientific Method – the process by which scientists first identify a problem, then they select a methodology to collect data in order to help solve the problem, then they analyze and interpret the information, and come up with a hypothesis, after several test, form a theory
Hypothesis – a theoretical explanation where the geologist

How did the Earth form?
- Nebula – a cloud of gas and dust particles
- Bulbous core & flattened disc – created by gas and dust rotate and contract
- Sun created from a nuclear fusion
- Planets - dust in the outer disc condensed to form rocks and metals that combined to form large rounded planets and
- Planetismals – much smaller, irregularly shaped planets
- Accretion – the process of building large bodies of matter thru collisions and gravitational attraction
- Terrestrial planets (ex: Mercury, Venus, Earth, Mars) – form close to the sun, small, dense, rocky
- Jovian planets (ex: Jupiter, Saturn, Uranus and Neptune – low density, large, further from sun

What was the early earth like?
Differentiation – process of zonation of different materials within a planet
- Heavier metals (iron and nickel) settle towards the center, lighter metals (silica and oxygen) rise towards Earth's surface

1.10 Meteorites – small solid particles of rock, metal, and or ice/orbiting the Sun
1) iron (rare but look unique easily found) – iron mixed with small amount of nickel
2) stony-iron – iron-nickel alloy and silicate minerals in about equal parts
3) stony meteorites (most common, look like earth's rocks) – silicate minerals (plagioclase, olivine, pyroxene) and may contain small amount of iron-nickel alloy

90% are Chondrites – contain round silicate grains aka chondrules
10% are Achondrites – lack chondrules
Carbonaceous chondrites – composed mostly of serpentine or pyroxene and contain up to 5% organic materials, believed to have same composition as the original material from which the solar system was formed
Achondrites – similar to terrestrial rocks in composition (basalt) and texture (igneous rocks)

Internal Structure of the earth
- Core – composed of iron alloy (iron + nickel +silicon)
- Mantle – composed of Fe-Mg silicates (form a rock called **peridotite)**
- Outer crust – composed of lighter rocks such as basalt and granite

Basalt – a fine-grained, mafic, igneous rock composed predominantly of ferromagnesian minerals and with lesser amounts of calcium rich plagioclase feldspar
- Lithosphere plates – large pieces of crust and uppermost rigid mantle broken from mantle convection
- Asthenosphere – the weak layer, more mobile

Formation of the Early Atmosphere
- Outgassing – water and gaseous elements released during volcanic eruptions

Early Life Forms
- Prokaryotes –microorganisms, earliest life forms preserved in the geological record
- Stromatolites – organic structures grown by prokaryotes by trapping sediments

What is the "Earth System"?
Earth System – a small part of the larger solar system but also has its own component parts or subsystems (aka spheres) - include atmosphere (gases), hydrosphere (water) , biosphere(living) and geosphere (rock or other inorganic Earth materials)
- External energy source – sun, drives atmosphere and hydrosphere

- Internal energy source – geothermal heat, radioactive decay of minerals with Earth, drives plate movement, volcanic eruptions, and earthquakes

Rock cycle – conceptual model that links rock-forming process that operate in Earth's crust

- Magma – molten rock
- Igneous – when magma solidifies
- Sedimentary – unconsolidated sediment becomes lithified (cemented/consolidated into rock)
- Metamorphic - subjected to heat and pressure, if high enough temperature rock melts to become magma completing the cycle

Chapter 2: Plate Tectonics

What is Plate Tectonics?

- Plate Tectonics – Earth's surface is divided into a few large, thick plates that move slowly and change in size
- Continental Drift – continents move freely over the Earth's surface, changing positions relative to one another
- Sea-floor spreading – hypothesis that the sea floor forms at the crest of mid-oceanic ridges, then moves horizontally away from the ridge crest toward and oceanic trench, two sides of the ridge are moving in opposite directions like slow conveyer belts

How did the plate tectonics theory Evolve?

The Early Case for Continental Drift:

- Paleoclimatology – the study of ancient climates

Wegener studied climates, rocks and fossil, magnetic poles – supported the continental drift

Renewed Interest in Continental Drift

Study of the Sea Floor

- Multibeam sonar – measures water depth and draws profiles of submarine topography
- Sidescan sonar – measures the intensity of sound reflected from the ocean floor and provides detailed images and information about sediments and bedforms on the sea floor
- sub-bottom profilers - examine the strata (layers) beneath the floor of the lake/ocean
- seismic reflection profiler – louder noise, lower frequency, reflects from layers within sediment and rock, records water depth and reveals internal structure of sea floor (Ex: faults, folds)
- Rock dredge – an open steel container dragged over the ocean bottom
- Rock corer – steel pipe dropped vertically into mud and sand of ocean floor
- Sea-floor drilling – drilling derrick
- Submersibles – small research submarines, observe, photograph and sample rock and sediment

Geophysical Research

- Polar wandering – an apparent movement of the Earth's plates

Recent Evidence for Continental Drift

- Rocks in Brazil and African country Gabon are very similar
- GPS allows us to watch continents move in real time

2.1 Measuring Plate Movement in Real Time

- Space geodesy – a space-based technique for taking very precise measurements of points on the earth's surface (ex: very-long-baseline interferometry (VLBI), satellite laser ranging (SLR), GPS)
- GPS is the most useful technique for studying earth's movements

What is Sea-Floor Spreading?

Wegener – thought ocean floors remained stationary as continents moved

Harry Hess 1962 at Princeton – suggest that sea floor might be moving too
- Spreading axis (spreading center) – the ridge crest (MOR) with the sea floor moving away from it on either side
- Subduction – the sliding of the sea floor beneath a continent or island arc
- Convection – a very slow circulation of a substance driven by differences in temperature and density within that substance

How Old is the Sea Floor?
- Fairly young only 200 million years old

What are plates and how do they move?
- Plate – a large, mobile slab of rock making up part of the Earth's surface
- Lithosphere – the rigid outer shell of the Earth, 70 to 125 more kilometers thick, includes rocks of the crust and the uppermost mantle
- Asthenosphere – a region of the Earth's outer shell beneath the lithosphere, is of indeterminate thickness and behaves plastically
- Divergent plate boundary – boundary separating two plates moving away from each other
- Convergent boundary – a boundary between two plates that are moving toward each other
- Transform plate boundary – boundary between two plates that are sliding past each other

How do we know that plates move?

Paleomagnetic Evidence
- Magnetic reversals – a change in the Earth's magnetic field between normal polarity and reversed polarity.
- Normal polarity – compass points north, enters earth
- Reversed polarity – periods when the lines of magnetic force run from the south pole to the north pole and compass needles point to the south, leaves earth
- Paleomagnetism – a study of ancient magnetic fields
- Magnetic polarity time scale – records the pattern of magnetic reversals over time
- Anomaly – a deviation from average readings of magnetic strength
- Magnetometer – an instrument that measures the strength of the Earth's magnetic field

Marine Magnet Anomalies

The Morley-Vine-Matthews Hypothesis – pattern of magnetic anomalies on one side of the MOR was mirror image on the other side, magnetized dikes form parallel to rift valley = cause of anomalies
- Predicts age of sea floor

How fast do plates move?

Predicting Sea-Floor Age
- Similar to dating tree rings

Another Test: Fracture Zones and Transform Faults
- Transform fault (Tuzo Wilson) – the portion of a fracture zone between two offset portions of ridge crest (earthquakes occur at points where movement is opposite directions)

What Happens at Plate Boundaries

Divergent Plate Boundaries – to create or open new ocean basins
- Graben – a down-dropped fault block
- Ex: Red Sea – divergent margin - rifting before uplift, crust is thinned, fault break crust, shallow earthquakes, and basalt eruptions, high heat flow
- Passive continental margin - transition between oceanic and continental crust, a thick sequence of marine sediment blankets the thinned continental rock

Mid-Ocean Ridges – a giant mountain range that lies under the ocean and extends around the world
- Rift valley – a tensional valley bounded by normal faults, are found at diverging plate boundaries on continents and along the crest of the mid-oceanic ridges

Geologic Activity on Ridges
- Shallow-focus earthquakes – from 0-20km below the sea floor
- High heat flow – heat loss at the ridge crest is a lot higher
- Basalt eruptions – occur in and near the rift valley on ridge crests (ex: Iceland)
- FAMOUS ALVIN – French-American Mid-ocean Undersea Study – 40 submersible dives
- Black smokers – chimney-like mounds around the hot spring

Biological Activity on Ridges
- Presence of exotic, bottom dwelling organisms
- Thermophyllic – heat, sulphur loving bacteria
- Geomicrobiology – bacteria's role in the precipitation of minerals

Ridges and Ore Deposits

Transform Boundaries – where one plate slide horizontally past another plate
- Marked by shallow-focus earthquakes

Convergent Plate Boundaries

Ocean-Ocean Convergence – two plates capped by sea floor converge, one plate subduct under another
- Oceanic trench – a narrow, deep trough parallel to the edge of a continent or an island arc
- Island arc – a curved line of islands
- Accretionary wedge (subduction complex) – inner wall of a trench toward the arc, thrust-faulted and folded marine sediment and pieces of oceanic crust
- Forearc basin (trench side) – between accretionary wedge and the volcanic arc
- Backarc region (other side of arc)

Ocean-Continent Convergence
- Active continential margin – when oceanic crust subduct under continental lithosphere
- Magmatic arc – a line of batholiths or volcanoes, generally the line is curved

Continent-Continent Convergence – close ocean basin
- Suture zone – collisional margins, where two continental plates join or subduction zones

2.2 British Columbia and the Juan de Fuca Plate/Cascadia Subduction Zone
- Subduction of Juan Plate beneath North America cause large and frequent earthquakes

Backarc Spreading
- Backarc oceanic crust if found in most ophiolites

2.3 Oceanic Crust and Ophiolites
- Gabbro - dark, coarse-grained, intrusive mafic igneous rocks chemically equivalent to basalt

Convergent Boundaries and Ore Deposits

How do mountain ranges form?

Orogenies and Plate Convergence
- Orogeny – mountain building, an episode of intense deformation of the rocks in a region, generally accompanied by metamorphism and plutonic activity

Ocean-Continent Convergence – (Ex: The Andes)
Arc-Continent Convergence – intervening ocean is destroyed by subduction, flipping subduction zone
Continent-Continent Convergence – (Ex: Appalachian Mountains)

2.4 Canadian Rocky Mountains – accretion of micro continents

2.5 Wilson Cycle (Tuzo Wilson) – continued opening and closing controlled by plate tectonics

What Causes Plate Motions?

1) Mid-ocean ridge crests are hot and elevated while trenches are cold and deep
2) Ridge crests have tensional cracks
3) The edges of some plates are subducting sea floor, while the edges of other plates are continents (which cannot subduct)

- Ridge-push and slab-pull (thought to cause rapid plate motion) and trench-suction

How are mantle plumes and hot spots related?

- Mantle plumes – narrow column of hot mantle rock that rises and spreads radially outward

Seamounts, Guyots, and Aseismic Ridges

- Seamounts – conical mountain rising 1,000 meters or more above sea floor, scattered along MOR, form islands
- Guyots – eroded flat-topped seamount found mostly in western Pacific Ocean
- Aseismic (locked) ridges – submarine ridge with which no earthquakes are associated

2.6 The Geological Significance of Aulacogens

- Aulacogens – failed rifts, host to petroleum (ex: St. Lawrence rift)

Why is it important to understand plate tectonics?

2.7 Plate Tectonics and Earthquake Risk in Southern Ontario

- Earthquakes focused around suture zones or terrane boundaries
- Plates move 2.7cm/year
- Central Meta-sedimentary Belt Boundary Zone (CMBBZ) – seismogenic structure Pickering nuclear plant is built on top of it

Chapter 3: Earthquakes

What Causes Earthquakes?

- Earthquake – a trembling or shaking of the ground caused by the sudden release of energy stored in the rocks beneath the surface
- Seimic Waves – a wave of energy produced by an earthquake
- Elastic rebound theory – the sudden release of progressively stored strain in rocks results in movement along a fault

3.1 Indonesia/Sumatra Earthquake and Tsunami, December 26, 2004 – largest earthquake 9.3

Why do Earthquakes cause so much damage?

- Focus – the point within the earth from which seismic waves originate in an earthquake
- Epicenter – the point on the earth's surface directly above the focus of an earthquake

Body waves – within earth

- P wave – a compressional wave (seismic wave) in which rocks vibrate parallel to the direction of the direction of wave propagation
- S wave – a seismic wave propagated by a shearing motion, which causes rock to vibrate perpendicular to the direction of wave propagation

Surface waves – a seismic wave that travels on the Earth's surface

- Love waves – a type of surface wave that causes the ground to move side to side in a horizontal plane perpendicular to the direction the wave is travelling
- Rayleigh waves – a type of surface wave that behaves like a rolling ocean wave and causes the ground to move in an elliptical path

How do we know where earthquakes occur?

- Seismograph – a seismometer recording device that produces a perm record of earth motion
- Seismogram – paper record of earth vibration

Determining the location of an earthquake

- Travel-time curve – a plot of seismic-wave arrival time against distance
- Depth of focus – distance between the focus and the epicenter of an earthquake

Shallow focus : 0-70km deep
Intermediate focus: 70-350km deep
Deep focus: 350-670km deep

Measuring the size of an earthquake

- Intensity – a measure of an earthquake's size by its effect on people and buildings
- Modified Mercalli scale – scale expressing intensities of earthquakes (judged on amount of damage done) in Roman numerals ranging from I to XII
- Magnitude – a measure of the energy released during an earthquake
- Richter scale – a numerical scale of earthquake magnitudes
- Moment magnitude – an earthquake magnitude calculated from the strength of the rock, surface area of the fault rupture and the amount of rock displacement along the fault

What kinds of damage can earthquakes cause?

- Ground motion – trembling and shaking of land can cause buildings to vibrate
- Fire – broken gas and water mains
- Landslides & Liquefaction
- Aftershock – small earthquakes that follow a main shock
- Permanent displacement of the land surface – scarp (low cliff, tear in ground)

Tsunami (seismic sea waves) – huge ocean wave produced by displacement of the seafloor
- most are associated with subduction zone earthquakes – which tend to be some of the strongest

3.2 Earthquakes in Canada Eh?

- most earthquakes occur in Cascadia subduction zone off western coast of BC, St Lawrence and Ottawa river valleys

3.3 Earthquake Engineering

- building on solid bedrock, using flexible wood, steel and reinforced concrete

Where do earthquakes occur on a global scale?

- Circum-Pacific Belt – major belt around the edge of the Pacific Ocean on which most composite volcanoes are located and where many earthquakes occur – ocean trenches,
- Mediterranean-Himalayan Belt – a major concentration of earthquakes and composite volcanoes that runs thru the Mediterranean Sea, crosses the Mideast and the Himalaya, and passes thru the East Indies
- Benioff zones – distinct earthquake zone that begins at an oceanic trench and slopes landward and downward into Earth at an angle of about 30-60 degrees
- Island arc – Benioff zones slope under curved line of islands
- Shallow focus – crest of MOR, near basaltic volcanoes

What is the relationships b/w earthquakes and plate tectonics?

Earthquakes at plate boundaries

Divergent boundaries (ex: African Rift Valleys) – shallow earthquakes
Transform boundaries (ex: San Andres Fault) – shallow earthquakes, strike-slip motion

Convergent Boundaries (ex: Himalayas)
- Collision quakes – two continents – shallow quakes (ex: Himalayas)
- Subduction quakes – ocean and continent – underthrusting

3.4 Waiting for the Bid One in British Columbia
- Crustal earthquakes – North American plate
- Intraplate earthquakes - Juan de Fuca plate
- Subduction earthquakes – plate boundary

Subduction Angle
- steeper when colder and denser oceanic plates subduct, shallow when younger and warmer oceanic plates subduct
- faster rate of convergence = shallower angle

Earthquakes away from plate boundaries
- intraplate – within plate quakes, areas of thinned or weakened crust

Can we predict when earthquakes will occur?
- properties of rock, water levels in wells, interval between eruptions of Old Faithful, surface of Earth tilts and changes in elevation, animal behavior, foreshocks,

3.5 What to do before, during, and after an earthquake

3.6 Waiting for the Big One in California – San Andres Fault

3.7 Measuring Ground Displacement Caused by Earthquakes – InSAR using electromagnetic radiation

Chapter 4: The Earth's Interior

4.1 Deep Drilling on Continents

4.2 Canadian Lithoprobe Project -"dancing elephants"

What can we learn from the study of seismic waves?
- Geophysics – the application of physical laws and principles to a study of the Earth
- Seismic reflection – the return of part of the energy of seismic waves to the Earth's surface after the waves bounce off a rock boundary
- Seismic refraction – the bending of seismic waves as they pass from one material to another

What is inside the earth?

Crust – the outer layer of rock, forming a thin skin over the Earth's surface
- Felsic – rocks high in feldspar and Silicon – continental crust
- Mafic – rocks high in magnesium and iron (ferric) – oceanic crust
- Mohorovicic discontinuity (Moho) – the boundary separating the crust from the mantle beneath

Mantle (670km) – a thick shell of rock that separates the Earth's crust above from the core below
- Upper mantle – diff from continental and oceanic crust, is most likely ultramafic rock (dense igneous rock, lack felderspar ex: periodite)
- Lithosphere – the strong and brittle outer shell of the Earth, 70 to 125 more kilometers thick
- Asthenosphere – a region of the Earth's outer shell beneath the lithosphere, is of indeterminate thickness and behaves plastically – low velocity zone

4.3 A CAT scan of the mantle – seismic tomography uses earthquake waves,

4.4 Diamonds – A window into the mantle – diamond bearing igneous rocks - kimberlite pipes
- Diamonds eventually breakdown to for graphite
- First diamond mine in North America = Ekati mine near Yellowknife in NWT

Core – the central zone of the Earth
- P-wave shadow zone – the region on the Earth's surface, 103-142 degrees away from an earthquake epicenter, in which P-waves from the earthquake are absent
- S-wave shadow zone – the region on the Earth's surface, any distance that is more than 103 degrees from the earthquake's epicenter, in which S-waves are absent

Composition of the core – core is made of metal not silicate, most likely iron (studying meteorites)
The Core-Mantle Boundary – ultra-low velocity zone (ULVZ) – P wave velocities dramatically decrease
- Convection – a circulation pattern in which low density materials rise and high density sinks

How does the elevation of continents change?
- Isostasy – the equilibrium between adjacent blocks of crust resting on a plastic mantle
- Isostatic adjustment – concept of vertical movement of sections of the Earth's crust to achieve equilibrium
- Crustal rebound – the rise of the Earth's crust after the removal of glacial ice

What can gravity tell us about the earth's crust?
- Gravity meter – an instrument that measures the gravitational attraction between the Earth and a mass within the instrument
- Positive gravity anomaly – greater than normal gravitational attraction, over an area underlain by denser rocks than those of the surrounding region (ex: a granite pluton)
- Negative gravity anomaly – less than normal gravitational attraction

How does the earth's magnetic field change through time?
- Magnetic field – region of magnetic force that surrounds the Earth
- Magnetic poles – an area where the strength of the magnetic fields is greatest and where the magnetic lines of force appear to leave or enter the earth

Magnetic Reversals
- Curie point (580 for magnetite) – the temperature below which a material becomes magnetized
- Paleomagnetism – a study of ancient magnetic fields

4.4 Earth's Spinning Inner Core

Magnetic Anomalies
- Magnetometer – an instrument that measures the strength of the Earth's magnetic field
- Positive magnetic anomaly – greater than average strength of the Earth's magnetic field
- Negative magnetic anomaly – less than average strength of the Earth's magnetic field

4.6 Magnetotellurics: New Tool for Investigating the Earth's Interior
- Magnetotellurics – a new geophysical approach being used in remote regions of the Canadian Arctic to investigate and map structures within the underlying crust and mantle

How hot is the earth's core? What is the origin of the earth's heat?
Geothermal Gradient – rate of temperature increase associated with increasing depth beneath the surface of the Earth (normally about 25oC/km)
Heat Flow – gradual loss of heat (per unit of surface area) from the Earth's interior out into space

Chapter 19: Time and geology

What is Uniformitarianism?

- Uniformitarianism – principle that geologic processes operating at the present are the same processes that operated in the past. “The present is the key to the past” (uniform rate)
- Actualism – physical laws are independent of time and location (same meaning as uniformitar..)

Geological Time Scale – a sort of calander to which events and rock units can be referred

- Earth was only 6,000 years old – biblical chronology, Noah’s flood
- features we observed in rocks and landscapes where supernaturally and catastrophically

James Hutton – “father of modern day geology”

Charles Lyell – *Principles of Geology* book

geological features could be explained by present-day processes

How can the Sequence of Past Geological events be determined?

Numerical Age (absolute age) – age given in years or some other unit of time

Relative Time – the *sequence* in which events took place (not measured in time units)

- ex: Grand Canyon can be analyzed in 4 parts:

horizontal layers of rock

inclined layers

rock underlying the inclined layers (plutonic + metamorphic rock)

the canyon itself, carved into these rocks

Principles Used to Determine Relative Age

- Contacts – boundary surface between two different rock types or ages of rocks
- Formations – bodies of rock of considerable thickness with recognizable characteristics that make each distinguishable from adjacent rock units, named after local towns or landmarks

Stratigraphy – subdiscipline of geology, that uses interrelationships between layered rock or sediment to interpret the history of an area or region uses 4 principles:

1) Original Horizontality – the disposition of most water-laid sediment in horizontal or near horizontal layers that are essentially parallel to the Earth’s surface
2) Superposition – a principle or law stating that within a sequence of undisturbed sedimentary rocks, the oldest layers are on the bottom and the youngest on the top
3) Lateral Continuity – principle that states that an original sedimentary layer extends laterally until it tapers or things at its edges
4) Cross-Cutting Relationships – a principle or law stating that a disrupted pattern is older than the cause of disruption

Other Time Relationships:

- Inclusion – fragments included in a host rock are older than the host rock

Unconformities - a surface that represents a break in the geological record, with the rock unit immediately above it being considerable younger than the rock beneath it

1) Disconformity – a surface that represents missing rock strata, but beds above and below that surface are parallel to one another
2) Angular Unconformity – an unconformity in which younger strata overlie an erosion surface on tilted or folded layered rock, implies the following sequence of events from oldest to youngest:

Deposition and lithification of sedimentary rock

Uplift accompanied by folding or tilting of layers
Erosion
Renewed deposition on top of eroded surface
3) Nonconformity – an unconformity in which an erosion surface on plutonic or metamorphic rock has been covered by younger sedimentary or volcanic rock
Crystallization of igneous or metamorphic rock at depth
Erosion of a least several kilometers of overlying rock (the great amount of erosion further implies considerable uplift of this portion of Earth's crust)
Deposition of new sediment, thick eventually becomes sedimentary rock, on the ancient erosion surface
How can rock units be traced from one area to another?
- Correlation – determining time equivalency of rock units, rock units may be correlated within a region, a continent, and even between countries
Physical Continuity – being able to physically (visually) follow a rock unity between two places
Similarity of Rock Types – same sequence of rocks
- Tillites – glacially deposited sedimentary rock
- Key bed – a very distinctive layer
Correlation by Fossils
- Paleontologist – specializes in the study of fossils
- Faunal succession (William Smith) – a principle or law stating that fossil species succeed one another in a definite and recognizable order; in general, fossils in progressively older rock show increasingly greater differences from species living at present
- Index fossil – a fossil from a very short-lived, geographically widespread species known to exists during a specific period of geological time
- Fossil assemblage – various different species of fossils in a rock layer

How do we use Relative Dating to Understand Geological Time?
The Standard Geologic Time Scale – a worldwide relative time scale based on fossil assemblages
- Relative time scale: 3 **eras** which are subdivided into **periods** which are subdivided into **epochs**
- Precambrian – the vast amount of time that preceded the Paleozoic Era
- Paleozoic Era ('old life')– began with the appearance of complex life, as indicated by fossils
- Mesozoic Era ("middle life') – dinosaurs became the dominant animals
- Cenozoic Era ('new life') –

Quaternary Period – the youngest geologic period, includes present time
Pleistocene Epoch – an epoch of the Quaternary Period characterized by several glacial ages
Holocene Epoch (Recent) –

How can we determine the absolute age of rocks?
- Oldest rock from northwest Canada = 4.03 billion years old
- Oldest known mineral, zircon, from Austrailia = 4.4 billion years old

Isotopic Dating – determining the age of a rock or mineral thru its radioactive elements and decay products (previously and somewhat inaccurately called *radiometric* or *radioactive* dating)
- Geochronologists – specialize in isotopic dating
- Isotopes – atoms (of the same element) that have different numbers of neutrons but the same number of protons (40K becomes 40Ar, 238U decays to 206U=206Pb)
- Radioactive decay – spontaneous nuclear disintegration of certain isotopes with unstable nuclei

Alpha emission – ejection of two protons and two neutrons from a nucleus
Beta emission – release of an electron from a nucleus
Electron capture – proton in the nucleus captures an orbiting electron

19.1 Highlights of the Evolution of Life through Time

- Oldest fossils are prokaryotes (lack nucleus) = 3.5 billion years ago
- Eukaryotes (single-celled, have nucleus, reproduce sexually) = 1.4 billion years ago
- Jellyfish + worms (multicellular) = 700-550 million years ago
- Ediacaran biota (soft-bodied animals) = 565-543 m.y. ago – found at Mistaken Point NFLD
- Paleozoic – greatest mass extinction ever to occur 95% species died, mostly ocean species
- Mesozoic – dinosaurs and mammals, second largest extinction 75% of species died
- Cenozoic – age of mammals, hominids

19.2 Demise of the Dinosaurs – Was it Extraterrestrial?

- Walter Alvarez and Luis Alvarez – hypothesized that extinction was caused by large asteroid
- Marked by (Cretaceous and Tetiary Period) K-T boundary – has abundant Iridium content
- Chicxulub crater near the coast of Mexico's Yucatan peninsula

What is Radiocarbon Dating?

- Ratio of 12C and14C in organic remains determine the time elapsed since death of organism

Cosmogenic Isotope Dating (surface exposure dating) – uses the effects of constant bombardment by neutron radiation coming from deep space (cosmogenic) of material at Earth's surface

19.3 Radon, A Radioactive Health Hazard

- Radon – a odorless, colorless gas, can caused lung cancer, product of 238U decay to 206Pb, has half life of only 3.8 days
- where bedrock is granite, gneiss, limestone, black shale, or phosphate rock – high uranium
- Health Canada says exposure should only be 800 Becquerel per cubic meter
- Prevent – good air circulation thru house, basements made airtight

19.4 Calculating the age of rock

When can Isotopic Dating Techniques Be Used?

Isotopic age to be accurate

- Isotopic system has remained closed – rock collected must show no signs of weathering or hydrothermal alteration
- There were no daughter isotopes in the system at the time of closure or make corrections for probable amounts before "clock" was set
- Must be sufficient parent and daughter atoms to be measured by the mass spectrometer

How Reliable is Isotopic Dating?

- Confirm with relative age dating

Combining Relative and Numerical Ages

- Precambrian Eon – the largest unit of geological time

Prearchean (Hadean) Eon –

Archean Eon -

Proterozoic Eon ('beginning life')–

Phanerozoic Eon ('visible life') – Paleozoic Era, Mesozoic Era, Cenozoic Era

How Old Is the Earth?

- James Ussher 1625 – Bible to determine earth's age
- Lord Kelvin 1866 – rate at which Earth loses heat, forgot about radioactivity
- Earth is now regarded as between 4.5 and 4.6 billion years old – meteorites and lunar rock

Comprehending Geologic Time

19.5 Mapping Time and Terrain

- Geographic Information Systems and digital mapping technology

Chapter 20: Geological History of Canada

Canada: A Young Nation, But an Old Country

- Acasta Gneiss (4 Ma)- North West Territories, which forms part of the Slave Province of the Canadian Shield
- North America was essentially complete by 65 million years ago
- Last ice sheet – 12,000 years ago left southern parts of country, 6,000 years ago finally melted in Labrador
- Baffin Island – remnants of this vast ice sheet still survive on Baffin Island as Penny and Barnes Ice Caps

What are the main geological "Building Blocks" of North America?

Geologic Jigsaw

- Craton – the ancient core of North America, composed of a complex assemblage of several distinct geologic provinces
- Geologic provinces – broad regions of similar rocks, with characteristics that differ significantly from rock types present in adjacent areas

Sub-Provinces – fault-bounded units containing similar rocks types, structures and mineral deposits

- Terranes – provinces + subprovinces, discrete fragments of oceanic or continental material that have been added to a craton at an active margin by accretion (material is added to a landmass)

The North American Craton versus the Canadian Shield

- North American Craton – a large, continent-sized block of distinct geology aking up the basement of much of North America (and Greenland)
- Canadian Shield – exposed part of the craton, and consists of a gently undulating surface that rises inconspicuously, almost like an arch, in its center (peneplain)

consists predominantly of very old, Archean and Proterozoic rocks (age 1-4 Ga years old, lack fossils)

- Peneplain – "almost plain", caused by erosion and beveling

Margins of Shield are buried below younger sedimentary rocks, ancient peneplain surface now forms an unconformity between the craton below and younger rocks above

Grand Canyon in Arizona –unconformity separates metamorphic rocks of the craton from overlying Paleozoic cover rocks

- Cover strata – younger sedimentary strata that bury the more ancient craton around its margins

Deposited when the outer margins of the craton were depressed and flooded by shallow seas – occurred during orogenies , collision of other landmasses with the craton

Cover rocks – thicker than 10km

The Geologic Jigsaw of the North American Craton

- Geological provinces (Sir William Logan) – areas of the shield with distinctive geological characteristics

20.1 The Sudbury Impact Structure: Collision of an Ancient Meteorite

- Oval shape crater – squeezed by Penokean Orogeny,

depth of 35km, rich in nickel, copper and platinum ores

- Shatter Cones – V-shaped cones that form when rocks are struck violently during a meteorite impact event
- Breccia (Pseudotachylite Glass) – formed by disintegration and mixing of rock when hit by a large meteorite and broken into angular fragments

Deconstructing North America:

1) The original NA continent, **Arctica** which started to form about 2.5 billion years ago from smaller continents and was completed by about 1.9 billion years ago when old Archean cratons (ex: Slave, Nain provinces) were welded together by the Trans-Hudson Orogen and others
2) Added to the North American continent during the formation of **Nena** about 1.8 billion years ago after the Penokean Orogeny
3) Added During the Formation of **Rodinia** about 1.3 billion years ago during the Grenville Orogeny
4) Added during the formation of **Pangea** about 600 million-300 million years ago – Appalachian Mt
5) Added after the breakup of **Pangea** about 250 million years ago – Corillera

How Did the North American Continent Evolve?

(5) Stages in the Evolution of the North American Continent

- Orogens – consists of crushed and deformed rocks that represent the remains of mountain belts or volcanic arcs formed during collision (ex: Trongat and Wopmay)
- Wilson cycle – process of repeated continental aggradation and breakup forms supercontinents
- Supercontinents – a giant conglomerate of all the continents on Earth

Stage 1: Arctica – North America in the Archean Era (4-2.5 Ga)

- Arctica – The original North American continent, begun to form 2.5 Ga years ago , finally assembly 2 Ga years ago, included present-day Siberia

Slave Province (3.96 – 4.05 Ga) – oldest rocks on Earth found in Acasta Gneiss of the Northwest Territories, diamonds in kimberlite pipelines

Superior Province – mineral wealth (gold, zinc, copper, silver)

- Subprovince –fault-bounded subdivisions of a geological province that contain similar rock types, structure and mineral deposits, subprovinces within Superior Province record clear evidence of the operation of plate tectonics in the ancient past

Plutonic subprovinces – composed of granite and record the intrusion of giant plutons into the Superior Province

Greenstone subprovinces – consisted of metamorphosed sea-floor volcanic rocks (basalt) originally formed on the floor of ancient Achean oceans, contain BIFs, and records the first large-scale production of oxygen by single-celled cyanobacteria

Metasedimentary subprovinces – consists of deep-sea Archean ocean sediments,

- Gowganda glaciations (2.4 Ga)– a major glaciations at the southern continental margin of Arctica

Form part of the Huronian Supergroup of Ontario, famous for uranium deposits near Elliot Lake

Stage 2: Nena and Rodinia – North America in the Proterozoic Era (2.5 Ga – 570 Ma)

- Nena (North Europe and North America) - A supercontinent that existed between 1.9 and 1.3 Ga years ago recorded by the Penokean Orogeny

Southern Province, Yavapai and Mazatzal Orogenies added to Arctica around 1.9 Ga

Penokean Orogeny - created a major Himalayan-type mountain, now eroded but remain as the Penokean Fold Belt along the northern border of Lake Huron Ontario

Stage 3: The Grenville Orogeny and Formation of Rodinia

- Grenville Orogeny – the result of a long-lived collision between ancestral South and North America between 1.3 and 1 billion years ago

Formed current day southern Greenland to Northern Mexico, accretion of smaller land masses created Rodinia

- Rodinia – A supercontinent that formed about 1,000 million years ago

The accreted and deformed rocks now underlie much of Southern Ontario and Quebec extending thru the Maritimes and into Newfoundland

- Grenville orogenic belt (Grenville Province or Gren vill Orgen) – dominated by banded gneisses, highly metamorphosed sediments, and igneous rocks

Eroded to peneplain 800 million years ago, now forms the exposed Canadian Shield

Made up of smaller terranes: highly deformed remnants of island arcs, microcontinents, pieces of ocean floor that were not subducted, welded together by the intrusion of granite pluton and dikes

Rodinia Breaks Apart (750 Ma – 570 Ma)

- Triple junction – consists of interlinked *grabens* the eventually grow and widen into a new ocean basin (failed grabens are called *aulacogens)*
- Panthalassic Ocean – ancestral Pacific Ocean, the first break: Antarctica + Australia broke from western margin of North America
- Iapetus Ocean – ancestral Atlantic Ocean, last break: Europe + Africa broke from eastern margin of North America
- Cambrian Explosion – proliferation of early life forms such as those of Burgess Shale and the Mistaken Point Formation

Stage 4: Pangea – North America in the Later Paleozoic and Some of the Mesoic

- Baltica – modern Europe
- Laurentia – modern North America
- Laurasia = Baltica + Laurentia
- Taconic Orogeny (Caledonian Orogeny) – formed mountains in Wales, Scotland, Scandinavia similar to Andes' Mountains (arc of volcanic islands rose above an active subduction zone and andesitic volcanoes) off the eastern coast of North America

Marker horizons – ash beds, within thick sedimentary strata that cover the outer margins of the North American craton

Bentonite – weathered ash that can be fingerprinted

Intracratonic basins – form on the craton and are underlain by continential crust rather than oceanic crust (ex: Appalachian Basin has more than 10km of Paleozoic sediments)

- Queenston Delta – drained the North Slopes of Taconic Mountains and spread fossiliferous sediment inland, across outer margins of the North American craton

Delta - a body of sediment deposited at the mouth of a river when the river velocity decreases as it flows into a standing body of water

- Petrolia – first oil strike in 1858, organic matter from early Paleozoic shades of Devonian age

Predated major discovery at Titusville, Pennsylvania in 1859

- Ophiolites – portions of the entire ocean floor, including spreading centers and their gabbroic and basaltic rocks were thrust up and preserved in southern Quebec and along western coast of Newfoundland

20.2 The Oldest Animals in the World

- Burgess Shale – chordates found in Yoho National Park in British Columbia

Walcott's Quarry – richest fossil finds discovered by Charles Walcott in 1909

- Ediacara Fauna – oldest fossils in Newfoundland in the Mistaken Point Formation

Charnia masoni – a large frond-like organism almost 2meters in length, similar to modern day lichen that lived on sea floor

- Twitya Discs – deposited at same time as those at Mistaken Point Formation, found in the Mackenzie Mountains of the Northwest Territories on the opposing paleo-Panthalassic coast of N.America

How were the Atlantic Provinces Added to Canada?

- Pangea was completed in late Carboniferous when Laurasia docked with Gondwana

Acadian Orogeny – Devonianafe collision

Alleghenian Orogeny – Carboniferous collision, which were responsible for the buckling and thrusting of previously deposited sediments

Appalachian Mountains – eroded remnants of these orogenic events

Most famous accreded terranes = Miramichi-Bras d'Or, Meguma, and Avalon terranes, now make much of New Brunswick, Cape Breton Island, Nova Scotia, Newfoundland

- Maritimes Basin – formed during late Carboniferous, A series of interconnected mountains and basins that existed in the Maritime provinces from the late Devonian to the Permian

Microscopic algae thrived, eventually produce oil shales (ex: southern New Brunswick)

- Cyclothems – repeated cycles of coal, fluvial, and marine deposits (ex: Nova Scotia)

Where did British Columbia Come From?

Stage 5: Canada in the Mesozoic: Pangea Breaks Apart and British Columbia Is Swept Up

- Tethys Ocean – Laurasia separated from Godwana

Eastern Canada became a passive continental margin in late Jurassic

- Canadian Cordillera – Land masses swept up and accreted onto western North America (British Columbia, Alberta, Yukon, and Northwest Territories), formed belts since mid Jurassic

Columbian Orogeny – oldest collision event where the

Foreland Belt – rocks affected by Intermontane Belt

Omineca Belt – the boundary or *suture* between Intermontane and Foreland, zone of intensely metamorphosed rocks intruded by plutons

Intermontane Belt - dock with western N.America during Columbian Orogeny

Laramide Orogeny – may not be a single event, accreted Insular Belt

Coast Belt – suture b/w Intermontane +Insular, cover by Coast Plutonic Complex

Insular Belt – modern day Vancouver Island, consist of Wrangellia and Alexander terranes

- Western Interior Sedimentary Basin – foreland basin develop in response to the weight of thickened thrust belts depressing the surrounding crust (Ex: Alberta)

Experienced many changes in water depths = alternations of shallow marine sandstones and deeper-water shales = formed gas and oil reservoirs, dinosaur fossils

Hydrocarbon traps – where oil and gas that would otherwise escape to the Earth's surface became trapped, first major oil discovery in 1913 Turner Valley, south of Calgary

Potash – potassium chloride (sylvite) essential nutrient for plant growth, Saskatchewan is the world's largest potash producer

Where can we find Dinosaurs in Canada?

- First dinosaur fossil - Royal Tyrrell Museum of Paleontology – named after JB Tyrrel who found the first fossil remains in Alberta in 1884
- Oldest dinosaur fossil – Triassic age, found at Burntcoat Head, Nova Scotia

Coelophysis – a small bipedal dinosaur – footprints found near Rossway, Nova Soctia

Why Did the Dinosaurs Disappear So Suddenly?

- Massive meteorite impact that hit Yucatan Pennisula, modern day Mexico

How did the Canadian Rockies Form?

- Formed by layered sedimentary rocks that were displaced eastward by about 150km as a result of compression caused by collisional events along the western margin of North America
- Formed as a result of deep glacial erosion and mass wasting during glaciations of past 2.5 Ma

When did the Ice Sheets Develop?

Canada in the Cenozoic: The Arctic Cools Down

- Key contributors of global climate change – radical changes in ocean and atmospheric circulation caused by the closure of the Tethys Ocean as India slammed into Asia = Himalaya

Canada in the Quaternary: Ice Sheets Come and Go

- Nunataks – an isolated bedrock peak completely surrounded by glacial ice
- Corilleran Ice Sheet – western Canada, covered Rockies and BC
- Laurentide Ice Sheet – larger than Corileran, covered Prairies, High Arctic down to United States

3 kilometers thick, 33x106 km3 in volume

Last remnants melted in northern Quebec 6,000 years ago

Canadian Landscapes Produced by Glacial Erosion

- Classical glaciated landscape – fjord-indented coastline of BC

Fjord – a coastal inlet that is a glacially carved valley, the base of which is submerged

Rocky Mountains – high angular mountain tops with frost-shattered summits and narrow, glacially excavated troughs (prone to landslides)

- Passive margin uplift – uplift of the margin of a continent caused by rifting

20.3 Tors and Gold: Relics of Early Cenozoic Warmth?

- Saprolite – a thick clayey layer, formed around 40 Ma
- Core stones – unweathered portions if the parent rock
- Tors – core stones exposed on the surface
- Gold – that was finely dispersed in bedrock was chemically concentrated during weathering leaving large nuggets at the base of the saprolite

20.4 Cold Winds and Ancient Soils

- Periglacial conditions - Yukon and Alaska was too dry and too cold for glacial ice to form

Loess – large parts of landscape buried under deposits of windblown silt and sand

20.5 How Did the Great Lakes form?

- From glacial erosion and over-deepening of a much older mid-continent river system
- Largest ancient lake = Glacial Lake Agassiz

Canadian Landscape Features Produced by Glacial Deposition

- aquifers – huge volumes of groundwater stored in thick glacial sediments, Southern Canada
- drumlin field – contain many hundreds of elongate hills, Peterborough, ON and Yarmouth, NS

flutes – narrower hills

- moraine – a body of till either being carried on a glacier or left behind after a glacier has receded

hummocky moraine – dimpled surface, with hollows that are often filled with water

- Erratic – an ice-transported boulder that does not derive from bedrock bear its present site
- Megablock – large mass of rock moved *under* the Laurentide Ice Sheet, flowed over softer sedimentary socks in Alberta and Saskatchewan
- Glaciotectonic defomations – moraine + megablock, ability of ice sheets to quarry and deeply disturb the landscape over which they flow
- Soft glaciomarine clays = quickclay landslides (ex: South Nation River valley in Ontario)

Canada's Geology: A Project in Progress?

- Intracratonic earthquakes – occur in central and eastern Canada record displacement along buried aulacogens and ancient terrane boundaries in the craton
- Isostaic rebound – landmass slowly rise in elevation recording unloading of crust following the retreat of the ice sheets

20.64 Billion Years of Canadian Geology in Summary

- Wilson Cycles – repeated formation and breakup of supercontinents

1) Formation of Rodinia - addition of Grenville Belt to eastern North America
Modern day Ontario, Quebec and Labrador
2) Breakup of Rodinia – surrounded by passive margins along Paleo-Pacific and Iapetus Oceans
Recorded the earliest diversification of complex organisms (Burgess Shale)
3) Pangea begins to form – western passive margin, approaching terranes from Africa
Orogenic events, ophioite complex (closure of Iapetus Oceans)
4) Pangea forms – western passive margin, Godwana + Laurasia together
Appalachian Basin, Michigan Basin, Maritime Canada
5) Pangea breaks up – forming early Atlantic Ocean, BC terranes approach, Dinosaurs
Western Interior Sedimentary Basin = Alberta, glaciations = Rocky Mountains
6) Modern day – Pacific Ocean, BC, Rockies, Maritime Canada, Atlantic Ocean

Why is it important to understand the geological history of Canada?

- Brownfield sites – sites used previously for commercial, industrial, or residential purposes
- Walkerton, Ontario in 2001 – drinking water tainted by animal waste
- Mineral wealth on Canadian Shield