Fragile System

What is density?
Density is mass/volume, or how much mass fits into a space.

How does density relate to stratification?
Density relates to stratification because less dense materials float on top of denser materials; therefore, the atmosphere, the ocean and the Earth are all layered in terms of density.

Explain why disaster scales are based on the Order-of-Magnitude concept, and interpret graphs with logarithmic scales.
Disaster scales are based on the Order-of-Magnitude concept because the "power" indicates intensity of the disaster
Graphs are interpreted with logarithmic scales because most of the graph is off the scale if we use an exponential curve; a log graph is much nicer.

Relate natural disaster risk and intensity to frequency, return period and consequences (costs).
More intense disasters occur less frequently, less intense disasters occur more frequently
Natural disasters are <u>rare</u> events.
The return period, or RP, is the average number of years between disaster events of the same magnitude (M). It is by no means a prediction of when the next disaster of the same scale will next occur, but is an average measurement dividing the time span of the data by the number of cases of the same magnitude. RP(M) = (time span of data)/(# of cases of mag. M)

Explain how recent disasters were associated with the concentration or dilution of energy.
It takes time for energy to build up and to be released.

Compare tectonic rock, hydrologic and biogeochemical cycles.
List the 1st and 2nd most common elements in the earth, ocean and atmosphere.
<u>Earth core</u>: iron, nickel
<u>Earth's crust:</u> oxygen, silicon
<u>Ocean</u>: oxygen, hydrogen
<u>Atmosphere</u>: nitrogen, oxygen

Describe how viscosity and compressibility relate to phase of matter.
Viscosity is a measure of how much fluids resist flowing or changing their shape
Compressibility is the ability to be squeezed or expanded, so that the mass fills less or more space, and is a result in a change in density (mass/volume) of the object, because of the volume change.
<u>Solids</u>: not very fluid, not very compressible
<u>Liquids</u>: very fluid, not very compressible
<u>Gases</u>: very fluid, very compressible

Diagnose the type of strain by the way a material deforms.
Strain is the change in shape or size of a solid object (deformation)
<u>Elastic</u>: an object changes shape when forced by springs back to original when force is released
<u>Plastic/ductile (very plastic):</u> the object permanently changes shape or deform when forced
<u>Brittle</u>: not plastic; fractures instead of bending

How does gravity affect motion and energy?
Gravity is a force that attracts matter to each other. Objects of mass m near the earth's surface are pulled with the force, F = mg

List 5 types of energy, and describe what causes them to vary.
1. work (W = Fd, unit: 1J = 1Nm)
2. potential energy (PE = gmz) *z = distance
3. kinetic energy (KE = $1/2mV^2$)
4. sensible heat ($Q_H = mC\partial T$)
5. latent heat ($Q_E = L\partial m$)

- when solids melt into liquids, or when liquids evaporate into gases, sensible heat becomes stored (hidden) as latent heat
- when gases condense into liquids or when liquids freeze into solids, latent heat is released into sensible heat
- Latent heat (L)
    - Latent heat of vapourisation (L_v)

- Latent heat of fusion (L_f)
- Latent heat for water
    - $L_v = 2.5 \times 10^6$ J/kg
    - $L_f = 3.34 \times 10^5$ J/kg

Explain the 5 main concepts for understanding natural processes as hazards.
1. Hazards can be predicted through scientific analysis
- scientific methods
- to predict a natural disaster
    - identify the location of a hazard
    - determining the probability that an event of a given magnitude will occur

2. Risk analysis is an important element of understanding the effects of hazardous processes
- considers both the probability that a damaging event will occur and the consequences of that event
- difficult to assign probabilities to geologic events because known record of past events is too short/incomplete

3. Linkages exist among different natural hazards and the physical environment
- earthquakes--> landslides + tsunamis, hurricanes --> flooding + coastal erosion

4. Damage from natural disasters is increasing
- due to growth in population, property development in hazardous area, poor land use practices

5. Damage and loss of life from natural disasters can be minimized
- direct (death and damage) and indirect effects (starvation, distress, unemployment)
- requires an integrated approach that includes scientific understanding, land-use planning and regulation, engineering and proactive disaster preparedness

Explain (with examples) how energy conservation applies to natural disasters.
Energy is conserved when it is changed from form to form.
For example:
1. Kinetic energy of an asteroid is converted into sensible and latent heat when it strikes Earth
2. Heat causes water to expand into steam in the Earth's crust which does work, pushing magma, some of which rises into volcanos (increasing PE)
3. Potential energy (PE) of rocks high on the slopes of a volcano are converted into kinetic energy (KE) when they fall down during a landslide or lahar.

Describe relationships between force, pressure, stress, strain, energy, and power.
A ***force*** (F) pushes or pulls (unit: $1N = 1kgm/s^2$).
Pressure (P) is the force per unit surface area, applied perpendicular to the surface. (unit: $1Pa = 1\ N/m^2$)
Stress is force per unit surface area, applied parallel or perpendicular (normal) to the surface (unit: $1Pa = 1\ N/m^2$)
Stress* causes *strain; it tends to strain or deform objects. How the object is deformed depends on the property of the object, whether it is ductile or brittle.
Power is the rate of doing work or the rate of consuming energy (J/s)

Describe population growth and explain why it is important for natural disasters.
The world population growth was exponential over the past 8000 years. Growth rates worldwide are around 1.14% to 1.19% per year. The number of years for population to double, or the doubling time in years, DT = 70 / (%growth rate per year). This only applies to an exponentially growing population

Explain how Earth's carrying capacity and overpopulation are related to the fate of the human race, and anticipate your role in it.
The Earth's carrying capacity is dynamic and may increase with technology, such as production of synthetic materials. Carrying capacity is limited by the resources available on Earth, and with the increase in population density, these resources are quickly depleting. To a point where all resources are used up the human race will have reached carrying capacity because there is nothing we can survive on.

Carrying capacity: the population that can be sustainably supported within a given domain (eg. Earth), given the quantity of food, habitat (living space), natural resources (energy/fuel, water, clean air), sanitation, medical care, etc.

Overpopulation: population that exceeds the carrying capacity of an area or environment

Earthquakes

Use concepts of (1) stress causing strain and (2) plastic versus brittle deformation to explain how energy is released causing earthquakes.

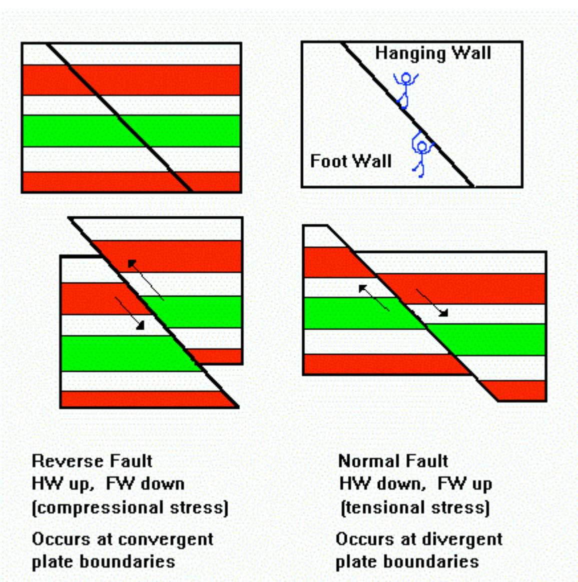
Stress is defined as force per unit area (Units: N/m2 = Pa). There are 3 different types of stress: compression, tension and transverse. Compression forces act towards each other. Tension forces act against each other and transverse stresses act parallel across a plain.

Strain is the deformation in response to stress. Objects change size, shape or volume when stress is applied. There are 3 different kinds of deformations that can occur: elastic, plastic and brittle deformation. ***Elastic*** deformation is a temporary change in shape or size and is reversible if we remove the stress. ***Plastic*** (ductile) deformation is a permanent change in shape or size, and the change is irreversible. Plastic deformation produces folds in some rocks that have a softer property or rocks that are closer to the core (because of high temperature). This usually occurs at high temperature, high confining pressure and low strain rate. ***Brittle*** deformation occurs when there is loss of cohesion due to stress and the material breaks, producing faults. This usually occurs at low temperature, low confining pressure and at high strain rate. In general, rocks that are closer to the Earth's surface are more brittle.

To summarize, stress causes strain. The 3 types of stress are compression, tension and transverse and the 3 types of strain are elastic, plastic and brittle. The type of strain is dependent on how the stress is applied, the temperature and the properties of the object. Earthquakes are due to brittle deformation (the formation of faults).

Recognize visual evidence of tectonic forces in rocks and landscapes (e.g. fault types, folding)

Faults are large brittle fractures in a rock body, and is the point of origin for most earthquakes. Small scale movements are termed ***fractures***, while bigger km-scale movements are termed faults. There are 3 types of faults: normal, reverse and strike-slip fault. ***Normal faults*** are caused by tension, and blocks move away from each other. The hanging wall block moves down relative to the footwall. ***Reverse faults*** are caused by compression, and blocks move towards each other. The hanging wall block moves upwards relative to the footwall. ***Strike-slip faults*** are caused by shear stress. The motion is lateral, and the fault itself is vertical; therefore, there is no hanging wall or footwall blocks.



The hanging wall block is the block above the fault.

The footwall block is the block below the fault.

Explain the global distribution of earthquakes (i.e. rare, large and frequent small quakes) in terms of tectonic plate interactions and the forces that drive them.

Large earthquakes are generally rare, while smaller quakes occur more frequently. Most earthquakes occur at plate margins. There are three types of plate margins: divergent margins, convergent margins and transform boundaries. ***Divergent margins*** occur when plates move apart, and are often associated with volcanism and many smaller scale earthquakes. ***Convergent margins*** occur when plates move towards one another. They lead to small to very large earthquakes. Subduction zones are where the largest earthquakes occur. There are three types of convergent margins: continental plate convergence, oceanic plate convergence and continental/oceanic convergence. The older, denser (oceanic) plate will dive beneath younger ones (continental). ***Transform***

boundaries cause frequent moderate to large scale earthquakes, but <u>not as big as the quakes seen at convergent margins</u>.

Earthquakes can also occur <u>within</u> plates, but are less common. They can also be large and damaging and may occur along old plate boundaries.

What is the difference between strike-slip faults and transform faults?
Strike-slip faults are a simple offset, one of the three fundamental types of faults, where transform faults are faults formed between two different plates moving away from a spreading center.

Describe how the Earth builds, stores, and releases energy in earthquakes. (pg. 46)
The Elastic Rebound Theory describes how earthquakes build energy. First, a pre-existing fault is locked by friction. If the two blocks are under stress, pressure builds and causes elastic deformation (strain). When stress is high enough, friction is overcome and movement takes place, causing brittle deformation of the surface. Stored energy is released as seismic waves and an earthquake occurs at the hypocenter (focus). The energy move as seismic waves through the rock. The two blocks have moved relative to each other and slip occurs along the fault. Each block returns to its undeformed shape and elastic strained is dropped after the earthquake. Strain is slowly accumulated again until the next one. The amount of slip can be measured by markings the distance between two markings, such as a fence that has been separated, or a road marking that has been offset.

Describe how an earthquake moves through the Earth (know types of seismic waves).
During an earthquake, energy is released at the hypocenter. This energy moves as seismic waves through the Earth, and seismic waves are like sound waves in a rock. There are two types of seismic waves: body and surface waves. ***Body waves*** are categorized as P waves (primary) and S waves (secondary). P-waves are fastest and can travel through solids and fluids. S-waves are slower than P waves, and travel through solids only. Surface waves are slower than body waves. As the name suggests, they move along the surface, and therefore cause more damage than body waves. and are categorized as Rayleigh waves and Love waves.

Describe how an earthquake is recorded and how to locate the epicentre.
The seismic waves of an earthquake is recorded using a seismograph. A seismogram is a record of an earthquake. With one station, we can map out how far away the quake is by recording the time between P and S wave arrivals. With 3 stations, we can triangulate the location of the hypocenter and the epicenter.

Compare and contrast the meanings and uses of earthquake magnitude and intensity scales
The magnitude of an earthquake is a measure of the <u>energy released</u>, and is a quantitative scale. The best known example of a magnitude scale is the ***Richter scale***. It measures the order of magnitude by the amplitude, or height of the waves on the seismogram. This method is not accurate for large or distant earthquakes because it underestimates low-frequency shaking. Therefore, this is no longer in use.

A better method is the ***Moment Magnitude scale***, which measures strain energy along rupture surface. With each number higher on the scale is about 32 times more energy released and 10 times more shaking.

Intensity scales are qualitative (descriptive) measurements, and it is what we *feel* in an earthquake. We use the ***Modified Mercalli Scale***, which ranges from 1 (felt by few) to 12 (total destruction. Intensity relates to ground motion during an earthquake, and how we perceive earthquakes depends upon several factors, listed in the next question.

Given any structure, ground type and earthquake location, predict the types and extent of damage likely to be caused by all four seismic waves.

1. Magnitude
   The lower the magnitude, the less intense, since with less energy, waves are less powerful
2. Distance from the epicenter
   The further the location is from the epicenter, the less intense the saves are felt, since seismic waves weaken as the travel a distance.
3. Foundation (ground) material
   Bedrock is less intense than well compacted sediment, and water saturated sediment may liquefy and cause buildings to sink or topple over intact.
4. Structural resistance
   This is the building reaction to ground motion and depends largely on the building design (how stable it is) and the materials the building is constructed of. In general, brick and concrete are bad and wood, steel and reinforced concrete are good building materials to resist an earthquake.
5. Duration
   A more intense earthquake would sustain a longer period of time, whereas a less intense earthquake would be shorter.

Why is earthquake prediction is difficult?
Earthquake prediction is difficult because many earthquakes do not have foreshocks.

What is the difference between prediction and forecasting?
The difference between a prediction and a forecast is that a ***prediction*** is saying an earthquake of a given magnitude will occur in a defined region within a specific period of time. A prediction is specific and therefore highly unreliable. Some examples are:
- deformation at the surface
- foreshock occurrence and strength - many earthquakes don't have foreshocks!
- properties of the crust, both physical and chemical
- animal behaviour

A ***forecast*** is less specific and is a probability statement:
The best way of predicting an earthquake is to use evidence of <u>past quakes and seismic gaps</u> to find frequency of quakes, which is useful for long term, <u>imprecise</u> forecast.

<u>Other predictors of earthquakes are:</u>
1. land level change (GPS)
2. seismic gaps (related to past earthquakes and,
3. physical and chemical phenomena (groundwater levels, temperature and chemistry)

Be aware of earthquake hazards and notice how they can be the cause of other natural disasters
1. ***Ground shaking/rupture***
    - buildings may fall down
    - buildings on bedrock or compacted sediments are safer and wet, loose sediments undergo harsher and longer shaking
    - can also sever transportation corridors; bridges may collapse
2. ***Liquefaction***
    - shaking causes unconsolidated soils to liquefy
    - ground loses cohesion and flows
3. ***Fire***
    - gas and electrical lines and water lines severed
    - buildings collapse and burn
    - can make urban areas inaccessible to fire fighters
    - fire after earthquakes are very dangerous
4. ***Tsunami***
5. ***Ground failure/landslide***
    - earthquakes trigger landslides
    - VERY important in BC

Be aware of large and local earthquakes (why are we expecting an earthquake in BC?)
We are expecting an earthquake in BC because we are located near the Cascadia Subduction zone. The Cascadia Subduction zone is >1000 km long and is a young oceanic plate that is hot and buoyant. It doe not subduct smoothly and subsequently, the plates are locked and stress builds up. Stress causes strain, and this leads to elastic deformation. Some stress in the continent causes brittle deformation. Smaller earthquakes occur, around 1000 per year in BC. Earthquakes occur in BC about 1600 per year, which is about 4-5 a year. However, most are small earthquakes and larger earthquakes are very rare. We expect at least one magnitude 8 or 9 quake in the next 1000 years, and there is a more immediate concern for the crustal quake in the NA plate.

<u>The possible damages in BC are:</u>
1. Liquefaction on unstable ground
2. Shaking: concrete pillar construction
3. Shaking: transportation corridors
4. Fire: extensive natural gas network
5. Landslides

- some estimates of more than 5000 fatalities in the Lower Mainland alone

Know what to do in the event of an earthquake (survival techniques)
<u>Before an earthquake:</u>
- look around to see what may fall on you
- anchor these objects
- locate safe spots
- act it out for children

During an earthquake:

- stay calm and get out of the kitchen
- stay under strong tables or desks (duck, cover and hold)
- stand under archways or inside corner of a room
- avoid doorways
- do not move until shaking stops

After the earthquake:

- deep breaths
- help the injured or get help
- get out of the damaged buildings
- turn off utilities (water, gas, electricity) if damaged
- do not use the phone if possible
- be prepared for at least 3 days without help
- earthquake kit

Volcanos

What are volcanos?
Volcanos form where magma and gas leak out from the Earth's crust and mantle. Magma is created by the melting of pre-existing rock in the Earth's interior and it reaches the surface through fractures and erupts as lava or as pyroclastic material. Magma moves along cracks in the Earth's crust called ***dikes***.

Explain what magma density and magma viscosity are.
Low density materials surface above high density materials. For magma to rise through the crust, it must be (1) less dense than the crust (2) runny enough to flow, or have low enough viscosity and (3) hot enough to stay liquid. Magma has <10% of gas dissolved in it (H_2O, CO_2, SO_2, Cl) therefore this decreases viscosity and decreases density.

Viscosity is the resistance to flow, or the runniness of the substance. This is controlled by the chemical composition and the temperature. Magma viscosity is determined mainly by silica content and temperature. Magmas with high Si are cooler, more viscous and have more dissolved gases than magmas with low Si contents. As dacite, rhyolite or other high viscosity magmas move toward Earth's surface and experience lower pressures at shallow depths, dissolved gases come out of solution. Rapid degassing of high viscosity magmas trigger explosive eruptions. In contrast, basalt and andesite magmas have low viscosities and low gas contents, These magmas tend to flow as lava rather than explode when the reach the surface

List the different categories of volcanic rocks and explain the differences between the magmas they came from.
Magma is composed of several different types of rocks:
1. Rhyolite (Felsic) rocks
2. Intermediate rocks: Andesite and Dacite
3. Basalt (Mafic) rocks

Felsic rocks	Mafic/basaltic rocks
low density minerals (quartz, feldspar)	more dense minerals
light color	dark color
light weight	heavy weight
Ex. granite, rhyolite	Ex. gabbro, basalt

Intrusive and Extrusive rock
Intrusive rocks are magma that freezes in the crust, they form large crystal.
Extrusive rocks are quick cooling, producing tiny crystal. Extrusive rocks derive from magma that has been exposed to the surface.

Explain why some magmas erupt explosively (as pyroclastic material) and some magmas erupt effusively (as lava).

Felsic magma	Mafic magma
high gas content + gooey	low gas content + fluid
explosive eruptions	quiet (effusive) eruptions
gas kept under increasing pressure	gas escapes, pressure released
dangerous	safe
melt at low temperature	melt at higher temperature
high viscosity	lower viscosity
continental	oceanic
high Si, Al, K, Na and Ca	high Fe and Mg, low Al and Si

Explain the differences between pahoehoe and a'a lavas.
Pahoehoe is a Hawaiian term for smooth, ropy lava. Pahoehoe lavas are limited in volume and flow down channels. They flow faster than a'a lava, and generally exhibits fluid-like textures once solid.

A'a lavas are quite blocky on the surface and cooler than pahoehoe lava. Below the cooled surface, the lava is fairly coherent and much hotter. There are larger volume and thicker flows associated with a'a lavas in comparison to pahoehoe lavas.

Describe the different types of volcanic eruptions and how they are related to magma properties.
Types of volcanic eruptions:

Hawaiian	Strombolian	Vulcanian	Pelean	Plinian		Phreatomagmatic
Basaltic magma	Basaltic/ andesitic magma	Viscous andesitic/ rhyolitic magma	Dome collapse	Andesitic/ rhyolitic ash		Contact between magma and water
Low viscosity	Bombs, lavas	Continuous	Block-and-ash flows	Pyroclastic flows		May be any type of eruption in contact with water
Non explosive	Mildly explosive	Very explosive	Violently explosive	Violently explosive		Violently explosive

Describe the distribution of the world's active volcanoes.
Approximately two thirds of all active volcanoes on land are located along the *Ring of Fire*, which surrounds the Pacific Ocean. The volcanoes lie above the subduction zones bordering the Pacific, Nazca, Cocos, Philippine, and Juan de Fuca plates.

List the three types of plate boundaries and the different types of volcanoes that occur at these plate boundaries.

1. Subduction zones (convergent)

In a subduction zone, oceanic crust, which is denser than continental crust and commonly covered by thick, wet sediments is carried into Earth's mantle. Rising heat and pressure dry out the subducting crust in a process called dehydration. Water lowers melting temperature of overlying mantle rocks and causes them to melt, forming magma that rises through the crust to erupt on the surface.

Stratovolcanos occur at subduction zones and thus are the most common type found around the Pacific Rim BC is associated with the Cascadia subduction zone. More than 80% of terrestrial volcanic eruptions have come from volcanoes above subduction zones. Andesite is the dominant volcanic rock, produced by mixing of basaltic magmas with continental crust and fractionation. Continental crust has a higher silica content than basaltic magma; thus, andesite has a silica content between those of basalt and rhyolite.

2. Mid-ocean ridges (divergent)

In other areas, plates move away from one another instead of colliding. Commonly, this occurs in the oceans along mid-ocean spreading ridges, where basaltic magma derived directly from the asthenosphere, part of the Earth's upper mantle, rises to the ocean floor to create new crust. This magma mixes very little with other materials, therefore the lavas are made almost entirely of basalt. Where spreading ridges occur on land such as Iceland, ***shield volcanoes*** are formed.

Describe the type of volcanoes that occur at hot spots.

1. Hot spots beneath the oceans

Volcanoes are found where hot mantle material wells up beneath a plate at a stationary point rather than at the boundary between two plates. The upwelling mantle material, focused on a single spot, creates a volcano. However, the plate continues to move slowly and a series of volcanoes form, becoming progressively older in the direction of the plate movement. An example would be the Hawaiian islands, built from submarine eruptions of basaltic lava similar to those at mid-ocean ridges

2. Hot spots beneath continents

Caldera forming occur in this tectonic setting, and they are extremely explosive and violent. They are associated with dasitic and rhyolitic magmas. An example would be Crater Lake.

What are volcanic domes?
Volcanic domes are steep sided mounds of lava that form around vents from the eruption of highly viscous, Si rich magmas (felsic)

Describe the tectonic setting of British Columbia and determine the dominant type of volcano that occurs here.
BC is located close to the Juan de fuca plate, which is subducting beneath the North America plate. Crustal rocks melt above the Juan de Fuca plate beneath the Cascade Range and the southernmost Coast Mountains. THe magma rises to the surface to form the Cascade volcanoes.

The Cascade Volcanoes (also known as the Cascade Volcanic Arc or the Cascade Arc) are a number of volcanoes in a volcanic arc in western North America, extending from southwestern BC through Washington and Oregon to Northern California, a distance of well over 700 mi (1,100 km). The arc has formed due to subduction along the Cascadia subduction zone.

The Cascade Arc includes nearly 20 major volcanoes, among a total of over 4,000 separate volcanic vents including numerous ***stratovolcanoes, shield volcanoes, lava domes, and cinder cones***, along with a few isolated examples of rarer volcanic forms such as tuyas.

Describe the morphology, dominant rock type and typical eruption style of the different types of volcanoes.

Volcano Type	Shape	Si Content	Viscosity	Rock Type	Eruption Type
Cinder cone	Steep cone, commonly with summit crater	Low	Low	Basalt	Explosive activity
Shield volcano	Gentle arch or dome with gentle slopes	Low	Low	Basalt	Lava flows, some explosive activity
Composite/ Stratovolcano	Cone-shaped with steep sides	Intermediate	Intermediate	Andesite	Combination of lava flows and explosive activity
Volcanic dome	Dome shaped	High	High	Rhyolite	Highly explosive

- ***tephra*** (fragmented debris) can be erupted from shield volcanoes; tephra range in size, may form bombs, when accumulated, called pyroclastic deposits which, when fused, form pyroclastic rocks
- Stratovolcano has <u>interlayered</u> lavas and pyroclastic deposits that give its conical shape, the lava is rather viscous and rarely flow more than a few km from the vents.
- Cinder cones are relatively small and round/oval in form, and have a crater at their top
- some cinder cones flank larger volcanoes, lie along normal faults or along cracks or fissures

Explain how the size of a volcanic eruption is estimated.
The size of a volcanic eruption is estimated using ***VEI, or Volcanic Explosivity Index***, which is a logarithmic scale that describes the size of an explosive volcanic eruption.
<u>Key characteristics defining VEI:</u>
- volume of ash produced
- height of eruption cloud above the vent
- duration of eruption

In the scale of 0 to 8 of VEI, each interval represents an increase in a factor of ten. For example, an eruption of VEI 4 is 10 times larger than a 3 and 100 times larger than a 2.

Explain what lava flows, fire fountains, lava bombs and volcanic ash are and how they form.
Lava flows are flows of basaltic lava; basaltic lava flows such as pahoehoe and a'a flow because of the low silica content and non-explosive property of the lava (mafic). It has a low viscosity but usually travels fairly slowly (0.01-30 km/h)

<u>Hazards</u>: can cause millions of dollars of damage to property, can kill thousands and cause homelessness, create fires, destroy water tanks, explode fuel tanks, flood, famine and poisonous gases

Fire fountains are when basaltic lava contain a significant amount of gas and a small explosive eruption occurs. As the partially liquid drops fall back to the ground, they may coalesce to form a lava flow

<u>Hazards</u>: the lava can be hot

Lava bombs are smooth surfaced, shaped by fragmented debris rotationally falling and cooling. They usually lie close to the origin of eruption.

Hazards: if close to the eruption, or if the volcano was highly explosive, may be a danger

Volcanic ash, or pyroclastic falls are dangerous because during explosive volcanic eruptions, ash falls downwind of the volcano. The ash may be deposited over a vast area.

Hazards: breathing ash can be deadly because it has glass-like qualities, the darkness can be very scary and roofs may collapse from the weight of the ash where people are trying to shelter. They may also be hazardous to aircrafts because ash may be sucked in by the engines and stop. Windshields are scratched and break, and can cause turbulence.

Other impacts: buildings collapse under weight, respiratory illness such as asthma and bronchitis and silicosis, damage to machinery, contaminate surface water and kill aquatic life, increase acidity of water and destroy vegetation and crops

Explain what pyroclastic flows, lahars, volcanic domes, sector collapses, lateral blasts and toxic gases are and how they form. Describe their hazards.

Pyroclastic flows are the most lethal eruptive phenomena, since dense avalanches of hot gas, ash and volcanic rock fragments cascade down the slopes of a volcano.

How they form/origin:

- small fountain
- collapse of a volcanic column
- dome collapse

Hazards: They usually stay in valleys but if they get big enough, they can flow over ridges, or even over water. Their velocity is generally high, and can range from 50-500 km/hr, and their temperature can reach up to 1000C. People caught in pyroclastic flows have no chance of survival.

Lahars are flows of water and loose volcanic debris (mud and volcanic rock), and can come down in blocks; they are especially prevalent at snow-clad and ice-clad volcanoes

How they form:

Hazards: They usually flow along valleys and are very dangerous. Their speed is slower than pyroclastic flows but can reach up to 50 km/hr and up to 200C. They are escapable with forewarnings.

eg. Mr. St. Helens, Mt. Pinatubo

Volcanic domes/Lava domes are roughly circular mound-shaped protrusion resulting from the slow extrusion of viscous lava from a volcano. The geochemistry of lava domes can vary from basalt to rhyolite although most preserved domes tend to have high silica content. The viscosity prevents lava from flowing very far.

How they form: slow extrusion of viscous lava from a volcano

Hazards:

Sector collapse occurs when a volcanic edifice is weakened and part of the volcano collapses. During a collapse, a debris avalanche occurs and a scalloped scar remains.

How they form: weakening of a part of the volcano

Hazards: debris avalanche, can lead to lateral blasts

Lateral blasts are eruptions that take place on the flanks of a volcano instead of at the summit

How they form: Lateral eruptions are typical at rift zones where a volcano is breaking apart. Since it is easier for molten rock to flow laterally out the sides of weak flanks, the flank gives way before magma is pushed up through a conduit that feeds magma to the summit. These features are commonly found at shield volcanoes and produce basaltic lava flows and cinder cones

Hazards: ?

Toxic gases are the gases released by volcanos and are typically highly acidic, (pH 1) and in comprised of H_2O, CO_2, HCl, SO_2 and HF.

How they form: released from cracks or fumaroles, or from volcanic eruptions

Hazards: breathing in these gases can cause asphyxiation (O_2 deficiency) and death

Explain what a volcanic hazard map is and why they are useful.

A volcanic hazard map is produced by compiling existing data and examining the type and distribution of deposits from past eruptions to predict the future. They map out the relative locations of ash fall, pyroclastic flow, lahars, bombs and lava flows, and the regions that are in immediate danger of each threat.

What is the best technique to reduce a pyroclastic flow threat?

The best way is to prevent construction/evacuate around the base of stratovolcanoes.

List the the primary volcanic hazards?
1. Lava flows
2. Pyroclastic falls (ash fall)
3. Pyroclastic flows
4. Sector collapse
5. Lahars
6. Toxic gases

What are the other natural hazards linked to volcanoes?
1. Fire (ignited by lava flows, pyroclastic flows, superheated bombs)
2. Earthquakes (preceding an eruption)
3. Landslides (sector collapse and lahars)
4. Tsunami (triggered by sector collapse)
5. Floods (triggered by volcanic eruptions beneath glaciers)
6. Climate change (ash and SO_2 can remain in the atmosphere for more than a year)

How do pre-eruption quakes differ from eruption quakes?
Pre-eruption quakes come in swarms, and their magnitude are usually less than M5. They increase in number, are close to eruption location and become shallower.
Eruption quakes are sustained of magnitudes M2 to M6, are close to eruption location and also become shallower.

List the different volcano monitoring techniques and the instruments that are used.
<u>The following methods are useful because magma moves upward from deep to shallow, causing the volcano to bulge and change shape to allow magma movement:</u>
TM (tiltmeter) measures the changes in the angle of slope.
GPS measures changes in position
Traditional surveying
InSAR measures by satellite the changes in elevation (cm-m) using regular radar surveys. The brighter the color, the greater the change in elevation

<u>The following techniques are used to monitor gas emissions:</u>
COSPEC is a correlation spectrometer that identifies new gas rich magma. It is dangerous because surveyors need to be close to "look" thorugh the volcanic gas by examining the UV light from the sun. CO_2 and SO_2 have distinctive signals when they deflect UV light, and from this technique, total amounts of each are calculated
FTIR is an infrared spectrometer; similar to COSPEC
Direct sampling

<u>Satellite monitoring tracks the following:</u>
Thermal pulse
Ash tracking
SO_2 tracking
- satellite monitoring is ideal for early warning for airline routes and remote areas and have global coverage, but is expensive

<u>Other techniques:</u>
AFMs, or acoustic flow monitors monitors lahars
Thermal videos

Discuss the way British Columbia's volcanoes are monitored.
By seismometers, mainly!

Evaluate the hazards to Vancouver associated with an eruption from Mt Baker.
Mt. Baker is a significant lahar hazard in surrounding valleys such as abbotsford, which is inhabited by approximately 1600000 people. However, lava and pyroclastic flow hazards are low because immediate areas to Mt. Baker are uninhabited.

The volcano that is greatest risk to Canada is in the US, Mt Baker. It is a great stratovolcano formed by numerous eruptions over the past 30000 years. The hazards of greatest concern are ash fall, landslides, lahars and the filling of river valleys with sediment.

A major eruption of Mt Baker could spread ash over Vancouver, Abbotsford, Chilliwack, and other cities and towns in southern BC. The ash would at least temporarily paralyze air and ground traffic. The rocks around Mt Baker's summit crater have been extensively altered to soft clay minerals by the circulating, hot acidic groundwater. The altered rocks could fail if the volcano became inflated with magma at the onset of an eruption. Landslides could also occur on the steep flanks of the volcano.

During the eruption of Mt Baker, hot volcanic debris would mix with water melted from snow and ice on the summit and flanks of the mountain to form large lahars that would rush down nearby river valleys. In the worst case scenario, a large lahar might reach Bellingham. Lahars might also enter Baker Lake, a reservoir near the base of the volcano and displace enough water to overtop the dam or cause it to fail. Failure of the dam would cause lahars for the communities below.

Landslides

Explain how the impact of landslides depends on 1) population density, 2) economic infrastructure, and 3) population preparedness.

1. The higher the population density, the more people may be affected when a landslide hits an area. Conversely if there are no inhabitants, a serious landslide will not kill anyone.
2. Landslides can cause a lot of damage to infrastructure if they are built in a location prone to landslides.
3. A hazard map can allow the population to be more prepared in case of a landslide, as well as avoiding building roadways near steep slopes, installing nets to catch rockslides, building barriers, removal of unstable material, drainage and anchors, etc. This can reduce the number of deaths in the event of a landslide.

Explain why British Columbia has the highest frequency of landslides in Canada and what we should expect as our population expands into the mountains.

Amount of rain
High slopes

How do we identify potential landslides?

1. Cresent-shaped cracks or terraces on a hillside
2. A scalloped or recessed crest of a valley wall
3. A tongue-shaped area of bare soil or rock on a hillside
4. Large boulders or piles of talus at the base of a cliff
5. An area of tilted, or jack-strawed, trees
6. Trees that are convex at their base but straight higher up
7. Exposed bedrock with layering that is parallel to the slope
8. Tongue-shaped masses of sediment at the base of a slope or at the mouth of a valley
9. A hummocky, or irregular and undulating, land surface at the base of a slope

Distinguish between the 3 main failure modes (falls, flows, and slides) and how they are influenced by geology.

1. ***Falls***
    - steep slopes (rock falls)
    - material detach due to weakness
    - falls due to gravity and is therefore very fast
2. ***Flows***
    - slow to fast
    - consists of soil, mud and wet debris
    - water is very important
    - fluid/plastic flow of material
3. ***Slides***
    - slow to fast
    - consists of soil, rock and debris
    - move as a coherent mass along the surface of failure
    - 2 types:
        - <u>curved surface</u> slides are rotational, constituted of weak material and there is a curved scarp above the slide
        - <u>flat surface slides</u> are traditional slides and are usually of stronger material sliding from the plane of weakness
4. ***Combination***
    - any combination of fails/flows/slides

Categorize, identify, and name a variety of different landslides.

There are different types of landslides because earth materials may fail and move downwards in many ways.

<u>4 variables underpin most landslide classifications:</u>

1. mechanism of movement (fall, topple, slide, flow or complex movement)
2. type of material (rock, consolidated sediment, or organic soil)
3. amount of water present
4. rate of movement (usually classified as fast if it can be discerned with the naked eye)

Common types of mass movement:

Mechanism	Mass movement type	Characteristics
Fall	Rock fall	Individual rocks bound downward or fall through the air.
	Slump	Coherent blocks of rock or sediment slide on an upward curved surface; also called a rotational landslide.
Slide	Debris slide or avalanche	Sediment or soil slides on an inclined surface; also called an earth slide
	Rock slide	Large blocks of bedrock slide on an inclined surface, typically bedding planes, foliation surfaces or joints
	Rock avalanche	A type of rockslide in which the fragmented rock mass flows at very high velocities, commonly for long distances.
	Creep	Slow downslope movement of rock and soil. Sackung is deep seated creep of large masses of fragmented rock along poorly defined slip surfaces
Flow	Earthflow	A flow of wet, deformed soil and weathered rock
	Debris flow	A cement-like mixture of rock, sand, mud, plant debris and water travels rapidly down a stream channel or ravine; includes mudflows and lahars
	Complex	combination of two or more types of mass movement

Define Angle of repose.
The angle of repose is the steepest angle a slope can maintain before it collapses.

Assess the balance between the strength of the slope and the destabilizing forces acting on it (Factor of Safety).
The Factor of Safety (Fs) is the ratio of shear strength (resisting forces) to shear stress (driving forces). At the angle of repose, shear stress is balanced by shear strength, and Fs is equal or slightly greater than 1.

$$Fs = \frac{\text{resisting forces}}{\text{driving forces}}$$

Therefore, if resisting forces are lesser than driving forces/stress imposed on the system, Fs would be low and the system would subsequently be unstable. When resisting forces are greater than the stress, Fs would be greater than 1 and the system is stable. No landslides would occur in this case.

Compare and contrast landslide causes and landslide triggers.
Landslide ***causes*** are often long-term, leading to instability of the slope, decreases shear strength but does not initiate movement.

Landslide ***triggers*** are usually short-term events that translate instability into motion (initiates failure). There can be many causes, but only one trigger.

List and describe several external causes of landslides.
<u>External causes of landslides:</u>
1. ***High slope angle***: steep slope = more movement
2. ***Undercutting***: lower part of the slope is removed leading to lack of support
3. ***Overloading***: adding weight of buildings, roads, vegetation
4. ***Vegetation***: roots bind loose material and removal can make slopes unstable; however, too much heavy vegetation can cause overloading
5. ***Climate***: if temperature and rainfall is high, sediments are loosened, rocks are weathered and fractured and the earth is saturated , decreasing friction and shear strength and also causes overloading

List and describe several internal causes of landslides.
Internal causes of landslides:

1. water content
    - increases rate of weathering
    - frost wedging in colder climates allows water to enter cracks and fracture rock and freezing causes fracture apart

- 3 cases:

No water	Some water (moist)	Too much water (saturation)
low angle of repose	high angle of repose	very low angle of repose
dry sand	moist sand	saturated sand
	cohesion properties of water increases friction and shear strength	adds weight, overloading
	sandcastle effect	decreases friction and shear strength

2. Inherently weak materials
    - for example, clay is more stable when salt is added because clay particles will be attracted to each other
    - shaking and compaction destabilizes clay because electrostatic Van der Waals forces are weak and easily broken
    - salt content is lowered by percolating groundwater
3. Adverse geologic structures
    - structures inherently in rock that make it closer to failing
    - unfortunate bedding or fracture orientation
    - structures angled in an unstable direction or layered precariously

List several landslide triggers.
Some landslide triggers include:
- intense rainfall
- rapid snowmelt
- water-level change
- volcanic eruption
- earthquake shaking
- rapid erosion
- anthropogenic (caused by humans)

Compare and contrast several key triggers and causes of landslides and how they affect the force balance equation (i.e. Factor of Safety).
For example, inherently weak materials will decrease the force of cohesion and decrease shear resistance and therefore the factor of safety is low. We will see mass movement in this case.

In adverse geological structures, there is a decrease of friction which means there is a decrease in resistance which increases the factor of safety.

In water saturated materials, there is a very low angle of repose because of the increase in weight (increase in shear stress) and a decrease in friction (decrease in shear strength/resistance) and therefore Fs is low.

Explain how liquefaction landslides develop in sensitive marine clays.
Quick clay is a unique form of highly sensitive marine clay, with the tendency to change from a relatively stiff condition to a liquid mass when it is disturbed. Undisturbed quick clay resembles a water-saturated gel. When a mass of quick clay undergoes sufficient stress, however, it instantly turns into a flowing ooze, a process known as liquefaction. A small block of quick clay can liquefy from a stress as simple as a modest blow from a human hand, while a larger deposit is mainly vulnerable to greater stresses such as earthquake vibrations or saturation by excess rainwater. Quick clay behaves this way because, although it is solid, it has a very high water content, up to 80%. The clay retains a solid structure despite the high water content, because surface tension holds water-coated flocs of clay together in a delicate structure. When the structure is broken by a shock, it reverts to a fluid state.

List and describe the site conditions (Causes and Trigger) that lead to the development of the Rissa quick clay slide in Norway.

Causes:

- Many years ago, during deglaciation the sea transgressed to the retreating ice
- marine clay up to surface elevations of 200m above present sea level
- bedrock is undulated, valleys were filled with marine sediments
- rain and surface water subject the marine clay surface to erosion
- with time the top 5 meters have altered to a weathered crust of stiff fissured clay
- at the same time, an upward flow of fresh groundwater from fissures in bedrocks and through sand layers gradually leeches the salt out of the water of marine sediments
- marine clay liquefies when subject to impact or disturbance

Trigger:

- the slide was initiated in a farmhouse, where a new wing was to be added to an existing barn
- during the excavation for the basement; the soil matter were placed down by the shoreline of the lake
- the slide progressed retrogressively
- the mass of the slide created small wave on the lake
- waves on the lake propagated to the city of Leira across the lake and caused a great deal of damage

Relate the type of landslide damage expected as a function of its velocity.

Falls are very fast.
Slides are slow to fast.
Flows are slow to fast.

Identify tell-tale signs of an unstable slope.

1. debris below
2. scarp from pre-existing landslide
3. undercutting
4. steep slope
5. deforestation

What are some linkages between landslides and other natural hazards?

Earthquakes, volcanoes, storms and fires can all cause landslides. Landslides may be responsible for flooding if they form a debris dam across a river. A large landslide can also trigger a tsunami or cause widespread flooding if it displaces water out of a lake or bay.

Compare and contrast avoidance, prevention, and protection strategies for dealing with landslide hazards.

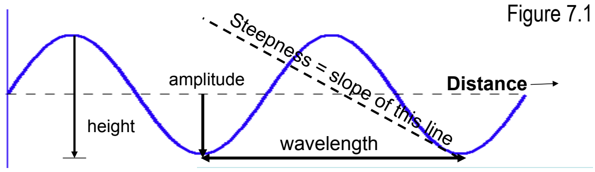
Avoidance- move to a different area, avoid the problem
Prevention- do something to make sure events do not start
Protection- protect the area that might be affected by a landslide

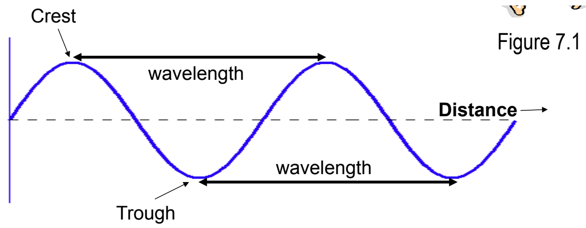
List the mitigation techniques commonly used for avoidance, prevention and protection strategies.

1. ***Avoidance*** by hazard mapping, modeling (computer), geological mapping (surrounding geological features) and determining the frequency (total number of events per year) and magnitude
2. ***Prevention*** by anchoring (cables), removal (of unstable material), stabilizing slopes (increase resisting force at the toe of landslide) and drainage (of water)
3. ***Protection*** from debris flow, setting up rock fall nets, barriers and netting

Waves

Identify key properties of waves.





The shape of the wave:
Crest is the highest point of the wave
Trough is the lowest point of the wave
Wavelength (L or λ) is the distance for one full cycle (crest to crest or trough to trough)
Wave height (H) is the vertical distance from crest to trough
Amplitude (a) is half of the height, or (1/2)H
Steepness is the height divided by the wavelength, or H/λ

Wave motion:
Period (T) is the time for one wavelength to pass a point (in seconds/cycle)
Frequency (f) is the number of waves per time (in cycles/second)
Celerity (c) is λ/T, or distance over time (in m/s). This if often just called speed.

Waves require a medium and a generating force. The generated waves carry ENERGY through the medium.

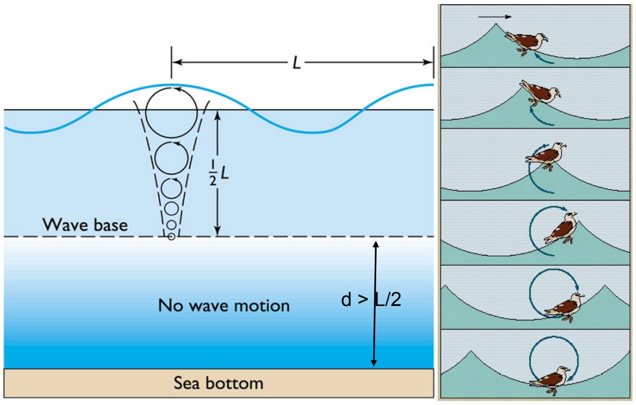
Use these properties to determine wave speed and behavior in either shallow or deep
In ***deep*** water, longer waves travel faster than shorter waves. Waves travel in orbitals

In ***shallow*** water, waves travel slower over shallower depth. Waves travel in elliptical. Wavelength is not important in shallow water.

Deep water waves	Intermediate waves	Shallow water waves
Deep water wave: $d \geq \frac{L}{2}$	Transitional/ Intermediate waves: $\frac{L}{20} < d < \frac{L}{2}$	Shallow water wave: $d \leq \frac{L}{20}$
Wave does not 'feel' the ocean floor – • Wave speed (c) depends on wavelength (L) $c = \sqrt{\frac{gL}{2\pi}}$ OR • Speed can also be expressed with L and T $c = \frac{L}{T}$ • T is easy to measure (e.g. w/a watch), so with some math…. $c = 1.56T$		Wave 'feels' ocean floor • Speed is determined by DEPTH (d) only $c = \sqrt{gd}$ $c = 3.1\sqrt{d}$

Explain how waves move matter and energy.
Water moves back and up, and then down and forward, in a ***circular motion*** (in orbits). Energy passes through the water, but there is no net movement of the water! Wave orbits are the largest at the surface and orbits decrease/attenuate with depth. Orbits disappear below d> λ/2.

At wave base, orbit is 1/23rd of orbit at the surface. At d> λ/2, there is essentially NO movement. Orbital motion decreases with depth in open water. Water remains in place and is the medium for the wave energy to travel through (except near the shore).



Describe the forces that generate waves, eliminate waves, and return the ocean to a flat surface.
<u>Basic wave classification is based on:</u>
1. Generating force- force that adds energy to the water
- gravity of sun and moon generates tides
- earthquakes, volcanoes and landslides generate tsunamis
- wind generates ripples, chop and swell

2. Restoring force- force that returns water to its undisturbed state
- surface tension
- gravity

Explain the factors that determine the roughness of the sea.
3 factors that affect the growth of wind waves are:
1. wind speed
2. wind duration
3. fetch (uninterrupted distance over which wind blows)

There is a maximum state (fully developed sea).

Define wave breaking, and determine when a wave will break.
A ***breaking wave*** is a wave whose amplitude reaches a critical level at which some process can suddenly start to occur that causes large amounts of wave energy to be transformed into turbulent kinetic energy.

Breaking waves = release of energy
<u>The two factors that contribute to breaking waves:</u>
1. Steepness (H/L)>= 1/7
- wave is too high for its wavelength; the wave become unstable and collapses

2. Height/Depth = 3/4
- the base of the wave is restricted by the ocean floor, but the crest is not. The crest collapses forward
- friction causes waves to slowly lose energy and die

Explain differences between plunging and spilling breakers.
We get small, gentle SPILLING breakers in the case of a gentle slope, because waves energy is lost over a wider area. We see large distances between depth contours in the arial view.

We see large, violent PLUNGING breakers in the case of steep slopes, because of sudden releases of energy. Plunging breakers are potentially deadly (short distance between depth contours.

Predict the type of breaker that will be found on a given beach.
When waves reach the shoreline, refraction occurs. Wave fronts approach the coast at an angle. Wave section entering <u>shallow</u> water first slows down, and the offshore part of the wave crest continues at a <u>faster</u> speed. Wave <u>bends</u> towards the shore (towards the slow end)

Wave normals show direction of wave motion. They run <u>perpendicular</u> to line of crests, troughs. Waves <u>converge on headlands</u> because more energy is released. Contrarily, waves <u>diverge in embayments</u> because less wave energy is released.

Rip currents are concentrated return currents from advancing waves. Horizontal current, flowing out to sea, pulls swimmers away from shower (not underwater). To escape a rip current, swim parallel to the shore.

Describe how coastlines affect waves, and how waves affect coastlines.
When waves reach the shoreline, refraction occurs. Wave fronts approach the coast at an angle. Wave section entering shallow water first slows down, and the offshore part of the wave crest continues at a faster speed. Wave bends towards the shore (towards the slow end)

Wave normals show direction of wave motion. They run perpendicular to line of crests, troughs. Waves converge on headlands because more energy is released. Contrarily, waves diverge in embayments because less wave energy is released.

As a result of refraction, waves approach shore at an angle. Beaches change shape as a result of longshore drift. ***Longshore drift*** consists of the transport of sediments (generally sand but may also consist of coarser sediments such as gravels) along a coast at an angle to the shoreline, which is dependent on prevailing wind direction, swash and backwash. This process occurs in the littoral zone, and in or within close proximity to the surf zone.

The result is delicate coastal features. In Barrier Islands, tombolos are created by littoral/longshore drift. Coastlines are temporary and are subject to rapid change

Compare the effects of breakers, groins, seawalls, and other structures on coastal erosion.
Artificial barriers:
1. Groins
- artificial coastal barriers modify normal sediment transport, which causes sediment deposition and erosion in new areas.
- groins ELONGATE structures built perpendicular to the shoreline to trap the sediments (to save the beaches)
- in the 1960s, beaches groins are built to prevent beach erosion. For political reasons, groin construction began in the east. This is bad news for western neighbors!

2. Jetties
- jetties protect an inlet or harbor
- jetties limit this, locking the inlet in place
- jetties are often built in pairs, on each side of an inlet
- jetties are similar to groins, deposition is on the updrift side and depletion is on the downdrift side
- without jetties, inlets will be filled in with sediment due to longshore drift

3. Breakwaters
- tethered float breakwaters dissipate wave energy but allow flow of sediments

4. Sea walls
- sea walls reflect waves with very little energy loss
- waves reflecting off the wall erode sediments and the wall eventually collapses
- beach loss eventually occurs in front of a seawall for a beach experiencing net long term retreat

Determine how two waves will interact, and explain constructive and destructive interference.
Wave interference:
During ***constructive interference***, crests and troughs line up, forming bigger waves (high energy packet)
During ***destructive interference***, crests line up with troughs, forming smaller waves (low energy packet)

Discuss wave reflections, standing waves, and resonance.
Wave Reflections: waves are reflected when they hit a boundary

Standing waves is a wave that remains in a constant position. Two opposing waves combine to form a standing wave. This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference between two waves traveling in opposite directions. In the second case, for waves of equal amplitude traveling in opposing directions, there is on average no net propagation of energy. In a resonator, standing waves occur during the phenomenon known as resonance.

Resonance is the tendency of a system to oscillate at a greater amplitude at some frequencies than at others. These are known as the system's ***resonant frequencies***. At these frequencies, even small periodic driving forces can produce large amplitude oscillations, because the system stores vibrational energy.

Seiche is the resonant waves in a body of water. Tsunami in a harbour/bay is one example. Earthquakes, landslides and wind are also causes. Every enclosed body of water has a natural resonance. The resonance period is longer for larger bodies of water. The period depends on the complexity of the water body and shoreline. Seiche can produce ***standing waves***. An earthquake triggered landslide caused an 11.5 hour seiche.

Relate wave interference and resonance to marine hazards.
Most hazardous for ships at sea are ***rogue waves***. They are common where a strong current flows against wind driven waves from storms. Rogue waves are generated by ***constructive interference***; they can be very dangerous and unpredictable, especially if oversteepened. They are also called monster wave, or freak wave. Rogue waves can be 3-4 times larger than other waves in the same area. They can appear and disappear very quickly.

Explain how a tsunami differs from more common ocean waves.
In the open sea, the typical tsunami features are:
Wavelength (L) 200-400km
Wave speed (c) 200 m/s
Wave height (H) 0.5-1m (small!)
Period (T) 10 min-1 hr
Steepness <<<1

For a common wind driven ocean wave, the wavelength and period is relatively short. Water rotates in circles. Breakers arrive and recede quickly.

For a tsunami coming ashore, wavelength and period are ultralong. Water flows straight. There is HUGE mass of water coming onshore for several minutes.

Discuss why tsunami come ashore so violently.
When a tsunami comes ashore, ***shoaling*** occurs. Shoaling is when the wavelength drops, but the height increases and period stays the same. A tsunami coming ashore is like a rapidly rising tide. Celerity (c) is close to 60 km/hr so you can't outrun it. L decreases from 100km to 20km, H increases from 1m to 30m or more, and there is massive destruction from both advance and retreat of water.

Describe how tsunami form.
Tsunamis form from rapid displacements of large amounts of ocean water. They are caused by:
1. earthquakes
    - vertical submarine fault motion transmits energy to the water column
    - tsunamis are common results of large subduction-related earthquakes
    - you need the RIGHT KIND of earthquake
        - tsunami is unlikely at a strike-slip fault because 2 plates are sliding along each other and there is no vertical motion
        - one tectonic plate must move over/under another thrust motion (reverse/normal fault)
        - in subduction zones, stuck area ruptures, releasing energy in an earthquake
2. volcanic eruptions
    - eruption on land creates a landslide into water
    - landslide without volcano can also work
    - in an eruption under water, volcano top moves, gas and lava is ejected
3. meteor impacts (biggest)
4. landslides
5. icebergs falling from glaciers (smallest)

Identify tsunami warning signs, and know how to respond.
DART buoy system, or Deep Ocean Assessment and Reporting of Tsunami measures pressure changes caused by open ocean tsunami. This system verifies if tsunami exists.

Who's in charge?
1. Pacific Tsunami Warning Center (PTWC)
2. West Coast and Alaska Tsunami Warning Center (WC/ATWC)

To survive a tsunami:
- heed natural warnings; be prepared when there is an earthquake or receding ocean
- heed official warnings
- abandon belongings
- head for high ground and stay there; waves could last for hours. Don't count on roads, which may be damaged from an earthquake

- if time is lacking, go to an upper floor or roof of a strong building
- if time is really lacking, climb a tree or climb onto something that floats
- help neighbors
- expect devastation

Describe the processes responsible for a storm surge, and identify where in a hurricane the maximum surge will occur.
A storm surge is not a true wave; it is a local change in sea level (10m+). Storm surges come from two sources:
1. Low pressure in the hurricane eye (small)
2. High windspeeds and rotation (large) --> maximum surge occurs
Storm surges may last a few hours or a few days. They amplify damage from hurricane driven waves.

List 2 causes of eustatic (global) changes in sea level.
1. Formation and melting of ice sheets ON LAND
    - since last ice age, sea level rose 120m, mostly from melting ice! If remaining ice melts, sea level could rise another 60-70m

2. Thermal expansion- increased volume due to increased ocean water temperature
    - thermal expansion is the largest contributor to global sea level rise today

List 2 causes of regional changes in sea level.
1. Isostatic rebound
    - rise /fall of land due to glacier melt, which continues today

2. Tectonic movements
- In N. America, Atlantic coast SUBSIDING and Pacific coast EMERGING; Cascadia Subduction Zone is forcing land up

Relate these changes to risks for coastal communities.
Sea level rise may cause:
1. <u>submergence</u> of low-lying areas
2. increased <u>erosion</u>
3. increased <u>coastal flooding</u>
4. inundation of natural ecosystems

Shoreline moves horizontally at 1000x the rate sea level rise, for low slope shores. So, if sea levels rise about 15cm, shoreline moves inland 150m! To prevent this, Cape Hatteras lighthouse was moved inland 1km so it wouldn't fall into the sea. <u>Much of BC mainland is presently submerging!</u>

Describe the impact of sea ice and permafrost melt on erosion in the Arctic.
Climate change is a problem right now; ice is disappearing from the Polar seas. According to Archimedes' principle, "any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object." Therefore, floating sea ice is not a problem. However, permafrost (soil frozen during the year) covers the Arctic. The permafrost reinforces the soil and limits erosion. It is now disappearing; when it is gone, erosion rates will increase, which will be a coastal threat.

<u>Barrow Alaska:</u>
Arctic coastal community is protected from storms/waves by:
1. sea ice (absorbs waves, reduces fetch)
2. buffs (with permafrost)
3. lagoons

<u>What happens when the ice is gone?</u>
1. waves crash in- storm surge
2. lagoons flood
3. buffs erode
Devastating surges used to arrive occasionally, but is becoming more common. Erosion accelerated as permafrost melts. Most vulnerable are the housing along the coast, utility corridors and pumping stations and transportation infrastructure.

Describe the impact of Mississippi erosion efforts on New Orleans.
New Orleans is built on the Mississippi delta. Mississippi concentrates sediment (silt, sand, etc) from a huge watershed. Sediment drops out Gulf of Mexico
As a result, sediment builds up in a delta and fans out as new, low elevation land.

Storms

Be wary of the main storm hazards.

The main hazards of a thunderstorm are:

1. lightning
2. tornado
3. hail
4. downpours of rain/local flooding
5. downbursts of air/gustfronts

The main hazards of a hurricane are:

1. they contain thunderstorms
2. storm surge/coastal flooding
3. high waves
4. coastal erosion
5. rain and hail hazards

Describe the different types of lightning, how they form, and what happens when they strike something.

Lightning can be ***Intracloud (IC)*** or ***Cloud-to-ground (CG)***. IC occurs 10 times more frequently than CG lightning. CG lightning can be positive (+) or negative (-). Negative strikes are more numerous and come from cloud base. Positive strikes are less frequent and come from the anvil. Lightening from the anvil travels a longer distance which can happen only with more volts. (to make a spark in air you need 3 billion volts/km). Therefore, they are often stronger and are the primary cause of natural wildfires. 10-25% of Canadian CG lightning is positive.

How can we tell the distance of lightning and what do we do if lightning strikes?

Since sound travels slower than light, we can count the number of seconds between when you see the lightning and when you hear the thunder. Divide that number by 3 and we can estimate the range in kilometers to the lightning. For example, if there is a 9 second difference, 9/3 = 3 km.

If there is only 30 seconds or less between when we see flash and hear the thunder, move indoors and stay there until 30 minutes after the last lightning or thunder. Safe places include fully enclosed metal vehicle with windows up, or substantial permanent building but do not use hard wired telephones.

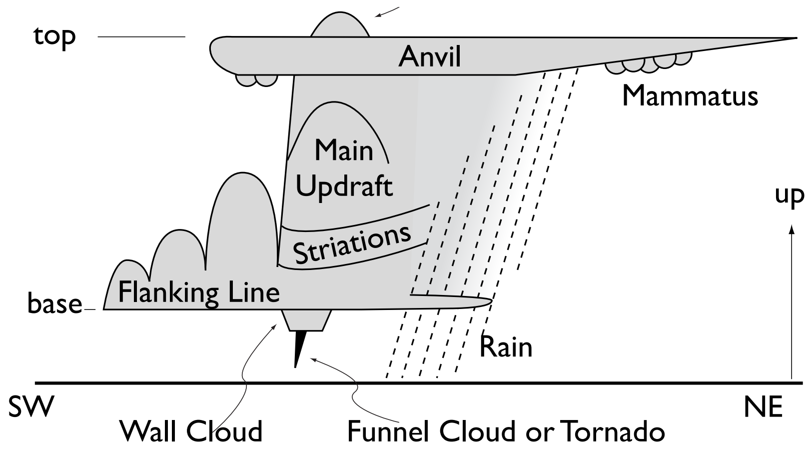
If we are stuck outdoors, avoid unsafe areas such as small structures, huts or rain shelters, metallic objects, or trees, water, open fields, hill tops, etc. Do the "lightning-safety crouch" with feet together, hands over ears. Try reviving those struck by lightning with CPR.

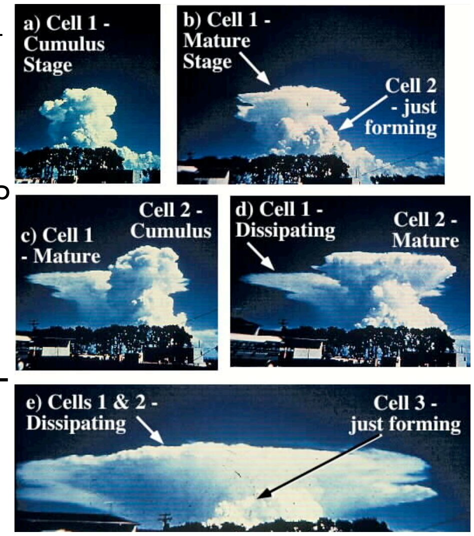
Recognize thunderstorms, be able to identify Tstorm components, and explain how they evolve.

Thunderstorms are thick clouds with lightning and thunder. The cloud top is near the top of troposphere and the cloud base is near the ground. Thunderstorms contain strong updrafts and downdrafts. If there are very strong updrafts, the then dome of clouds overshoots above the anvil, which can be 100s of km in diameter. The main updraft (stem) is 15 km in diameter. The storm derives its energy from ***temperature*** and ***humidity***.

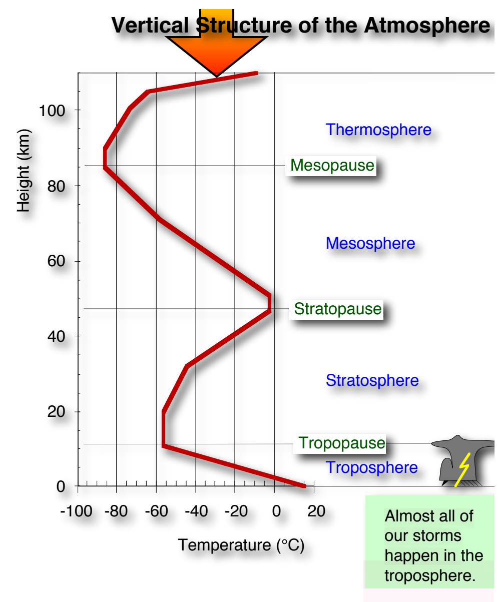
Cumulonimbus (CB)/thunderstorms are made of large cells that evolve during 15-30 minutes. Most thunderstorms contain 2 or more cells, called multicell thunderstorms. Sometimes a very large, rotating single-cell thunderstorm forms, called a supercell T storm. They can cause tornadoes, large hail, frequent lightning, heavy rain and strong winds. Some types of supercell are:

1. low precipitation
2. classical
3. high precipitation





Explain how storms get their energy from the sun.
<u>Solar energy is absorbed at 3 different heights:</u>
1. thermosphere (top)
- absorption of non-visible light
2. stratopause (middle)
- absorption of UV by "good" ozone
3. earth surface (bottom)
- light shines through lower atmosphere with little direct heating of air, but heats the ground instead
- the warm ground heats air in troposphere and powers storms

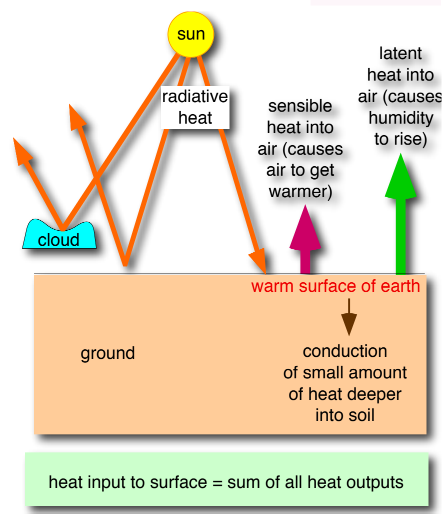


Some solar energy reflects <u>back into space</u>:
- some are intercepted by clouds and scattered back to space
- some reflected from the ground

Some solar energy is absorbed by the <u>ground</u>:
- warms the surface
- changes into:
  - ***Sensible heat*** that warms the air and <u>cause temperature to rise</u>
  - ***Latent heat*** that evaporates water from lakes and vegetation, <u>increasing humidity</u>

**Temperature and humidity fuels storms!

<u>The daily cycle:</u>
Solar heating during the day (input) is like a charging battery.
At night, there is infrared radiation (IR) cooling, which is a loss, like discharge
The greatest accumulation of heat is near sunset every day, at the end of each charging cycle.
Late afternoon and early evening is the most likely time of day for Tstorm formation.



Explain the main characteristics that make a supercell so much nastier than a normal Tstorm.
A ***supercell*** is a thunderstorm that is characterized by the presence of a ***mesocyclone***; a deep, continuously-rotating ***updraft***. For this reason, these storms are sometimes referred to as rotating thunderstorms. LP supercells are usually found in climates that are more arid, such as the high plains of the United States, and HP

supercells are most often found in moist climates. Supercells can occur anywhere in the world under the right pre-existing weather conditions, but they are most common in the Great Plains of the United States.
Supercells are usually found isolated from other thunderstorms, although they can sometimes be embedded in a squall line. Because they can last for hours, they are known as quasi-steady-state storms. Supercells have the capability to deviate from the mean wind. If they track to the right or left of the mean wind (relative to the vertical wind shear), they are said to be "right-movers" or "left-movers," respectively. Supercells can sometimes develop two separate updrafts with opposing rotations, which splits the storm into two supercells: one left-mover and one right-mover.

Supercells can be any size – large or small, low or high topped. They usually produce copious amounts of hail, torrential rainfall, strong winds, and substantial downbursts. Supercells are one of the few types of clouds that typically spawn tornadoes within the mesocyclone, although only 30% or less do so.

1. Overshooting top
This "dome" feature appears above the anvil of the storm. It is a result of the powerful updraft. If an observer at ground level is too close to the storm, they cannot see the overshooting top.

2. Anvil
Formed in the uppermost parts of thunderstorm, the anvil is cold and virtually precipitation free. Since there is so little moisture in the anvil, winds can move freely. The clouds take on their anvil shape when the rising air reaches 40,000-60,000 or more feet. The anvil's distinguishing feature is that it juts out in front of the storm like a shelf.

3. Precipitation-free base
This area, typically on the southern side of the storm in North America, is relatively precipitation free. This is located beneath the main updraft, and is the main area of inflow. While no precipitation may be visible to an observer, large hail and rain may be falling from this area. It is more accurately called the main updraft area.

4. Wall cloud
The wall cloud forms near the downdraft/updraft interface. This "interface" is the area between the *precipitation area* and the *precipitation-free base*. Wall clouds form when rain-cooled air from the downdraft is pulled into the updraft. This wet, cold air quickly saturates as it is lifted by the updraft, forming a cloud that seems to "descend" from the precipitation-free base. Wall clouds are common and are not exclusive to supercells: Only a few actually produce a tornado. Wall clouds that persist for more than ten minutes, wall clouds that seem to move violently up or down, and violent movements of cloud fragments (scud or fractus) near the wall cloud are indications that a tornado could form.

5. Mammatus clouds
Mammatus (Mamma, Mammatocumulus) are bulbous or pillow-like cloud formations extending from beneath the anvil of a thunderstorm. These clouds form as cold air in the anvil region of a storm sinks into warmer air beneath it. Mammatus are most apparent when they are lit from one side or below and are therefore at their most impressive near sunset or shortly after sunrise when the sun is low in the sky. Mammatus are not exclusive to supercells and can be associated with developed thunderstorms and cumulonimbus.

6. Precipitation area
This is the area of heaviest precipitation. Between the precipitation-free base and the precipitation area, a "vaulted" or "cathedral" feature can be observed. In *high precipitation supercells* an area of heavy precipitation may occur beneath the main updraft area.

7. Flanking line
A line of smaller cumulonimbi, or cumulus that form in the warm rising air pulled in by the main updraft. Due to convergence and lifting along this line, landspouts sometimes occur in this region.

LP supercells contain a small precipitation (rain/hail) core separate from the updraft. This type of supercell may be easily identifiable with "sculpted" cloud striations in the updraft base or even a "corkscrewed" or "barber pole" appearance on the updraft, and sometimes an almost "anorexic" look compared to classic supercells. This is because they often form along dry lines, thus leaving them with little available moisture despite high upper level wind shear. They usually dissipate rapidly rather than turning into classic or HP supercells, although it is still not unusual for them to do the latter, especially if they happen to collide with a much moister air mass along the way. Although these storms usually produce weak tornadoes, they have been known to produce strong ones. These storms usually produce hail less than 1.00 inch in diameter but can produce large hail even with little or no visible precipitation core, making them hazardous to storm chasers and people and animals caught outside. Due to the lack of a heavy precipitation core, LP supercells can sometimes show weak. Funnel clouds, or more rarely, weak tornados will sometimes form midway between the base and the top of the storm, descending from the main Cb (cumulonimbus) cloud. Lightning is rare compared to other supercell types, but it is not unknown and is more likely to occur as intracloud lightning rather than cloud-to-ground lightning.

LP supercells are quite sought after by storm chasers, because the limited amount of precipitation makes sighting tornadoes at a safe distance much less difficult than with a Classic or HP supercell.

The ***HP supercell*** has a much heavier precipitation core that can wrap all the way around the mesocyclone. These are especially dangerous storms, since the mesocyclone is wrapped with rain and can hide the tornado from view. These storms also cause flooding due to heavy rain, damaging downbursts and weak tornadoes, although they are also known to produce strong to violent tornadoes. They have a lower potential for damaging hail than Classic and LP supercells, although damaging hail is possible. It has been observed by some spotters that they tend to produce more cloud-to-ground and intracloud lightning than the other types. Also, unlike the LP and Classic types, severe events usually occur at the front (southeast) of the storm.

Be able to recognize thunderstorms in radar and satellite images.
Satellite images:
The anvil cloud is oval in shape, and there is a shadow under the anvil cloud. The lumpy region of updraft overshoot pinpoints the violent stem portion of the mushroom cloud These are all clues to help identify Tstorms from satellite images.

Radar images:
Radar can see precipitation inside the storm (the up and downdraft stem of the mushroom cloud)
Disaster Intensity Scale for Rainfall is measured in dBZ, which is a radar echo intensity (in decibals). Rainfall is categorized in 6 levels, from 'mist to light' to 'moderate' to 'heavy' to 'very heavy' to 'intense' to 'extreme'. Downpours of rain can cause flash floods in the intense and extreme rainfall case. By tracking past movement of Tstorm cells on radar, we can warn people in their paths.

Explain the behavior of downbursts and gust fronts, and identify their associated cloud & dust features.
Downbursts are cold (dense) air sinking. Thunderstorm can create dense air where rain falls due to precipitation drag and evaporative cooling. They are often invisible and therefore a hazard to aircraft.

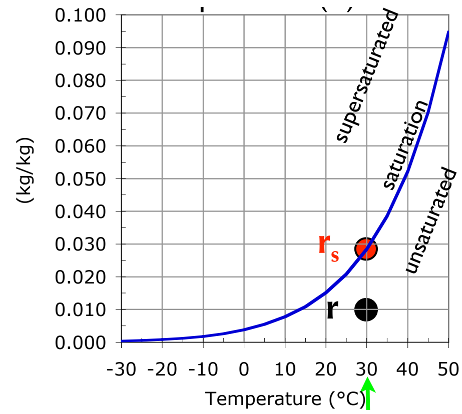
Gust front is the leading edge of straight-line winds. Downburst air hits the ground and spreads out. They are visible as a haboob/sand storm (if dry ground) or as an arc cloud (if moist air). Gust fronts can destroy weak structure such as mobile homes, and can blow down large trees. They are a hazard to aircraft during takeoff and landing.

Describe why the fact that cold air holds less water vapor is critical in explaining how Tstorms can extract energy from humid air.
Storms have special organization and capability to draw in humid air, then cause it to condense and release its heat into the storm, which results in precipitation and violent winds.

Storms are related to the concepts of:
1. ***humidity*** - the amount of water vapor in the air (many ways to quantify humidity)
- Air is a mixture of gases, of:
    - 0-4% water vapor
    - 78% N
    - 21% O
    - trace gases
    - liquid water droplets
- the ***mixing ratio (r)*** is the amount of water vapor divided by the amount of all other gases. For example, if you mixed 2 parts water vapor and 5 parts other gases, r = 2/5 = 0.4

2. ***saturation*** - equilibrium between evaporation and condensation
- water vapor can easily condense into liquid; the constant exchange of water molecules occurs between adjacent vapor and liquid
- if there are too many water molecules in the air, then excess condenses into liquid, causing the air to become drier
- if there are too few vapor molecules in the air, then evaporation exceeds condensation and air becomes moister
- if there is insufficient liquid water for evaporation, humidity can remain below the saturation value

- mixing ratio therefore approaches an equilibrium called saturation.
- ***saturation value***: maximum humidity that air can hold
    - Saturation Mixing Value (r_s) increases exponentially with Temperature (T)
    - important in controlling atmospheric humidity
    - warmer air can hold more water vapor at equilibrium than colder air
    - air containing this max amount is saturated
    - air holding less than the max amount is unsaturated



3. ***latent heat***
- flux of heat from the Earth's surface to the atmosphere that is associated with evaporation or transpiration of water at the surface and subsequent condensation of water vapor in the troposphere. It is an important component of Earth's surface energy budget

4. **advection**
- a transport mechanism of a substance, or a conserved property, by a fluid, due to the fluid's bulk motion in a particular direction
- change in a property of a moving mass of air because the mass moves to a region where the property has a different value (*e.g.,* the change in temperature when a warm air mass moves into a cool region). Advection can refer to either the horizontal or vertical components of the motion.

5. ***adiabatic cooling***
- when air rises, it cools roughly 10C/km
- cooler air can hold less water as vapor, therefore, must condense into liquid droplets
- however, condensation releases latent heat

**
If the Saturation Humidity value becomes smaller than the actual humidity, then condensation occurs. This condensation does 3 things:
1. releases sensible heat into storms
2. reduces humidity down to the equilibrium (saturation) value
3. produces or increases liquid cloud drops, which can grow to becomes rain drops

Rainfall/precipitation
- have strong radar reflectivity (large dBZ)
- heavy rainfall rate (RR) is measured by increase of depth of water in a raingauge (mm/hr)
- average warming rate: the average temperature change over time, or

$$\partial T / \partial t = a \bullet RR$$

where a = 0.338K/mm (of rain) for T storm 11km thick

Be able to recognize tornadoes and wall clouds.
Tornados are violently rotating columns of air, in contact with the ground. All violent tornados come from supercell thunderstorms. Most tornados are made visible by cloud water droplets (funnel cloud) and/or dust and debris from the ground (the debris cloud) Some tornados are invisible.

Explain why supercell thunderstorms spawn the most dangerous tornadoes.
Only a small percentage of thunderstorms have tornadoes. In North America, most thunderstorms move from southwest (SW) toward northeast (NE).
Supercell storms are:
- strongest
- most likely to have tornadoes
- but not all supercells spawn tornadoes

Best thunderstorms viewing is:
- off to the side of the storm path
- preferred side is to the southeast of the storm
- look at the storm toward northwest

Relate the Enhanced Fujita scale to different amounts of damage.

Scale	Rotation (k)m/hr	Expected damage	Evidence	% or tor. in Canada
EF0	105-137	Light or Gale		45%
EF1	138-177	Moderate	Minor damage to house	29%
EF2	178-217	Significant	Roofs blown off	21%
EF3	218-266	Severe	Inner walls intact	4%
EF4	267-322	Devastating	Inner walls down	1%
EF5	>322	Incredible	Debris is scattered	almost 0

Describe safety procedures near tornadoes.
Tornadoes are short lived, usually in minutes. Their damage path is typically narrow (the width of a house to a city block) and their paths are often one to tens of kilometers long.

<u>The safest places to be, if indoors, is:</u>
- below ground in a basement or storm cellar
- get out of mobile homes, which is the worst place to be in a tornado

<u>The safest place to be, if outdoors, is:</u>
- in a ditch or hole
- place your body below the "line of fire" of fast moving debris

<u>The safest, if in a car, is:</u>
- drive away from the tornado on best convenient road
- preferably to the right or left of translation direction of tornado
- do not hide under highway bridge or overpass

Identify the times and places for high tornado risk.
Tornado outbreaks are when there are 6 tornadoes in one day and one region, or many tornadoes during a week approximately. Warm and humid areas are places for high tornado risk. Late afternoon and early evening are times for high tornado risk because most heat cumulates near sunset.

Recognize mammatus clouds and the flanking line, and describe their relationship to Tstorms.
Mammatus are most often associated with the anvil cloud and also severe thunderstorms. They often extend from the base of a cumulonimbus. When occurring in cumulonimbus, mammatus are often indicative of a particularly strong storm or maybe even a tornadic storm. Due to the intensely sheared environment in which mammatus form, aviators are strongly cautioned to avoid cumulonimbus with mammatus.

Explain how vertical and horizontal winds are created by heat released in storms.
Forces in the atmosphere are:
1. buoyancy force (vertical), causes up and downdrafts, and
2. pressure-gradient force (PGF) (horizontal/vertical), which causes horizontal winds

Forces create winds. The relationship between forces and motion is described by F = ma, or <u>Newton's Second Law</u>.

Temperature alters buoyancy to drive vertical winds, based on the principle that warm air rises (updrafts) and cold air sinks (downdrafts). This is because <u>*temperature affects the density of air*</u>**,** and <u>density affects buoyancy</u>. The buoyancy o an air parcel depends on the difference between the parcel temperature and the temperature of the surrounding air. For example, buoyancy causes hot air balloons to rise. *Buoyancy also drives thunderstorms, because condensation in thunderstorms releases latent heat. Latent heat warms the Tstorm air, making it buoyant and causing the air to rise. This is what drives the violent updrafts in ***thunderstorms***.

Temperature alters pressure to drive horizontal winds. P = F/A (N/m^2)
Consider a vertical slice through a hurricane, but with air initially cool everywhere. In the center core of a hurricane are lots of thunderstorms. Condensation in these storms makes the core warmer. But as the air warms in the core, the air expands. Namely, warm air is less dense than cool air, hence it takes up more space. This causes pressure at the top of the core to be greater than surrounding pressures. The horizontal pressure gradient

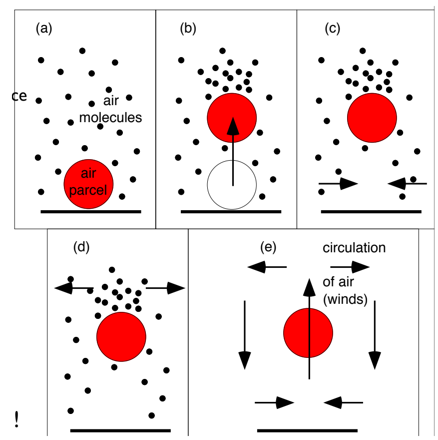
at the top of the hurricane creates outward spiraling winds. These winds remove air molecules from the core. Fewer molecules in the core causes lower pressure at the surface, because pressure is the weight of all the overlying air. This low pressure at the bottom of the core creates a pressure gradient that sucks in air. This gives the spiral inflow into the bottom of a hurricane. This inflow advects in more fuel (warm humid air), making the hurricane stronger.

Explain what the continuity effect is, and how it ties vertical and horizontal motions into circulations.
Continuity links vertical and horizontal winds in circulations. Air molecules tend to spread themselves smoothly and evenly; they don't leave any gaps/vacuums. They don't get bunched together. Air is continuous.

Continuity causes circulations:

a. air molecules are smoothly and evenly distributed in space
b. buoyant air parcel rises, leaves hole where it used to be -> a partial vacuum has lower pressure than surrounding air
c. surrounding air sucked into hole to maintain continuity
d. air above the rising parcel is compressed: has higher pressure, expands laterally
e. net result: initial vertical motion due to buoyancy generates horizontal motion in surrounding air = **CIRCULATION**

In real life, circulations develop smoothly and continuously to try to maintain continuity as air parcels start to move. Circulations can be driven: by buoyancy in the vertical or by horizontal pressure gradients. Vertical and horizontal motions are linked by the effect of continuity.



Overall Summary of how heat turns into motion:

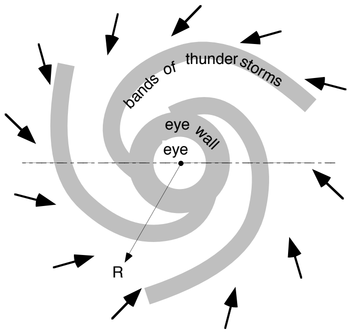
1. Forces create winds
2. Temperature alters buoyancy
- vertical forces => vertical winds
3. Temperature alters pressure
- horizontal forces => horizontal winds
4. Continuity links vertical and horizontal winds into circulations

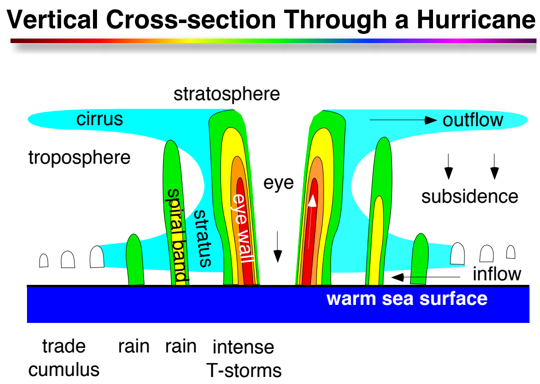
Describe rain and hail hazards of Tstorms, and state actions you can take to be safe near Tstorms.
Rain hazards:
Thunderstorm rain can be heavy, covering a small area, very large raindrops, very transient, moving with the storm. Downpours can cause flash floods and reduced visibility while driving, and can trigger landslides. For safety, move to high ground and don't drive through water of unknown depth.

Hail hazards:
Hail is hazardous because they can damage crops, livestock, injure/kill people and damage property (cars, windows). They can come from large Tstorm, but are most common with Low precipitation (LP) supercells. For safety, get indoors. If in a car, U-turn to leave the hail area, or park under a roof. If the car is exposed to strong hail, pull over to the side of the road and park and close your eyes to keep glass shards out.

Identify the components of a hurricane.
Hurricanes and typhoons are tropical cyclones, with surface winds turning counterclockwise (in N. Hemisphere) and spiraling in.
Eye is the center of the hurricane. It is relatively clear, relatively calm and pressure is low at sea level.
Hurricanes are made of thunderstorms:
Eye wall is the ring of thunderstorms around the eye
Spiral bands are the bands of Tstorms extending out from the eye wall.

What is needed to start a hurricane?
1. Warm sea surface, above 26C
2. Coriolis effect
3. Deep enough waters >60m so cold and warm waters do not mix





R is the radial distance from center of the eye, and arrows represent wind direction near the ocean surface. Gray represents bands of thunderstorms

How are tropical cyclones organized to create their own fuel?
Compare with individual thunderstorms:
• use the warm, humid boundary-layer air as fuel.
• consume nearby supplies of fuel.
• run out of fuel and die.
• are short lived (about an hour or less).

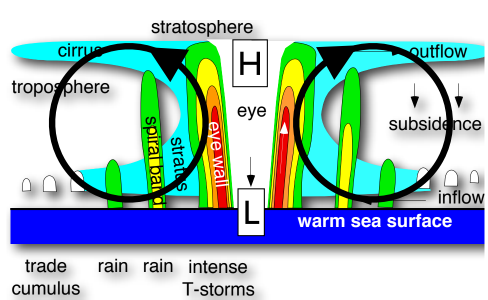
Exceptions (longer-lasting thunderstorms) if properly organized:
• ambient atmosphere happens to have right amount of wind shear that:
- continually blows fresh fuel into storm
- or blows Tstorm to new regions having boundary-layer fuel.
• namely, Supercell

Explain how hurricanes get and utilize heat energy, and why hurricanes can exist for weeks.
Hurricanes and their Tstorms are long lasting because they manipulate the environment to continually create new fuel from heat stored in the ocean. Fuel is created by the low pressure in the eye in boundary-layer (BL) air. As air gets closer to the eye, it moves faster. Faster winds create larger ocean waves. Evaporation from ocean surface is enhanced with spray from waves, which adds significant amounts of moisture into the boundary-layer air. Finally, when boundary-layer air reaches base of eye wall, it is warm, exceptionally humid, and contains tremendous amounts of sensible and latent heat fuel.

A warm sea surface is needed for self-fueling. Self-fueling works only if ocean surface temperatures are >26C AND warm surfaces waters are more than 60m deep (so that turbulence within the ocean caused by surface waves doesn't mix cold waters up to the surface.

Hurricanes can last for weeks, in spite of all the air molecules continually being blown into the core. This is because heavy condensation and precipitation from thunderstorms in the eye wall cause the hurricane core (eye + eye wall) to become very ***warm*** relative to its surroundings. The warm core creates high pressure at the core top, and low pressure at the core bottom. The results is a vertical circulation
- strong updrafts in the eye wall thunderstorms
- outflow at the hurricane top away from the core
- weak downward motion (subsidence) in the eye and outside the hurricane
- inflow at hurricane bottom towards the core
- cycles back into base of eye wall Tstorms as a complete circulation

When is hurricane season and where do hurricanes form?
Hurricane season is in the late summer and in early fall, when waters are warmest with maximum extent and depth. Official N. Atlantic "hurricane season" is June through November. most N. Atlantic hurricanes occur August through October.



Hurricanes form in the tropics, but NOT at the equator. Coriolis (earth's rotation) effect is stronger near poles. Favored hurricane formation latitudes are where there is BOTH warm sea surface temperature and nonzero Coriolis. Hurricanes do not form at the equator, because there is no Coriolis effect there.

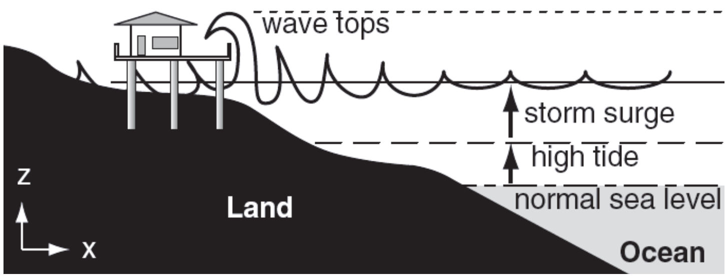
How are hurricanes measured?
Hurricanes are measured by the Saffir-Simpson Hurricane Wind scale. Hurricane categories are as follows: TD, TS, 1, 2, 3, 4, 5. A category 5 has the lowest eye pressure and greatest storm surge height.

List the requirements for hurricane existence, describe how hurricanes evolve, and what causes them to die.
Hurricanes can persist only if:
1. Central pressure in eye remains low (to create wind, waves and to suck in fuel of warm humid air)
2. the hurricane remains over the warm ocean
3. Coriolis force

Hurricane paths are steered by the general circulation in the atmosphere
- Westerlies
- Burmuda high
- Trade winds

Hurricanes weaken and die if:
1. cannot generate sufficient fuel of warm, humid air
- this happens when hurricanes move over colder water or land
2. larger scale weather systems interfere

Describe the risks associated with hurricanes, and appropriate safety procedures.
Storm surge:
The atmosphere drives an ocean disaster. Strong winds drag ocean water, raises sea level, and causes water to pile up against the shore. This is called a storm surge, causing coastal flooding.



In countries such as the USA, inland and urban flooding caused by heavy rains cause the most hurricane related deaths. In countries such as Bangladesh, coastal flooding caused by the hurricane storm surge causes the most deaths. Knowledge of past hurricane tracks is not the best predictor. Computer models of the atmosphere give conflicting forecasts. Therefore, there is uncertainty until the hurricane gets close to shore.

Hurricane predictions are inaccurate. Therefore, forecast maps of hurricane danger usually include probabilities. For safety, don't buy or build houses on or near the beach in SE USA. Plan in advance for evacuation. Don't "ride out" the storm. Most of these those rare hurricanes hit Atlantic provinces. Some former hurricanes cause heavy rain and flooding over ON & QC. However, hurricanes are rare in Canada overall.

Impacts

TOPIC 1: Extinctions

1. Concept of a biosphere
Understand the concept of a biosphere and Earth System Science and that the biosphere has evolved over time.
The biosphere is a thin "layer" of life on Earth's surface. The biosphere is composed of ecosystem, such as a pond ecosystem.

Earth System Science:
Biosphere
Hydrosphere
Lithosphere
Atmosphere
Anthrosphere = the sphere that can be affected by human activities

2. Principles of Stratigraphy
Distinguish between the oldest and youngest portion of a geological section using principles of superposition, original horizontality and cross cutting relationships.
Superposition - In layered strata (sedimentary rocks or lava flows) "what's on top is the youngest"

Original horizontality - "If it's tilted or folded it was originally flat"

Cross cutting relationships - an unconformity is just one example of a cross-cutting relationship
- inclusions, faults, etc.

3. Biostratigraphy
Describe the concept of faunal succession and the use of fossils in correlation and in the subdivision of Earth history.
The biosphere is composed of individual species that have evolved through time. Knowing this can help our understanding of the passage of time on Earth. The passage of time is recorded in rock layers. ***Stratigraphy*** is the study of the layers of rock (strata).

The ***principle of faunal succession*** is based on the observation that sedimentary rock strata contain fossilized flora and fauna, and that these fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances. This principle, which received its name from the English geologist William Smith, is of great importance in determining the relative age of rocks and strata.The fossil content of rocks together with the law of superposition helps to determine the time sequence in which sedimentary rocks were laid down. In practice, the most useful diagnostic species are those with the fastest rate of species turnover and the widest distribution; their study is termed biostratiagraphy, the science of dating rocks by using the fossils contained within them.

Strata of like age can be dated and correlated by the fossils they contain.

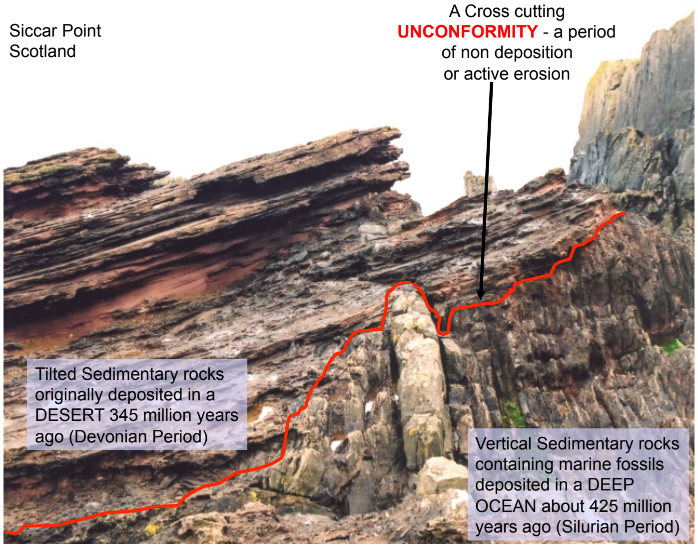
Recognize the qualities that make fossils useful in biostratigraphy.
Fossils are evidence of former life. To become fossilized, an organism must be:
1. be dense, have robust hard parts such as teeth, shells or bones
2. rapid burial, which protects organism from being scavenged and disintegrated

The best fossil species for biostratigraphy are:
1. SHORT range = higher RESOLUTION
2. Common
3. Lived in environments where fossilization is likely to occur
4. Present in many different environments

For example, commonly used fossils in the Mesozoic are Ammonites.

4. Historical Figures
Identify important historical figures in the development of stratigraphy and biostratigraphy
Nicholas Steno (Late 1600's)
1. Superposition - In layered strata (sedimentary rocks or lava flows) "what's on top is the youngest"
2. Original horizontality - "If it's tilted or folded it was originally flat"

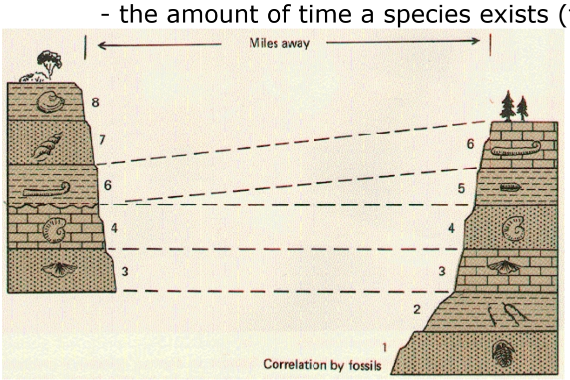
James Hutton (Late 1700s)
1. Cross cutting relationships



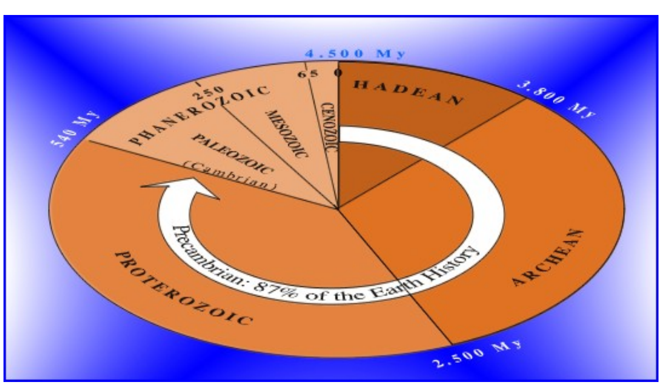
- an unconformity is just one example of a cross-cutting relationship
  - inclusions, faults,

<u>William Smith (1799)</u>

1. Principle of faunal succession - fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances
    - as a result, strata of like age can be DATED and CORRELATED by the fossils they contain. This only works because species have evolved through time
    - the amount of time a species exists (from evolution to extinction) is a ***fossil range***



5. The concept of deep time
Appreciate the scale of changes that can occur over geological time scales

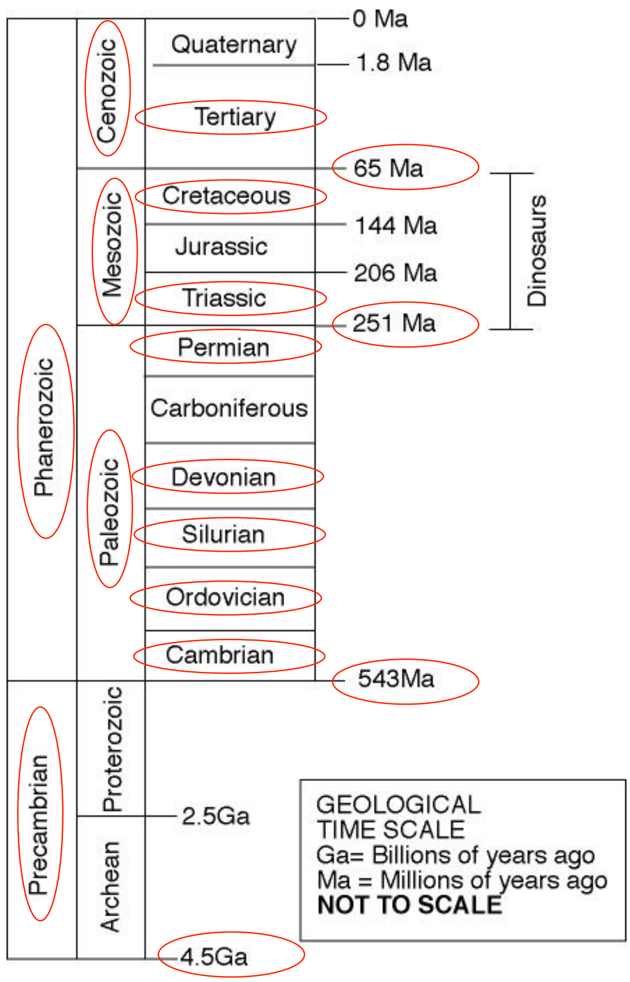


• The Geological concept of DEEP TIME 31

List some of the major subdivisions /ages of the geological time scale and appreciate the relative scale between the Phanerozoic and the Precambrian
Precambrian- evidence of first eukaryotes
Cambrian (Cambrian explosion; sudden burst in diversity)
Ordovician- diversification
Silurian
Devonian
Carboniferous
Permian
Triassic
Jurassic
Cretaceous
Tertiary
Quaternary

<u>Cause/Factors contributing to Cambrian Explosion:</u>
- increase in atmospheric O_2, especially critical to supporting evolution of predators with high metabolic demands (also in the ocean)
- Cambrian saw proliferation of bilateral body forms

Understand how extinction events are linked to the structure of the geological time scale



6. Mass extinction events
Define the characteristics of a mass extinction
1. at least 30% of species lost
2. broad range of ecosystems
3. short/sudden

List the 'big 5' mass extinction events and their order through time.

1. Cretaceous/Tertiary (KT)
2. Late Triassic
3. Permo/Triassic (allows evolution of dinosaurs)
4. Late Devonian
5. Late Ordovician (earliest)

Distinguish between broad extinction producing phenomena.
Mass extinctions can be:
1. Biologically-Based, due to competition, predation or pathogens

2. Physical Earth-Based
- changes in continental configurations, or changes in climate/ocean cyclicity/sea level
    - eg. Gondwana moves South
- The greater the landmass, the lower the biodiversity
    - eg. Permo-Triassic Extinction
- Atmospheric Volcanism
- Greenhouse/cold house effects

3. Combination of many factors
- "bad day for the biosphere"
- the worst day was the Permo/Triassic 251mya, where 95-98% of all species went extinct in less than 1 million years

Describe the late Ordovician and Permo-Triassic extinction
Late Ordovician Extinction: Gondwana moving south

The Cause of the ***Permo-Triassic extinction*** may be due to several factors:
1. Continental configuration leading to a drop in biodiversity
2. Sea level falls, therefore less ocean ridge activity
3. Oceanic stagnation - anoxia
4. Possible extra terrestrial impacts
5. Climate change
    - Siberian Traps Blood Basalt- massive volcanic activity 2-3 million km^3 basaltic lava
    - CO_2 released causes Greenhouse warming, which raised the global temperature by 5C
    - warms oceans, melts gas (methane) clathrates
        - methane from decay of organic material. CH_4 is trapped in water ice, which is common in deep ocean sediments
    - Methane is a better greenhouse gas than CO2, leading to further increase in global temperature by 5C, making it 10C warmer overall

The Permo-Triassic extinction kills off many creatures, which clears "ecological space". A new reptile, the dinosaurs, evolves during the Triassic and takes advantage of this.

<u>TOPIC 2: Case study, the K/T extinction</u>
1. K/T Extinction
Describe the character of extinctions at the K/T boundary.
Extinction at the K/T boundary was 54mya. This extinction killed the dinosaurs on land, and at least 50% of ALL species were lost. On land, nothing over 25kg survived. Not only did the terrestrial species suffer; this extinction also impacted the species in marine environments. Ammonites and marine reptiles were also wiped out; at least 80-90% marine species were lost.

Discuss the evidence used to support the K/T impact.
Walter and Luis Alverez discovered latest Cretaceous clay layer is enriched in iridium; the iridium anomaly and clay layer is global. The source of such high iridium is only found on comets and meteorites.

<u>Further evidence suggests that:</u>
1. ferns are the first to colonize a fire impacted landscape. There was a massive spike in fern spores just after the K/T impact
2. Soot layers associated with the iridium layer gives evidence of massive global fires
3. Tektites, or natural glass produced by melting rocks during the impact
4. Shocked Quartz is another "impact" feature.
5. Tsunami deposits is evidence of almost GLOBAL tsunami activity at the end of Cretaceous

Describe the location and probable nature of the K/T impactor.

"The Smoking Gun"
- drilling off coast of Mexico - Yucatan Peninsula, we find "odd" rocks
    - Suevite: a breccia (fractured rock) showing evidence of melting
    - completely melted rocks
- the suevite sits in core store for years until geophysics reveals a crater 180km across
- ***Chixulub Impact Crater*** "tail of the devil"
- tsunami deposits, shocked quartz and tektites (thicker towards this structure)

Describe the initial and long-term effects of the impact and their environmental consequences.
We can tell that the meteor (Chixulub) impacted with shallow entry, impact body was 10km across because most of the "ejecta" is towards NW. The impact was equivalent to 6.2 x 10^7 tonnes of TNT, causing 100km^3 of rock to be vaporized.

In the ***short term***, everything close by was vaporized, forest fires and giant tsunamis were created.

In the ***long term*** the sunlight was shut off from weeks to several months due to the ash, photosynthesis stopped on land AND in the oceans. After the dust clears, water vapor remained in the atmosphere, creating a greenhouse effect. There were more greenhouse gases, Yucatan limestones were vaporized, and the average global temperature rises up to approximately 10C. There was a rapid shift in environmental conditions. Also, acid rain was formed by the high energy blast that caused N and O and water vapor to form nitric acid. This acid rain acidified oceans and soils on land.

Yucatan ***evaporites*** are salts precipitated by evaporating bodies of water. Evaporites are rich in minerals like Gypsum, which is rich in sulfates, produced a week sulfuric acid, creating MORE acid rain. Today, we call it the salt flat, Death Valley.

This impact is large because it hits the base of the food chain in oceans and land. This caused indirect effects through the disruption of food webs, traveling up the trophic levels.

Consider other potential causes of the K/T environmental collapse.
<u>Evidence</u>
Once the K/T theory was proposed, it excited scientists in the world, and the search for facts shifted into high gear.
1. The clay layer was found on the continents, thus ruling out the possibility that the iridium enrichment was due simply to a chnage in ocean composition
2. the K/T boundary clay minerals have a different composition from clays int he limestone layers above and below it; they ight be explained by a mixture of one part asteroid to 10 parts Earth crust
3. Quartz grains are present with shocked crystal structures, indicating a short and violent impact. Shocked quartz, with its planar deformation features, has been found only in association with impacts, so its discovery at the K/T boundary is strong evidence of impact
4. Sand size spherules of minerals are present, suggesting a melting and resolidification
5. Ratios of the radioactive element rhenium to its decay product osmium are similar to those in meteorites and are quite different from the ratios in Earth surface rock
6. Abundant microscopic diamonds, found in some meteorites, occur in the K/T boundary clay layer
7. Carbon rich grains with fluffy structures indicative of fire are abundant in the K/T boundary clay layer

<u>Problems for Life from Impacts?</u>
1. Earthquake of monumental magnitude along with numerous gigantic aftershocks
2. Wildfires would rage regionally or even globally, since the impact ejected a lot of hot debris
3. Huge amounts of nitrogen oxides in the atmosphere would fall as acid arin and acidify surface waters
4. Dust and soot in the atmosphere would block sunlight and turn day into light, thus making photosynthesis difficult and plunging much of the world into dark wintry conditions for weeks to several months
5. After the atmospheric dust settled, the water vapor and CO2 remaining in the atmosphere would lead to global warming for years

<u>Additionally</u>:
1. Tsunami
2. Bubble of steam up to 500 km3 volume that blows into the upper atmosphere carrying Earth rock and asteroid debris
3. K/T asteroid landed in shallow tropical marine water underlain by limestone (vaporization of limestone, increasses atmospheric CO2)
4. after winter causing asteroidal dust settled the added CO2 in the atmosphere could have elevated Earth's climate into global warming conditions

- Deccan Traps Flood Basalts (like Siberian trap but over India, Siberian traps for P/Tr)

- India: acid rain, ozone depletion, climatic greenhouse effects
- continued environmental degradation related to break up of Pangea
- many species already going into extinctions
- Cretaceous biosphere already stressed
- K/T impact was the "final nail in the coffin"
- impact probably the causal factor in the extinction of the terrestrial dinosaurs
- avian "dinosaurs" still exist today (birds such as the ostrich

**

Baptistina (Asteroid 298) fragments 160Ma
• Composition the same as K/T impactor? Still debated!
• Responsible for a number of other impacts including Tycho?

TOPIC 3: Impacts
1. Our place in the solar system / galaxy
Describe the type and location of potential impactors and rate of meteoroid influx
Source of ET debris
1. ***Comets***: "dirty snowballs", commonly around 15km in diameter
- come from the Oort Cloud and Kuiper Belt
- the Oort cloud comprises of many billions of comets
- solar winds sublime the ice; therefore the comet has a "tail"
- comets "fall" into inner solar system - Earth crossing orbits
- are comets implications for development of life on Earth?
- November of every year, we see the Leonid Meteor Shower
- the Tail of comet Tempel-Tuttle (33 year return time) creates a "band" of meteoroid debris
- a ***meteorite*** is an object that survives impact with the Earth's surface

2. ***Asteroids***
- smaller than planets, larger than meteoroids (***meteoroids***: sand-boulder size)
- common in a series of belts between Mars and Jupiter

Asteroid: A relatively small, inactive body, composed of rock, carbon or metal, which is orbiting the Sun.
Comet: A relatively small, sometimes active object, which is composed of dirt and ices. Comets are characterised by dust and gas tails when in proximity to the Sun. Far from the Sun it is difficult to distinguish an asteroid from a comet.
Meteoroid: A small particle from an asteroid or comet orbiting he Sun.
Meteor: A meteoroid that is observed as it burns up in the Earth's atmosphere - a shooting star.
Meteorite: A meteoroid that survives its passage through the Earth's atmosphere and impacts the Earth's surface.

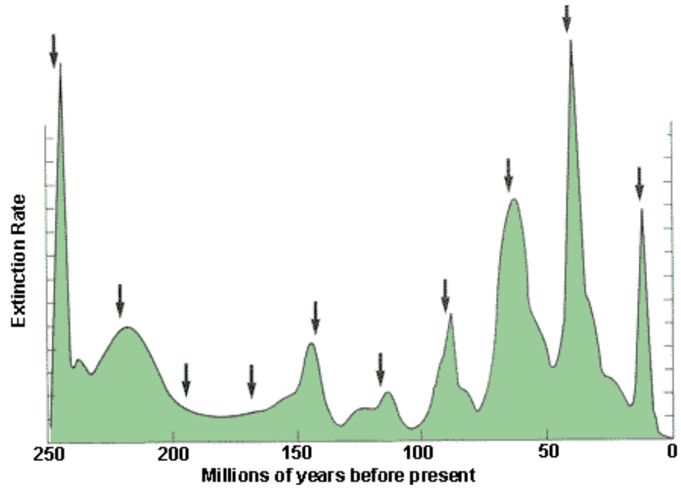
2. History of impacts
List some of the major impact features preserved on the Earth's surface and explain why impact craters appear to be rare on Earth.
Rates of meteoroid influx is about 100000 million every 24 hours. However, most burn up entirely 60km above the surface. They travel at 11-30km/second (70000mph). The atmosphere acts like a brick wall, and the meteoroid "skips" at shallow angles.

Impact craters may appear rare on Earth because they may be submerged underwater or gradual changes in the biosphere may have covered the evidence.

Until recently (1960's) impact on Earth is believed to be improbable. Moon craters are extinct volcanoes. Large circular structures associated with ejecta, shocked quartz, iridium etc.

Manicouagan Crater, Northern Quebec from the Late Triassic. At least 4 other impacts at SAME time, including Saint Martin Crater in Manitoba and Rochechouart Crater in France.

3. Periodicity of mass extinctions and possible ET driving mechanisms
Describe the hypothesis proposed by Raup and Sepkoski (1984)



<u>Gravitational "kicks" from...</u>

1. Nemesis the companion sun
- red dwarf star - smaller, cooler than our sun
- black hole?

2. Planet X?

3. Moving through the galactic plane
- just been through a "Raup-Sepkoski" period.. are we safe?
- we were in the "danger zone" 1mya, but how reliable is the data?
- dates are challenged, because spacing is not always consistent, statiscally non significant to have only 5 mass extinctions?

<u>How concerned should we be?</u>
- do not have to have a mass extinction event to be bad
- civilization killer... random but probably 1 in a million years
- the risk of your death by an impact event is 1 in 20000, which is the same as the risk of death in an air crash.

4. Recent history of impacts and risk assessment
List and describe some recent impacts and "near misses".

A recent impact was in Tunguska, Siberia in 1908. There were air bursts above 8km above surface, but no crater was created. However, the shock wave traveled twice around the Earth. The meteoroid was 50m in diameter and travelled at 15km/second. A 1000km^2 forest was devastated, charring for 5000km^2.

A recent near miss is on May 19, 1996. The asteroid was 150m in diameter and missed Earth by 543000km. The crater would have been Meteor Crater Sized (1km in diameter) and the energy released would have been twice of Mt Saint Helens.

A second near miss was on March 2, 2009. The Asteroid 2009 DD45 was about 40m in diameter. It was 70000km away from Earth, which was about 1/5 the distance between the Earth and the moon, or twice the distance of Earth communication satellites.

5. Impact risk and mitigation
Understand the risk associated with an impact hazard.

An impact is quite hazardous, as proven by Shoemaker Levy 9, which made an impact with Jupiter. It collided with the force of several million tons of TNT. If it had hit the Earth, it would have wiped out life to the microbial level. The moon and Jupiter are our impact shields.

The Torino scale communicates the potential threat on the scale of 0-10, and assesses the risk of Near Earth Objects (NEO).

- spaceguard survey
- plan to survey NEO's
- survey all asteroids >1km
- was 90% complete in 2008
- impact hazard was unique:

1. potentially the most devastating

2. ONLY natural disaster that can be entirely avoided
- most important factor is TIME

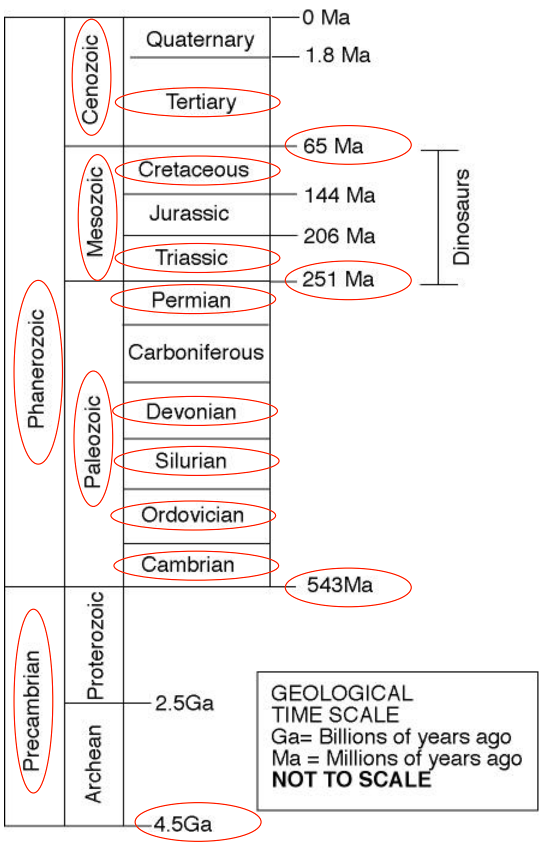
List possible mitigation strategies and appraise their relative effectiveness
1. Fragmentation
- blow it up
- to be effective would have to DRILL
- risky, difficult to predict because the meteoroid could break of into multiple pieces and strike the Earth at multiple points

2. Sudden Orbit adjustment
- requires warning period
- explode nuclear warhead, smash projectiles into asteroid/comet surface

3. Steady State Orbit adjustment
- requires warning period but more predictable
- chemical, electric or nuclear propulsion
- mass drivers - excavate and accelerate material away from asteroid
- ablation systems: irradiate surface with laser or focus sunlight from large mirrors
- riding the solar winds
- Solar sails (mirrors) or coating asteroid with high reflectivity material requires LONG warning period

All of these methods are useless unless we have advanced warning. The risk is 1 in 20000, and there are other more pressing issues such as cancer, HIV, earthquakes, global warming, poverty, etc. Meteor impacts are at low frequency, but if it occurs, will have HIGH impact on civilization

Overall:
List some of the major developments in the history of life on Earth.



Describe some of the features and processes of crater formation.

Provide examples of Canadian Impact Craters.
Sudbury and Wanapitei, Ontario
Holleford, Ontario
Slate Islands, Ontario
Brent, Ontario
Haughton, Nunavut
Pingualuit, Quebec

Fragile System Part II

Synthesize your knowledge of individual disasters into a coherent understanding.

Analyze your neighborhood's risk to various natural hazards, and recommend activities to mitigate some of the future risk.

Critique your own and your family's preparedness. Design plans to be better prepared, and implement them.

Evaluate the actual situation when faced with a natural disaster, make decisions based on available (often incomplete) info, and take well-reasoned action to enhance your survival.

Make well-informed life decisions, such as where to live and work, who to vote for, how best to utilize your tax dollars. These will require you to synthesize your knowledge of disasters with broader societal issues.