Ch 1: intro to natural hazards

Most tsunamis are triggered at SUBDUCTION ZONES — long, narrow strips of Earth's lithosphere (outermost layer containing the crust and upper mantle) where one tectonic plate moves beneath another.

2 tsunami warning signs:
1) Strong ground-shaking close to the epicenter
2) A rapid withdrawal of the sea to very low levels

Defining and minimizing disasters

Natural hazards are caused by both internal (from inside Earth) and external processes (from the sun). PROCESSES are the ways in which events affect the surface of the Earth.

HAZARD = any natural process that threatens human life or property
RISK = the probability of a hazardous event times the expected damage
DISASTER/CATASTROPHE = events that cause serious injury, loss of life, and property damage in a brief amount of time over a specific area (catastrophe tends to be more severe and takes longer to recover from)
MITIGATION = efforts to prepare for disasters to minimize their effects

What we can do to minimize impact of disasters:
- Improve existing warning systems and install new ones
- Improve communication infrastructure and chain-of-command protocol so emergency officials in coastal communities are warned ASAP
- Public education program ➞ where to go, where to take, how to get into
- Evacuation routes should be publicized + marked by signs

Role of time in understanding hazards

Hazards are recurrent events. Thus, by combining our knowledge of a history of past events with a surveying of geologic features created by the past disasters, our hazard forecasts and warnings will become more accurate.

The geologic cycle

The 4 associated sequences of the Earth processes that produce the minerals, fuels, land, water, and atmosphere needed for survival through physical, chemical, and biological forces. They are all include a renewal process, are driven by energy, and are cyclic. They do not all relate to the movement of the Earth's crust.

The tectonic cycle

The creation, movement, and destruction of tectonic plates. Oceanic plates are denser than continental plates and thus will always move underneath continental plates.

DIVERGENT BOUNDARIES: two plates pulling away from each other. If its in the ocean, then it is known as SEAFLOOR SPREADING, where magma comes up to create new crust.

CONVERGENT BOUNDARIES: two plates collide into each other, usually resulting in a subduction zone. If an oceanic plate goes under a continental plate, then the oceanic plate heats up as it moves under and releases gases that melt the lower crustal rocks. Magma moves up slowly until it reaches the surface and erupts, building volcanoes. Colliding plates with similar density usually produces mountains. Ocean plates — older one subducts younger one

SUBDUCTION adds material to continents (sediments/rock/crustal fragments on the subducting plate are added to the continent.

TRANSFORM (shear/transverse) BOUNDARY: two plates slide horizontally past each other.

HOTSPOTS: an almost stationary source of heat within the mantle (mantle is just below crust) that produces volcanoes at specific, fixed points of Earth's surface as plates move over it.

The rock cycle

The recycling of 3 major groups of rocks; it is driven by energy from the core and sun.

IGNEOUS ROCK: crystallization of molten rock.

SEDIMENTARY ROCK: sediment is produced as rocks at/near the surface break down chemically and physically (WEATHERING). LITHIFICATION then compacts and cements these sediments into sedimentary rock.

METAMORPHIC ROCK: the morphing of rock by chemical fluids, pressure, or heat (naturally occurring agents). If sedimentary rock is buried deep enough, it will melt and thus the potential for the cycle to start all over again is renewed.

The hydrologic cycle

The cycling of water form the oceans to the atmosphere, continents and islands, and back to the oceans. It is driven by solar energy and by evaporation, precipitation, surface runoff, and subsurface flow.

RESIDENCE TIME: avg. amount of time that a drop of water spends in any one compartment

Biogeochemical cycles

The transfers of cycling of elements through the atmosphere, lithosphere, hydrosphere, and biosphere; it is intimately related to the other cycles — tectonic provides water, gases, heat, and energy for transferring dissolved solids in gases, aerosols, and solutions. The other cycles transfer and store chemical elements by a series of compartments/reservoirs (water, soil, and rock).

Fundamental concepts for understanding natural hazards

1. Hazards can be predicted through scientific analysis; most can be predicted from a history of similar events, patterns in their occurrences, and by warning events that precede them

2. Risk analysis is an important part of understanding the effects of a hazard; you can use risk analysis to assess the probability that a hazard will occur and what its severity will be. This helps people decide whether or not living in a hazard prone area is worth the risk.

3. Natural hazards are linked together and to the physical environment; one hazard will often produce another. I.e. Loose rocks are more prone to landslides than granite.

4. Damage from natural disasters is increasing due to population growth, property development in dangerous areas, and poor land-use practices. Higher magnitude events occur less often and lower magnitude events occur a lot [inverse relationship].

5. Damage from disasters can be minimized by using science, good land-use planning and regulation, engineering, and being prepared and proactive

Hazards are natural

Attempts to control hazards (like flood control) may amplify its hazards. The best way to mitigate hazards is to identify their location, and to avoid putting people and property there.

Prediction and warning

To forecast and event and issue a warning, we must first:

1. Locate the hazard (by creating maps of geological features, past history of hazards, etc)
2. Estimate the probability that it will occur (using history of events + current geography)
3. Identify any precursor events that may signal the hazard
4. Try to predict when the hazard will occur
5. Warn the people — even if it doesn't occur, communities will be left off better prepared and informed than before.

Minimizing damage from hazards

Proactive planning is just as important as our actions right after a hazard:

Reactive recovery:

1) Emergency Work — normal activities have ceased or changed. Focus on search and rescue, clearing of rubble, and repairing roads and utilities.
2) Restoration — normal activities return, refugees return, rubble is mostly cleared
3) Reconstruction I — bridges, buildings, and other structures are rebuilt with hazards in mind. Normal activities are at pre-disaster levels of greater
4) Reconstruction II — activities improved and developed, major construction projects are completed.

Proactive: avoiding and adjusting to hazards

Good land use planning → not building near hazard-prone areas, requiring stricter building regulations to reduce potential damage from landslides, earthquakes, etc. Also being prepared: knowing evacuation routes, having survival kits ready, educating yourself on disasters.

Return period: RP

RP is the average amount of years that pass between hazards. Determined by dividing the time span of data by the number of hazards that has occurred.

I.e.. 70 years/2 (for number of floods that occurred during those years) = 35 year flood

Some hazards concentrate energy for a long time and release it all very fast (earthquakes, volcanoes, hurricanes, storms, landslides). Others form in a very short time and dilute their energy over a long period of time (tsunamis, floods).

Composition of the Earth, ocean, and atmosphere

The Earth's core is mostly iron and nickel; the crust is oxygen and silicon. The ocean's made mostly of oxygen and hydrogen, while the atmosphere is composed of nitrogen and oxygen.

VISCOSITY: a measure of how much fluids resist changing their shape (the greater the viscosity the more it resists change & thus needs more force to change it). Air has low viscosity.

COMPRESSIBILITY: how much an object can be squeezes d or expanded so that it fills more or less space. Results in a change in density (mass/volume) because of the volume change.

Strain

ELASTIC: ability of an object to change shape and spring back when there's no more force
PLASTIC: ability to permanently change shape when forced. Ductile = very plastic

Energy

Disasters release energy, and energy causes things to move or change.

FORCE: a force pushes or pulls. It is measured in newtons (N). 1 N = 1(kg x m/s^2)
GRAVITY: a force that attracts matter (masses) to each other. F= m x g where g = 9.8 (m/s^2)

WORK ENERGY: the force that pushes an object, time s the distance the objet moves. W=f x d. It is measured in joules
POTENTIAL ENERGY: the work needed to raise an object of mass (m) at a distance (z) against the pull of gravity (g). PE = g x m x z
KINETIC ENERGY: a moving object possess kinetic energy. KE = 0.5 x m x V^2, where m = mass and v = velocity
SENSIBLE HEAT: the heat we can feel in the form of temperature
LATENT HEAT: heat stored as solids melt in liquids, or when liquids evaporate in gases. It is releases when gases condense into liquids or liquids freeze into solids.

Energy conservation

Energy is conserved when it changes from form to form. I.e. Kinetic energy of an asteroid is converted into sensible heat when it strikes Earth, or heat causes water to heat the earths crust, which does WORK pushing magma, which rises (potential energy) to create volcanoes.

Natural disasters require energy to continually build up (concentrate) before releasing it all suddenly

POWER: the rate of doing work or of using energy. Measured in joules/sec.
PRESSURE: force per unit squared that is applied perpendicular to the surface (straight down)
STRESS: force applied parallel to the surface (sliding)

World population

Doubling time = 70/% growth rate a year. DT applies only to exponentially growing populations
CARRYING CAPACITY: the population that the Earth can comfortably sustain without risking environmental degradation

Most common **elements** in order

Earth Core → iron, nickel	IN
Earth Crust → oxygen, silicon, aluminum	OSIAL
Ocean → oxygen, hydrogen, chlorine	OHCL
Atmosphere → nitrogen, oxygen, argon	NOAR

Ch 3 – Volcanoes

Mount Unzen, 1991 Japan

In 1991, a violent eruption forced thousands to evacuate. By the end of 1993, it created more than 8000 superheated flows of hot gas, ash, and large rock fragments and damaging flows of volcanic debris and water (lahars). 3 lessons to take from this: 1) the eruption had historical precursors, 2) two hazardous process occurred at the same time (pyroclastic flows and lahars), and 3) evacuation saved peoples lives.

3.1 What are igneous processes?

Rocks melt to form magma, and then magma solidifies into new rock. Igneous rocks form where magma hardens below Earth's surface or where lava, ash, and pumice erupt onto Earth's surface. Through field observations, laboratory experiments, and measuring the abundance of different elements in rocks (geochemical analysis), geologists study these processes.

3.2 How are igneous rocks classified?

Two general categories based on where they form:

- Extrusive (volcanic) rocks → igneous rocks that form above surface. Form from lava/pyroclastic debris.
- Intrusive (plutonic) rocks → rocks that form below the surface

Mafic → dark rocks rich in dense minerals like magnesium and iron. Felsic → light rocks rich in low density minerals like feldspar, quartz, and silica. 2 ways to name igneous rocks: composition and texture.

The first component in classification: composition (minerals present in magma)

Each mineral in magma solidifies at a certain temperature; as magma cools, minerals appear when that temperature is reached. Magma is mostly silica (silicon and oxygen, 2 most common elements in Earth's crust); igneous rocks are mostly silicate materials → feldspars, pyroxene, olivine, and quartz.

Gases are also present in all magmas as water vapor, carbon dioxide, and sulfur (smelly). Vesicles form when liquids surrounds the bubbles formed when gas escapes from magma.

Magma → mixture of liquid melt, crystals, and dissolved gasses
Lava → same mixture but the gasses have mostly escaped

Geologists divide magma and igneous rocks according to silica abundance:

- Mafic and ultramafic rocks → hot, low viscosity (runny), high density MG and FE, dark color.
- Intermediate rocks → equal levels of feldspar, magnesium- and iron-rich minerals, grey shade.
- Felsic rocks → colder, high viscosity (explosive), low density silica; light color

Viscosity is determined by silica content and temperature. Hotter rocks (that melt) have low viscosity; mafic rocks have low viscosity because they're found closer to the core (hot) while felsic rocks are found closer to the crust (cold). More silica = higher viscosity and more gas it can hold
Mafic rocks are low-silica = low gas content and low viscosity (meaning they are runny); gas is able to escape and thus pressure is decreased → quiet, safe eruptions.
Felsic rocks are high-silica = high gas content and high viscosity (they are gooey); gas cannot escape, increasing pressure → explosive destructions

The second component in classification: texture (size of crystals)

Aphanitic → invisible. Rapidly cooling volcanic rock or shallow plutonic rock results in small, fine, crystals. The surface is much cooler than the temperature needed for magma to solidify, allowing it to cool fast. Can make glass, which is commonly found on the surfaces of lava flows.
Phaneritic → visible. Underground rock insulates magma to let it cool slowly, forming large crystals with a coarse-grained texture.
Porphyritic → Igneous rocks with at least 2 distinct crystal sizes (occur when magma cools slowly and then moves into colder environments where it cools fast).

Pyroclastic materials are usually glassy because the small fragments quickly lose heat to the cool air.
Obsidian is felsic (light) glass that appears black because of magnetite grains dispersed through it.

Classifying pyroclastic debris

Classified by size and whether its compacted or loose. Bombs → largest, lapilli → intermediate, volcanic ash → smallest. When these fragments are compacted in rock, the terms agglomerate (bomb), lapillistone (lapilli), lapilli tuff (in between ash and lapilli), and tuff (ash) are used.

Pumice (felsic) → lightweight, highly vesicular felsic lapilli (dacite & rhyolite)
Scoria or Cinder (mafic) → lightweight, highly vesicular mafic lapilli (basaltic & andesitic)

Naming igneous rocks: composition and texture

Peridotite → ultramafic, phaneritic (dark colour, low silica, large crystals); part of Earth's mantle
Basalt → extrusive mafic, fine grains; **gabbro is** coarse-grained version of basalt; part of ocean crust
Andesite and diorite → intermediate-composition rocks
Dacite and tonalite → between andesite and rhyolite (intermediate-felsic).
Rhyolite and granite → felsic rocks

Basalt is the most common volcanic rock, and rhyolite the least. A volcanoes shape is related to the viscosity of their magmas, which is determined by silica content and temperature. High silica = cooler, more viscous, and more dissolved gasses. Gasses are released out of the liquid as magma moves up and pressure decreases, resulting in explosive eruptions.

3.3 Where do volcanoes appear?

Most active volcanoes exist at or near divergent and convergent plate boundaries, like at the subduction zones along the Ring of Fire (borders Pacific Ocean), hot spots (Hawaii, Yellowstone), mid-ocean ridges (Iceland), and continental rift zones (East Africa). In North America, the area most at risk is in the mountainous regions of the Pacific Northwest and northwest and central B.C.

The tectonic setting determines the type of volcano present:

1) Subduction zones: the oceanic crust becomes dehydrated (rising heat and pressure dry the crust) as it subducts under the continental plate into the Earth's mantle. The expelled water lowers the melting point of the mantle rock, causing it to melt and form magma. Stratovolcanoes commonly form here.
2) Mid-ocean ridges: formed at divergent boundaries where basaltic magma right from the mantle rises to create new crust. Spreading ridges on land create shield volcanoes.
3) Hot spots beneath the oceans: the mantle heats up at a fixed point beneath a plate rather than at the boundary between 2 plates. As the plate continues to slowly move, it creates a series of volcanoes.
4) Hot spots beneath the continent: creates caldera-forming eruptions (traps gas), which can be extremely explosive and violent, releasing large amounts of ash and dacitic/rhyolitic magma.

Mt. Baker = active stratovolcano. Greatest hazards = ash fall, landslides, lahars, and the filling of river valleys with sediment, causing the riverbed to rise & damaging infrastructure on the valley floors.

Plutonic rocks in the landscape (underground & intrusive)

Plutonic igneous rocks are more resistant to erosion; they can become hills, ridges, and mountains. Dikes are steeply inclined intrusions that cut across sedimentary layers. Sills are gently inclined or horizontal intrusions that run parallel to rock layers. Batholiths are solidified magma chambers.

Volcanoes form where dikes, sills, and batholiths are near the surface.
Volcanic necks form when a pipe of magma that feeds a volcano solidifies; erosion exposes these necks.

Volcanic rocks in the landscape (surface & extrusive)

Lava flows are the most common volcanic landscape feature. Basaltic lava flows aren't very thick but cover very large areas. Intermediate and felsic flows are very thick but stay close to where they erupt. Lava domes → lava seems not to flow, instead it squeezes out of the vent to form large mounds.
Pahoehoe → basaltic lava; surface hardens into smooth, wrinkled, rope-like flows.
A'a → basaltic lava; viscous rubbly lava flows where the surface hardens but the lava keeps flowing, breaking the crust. Flows slower than pahoehoe.
Pyroclastic-fall deposits → pyroclastic fragments fall from the sky; larger rocks land closest to the volcano, and fragments become smaller the further you are from the volcano (uniform decrease in size)
Pyroclastic-flow deposits → heated pumice and ash fly down the volcano at hurricane speed.

Types of volcanoes

Formed by the accumulation of lava flows and pyroclastic deposits around the crater from which they erupted. Volcano shape is affected by the shape of the conduit and the type of eruption.

Cinder cone → small explosive mafic volcanoes formed by a single, prolonged eruption lasting 1-20 years. Slopes are 30-35 degrees. Mostly releases loose bombs and lapilli, some lava flow.

Dome complexes → medium volcanoes made of many volcanic domes that build on each other. Intermediate-felsic composition (dacite and rhyolite). Very viscous (not runny), silica-rich magma = highly explosive. Made by several eruptions from 1000 to 100,000 years.

Composite volcano (stratovolcanoes) → medium to large volcanoes made of lava flows, lava-flow rubble, and pyroclastic debris. Explosive → high silica = colder & more viscous, so lava doesn't travel far. Slopes greater than 25 degrees. Formed by rare to frequent eruptions over several hundred thousand years. Responsible for the most deaths.

Shield volcano → small to giant mafic volcanoes made of many thin and widespread basaltic lava flows. Non-explosive (very hot & runny). Gentle slopes usually less than 15 degrees. Active for a few hundred to a few million years. Forms the largest volcanoes on Earth. Mostly lava flows but some debris (tephra).

Maars → very violent, produced by the interaction of magma and groundwater. Water turns into steam which drives a violent explosion that forms a crater (similar or meteor impact).

Ice-contact volcanoes → many volcanoes and lava flows erupt beneath or against glaciers, which may melt the ice and produce huge floods. Usually result in oddly shaped volcanoes produced by rapid cooling of lava when they came into contact with ice and water.

Caldera (super-volcano) formation (not craters, craters are smaller)

Calderas are depressions at the top of a volcano formed when the roof of the magma chamber collapses due to the movement of magma out of the chamber (through eruptions). FELSIC AND EXPLOSIVE!

Different types of eruptions

Hawaiian → low viscosity, non-explosive basaltic magma. Results in lava flows or fountains.
Strombolian → mildly explosive basaltic/andesitic magma. Results in bombs and lavas.
Vulcanian → viscous, very explosive andesitic/rhyolitic magma. Results in column of ash.
Pelean → very explosive (viscous, high silica*) dome collapse. Results in pyroclastic flows.
Plinian → very explosive (*) andesitic/rhyolitic ash. Results in column of ash and pyroclastic flows.
Phreatomagmatic → contact between magma and water, very explosive.

Volcanic features

Craters → depressions at the top of volcanoes that form by explosion or collapse at the peak (summit).
Vents → openings through which lava and pyroclastic debris erupt. Vents that form elongated cracks are called fissures, which can produce large lava flows called flood basalts.
Hot springs → groundwater that becomes heated when it touches hot rock.
Geysers → boiling underground water that periodically releases steam and hot water; steam-driven.
Resurgent Calderas → very dangerous, but very rare. Releases huge amounts of pyroclastic materials.

Why don't all magmas erupt?

Density is part of the reason why some magma solidifies underground or others erupt. Mafic magma rises easily through the oceanic crust (basalt), but has a harder time rising through felsic continental crust (mafic is higher density than felsic). Fractures in the crust allow mafic magma to creep through; otherwise it stays between the crust and mantle and forms a gabbro sill. If the magma can partially melt the crust, it may form felsic magma, which can rise further but usually cools before it reaches the surface.

Pluton crystallization produces economic resources

There are many economically important elements (gold silver, copper, zinc, nickel, etc) present in tiny amounts in magma; these are concentrated into pegmatites, a coarse-grained rock with very large crystals.

3.4 Why are there different types of volcanoes and volcanic eruptions?

1. Amount of gas

The dissolved gasses in magma is kept under pressure underground; pressure decreases when it moves towards the surface and the gasses turn into bubbles, rapidly rising and exploding out of the volcano. These rapidly expanding gas bubbles cause the liquid magma to blow up, which freezes in the air as ash. Water vapor (gas) dissolves more in felsic magma than mafic, which is why felsic magmas are explosive.

This water vapor can come from the mantle, where minerals that contain water release their water into the magma as the mantle melts. Subduction also carries water into the mantle and triggers melting at subduction zone (lots of dissolved water = more dissolved gas = violent subduction zone eruptions).

2. Viscosity (resistance to flow)

More silica = more viscous (less easy to flow). Basaltic lava flow = like ketchup, rhyolitic = like peanut butter. Gas bubbles cannot rise and dissolve through the viscous flow, so pressure rises (big explosion).

3.5 What hazards do volcanoes present?

Divided into primary (direct) and secondary (indirect) effects.

Primary → lava flows, ash falls, bombs, pyroclastic flows and surges, lateral blasts, and poisonous gases.
Secondary → lahars, debris avalanches, landslides, water contamination, floods, fires, tsunamis.

Volcanic Explosivity Index (VEI) → measures size of a volcanic eruption; looks at volume of material erupted, height of eruption cloud, and how long it erupted.

Lava flows

One of the most common products of volcanic activity. 3 types, basalt, andesite, and rhyolite:

Basalt → most common. Low viscosity (fluid) & high eruptive temperatures; few miles/ph. A'a (rubbly/blocky) and pahoehoe (smooth) lava flows. Most travel slow enough for us to avoid, but can really damage property and the environment.

Pyroclastic flows and surges

Pyroclastic flows → most lethal and eruptive; hot gas, ash, and rock fragments fly down the slopes of a volcano during an eruption. It may form when ash rising above the volcano collapses, when it pours over the edge of a caldera, or when a lava flow or dome on a steep slope collapses

Pyroclastic surges → dense clouds of hot gas & rock debris. Faster & more violent than pyroclastic flows.

Lateral blasts

Gas, ash, and rock fragments are blown from the sides of the mountain; very fast and damaging.

Ash falls

Finely broken volcanic rock and gas that is carried by wind & rain into the atmosphere. Many hazards:

- Vegetation can be destroyed. Long term → ash enriches soil and increases soil moisture
- Contaminate water. Can clog the gills of fish, destroy habitats & increase acidity, killing aquatic life.
- The piling of ash on roofs can damage buildings (1 cm of ash = 2.5 tons of weight)
- Damage mechanical and electrical equipment due to extra weight, and its rough and grinding nature
- Ash can melt inside plane engines and turn to lava due to the high temperatures of the engines

Some agricultural villages settle near volcanoes because of the fertile ash-soil. This leaves them at increased risk of destruction by lava flows, pyroclastic flows, lahars, and pyroclastic-fall deposits.

Poisonous gases

Water vapor and carbon dioxide are two most common gasses (many more emitted); in high concentrations these are toxic. Carbon dioxide can suffocate people; sulphur dioxide reacts with water to produce sulphuric acid (damages crops, contaminate water) and acid rain.

Vog (volcanic material and fog). Sulphur dioxide, steam, other gases, and water vapor form vog and acid rain. Causes troubles breathing (& asthma), headaches, sore throats, watery eyes, and flu-like symptoms.

Edifice/sector collapse

Side of a volcano collapses (can be during or not during an eruption). Magma moves up from the chamber below, making the volcano inflate. The slopes then become unstable and collapse. Large collapses (sector) can be triggered by ground shaking, steam venting, rising magma, or an earthquake.

Debris flows and other mass movements

Debris flows = lahars. Most serious secondary (indirect) effect. Caused when snow/ice is melted by hot pyroclastic debris (mix of sediments, large rocks, snow or ice), or if it rains hard enough to erode pyroclastic deposits. The mud-like flows then rush downhill, possibly removing vegetation from the land, making it more vulnerable to debris flows and landslides.

Mount St. Helens 1980-2006: from lateral blasts to lava flows

Before explosion: earthquakes and small explosions; bulge appears on north side. A later earthquake causes the bulge to break into debris and flow down the sides. During this time the mountain erupts with a lateral blast, and causes pyroclastic flows down the side of the mountain. Within an hour, a large column of ash and gas form, falling over neighboring states. Caused several lahars too.

Indirect volcanic hazards

Waves creates by caldera collapse may ruin coastal villages (Krakatau), or pyroclastic flows may devastate the farmland and lead to famine.

3.7 Effects of volcanoes

Most volcanic eruptions occur in sparsely populated areas so they cause little damage. In populated areas it could result in a catastrophe, killing thousands of people and causing millions of dollars in damage.

3.8 Linkages between volcanoes and other natural hazards

Plate tectonics determine what kind of eruption you get (shield, strato (composite), cinder, dome) because it depends on where it melts and what the composition of the crust is (mafic, felsic?). Also linked to fire, earthquakes (magma rises through crust), landslides, tsunami (sector collapses), floods (when volcanoes explode near glaciers), and climate change (ash blocks sunlight, cooling Earth).

3.9 Natural service functions of volcanoes

Gases and water vapor released by volcanoes billions of years ago formed the atmospheric and hydrologic systems that allowed life to appear and evolve. Also created new land and made soil fertile.

Volcanic soils → Breakdown of lava and pyroclastic debris provide lots of nutrients for crops to thrive.
Geothermal power → internal heat of volcanoes can generate power for nearby areas.
Recreation → gives rise to health spas and hot springs, hiking, snow sports, tourism, and field trips.
Creation of new land → like Iceland, Hawaii.

3.10 Reducing the volcanic hazard

No human activity affects volcanoes, but we can minimize the loss of life and property from eruptions.

Forecasting

By looking at the composition of the first magma erupted, we can loosely forecast the eruption style and therefore its hazards. We can also study lava flows and pyroclastic debris from past eruptions. Then we can decide which areas are at risk. Forecasts are NOT predictions. It estimates the probability that the hazard will occur in a particular way within a set time. Think weather forecast. Can try to forecast by:

- Monitoring seismic activity → earthquakes help us monitor the movement of magma as it moves up
- Monitoring thermal, magnetic, and hydrologic conditions at the volcano → magma that moves beneath the volcano before erupting will change volcanic conditions. Can sense rise in heat flow, and old rock melted by new magma may have their magnetic properties changed.
- Seeing if the volcano tilts or swells → or if cracks open, or if volcanic lake water levels change
- Keeping track of what gas it emits → changes in CO_2 and sulphur dioxide may precede rising magma
- Studying the geologic history of the volcano → dating lava flows, pyroclastic deposits.

Hazard maps

Made by determining the silica content (lets you know how explosive it is) and when it previously erupted (through deposits/historical records). Lists possible hazards and which areas may be affected.

Seismic monitoring (most important tool!!!!)

Uses seismic stations (ideally 6+) to locate the depths of quakes caused by magma rising through the rocks. Pre-eruption quakes → comes in swarms of 5.0 or less. Occur close to eruption location. Eruption quakes → sustained, 2.0-6.0. Occur close to eruption location.

Ground deformation (Volcano changes shape)

Looks at angles of sides (is it swelling or bulging?), distance across the summit, and heigh of the summit.

Satellite Monitoring

InSAR → Satellite measurements that detects changes in elevation
Global coverage, can do every 15 mins, ideal for remote areas and for early warnings for airplanes

Gas Emission & Monitoring

Identifies new gas-rich magma. Gas my decrease before an eruption, indicating a sealing of the system. Calculates the total amount of CO_2 and SO_2

COSPEC & FTIR calculates CO_2 and SO_2 by examining volcanic gasses through UV light from the sun (carbon dioxide and sulfur dioxide has distinctive signals when they deflect UV light)

3.11 Perception of and Adjustment to the Volcanic Hazard

People live near volcanoes for several reason: 1) they were born there (or perhaps all of the land is volcanic, like Hawaii), 2) land is fertile and good for farming, 3) they think an eruption is unlikely, 4) they want to take the risk, 5) they are unaware of any risk, or 6) they may not be financially able to move.

Apart from leaving the area, we can try to deflect lava flows (bombing, pumping water into lava to cool and slow it, building a wall). Bombing → most effective in areas where lava is stuck to a narrow channel bounded by solid lava; bombing blocks the channel, causing the lava to pile up and break through upstream.

- Dissolved (in magma as liquid) vs exsolved gas (present as a gas in a bubble in the magma)
- Continental volcanic arc → convergence of continent and oceanic plate, water coming out of oceanic plate is heated up, causes melting of above crusts and magma comes out along continental border (arc)
- Heat, water, and lower pressure affects melting of rocks
- Gas and viscosity determine type of eruption (explosive or not)
- As magma rises and pressure decreases the nature of the liquid in the magma (which is just gas under pressure) becomes unstable and changes into bubbles
- Dome collapse can cause pyroclastic flows
- Sector collapse = landslide → can cause debris avalanche
- Mt St. Helens triggered by landslide
- Gasses → builds pressure and bubbles
- Difference in viscosity due to silica content (but a little bit of gas can make lava runny — negligible)
- Hotspot under continent → hard for gas to escape, builds up really large magma chambers, eruptions cause lots of magma to escape, making the rock very weak. When it collapses... → caldera
- Mt baker = significant lahar hazard in surrounding valleys (Abbotsford). Lava and pyroclastic flow hazard for those close to Mt. Baker (low risk because areas near Mt. Baker are sparsely inhabited)
- Silica (due to its chemical composition) is viscous by nature
- Block and ash flows = pyroclastic flows

Ch 4 – Landslides

Normal strength = perpendicular to slope. Know about Hope Landslide, La Conchita, Portuguese bend, Rissa, where highway 99 is.

Portuguese Bend, California (still a hazard)

Road-building and changes in sub-surface drainage due to humans settling in the area reactivated the ancient landslide. It is a very slow-moving landslide that has been accelerated by more-than-usual rainfall. They drilled wells in the wet rocks to remove groundwater, drying out and stabilizing the rocks.

Hope land slide 1965 (Canada's largest)
Huge mass of rock detaches from mountain hits a lake and sends muddy debris up the valley wall, back down the slope, and then up and down the valley. Highway 3 was buried and 4 died. Trigger unknown, but cause is — adverse geological structures (weathered layers of volcanic rock that lay parallel to slope).

Rissa Landslide (quick clay)
Cause = presence of leda clay, leeching of salt by freshwater,
Trigger = excavation of land and dumping it on border of land near lake (overloading)

4.1 An introduction to landslides
Mass movement → general term for any movement of material down a slope.
Landslide → rock fall, debris flows, and slow moving bodies of solid rock that move downhill due to gravity. Can be fast or slow with small or large volumes of sediment/rock.

Slope processes
Most slope surfaces are a combination of straight and curved segments → segmented slopes. Rock fragments that fall off the side of steep slopes gather below in what is called the talus slope.

Slopes can be convex, concave, straight, or a combination of the 3; the shape depends on the rocky type and climate. Free-face slopes are more common in mountains, hard rocks, and dry environments.
Free face = near-straight part at the bottom of a convex slope? Steep slopes?

Types of landslides
4 important factors:
1) The type of movement (fall, slide, flow, or complex movement involving more 2 or more)
2) The type of material (rock, compacted sediment, or organic soil/earth)
3) Amount of water present
4) speed (fast = can be seen with naked eye)

Falling → very fast, occurs on steep slopes. Material falls off because of weakness and gravity.
Sliding → slow to fast, usually whole blocks of soil, rock, or debris move down along a surface of failure.
Slumping → rotational sliding. The failure plane is curved upwards. Usually weak material, med speed.
Translational Slide → slow to fast, usually strong material moves as a whole along a flat surface.
Flow → slow to rapid downhill movement of sediment, usually with help of water.
- → creep → very slow flow (mm to cm a year).
- → sackung → huge, slow-moving landslides. Type of creep.
- → topples → slow creep-like movement where rocks pivot about a point

Subaqueous landslides → a slump or slide that occurs underwater changes into a debris flow or turbidity current (rapid flow of mud, sand, and water along sea floor). Can be triggered by earthquakes.
Complex landslides → may form when water-saturated sediments flow from the lower part of a slope and weaken the upper part, causing slump blocks to form.

Landslide Impacts
There are a few things that determine the human and economic impacts of landslides: 1) Population density, 2) cost of infrastructure, and 3) how prepared the affected population is.

Landslide fatalities are reported as ~7500 a year, but in actuality is probably more because most of the deaths caused by landslides are associated with the landslide trigger (earthquakes, floods, volcanoes).
Landslides in BC: Return period is about 25-100 years. Occurs due to our mountainous terrain, complex geology, loose glacial sediments, high amounts of rain and snow, and frequent earthquakes.

Forces on Slopes

Slope stability is measured by a factor of safety (FS), a ratio of resisting forces (forces that keep it from moving down) to driving forces (forces that move rock down a slope). FS > 1 means that resisting forces are greater than driving, so the slope is considered stable.

Resisting force = Shear strength (S) of slope material → slope's ability to resist shearing motion; to resist sliding or flow along potential slip planes (planes of weaknesses), weak spots in the slope like fractures.
Driving forces = Shear stress (τ) → motion of shifting layers from side to side across a plane. Factors in gravity, weight of slope material (including weight by man-made buildings) & amount of water in slope.
Angle of repose = steepest angle a slope can maintain with collapsing. FS = 1 (or just above 1)

Driving and resisting forces are affected by many factors:

EXTERNAL CAUSES → factors outside of the slope that affect stability

1) Slope and topography → steeper slopes = greater driving forces = greater chance of failure. Relief = height of hill or mountain. High relief = hilly and mountainous and prone to landslides.

   Debris flows are mixtures of mud, debris, and water. They can be fast or slow, like mud or wet concrete, and travel through streams, channels, 'chutes' on steep slopes, or fan out across the surface. They can release a huge range of material.

2) Climate → characteristic weather of a place. Influences how much water and vegetation is in a region.
   Dry and semi-dry areas have little vegetation, think soils, and bare rock. Talus slopes are common. Rock falls, debris flows, and shallow soil slips can occur here.
   Humid and sub-humid areas haves lots of vegetation and thick soil. More water = increased weathering of rocks. Complex landslides, soil creep, rockslides, slumps, and debris flows can occur here.

3) Vegetation → affected by climate, soil type, topography, and fire history. Vegetation resists surface erosion by rainwater while still letting water get into the slope; roots can add strength and cohesion to slope materials, or can add weight to a slope, making it more likely that the slope will fail.

4) Overloading → Adding weight (due to buildings, roads, landslides)
5) Undercutting → Removing the lower part of the slope (material that was supporting the slope)
6) Time → contributes to weathering, rate of creep, and fluctuation in ground water.

INTERNAL CAUSES → factors within the slope itself that determine its stability

1) Type of material → mineral composition, degree of compaction, and planes of weaknesses. Rotational slides (curved slip surfaces) are most common in unconsolidated sediment and weak rock types.
   Translational slides (straight) result from fractures, bedding planes, weak clay layers, and metamorphic foliation. Debris avalanche is a very shallow slide of sediment over bedrock; it is a type of translational slide. Colluvium is the material that accumulates at the foot of a slope (from debris avalanches).

2) Water → adds weight to slopes. In sediment it can help or hurt, depending on amount of water.
   Lots of water = vulnerable to shallow soil slips and debris flows.
   If waters gets deep into the slope, slumps may occur.
   Streams can also erode the base of a slope and decrease slope stability.
   Liquefaction → water saturated material loses its strength and flows as a liquid. Depends on structure of sediment. When loosely packed grains are disturbed, the forces binding the grains drop to zero.
   Thaw flow slides → the melted layer of permafrost (active layer) flows downhill.

In rock water reduces shear strength along planes of weakness. When water freezes it expands; if it freezes in rock fractures it can force fractures apart, destabilizing slopes and triggering rock falls.

3) Adverse Geologic Structures → unfortunate bedding or fracture location angled in unstable directions.

4.2 Geographic regions at risk from landslides

Mountainous areas (high relief areas) with steep slopes are most prone to landslides. Common in B.C, Yukon, Alberta, and Appalachian mountains. Urban development, tree-cutting, and changing global climate patterns (change in precipitation) are all factors in landslide-prone areas.

Southern California Landslide: La Conchita 1995 and 2005

2005 reactivation of an old 1995 landslide was unprepared for but its damages could have been minimized. 4 factors contributed to it: steep or high slopes, weak rocks, history of past landslides, and periods of intense rainfall. 4 Possible solutions to the recurring problem of landslides: stabilize the slope, change the land use (from homes into a park), install an effective warning system (measure rainfall and slope movement), or do nothing and just face future losses.

4.3 Effects of landslides and linkages with other natural hazards

In North America landslides cause about 30 deaths a year and $1-3 billion dollars in damage.
Direct effects → being stuck in or buried by debris. Damage to homes, roads, and utilities. Delay travel.
Indirect → floods, blockage of salmon migration routes (economic losses).

Linkages between landslides and other natural hazards

Linked to earthquakes (trigger slides), volcanoes (lahars), storms (water), fires (weaken slopes) and floods (if debris forms a dam across a river). Landslides can also trigger tsunamis by displacing water.

4.4 Natural service functions of landslides

Few benefits. Includes the creation of new habitats in forests → ecological disturbance by landslides in old-growth forests provides open spaces and makes way for plant and animal diversity. Creation of aquatic ecosystems → lakes dammed by debris can also be a new habitat for aquatic organisms. Valuable minerals may also be freed by weathering and transported downhill by mass wasting.

4.5 Human interactions with Landslides

Urban development, building of transportation networks, and exploitation of natural resources all affect the magnitude and frequency of landslides. Some of the most common activities that cause landslides are:

Timber harvesting

2 controversial practices: 1) clearcutting → taking away all trees from a large piece of land (loss of traction from roots), and 2) road building (interrupts surface drainage, chances subsurface movement of water, and can change the distribution of materials on a slope by the taking out of/dumping of slope materials).

Urbanization

Building on steep slopes, saturation of a slope, removing vegetation and soil, cut-and-fill construction (removing the material from the upper slope and placing it near the bottom), and additional weight from human structures or deposits of fill all severely destabilize slopes.

4.6 Minimizing landslide hazard and risk

Identify areas of potential landslides → these are a few indicators of potentially unstable slopes: crescent-shaped cracks or terraces (land looks like series of steps) on a hillside, tongue-shaped areas of soil or rock on a hillside, piles of talus at the base of a cliff, areas of tilted trees, or exposed bedrock with parallel layering of the slope. Maps can then be created to assess the hazard and risk.

One can make hazard maps and models to estimate which areas are at risk for landslides and what the consequences will be.

Prevention and Protection → good engineering practices can help minimize hazards, like:

- Surface and subsurface drainage (to keep water from running across or getting into the slope)
- Removing the unstable material all together (blow it apart)
- Grading can remove unstable slope materials → used properly cut-and-fill practices can reduce the steepness of a slope and increase resisting force by placing fill at the base.
- Cutting a series of benches (steps) into the slope has similar effects.
- Building anchors to support slopes. They must be put well below the base of a slope, backfilled by permeable gravel, and contain drainage holes to let water out of the slope. Bolts can secure unstable rock slopes
- Building barriers and nettings. Heavy metal screens and rock fences can catch small rockfalls.
- Building retaining walls to support slopes. Like a concrete wall up against the slope.
- Debris flow protection. 1) Using barriers to remove the debris from water (water less dangerous without debris in it). 2) Use concrete-lined channels to prevent more debris from being incorporated into the flow. 3) Use boulder-embedded channels to decrease the flow's velocity and its ability to erode.
- Scaling: Workers knock loose materials off slope. Effective if slopes are steep enough that small forces (ie humans) can trigger falls of loose material. Effective against: Steep Rock Falls (or topples). Low cost.

Landslide warning systems → monitoring surface changes, water levels, rock falls, geophones (pick up vibrations from moving rocks), and fences linked to signal systems (signals sent when large rocks hit the fence → trains can stop before they reach the danger zone).

4.7 Perception of and adjustments to landslide hazards

The danger of landslides do not prevent development in that area → people are not convinced by technical information and because large landslides are infrequent, evidence of past events isn't readily available and convincing enough.

Adjustments to landslide hazards

Only sure way is to avoid building in landslide-prone areas. As with earthquakes, placing important facilities like hospitals, schools, energy buildings, and police stations away from landslide-prone areas is important. Installing an effective drainage system also reduces the water pressure.

Ch 5 - Lightning, Thunder, and Tornadoes

Adiabatic processes → change in temperature of air parcel without gain or loss of heat from outside the air parcel. **Remember:** warm air rises, and when it rises it becomes cooler.

Rising air experiences a drop in temperature, even though no heat is lost to the outside. The drop in temperature is a result in a decrease in pressure at higher altitudes. If the pressure of the surrounding air is lower than that of the rising air parcel, the parcel will expand. As it expands the molecules of air are doing work, affecting the parcel's temperature (average kinetic energy of the air molecules in parcel). Laws of Thermodynamics → inverse relationship between the volume of an air parcel and its temperature. During either expansion or compression, the total amount of energy in the parcel remains the same (none is added or lost). The energy can either be used to do the work of expansion, or to maintain the temperature of the parcel, but` it can't be used for both. If the total amount of heat in a parcel of air is held constant (no heat is added or released), then when the parcel expands, its temperature drops. When the parcel is compressed, its temperature rises. In the atmosphere, if the parcel of air were forced to descend, it would warm up again without taking heat from the outside. This is called adiabatic heating and cooling.

5.1 Processes of Lightning Formation

Intra-cloud (ICL) lightning (cloud-to-cloud lightning) occurs when the voltage gradient within or between clouds overcomes the electrical resistance of the air. Releases a very large and powerful spark that usually travels between positive and negative charge centers within the thunderstorm → causes sky to light up. Usually called **sheet lightning** since the spark is covered by the clouds. 80% of lightning is ICL.

Cloud-to-ground lightning (CGL) is when the negative charges at the cloud base repels (-) on the ground below, attracting (+) charges directly below the cloud and establishing a large voltage difference. There are **(-)** and **(+)** strikes. 20% of lightning is CG.

Steps: electrification of a cloud → path for electrons to flow from cloud to ground → electricity discharges to produce lightning.

Charge Separation

For lightning to occur a separation of (+) and (-) charges must take place — negative **usually** gathers at the bottom and positive near the top. Since lightning only occurs in precipitating clouds with beyond freezing temperatures, collisions between ice crystals and soft hail are thought to be responsible for electrification. Hailstones usually gather negative charge and then fall downwards towards the base.

Runaway Discharges

Lightning is believed to be a result of very fast moving electrons. As electrons move faster (due to an electric field) resistance falls and allows the electron to gain more speed and creates a huge amount of energy. More runaway electrons are created when electrons collide with other atoms; when these accumulate in a small space, the energy is released in a **runaway breakdown**.

Leaders, strokes, and flashes

Negative Strikes → **Stepped leader** → occurs just before lightning in CGL. Negatively charged air from the cloud base branches out (steps); when it touches the ground, a pathway is created for electrons to flow, producing the lightning **stroke** and **return strokes**. **Dart leaders** are produced after the initial stroke; several strokes are called a lightning **flash**, which transfers electrons from the cloud to the ground and neutralizes the negatively charged ions near the cloud base. More common than positive strikes.

Positive strikes → comes from anvil of the cloud; positive charges react with negative charges at the ground to result in strikes that send positive charges to the ground.

Types of lightning

Ball lightning → less common than strokes and leaders. Looks like a round, glowing mass of electrified air that rolls through the air before dispersing or exploding. Some forms are attracted to conductors while others tend to flow through closed spaces or windows and doorways. Thought to be caused when lightning reduces silicon compounds in the ground into unstable components, where they condense into groups and float in the atmosphere because they are so light. Their visible light is due to oxidization.

St. Elmo's Fire → ionization (conversion of atoms into ions) in the air causes tall objects to glow and continuously emit blue-green sparks. Usually occurs just before CGL and produces hissing noises.

Sprites → large red mass with blue-green tentacles, short-lived electrical bursts that rise from cloud tops just as lightning is produced below. Very rare.

Blue jets → Upward-moving lightning that comes from the tops of the most active thunderstorm regions.

Thunder

Sound created when air expands explosively due to a major increase in temperature. Sound travels much slower than light. To estimate your distance from lightning in km's, count the number of seconds between when you see and hear the lightning, and divide that by 3. Doesn't work for strokes far away as their sound waves don't reach the listener → **heat lightning**.

5.2 Lightning safety

- Lightning kills an average of 69 people a year in US and 7/yr In Canada
- Take cover in a building, don't touch electrical appliances or telephones, don't stand on high areas or under tall objects as they may serve as natural lightning rods
- Cars are relatively safe because electricity will flow around the car body rather than through the interior

5.3 Air Mass Thunderstorms and Severe Thunderstorms

Air mass thunderstorms → most common and least destructive. Usually lasts less than an hour, occurs in small area. Consists of many individuals **updrafts** (upward air — **cells**) that each undergo 3 stages:

1) **Cumulus stage**: Usually occurs at night when air is cool. Warm, unstable air rises (from surfaces that undergo more rapid heating than others — **convection**) and condensates to form clouds. Evaporating cumulus clouds add water vapor; if air becomes humid enough and dew point is reached, the clouds will stay as water and expands outwards instead of evaporating. The higher it goes the colder it gets.

2) **Mature stage:** Most intense stage of precipitation, lightning, and thunder. Heavy precipitation drags air toward the surface → **downdrafts** **(20-90 km/hr)**. These are strengthened due to evaporation of raindrops in the outer part of the cloud, which makes it cooler, denser and prevents it from rising further. Interior dominated by updrafts while exterior dominated by downdrafts → intensifies storm. Downbursts (see below) draw in warm air needed to create new cells.

3) **Dissipative stage:** Continued precipitation causes downdrafts to occupy the cloud base; when the base is full, updrafts cannot rise, stopping the supply of water vapor and causing the storm to dissipate.

Air mass TS' are usually multi-cell with an anvil shape. The thunderstorm's energy is determined by temperature and humidity (how much water vapor is present). **Mixing ratio** = amount of water vapor divided by amount of all other gases.

Severe thunderstorms

- Water vapor supply not cut off because downdrafts and updrafts are separated from each other by wind shear (difference in wind speed and direction)
- Wind speeds over 93 km/hr, hailstones larger than 1.9 cm in diameter, can create tornadoes
- **Mesoscale** → area size of 10-1000 km that allows wind, temp, and humidity to create severe storms
- **Squall lines** → elongated line of severe thunderstorms. Needs wind shear!
- **Supercells** → most violent storms that contain a single cell. Needs wind shear, high water vapor content, something to trigger uplift, and potential instability. Often rotates as a **mesocyclone**, and can spawn tornadoes — rotation too slow to be seen by naked eye.

3 clues to identify a thunderstorm: 1) oval shape of anvil cloud, 2) shadow under anvil cloud, and 3) lumpy region where the cloud updraft overshoots, pinpointing the violent stem portion of the anvil cloud.

Doppler radar: can see hooks (common of supercells), which usually means that tornadoes will form. Also see precipitation inside the storm (in the updraft and downdraft stem of the anvil cloud — overshoot area).
Satellite: see the tops of anvil clouds
dBz: 'radar echo intensity (in decibels).' Measures rain intensity. Can keep track of movement.

Downbursts, derechos, and microbursts

Downbursts: created by strong downdrafts; they are cold gusts of wind that reach 270 km/hr. When they reach the ground they spread out. If the winds descending in a downdraft are extremely fast, they can also bring destructive winds. This happens in microbursts as well.
Gust fronts → cold, dense air created by downbursts. It displaces warm air upwards and can create:
- **Arc clouds** (form along gust fronts when the warm air is lifted), or **haboobs** (dust and sandstorms)

Derechos: also created by downdrafts; these are very powerful, widespread, straight-line winds (like squall lines). They can last for hours and reach speeds higher then 200 km/hr.
Microbursts: downbursts with small diameters (>4 km). Can create strong wind shear — air flowing in one direction may be opposite of air flowing in another direction. Especially dangerous for planes, they may be pushed upwards on one side and suddenly pushed down the other.

The sun: source of atmospheric heat

- Some solar energy absorbed at thermosphere (top atmosphere), stratopause (middle), and bottom (Earth's surface). Some energy reflected by clouds + ground, some absorbed by ground → causes heating of ground, NOT AIR → warm ground heats air (troposphere — where most storms occur)
- Sunlight absorbed by ground changes into **sensible heat** (warms the air and causes temperature to rise), and **latent heat** (evaporates water from lakes, vegetation, and causes humidity to increase, which if saturation is reached, causes gasses to condensate into liquids! = CLOUDS AND STORMS)
- Ground contains most amount of heat at sunset — it has taken in rays all day, but hasn't released it yet because night hasn't come yet.
- **Late afternoon and early evening → more likely time for thunderstorm formation!!**

5.4 Geographic and Temporal Distribution of Thunderstorms

- Most likely to occur in areas where moist air is constantly uplifted → tropics. Lifting of air usually due to strong solar heating
- Central Africa, Florida peninsula, southeast US, southeast south America, and Malaysia/Thailand areas.

5.5 Tornadoes

- **Tornadoes** are violently-rotating columns of air that come into contact with the ground. They come from supercell thunderstorms and usually rotate counterclockwise in northern hemisphere (opposite in south). Result from very large difference in atmospheric pressure over short distances.
- TORNADOES CAN BE INVISIBLE. There are many tornado outbreaks in a year (6 in one day)
- Vary in shape and size, most only last for a few minutes (can last hours). Averages 50km/hr.

Tornado formation

Although most come from supercells, they can come from any situation that produces severe weather.

Steps in supercell tornado developments:
1) Wind shear causes slow rotation within cloud interior and produces **mesocyclones** (rotating air in vertical path upwards) and **striations!** Creates tornadoes 20% of the time, precedes them by ~30 mins.

2) Wall clouds are the isolated lower part of cloud base that is formed by mesocyclones. SW of storm
3) Funnel cloud → narrow, rapidly rotating wind and water from base of wall cloud → exactly like tornadoes, but it hasn't reached the ground yet.
4) Debris cloud → dust and debris from ground connects with funnel cloud = tornadoes

The location and timing of tornadoes

- Some in southern Ontario (great lakes area, most occur in June), but most occur in US. WHY?
  - Because it covers a wide range of latitudes. Eastern region is quite flat with no major mountains extending from east-west → allows for collision of tropical air with continental polar air = tornadoes
- Tornado alley = east texas to eastern Kansas and Nebraska
- Most occur during spring when air mass contrasts are strong (May-June)

Trends in US tornado occurrence

Thought to have doubled from 1950-1990s, but this may just be because more have been reported as population in rural areas increases. Doppler radar network also improves detection & more people participate in national storm spotter network. Idea that human activities → tornadoes is still debatable.

Tornado damage

- Most damage caused by flying debris and rotational winds. Narrow damage path about 1-10 kms long.
- **Suction vortices** → small zones of intense rotations (what we usually think of as tornadoes)
- Translational winds (moving right across the surface) can move 0-100km/hr (usually 50 km/hr)
- Rotational winds (rotating within center of tornado) can be 65-480 km/hr → cause most damage
- Damage measured by **fujita scale**. EF0 = very weak (breaks windows) EF5 = destroys whole buildings
- Most kill no one because they are small and don't last long

Tornado safety

- Stay indoors and in the basement. If you have no basement, crouch on lowest floor away from windows and if possible cover yourself with padding.
- Evacuate from mobile homes; if you cannot find outside shelter, lie flat on low ground or in ditches.
- If you're in a car, drive at right angles to the tornadoes path

Tornado watches

- 6-12 hour forecast of a broad region within which tornadoes are favorable or likely to occur
- Continue normal activities but continue to check forecast and listen for announcements on radio

Tornado & thunderstorm warnings

- It has already occurred, tells you where it is, where it's moving, and where it may hit.
- Warning come 15 minutes OR LESS before a tornado hits you. Go to shelter IMMEDIATELY

Ch 6 - Tropical storms and hurricanes

6.1 Extremely strong tropical storms around the globe: the tropical setting

Atlantic & eastern Pacific = **hurricanes,** far west Pacific = **typhoons**, over the Indian Ocean and Australia = **cyclones**. Typhoons tend to be larger and stronger than the others. Western north Pacific (southern China area) = hit with the most typhoons.

Trade wind inversion → Warm layer of air that descends from high-pressure cells of Atlantic and Pacific Oceans and are usually prevented from reaching the ground by the **marine layer**, which is cool and moist. In the far west, the greater height of the inversion allows for more convection [circulation], so hurricanes are more likely to occur along here.

6.2 Hurricane Characteristics

Most powerful of all storms. Wind speeds of 120 km/hr or greater. Live longer and are larger (in diameter, equal in height) than tornadoes. Fueled by latent heat released by condensation in areas with deep layers of warm water, like tropical oceans. Prime hurricane months: Northern hemisphere → August-October, when waters are warmest w/maximum depth. Southern Hemisphere = January-March

Hurricanes do not occur at the equator b/c there is no Coriolis effect. There occur at about 10-30 degrees latitude.

6.3 Hurricane structure

- Contain many thunderstorms with bands of clouds & rain spiraling counterclockwise inwards (in N. Hem).
- The pressure difference (gradient) and wind speed increases gradually toward the center of the storm (**eye**), and increase rapidly near the **eye wall**.
- The center is much warmer than the surrounding air.
- Horizontal pressure differences decrease with height (altitude). They vary the least at the very top. Greater difference in pressure at the lower parts = high pressure, makes the lower part spin counterclockwise, but in the upper portion it spins clockwise (in N. Hem).

The eye and eye wall

Eye → area of mostly clear skies, slowly descending airs, and light winds. The size of the eye gives some clue as to whether the hurricane is intensifying or weakening (smaller = intensifying).
Eye wall → lies along margin of the eye. Zone of most intense activity.
Double eye wall → some intense hurricanes develop 2 eye walls as surrounding rain bands contract and intensify. As the inner eye wall contracts further, it begins to dissipate and gives way to the outer wall.
Hot towers → localized portions of eye walls that rise to greater heights than the rest of the eye wall. Usually precedes hurricane intensification.

6.4 Hurricane Formation

Tropical disturbance (disorganized groups of thunderstorms w/weak pressure differences and little rotation) → **tropical depression** (low pressure, organized group of thunderstorms) → **tropical storm** (depressions with wind speeds above 60 km/hr) → **hurricanes** (storm with wind speeds of 120+ km/hr).

Conditions necessary for Hurricane Formation

- Release of latent heat released by evaporation from ocean surface. Warmer water = more evaporation
- Deep surface layer (several 10's of meters deep) with temperatures above 27 degrees celsius.
- Coriolis effects (makes 0-5 degrees unable to form hurricanes)
- **Unstable air** conditions throughout the troposphere (warm air that tends to rise and precipitate)
- Little vertical wind shear, which would disrupt the spin and transfer of heat in a hurricane..

Self-maintaining once formed: the low pressure in the eye sucks in boundary-layer air; as air gets closer to the eye it moves faster and creates larger ocean waves. The spray from ocean waves increases evaporation and adds more moisture into BL- air, so that when this air reaches the eye wall it is humid, warm, and contains large amounts of heat. Release of latent heat (through condensation) in cumulus clouds causes air to warm and expand upwards. This expansion causes air to diverge outwards, creating a vacuum at the bottom and encouraging air to converge at the surface [circulation]. Leads to more updraft & condensation.

However, due to the wave turbulence it causes in the ocean, hurricanes cause the temperature of the sea surface to cool, limiting the supply of latent heat. Can also die if it moves over colder water, land, or other large-scale weather systems interfere (like giant cold fronts).

They can last for weeks because condensation and precipitation from thunderstorms in eye wall causes eye core to become very warm relative to its surroundings, creating HIGH PRESSURE at the top of the eye and LOW PRESSURE at sea level → propels vertical circulation. (wind goes from HIGH → LOW)

6.5 Hurricane movement and dissipation

Tropical disturbances and depressions move in direction of trade winds, Westerlies, and Bermuda High. Tend to go west from Africa. Tropical storms are affected by higher altitude winds and water temperature, usually moving towards warmer seas and towards the poles.

Hurricane paths

- Not 100% predictable. North towards the central Gulf of Mexico coast, and from Haiti to West Atlantic.
- Tend to move along East coast of North America & disappear as they move further north, due to differences in water temperatures. They can still cause heavy rains and flooding.
- As it hits land, it may die within a few days. Still brings in huge amounts of water vapor & heavy rainfall

6.6 Hurricane Destruction and Fatalities

Wind (120+ km/hr) → Damage and even destroy well-built homes. Sends debris flying everywhere.
Heavy Rain → cause flooding and landslides
Tornadoes → found in clusters within hurricanes, usually in the right-forward quadrant.
Storm surges → rise in water level caused by the hurricane. Strong winds drag ocean water, cause the sea level to rise, and causes water to pile up against the shore and onto land. Heavy waves & debris in waves also erode inland structures, sometimes causing buildings to collapse.

Hurricane winds and storms surges are most intense on the right-hand side of the storm **relative to the direction its moving in**. This is because the right-hand side winds gain added speed by moving in the direction of the storm as well. Faster winds in direction of shore = greater storm surge.

Most deaths caused by flooding. In USA, flooding caused heavy rain caused the most hurricane related deaths. In Bangladesh, flooding caused by storm surge caused the most deaths.

6.7 Hurricane forecasts and advisories

- Knowledge of past hurricane tracks is NOT THE BEST PREDICTOR
- Computer models of the atmosphere (collected by pilots) give CONFLICTING RESULTS
- Uncertainty until the hurricane gets close to shore.
- **Hurricane watch** → predict a hurricane will reach land in MORE than 24 hours.
- **Hurricane warning** → predict a hurricane will reach land in LESS than 24 hours, but do not guarantee a storm will hit a particular place → forecast maps include PROBABILITIES a hurricane will hit

Hurricane intensity scale

- Measured by the **Saffir-Simpson Hurricane Intensity Scale**. 5 categories based on avg. Wind speeds.
- Higher category hurricanes = LOWER CENTRAL PRESSURE & LARGER STORM SURGES

Atlantic multidecadal oscillation (AMO) → 25-40 year oscillation in water temperature. Plays major role in creasing hurricane activity. LITTLE EVIDENCE to support theory that gloval warming has increased hurricane activity, but it may have increased the INTENSITY of hurricanes already formed.

HURRICANE JUAN

- Hit Nova Scotia as category 1-2. Only reached there because of 2 reasons: 1) unusually high sea-surface temperatures (SST), and 2) fast movement of the storm northwards

- Condensation of gas releases latent heat and fuels storms
- Wall clouds → clue that thunderstorms have a fast enough rotation and is likely to cause a tornado
- Do not worry about MCCs and MCSs
- CGL = most dangerous kind because it touches the ground and can kill us
- Colder air = drags air down faster
- Induction → positive charges in air attract negative charges to cluster beneath the positive anvil cloud, which then rise up to meet the positive charges.
- Arc cloud visible evidence of an arriving gust front
- How does heat release (condensation) cause horizontal winds → center of a hurricane very warm, but far away the air is a normal, cooler temperature. Atmosphere → pressure higher at ground than at low. Pressure decreases slower in hot air, but faster in cold air, so pressure inside core decreases slower and is higher than pressure outside core. Pressure goes from high → low, so precipitation
- Condensation makes air warmer, warm air rises → updraft
- Droplets formed in updraft travel along anvil, and then falls → downdraft.
- Continuity effect → air spread out evenly. Important for circulation → air in a downburst spreads out to prevent leaving a vacuum where the downdraft came from.
- Supercell storms (thunderstorms) & tornadoes → most likely to form at sunset
- Supercell last longer, tap into more of the fuel supply, conditions that form supercells often have rotating winds → reason why hazards are greater from supercells rather than multicells.
- Supercells most favorable in springtime → need cold, arctic air and warm air from tropics
- Hurricanes warmest in ocean after they've been heated in summer
- Hook shape may be caused by rotation in storm, may indicate thunderstorm.

Ch 7 – Waves

Headlands → land just outs into sea.
Bays → deep recesses in shoreline (boundary between land and sea)
Beaches → result of sediment moved by waves and tides.
Estuaries → previously eroded stream valleys that submerge because of sinking land or rising sea-levels. Freshwater and seawater mix
Delta headlands→ sediment deposited at the mouth of a stream faster than erosion occurs.

7.1 What factors determine the shape of a shoreline?

- Availability of loose sediment. Sediment deposition = shoreline advances outwards
- Shoreline material's ability to resist erosion → erosion = shoreline advances inwards
- Strong rocks = strong resistance to erosion = headlands. Weak rocks = bays
- Rise and fall in sea level = shorelines shift landward or seaward.
- Tectonic motion → crust lifts up = seafloor lifts above sea level, crust sinks = seafloor below sea level.

7.2 How do waves form and move in water?

Waves: disturbances that **transport energy** through a medium (like air, rock, or water).
Crest: highest point of a wave **Trough**: lowest point of a wave
Wavelength (λ or L): distance for one full cycle (from crest to crest, trough to trough, etc). Unit: METERS
Wave height (H): vertical distance from crest to trough
Wave period (P): time for one wavelength to pass from crest → trough → crest again. Unit: SECONDS
Amplitude (A): distance from crest of trough to the ocean surface. $A = H/2$ Unit: METERS
Steepness: ratio of wave height to length. $S = H/L$ (λ) (crest → trough, diagonal slope)
Frequency: # of waves per unit of time. Unit: HERTZ
Celerity: Wave speed. C = Wavelength/Period = L/T Unit: METERS PER SECOND

How water waves form

Wind blowing across water = waves. Energy and momentum of moving air is transferred to the water. Wind speed, duration, and how long it touches water affects wave height, length, and period.

Generating forces: Wind, impacts (meteors, landslides, earthquakes), and gravity add energy in
Restoring forces: Gravity and surface tension **rebound disrupted surface**s. Usually overcompensates, creating a small ridge, causing restoring forces to pull it back down again, overcompensating again and creating another small ridge, etc. (pond rippling effect).

How waves move water

Wave base depth → d = L/2. At and above the wave base, matter moves in circular orbits whose size decreases with depth. Below the wave base, there is almost no motion. If water depth = wave base depth (seafloor), then orbits flatten until motion is horizontal. Shallow depth = breakers.

Refraction → explains why wave crests are parallel to shore. It is when waves approach shore at an gale, causing those closest to shore (refracting waves) to touch bottom, slow down, and bunch up. Offshore waves in deep water continue towards shore and spread, causing waves to bend parallel toward the shore.

How water behaviour relates to depth

Deep-water waves: water depth > wave base. Wave does not 'feel' bottom. Wave speed depends on wavelength. C = 1.56P (meters or secs)
Shallow-water waves: water is MUCH shallower than wave base. Wave swishes back-and-forth. Wave speed depends on water depth. $C = 3.1\sqrt{d}$ (meters)

How waves generate currents

Longshore currents → water currents that move parallel to the shore b/c refracting waves force water to move along shore in direction of wave motion.
Rip currents → currents move water away from the coast (water pulled back to sea by gravity).

How tsunami waves are different from other waves

- Usually arrive without warning as a a series of several waves of incredible intensity and height
- They do not break on the beach → floods inland and then withdraws, but new wave comes shortly after.
- Tsunamis have longer wavelength, larger period, and faster speed.

This is because wind speeds can't generate the energy needed for tsunami type waves. Tsunamis are caused by **sudden displacement of water over the entire depth of the ocean**, not just at the surface.

What eliminates waves?

Turbulence and **friction** takes energy out of the wave, transferring it to heat and particle motion.

What determines the state of the sea?

How large wind waves become depends on: wind speed, duration, and **fetch** (distance that wind blows without being interrupted). 45+ hour winds = 40 knots, about 600 miles of fetch.

Fully-developed sea: when energy from the wind = energy out from breaking (max energy in sea). Results in waves with many wavelengths.

When and how waves break

Waves **shoal** as they move into shallower water, causing an increase in wave height, amplitude, and steepness, and a decrease in wavelength & speed. When steepness is too high, or depth is too shallow, the water at the crest moves faster than wave trough → **breaker** (turbulent mass of agitated water rushing onshore). When the wave breaks, energy is transferred into sound waves & mechanical energy to move sediment.

The type of breaker depends on the slope:
Gentle slope = **spilling breaker** (small, gentle breakers whose energy is gradually lost over a large area)
Steep slope = **plunging breaker** (large, violent breakers whose energy is suddenly lost over small area)

Since slope doesn't change every day, surfing waves also depend on: local wind, swell from storms, and constructive & destructive interferences.

7.3 How do waves form shoreline landscapes?

How waves erode, transport, and deposit sediment

When waves **converge** at a point (usually at headlands) more energy is focused onto the point, eroding the headland (or shore). Waves then **diverge** in bays, where energy is spread out over the whole bay and longshore currents deposit sediments, creating shores.

Wavelength compared to depth determines whether the wave is in shallow or deep water. Velocity of waves in deep water depends on wave length, shallow water depends on wave depth. Tsunami uses shallow water wave equation.

- Refraction → result of change in wave properties. Velocity in shallow water wave decreases, but deep water waves are still moving fast, so it catches up with the shallow water waves. Erodes headlands and deposits sediment in the bay, straightening the shore
- Not every beach has a rip current → only if there is something to stop backwash, then the rip current is generated
- Generating → anything that creates waves (energy in)
- Restoring → brings waves up and down → allows waves to form because it allows for elasticity
- Eliminating → turbulence in water, friction between waves and sea floor (energy out)

EUSTATIC Sea-Level Change → Changes sea level worldwide

Caused by either change in the ICE SHEETS ON LAND (terrestrial) or SEA TEMPERATURE.

Sea-level decrease

- Freezing ice means less water is in the ocean and stuck on the land → lowers the sea level.
- Colder water makes water contract, decreasing the volume and global sea level.

Sea-level rise

- Melting ice causes water to flow from the land into the ocean, making sea levels rise.
- Warmer water makes water expand, increasing the volume and global sea level

REGIONAL sea level change → confined to local area (local relative change)

Emergence → land rises from the ocean, lowering sea level.
Submergence → land sinks into the ocean, raising sea level.

Regional sea level change is caused by:

1. **Isostatic rebound** → emergence and submergence of land depending on the weight of the ice sheets on it. If the ice freezes on land, it is heavy and causes the land to sink (submerge), raising the relative sea level. If the ice melts, the ice sheet is lighter and causes the land to rise, lowering the relative sea level.

2. **Tectonic movement** → In a subduction earthquake zone, the bottom plate goes under the top plate, raising the sea level around it. The top plate goes over the bottom plate, lowering the sea level around it.

Risk from rising sea levels

1) Low-laying areas and ecosystems become submerged under water
2) Coasts become flooded more often
3) Aquifers get contaminated
4) Exposure to storm surge increases (surge caused by low pressure in the eye & high windspeed pushing on the ocean's surface)
5) Erosion increases

Permafrost → permanently frozen soil that covers the arctic. Permafrost reinforces the soil and limits erosion because it keeps the soil solid and frozen. When it melts, erosion increases.

Sea ice → offshore ice that acts as a **porous breakwater** and **reduces fetch**; both functions dissipate wave energy and keeping the shore safe from storms. If the sea ice melts, erosion increases since the shore is exposed to storms.

Rivers

Storms, floods, and weathering erodes the sediments that are further inland, these sediments collect in rivers and are carried downstream, where they are deposited at the river mouth. When these sediments build up, they form a delta, and as the delta builds up, the river mouth shifts to the path of least resistance, forming a new delta. Over time, these deltas build up and become a **storm buffer**.

The Mississippi river

They took measures to reduce the incoming sediment, and locked the river mouth in place through an engineered outlet system. They also continue to remove sediment from the delta and along the river to maintain shipping lanes. This has resulted in the land **SINKING** because the old sediment settles and no new sediment replaces it. The wetlands are also cut off from the river, so saltwater intrudes and kills the freshwater plants → **ERODES THE MARSHES, NO PROTECTION AGAINST STORMS, EROSION INCREASES**. **THE MISSISSIPPI DELTA IS DISAPPEARING AND NEW ORLEANS IS SINKING**. Some propose building newer, stronger, and higher levees.

Ch 8 - The Great Dyings

Biosphere & brief history of life

Biosphere: thin "layer" of life on the Earth's surface that is composed of ecosystems. Composed of the biosphere, hydrosphere, lithosphere (Earth's tectonic plates), and atmosphere. It has changed over time.
Stratigraphy: study of the layers of rock (strata) → passage of time is recorded in rock layers
Superposition: the layer of rocks at the bottom are older than the layer of rocks at the top
Original horizontality: what rock is tilted or folded was originally flat
Cross-cutting unconformity: a period of time where there is no deposition or active erosion

Archaea, bacteria, and eukarya → 3 major branches of life. Archaea are the oldest (3.85 BA).

3.65 BA – photosynthetic bacteria use CO2 from atmosphere to produce O2 (photosynthesis) → Built up enough oxygen in the atmosphere to build Ozone (O3), protecting Earth from sun's UV rays. Allows more life to come onto shallow waters and land.
1 BA – sexual reproduction appears
543 MA – Cambrian explosion – animals with hard parts begin to appear (makes good fossils)

Biostratigraphy → using fossils to date how old rock layers are

Principle of faunal succession: time periods can be recognized by the type of fossils they contain because fossils follow one another in a definite, irreversible time sequence. Only works because animals evolve!! (If they didn't, you wouldn't be able to put them in a definite time frame)

The best fossil species for biostratigraphy:

1. Short time period (that the fossil lives) = more accurate age estimate (higher resolution)
2. Common all over the world
3. Lived in environments where fossilization is likely to occur (where they can be buried by sediment/kept away from oxygen and predators)
4. Present in many different environments

Historical Figures

James Usher: archbishop of Armagh, believed that Earth was created in 4004 BC (added up dates in Bible)
Nicholas Steno: created principles of stratigraphy, like superposition & original horizontality
James Hutton: crosscutting relationships → cross-cutting unconformity
William Smith: Principle of faunal succession
George Cuvier: found mammoth remains in Europe, but no mammoths were living in Europe → concluded that mammoths were once living, now they had become extinct

The concept of deep time

Earth is ~4.6 billion years old, and is divided into time periods → many of these time periods are based on extinction events, especially in the **Phanerozoic**, which has more extinction events than the **Precambrian**).

The **Precambrian** eon is 87% of the Earth's history → geological concept of DEEP TIME. The radiation of new species defines new geological time periods/groups of period.

PERIODS

Cold → Cambrian (543 MA)
Oysters → Ordovician
Seldom → Silurian
Develop → Devonian
Classy → Carboniferous
Pearls → Permian
Their → Triassic (251-206 MA)
Juices → Jurassic (206-144 MA)
Congeal → Cretaceous (144-65 MA)
Too → Tertiary (65-1.8 MA)
Quickly → Quaternary (1.8-0 MA)

ERAS

Paleozoic → Cambrian to Permian (543MA – 251 MA)

Mesozoic → Triassic to Cretaceous (251-65MA)

Cenozoic → Tertiary and Quaternary (65 MA – Now)

Phanerozoic Time Scale

Mass extinction events

Characteristics:

1. At least 30% of species are lost.
2. Occurs over a broad range of ecosystems
3. Short and sudden time period (million years)

BIG 5 MASS EXTINCTION EVENTS (in the Phanerozoic Eon):

1. Late Ordovician (443 MA)
2. Late Devonian (360 MA)
3. Permo/Triassic (P/T) (253 MA) → largest extinction events that permits the evolution of dinosaurs
4. Late Triassic (206 MA)
5. Cretaceous/Tertiary (KT) (65 MA) → Kills dinosaurs

What causes mass extinctions?

1. **Biologically based:** Competition, predation, and pathogens (diseases, viruses)

2. **Physically based:** Changes in continental configuration, changes in climate/ocean cyclicality/sea level. Changes in atmosphere (Volcanism can have cooling and then warming (greenhouse) effects). The greater the landmass the lower the biodiversity (in animals).

3. **Extraterrestrial based:** Asteroids, comets
4. **Many factors:** P/T extinction killed 95-98% of all living species, occurred in less than 1 MYA

1. Late Ordovician extinction (443 MA)

Gondwana (name of massive continent) moves to the south pole, freezes over. Causes sea level to sink, waters retreat and shallow reefs are exposed → kills many creatures.

2. Permo-Triassic extinction (251 MA)

Caused by many factors:

1. **Continental configuration** → many continents were joined together, resulting in less shoreline exposed & less diversity. More competition amongst animals. **Pangaea forms**.
2. **Sea level fall** → less ocean ridge activity → seafloor spreading slows, volcanic ridge shrinks, more water can be held in ocean = retreat of water from continent to ocean
3. **Ocean stagnation** → **anoxia** (absence of oxygen). Polar ice waters disappear, doesn't sink to bottom and cause circulation of the oceans → oxygen levels in atmosphere drop to >15%. Stagnant oceans kill deep-water organisms, and climate changes can cause surface-water organism to die.
4. **Possible extra-terrestrial impacts**
5. **Climate change** → Siberian Traps (site of massive volcanic activity) → releases lots of CO_2 into the air, causing greenhouse warming and raises global temperature about 5°C. Causes warming of oceans, which melts gas clathrates and releases methane → methane is better GHG than CO_2 → another 5°C increase in temperature. **Mass desertification occurs**, probably makes env't unsuitable for living.

Life during and after the P/T extinction

- Tropical seas were almost eliminated after a long ice age (beginning of permian period was an ice age)
- Shallow marine water was reduced worldwide
- Only one major landmass existed, placing pressure on species in certain areas
- Great deserts on land
- Deep ocean water probable became anoxic & CO_2-rich, and sea-level rose
- The climate warmed, probably as a result of greenhouse gases from Siberian Traps.
- AFTER → cleared space for dinosaurs and survivors of the extinction to thrive

3. The Cretaceous-Tertiary Extinction (65 MA)

- At least 50% of all species were lost
- Killed the dinosaurs (anything over 25kg has a hard time surviving) and 80-90% of marine species

Evidence of extinction

1. Walter and Luis Alvarez find a clay layer full of iridium (which only falls on Earth from extraterrestrial objects and in very minute quantities — found about a 2 cm layer). **Clay layer/iridium found globally**.
2. Transition from Cretaceous to Tertiary saw a massive spike in fern spores → fern spores are the first to colonize places after forest fires → evidence of a global fire
   - Soot layers found in rock strata w/iridium layers → evidence of massive global fire
3. **Tektites** → natural glass that is produced by melting rocks during impact → suggests impact occurred
4. Shocked quartz → impact feature. **Cross-hatched (stress) lines** called **shock lamellae** found in quartz
5. Tsunami deposits → look at rock layers to tell when tsunami happened → shows almost global tsunami activity at the end of the cretaceous period.
6. Sand size minerals suggest a melting and re-solidification. Diamonds also found.
7. Ratios of radioactive element rhenium (found in clay layer) to its decay product osmium are similar to those found in meteorites (and different from ratios in Earth's surface rock).
8. The Chicxulub crater → accounts for many of these effects. Found in the Yucatan Peninsula off the coast of Mexico. Layer of **suevite** (partially melted **breccia** → fractured rock) shows evidence of melting
   - Showed tsunami deposits, shocked quartz, and tektites were thicker towards the crater
   - Found ejecta layer at Yucatan, mostly directive NW (so they think it hit in that direction)

How it hit Earth & probably effects

- 10km meteor hit Earth at probably about 20-30 degrees (shallow entry) from the South-East.

Initial effects

- Probably vaporized all rock/trees close by, etc.
- Sends out a heat pulse that causes trees and plants to spontaneously combust = forest fires.
- Impact into Earth displaces land and causes tsunamis.

Long-term effects

- Displacement of material in atmosphere = blocks out sunlights and causes winter-like conditions for weeks-several months. Photosynthesis virtually stops on land and in oceans
- After the dust clears, water vapor remains in the atmosphere and causes greenhouse effect = warms Earth. More GHG b/c vaporization of Yucatan limestone ($CaCO_3$) produces CO_2. Temp rise about 10°C?
- Rapid shift in env'tal conditions → Earth is cold for a few months, then desert like for years-decades
- High energy blast melts air, causes nitrogen and oxygen to form oxides of nitrogen, which combines with water vapor in the air to form acid rain. Acrid rain acidifies oceans and soils on land
- There are also **evaporites** (salt created by evaporating bodies of water) → creates large salt lands
- Hits the base of the food chain in oceans and on land → microplankton

Other potential causes of the extinction

- **Deccan Traps Flood Basalts** → In India. Could cause acid rain, ozone depletion, climatic GH effects
- Continued environmental degradation as Pangaea breaks up
- Many species were already going into extinction, but dinosaurs last up to the impact

Conclusion

- The cretaceous biosphere was already stressed, but the K/T meteor was the final act to do it in
  - Meteor was probably the causal factor in the extinction of "non-avian" dinosaurs (birds are alive)
- **Baptistina** → asteroid that may have fragmented and created the asteroid that caused KT extinction

Quaternary extinctions

- Many large animals (<45kg) are going extinct, possibly because of humans ("blitzkrieg" hypothesis)

- Appears that wherever humans felt, extinctions followed. → however, rapid climate change cannot be ruled out.
  - Some refute the climate change hypothesis because:
    1. More animals died off then plants → why would animals die off faster than their food supply?
    2. Large mammals are homeotherms → shouldn't have been affected that much by climate change
    3. More habitable land uncovered in the last 11,000 years as glaciers retreat
    4. No equivalent extinctions of large-bodied animals during earlier phases of the ice age

Humans in Australia

Humans migrated there about 56,000 years ago. By 46,000 BC, 23 out of 24 genera of large bodied animals were extinct. Because it happened in different times than ice-age extinctions, main case is thought to be humans → hunted herbivores, and carnivores died b/c there was no herbivores to eat.

Humans in Madagascar and New Zealand

Humans known to be the main cause of extinctions here (mainly large, flightless birds killed). Human's effects on the env't did not just start happening after the Industrial Revolution → happened before them, accompanying every human advance from toolmaking, to control of fire, to agriculture, and to taming of animals, but the # of human-induced/related extinctions has risen in the last 12,000 years.

Chapter 9 – Hazards from Space

Space weather hazards – Impacts

Comets: "dirty snowballs". Usually around 15km in diameter. They come from the Oort Cloud (envelop milky way) and Kuiper Belt. Develop tails. The ice in comets is made of carbon, hydrogen, oxygen, and nitrogen (CHON) → the basic building blocks for life. Was life made possible by comets?

Meteoroids: asteroids and comets that orbit the sun (sand-boulder size). Become meteors if they enter the atmosphere and survive the impact (no tail). Can be stony or iron-rich. Most collected are iron-rich. About 100,000 million enter our atmosphere every 24 hours, but most burn up before reaching ground. Hit the atmosphere at 11-30km/second, and when it travels that far the atmosphere acts like a brick wall.
Asteroids: small, rocky, metallic bodies found orbiting the sun. Bigger than meteoroids. Several asteroid belts are found in between Mars and Jupiter. No tail.

History of impacts

In Earth Earth, there were probably multiple impacts, but the craters have been eroded because of tectonic activity (subduction and continental collision), and weathering.

Some major impact features

Manicouagan Crater → North Québec. About 75 km diameter, occurred in the Late Triassic at the same time as at least 4 other impacts, like the Saint Martin Crater → Manitoba, 100 km diameter; and Rochechouart Crater → France, 25 km diameter.

In the late Triassic period, the continents were arranged so that all these craters lined up along 22.8°N latitude → indicates that a fragmented comet/asteroid hit Earth, causing these multiple impacts.

The crater-forming process

Amount of energy released upon impact depends on the speed and size of the body.

Simple craters → formed by smaller meteorites. Has raised rims and concave bottoms lacking central uplifts.

Complex craters → formed by rage bodies. Has central uplifts and collapsed outer rims. Much of the asteroid and crater rock s melted and vaporized because theres so much heat and pressure. Sometimes new minerals (like diamond) are created, and other minerals (like quartz) will have its atomic structure changed. Forms a central uplift (transient crater phase) before the fractured walls of the transient crater fail and slide in, creating the final crater with a fractured rim.

Canadian impact craters

- Sudbury, Ontario → site of largest and oldest impact crater in Canada. Is home to the world's largest nickel deposit → melting from the impact concentrated the nickel that were already there.
- Wanapitei, Ontario → underwater found by gravity survey (fractured rock less dense than unaltered rock)
- Holleford, Ontario → identified by aerial photographs, saw circular features.
- Slate Islands, Ontario → found **breccia** (broken fragments of rock cemented together) on the islands that had a unique magnetic direction (paleomagnetic signature) that was acquired almost instantly

Tunguska, Siberia 1908

No impact crater happened as the meteoroid exploded 8 km above ground. Sent a heat and air pulse outwards, sent a bluish-white streak into the sky, created an extremely bright sunset and night, and was recorded around the world.

Biggest "near events" of the 20th century

May 19, 1996 → 150m diameter asteroid, would have release 2x as much energy as Mt. St. Helens.
March 2, 2009 → 40m diameter, missed Earth by about ⅕ the distance between the Earth and the moon
Shoemaker-Levy 9, May 16-22, 1994 → hit Jupiter, equivalent of several million tons of TNT, would have wiped out life on Earth to a microbial level

Impact risk and mitigation

Odds are extremely small that a large asteroid will hit Earth during our lifetime — but if it does, the risks are extremely high. Uses Torino Scale to measure likelihood of impact and its damage.
There are over 2,000 near-Earth objects (NEOs) → 25-50% of them will eventually hit Earth. 90% of these potential impactors are near-Earth or short-period comets, the other 10% are intermediate- or long-period comets (defined by greater than 20-yr. Return periods). But the average interval of time between impacts is greater than 100,000 years.

How to avoid

- Locate NEOs, determine their orbits, and figure out immediate threats. Try to alter its collision course by:
    - **fragmentation:** blow it up by drilling into it. Difficult to predict, could create multiple impact risk.
    - **Sudden orbit adjustment** → blowing it apart with a nuclear explosion, but requires warning period
    - Attaching a rock engine to drive it away
    - **Ablation:** use a big mirror to focus sunlight to vaporize its surface enough to change its surface
    - **Steady state orbit adjustment** → Sending robots out to excavate and accelerate material away from the asteroid. More predictable but required a warning period.
    - Launch a spacecraft, have it hover near the asteroid, and hope that the gravitational pull will move it in a direction away from Earth

The Nemesis theory by Raup & Sepkoski → a companion star orbiting the Sun perturbs the Oort comet cloud every 26 million years causing comet showers in the inner solar system. One or more of these comets hits Earth and causes a mass extinction.