Student Information

Geologic Time

Relative Age Dating – put geologic events in order by considering these principles:

Faunal succession – No life form is exactly duplicated at another point in time.
Uniformitarianism – "The present is the key to the past."
Original horizontality – Sediments are deposited in flat-laying layers.
Cross-cutting relations – A fault or dike that cuts across layers is younger than the layers.
Correlation – Two rocks containing the same fossil must be the same age.
Superposition – If undisturbed, the oldest layer is on the bottom, the youngest is at the top.
Included fragments – Pieces of rock (xenoliths or intraclasts) in a rock are older than the rock they are in.
Unconformity – a break in the rock record due to erosion or nondeposition. **Angular unconformity**: layers above and below are not parallel. **Disconformity**: layers above and below are parallel.

Absolute Age Dating – find a numerical age for a rock by radiometric dating techniques, counting tree rings or varves, or using index fossils.

Radiometric Dating

When an igneous rock forms, it contains an amount of parent isotope. That isotope instantaneously starts to spontaneously decay to form daughter isotopes. Scientists (geochronologists) can measure the amount of parent and daughter isotopes in a rock sample and determine how many half-lives have passed. The age of the sample is calculated:

Age = (# of half-lives) X (length of half-life)

Half-life – the length of time for half a radioactive parent sample to decay and become a stable daughter. It is unique for each radioactive isotope. It never changes.

Sources of Error in Radiometric Dating

- Daughter isotope may have been present when the rock formed, so the sample will appear older.
- Daughter isotopes may have escaped from the rock (e.g. argon gas), so the sample will yield a younger age.
- Some parent/daughter isotopes may have been added to the sample, so the sample will yield a younger or older age, respectively.

Scientists can correct for possible errors by using more than one radiometric isotope and comparing the ages obtained.

Student Information

Numerical age ranges for sedimentary rocks can be obtained by radiometric dating sills, dikes, or lava flows which underlie, overlie or intrude them.

Carbon 14 has a short half-life (5730 years) and is predominantly used to date organic material.

Geologic Time Scale: Review the events written on the geologic time scale.

Fossils: Review the fossil phyla. You must be able to recognize the phyla, know where and how they lived, approximately when they lived, and the living relatives, if any.

A **fossil** is a replica of an organism.

- Hard parts preserve most easily.
- Generally fossilized in water where most sediments accumulate.
- Rapid burial required to prevent scavenging and decay (i.e. seal from oxygen and bacteria).

Fossilization of **soft** parts (a replica, not the soft parts themselves) requires that the entire organism must be buried shortly after death in deep, low-oxygenated water.

Trace fossil - a sedimentary structure made by an organism such as a footprint, burrow, or feces

Index fossil – a plant or animal fossil especially useful in correlating strata; It must be short-lived, geographically widespread and abundant, and easily identified.

Methods of Fossilization

Original preservation – original skeletal material or soft tissues remain e.g. frozen wooly mammoth

Carbonization – a "picture" in carbon; common plant fossilization method

Replacement – a mineral (e.g. quartz) takes the place of the original structure

Permineralization – a mineral fills in the pore spaces of the original structure

Mold – sediments solidify around the shell, water flowing through dissolves the shell, and the hollow remaining shows the external features of the shell

Cast – sediments fill in the mold and show only the external features of the shell, no internal structure is present

Punctuated equilibrium – a model for evolution that predicts that life forms remain unchanged for long periods of time and then, suddenly, undergo a major change followed by a long period of stability.

Adaptive radiation – animals adapt to the environment they are in and, consequently, are different from their parents.

Natural selection – a principle of the theory of evolution: survival of the fittest.

Internal Processes and Structures

Evidence for Plate Motion

- Earthquakes
- Volcanoes
- Tropical fossils in northern climates, glacial features at the Equator, fossil seashells on mountain tops
- Polar wandering curve
- Magnetic stripes on the seafloor

Seafloor Spreading

- Plates separate as magma rises up from the mantle.
- Youngest rocks are along the ridge; oldest are furthest away.
- Magnetic stripes record polarity reversals.

Plate Boundaries and Associated Volcanics

Converging - two plates collide. Subduction occurs between oceanic plate and oceanic or continental plate. Composite volcanoes (explosive, andesitic, layers) form above the boundary. Mountains are uplifted at continent-continent collisions. Compressional forces generate folds and reverse and thrust faulting.

Diverging - two plates separate (e.g. Mid-Atlantic Ridge, Juan de Fuca Ridge). Characterized by tensional forces, normal faulting, newly created crust, smooth flowing flood basalts.

Transform - two plates move horizontally past each other (e.g. San Andreas Fault). Characterized by a shearing force, strike-slip faults, and no addition or reduction in crust.

Mountains Around the World

- Himalayans (N. India) and Alps (N. Italy) – formed by collision between two continents.
- Andes (South America) and Cascades (U. S.) – volcanic chains formed on continental crust above subduction zones.
- Appalachians and Cordilleran (North America) – formed by the collision of micro-continents and volcanic island arcs with the margins of the continent.
- Aleutians (Alaska) and Japan – volcanic islands formed above a subduction zone between oceanic plates.

Cause of Plate Motion

- **Convection currents** in the asthenosphere drag the plates along or/and **gravity** pulls on cool plates being subducted.

Origin of Magma

- The temperature of the Earth gets hotter with depth (**geothermal gradient**) at a rate of 30°C/km. It is hot enough in the upper mantle (50-250 km) to melt rock. Different minerals melt at different temperatures. More heat is required to melt rock under great pressure.

Isostatic Adjustment

- The crust adjusts up and down as it floats on the mantle. If a load is removed, as with a melting glacier, it moves up. If a load is added, as with formation of a volcano, it subsides.

Volcanic Features

Hotspot - a stationary plume of magma that rises and breaks through a lithospheric plate. The plate moves and eventually the magma comes through at a different location on the plate. Shield volcanoes form (basaltic, smooth-flowing, low and wide outline).
Columnar joints – fractures that form as lava (generally basaltic or andesitic) cools and contracts into polygonal columns perpendicular to the cooling surfaces.
Volcanic dome – lava mound that forms when viscous magma (felsic) oozes out, like toothpaste, and piles up near the vent.
Lava plateau - upland formed by flood basalts on a continent.
Nuée ardente - a hot, fast, ash flow that burns everything in its path as it travels down the side of a volcano; commonly associated with andesitic volcanism.
Pillow lava - basaltic lava extruded under water where it forms bulbous pillows with glassy crusts and coarser crystals inside.
Aa lava - slightly cooled and so thicker, basaltic lava that breaks into sharp, blocky chunks as it flows; hard to walk on.
Pahoehoe lava - a basaltic lava flow that develops a wrinkled, ropy surface as the flow underneath continues to move.

Plutonic Features

Batholith – a large, complex intrusion of numerous plutons.
Stock – a small intrusion.
Sill – an intrusion between parallel layers of sediment (or pre-existing flows).
Dike – an intrusion that crosscuts pre-existing rock layers or rock body.
Xenolith – fragment of unmelted country rock in an intrusive rock body.

Relationship of the Rock Cycle to Plate Tectonics

- Where magma is generated (diverging plates or subduction zones) igneous rocks form. Where plates collide, metamorphic rocks form. Where rock is exposed and weathered, or shelly creatures thrive, sediment is formed, transported and deposited on the Earth's surface. The composition of the sediment reflects the source terrane.

Earthquakes

Creep – plates slowly move past each other; no build up of pressure.

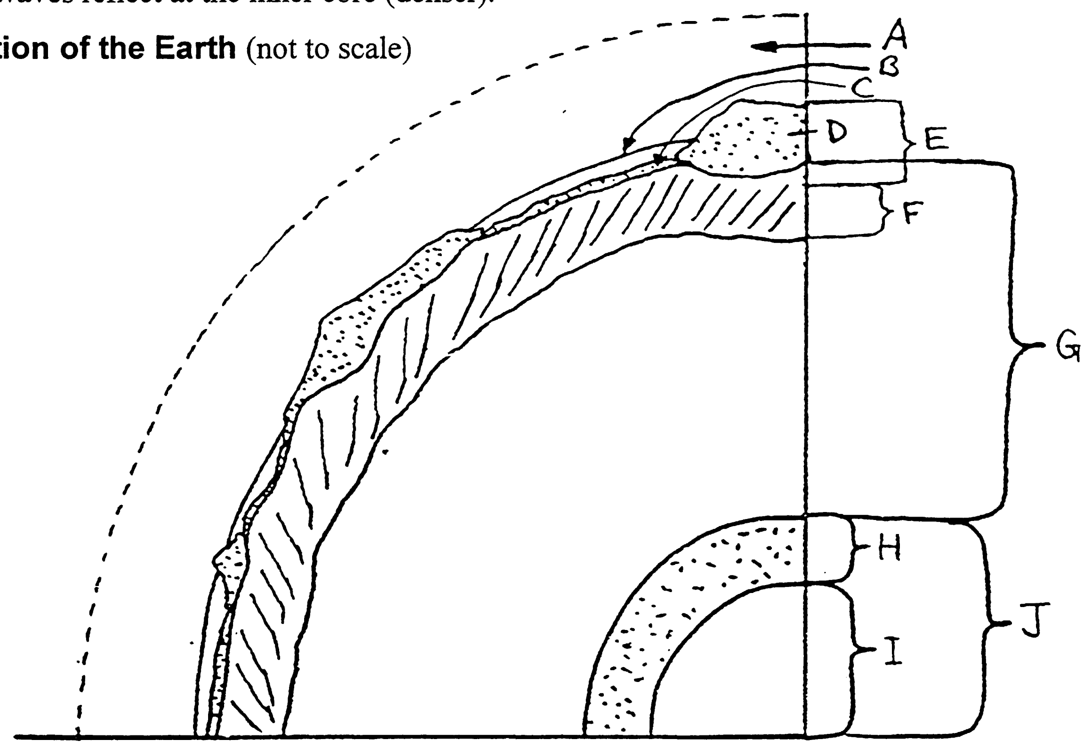
Elastic rebound – plates continue to move slowly and deform, but are frozen along the actual boundary. Pressure builds until the jam breaks and the plates move back into their original shapes in offset positions.
Magnitude – a measure of ground motion (up by factors of 10) and energy release (up by factors of 30). Measured with the Richter Scale, which has no maximum value.
Intensity – a measure of earthquake damage. Based on the Mercalli Scale in which total destruction is 12.

- **Epicentre location** can be determined by measuring the difference in arrival times of P (faster) and S waves at three seismograph stations, referring to a Time-Distance graph to determine how far away the earthquake occurred from each station, and drawing great circles with radii equal to each distance to see where they intersect.
- **Seismic Risks**
  Geographic location: e.g. if you live near an active plate boundary
  Topography: e.g. if you live next to a mountain face that will slide during an earthquake
  Ground strength: e.g. bedrock is more stable than sediments
  Proximity to faults: the further away, the better
  Construction design: difficult to do using scale models; specifications always change
- **Earthquake Prediction**
  Dilatancy data: the amount of water pore spaces, lubricates fault surfaces, affects water table levels.
  Seismic gaps: area along an active fault that has not moved in a long time.
  Animal behaviour: dogs and cats go astray.
  Land rising: caused by pressure buildup along a fault.

Evidence of a Layered Earth

- Seismic waves speed up at the Moho (between the crust and mantle).
- S-waves disappear at the outer core (liquid).
- Seismic waves refract (bend) at boundaries.
- Some P-waves reflect at the inner core (denser).

Cross-section of the Earth (not to scale)



A - atmosphere, 80 km, 78% N, 21% O, 1% other
B - ocean, average depth 4 km, deepest 11 km (Marianas Trench), water
C - oceanic crust, average 10 km thick basalt
D - continental crust, average 50+km thick, granitic (average)
E - lithosphere, 50-100 km thick, solid
F - asthenosphere, to 500 km thick, solid, but plastic
G - mantle, base of crust to 2900 km, silica and ferromagnesians
H - outer core, 2900 to 5000 km, liquid
I - inner core, 5000 to 6370 km, solid
J - core, 2900 to 6370 km, iron and nickel
Moho seismic discontinuity - between D (continental crust) and G (mantle)

- Whether a rock behaves plastically (i.e. changes in shape permanently) or brittly (i.e. breaks) depends on temperature (high = more plastic), confining pressure (higher = more plastic) and the intrinsic characteristics of the rock.

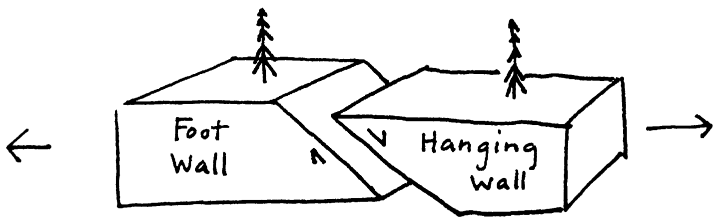
Student Information

Structures

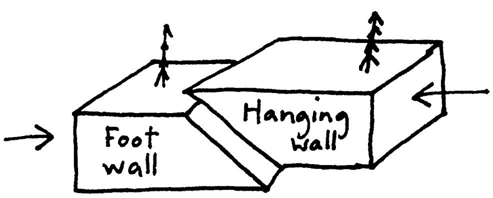
Fault - break in rock along which there is movement.
Joint - fracture in rock along which there is no movement.

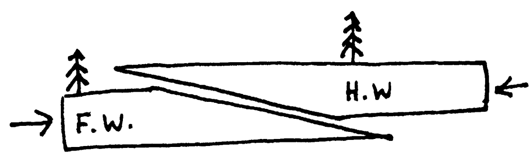
1. Dip-Slip Faults (vertical movement)

Normal - tensional forces (e.g. divergent plates)



Reverse - compressional forces (e.g. convergent plates) or **Thrust** (low-angle)

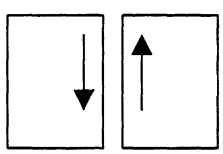




2. Strike-Slip Faults (horizontal motion; shear forces)

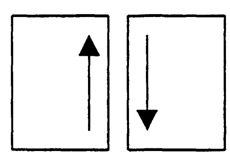
Left Lateral

map view



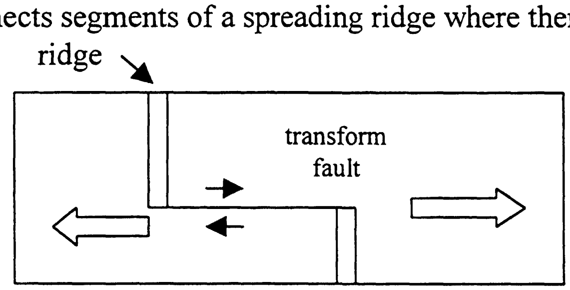
or

Right Lateral



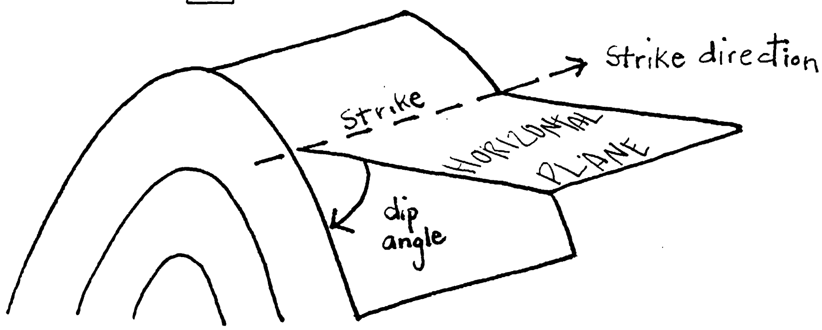
map view

Transform - connects segments of a spreading ridge where there is plate rotation



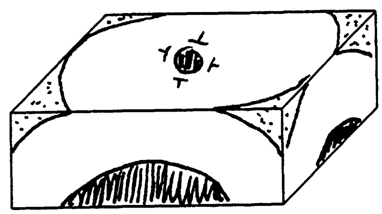
Student Information

Strike and Dip – orientation measurements used to describe geologic structures.
Strike - the compass orientation of the line of intersection of a horizontal plane with the structure.
Dip - the angle between the horizontal plane and the slope of the structure.
Strike and Dip Symbol - ⊥ looks like a capital T and is only drawn on maps.



Dome

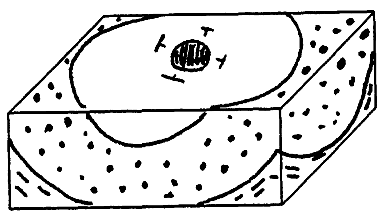
- oldest in the middle
- looks like an upside-down bowl



Strike is always parallel to the contact lines on the map.

Basin

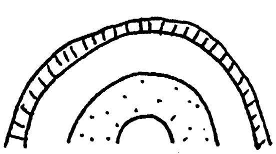
- youngest in the middle
- looks like a bowl

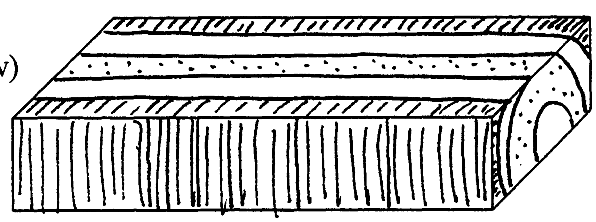


Anticline (anthill)

- oldest in the middle (in map view)

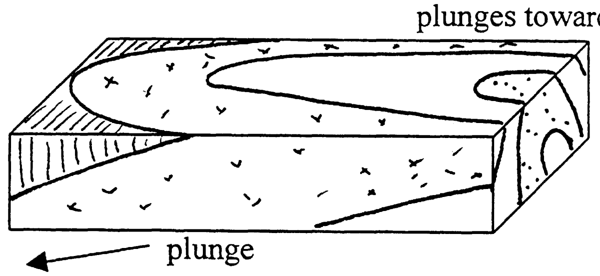
cross-section





Plunging Anticline

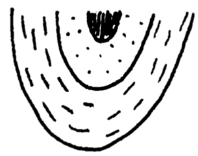
plunges toward the nose

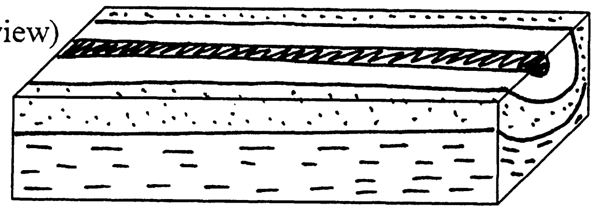


plunge

Syncline (smile)

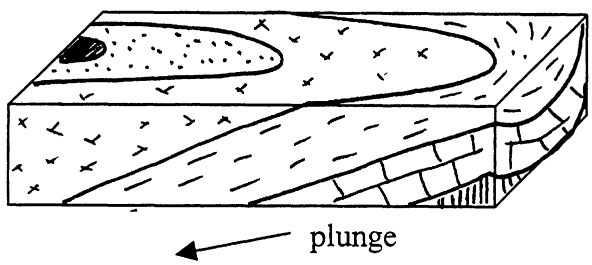
- youngest in the middle (in map view)
  cross-section



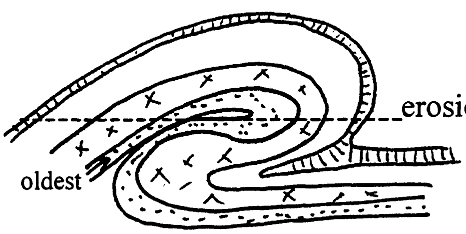


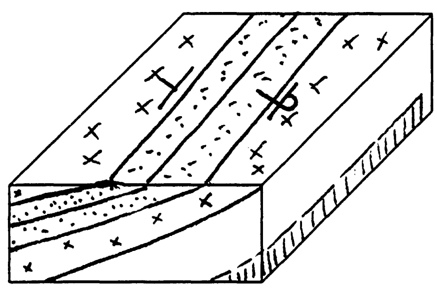
Plunging Syncline

plunges toward the open end



Overturned Fold





Surface Processes

Weathering and Erosion

Weathering - the breakdown of rock in place.
Erosion - the transport of rock by wind, water, or ice.
Physical (mechanical) weathering - physical breakdown of rock without chemical change (e.g. ice wedging, exfoliation).
Chemical weathering - breakdown of rock caused by chemical reactions with the minerals (e.g. acid rain dissolution, iron oxidation to rust).

- Bowen's Reaction Series order of mineral crystallization is opposite the order of susceptibility to chemical weathering. Olivine breaks down most easily; quartz is most stable.

Biological weathering - breakdown caused by living organisms (both physical and chemical) (e.g. acids produced by organic decay, root wedging).
Mass wasting - downslope movement of rock material and soil due to gravity and triggered by heavy rainfall or earthquake activity, etc. It includes many types and speeds of travel.

- Mass wasting can be controlled by planting vegetation on slopes, dewatering slopes, building retaining walls and barriers, etc.

Running Water

Load - the material carried by a stream.
Bedload - the sediment rolled along the stream bottom.
Suspended Load - the sediment carried in suspension.
Solution Load - the sediment (e.g. elements and compounds) dissolved in the water.

- **Sorting** by sediment size occurs in a stream according to the speed of the water. e.g. If a stream slows down locally, some of the coarsest sediment transported as bedload will be deposited.
- **Erosion and deposition** are greater when the stream carries a greater load, moves faster (e.g. along a steeper gradient), discharges more water, and/or there are more erodible sediments in the channel.
- **Meanders** have erosion on the outside of the curve and deposition along the inside.
- **Water transported particles** are most likely to be: round and smooth (physically mature), chemically mature, fine to medium-grained, and well-sorted.
- **Wind transported particles** are likely to be: well-rounded, pit-marked, chemically immature, very fine-grained, and very well-sorted.

Glaciers

Erosional Features

U-shaped valley - a valley generated by glacial erosion.

Hanging valley - a valley formed by a tributary valley glacier feeding into a larger valley glacier.
Cirque - a bowl-shaped excavation at the head of an alpine glacier.
Horn - a multi-sided mountain peak formed by three or more glaciers.
Arête - an erosional remnant ridge between two parallel valley glaciers or adjacent cirques.
Striations - scratch marks on bedrock made by rock debris carried in a glacier.

Depositional Features

Erratic - a large rock deposited by a glacier.
Moraine - till deposited by a glacier.
Ground Moraine - hummocky till layer deposited at the base of a receding glacier.
Terminal Moraine - till mound deposited at the front edge of a glacier at its farthest extent.
Recessional Moraine - till mound deposited at the front edge of a glacier during a standstill as it recedes.
Lateral Moraine - till mound deposited at the edge of a glacier.
Medial Moraine - till mound deposited at the boundary of two (valley) glaciers as they recede.
Kame Terrace - sediments deposited in meltwater lakes along the edge of a glacier.
Esker - stratified sands and gravels deposited by a stream on or in a glacier; identified on a glaciated landscape as a sinuous ridge.

Ground Water

- The **water table** is the top of the **Zone of Saturation** where all pore space is filled with water. Above it lies the **Zone of Aeration** where pores are partly filled with water and air.
- A **perched water table** lies above the regional water table in places where impermeable rock, such as a layer of shale, acts as a barrier trapping water above it.
- A **confined water table** is overlain and underlain by impermeable rocks. It is the source of artesian water wells.
- An **aquifer** is a body of rock capable of holding groundwater because of great porosity and permeability, such as sandstone.
- **Porosity** is a measure of the volume (abundance) of holes in a rock. The greater the porosity the more water a rock body can hold.
- **Permeability** is a measure of the interconnectedness of the pores. The greater the permeability, the more readily water can move through a rock.

Geology of BC

History

At the beginning of the Mesozoic Era (225 my), the west coast of Canada in British Columbia was near Salmon Arm. The core of the continent was made of granitic batholiths and volcanics that formed as the Earth cooled 4.5 billion years ago. It was overlain by younger sedimentary rocks (Paleozoic) that formed as the core of the continent was weathered and eroded forming sediments that were redeposited in rivers, deserts, and inland seas. A great wedge of sediment accumulated on the west coast of North America as rivers moved material from the interior to the Pacific Ocean. The entire landmass, which was part of Pangaea, was situated further South; the climate was tropical. There were many swamps filled with vegetation that accumulated as it died and fell to the ground. An inland sea covered Alberta and northeastern BC. The many marine organisms it supported were buried with the sediment deposited by the sea. Dinosaurs inhabited the adjacent land areas.

Pangaea broke up about 200 million years ago. Then, approximately 170 million years ago several strings of volcanic islands (terranes) collided with the western edge of the North American continent. The collision occurred over many millions of years; the plates were moving only a few centimeters per year. The sedimentary layers that had been piling up along the coast were folded and faulted (thrust faults) by the compressional forces, forming the Rocky Mountains. (Had the crumpling and telescoping not occurred, BC would be 300 km wider.) Erosion wore the Rockies down at the same time and has continued to do so ever since then. (Had erosion not occurred, the mountains would be 10 km higher than they are today.)

The volcanic islands that collided with North America have been deeply eroded over time. Isostatic uplift has brought their deeply-formed, batholithic roots to the Earth's surface. The Coast Mountains north of Vancouver, which extend along the edge of the continent to Alaska, are the roots of such islands.

More recent volcanics have cross-cut the Coast Mountains forming, for example, Mt. Garibaldi near Squamish (Pleistocene) and Mt. Edziza north of Terrace (Recent).

A **hot spot** has formed the Anahim chain of volcanoes southeast of the Queen Charlotte Islands. The North American plate has been moving northwestward over the stationary hot spot forming a linear belt of volcanoes with the oldest at the west end and the youngest furthest east.

The Juan de Fuca plate is being subducted under the North American plate. Composite volcanoes in the Cascade Mountains, like Mount St. Helens, Mount Rainier and Mount Baker, have formed above this boundary. Motion along this plate boundary also threatens a big, 9.5 magnitude earthquake expected in this area.

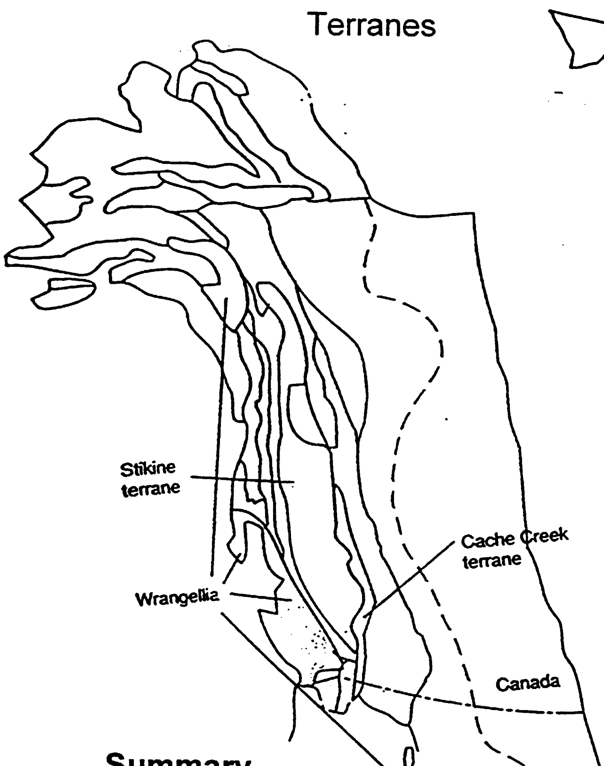
Rock Types

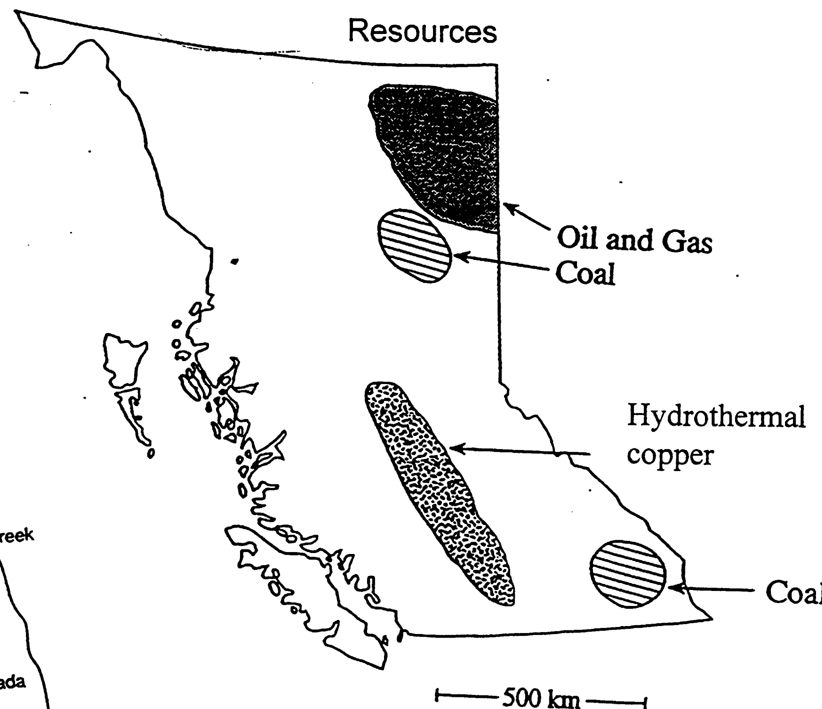
British Columbia has all three rock types:

- **Igneous** - where there were/are volcanoes, roots of volcanoes, cross-cutting dikes or sills.
- **Sedimentary** - in the Rocky Mountains and local areas across BC from erosion of uplifted areas during mountain building. (Sedimentary rocks make up 3/4 of the continent's exposed rock.)
- **Metamorphic** - in collision zones (from 170 million years ago or the current subduction zone) where significant T, P and water content changes alter rocks.

Resources

The sedimentary layers in the Rockies contain **coal** that formed from vegetation falling into the swamps before the collision. Northeastern BC and Alberta have **oil and gas** derived from the marine organisms that lived and died in the inland sea. **Metallic minerals**, such as copper sulphides, form by magmatic processes and, consequently, are found near the Coast Mountains (roots of ancient volcanoes), the Anahim chain (hot spot volcanoes), and the Cascade Mountains (subduction volcanoes).





Summary

British Columbia formed by elongated segments of mini-continents (terranes) that drifted across the Pacific and docked onto ancient North America. These collisions pushed up the Rocky Mts. Erosion by glaciers, rivers, mass wasting, and wind has formed the landscape seen today.

Minerals

Silicates

Silicates are a class of minerals that make up most of the Earth's crust. (Oxygen makes up 46.6% and silicon makes up 27.7% of the crust.) They include all common rock-forming minerals, i.e. all those in Bowen's Reaction Series, and many, many more.

Definitions of Mineral Properties

Cleavage – breaks along one or more flat planes
Fracture – breaks along irregular surfaces (**not** along flat planes)
Hardness – resistance to scratching (**not** resistance to breaking; mineral may be brittle)
Specific gravity - similar to density, a measure of how heavy a mineral is relative to its size
Colour – as seen in regular daylight, it is a property that may vary for one mineral
Streak – colour of the mineral powder, a property that does not vary for a mineral
Lustre – the way a mineral reflects light, metallic (like a metal) or nonmetallic, which includes vitreous (glassy), earthy, pearly, dull, adamantine, etc. Metallic minerals generally have a dark streak; nonmetallic minerals generally have a light coloured streak.
Special Properties - magnetism, e.g. magnetite
reaction with acid e.g. calcite and other carbonates
double refraction, e.g. calcite
fluorescence, e.g. fluorite
salty taste, e.g. halite, sylvite
radioactivity, e.g. K-feldspar, uraninite

Select Minerals

Quartz	hexagonal prismatic crystals, fracture, hardest common mineral (H=7), many colours, vitreous, framework silicate
Mica	muscovite (light) and biotite (dark) are common, sheet silicate, common in metamorphic rocks (lines up under pressure creating foliation)
Garnet	hard (H=7), red (and other colours), vitreous, forms during metamorphosis in some shales, semi-precious gemstone
Asbestos	fibrous, forms during metamorphosis of ultramafics, good insulator, carcinogenic
Hematite	iron oxide, various colours, but always has a reddish-brown streak
Galena	lead sulphide, very dense, metallic, cubic crystal structure
Pyrite	Fool's Gold, metallic, commonly associated with gold, source of acid rock drainage
Chalcopyrite	Fool's Gold, metallic, mined for copper, less dense than real gold
Bornite	peacock ore, metallic, mined for copper
Graphite	carbon, metamorphic origin, high temperature lubricant, pencil lead
Gold	Native element, unattached to other elements, very high density
Fluorite	cubic crystals, cleaves octahedrally, purple and green common, vitreous

Rocks

Rock Cycle

- One rock type can change into another type by natural, physical and chemical forces acting on it. **Igneous rocks** form by melting pre-existing rocks and solidification of that magma. **Sedimentary rocks** form from the weathering and erosion of pre-existing rocks, deposition and lithification. **Metamorphic rocks** form by the application of heat and/or pressure to, or by chemical reactions in pre-existing rocks.

Igneous

- If magma cools slowly (intrusive/plutonic), there is more time for large crystals to grow.
- If magma is thin (i.e. runny), it is easier for large crystals to form.
- If magma cools quickly (extrusive/volcanic), a glassy and/or frothy (vesicular) texture may result.
- Magma near the surface is under less pressure, so gas dissolved in it can "undissolve" to form bubbles in the magma.
- **Pyroclastic textures** result from explosive volcanic eruptions.
- A **porphyry** has two crystal sizes that record two cooling stages of the magma.
- **Felsic** magma is viscous (thick) and light-coloured, has a relatively low density, erupts explosively due to trapped gases, is extruded as rhyolite and intruded as granite, and forms **composite volcanoes**.
- **Intermediate** magma has properties similar to felsic magma, but is extruded as andesite and intruded as diorite.
- **Mafic** magma is thin (relatively runny) but dense, is very high temperature, erupts in relatively smooth flows to form gently-sloping **shield volcanoes**, and is extruded as basalt and intruded as gabbro.
- **Intrusive** features include: sill (parallel), dike (cross-cutting), **xenolith** (unmelted fragment of country rock).

  Obsidian: glassy (can be vesicular), has cooled very quickly, exhibits conchoidal fracture and is generally felsic in composition.

  Pumice: vesicular, cooled quickly from an explosively erupted, frothy magma, and floats on water.

  Pegmatite: very coarsely-crystalline intrusion that formed from a thin (runny), very slowly cooled magma.

  Tuff: volcanic ash glued together.
- **Bowen's Reaction Series** explains the order in which mineral crystals form from a melt as it cools. Olivine forms first; quartz forms last.
- Be able to use the Minerals in Igneous Rocks chart to identify unknown rock samples by the percentage of minerals present and to identify compositionally equivalent rocks.

Sedimentary

Clastic - made of broken rock or mineral grains glued together (lithified); e.g. conglomerate (coarsest), sandstone, shale (finest), breccia (angular)
Chemical - precipitated from solution, crystals may be visible; e.g. limestone ($CaCO_3$), chert (SiO_4), evaporites (gypsum, halite)
Stratification – layering in a sediment or sedimentary rock
Cross-bedding - inclined stratification deposited by big ripples moving in water or air
Ripple marks - asymmetrical in flowing water (e.g. streams), symmetrical in waves (e.g. beach, lake)
Mud cracks – V-shape structures that form in fine-grained sediments that have dried up. They are widest at the top.
Graded bedding - decrease in grain size up through a bed caused by rapid settling of sediment suspended in a turbulent flow (e.g. turbidite)
Varves - annual layers of fine sediment deposited on a glacial lake bottom

- The further sediment has been transported, the more physically mature it will be.
- The longer sediment is in contact with water, the more chemically mature it will be.

Metamorphic

- Pre-existing rocks are changed by heat and/or pressure and/or chemical reactions into other types of rocks. For example:

Shale (sedimentary) → **Slate** (micas line up under P; cleavage) → **Phyllite** (more foliation) →
→ **Schist** (micas larger; imperfect foliation = schistosity) → **Gneiss** (under greater pressure, under certain conditions)

Granite (igneous) → **Gneiss** (compositional banding = gneissic banding)
Conglomerate (sedimentary) → **Meta-conglomerate** (stretched pebbles, break across pebble)
Limestone (sedimentary) → **Marble** (coarser crystals)
Sandstone (sedimentary) → **Quartzite** (recrystallized quartz grains)

Foliation - planar structure in a metamorphic rock caused by parallel alignment of linear or planar minerals (as seen in slate, phyllite, schist, and gneiss)
Non-foliated – lacking metamorphic foliation and consisting predominantly of equidimensional grains (e.g. quartzite, marble)
Compositional banding – metamorphic foliation caused by recrystallization of minerals in the rock and segregation into bands of differing composition or texture
Contact metamorphism – changes in country rock caused by the heat of a nearby intrusion
Regional metamorphism – high T and P changes to bedrock over a large area due to deep burial or tectonic collision
Chill margin - edge of an intrusion exhibiting relatively fine crystal size due to rapid cooling of the magma adjacent to the country rock

Mineral Resources

Economic Minerals:

- are profitable to mine
- must be adequately concentrated and in great enough volume
- mining depends on supply and demand and value (selling price)
- mining requires physical accessibility
- mining requires assurance of environmental protection

Magmatic Deposits

Kimberlite – isolated ultramafic pipes from mantle-derived magma, bearing diamonds locally.
Fractional crystallization – accumulations of mineral crystals that settle to the bottom of a magma chamber, e.g. chromite and magnetite.
Pegmatite – very coarsely crystalline rock commonly formed from residual magma with higher concentrations of rare elements – e.g. lithium, boron, and uranium.
Hydrothermal – minerals precipitated from hot, metalliferous fluids that have escaped from cooling magma (or groundwater heated by adjacent magma), commonly sulfide ore or Native elements, e.g. copper, lead, zinc, gold, silver, platinum, uranium.

- **Magmatic activity** commonly occurs along plate boundaries, so mineral deposits are commonly found along ancient boundaries.

Minerals and Metals of Value (see tables provided/created in class)

Formation of Natural Gas and Oil

Numerous marine organisms that live in the water column, and are rich in carbon and hydrogen, settle out on to the seafloor when they die. If they are rapidly buried by sediment, the organic tissues do not decay. Burial is accompanied by an increase in P and T, which slowly over time causes chemical reactions that break down the large complex organic molecules into simpler hydrocarbon molecules. As breakdown continues, large thick hydrocarbons become progressively smaller and thinner until, finally, very simple, light, gaseous molecules (natural gas) are formed. This process mostly occurs between 50-100° C. At higher temperatures methane gas (CH_4) forms. Oil and gas formation takes time. No petroleum is found in rocks younger than 1 to 2 million years old.

Porosity - the volume of pore space in a rock.

Permeability - the interconnectedness of pore space in a rock. A good oil reservoir has high porosity and high permeability.

Oil traps - porous and permeable reservoir rock with an impermeable cap rock that prevents the oil/gas from migrating to the surface.

Coal

Coal is the remains of land plants that have fallen into and accumulated in a tropical swamp.

Stages of Coal Formation

peat ⟶ **lignite** ⟶ **subbituminous** ⟶ **bituminous** ⟶ **anthracite**
low heat, low carbon ⟶ high heat, high carbon
softer ⟶ harder

- The higher the T and P, and longer the time, the harder and higher heat coal is produced.
- If the burial T is too high, the organic tissues metamorphose; graphite is formed. (Graphite does not burn.)

Methods of Exploration

- Gravitational survey, look for gravitational high
- Magnetic survey, look for magnetic high
- Soil sample geochemical analysis
- Mapping bedrock geology and interpreting history
- Drilling and coring
- Drilling and geophysical logging