**Lecture 1: Introduction to Natural Hazards**

*Based on Chapter 1 in Textbook*

**Natural Processes and Energy Sources**

* Processes: Physical, chemical, and biological ways in which events affect Earth’s surface
* Internal processes come from forces within Earth
  + Plate tectonics
  + Result of internal energy of Earth
* External processes come from forces on Earth’s surface
  + Atmospheric effects
  + Energy from the Sun

Hazards: Probability that a specific damaging event will happen within a particular period of time

Risk: A function of the hazard, exposure, vulnerability, and coping capacity

Disaster: Hazardous event that occurs over a limited time in a defined area

Catastrophe: Massive disaster that requires significant amount of money or time to recover

**Trends**

* Recently, there has been an apparent increase in natural disasters
  + Japan tsunami, Nepal earthquake, Haiti earthquake, Hurricane Katrina, 2015 heat wave in southern India
* The United Nations designated the 1990s as the International Decade for Natural Hazards Reduction
  + Mitigation
    - Reduce the effects of something
    - Natural disaster preparation

Look at slide 24 for Table 1.1: Effects of Selected Hazards in Canada and the United States

**Magnitude and Frequency of Hazardous Events**

* Impact:
  + Function of magnitude and frequency
  + Also influenced by other factors (e.g. climate, geology, vegetation, land-use, population)
* Magnitude-Frequency Concept:
  + Inverse relationship between magnitude and frequency
  + M = Fe-x
* The history of an area gives clues to its potential hazards
  + Maps, historical accounts, weather and climate data
  + Rock types, faults, folds, soil composition

**Geological Cycle**

* Conditions govern the type of location, and intensity of natural process
* Sub-cycles: tectonic cycle, rock cycle, hydrologic cycle, & biogeochemical cycles

**Rock Cycle:**

* Rocks are aggregates of one of more minerals
* The rock cycle refers to recycling of three major rock types
* Different rocks are formed by different processes
* Rock types in a location give clues to the geological past and present
* Igneous rocks: form from crystallization of magma
* Sedimentary rocks:
  + Rocks are weathered into sediment by wind and water
  + Deposited sediment is converted into sedimentary rock by lithification
* Metamorphic rocks: rocks are changed through extreme heat, pressure or chemically active fluids

**Hydrologic Cycle:**

* Solar energy drives movement of water between atmosphere and oceans and continents
* Processes include: evaporation, precipitation, surface runoff, and subsurface flow
* Water is stored in compartments such as oceans, the atmosphere, rivers, streams, etc.
  + Residence time is the estimated average time that a drop of water spends in any compartment
  + Only a small amount of water is active at any given time

**Biogeochemical Cycles:**

* The transfer or cycling of an element or elements through the atmosphere; carbon, nitrogen, phosphorus
* Elements and chemical compounds are transferred via a series of reservoirs
* The amounts of elements in each reservoir, and their rates of transfer between each, are known only approximately

**Fundamental Concepts for Understanding Natural Processes as Hazards**

**1. Hazards can be understood through scientific investigation and analysis**

* Scientists observe hazardous events and form a possible explanation
  + From this explanation, a hypothesis is formed.
  + Data is collected to test a hypothesis.
* Allows for identification of where hazards occur, their magnitude, and their frequency
* Knowledge of past events can be used to determine future risks

Hazardous Processes are Natural 🡪They are a result of natural forces. Although we can, to a degree, control some hazards, many are completely beyond our control. The best solution is preparation!

Prediction: Specific date, time, and magnitude of the event

Forecast: Less precise and has a range of probability for the event

\*\* Some hazards can be predicted, most can be forecasted

Hazard Reduction

* Identify the location of a probable event
* Determine the probability of event
* Identify any precursor events
* Forecast or predict the event
* Issue a warning the public

**2. An understanding of hazardous processes is vital to evaluating risk**

* Risk = (probability of event) x (consequences)
  + We will be coming back to this concept
* Consequences: deaths and injuries to people, damage to property, economic effects, etc.
* Acceptable risk is the amount of risk that an individual or society is willing to take

**3. Hazards are linked to each other and the environment**

* Hazards are linked to each other; some events may cause others
  + Ex: Earthquakes and landslides
* The physical environment is linked to hazards
  + Ex: Some rock types are prone to subsidence and landslides

**4. Population growth and socio-economic changes increase the risk from natural hazards**

* Concentration of population creates greater loss of life in disaster
* Exponential human population growth puts greater demand on Earth’s resources
* Population growth in developing countries is far outstripping that in wealthy jurisdictions

**5. Damage and loss of life from natural disasters can be reduced**

* Effects from a disaster can be: (really important!)
  + Direct – people killed, buildings damaged, etc.
  + Indirect – crop failures, starvation, emotional distress, etc.
* Recovery from disaster
  + Emergency work; Restoration of services and communication lines; Reconstruction
* Move from a reactive response: recovery from disasters and restoration
* To a proactive response: avoiding and adjusting to hazards
  + Land-use planning; Building codes; Insurance; Evacuation; Disaster preparedness; Artificial control

Natural Service Functions

* These are benefits that hazards provide
* Examples: Floods provide nutrients for soil; Landslides form dams to create lakes; Volcanoes create new land

**Lecture 2: Wildfires and Internal Structure of Earth and Plate Tectonics**

*Based on Chapter 13 & 2 in Textbook*

**WILDFIRES**

**Fort McMurray – re-entry**

* Wildfire is no longer an imminent threat to the community;
* Critical infrastructure is repaired to provide basic service;
* Essential services, such as fire, EMS, police and health care, are restored to a basic level;
* Hazardous areas are secure;
* Local government is re-established

**Long term implication:**

* Property, economic damage (pension…)
* Insurance may not cover all things
* Education delayed (damage to schools and institutions)
* Stigma of wildfire surrounding area could harm property value, job attractiveness and more

**Introduction**

* Wildfire is an ancient phenomenon
  + Dating back more than 350 million years
* Before humans, fires would burn until they ran out of fuel naturally
* After a fire, colonizing plants become established on the burned landscape
* Natural fires allowed humans to harness fires for heat, light, and cooking

**Wildfire as a Process**

* A self-sustaining, rapid, high-temperature biochemical reaction
* 3 requirements 🡪 fuel, oxygen, heat (if any of these is removed, the fire goes out)

**Pre-ignition Phase**

* Vegetation is brought to a temperature and water content at which it can ignite and burn
* Preheating 🡪 Vegetation loses water and other chemical compounds
* Pyrolysis 🡪 Processes that chemically degrade the preheated fuel | Products include volatile gases, mineral ash, tars, and char
* Heat radiating from flames causes preheating and pyrolysis in advance of the fire

**Combustion Phase**

* Begins with ignition
* Involves external reactions that liberate heat and light
* Ignition does not necessarily lead to a wildfire
  + Wildfires only develop when vegetation is dry and has accumulated in quantities to carry the fire across the land
* Ignition is not a single process but occurs repeatedly as the wildfire moves

Types

1. **Flaming Combustion** 
   1. Rapid high temperature conversion of fuel to thermal energy
   2. Characterized by flames and large amount of unburned material
2. **Smoldering Combustion** 
   1. Can take place at lower temperatures
   2. Does not require rapid pyrolysis

* Wildfires transfer heat mainly by convection
  + Radiation also plays a role
* Convective and radiant heating increase the surface temperature of the fuel
* As heat is released, air becomes less dense and rises
  + Rising air removes heat and combustion products from the zone of flaming
  + This process pulls in the fresh air required to sustain combustion

**Extinction Phase**

* The point at which combustion, including smoldering, ceases
* A fire is considered extinct when it no longer has sufficient heat and fuel to sustain it

**Fuel**

* Consists of leaves, twigs, decaying material, grasses, mosses, ferns, shrubs, trees
* Smaller fuels burn most readily and most vigorously
* Organic materials can dry and decay during disease or drought, allowing it more easily burn
* The density of trees is an important factor
  + Boreal forests of Canada contain abundant fuel and easily sustain wildfires once they start

**Topography**

* Drier fuels are found on:
  + South-facing slopes in the Northern Hemisphere
  + Slopes exposed to prevailing winds
* In mountainous areas, winds tend to move up or down canyons, providing easy paths for wildfires
* Wildfires preheat fuel upslope from the flames
  + This increases the rate of movement and the spreading of a fire moving upslope

**Fire Environment: Weather**

* Large wildfires are most common following droughts
  + Fires spread more rapidly under hot, dry conditions
* Winds greatly influence the spread, intensity, and form of a wildfire
  + Strong winds help preheat adjacent unburned fuel
  + Winds can carry burning embers that may ignite spot fires far ahead of the flaming front

**Types of Fires**

1. Surface fires
   1. Move close to the ground • Some may burn the soil just under the ground surface • Differ greatly in their intensity
2. Crown fires
   1. Move rapidly through the forest canopy by flaming combustion • Can be fed by surface fires that move up tree limbs or can spread independently of surface fires • Large crown fires are generally driven by strong winds • Intermittent crown fires consume the tops of some trees whereas continuous crown fires consume the tops of all or most trees • Such as Fort McMurrary fire

**Geographic Regions at Risk from Wildfires**

* 70% of all forest fires occur in the tropics
* Most areas of North America are at risk during prolonged dry weather
* The specific geographic region at greatest risk shifts from year to year, depending on the weather
* More than $400 million is spent fighting wildfires in Canada each year

**Effects on the…**

**Geological Environment**

* Fires may leave a near-surface, water-repellant hydrophobic layer
  + Increases surface runoff and erosion
* Soil erosion and debris flows are common following wildfires
  + Significantly greater likelihood on steep slopes charred by a severe burn

**Atmosphere**

* Increase the concentration of particles in the atmosphere
  + Can remain for months
  + Can be observed thousands of kilometers downwind of large fires

**Links with Climate**

* Climate change increases the intensity and frequency of wildfires
* Caused by changes in air temperature, precipitation, and the frequency of severe storms
  + More insect infestations make trees more vulnerable to fire
  + Ex: Mountain pine beetle in British Columbia 🡪 responsible for killing trees

**Impacts of Wildfires on Plants and Animals**

* Vegetation
  + A fire can burn millions of hectares of forest
  + Some plants use fire to propagate
  + Renewal after fire: fireweed
* Animals
  + Most animals are able to escape advancing fire
  + Aquatic species may suffer from increased sedimentation
  + New habitats are produced for grazing animals
* Humans
  + Smoke and haze can cause eye, respiratory, and skin problems
  + Destroys personal property

**Natural Service Function of Wildfires**

* Benefits to soil
  + Increases nutrient content
  + Reduce populations of micro-organisms
* Benefits to plants and animals
  + Reduces competition for sunlight and rainfall among plants
  + May trigger a release of seeds in some species
  + Removes surface litter for grasses
  + Recycles nutrients in the ecosystem
  + Grazing animals find new forage in plants that proliferate following fire

**Fire Management**

* Aim is to control wildfires for the benefit of ecosystems while preventing them from harming people and destroying property
* Fire management in Canada is a provincial and territorial responsibility, except on federal lands
* Scientific research on the role of fire in ecosystems is critical to fire management
* Research is needed to better understand the fire regime, or pattern of fire activity in an area, including:
  + Types of fuel present in plant communities
  + Typical fire behavior and the amount of biomass removed
  + Fire history of the area, including fire frequency and size
* Remote sensing is an important tool for fire management
  + Satellite imagery is used to map vegetation and determine fire potential
* Fire suppression
  + A common practice is to steer the fire into an area with no fuel, called a fire break
  + Reliance on fire suppression has led to a build-up of fuel in forests and an increase in potential for high-intensity fires
* Prescribed burns are used to counter the build-up of fuel
  + More frequent, smaller fires result in fewer large fires
  + Planners of prescribed burns face the difficult task of predicting the fuel and weather under which they can safely control the fire

**Perception of the Wildfire Hazard**

* People who live in fire-prone areas generally do not fully appreciate the risk they face
* Ex: California
  + Development continues on brush-covered hills
  + Demand for hillside property has raised property values
  + Insurance may give people a false sense of security

**Reducing Wildfire Risk**

* Risk can be reduced several ways:
* Fire Danger Warnings 🡪 Rating systems to alert land managers, residents, and visitors
* Education 🡪 Community awareness programs and fire safety presentations in schools
* Codes and Regulations 🡪 Enact building codes that require fire-resistant materials
* Fire Insurance 🡪 Allows people whose property has been destroyed by a fire to be reimbursed for part or all of their losses
* Evacuation 🡪 Most common response to wildfires; Ensures personal safety but does not protect homes
* Structural Protection 🡪 Actions taken to protect homes from a wildfire

**INTERNALE STRUCTURE OF EARTH AND PLATE TECTONICS**

**Internal Structure of Earth**

* Earth is layered and dynamic
* The internal structure of Earth can be considered in two fundamental ways:

1. By composition, state, and density
2. By strength

Hint: Juan de Foca Plate

* Being dragged underneath where North America sits, therefore, can be responsible for any earthquakes
* (Only name you will need to know for plates)

Hint:

* Continental crust is less dense than oceanic crust
* Hint: know this fact, numbers (i.e. 2.8 & 2.9 are not important)
* This difference in density is the factor that cause multiple natural disasters

**Structural Layers of Earth**

Inner core

* Solid 🡪 1300 km in thickness 🡪 High temperature 🡪 Composed of iron (90% by weight) and other elements (sulphur, oxygen, and nickel)

Outer core

* Liquid 🡪 2000 km in thickness 🡪 Composition similar to the inner core

Mantle

* Solid 🡪 3000 km in thickness 🡪 Composed of iron-rich and magnesium-rich silicate rocks

Crust

* Outer rock layer of Earth
* Mohorovicic discontinuity
  + Separates lighter crustal rocks from the denser mantle
  + All this means is there is a distinct change between the rocks

**Lithosphere and Asthenosphere**

Lithosphere

* Cool, strong outermost layer of Earth
* Think of this layer as being made of glass; easily breaks

Asthenosphere

* Constitutes all but the uppermost part of the mantle
* Hot, slowly flowing layer of relatively weak rock
* Think of it like a semi-plastic

**Continents and Ocean Basins**

* Crustal rocks are less dense than the mantle rocks below
  + Continental crust is less dense than oceanic crust
  + Oceanic crust is relatively thinner
* Oceanic crust underlying today’s ocean basins is less than 200 million years old, whereas some continental crust is up to several billion years old
* To simplify, since it is denser, oceanic crust goes underneath continental crust

**Convection**

* Earth’s internal heat causes magma to heat up and become less dense
* The less dense magma rises 🡪 Cooler magma falls back downward

**How We Know about Earth’s Internal Structure?**

* Most of our knowledge of Earth’s structure comes from seismology (means: study of earthquakes)
* Earthquakes cause seismic energy to move through Earth
  + Some waves move through solid, but not liquids
  + Some waves are reflected
  + Some waves are refracted (they change direction)
  + Information on wave movement has allowed scientists to deduce the structure of Earth’s interior and the properties of its layers
* What have we learned about Earth from earthquakes?
  + Where magma is generated in the asthenosphere
  + The existence of slabs of lithosphere that have sunk deep into the mantle
  + The variability of lithospheric thickness, reflecting differences in its age and history
  + What is liquid and what is solid (we will come back to this)

**Plate Tectonics**

* Tectonic refers to the large-scale geologic processes that deform Earth’s lithosphere
  + Produce ocean basins, continents, and mountains
  + Driven by forces deep within Earth
* The lithosphere is broken into pieces
  + Lithospheric plates
* Plates move relative to one another

Hint: don’t memorize names of plates

**Plate Boundaries**

* These are delineated by earthquakes and active volcanoes
  + Geologically active areas
* Plate boundaries are defined by areas of seismic activity
* Dynamic events on the Earth’s surface occur when plates move.
  + Diverge (when things pull apart in the middle of the ocean; Iceland is slowly being pulled a part), converge (when they converge together; this is when plates are going under each other 🡪 think of a small car going under a big one), or slide past each  other (transform)

**Seafloor Spreading**

* This is the mechanism for plate tectonics
* At mid-ocean ridges new crust is added to edges of lithospheric plates
  + Continents are carried along plates
* Crust is destroyed along other plate edges
  + Subduction zones; this will cause geological activity
* The rate of production of new lithosphere at spreading centers is balanced by consumption of lithosphere at subduction zones

**Sinking Plates Generate Earthquakes**

* Sinking ocean plates come in contact with the hot asthenosphere
* Plates melt to generate magma
* Magma rises to produce volcanoes; sometimes does not cause volcanic activity
* Earthquakes occur along the path of the descending plate

**Plate Tectonics is a Unifying Theory**

* Explains a variety of phenomena
* Convection within Earth’s mantle likely drives plate tectonics

**Types of Plate Boundaries**

* Three basic types: divergent, convergent, and transform
* The boundaries are broad zones of intense deformation

**Divergent Plate Boundaries**

* Where two plates move away from one another
* New lithosphere is created at these boundaries
* Divergence between two ocean plates:
  + Causes mid-ocean ridges
  + Seafloor spreading
  + Ex: Mid-Atlantic Ridge

**Convergent Plate Boundaries**

* Where two plates collide head-on
* Oceanic-continental collisions result in subduction zones
  + Denser ocean plates sink and melt
  + Melted magma rises to form volcanoes
* Collisions between two continental plates results in a continental collision boundary
  + Neither plate subducts, instead the plates crumple together
  + Large mountains form such as the Himalayas
  + Earthquakes are pressure overtime; think about when you rub your hands together slowly, there is pressure & friction then your hands do a little jump just like an earthquake

**Transform Plate Boundaries**

* Where the edges of two plates slide horizontally past one another
* Most common on the ocean floor but some occur within continents
* Ex: San Andreas Fault 🡪 Separates the Pacific plate and the North American plate

**Rates of Plate Motion**

* Plates move a few centimeters per year
* Although the central portions of plates move at a steady slow rate, movement may not be steady at plate boundaries
* Plates can displace by several metres during a great earthquake

**A Detailed Look at Seafloor Spreading**

* Mid-ocean ridges were discovered by Harry H. Hess
* Validity of seafloor spreading was established by:
  + Identification and mapping of ocean ridges
  + Dating of volcanic rocks on the floor of the ocean
  + Understanding and mapping of the paleomagnetic history of ocean basins

**Magnetic Stripes**

* Scientists used ships to tow magnetometers along the ocean floor
  + These are instruments that measure magnetic properties of rocks
* Rocks on the ocean floor are magnetically striped parallel to mid-ocean ridges
  + Areas of normal and reversed magnetism

**Driving Mechanisms**

* Two possible driving mechanisms for plate tectonics 🡪 Ridge push and slab pull
* Ridge push is a gravitational push away from crests of midocean ridges
* Slab pull occurs when cool, dense ocean plates sinks into the hotter, less dense asthenosphere
  + Weight of the plate pulls the plate along
* Evidence suggests that slab pull is the more important process

**Plate Tectonics and Hazards**

* Divergent plate boundaries (Mid-Atlantic Ridge) exhibit earthquakes and volcanic eruptions
* Boundaries that slide past each other (San Andreas Fault) have appreciable earthquake hazards
* Convergent plate boundaries where one plate sinks (subduction zones) contain explosive volcano and earthquake hazards
* Convergent plate boundaries where continents collide (Himalayas) have high topography and earthquakes

**Hot Spots**

* Concept developed by Canadian Geophysicist J. Tuzo Wilson
* Volcanic centers away from plate boundaries resulting from hot material from deep in the mantle
* Magma moves up through the mantle and overlying plates
  + Found under both oceanic and continental crust
* Plates move over hot spots creating a chain of volcanoes
  + Ex: Hawaiian Islands, Yellowstone National Park

**Lecture 3: Earthquakes and Volcanoes**

*Based on Chapter 3 & 5 in Textbook*

**EARTHQUAKES**

**Earthquake** 🡪 motion or trembling of the ground caused by the sudden displacement of rock | Most common cause is the moving of tectonic plates

**The Toll of Earthquakes**

The consequences of an earthquake depend on:

* Magnitude
* Depth
  + The closer the earthquake to the earth’s surface = the more damage it can cause
* Direction of fault rupture
* Distance from populated areas
  + Population density is just as value of a cause
* Nature of the local earth materials
  + Ex. Sudbury is on hard rock shield = less likely to feel earthquake | Mexico on soft sand = more likely to fell earthquake
* Engineering and construction practices

Differences in some of these factors explain why a M 7.0 earthquake in Haiti (2010) killed ~ 240,000 people but a M 6.9 earthquake in California (1989) killed less than 70.

**Earthquake**

**Introduction**

* Result from the rupture of rocks along a fault
  + Energy is released in the form of seismic waves
* Mapped according to the epicenter
  + The is directly below the epicenter
  + Ex. The earthquake was a size 6
* Measured by seismographs
* Compared based on: Magnitude & Intensity (how much damage has occurred or how many people are affected)

**Magnitude**

* Measured by moment magnitude (Mw)
* The scale is logarithmic and based on powers of ten
  + Ground motion for a M 3 is 10 times that of a M 2.
  + Amount of energy released for a M 3 is 32 times that of a M 2
* Smaller earthquakes are more frequent than larger ones

Hint: magnitude: very minor =2-2.9, minor = 3, light =4, moderate = 5, strong = 6, major = 7-7.9, and great = 8-higher

**Intensity**

* Measured by the Modified Mercalli Intensity Scale
* The scale is qualitative and based on damage to structures and people’s perceptions
  + Qualitative is more important quantitiative
* Modified Mercalli Intensity maps show where the damage and perceived shaking is most severe
  + Data is now collected using the Internet.
* Shake maps use seismograph data to show areas of intense shaking.

**Processes**

* Earthquakes commonly occur at or near plate boundaries
  + There is a lot of stress put on these rocks
* Plate boundaries may contain faults
  + Material tends to be semi-plastic that can break
* Friction along plate boundaries exerts strain or deformation
* When stress on rocks exceeds their strength, the resulting rupture produces seismic waves

**Fault Types – Dip Slip**

* Vertical movement
* Three types of dip-slip faults based on which way the bounding earth materials move
* Walls on an incline are defined as: hanging wall & footwall block
* Image: if you took the footwall block away then the hanging wall will fall over. Do not assume hanging wall is always on the left and footwall is always on the right.

Hint: this will be a quiz or midterm question (based on slides 19-22)

* Normal fault 🡪 The hanging wall has moved downward relative to the footwall.
* Reverse fault 🡪 The hanging wall has moved up relative to the footwall. | If the fault plane angle is 450 or less, it is a thrust fault.
* Blind faults do not extend to the surface.

Hint: Be able to draw this and understand | If pushed together then hanging wall moves up considered reverse fault | If pulled apart, hanging wall falls, considered normal fault

**Fault Types – Strike Slip**

* Horizontal movement

**Fault Activity and Tectonic Creep**

* Active faults - movement during the past
* Potentially active faults - movement during the past 2.6 million years
* Inactive faults - no movement during the past 2.6 million years
* Tectonic creep occurs when movement along a fault is so gradual that earthquakes are not felt
  + Can slowly damage infrastructure

**Seismic Waves**

**Body Waves**

* Travel within the body of the Earth 🡪 Able to discover what the interior of the earth is like based on the numerous earthquake wave types that have occurred over the years

Two types:

1. P waves (primary or compressional waves)
   * Move fast with a push/pull motion
   * Can travel through solid, liquid, and gas
2. S waves (secondary or shear waves)
   * Move slowly with a back-and-forth motion at right angles to the direction the waves are moving.
   * Can travel only through solids

**Surface Waves**

* Travel along Earth’s surface horizontally and vertically and can produce rolling motion
* Move more slowly than body waves
* Are responsible for damage near the epicenter

Two types:

1. Love waves - cause horizontal shaking
2. Rayleigh waves - rolling waves, elliptical motion
   1. Most dangerous types, slowest

* Primary is the fastest and then Rayleigh is slowest (move down image)

**Earthquake Shaking: Distance to the Epicentre and Focal Depth**

* Seismographs record arrivals of waves to station sites
* P waves and S waves travel at different rates and arrive at each station at different times
* Distance to the epicentre can be found by comparing travel times of the waves using triangulation
* Focal depth influences amount of shaking due to attenuation

**Local Soil and Rock Conditions**

* Local geology influences the amount of ground motion
  + Dense rocks (e.g. bedrock) transmit earthquake energy quickly
  + Seismic waves slow down in heterogeneous rocks, unconsolidated sediment and sediment with high water content
* Amplification occurs when energy is transferred from P waves and S waves to surface waves
* More damage can occur in areas farther away from the epicentre depending on local ground conditions

**The Earthquake Cycle**

* Inactive period where builds in the fault
* Period of small earthquakes where the stress begins to release, causing strain
  + As rock begins to strain it can either release very small earthquakes
* Foreshocks occur prior to a major release of stress 🡪 This stage does not always occur
* Mainshock
  + When the fault releases the majority of the stress
  + No recorded events since it is inevitable
* Aftershocks
  + Releases of stress after a major earthquake
  + Don’t have to happen but can

**Geographic Regions at Risk from Earthquakes**

* Earthquakes are not randomly distributed
* Most occur along plate boundaries 🡪 “Pacific Ring of Fire”: Japan, Western U.S./Canada, Indonesia, New Zealand | Himalayan Mountains | Middle East
* However, not all areas at risk are near plate boundaries

**Plate Boundary Earthquakes**

* Strike-slip earthquakes 🡪 Occur on transform faults; Ex: San Andreas and Queen Charlotte faults
* Thrust earthquakes 🡪 Faults separating converging plates; Ex: Cascadia subduction zone
* Normal fault earthquakes 🡪 Occur on diverging plate boundaries; Ex: Mid-Atlantic Ridge

**Intraplate Earthquakes**

* Earthquakes that occur within plates
  + Ex: New Madrid seismic zone in Missouri | Southern Quebec and eastern Ontario
* Hint: not concerned with knowing examples, however, know that there can be earthquakes within the North American plate for example. Because these massive plates have little spots of weakness. Think of pouring concrete letting it dry, and then pouring another layer.
* Intraplate earthquakes are often smaller than plate boundary earthquakes.
  + However, they can cause considerable damage due to the lack of preparedness and because they can travel greater distances through dense continental bedrock

**Effects of Earthquakes and Linkages**

Shaking

* Causes damage to buildings, bridges, dams, tunnels, pipelines, etc.
* Measured as ground acceleration
* Buildings are damaged due to resonance
  + Def. a phenomenon in which a vibrating system or external force drives another system to oscillate with greater amplitude at specific frequencies

Ground Rupture

* Displacement along the fault causes cracks in the surface and fault scarps

Liquefaction

* Water-saturated loose sediment turns from solid to liquid, causing buildings and land to subside
* Land-level changes: whole area of an earth falls a couple of metres
* Landslides

Fires

* Ground shaking and surface rupture can sever electrical power and gas lines

Disease

* A loss of sanitation and housing, contaminated water supplies, and disruption of public health services all contribute

**Natural Service Functions of** **Earthquakes**

* Water, oil, and natural gas may be rerouted due to faults
  + Faults can channel groundwater to the surface at springs
* New mineral resources may be exposed
  + Some minerals are preferentially deposited in veins
* Scenic landscapes may form; Ex: Rocky Mountains

**Human Interaction with Earthquakes**

* The weight from water reservoirs may create new faults or lubricate old ones
* Liquid waste disposals deep in the Earth can create pressure on faults
* Pumping of oil and gas and hydraulic fracturing can both cause small earthquakes
  + HF is a technique in which rock is fractured or cracked due to high pressure liquid, specifically water, for the purpose of extracting oil and gas from deep rock
* Nuclear explosions can cause the release of stress along existing faults

**Minimizing the Earthquake Hazard**

* Earthquake Hazard Reduction Programs
* Five major goals: (1) Operate national seismograph networks (2) Develop an understanding of earthquake sources (3) Determine earthquake potential (4) Predict effects of earthquakes on buildings and other structures (5) Communicate research in order to educate individuals, communities, and governments

**Estimating Seismic Risk**

* Hazard maps show earthquake risk
* May show epicentres of historic earthquakes
* Complex maps show probabilities and ground acceleration

**Short-Term Prediction**

* Forecasting 🡪 specifies the probability of an earthquake occurring
* Prediction 🡪 specifies when and where an earthquake will occur
* Precursors
  + Pattern and frequency of earthquakes
  + Land-level change
  + Seismic gaps along faults
  + Physical and chemical changes in Earth’s crust
* Pattern and frequency of earthquakes
  + Foreshocks and microearthquakes
* Land-level change 🡪 uplift or subsidence
* Seismic gaps 🡪 areas that have not seen recent earthquakes
* Physical and chemical changes in Earth’s crust 🡪 changes in electrical resistivity and groundwater levels

**Status of Earthquake Prediction and Forecasting**

* Some success with earthquake predictions
* Predictions need to be scientifically reviewed
* Difficulty in predicting or forecasting earthquakes
* Research projects like SAFOD help gain better understanding of earthquakes and potentially better predictions
* Earthquake warning systems
  + Current warning systems provide 15 seconds to 1 minute of warning

**Perceptions of and Adjustment to the Earthquake Hazard**

Perception

* One community’s experience does not stimulate other communities to improve their preparedness

Community Adjustments

* Critical facilities must be located in earthquake safe locations
* Requires detailed maps of ground response to seismic shaking
* Buildings must be designed to withstand vibrations
* Retrofitting old buildings may be necessary
* People must be prepared through education
* Insurance must be made available

**Personal Adjustments before, during, and after an Earthquake**

Before the shaking starts

* Make sure that your home is structurally sound
* Secure large objects
* Turn off gas, water and electricity
* Make a personal plan of how to react to a earthquake

During the shaking

* Do not panic!
* Move away from windows, protect your head and face

When the shaking stops

* Leave the building
* Check for damage and injuries

**VOLCANOES AND VOLCANIC ERUPTIONS**

* Most active volcanoes are located near plate boundaries
* Mid-ocean ridges and subduction zones are sites where molten rock reaches the surface
  + Magma is molten rock | Lava is magma on the Earth’s surface
* 2/3 of all active volcanoes on land are located along the Ring of Fire which surrounds the Pacific Ocean

**Why is it important to understand how volcanoes work?**

* To understand/predict volcanic hazards
* # killed: Laki (1783) = >10,000 | Iceland Mt Pelee (1902) = >30,000 | Martinique Mt St. Helens (1980) = 57 | Nevado del Ruis (1985), Columbia = >20,000 | Montserrat (1995), Martinique = 19
* These numbers are estimates; except Mt. St. Helen b/c people direct camped beside to see when it would erupt
* Do not know if these deaths are direct results of volcano or other side effects that occur because of volcano

Geothermal energy 🡪 countries such as New Zealand, Iceland, Canada (B.C) use this for energy purposes

Pyroclastic debris 🡪 lava and rock fragments ejected in a volcanic eruption

* Types: volcanic bomb, lapill (if it is dime size or smaller than it is lapill) & Ancient volcanic ash layers (if it is microscopic then it is ash. Image depicts massive wall of ash layers)

Volcano 🡪 hill or mountain produced by volcanism

Vent 🡪 opening through which eruption takes place

Crater 🡪 depression over the vent

Caldera 🡪 depression > 1km wide

* Caldera usually happens when a large volcano has failed
* It has fallen in on itself

**How Magma Forms**

* Most magmas come from the asthenosphere (which is the semi-liquid layer)
  + Weak, but not liquid, layer of rock

Three main ways in which silicate rocks can melt:

1. Decompression
   * Pressure exerted on hot rock is reduced
   * Occurs at divergent boundaries, continental rifts, and hot spots
2. Addition of volatiles
   * Chemical compounds that lower the melting temperature of the rock
   * Think of adding salt to a driveway à this is essentially changing melting point
3. Addition of heat
   * As magmas rise, they release heat to overlying rocks

**Magma Properties**

* Magma is composed of melted silicate minerals and dissolved gases
* Two most abundant elements in magma are silicon (Si) and oxygen (O); when combined, they are referred to as silica (SiO2)
* Volcanic rocks are named depending on the amount of silica present in the rock
  + basalt, andesite, dacite, rhyolite
  + Hint: only know basalt because it is the most common. Won’t ask you to memorize difficult ones for exam but will for quiz because you can look it up
* Affect style of eruption and type of volcano produced
  + Silica content of magma is critical
* Silica-rich (felsic) lavas
  + Very viscous, flow slowly | gases cannot escape easily | violent eruptions, explosive | ex. rhyolite
* Silica-poor (mafic) lavas 🡪 low viscosity | flow easily | gases escape easily | quiet eruptions, lava flows | ex. basalt
* Intermediate lavas - ex. Andesite
* Silica content affects viscosity
  + Silica-rich magma does not flow easily and has a high viscosity
  + Viscosity affects the flow of lava and therefore the shape of the resulting volcano
* Volatile content determines how explosive the eruption will be
  + High concentration of dissolved volatiles will explode violently
  + Volatile content increases with increasing silica content
* In explosive eruptions, tephra (this is the combination of everything) is ejected
  + Small fragments of pyroclastic debris
  + An accumulation of tephra is a pyroclastic deposit

**Types of Volcanoes**

* Different shapes and eruptive styles are based on the chemistry and viscosity of magmas

**1) Shield Volcanoes**

* Largest volcanoes in the world
  + Gentle slopes built almost entirely of lava flows
  + Resembles a warrior’s shield
  + Common in Hawaiian Islands, Iceland, and Indian Ocean
* Associated with basaltic magma
  + Low viscosity, low gas content, no fractionation
  + Hint: don’t really need to worry about the term fractionation
* Gentle flowing lava with non-explosive eruptions
* Can form lava tubes underground
  + Lava that cools from the outside in

**2) Composite Volcanoes**

* Explosions are more violent but less frequent
  + Produce a combination of lava flows and pyroclastic deposits
* Conical in shape, also called stratovolcanoes
  + Many active volcanoes on west coast of North America
* Eruptions involve andesitic or dacitic magmas
  + High silica and low viscosity

**3) Volcanic Domes**

* Form around vents from the eruption of highly viscous silica-rich magma
* Not as common
* Exhibit explosive eruptions; slightly explosive
* Small domes often form within the crater after an eruption

**4) Cinder Cone Volcanoes**

* Small volcanoes
* Built from small pieces of red or black basalt
* Found on the flanks of larger volcanoes, along some normal faults, and along cracks or fissures
* Tephra from extinct cinder cones is the “lava rock” used widely in commercial landscaping

**Maars and Ice Contact Volcanoes**

* The violent interaction of magma and groundwater produces maars
  + Roughly circular volcanic craters commonly filled with water
* Ice Contact Volcanoes
  + Erupt beneath or against glaciers
* Subglacial volcanoes erupt, rapidly melting ice and produce huge floods known as
* Ex: Iceland, Mt. Garibaldi

**Volcanic Features**

* Hot springs 🡪 Hot rocks heat groundwater that discharges at the surface
* Geysers 🡪 Groundwater boils in an underground chamber, erupting steam at the surface | Boils, explodes, falls back into chamber, repeat
* Resurgent Calderas and Super Eruptions
  + Very rare but extremely violent eruptions from supervolcanoes
  + Produce huge amounts of ash and form calderas
  + Most recent North American caldera eruptions were Yellowstone National Park
    - Argued that it occurred 700,000 or 1.6 million years ago it erupted
    - It is a supervolcano because it is believed to be feeding from one source, rather than multiple ones

Hint: Hot spot tend to be shield volcanoes

**Geographic Regions with Active Volcanoes**

* Ring of Fire
  + Pacific Ocean subduction zones
  + Highest risk in Canada is in northwestern and central B.C.
* Hot spots
  + Hawaii and Yellowstone National Park (Yellowstone picks up continental material along the way, causing it to be more violent and explosive)
* The volcano that poses the greatest risk to Canada is Mt. Baker in northern Washington State.
  + An eruption could spread ash over Vancouver

Hint: Highest Mountain in Canada – Mount Logan (X-men)

**Effects of Volcanoes**

* 50 to 60 volcanoes erupt each year
  + Most eruptions are in sparsely populated areas
* Nearly 100,000 people have been killed by eruptions in the past 100 years
* 500 million people live in the vicinity of volcanoes
  + Japan, Mexico, Philippines, Indonesia
  + Western North America

**Volcanic Hazards**

Primary effects 🡪 lava flows, ash fall, volcanic bombs, pyroclastic flows, pyroclastic surges, lateral blasts, and poisonous gases

Secondary effects 🡪 lahars, debris avalanches, landslides, groundwater, and surface contamination, floods, fires, and tsunamis

* The size of an eruption can be quantified using a scale called the **Volcanic Explosivity Index (VEI)**

**Lava Flows**

* Occur when magma reaches the surface
* Can move slowly or rapidly depending on viscosity and temperature
* High viscosity moves more slowly
* Basaltic lava flows are the most common
  + Pahoehoe 🡪 Harden with a smooth ropy texture | Travel at speeds of up to a few kilometres per hour
  + Aa 🡪 Harden with a rough, blocky texture | More viscous, travels at rates of a few metres per day | Legend: Hawaiian people said it is hard to walk on and initial response is “Aaaa”

**Pyroclastic Flows and Surges**

* Flows - avalanches of hot rock, ash, volcanic rock fragments
* Can move at speeds up to 150 km/h
* Surges - dense clouds of hot gas and rock debris produced by explosive interaction of water and magma
* Can move at speeds of more than 360 km/h

**Lateral Blasts**

* Rock fragments, gas, and ash that are blown horizontally from side of volcano

**Ash Falls**

* Ash blown high into the atmosphere during a volcanic eruption and then falls over large areas
* Vegetation may be destroyed
* Surface water may be contaminated
* Buildings may be damaged as ash piles up on roofs
* Health hazards (respiratory illnesses)
* Mechanical and electrical equipment can be damaged disrupting electrical power
* Aircraft engines can experience failure

**Poisonous gases**

* Carbon dioxide, carbon monoxide, sulphur dioxide, hydrogen sulphide, chlorine, hydrofluoric acid

**Edifice or Sector Collapse**

* The flank of a volcano may collapse due to ground shaking from steam venting, magma ascent, or an earthquake

**Debris Flows and Other Mass Movements**

* Lahars - large amounts of loose volcanic ash and other pyroclastic material become saturated with water and rapidly move downslope

**Mt. St. Helens**

* Prior to erupting in 1980, it was dormant for 120 years
* In March, 1980 seismic activity and small explosions were observed
* May 1, 1980 – a bulge began to grow on the northern flank of the mountain at rate of 1.5 m per day
* May 18, 1980, 8:32 am – A M 5.1 earthquake triggers a landslide/debris avalanche of the bulge area
* Seconds later, a lateral blast from the bulge area occurred at rate of 480 km/h
* One hour after the blast a vertical cloud of ash extended into the stratosphere
* 9 hours of ash fall covers areas of Washington, northern Idaho, and western Montana.
  + Pyroclastic flows came down the northern slope
* Mudflows occurred at speeds of 55 km/h

The Aftermath

* 57 people were killed
* Flooding destroyed over 100 homes
* Forests to the north of the mountain were flattened
* Damage exceeded U.S. $1 billion
* September 23, 2004, Mt. St. Helens reawakened
  + Magma began moving up toward the crater floor
  + The mountain is monitored with seismographs to continuously record events

**Linkages between Volcanoes and Other Natural Hazards**

* Earthquakes 🡪 Commonly precede or accompany volcanic eruptions
* Landslides 🡪 Sector collapses can cause tsunamis if they enter water
* Fire 🡪 Hot lava may ignite plants and structures
* Climate Change 🡪 Volcanic ash from an eruption can temporarily cool climate

**Minimizing the Volcanic Hazard**

Forecasting the probability of a volcanic eruption is determined by information gained by:

* Monitoring seismic activity
  + Shallow earthquakes can precede eruptions
  + May not provide enough time for evacuation
* Thermal, magnetic, and hydrologic monitoring
  + Accumulation of hot magma changes temperatures, magnetic properties, and chemical properties of rocks and groundwater
* Land surface monitoring
  + Monitoring the growth of bulges or domes
* Monitoring volcanic gas emissions
  + Changes in carbon dioxide and sulphur dioxide emission rates may indicate movement of magma toward the surface
  + Changes over time
* Geologic history
  + Mapping of lava flows and pyroclastic deposits can be helpful in predicting future eruptive behaviour

**Perception of Volcanic Risk**

People live near volcanoes for a variety of reasons

* Place of birth | On some islands, all land is volcanic | Fertile land for farming | Believe an eruption is unlikely | Unaware of risk | Economic limitations

**Adjustments to Volcanic Hazards**

* Bombing 🡪 Block channels to cause lava flows to take a less damaging route
* Hydraulic chilling 🡪 Water used to chill and control lava flows
* Wall construction 🡪 Walls are used to redirect lava flows

**Lecture 4: Tsunamis**

*Based on Chapter 4 in Textbook*

**Japan Tsunami**

* Occurred on March 11, 2011, killing ~ 16,000 people
* Source was a M 9.0 earthquake beneath the seafloor
  + Subduction zone east of Honshu Island
* The direct damage from the earthquake and tsunami was U.S. $235 billion
  + Most expensive natural disaster in history
* Three nuclear reactors were damaged which led to their meltdown
  + Thousands of residents were forced to evacuate
* The tsunami propagated throughout the Pacific Ocean, causing 2 m high waves in Chile
* Only 58% of people in highest impacted areas heeded the tsunami warnings and evacuated to higher ground

Lessons from the Japan Tsunami

* Japan was unprepared for the size of the tsunami
* Earthquake and tsunami education is necessary for people who live on or visit coastlines
* Tsunamis can have unanticipated secondary effects
  + Destruction of nuclear reactors
* Scientific research on historic tsunamis has not yet found its way into the decision-making process
  + A warning system alone is not enough

**Introduction**

* Def. A tsunami is a series of waves caused by the displacement of a large volume of water.

Triggered by

* Largest earthquakes that cause uplift or subsidence of the sea floor à most common
* Underwater landslides à large rocks moving underwater causes a disturbance
* Volcano flank collapse
* Submarine volcanic explosion
* Asteroids
  + Can produce **mega tsunami**

Hint:

* 1883: Krakatoa Volcano Eruption | Damage: >36, 000 people killed, 35 m high waves
* 2004: Earthquake (**M** 9.1) in Sumatra | Damage: Killed ~ 230, 000 people

**Earthquake - Triggered Tsunamis**

* Earthquake rupture in the seafloor pushes water upwards
  + Generally, requires > M 7.5 earthquake
* Tsunamis move rapidly in the deep ocean
  + Can typically travel up to and over 500 km/h
  + Spacing (frequency) of crests is large and amplitude is small; people on large boats do not notice tsunami waves
* Tsunami nears land, loses speed, gains height
  + Depth of ocean decreases, slowing tsunami waves to 45 km/h
  + More water piles up, increasing amplitude and frequency
* Tsunami moves inland, destroying everything in its path
  + Can be metres to tens of metres high
  + Trough may arrive first, exposing the seafloor
  + Run up 🡪 furthest horizontal and vertical distance of the largest wave
  + More waves likely to follow

**Indonesia Tsunami**

* Occurred on December 26, 2004, killing ~ 230,000 people
* Source was a M 9.1 earthquake off west coast of Sumatra
  + Subduction zone between Burma and Indian and Australian plates
  + Hint: not to concerned with knowing plates
* No tsunami warning system in the Indian Ocean at the time
* Few people knew tsunami warning signs

Positive Stories from the Indonesia Tsunami

* In Thailand, a 10-year-old British girl saved people by recognizing the signs of the tsunami
* A port official on the Nicobar Islands warned people to go to higher ground after the earthquake
* Native peoples in some regions recognized the danger and moved to higher ground
* In Thailand, elephants sensed the tsunami and aided in moving handlers and tourists to higher ground

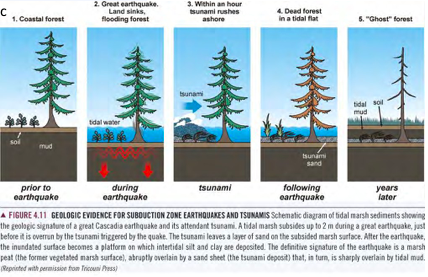
**Landslide - Triggered Tsunamis**

* Submarine landslides cause water to become displaced in lakes or oceans
* Landslides can fall into the ocean from mountains, causing waves to form
  + Ex: Lituya Bay, Alaska
  + Bay water surged to a level 525 m above normal
* Volcano flank collapse may also cause tsunami
* Lose energy over distance

**Volcanic - Triggered Tsunamis**

* Less common than earthquake-triggered
* The second deadliest tsunami was triggered by the Krakatoa eruption
  + Between Java and Sumatra
  + Eruptions on August 26 and 27, 1883
  + Explosion heard 5000 km away

**Geologic Evidence**



**Regions at Risk**

* Most coastlines of all oceans and some lake shorelines
* Coasts near the sources of tsunami
  + Earthquakes, landslides, and volcanoes
  + Subduction zones capable of generating M 9 earthquakes, such as Cascadia zone, Chilean trench, off coast of Japan
* Areas around the Pacific Ocean, Mediterranean Sea, and northeastern Indian Ocean

**Effects of Tsunamis**

Primary effects are related to flooding and erosion

* Shorten and coastline
* Debris erodes the landscape and damage structures
* Diminish with distance from the coast
* Deaths from drowning and the force of impact of the water

Secondary Effects

* Fires
* Contaminated water supplies
* Disease

**Links with Other Natural Hazards**

Causes *of* tsunami

* Earthquakes; Landslides; Volcanic eruptions; Asteroids

Caused *by* tsunami

* Coastline erosion and sediment deposition; Subsidence of coastlines

**Minimizing the Tsunami Hazard**

* Detection and warning
  + Monitor earthquake zones
  + Tsunami warning system
    - Seismographs to detect earthquakes
    - Tidal gauges to determine sea level changes
    - Buoy sensors to detect tsunami in open ocean
* Structural control
  + Building codes for susceptible coastline areas
* Tsunami inundation maps (run-up)
  + Show the height to which water is likely to rise
* Land use
  + Native vegetation may provide defense
  + Development of land must be monitored
* Probability analysis
  + Similar to earthquake analysis
* Education
  + Educate people on the signs of tsunami
  + Differences between tsunami watch and tsunami warning
* Tsunami readiness
  + Establish 24-hour emergency operation centers
  + Be able to receive tsunami warnings
  + Have ways to alert the public
  + Develop a preparedness plan with emergency drills
  + Promote community awareness programs through education

Perception and Personal Adjustment to the Tsunami Hazard

* If you feel an earthquake, leave the beach or lowlying area
* If you see the ocean receding, run from the beach
* A small tsunami in one location may be larger nearby
* Tsunamis have multiple waves
* If you hear a tsunami siren, move to higher ground
* Do not go down to the beach to watch the tsunami. If you can see it, you are already in danger

Secondary Effects of Earthquakes and Tsunamis

* Monstrous mosquitos
* Polluted water
* Loss of electricity, etc.

**Lecture 5: Flooding and Landslides**

*Based on Chapter 9 & 6 in Textbook*

* Stream and rivers are part of the hydrologic cycle
* Surface flow (runoff) finds its way to streams
* Streams are tributaries of rivers
* A region drained by a single stream is called a drainage basin, watershed, river basin or catchment
* The gradient of a river is determined by calculating its drop in elevation over distance
  + Greatest in its headwaters, decreases downstream, and is lowest at the river mouth, which is its base level
* The slope of a river is shown on a longitudinal profile
* The valley of a river is steeper-sided and narrower in its headwaters
* The floodplain is the flat surface adjacent to the channel

**Earth Material Transported by Rivers**

* Rivers move a tremendous amount of material
* **Bed Load** 🡪 Particles of sand and gravel that slide, roll, and bounce along bottom of a channel in rapidly moving water
* **Suspend Load** 🡪 Silt and clay particles that are carried in the water
  + Accounts for nearly 90% of the total load of most rivers
* **Dissolved Load** 🡪 Ions that are carried in solution in the water | Can be something as simple as salt, or as serious as E. coli

**River Velocity, Discharge, Erosion, and Deposition**

* Amount of erosion and deposition depends on stream area (A), velocity (V) and discharge (Q)
* Discharge is the volume of water flowing through a cross section of a river per unit time (V\*A = Q)
  + Hint: know this equation
* Changes in area lead to changes in velocity
  + Narrow channels have higher velocity than wide ones
* When a river slows, it deposits sediment creating an alluvial fan on land or a delta in water
  + A delta is piling up of sediments, has been used to build cities on

**Channel Patterns and Floodplain Formation**

Braided channels

* Contain a large number of intersecting channels
* Hint: will not be focusing too much on this type of pattern in the course

Anastomosing channels

* Two or more channels with stable islands or bars where sediment is temporarily stored

Meandering channels

* Migrate back and forth within a floodplain
* Velocity is higher on the outside of curves, causing erosion 🡪 Cutbanks
* Velocity is lower on the inside of curves, causing deposition 🡪 Point bars
* Floodplains are created during overbank flows
* During avulsion, a river abandons a looping section of the old channel, which is left as a meander cutoff
* Water moves at different speeds at different spots

**Flooding**

The magnitude and duration of a flood are determined by the:

* Amount, distribution, and duration of precipitation in the drainage basin à simply: how much precipitation is there
* Rate at which precipitation soaks into the ground à the slower it makes it to the river, the less change of flooding occurring
* Presence or absence of a snowpack
* Air temperature à if it is very hot then evaporation can begin or if it is cold, freezing can occur
* Speed at which surface runoff reaches the river
* Amount of moisture in the soil at the time precipitation starts

Can happen at different times of the year

* Ex: many large rivers flood in late spring after snowmelt
* Rivers along the Pacific Coast commonly flood in late fall
* Ice-jam floods occur during break up in spring
* Ice starts to melt in the South first and flows to the North but North still has ice causing the ice chips to jam rivers 🡪 happens in Winnipeg

A flood begins when a stream achieves bankfull discharge

* The discharge at which water first flows out of the channel

Flood discharge is the level of river surface at a point, or its stage

Hydrograph 🡪 A graph showing changes in discharge, water depth, or stage over time

Flood Stage 🡪 Indicates that a river has reached a level likely to cause property damage

Recurrence Interval 🡪 The average time between flood events of a certain magnitude

Hint:

- Normal runoff = non-urbanized region

- Urban areas are very good at moving water resulting in a high river discharge

**Flash Floods**

* Occur in the upper parts of watersheds and in small tributary basins of a large river
* Caused by intense rainfall of short duration over a relatively small area
* Common in steep-sloped arid areas with little vegetation, and following breaks of dams, levees, and ice jams
* Most people who die during flash floods are in automobiles

**Downstream Floods**

* Affect larger areas than flash floods and are commonly much more destructive and deadly
* Produced by storms of long duration or by rapid melting of snowpacks
* Characterized by a large slow rise and fall of discharge at a particular location
* Outburst floods are short-lived and result from the sudden draining of dammed lakes

**Glacial Lake Outburst Floods (GLOF)**

* Mass wasting event sudden-onset  outburst floods that result from  the failure of a moraine-dam, ice  dam or sudden release of water  from englacial (means water that is under the ice) or subglacial (means water over ice)… glacial is fine to say… reservoirs

1. Trigger | 2. Breach initiation and development | 3. Downstream routing of the outburst flood wave

GLOFs in Peru

* Recent glacier melt and recession = rise to the formation of moraine-dammed glacier lakes
* In the last 100 years, Peru - ~32,000 deaths
* 1st survey in 1952 found 223 lakes 🡪 In 2014: 880 glacial lakes

Research in GLOF 🡪 creating digital models to determine which way the water will move

**Geographic Regions at Risk for Flooding**

* Flooding is the most widespread natural hazard
* Developing countries suffer much greater loss of life than developed ones
  + Larger numbers of people at risk
  + Lack of monitoring and warning capabilities
  + Poor infrastructure and transportation systems
  + Inadequate resources available for effective disaster relief

**Effects of Flooding**

* Damage may be primary (caused directly by the flood) or secondary (resulting from disruption of services)
  + Hint: Have a good idea of the difference between these two because there will be a question on the midterm asking which is an example of a primary type of damage or which is a type of secondary damage
* Several factors affect the damage caused by floods:
  + Land use on the floodplain
  + Extent, height, and strength of dykes
  + Depth and velocity of floodwaters à deeper they are the worse they get
  + Rate of rise and duration of flooding à ex. The faster it occurs the less chance you have to run
  + Season of the flooding
  + Amount and type of sediment deposited by floodwaters
  + Effectiveness of flood forecasting, warning, and evacuation

**Natural Service Functions**

Fertile Land 🡪 Periodic deposits of nutrient-rich sediment enriches the soil for agriculture

Aquatic Ecosystems 🡪 Floods clear rivers of debris and carry nutrients downstream and into estuaries, increasing the food supply of aquatic organisms

Sediment Supply 🡪 Flooding keeps the surface of a delta plain above sea level | Ex: Mississippi Delta in southeast Louisiana

**Human Interaction with Flooding…**

A river generally maintains **dynamic equilibrium**

* Maintains the gradient and cross-sectional shape that provides the flow velocity it needs to move sediment load

**Land-use** changes can affect equilibrium

* Forest to agriculture increases the amount of sediment delivered to a stream
  + This will increase the gradient of the stream
  + The stream will flow faster until it can carry a greater amount of sediment
* Agriculture to forest will results in an opposite effect 🡪 more sediment and dirt will clog up river

**Dam Construction**

* Upstream of the dam, the river deposits sediment forming a delta
* Downstream water is devoid of sediment and will erode sediment
  + Slope of the stream will decrease until equilibrium is reached

**Urbanization**

* Increases the magnitude and frequency of  floods
* Urban areas have impervious cover and are served by storm sewers
  + Carry water to stream channels quickly
  + Reduction in lag time between peak rainfall and the flood crest
    - A short time is characterized by a rapid rise and fall in discharge
    - Lag time is the middle of the rainfall to the highest possible discharge
* Higher the discharge = higher chance of a flood occurring
* Urbanization reduces stream flow during the dry season
* Bridges may block debris, creating dams

**Minimizing the Flood Hazard…**

**Physical Barriers**

* Levees or dykes are barriers built to keep flood waters contained
  + Earthen levees, concrete floodwalls, reservoirs, floodways that bypass populated areas, storm-water retention basins
* Levee breaks cause higher energy flows and bottlenecks in upstream areas
* Physical barriers encourage development on the floodplains they are intended to protect

**Channelization**

* Examples of channelization include straightening, deepening, widening, clearing, and lining existing stream channels
* Degrades river and wetland ecosystems
* Benefits are greatest in urban areas with a high flood risk
* The Red River Floodway in Winnipeg has prevented many major floods
* Sometimes try to re-naturalize streams

**Channel Restoration**

* Attempts to return modified streams to a more natural state by
  + Removing urban waste from stream channels
  + Planting native trees and other vegetation along channel banks
  + Reestablishing deeper pools and shallower riffles within channels

**Flood Forecasts and Advisories**

* Specific dates and magnitudes cannot be predicted
* Outlooks of peak spring discharges can be made weeks in advance by using models
* Flood advisories or warnings may be issued in anticipation of severe weather conditions
* Northward-flowing rivers in Canada produce ice-jam flooding at about the same time each year

**Adjustments to the Flood Hazard**

* **Floodplain Regulation** 
  + The objective is to maximize the benefits that floodplains offer while minimizing flood damage and the cost of flood protection
* One approach is to disallow new development that would lessen a river’s access to its floodplain
* An important step is flood-hazard mapping
  + Useful in regulating development, purchasing land for parks, creating guidelines for future land use on floodplains
* **Flood Proofing**
  + Several methods are currently available:
    - Raising the foundation of a building above the flood hazard level
    - Constructing flood walls or earthen mounds around buildings
  + Using waterproofed doors, basement walls, and windows
  + Installing drains with pumps to remove water
  + Installing ground-level windows that open to allow floodwaters to pass through the building without washing it away
* Canada Water Conservation Assistance Act, 1953 🡪 Enabled the federal government to provide financial assistance to the provinces and territories for construction of works to conserve and control water
* Canada Water Act, 1970
  + Comprehensive planning including all water uses
  + Views of people affected should be sought
  + Non-structural flood control alternatives should be considered
  + Planning should take place on a watershed scale
* Flood Damage Reduction Program
  + Established in 1975
  + Operates under a series of federal-provincial and federalterritorial cost-sharing agreements
    - Agree to not build, approve, or finance developments in flood-risk areas
    - Will not provide flood disaster assistance for developments built after an area is designated to have a flood risk, except for flood-proofed structures
    - Encourage local authorities to zone on the basis of flood risk
* Relocating people from floodplains 🡪 Governments have selectively purchased and removed homes damaged by floodwaters

For video (this is ‘homework’) 🡪 https://www.youtube.com/watch?v=3q-qfNlEP4A

* Why did the event occur?
* What are the processes that trigger this event?
* What precautions were taken afterwards to help mitigate?

**LANDSLIDES**

Landslide and mass wasting 🡪 Terms used to describe the downslope movement of rock or sediment due to gravity

Types of landslides (hint: will not ask us to know every type ) are determined by:

* Mechanism of movement | Type of material | Amount of water present | Rate of movement

1971 - Saguenay River, Quebec 🡪 27 hectare landslide – 26 homes lost – 31 killed

1903 – Frank Slide, Alberta 🡪 buried town of Frank – killed 70 people – lasted ≈ 90 seconds

- Also called turtle mountain

- Mining had occurred, however, blamed events on faults within mountain structure

St. Jude, Quebec (May 10, 2010) 🡪 Landslide claimed lives of a family of 4

1969 - Aberfan, Wales 🡪 coal spoil heap failed – killed 144, predominantly school children

California 2018 🡪 mudslides follow fire - 21 deaths attributed - Fire creates a hydrophobic layer that is an ideal surface for mudslides to occur

**Types of Landslides**

1. Fall 🡪 Bounding of rock or blocks of sediment from the face of a cliff
2. Slide 🡪 Downslope movement of a coherent block of rock or sediment along a discrete failure plane
3. Slump 🡪 Failure plane is curved upward
4. Flow 🡪 Downslope movement of sediment in which particles move semi-independently of one another, often with the aid of water
5. Debris Flow 🡪 Typically move rapidly; mixtures of mud, debris and water
6. Creep 🡪 Very slow flow of rock or sediment
   1. Most common
   2. Sackung - slow movement of large masses of rock (Textbook only uses this term)
   3. Topple – a rock mass pivots about a point

**Forces on Slopes**

**Driving forces** 🡪 move rock or sediment down a slope

* The weight of slope material is the largest driving force
* Can include fill material and buildings

**Resisting Force** 🡪 oppose downslope movement.

* Shear strength of the material
  + Resistance of material to sliding or flowing along slip planes

**Factor of Safety (SF)** is the ratio of the resisting forces to the driving forces.

* Stable when greater than 1; unstable when less than 1

Driving and resisting forces are not static

* As local conditions change, these forces may change
* Factor of safety may increase or decrease

Forces on slopes are determined by:

* Type of material
* Slope angle and topography 🡪 something that is already closer to an angle of failure is more likely to fail
* Climate 🡪 certain climates have higher potentials for extreme weather events
* Vegetation
* Water
* Time

**The Role of Material Type**

Planes of weakness

* Occur in bedding planes, foliation planes in metamorphic rocks, joints, or zones along which Earth has moved before

Degree of consolidation

* Slumps are common in unconsolidated materials

Shape of slip surface

* Rotational slides or slumps are curved
* Translational slides are planar

**The Role of Slope and Topography**

Slope steepness

* Steeper the slope, the greater the driving force
* Steep slopes are associated with falls
* Moderate slopes are associated with flows
* Gentle slopes are associated with creep

Topographic relief

* Refers to the height of a hill or mountain above the land below
  + Landslides occur more frequently in areas of high relief

**The Role of Climate**

* Climate is the characteristic weather typical of a place or region over years or decades
* Influences the amount and timing of water that infiltrates or erodes a slope
  + Arid regions are prone to rock falls, debris flows, and soil slips; free-face and talus slopes are common
    - Talus slopes are a loose rock based slope
  + Humid and sub-humid regions are prone to complex landslides, creep, slides, slumps, and debris flows
    - Issue: has continues moisture or water

**The Role of Vegetation**

* Vegetation provides a protective cover that reduces the impact of falling rain
  + Raindrops are the most erosive b/c there are millions of them
* Plant roots add strength and cohesion to slope materials
* Vegetation adds weight to slopes
  + Increases the likelihood that the slope will fail

**The Role of Water**

* Water saturates soil, causing soil slips and debris flows
* Slumps develop months or even years following deep infiltration of water into a slope
* Water erodes bases of slopes which decreases stability
* Water can cause liquefaction or quick clay failure
  + Fine-grained material that loses strength when disturbed and flows like a liquid

**The Role of Time**

* Forces acting on slopes change with time
* Driving and resisting forces change seasonally as the water table fluctuates
* Chemical weathering of rocks occurs slowly over time

**Geographic Regions at Risk from Landslides**

* Landslides occur wherever there are significant slopes
* In Canada, landslides are most common in:
  + Western Cordillera region of B.C., Alberta, and Yukon
  + Appalachian Mountains of Quebec and New Brunswick
* Factors expected to increase landslide incidence:
  + Urbanization and development of landslide-prone areas
  + Tree cutting in landslide-prone areas 🡪 if you have a stable slope, and cut trees down… now, no longer have trees to absorb water, therefore, soil will be over saturated and erosion occurs
  + Changing global climate patterns resulting in increased precipitation

Hint: Saskatchewan 🡪 high amount liquefaction

**Effects of Landslides**

* 30 people are killed each year on average in North America; damage exceeds $1 billion USD per year
* Slides may damage homes, roads, and utilities constructed at the top, base, or side of a hill
* Slides may block roads and railways impeding travel, or may block streams causing flooding

**Linkages with Other Natural Hazards**

* Earthquakes, volcanoes, storms, and fires may cause landslides
* Landslides may cause flooding or tsunamis
* Ex: Grand Banks, 1929
* The headline is inaccurate as this is because “Tidal Wave” is cause by displacement of water which is tsunami

**Natural Service Functions of Landslides**

* Produce deposits that become mineral resources
  + Weathering frees mineral grains from rocks, and landslides transport these materials downslope
  + Gold and diamonds have been mined from landslide deposits
* Creation of new habitats in forests and aquatic ecosystems
  + Increases plant and animal diversity

**Human Interaction with Landslides**

* Expansion of urban areas and transportation networks, and exploitation of natural resources have increased landslide incidence.
* Grading of land surfaces for housing developments can initiate landslides on previously stable slopes.
* Timber Harvesting 🡪 Clear-cutting and logging road construction
  + Increases landslide-related erosion on unstable slopes
  + Interrupts surface drainage, alters subsurface movement of water, and can change the distribution of materials on a slope
* Urbanization
  + Removal of anchoring vegetation 🡪 sometimes these vegetation are holding soil back preventing landslides
  + Construction of roads and buildings 🡪 or adding weight
  + Installing septic systems, watering lawns, and gardens
  + Cutting the base of slopes
  + Place fill materials on slopes à same as construction

**Minimizing Landslide Hazard and Risk**

* Identification of Potential Landslides
  + Crescent-shaped cracks or terraces on a hillside
  + A scalloped or recessed crest of a valley wall
  + A tongue-shaped area of bare soil or rock on a hillside
  + Large boulders or piles of talus at the base of a cliff
  + An area of tilted trees
  + Trees that are convex at their base but straight higher up
  + Exposed bedrock with layering that is parallel to the slope
  + Tongue-shaped masses of sediment at the base of a slope or at the mouth of a valley
  + A hummocky, or irregular and undulating, land surface at the base of a slope

Hint: do not memorize all points, quite simple but just an extreme detailed list; bold points are the specific ones he mentioned in class

**Prevention of Landslides**

* Drainage Control
  + Objective is to keep water from infiltrating a slope
  + Drains can intercept and divert water
* Grading can improve slope stability
  + Material from the upper slope can be moved to the base
* Slope supports
  + Retaining walls constructed of concrete or brick

**Landslide Warning Systems**

* Provide time for people to evacuate
* Human monitoring for surface changes and small rockfalls
* Electrical systems, tiltmeters, and geophones
* Railways have rock fences linked to signal systems
* Wells can indicate dangerous amounts of water

**Perception of and Adjustment to Landslide Hazards**

* Perception of Landslide Hazards
  + Landslide hazard maps do not prevent people from moving into hazardous areas
* Adjustments to the Landslide Hazard
  + Siting of critical facilities 🡪 Hospitals, schools, police stations
  + Remedial Corrective Measures 🡪 Effective drainage systems to reduce water pressure

**Personal Adjustments**

* Seek an evaluation of the property by a geologist
* Avoid homes at the mouth of a valley or canyon
* Consult local agencies and engineering departments
* Monitor small landslides on the property
* Look for cracks in house walls, leaning retaining walls, doors or windows that stick, or uneven floors
* Be wary of leaks in swimming pools or septic tanks, trees or fences that tilt, or sagging or taut utility wires
* Avoid slopes with small springs
* Look for linear or curved cracks that might indicate instability
* Do not purchase property that is in an area prone to landslides

**Lecture 6: Avalanches**

*Based on Chapter 7 in Textbook*

**What is a snow avalanche?**

* Def. Masses of snow, generally more than a few cubic metres in volume, that separate from the intact snowpack and slide or flow downslope
* May travel as a coherent block or it may rapidly disintegrate into small particles that move independently of one another
* Most occur in remote, uninhabited mountains during fall, winter, and spring

Tip: What is the smallest size of an avalanche? Sluff

**Snow Climatology**

* The length of the snow season depends mainly on latitude and altitude
* The amount of snow on the ground depends on slope od the land, elevation, amount of snowfall, and winds
  + Snow accumulates on slopes less than about 45°

**Types of Avalanches**

1. Point-release avalanches

* Begin with failure of a small amount of loose fluffy snow
* Widens as it moves downslope
* Commonly happen after a heavy snowfall

2. Slab Avalanches

* Snowpack fractures along a weak layer at depth
* Moves as a cohesive block
* More dangerous than point-release avalanches

**Snowpack Structure**

* New snow that has not had time to bond to the layer below is susceptible to sliding.
* Compacted snow is less likely to move than light powdery snow.
* Weak layers required for slab avalanches can form by:
  + Wind
    - Blowing snow can build up on sheltered lee slopes
    - A win slab is a body of thick, poorly bonded snow deposited by wind
* Formation of hoar at depth in the snowpack
  + Hoar: Ice crystals deposited on snow when air is moist and cold
  + Layers of hoar generally have lower strength than the rest of the snowpack
  + Forms from air occupying spaces between snow crystals
* Formation of hoar at the surface
  + Ice crystals change slowly once buried
  + Overlying and underlying snow layers gain strength, leaving the buried surface hoar as a weak layer

**Avalanche Motion**

* Within a few tens of metres, a slab avalanche disintegrates into smaller fragments
* Dry avalanches generate a cloud of powdered snow that billows above the flowing mass
* Wet avalanches contain liquid water and do not achieve the high velocities of dry avalanches
* Dry avalanches have been clocked at 200 km/h (typically around this speed, or faster)
  + May have sufficient momentum to climb opposing slopes

**Avalanche Triggering**

* Most avalanches occur naturally during or soon after snowstorms
* Some happen when normal daytime heating or an inflow of warm air raises the temperature of the snowpack
* In most recreational accidents, a person triggers the avalanche
* Some avalanches are triggered intentionally as part of avalanche-control programs

**Avalanche Paths**

1. Start zone 🡪Where the snowpack fails
2. Track 🡪 Path of acceleration and maximum velocity
3. Run-out Zone 🡪 Deceleration and deposition

**Terrain Factors**

**Slope Angle**

* The most important terrain factor for avalanche formation
* Avalanches tend to occur on slopes with angles between 25 and 60 degrees
* Most large avalanches occur between 30 and 45 degrees

**Slope Orientation**

* Leeward slopes are more likely to have avalanches
* Sun-facing slopes are more prone to avalanches during sunny, warm weather; shaded slopes are more prone to avalanches in cold weather; shaded slopes are more prone to avalanches in cold weather & are known to accumulate snow

**Other factors**

* Convex slopes are more dangerous than concave ones
* Avalanches are more common on smooth slopes
* Vegetation may anchor the snowpack
* Gullies or ravines can funnel avalanches, increasing their destructive force

Tip: Flat areas are not at risk for avalanches, obvi!

**Impacts of Avalanches**

* Human deaths (600 in Canada since mid 1800s)
* Economic losses (destruction and blockage of roads, property damage)
* Damage to forests; soil removal

**Links and Natural Service Functions**

* Links to other Natural Hazards
  + Earthquakes can trigger avalanches; Climate change may increase snowfall
* Natural Service Functions
  + Increase local plant and animal diversity; Provides open areas for wildlife

**Human Interaction and Minimizing Risk**

* Increased human interaction with avalanches
  + Building developments are encroaching into areas prone to avalanches
  + Winter leisure and recreation activities have increased in popularity
* How do we minimize risk?
  + Locating structures away from areas prone to avalanches
  + Engineering structures to deflect snow
  + Reinforcing exposed structures
  + Triggering controlled avalanches with explosives
  + Forecasting

**Minimizing Risk**

* Location of Infrastructure 🡪 Risk is estimated by determining avalanche frequency, distribution, size
* Structures 🡪 Fences, nets, berms, and avalanche sheds (ramps the avalanche over the road) are used for protection
* Triggering 🡪 Explosive charges are projected from cannons, fired by artillery, or dropped from helicopters
* Forecasting
  + Based on four types of information:
    - Observed occurrences of avalanches
    - Stability and strength tests: shovel, compression, and rutschblock tests •(often use by skiers, dig out a small portion, test to see if impact with body weight will fail or not. Indicating whether it is safe to be on the snow)
    - Snowpack observations
    - Weather

**Avalanche Safety**

People involved in winter recreation in mountainous areas should consider these questions:

1. Is the slope prone to avalanches?
   1. Consider the slope angle and orientation
2. Is the snowpack unstable?
   1. Bulletins, recent avalanches, tests, weather
3. What are the consequences of being caught in an avalanche in this terrain?
   1. Size, type, wet or dry, topography of area (cliffs, trees, boulders)

**Avalanche Rescue and Survival**

* Survival depends on the length of time the person is buried and the burial depth
  + 92% survive if rescued within 15 minutes, only 30% survive after 35 minutes, almost 0% after 2 hours
  + Only 5 to 10% survive burial in more than 1.5m of snow
* Rescue
  + Avalanche cords
  + Avalanche transceivers
  + Probes
  + Shovels
  + Avalanche dogs