Erth 2415 Lecture Notes Natural Disasters

Natural Disasters (Carleton University)

ERTH 2415

Lecture 1
May 5, 2014

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-"Civilization exists by geologic consent, subject to change without notice" – Will Durant
-Orange = Important material
-Blue = Terms to remember
-Purple = Numerical figures to remember

Lecture Objectives
-Distinguish between natural hazards and natural disasters
-Know the 4 energy sources hat fuel the different natural disasters
-Be aware of several global and Canadian trends related to natural disasters
-Understand the notion of risk
>Make sure your understanding fits within the lecture objectives

What is a natural disaster?
-Etymology: dis "away, without (something negative)" + astro "star, planet"
-Originated with the ancient Greek people who believed it to be based on the pseudoscience of astrology
-Natural Disaster: An extreme natural event in which a large amount of energy is released in a short time with catastrophic consequences for life and infrastructure in the vicinity
>Ex: Huge hurricane that eroded the coast
>Finite in time involving a lot of energy
-Catastrophic consequences for people and the infrastructure around them

Natural Disaster – Attributes
-Significant causalities
-Destructive impact on infrastructure
-Disruption to society
-Large economic losses
-Call for exterior help (community is overwhelmed)
-Media Coverage
-Government involvement
-Impacts society
-Example: Toronto Ice Storm, although Ford did not call for exterior help
-If a hurricane occurred in a non-inhibited arctic island it would not be considered a natural disaster, as it would not impact society
-Misnomer: Gives the impressions that disasters are only the fault of Mother Nature
>Although they are often triggered by society.

Natural Hazards

-Natural Hazard: A source of danger that exists in the environment and that has the potential to cause harm
-Example: High water levels, Unstable snow and rock on mountain slope, lightning bolt
-Inevitable
-Vulnerability: What makes you weak, Likelihood that a community will suffer, both in terms of fatalities and physical damage, when exposed to hazards in the environment
-Natural hazard > vulnerability > disaster
-Ex: Toronto ice storm: Strong winds, ice rain, cold temp > aerial power lines > population without electrical heating for several days = deaths from hypothermia and asphyxiation
>If we were to bury the power lines we would not be vulnerable but resilient leading to limited power outages
-Ways to measure levels: Frequency: the number of times an event occurs within a certain length of time (generally similar events)
-Example: North Atlantic Hurricanes migrate up to Atlantic Canada and can cause tropical cyclones. On average (the frequency) we have 4/year.
-Return Period: Length of time between similar events
-Example: Severe hurricanes strike the US on average every 6 years
-Frequency and return period are the inverse of one another
>Ex: Frequency = 2 occurrences of heavy rain/ year, OR Return Period: 1 every 6 months
-Magnitude: Amount of energy fuelling a natural event
-Examples: Force of hurricane winds, amplitude of ground motion during an earthquake
>Low magnitude events occur frequently, high magnitude events are rare (there are many small earthquakes all of the time, once in a while there is a large one) (utilizing frequency)
>High magnitude events have a long return period (utilizing return period)

Sources of energy fuelling natural disasters
-4 Energy sources that fuel Earth's natural processes:
1) Earth's internal energy
>Earthquake
>Tsunami
>Volcanic Eruption
2) Gravity
>Mass Movement
>Snow Avalanche
3) Solar Energy
>Meteorological storm
>Flood
>Draught
>Wildfire
4) Impact Energy
>Impact with space objects

Origin of the Solar System

3 steps:
1) Formation of the solar nebula = Gravity (Force of attraction between masses separated by distance, pulls things closer together [never repulsive])
-Solar Nebula: Rotating disk of cosmic gas and dust
-Explains why all of the planets are rotating around the sun in the same direction
2) Planetary Accretion
- All planets formed at the same time (4.6 billion years ago [age of solar system]) and in a short length of time
-8 planets, 2 styles (Terrestrial Planets are made of rock i.e. earth, mercury, Venus, and mars and Giant planets are made out of ice i.e. Jupiter, Saturn, Uranus, Neptune)
>Difference = distance from the sun
>Furthest parts of solar system = comets (small bodies of ice)
-Impact energy (Ex: smacking hands together makes palms become warm)
3) Differentiation of the Earth: Process by which gravity causes denser material to gradually migrate to the center of a planet
>Density = small on the surface, increases from surface to center (our core is the densest part of the planet)
-Why is the center of the earth hot? Residual impact energy from planetary accretion alongside the decay of natural radioactive elements (Ex: uranium, potassium)

Global trends
-The number of man-made (Ex: badly designed building collapsing) disasters have been decreasing in recent years)
>Why? People are taking health and safety more seriously now
-The numbers of great Natural Disasters are increasing (there are more than man made)
-Geological disasters: constant (no change)
>Earthquake, tsunami, volcano
-*Weather disasters are becoming more frequent
>Flood, storm, heat wave, drought, wildfire
-*The number of natural disaster fatalities is increasing with time
-*Globally, communities are increasingly vulnerable
>Population growth (earths population is increasing)
>Development in risky areas
>Degradation of natural ecosystems
>Over-reliance on technology
-*Economic losses from natural disasters are increasing with time

Canadian trends
-*The number of natural disasters in Canada is increasing with time
>Climate change is partly to blame
-*The number of natural disaster fatalities in Canada is decreasing
>Heat wave in the 1930's was a disaster that caused the most deaths in Canadian history (vulnerable people generally die, i.e. babies, elderly)
>Nowadays people would be taken into an environment where there is air conditioning
>Reasons for successful outcome: Improved engineering, better warning system, education etc.

-*In Canada Economic Losses are mostly due to weather related disasters
>All disasters are weather related

Risk and mitigation
-Risk: Vulnerability x Hazard
-A severe hazard associated with low vulnerability has a lower risk level than a severe hazard associated with high vulnerability
-Example: Seismic (Earthquake) Risk in Toronto = Moderate Risk as there is a high vulnerability, and a low hazard
-Reducing Risk: 4 pillars of emergency management
1) Response = Short Term
>Immediate actions (paramedics, fire fighters etc.) to manage its immediate consequences
>Ex: A forest firefighter suppresses a nascent fire with an axe
2) Recovery = Middle Term
>Activities to put the situation back to normal (repair conditions to an acceptable level)
>the new normal may not be the same as before the disaster
>Ex: Removing debris after a mass movement to reopen transport corridor (Rock Slide on Sea to Sky highway in BC)
3) Mitigation = Long Term
>First part of feedback loops
>Reduces risk
>Ex: Structural (you are building something) mitigation: Building protective infrastructure: dams, floodways > schools in BC are currently being strengthened to better withstand earthquakes (this is proactive!)
>Ex: Non-structural mitigation: Weather warnings, evacuation drills, land-use policies > Clearly marked tsunami evacuation routes
4) Preparedness = Long Term
>Planning for disasters by putting in place resources to cope with them when they occur
>Ex: Preparing a home emergency kit (should be able to sustain you for 72 hours)

Lecture 2
May 5, 2014

Canada's Policy on Natural Disasters

What can increase structural vulnerability?
-Aging built infrastructure (ex: bridges in Montreal)
-Environmental degradation
-Unsustainable land use planning
-Urbanization

Social Factors that make a population vulnerable
-Health
-Age
-Gender

-Language
-Aboriginal Community Considerations

Emergency Management in Canada
-In practice, we focus on managing emergencies, and decide later whether or not it was a disaster
-Emergencies are current or imminent events that require prompt coordinated actions to reduce losses caused by natural, human induced, or malicious hazards
-"All-Hazards" emphasizes the leveraging of common capabilities across the entire emergency management systems (common identifiers)
>Improves the ability of emergency management to address unknown hazards or risks
>Overlaps natural disasters, terrorism, and human health (epidemics)

Disaster Costs
-Contradicts Canada being a resilient country as we are very exposed (we have such a large territory and have to deal with all elements)
-1.76 % of Canada's GDP is annually exposed to hazards
-Canada is the 15th most economically exposed country in the world
-DFAA, Disaster Financial Assistance Arrangements = Helping societies in need
-Ex: 2013 Toronto Flood cost $1 Billion
-Most emergencies in Canada are local in nature and are managed by the municipalities or at the provincial level
-The bottom up strategy (if the municipality cannot cope they call the provincial gov. etc.)

International Situations
-NATO, UN, NGO, Private sectors can all be involved in assisting (when a x cannot cope)
-International Decade for National Disaster Decrease 1990-1999 Goal: Decrease the loss of life, property destruction and social and economic disruption caused by natural disasters
-In developed countries there was a decrease in fatalities, but increase in cost
-Less developed countries experienced high levels of human and economic loss
-ISDR (mandated for 10 years, much more successful)
>Engaged local groups (what they thought could be done in their community)
-Canada's Platform for Disaster Risk Reduction
>Non-profit
>300+ members across four components (advisory committee, general membership, working groups, secretariat)
>Anyone can join!

Environmental Change
-Climate change is a factor in natural disasters, but it is not the only factor
-Hurricane Katrina, what made New Orleans a target for disaster? (The Hurricane was not the most extreme in history… so what went wrong?)

>Vulnerabilities: Faulty levee (dykes >neighborhood is lower than the water in the canal) design and implementation, a lack of town planning, large scale subsidence, draining of wetlands, and extraction of groundwater, inappropriately designed waterways

Community Resilience
-First thing responders do is clear the area. This is a costly approach, there may be a lot of things around that people know. If a disaster is happening, maybe the community can help more than would be expected.

Week 2: May 10
Lecture 3

-Quiz 1 opens Sun-Wed (Do on vacation)
>15 t/f, 10 MC
>Sometimes have to visit some websites
>Time limit: 6 hours time limit (designed to take an hour or two)
-Ch.14 (p. 296-422)

Impacts with Space Objects
-Blithfield Meteorite
>Diameter = 7cm

Sources of Extraterrestrial Debris
-Meteoroid: Extraterrestrial debris orbiting the sun (potential impactor)
>When the impactor enters the earth's atmosphere and it becomes … (it becomes below)
-Meteor: An impactor entering the Earth's atmosphere and becoming incandescent because of friction
>Come from fragments of Asteroids
-Asteroid: Small rocky body orbiting the sun
>Body's that are much smaller than a planet
-Main asteroid belt is located between the terrestrial and giant planets (the gap between them)
>Jupiter is huge and has created a disturbed gravity field around it, causing the droplets of solar nebula to not be able to form any new planets. This is the reason fo the asteroid size bodies
>Range from Tiny pebbles to Ceres (dwarf planet, 900km in diameter)
>40,000 objects with a diameter larger than 1km, which has serious contacts when coming into contact with the Earth
>Sometimes these asteroids collide with each other causing them to fly out from one another and at times impact Earth
-Near-Earth Asteroids (not in the Main Belt)
>Crossing the orbits of Earth of Mars
>Only 1/1000 of the Main Belt (much less of them in comparison), but they are much closer to us so therefore they are still dangerous

>Apollo (2 points of intersection between the 2 orbits, meaning there are 2 vulnerable locations for the Earth at certain times of year) and Atens (2 intersection points as well) asteroids cross the Earth's orbit

Secondary sources of extraterrestrial debris
-A few meteoroids are fragments of comets
-Comet: The small object composed of ice and rock debris moving through outer space (ex: Comet Eson, came around the New Year near the sun)
>Very far away from the sun (in the outer region of our solar system)
>Not a lot of material for planets to go here, therefore they are generally small bodies
>Referred to as "Dirty snowballs"
>Comet ice can sublimate (solid-gas [vapor])
>A tiny fraction travel to the inner solar system where they can impact Earth as they have highly eccentric orbits
>Ex: Halley's comet (well known because it has been seen multiple times in history, returns every 76 years)

How to Classify Meteoroids
-Classified according to their size (do not need to know the numbers, but need to know the size progression so what is the smallest and largest)
1) Cosmic dust = a few molecules – 1 mm (smaller than a grain of sand)
>Pass through the atmosphere unchanged
>Settles on the surface of the Earth
>Amounts to 10^5-10^6 kg/day (Earth gains weight)
2) Shooting stars = 1 mm (size of a grain of sand
>Its atmospheres protect Earth
>Melt in the atmosphere because of friction
>We see the streak of hot air
3) Meteorites = 1mm-100mm
>Pas through the atmosphere and fall on the Earth's surface
>Can split into large fragments mid air
>Only source of extraterrestrial rocks
>Sample-return mission without the commute
>Ex of a scenario: During entry, exterior melts and is stripped away (can be cold when reaching the surface)
>Come in 3 types: Stony (majority, have chondrules in them, 2.6 billion years old), Iron (body where they are from have differentiated), and Stony-iron
>Most famous Canadian meteorite: Tagish Lake, which fell in northern BC in 2000
>Ex of Canadian iron meteorite: Annaheim which was found in Saskatchewan in 1916, has the thumb print texture, valued at 100k
-Latest meteorite known as Grimsby fell in 2009
4) Asteroids = 100mm +
>Not slowed down by the atmosphere
>Explode on contact with the Earth's surface (create impact craters)
-The large the impactor, the more dramatic the impact
-Impacts with slow bodies occur frequently

-Two different definitions
>Small rocky orbiting the sun v. Impactor larger than 100 m in diameter

Celyabinsk
-Mid-air explosions
-2 unrelated events
>Cosmic coincidence
>Predicted that there would be a big asteroid coming (record) close to Earth (Apollo), but then there was also as a surprise a Fireball and the impact in Celyabinsk (Exploded 25km above ground, Stony meteorite, had a powerful shockwave which injured people by the broken glass (not falling debris))
>No craters
>Earth's atmosphere is a good shield (body was much larger before it entered the atmosphere)
>Impact simulator: Inputs (website) > Will be used on the quiz

Tunguska
-Mid-air explosion
-Massive fireball in the sky
-No crater because it exploded above the Earth's surface
-Occurred in sparsely populated area (no witnesses)
-Stony meteorite

The k/Pg boundary event
-Cretaceous (K) paleogene (Pg) boundary event
-Event that killed the dinosaurs (except the ones that evolved to become birds)
>65% of all species died, not just the dinosaurs
-Planet Earth is 4.6 billion years old (Ga)
-World's oldest rock found in NWT
-Time unit used in geology: Ma (Million year)
-Discovery of a worldwide iridium rich layer at the k/Pg boundary (rare element associated with meteorites)
-Impact (sudden event) of global consequences is related to the extinction
>Primary cause
>Impact consequences: Earthquake, tsunami, acid rain, dust blocking sunlight, abrupt climate change etc. (main cause of death of dinosaurs)
>Hunt for the impact crater, ex: Mexico, while drilling a bur hole encountered shattered rock
>Crater is in ucitan peninsula in Mexico
-Secondary cause of dinosaur extinction: Stress on life from extensive volcanism in India

Lecture 4 May 10

Close Encounters
-Take bodies 200+ meters or bigger and dates them (table 14.8)

-Appears as though either space has become a more dangerous place, or our detection capabilities have improved
-Near-Earth Object Program (NEO)
>Extended to 2010
>Lists closed approaches though a scale
>>The Torino Scale of Impact Hazards (10 Levels, 0 meaning no danger – 10 doomsday)
>NEOSSAT has dual purpose, tracks man made space debris and tracking near Earth asteroids

Crater Shape
-Astrobleme: astro="star, planet" + blema "wound" = impact scar*synonym for impact cater
-Crater diameter = 20x impactor diameter
-Craters with diameters >5km do not contain meteorites (impactor vaporized on impact)

Distinctive Characteristics of Craters under 5km in Diameter
-Circular feature (ex: similar to the mouth of volcano)
-Crater is steep-sided and closed
-Rim rocks are titled away from the crater
-Shattered rocks on the crater floor
-Large angular blocks of rock scattered around crater
-Presence of meteorite fragments
-Shatter cones
>A colonial fragment of host rock fractured by the shock wave generated by the impact (Striations radiate from the apex, terrestrial rocks)
-Shock mineral
>Does not need to have all of the features, but several of them are necessary

Simple Craters
-Diameter < 5km
-Meteorites might be found
-Raised rim (similar to a hill)
-Concave bottoms lacking central uplift (Ex: lake)

Pingualiuit Crater, QC
-Simple crater example
-Means large hill in Inuktitut
>Surrounding tundra is very flat
>Raised crater rim is a topographic high
>Important landmark (archeological site)
-Discovered when a pilot flew over it
-Impactite: Glassy material produced by partial fusion of the host rocks by the heat generated from the impact (found on site)
>Terrestrial rocks, Rich in iridium (element discussed in relation with the Chicksooloo impact)

Complex Craters
-Large impactor
-Diameter > 5km
-Collapsed rim
-Central uplift (area which rebounded, ex: island in the middle of the lake)
-No meteorites

Impact Crater in the World
-Not evenly distributed
-Only 160 worldwide
>25 in Canada, which is a large territory with very old (Precambrian) rocks

Craters in Canada
-Sudbury, ON has the largest and oldest impact crater
>2 Billion years old (1850 + 3Ma)
>Known for its nickel
-Pentlandite (nickel ore)
>Also found in Sudbury
-Wanapitei, ON lies within the limits of the Sudbury impact crater
>Crater within a crater
-Brent Crater = Stony meteorite which is near the northern boundary of Algonquin Park (it is a depression filled two kidney-shaped lakes)
>Geologists have drilled boreholes in it to understand (well studied crater)
>Distinctive factors: semi circular, steep-sided, shattered rocks on crater floor, large angular blocks around the crater
-Charlevoix, QC = Associated with an Earthquake (rare)
-Eau Claire, QC = Double-impact site: Age, size and separation of craters indicate impactors were a binary pair, two bodies closely bound by gravity
>Ex: asteroid Ida and its moon Dactyl
-Manicouagan, QC = located on Daniel Johnson hydro dam (when they flooded the area, the crater emerged)
-Haughton, NU = Shatter cones discovered in 1974 during geological exploration of Devon Island
>Used for research for mars in the Haughton-Mars Project (www.marsonearth.org)
>Have many conditions that resemble mars as much as possible on Earth (dusty, windy, cold)
-Whitecourt, AB = Youngest crater in Canada (Discovered in 2007 by local residents)
>Cross-hatch pattern found when sliced (as these meteorites are often covered in rust): Several iron meteorites exhibit this cross-hatch pattern due to intergrowth of nickel-rich and nickel-poor crystals
>>Material may be used on blades for knives and jewelry

Crater Counting
-Used in the absence of radiometric data to date the surface of space bodies
>The older the surface, the more craters there are
-Method has been calibrated with lunar data

-Ex: Allows you to estimate the age of mars
-Knowing the cratering rate, the age can be estimated (Ex: If rate is 1 crater of 1km in diameter per 10Ma, 4 craters of 1km = 40Ma)
-Must assume there has been no erosion, no plate tectonics (therefore this cannot work for Earth or Venus)
-Mars surface is divided into the Northern Plains, which are smooth and featureless (younger), and the Southern Highlands, which have a rough topography (older)

Gravity: Force of attraction between masses separated by distance
>Geophysically perfect Earth it would be spherical, homogeneous, and non-rotating.
>Earth however is the shape of an Ellipsoid, has irregular topography and does rotate as well as heterogeneities in the subsurface (creates different readings in different places)

Measuring Gravity
-Gravimeter (allows for gravity measurements to be taken as was done on the frozen lake in Wanapitei)
-Gravity data is processed to map heterogeneities in the subsurface
>High gravity values: subsurface region denser than the surrounding material (ex: rock with high concentration of metallic minerals)
>Low gravity values: region less dense than the surrounding material (Ex: cavity)

Finding Life on Mars
-Martian surface environment is inhospitable for life
>Atmosphere is thin (no protective ozone layer)

Lecture 5: May 13, 2014 "Most Important Lecture"

Plate Tectonics
-Where do earthquakes occur?
-What are their characteristics?
-Professor J. Tuzo Wilson = "Father of Plate Tectonics"

Earth's Internal Structure
- The theory of plate tectonics is central to understanding natural disasters related to Earth's internal energy
> Earthquakes and volcanoes do not occur at random locations most of them coincide with plate boundaries (most are linear patterns, earthquake and volcano pattern almost coincide)

Differentiation of the Earth
-Differentiation: Process by which gravity causes denser material to gradually migrate to the center of a planet (Density increases from surface to center)
>Similar to an onion
-Earth is differentiated into layers based on density and the physical properties/strength
-Density layers: Outer layer of the Earth = the Crust (made of lighter elements like silicon and oxygen [sand]) 35km under Ottawa, Mantle is made of more dense material

(magnesium and iron), outer and inner core of Earth is very dense and is made of solid and liquid iron
>Continental crust = Earth we walk on, thick, Oceanic crust = Sea floor, thin (continental crust has a lower density than oceanic crust)
-Buoyancy
>Earth can be described as a series of layers where less dense material floats on top of denser material
>Ice bergs (they are less dense, that is why the float in the ocean)

Strength Layers
-Starting on the outside and moving towards the center of the Earth
>Gaseous atmosphere
>Liquid hydrosphere (oceans of the world)
>Rigid lithosphere (what we are walking on, it is solid)
>Plastic asthenosphere (solid, soft plastic similar to plato as it has the ability to change its shape)
>>Lithosphere (tectonic plates)-asthenosphere boundary is at a depth of 100km
>Plastic mesosphere (more viscous than the previous)
>Liquid outer core
>Solid inner core
-Loops represent large convection cells in asthenosphere and mesosphere
>Convection is what drives the plate to move (heat transferred by fluid circulation) Ex: Convection oven, the fluid would be the hot air moving throughout
>Heat comes form the core of the planet

The Tectonic Cycle
-Tectonic: Deformation forces acting on the Earth's lithosphere and responsible for the creation of mountain ranges and faults (builds landscape)
-Tectonic cycle is also known as the 'conveyor belt' model
-Longest natural phenomenon on Earth (one cycle takes roughly 250 million years to complete)
-Plate boundaries connect together into a continuous boundary of belts, which divide the Earth's surface into several plates
-How plate tectonics work
>Continents move laterally, as part of rigid lithospheric plates that slide over a plastic asthenosphere (not the continents that really move, they are glued together in the lithospheric plates which are what are actually moving which are moving over something that is slick underneath them [the asthenosphere])
>Lithosphere: Continental and oceanic crust and rigid upper mantel
>Asthenosphere: Convecting upper mantle
-Convection in the asthenosphere is the driving force (fluid that is moving in the 'convection loop' is the driving force)
-Molten (lava) material is located on the sea floor in ocean ridges, which when it comes into contact with the sea water forms a solid (new lithosphere)
>This requires something to be destructed in order for something new to be created, as the Earth is not getting bigger to make room

>When one plate comes into contact with another one (collide), density will determine what happens (the denser one will sink below, and the less dense one will remain on the top). This is where the material gets destroyed and is referred to as a subduction zone (deep ocean trench)

Subduction
-Process in which a lithospheric plate descends beneath another, pulled down by gravity (Denser plate = subducting plate, less dense plate = overriding plate)
-Subducting plate gradually melts into the asthenosphere
-Only our planet has this recycling process

Plate Tectonics Supporting Evidence
-Ocean Studies
>Age of ocean basins
>Magnetization patterns on seafloor (most elegant evidence): Internal geometric field due to movement of liquid iron in outer core, Earth's rotation causes the movement, Magnetic poles do not coincide exactly with geographic poles but they are close. Earth's internal magnetic field changes over time (wander around the geographic poles). Normal polarity v. Reverse polarity (poles go opposite N&S)
>Paleomagnetism: As lava cools, magnetic materials align in the direction of the Earth's magnetic field
>Seafloor Spreading: Underwater surveys
>New sea floor is created along the place where there is red on the map as that is where the young floor is
>Bathymetry: Deep trenches where subduction is occurring = great depth of water
-Earthquake hypocenters and epicenters
>Hypocenter: Point of origin of an earthquake in the subsurface (something happened to create the Earthquake)
>Surface of the Earth is where the epicenter is (Show you where the edge of the plates are)
-Matching fossils and rocks types across continents
>Veganer scientist who advocated for continental drift put this theory forward
>Certain animals were incapable of swimming…

-Pangea: All the continents that used to be together before moving to their own areas

Our Tectonic World
-Pacific Plate: largest plate
-North American Plate (our plate): Edge on the west has a little plate (Juan De Fuca Plate)

Tectonic Environments
1) Divergent zone (Spreading Center): Tension (Dominant Deformation Forces)
2) Convergent: Compression = When the plates collide (Opposite of tension, Dominant Deformation Forces)

>Subduction zone: Where two oceanic plates collide, density determines overriding plate OR where oceanic plate collides with a continental plate (continent always stays on top)
>Continent-Continent collision zone: When two continental plates collide (the collision style is controlled by the density of the plates) Instead of diving and sinking, since neither want to go down they usually curl up (could build a mountain)
3) Transform fault: Material sliding past one another in a horizontal way (Shear) (Dominant Deformation Forces)
4) Hot Spot: (Not related to the edge of the plates) *Mostly important for volcanoes. Plume of slowly rising hot rocks that create volcanism on the Earth's surface, originates in the mesosphere and is anomalously hot and since the hot material wants to rise it goes up threw all of the sphere to come into contact with the surface therefore becoming a volcano. It is very long lived; in fact it lives longer than the tectonic cycle. Usually creates a chain of volcanoes. (Compression) (Deformation Forces)

Lecture 6
Plate Tectonics and Earth Quakes

Earthquakes
-Nomenclature in book to describe the magnitude of the Earthquake (Table 4.4)
-Most Earthquakes occur at plate boundaries
-Table 3.1 in the book is important to review for a full understanding
>Ex: Only in convergent zones are there deep Earthquakes

Spreading Centers (Divergent Zone) and Earthquakes
-Stress is released in frequent, strong, and shallow earthquakes
>tension = dominant force
-Formation of new oceanic lithosphere
1) Centering: Lithosphere centers over hot region at depth
2) Doming: Domes up due to thermal expansion, creates the tension and bulge
3) Rifting: Area is pulled apart by tension. It will crack on the side (Ex: African Rift Valley, 3 zones meet at the Afar triple junction [Red sea, Gulf of Aden, Rift valley])
>Some rifts do not fully develop into new oceans (failed rift)
4) Spreading
-Ex: Iceland

Convergent Zones and Earthquakes
-Compression (where two tectonic plates collide)
>Immense amount of energy is released
-Infrequent and great Earthquakes (occur at all depths: shallow, intermediate and deep earthquakes)
-Subduction zones
>At depth <30km = Crustal earthquakes (relatively shallow) due to compression in both overriding and subducting plates (Occurs in Victoria, BC). Contact surface between the two plates is called the Megathrust earthquakes due to shear stress are the world largest earthquakes. (Releases a large amount of energy)

>At depth >100km = Intra-slab Earthquakes due to cold rock being consumed into the hot asthenosphere (they are destroyed here). Potential for 3 different types of earthquakes, therefore the earthquake risk is very high.
-Cascadia megathrust fault is causing Vancouver Island to bulge up (The rupture of this megathrust will cause a rebound and a great earthquake with the possibility of a tsunami as well)
>Cascadia subduction zone: largest risk from crustal earthquake, catastrophic risk from a megathrust earthquake (lots of death a destruction)
>1700 Cascadia Earthquake (300 years ago) was the largest in Canadian history (magnitude 9) and triggered a tsunami
-Epicenters: Juan de Fuca plate, North American Plate

Continent-Continent Collision Zones
-Collision between Indian and Eurasian plates
>A long time ago (71 million years ago) India was an Island surrounded by oceanic crust. It is now colliding with the Eurasian continent (it has nowhere else to go). This is causing things to crumble therefore developing the rising Himalayas (the consequence of this continent collision)
>Creating a lot of stress in the lithosphere behind China
-The world's largest earthquakes are found here (infrequent and found at different depths)

Transform faults and earthquakes
-Shear stress, infrequent (stress needs to be build for a long period of time)
-Occurs in places like the Queen Charlotte fault (where the Pacific late and North American plate slide against each other in Northern BC)
-Real and idealized plates
-San Andreas fault, CA
>Transform fault accommodating horizontal movement between Pacific and North American plate, increased in length over time
>Do not create nor get rid of material
>Complex system of sub parallel faults: locked portions: stuck and refuse to move (deficient in earthquake activity), creeping portions (more frequent moderate earthquakes)
>1906 San Francisco Earthquake: magnitude 8.3, the ensuing city fire did 10x more damage (both a natural disaster followed immediately by a man made disaster [great urban fire])
>Officials downplayed the earthquake and addressed the entire incident as a man-made disaster in order to raise funds and support to rebuild the city in the same location
-Queen Charlotte fault
>Very active seismically
>Affects sparsely populated areas, therefore does not receive much attention
>Haida Gwaii earthquake 2012 7.7 magnitude earthquake

Hot Spot and Earthquakes
-Frequent, strong, and shallow earthquakes

-Occur beneath the volcano (when the magma moves up and pools in the chamber beneath the volcano)
-Ex: Hypocenters beneath Kilauea volcano in Hawaii
-Intra-plate earthquakes of eastern Canada
>Eastern North America is experiencing stress from opening of the Atlantic Ocean causing earthquakes where there are zones of weakness in the crust (zones of weakness: failed rifts, hot spot track, impact crater [Charlevoix is the only impact crater associated with earthquakes])

May 17
Lecture 7
***MIDTERM LEC 1-12**

Earthquakes and faults
-Sudden movements along faults cause earthquakes
-At the hypocenter:
>Stress from deformation forces build up until rocks fail
>Rocks fracture and shift
>Energy is released as seismic waves
-3 types of rocks (all horizontal sedimentary layers)
>When the layers are no longer continues they become a fault
>The center [hypocenter] is the point of failure then stem the S waves, then the P waves
-Fault: fracture across which two blocks of rock move relative to each other
>Classified according to the relative movement between blocks
>Major faults extend several kms in the subsurface and can be several km long as well (many are below ground)

Catalogue of faults
-Hangingwall: rock block above the fault
-Footwall: rock block below the fault
-Faults are good targets for orr (gold)
>Famous Dexter Porcupine fault
>Caused people to mine along the fault in the hopes of finding gold
>Rough and interlocking rocks (irregular surface)
>Full of special minerals (ex: gold)
>Stress needs to build up over many years for the rock to break and the system to move
-3 faults
1) Normal fault: The Rideau Rapids (surface expression of the Gloucester normal fault)
>Usually a fault zone, not a perfect line
>Rifting: area is pulled apart by tension causing the rocks to fracture along normal faults and in turn causing the central area to sag
2) Reverse fault: Hanging wall moves up relative to footwall, which happens when the system is in compression (Ex: Road cut)
>In convergent zones: India colliding with Eurasia, blocks of rocks have moved up, dominating style of fault in a convergent zone

3) Strike-slip fault (transform fault): The two rock blocks move alongside each other, horizontal movement (Ex: San Andreas fault after 1906 earthquake)
>Slip = amount of movement

What happens during an earthquake?
How is the energy released during an earthquake?
-Released in waves causing the ground to shake
-P waves
-S waves
-Surface waves
Characteristics of seismic waves

23 min 30 secs into next lecture

…..NEED TO FINISH

May 20 – Lectures 9 & 10 *Quiz 3 = Lecture 7,8, & 9
Lecture 9
Tsunami's and Mass Movements (Landslides)

Breaker wave: around Hawaii where people surf

Tsunami "Harbour wave"
-Natural hazard from Earth's internal energy
>Caused by earthquakes and volcanic eruptions, as well as a mass movement or an impact with a space body

Causes of Tsunami's
-Tsunami: Ocean wave most often generated by underwater disturbances of the seafloor
>Mostly triggered by large earthquakes
>Less commonly caused by volcanic eruptions, mass movement, or impacts with space bodies
>Disturbance on the seafloor
-Vertical motion of rock blocks on the sea floor
>Wave amplitude increases near the shore
-Earthquake caused tsunami
>Trigger is a linear source (fault on seafloor)
>Energy is released perpendicular to the main fault
>Can propagate a long distance (have the potential to carry energy far away from the point of the initial disturbance)
-Tsunami caused by a volcano or landslide
>Trigger is a point source, energy flows away radically (energy dies off more quickly), higher attenuation (more localized damage)

Geographical Occurrence
-Most tsunamis occur in the Pacific Ocean, which is surrounded by active volcanoes and subduction zones
-Rare in the Indian Ocean

Wave Characteristics
-Amplitude
>Maximum values is measured through calculating the equilibrium
-Zero attenuation (means always the same)
-Time between can be as long as one hour and as short as one second
-Velocity = m/s (length/time or wavelength/period) (meters/second)
-Water moving in forward-rotating circles
-Diameter of circles decrease in depth
-Sea level = equilibrium position
-High point in the wave = crest, low point in between = trough
-Depth = wavelength (measurement of one crest to the next) divided by 2
-Shoaling: When you are approaching the shore, the wave amplitude will increase

Wind-caused waves
-Everyday waves
-Created by friction between wind and water surface
>Usually a few meters high in amplitude
-Typical period of the waves = a few seconds (short wave length, usually confined to first 100m of water)
-Near shore breaker shape

Tsunami Waves
-Created by vertical movement on the seafloor (between two rock blocks)
-Piston effect of reverse faulting
-Amplitude: in open ocean <1m, near shore 6-15m
-Time period = 10-60 minutes (generally 2-5 waves) >Stay in the high ground for a few hours before returning home
>Long wavelengths that are always interacting with the seafloor, range of 100's of km
-Tsunami wave is similar to rectangle
-Destructive power
>High speed with lots of momentum
>Has the ability to go far into the land (a few km)
>Many people die from being hit by debris caused by the tsunami

Structural Mitigation
-Towers
>Ex: Evacuation tower
-Seawalls
>Destroys the ecosystem of the coast
-Floodgates

>Activated automatically to close if a tsunami wave was projected to come

Non-Structural Mitigation
-Early warning systems
>Pacific Tsunami Warning Center (est. 1948)
>>Screens earthquakes and predicts arrival times therefore being able to issue local tsunami warnings (epicenter is underwater, there must be a large magnitude), local authorities can also take action (i.e. order ships out of the harbor, evacuate the civilian population from the coastal area)
-Tsunami monitoring instrument
-Land use planning
>Computer modeling to identify coastal zones more likely to receive large waves (this is calculated by analyzing inshore topography and bathymetry)
-Public education
>Tells people where to go if something occurs (a clearly marked route leading to higher ground)
>If the ground shakes for more than a minute there is a high probability that a tsunami will arrive and head to high ground immediately (can occur in a matter of minutes)

Tsunami-genic Earthquakes
-Large
-Epicenter is underwater
-Vertical motion between rock blocks and the seafloor (normal or reverse faulting, tsunami energy is primarily directed perpendicular to the fault)

2004 Indian Ocean Tsunami
-Most destructive tsunami in historical times
>No one was prepared; there was no warning system
-Started with a megathrust earthquake in Sumatra, Indonesia
>Related to subduction; Indian plate was subducting under the Eurasian plate
>Epicenter was offshore
>Vertical seafloor displacement of roughly 10m
-Second hit from reflected wave
-Sri Lanka was hit the hardest (Indonesia)
>Engulfed entire coast (around the whole island)

2011 Tohoku tsunami (Japan)
-There was exemplary protection, but still not enough
-Megathrust earthquake
-4th largest earthquake ever recorded

Volcano-caused Tsunami
1883 Krakatoa, Indonesia
-Volcano had been acting up so people were expecting something
>The volcano literally blew itself apart (there was nothing left once it erupted)

Landslide-caused Tsunami
1929 Grand Banks, Canada
-Most devastating loss of life earthquake in Canada
-Earthquake triggered an underwater landslide on the continental slope (submarine landslide)
-Landslide generated a tsunami
>Struck Newfoundland (3 waves)
>Burin Peninsula most affected (40 villages were affected)
-Influenced future economy (long-term impact) as much of the income came from fishing

British Columbia and Tsunami's
-At risk from 3 types
1) Basin-wide Tsunami across the pacific
2) Regional Tsunami (have a few hours)
3) Local Tsunami from earthquakes from Cascadia subduction zone (have a few minutes)

Lecture 10: Mass Movements (Landslides)

Mass movements are often associated with water
Slope Instability
-Source of energy: Gravity (vertical, always points down)
-Attraction between snow or rocks (everything that falls down) and earth in this case
-Mass movement: Collective name for a variety of processes for the downslope movement of earth materials under the direct influence of gravity
>Battle between driving forces (want to move things down, component of gravity that is parallel to the slope) and resisting movements (who want to stop the movement, counteracts the diving force [inertia and friction are the resisting force])

External conditions of slope instability
1) Adding mass high on a slope
>External role of water: rain erodes material
2) Steepening of slope
3) Removing support at the base of the slope (very unstable, "overhang")
>Removal of lateral support decreases stability "rotational slide"

Internal conditions of slope instability
1) Presence of weak material
>Material that deforms plastically under stress and looses strength
>Ex: Clay decreases the coefficient of friction (crumbly material)
-Friction: Resisting force (at least two surfaces)
>Coefficient of friction, if it is higher it means things will not move
2) Fractures in rock (crack that has had no movement)
>Orientated in the slope direction are particularly unstable
>They are everywhere at different scales
3) Internal roles of water

>Adds weight to porous material (like a sponge) then it will absorb the water and become heavier creating problems
>May dissolve the glue between mineral
>Erosion (caves) in the subsurface
-Liquefaction *
>High pore pressure = Weak binding force (Grains are literally floating in water)
>Low pore pressure = strong binding force
-Congelifraction: Change from liquid water to ice causing a rock to disintegrate
>Going from liquid water to a solid = expansion in volume

Composition of the Earth's Crust
-Silicon and oxygen account for 75% (the two most abundant materials in the earth's crust)
>When combined together they create sand
>The building block of most of the rocks that we see is SI-O tetrahedron molecule (this is where four oxygen ions surround a much smaller silicon ion); they all combine with each other, and others to create sheets, rings, chains etc.
-Silicates = most abundant mineral group
>Clay is in this group
>Clay: General term used to describe a variety of complex sheet silicates
>Structure is a stack of thin sheets
>Sheet surface is negatively charged (attracts water molecules and positively charged ions)
-Mica = cousin of clay
>It is a sheet silicate
-Positive side of water molecules is attracted by negative charges n the surface of clay sheets
-Swelling clays: Groups of clays, which tend to swell when they are exposed to water, which causes the clay to lose strength
-Sensitive clays: Located along the Ottawa River Valleys, Can change their internal structure almost instantly
>Presence of salt is a key factor
>Can go from strong and stiff to a liquid
>Flocculate structure = strong and stiff (salt (is the glue) bind the clay sheet and silt together)
>Dispersed structure = liquid, soft and weak

The Rock Cycle
-3 types of Rock
>Igneous, Sedimentary, Metamorphic
>Classic, Hard, Punk
-Although mass movements can occur with any rocks, they generally occur with sedimentary rocks
>Many of which form from precipitation
-Limestone is soluble in water (as some minerals are)
>When put into contact with acidic water

>This can cause caves to form in the subsurface (can cause mass movements)
-Heavy rain, spring melt, cycles of freezing/melting and sharp fluctuations in ground water levels = all natural causes of mass movements
-Construction-work (vibrations etc), tunneling = human causes of mass movements

Classification of Mass Movement
-Classified according to:
1) Types of movement
2) Material involved (Rock, Debris: Coarse particles ie pebbles, Earth: fine soil ie. sand)
3) Speed of movement

4 Types of Movements
1) Falls
-Rapid, free-fall mass movement
-Fragments range in size
-Usually occur in cliffs that have been weakened by fractures (Ex: Mount St. Michaels in England)
>Freezing/melting cycles can contribute to the formation of talus slopes in mountainous areas
2) Slides
-Mass movement involving motion along a failure surface
-Material remains coherent as a block as it goes down
-Failure surface is well defined
-Two types of slides, Planear surface slides and Curved Surface slides
>Classified according to the nature of their failure surface
>Planear Surface – Translational slide: Slide in which earth material move parallel to planear failure surfaces (if material is unconsolidated, debris/earth slide; if material is bedrock, rockslide) Ex: Margaret Lake, NWT
-Lateral spread which is when movement of the earth material results from liquefaction of subjacent material, this causes everything to slide down as the materials become liquefied (it is related to distinct geological conditions found in northern environments such as Alaska)
>Phenomenon in which the strength of soil is reduced by rapid or violent shaking, or loading
>Steps to a lateral spread
1) Marine clays deposited in glacial regions
>Original clay structure: flocculated due to the presence of salt in seawater (stiff and solid), once it loses its salt the binding is weakened and it can turn soft
2) Glaciers melt. Uplift of the earth's surface
>Clays can now move above water level
3) Clays are leached by fresh water from rain and snowmelt
>Have lost their salt and are above seawater (now susceptible to change into a liquid)
4) Clays instantly change to dispersed structure
>Liquefaction
>Occurs without warning (triggering factors include: earthquakes)

>Ex: 1971 St-Jean-Vianney Lateral Spread (Retrogressive lateral spread in sensitive clays), 1993 Lemieux lateral spread
-Curved Surface – Rotational slide

Lecture 11: May 24

The Rissa Landslide Video
-Quick clays exhibit considerable strength until the load becomes to heavy
>Complete drastic change of consistency by remolding, which is altered when the salt is taken from the system
>Salt increases the strength
-Each subsequent slide resulted in a liquefaction of the clay
-The remodeled clay falling into the water created little waves
-Some debris flowed into the lake, others stayed in a compression zone at the shoreline
>Debris continues to flow after the slide itself is finished
-The landslide overtook the two main roads in the area
-Soil Sampling (undisturbed) after transport to the NGI laboratory it was extruded and repaired for various geotechnical tests
>Many routine investigations were carried out (I.e. shear tests to provide strength parameters for the stability calculations)
-Blasting: Holes are drilled and dynamite is inserted (5-10m below the surface) to break apart the residing clay (caused the remaining quick clay to flow out into the new area and reform to become the base of this new area)
>After several rounds of blasting the clay in this case was removed and concentrated to a new area
>This is how traces of the slide are wiped out
-The area has now ben cultivated and used as farm fields
*IMPT Learning Points as laid out in class
-Role of salt in the process: Provides the binding between the particles to allow for a stiff and strong state (when the clay is exposed to rain water the salt washes away and the clay is then susceptible to liquefaction)
-Liquefaction is triggered by too much weight (loading), an earthquake (shaking)
-Liquefied clay behaves like a liquid
-Happens very fast, there are no warning signs
-Lateral spread in sensitive clay = name of event
>Retrogressive event: Failure started on the shore of the lake and progressed further inland
-Mini tsunami created in the lake after the water column was disturbed
-Mitigation after the event to reduce the impact of future lateral spread: Utilized dynamite after mapping where the remaining material laid in order to secure the area around Rissa

Mass Movements II
-Ex: Rock Avalanche, Hope, BC

Classification of Mass Movements cntd'

-Two main criteria: Describe what is moving down; describe the type of movement (Ex: Rock fall)
>Transational slide
>Rotational Slides: Slide in which failure occurs on an over steepened slope, along a concave (semicircle) rupture surface (multiple blocks often fail, deep-seated [deep into the Earth])
-Foot of the slope = toe of the slide
-Slides: Little deformation within the moving material

Flows
-Material going down will be mixed in a turbulent mass (it will not be recognizable)
>Involves internal deformation
-Moves as a viscous fluid
-Two main types: Slow (creep) and fast (rock, debris or earth flow)
-Creep: Gradual, slow movement that usually occurs in soils with clay
>Expands in wet conditions (perpendicular to the slope)
>Contracts in dry conditions (vertical)
-Rock, debris, earth flows: Dynamic, mixture of rock fragments, soil and water flowing downslope as a viscous fluid (usually occurs in heavy rain)
>Earth flows are generally less deeply seated than rotational slides (there is no deep failure surface)
-Gelifluction: Type of flow observed in northern regions, linked to the melting of the top layer of permafrost (active layer = top layer)

Complex Events
-Combination of falls, slides and/or flows (all of what has been described)
-Most mass movements are complex events
-When it comes at a rapid speed it can be referred to as an avalanche
>Ex: Hope rock avalanche (60's), BC event, there were seismic stations to listen for earthquakes at the time, which depicted what exactly a mass movement looks like. In this case there was a small precursor event as well as a main avalanche
>Ex: Frank Slide, AB
>Geology of Turtle Mountain
>Top is hard and resistant, base is soft made of shale and a coal seam = no good
>Anticline: Fractures in the rock parallel to the slope (Fractures orientated in the slope direction are particularly unstable) >are in the shape of an A, their alternate (s) is in the shape of a small U
>"Mountain that Moves"
>Contributing factors included: heavy snow cover, cycles of freezing and melting opening cracks in the rock (gelifaction), coal mining'
>Miners became trapped under ground, but they knew where the coal seam was and had a feel for the geology, therefore they knew where to dig out

Subsidence
-Sinking of the land surface (Development of a sinkhole)
-Causes:

>Rapid subsidence: surface collapse of underground cavities, = natural: sinkholes
>Slow subsidence: Can occur when you pump out oil and gas
-Subside: collapsing into a void space
-Sinkholes: limestone is prone to this as it has the ability to dissolve in water
Ex: Palisser limestone in Canmore, Alberta (common in Florida as Florida is made out of limestone)
>Cover-subsidence sinkhole (cave is deep with a small depression)

Mitigation
-Economic impact on Canada
>Cost to people and to society
-Lateral spreads are typical of the Ottawa River Valley and the St-Lawrence River Valley
-Railways in Canada are experts in mass movements, as they must protect their tracks that surround mountains. Their protocol is to remove (Design more stable slopes, removing unstable material locally by rock scaling), reinforce (Rotational slide, Insert rock bolts and cylinder piles, add buttress with cement to rock bolts, shotcrete [spray cement which will freeze into place and is common in tunnels]), support (specially designed buttress), contain (lock block wall = cheap and effective), and protect the hazard (catchment net which catches flying boulders, concrete shed to protect the tunnel entrance, warning system [problem: wildlife is being caught in them] so now being phased out)

-Mystery object that was presented in class: Rock Bolt

Lecture 12

The Mid-Term Exam Structure: *Scantron = need pencil and eraser
-2 hours long
-Worth 45% of total grade
-Close book
-50 true/false questions and 50 M/C questions
-There will be at least one question from each lecture (fairly evenly spread)
-Covers lecture 1-12 (all about what was done in class and in lecture notes)

Snow Avalanches
-Snowpack: Composed of several layers with different characteristics (thickness, density, hardness etc.)
>These properties can change through time (i.e. the bottom layer will become more compacted over time due to the added snow on top)
- Cohesion: Property of the particles of a material to stick together (stickiness)
>Low-cohesions snow = fresh “powder” snow
-Weak layers within the snow pack are sandwiched between the stronger layers
>Form in 3 ways: When wind is increasing during a storm (wind increases alongside the time and density, inversion is created where the weak material is at the base and the strong material is at the top), depth hoar (commonly found at the base of the snowpack), surface hoar

-Hoar: comes from vapor that goes from gas to solid, formed by the deposition of water vapor into ice (often grow on existing crystals)
>Fragile, low-density, lots of void space around them
>Always a weak layer (less dense, more transparent than adjacent layers)

The Mechanics of Snow Avalanches
-Start zone: Most volatile part of the slope where unstable snow begins to slide
>Volatile place: Where the snow accumulates
-Avalanche will then follow a track down the mountain-side (can have multiple tracks)
-Because of compaction the snow the runout zone can be as hard as cement (this is generally where the victims will be, generally death is caused by asphyxiation)
-Size range
>Avalanche size1 = Sluff: too small to bury a person (relatively harmless to people)
>size 2: Buries a person, 3: buries a car, 4: buries railway train
>Can be large enough to bury a village, no longer around (5 sizes in the scale based on the mass of snow "Logarithmic scale" as it increases by 10)
-Wet snow moves slower than the dry powder snow
>Wet snow avalanches are the most destructive however as it hits harder

Point-release and Slab Avalanches
-Depends on cohesion
-Low-cohesion snow = point release
-Cohesive snow = Slab avalanche
-Point release: Starts at a point in the mountain, as it goes down the mountain it becomes wider in area and engages more snow from the sides (inverted V shape), similarities with flow of earth materials
>Involves thin layer on the surface
-Slab Avalanches: Weak layer in the layered snowpack, when the weak layer fails (fractures around a big slab, and then propagates underneath it causing nothing to be supporting the old slab therefore making the old slab go down).
>The most dangerous avalanches (greater cohesive force, bigger)
>Similar to slides as they maintain their coherence as they slide down and have a defined surface
-Crown fracture = slab is the height of a person

Conditions Decreasing Stability
1) Low friction: Several potential failure surfaces, melt-freeze crust might develop between snowfalls
2) Presence of weak material: It cannot support the weight of overlying layers, water-saturated snowpack
3) Slope angle of the start zone >50 degrees = frequent point-release 25-50 = infrequent <25 = slab
4) Wind (Ex: during a blizzard the wind is a large factor in determining where the snow will accumulate)
5) Fractures: Gravity causes snowpack to creep downslope
>Observed in snowpack's as well as glaciers

What Triggers Avalanches?
-Weather conditions: Most avalanches occur naturally during or soon after snowstorms
-Human activities: In 90% of recreational accidents it was the victim/ group members themselves that triggered the avalanche

Avalanche Victims
-Avalanche fatalities are increasing (although in the past few years it has gone down)
>People are exploring areas that years ago would have been out of the question
>Need more avalanche safety courses
>General victim profile: male in his 20's backcountry skier etc.

Survival
-Certain equipment that one should carry
-Key to survival is speed (the group must know what to do if one team member is buried, victims can wear transceivers that can usually be found within 5-15 minutes)
-Dogs do not work in Canada but they do in Switzerland (St. Bernard)
-Let go of skis, poles, and backpack to make you lighter. Use swimming motion to stay near the surface of the snow. If you are in over your head try to obtain an air pocket in front of your face… Stay calm

Mitigation Strategies
-Avoidance (Best mitigation strategy)
>Certain areas where people are told not to stop in their cars in the roads
-Ensure awareness and responsibility
-Avalanche bulletin (informs people of forecasted conditions and risks for 3 levels of altitude, this is based on information obtained from weather stations)
-In ski resorts they use dynamite to trigger avalanches so that they do not have any unexpected avalanches (gets rid of loose snow)

Avalanches in Canada
-Most avalanches in recent years have mainly occurred in BC
-Recent devastating one occurred in Northern Quebec on Dec. 311999 in an Inuit community (celebrating the millennium in the school gym, avalanche crushed the building and the people inside)
-Effects: Injuries and fatalities, traffic delays = economic impact

1910 Roger's Pass Avalanches
-When the railway was built there was a large amount of fatalities due to the avalanches

Lecture 13: May 27

Geometric Hazards
-Divided into 3 zones: Sub-auroral zone (Ottawa is located here), Auroral zone, Polar zone

Electricity and Magnetism

-Linked to solar energy

-Faraday's law is what governs magnetism

>Magnetic field variations induce an electric in a medium (this induced current then creates its own magnetic field)

>Variations in the Earth's natural magnetic field induces electrical ("telluric") currents that flow in the ground or on large conducting networks on the surface of the earth such as telephone lines, pipelines etc.

-Techniques that can be used:

>Magneto (magnetic field)-telluric (currents) sounding: Prospecting technique, record both at the same time and same place for a few hours a day

>Electromagnetic surveying: Prospecting technique, controlled experiment of an artificial magnetic field that includes currents in the subsurface ore bodies which generate a magnetic field that is recorded at the surface (determines conductivity in the ground surface, more precise than the previous, can be done from the ground or a helicopter or a plane [you create your own magnetic field in which you can control all of the parameters]). Allow you to estimate depth, shape and electrical conductivity f subsurface ore bodies

The Earth's Magnetic Field: Geometric Hazards

-Extreme variations of the Earth's magnetic field can have a significant effect of technological systems

-2 components: Internal (caused by liquid iron moving in earths outer core, slow variations, resembles that of a bar magnets, every few 0.1 Ma magnetic poles flip polarity) and external geomagnetic field (driven by solar activity / ionosphere & magnetosphere, disturbances affecting technological systems are caused by variations of the external geomagnetic field, this is the problematic one, last a few hours to a few days)

-Magnetic poles do not coincide exactly with geographic poles

>Every 100,000 years or so we flip the poles

-Solar Wind: stream of charged particles flowing away from the sun's corona in all directions

>Positive and negative electrical charges

>Takes 4-5 days to reach the earth

-Coronal holes: occur in a small-localized area of the suns surface, outer fringe of the sun)

>Now and then there are major events in which violent explosion het up material and shoot it in outer space (Ex: coronal holes)

>Strong gusts of solar wind can cause coronal holes (Charged particles and radiation are released from the suns corona in the vicinity of sunspots)

Solar Cycle

-Solar activity follows approximately an 11-year cycle

>Higher concentrations of sun spots = more energetic sun

>Galilei made the first sunspot observations in 1610

Magnetic Storm

-Temporary (hours-days) large-scale perturbation of the external geomagnetic field due to high solar activity
-Most common at the peak of the solar cycle and the declining phase of the solar cycle
-Earth's magnetosphere: Region around the Earth shielded from the solar wind by the internal geomagnetic field
>Extends several thousand kilometers above the Earth's surface (beyond the atmosphere)
>Solar wind compresses the magnetosphere sunward
-Interaction between the solar wind and the Earth's magnetosphere:
>1) Charged particles from the solar wind create currents in the ionosphere (100km above the Earth's surface) causes variations in the external geomagnetic field (EM induction), and induce telluric currents
>2) Charged particles from the solar wind are guided by the magnetic field lines towards the poles, which excite atoms in the upper atmosphere and emits light (aurora borealis)

Space Weather
-Changes environmental space conditions and is related to solar activity
-It can be predicted through satellite observations of the sun, knowledge of solar cycles, and obtaining geomagnetic data from international network of observatories
-ISES = International Space Environment Service

Consequences on Technological Systems
-There are many problems that can occur including the bombardment by charged particles, the disturbance in the ionsphere and the electromagnetic induction effects
1) Particle bombardment = Problems affecting satellites: Pressures from solar wind affect the satellite orbit, charged particles can interfere with circuitry, charge can build up can lead to a violent discharge
2) Ionospheric disturbances = Problems affecting the GPS: GPS signal delayed between the ground and a satellite, temporary loss of signal (Scintillation)
3) Electromagnetic induction = Extreme variations in the external geomagnetic field induce telluric currents along electrically conducting networks (telegraph [first], telephone, piplines etc.)
-Hydro Quebec 1989 9 hour blackout affected many people
>Induced telluric currents of high intensity on the La Grande network

Pipelines
-Lifespan = 20-40 years
-Cathodic protection system against corrosion allows the pipelines to maintain a certain optimal electrical potential
-During magnetic storms, telluric currents cause the potential to out of range, leaving the pipeline unprotected
-Mitigation: The Ottawa Geomagnetic Laboratory is currently developing space weather forecasts specifically designed for utility companies

Lecture 14
Plate Tectonics and Volcanoes

Composition of the Crust
-Silicon and oxygen account for 75 % of the crust
-8 elements form 98% of the crust
-Minerals are the building blocks of rocks
-Minerals: Naturally occurring inorganic solid with an orderly internal structure and individual characteristics
-Rock: Solid aggregate of one or more minerals

The Rock Cycle
-Processes by which older rocks are made into newer rocks
-Differentiation of the earth
>Inner core = solid iron (very dense)
-Crust = silicon and oxygen (less dense)
-Igneous rocks form by cooling and solidification from a molten liquid called magma
>Crystallization: Process of mineral formation in cooling magma
>Intrusive igneous rocks are slow cooling and have large crystals (cool at depth), Extrusive/volcanic igneous rocks are fast cooling, have small crystals and come into contact with the atmosphere (cool at surface)
>Classified according to their cooling environment (intrusive v. extrusive), and their mineral compositional expressed as a % of SiO2. These rocks can also be classified by their macroscopic features (color, texture, shape, size, and arrangement of mineral grains as well as the behavior of the magma)
-Sedimentary rocks
-Metamorphic rocks

INSERT PIC X2

Geochemistry
-Biochemistry: Studies structures of carbon
-Geochemistry: Studies structures of silicon and oxygen
>Building block for Si-O tetrahedron molecule (4 oxygen ions surround a much smaller silicon ion)
>Tetrahedrons then combine to form rings, chains, sheets, and 3D structures
-Silicates: Group of minerals containing silicon and oxygen combined with one or more elements

Magma
-Magma: Partially molten rock below the Earth's surface
>Referred to as lava once it reaches the surface
-Magma has 3 components:
1) "Melt": Liquid portion

2) Solids: Minerals are already crystalized from the "melt"
3) Volatiles: Gases that are dissolved in the "melt"

Viscosity
-Internal resistance of a liquid to flow
>The less viscous a fluid, the faster is flows (Ex: water = low viscosity, toothpaste = high viscosity)
-Most important property controlling magma behavior and therefore, eruptive style (Low magma viscosity = peaceful eruptions, high magma viscosity = explosive eruptions)
-3 different things control magma viscosity
1) % SiO_2: Magma with a high % of SiO_2 has more silicate chains, sheets, and 3D structures (more bonds between atoms increase viscosity)
-Basalt > Andesite > Rhyolite
2) Temperature: Atoms vibrate more vigorously at a high temperature (bounds between atoms tend to break therefore creating a decrease in viscosity)
-Basalt > Andesite > Rhyolite
3) Amount of solids in the melt
>More solids = higher viscosity
-Low viscosity magma tends to the reach the Earth's surface in a peaceful eruption
>Characteristics include: Basaltic magma (80% of magma that reaches the surface is basaltic), high temperature, low volatile content (high temperatures cause volatiles to escape easily)
-High-viscosity magma: Tends to form intrusive bodies and produces explosive eruptions when it reaches the Earth's surface
>Characteristics: Andesitic and rhyolitic magma, low temperature, high volatile content (volatiles become trapped in the magma and have to burst out to escape)

Volcanic Minerals
-Volcanism: Process by which magma rise into the crust and is extruded onto the Earth's surface and into the atmosphere
-Ejecta: Volcanic mineral extruded
-Lava: Magma that reaches the surface
-Pyroclastic: Material formed by volcanic explosion or aerial expulsion from a volcanic vent
-Volatiles: Mainly H_20, CO_2, SO_2
-High % SiO_2 = viscous lava that flows slowly and flows with a jagged upper surface (aa)
-Low % SiO_2 = fluid lava which flows quickly over large distances with a smooth upper surface (Pahoehoe: Flow wrinkles), and often exhibits columnar jointing (polygonal pattern on the flow surface)

Pyroclastic Material
-Classified according to particle size
>Ash: <2mm
>Lapilli: 2-64mm

>Scoria: >64mm (Bombs are ejected as incandescent lava fragments which were semi molten when airborne, blocks are ejected as solid fragments with angular shapes)

Plate Tectonics
-Earthquakes and volcanoes do NOT occur at random locations
-90% of volcanoes found are at the edge of plates (Ex: Pacific Ring of Fire)
-4 Tectonic environments:
1) Spreading Center Volcanoes
>Large volume of magma extruded at mid-ocean ridges (80% of magma reaching the Earth's surface)
>Formation of new oceanic crust
>Difficult to observe volcanic activity below sea level
>High temperature event = Smokers (they resemble chimneys)
>Peaceful eruptions (Magma derived directly from the asthenosphere, basaltic lava with a low SiO_2 content, a very high temperature, and a low viscosity)
>Pull apart movement of plates creates zones of low pressure (rocks melt partially, magma rises and flows easily. Ex: Volcanoes of Iceland)
2) Convergent Zone
-Subduction Zone
>Intense volcanic activity
>Volcanoes at the edge of the continents where one plate sub ducts beneath another (ocean-ocean convergence v. oceanic-continental convergence)
>10% of magma reaching the Earth's surface (Ex: Volcanoes of the Andres Mount St. Helen)
>Role of water: H_2O from subducting plate lowers the melting point of rock, partial melting is then induced in the overriding plate causing magma to rise and erupt
>Potentially explosive eruptions, low temperature, high viscosity
-Continent-Continent Collision Zone
>No volcanic activity
3) Transform Fault
>No volcanic activity
4) Hot spot
>Localized (large volume of lava in a small geographical area)
>10% of magma reaches the Earth's surface
>Only hot spot in Canada = Anahim
>Long lived (active for 100Ma)
>Chain of volcanoes: Aligned in the direction of plate motion, Age increasing with distance from hot spot (oldest likely to be extinct on the seafloor)
>Variable eruptive style
-Oceanic hot spot volcanoes
>Peaceful eruptions (magma does not mix much with thin oceanic crust)
>Low viscosity, low volatile content (Ex: Hawaiian volcanoes)
-Continental hot spot volcanoes
>Explosive eruptions
>High viscosity, low volatile content

Monteregian Hills, QC
-10 mountains aligned E-W over 200km
-Intrusive bodies (not volcanoes)
>less resistant host rock eroded away
>Formed by a Cretaceous hot spot (150 Ma ago)
>Overlying plate moving west (Youngest mountain: Mont Megnatic, Oldest: Oka)

Lecture 15: Eruptive Style and Landforms

How do volcanoes erupt?
-Internal heat
>Volcanoes are a mechanism by which Earth expels internal heat quickly
>Internal heat increases with depth (Anomalously hot zones: Hot spots and spreading centers)

From Rock to Magma
-What causes solid rock to melt?
>Decrease P (most important mechanism)
>Decompression melting
>Increase in temperature
>Increase water content
-Phase change from solid to liquid accompanied by volume expansion
>Fractures developing in overlying rocks

Volcanic Eruption
-Sudden occurrence of a violent discharge of volcanic materials
-Step by step
1) Hot, solid rock from asthenosphere rises closer to the surface
>Pressure decrease causes rocks to melt partially (Decompression melting)
2) Volume increase induces fractures
>More hot material rises, more rocks liquefy
3) Volatiles gradually come out of the melt
>Gas bubbles push magma upward
4) Magma fragments
>When bubbles > or = to 75%volume
>Powerful gas jet expels magma in the atmosphere

Eruptive Style
-There are two eruptive styles: peaceful and explosive
-Relation between tectonic environment, magma composition, and eruptive style

Eruption Type
-6 types of eruptions (a volcano can change eruption type through time)
-Relation between eruptive style, eruption type, magma composition, and volcanic landform

3 V's
-There are 3 factors that control volcanism and volcanic landforms
1) Viscosity
2) Volatiles
3) Volume of magma

Peaceful Eruptive Style
-Types: Icelandic, Hawaiian, Strombolian
-Composition: Basaltic magma and Strombolian volcanoes have Andesite magma
1) Viscosity: Low/medium magma viscosity
2) Volatiles: Low/medium volatile content
3) Volume of magma: Small to large volume

Icelandic-type Eruptions
-Common to spreading centers and hot spots
-Basaltic magma composition
-Low viscosity (lava flows like water)
-Low volatile content (volatiles escape easily)
-Small volume
-Lava plateau: Small area covered by nearly horizontal layers of solidified lava
>Surface rupture: Fissures (linear)
-Flood basalts: A special type of very large Icelandic eruptions from the geological past
>Largest volcanic events on Earth
>Very large volume of low-viscosity, lava with low-volatile content
>None have occurred in recent geological time
>Ex: Midcontinent rift, Lake Superior, Columbia River flood basalts

Hawaiian-type Eruptions
-Common to spreading centers and hot spots
-Basaltic magma composition
-Low viscosity
-Lava travels long distances
-Low volatile content
-Large volume (Eruptions commonly preceded by small earthquakes)
-Landform: Shield volcano
>Volcano in the shape of a flattened dome built by numerous flows of very fluid lava over a long time (broad and low)
>Surface rupture: central vent
-Minor earthquake activity caused by magma movement at shallow depth beneath the volcano
-Difference between Icelandic and Hawaiian = scale and surface rupture

Strombolian-type Eruptions
-Found in peaceful eruptive subduction zones
-Basaltic and andesitic magma
-Medium viscosity

-Medium volatile content (Lava pours out of a central vent, eruptions generate pyroclastic materials)
-Small volume (Pressure accumulates quickly in subsurface and is released in separate short duration bursts)
-Landform: Scoria cone
>Volcano in the shape of a conical hill formed by pyroclastic debris piled up next to a central vent
>Destroyed quickly by erosion
>Typically a monogenetic volcano (eruptive phase is a few year long, then the volcanic conduit becomes clogged and does not erupt again)
-Ex: El Paricutin volcano, Mexico (many animals perished but no direct loss of life, although a few died later of respiratory diseases)
>Born, developed, died 1943-1952 (initial period lasted 9 years, development of the Sapichu cone from a secondary conduit lasted 1 year, the reactivation of the principal cone lasted 1 year, and the gradual decline lasted 7 years)

Explosive Eruptive Style
-3 types: Vulcanian (Bas, And, Rhy), Plinian (And, Rhy), Caldera (And, Rhy)
-Medium/high magma viscosity, medium/high volatile content, small to very large volume

Vulcanian-type Eruptions
-Mostly found in subduction zones and hot spots
-Magma composition: Basaltic, andesitic, and rhyolitic
-Medium/high viscosity (eruptions alternate between medium/high viscous lave of varied composition and pyroclastic material)
-Medium volatile content
-Large volume
-Landform: Stratovolcano
>A large volcanic cone built of alternating layers of viscous lava and pyroclastic debris (steep-sided, symmetrical)
>Surface rupture: Central vent
>Ex: Mount Fuji, Kilimanjaro
>Width = Height (Mount Rainier)

Plinian-type Eruptions
-Volcano can change their eruption type through type
>Often precedes a more violent Plinian-type eruption
-Difference between Vulcanian and Pliian = height of eruption column (Plinian has a much higher eruption)
-Mostly found in subduction zones and hotspots
-Magma composition: Andesitic and Rhyolitic
-During the main phase:
>Medium/high viscosity

>High volatile content (volatile powered vertical eruption accompanied by pyroclastic flows, plumes up to 50km in the atmosphere with lots of pumice, landform: continued development of stratovolcano)
>Large volume
-During the final phase:
>High viscosity (lava behaves like a paste forming a plug in the volcanic conduit)
>Low volatile content (Few volatiles remain)
>Small volume
>Landform: Lava dome (Volcanic cone with a highly viscous blob of lava forming a half-ball shape over the vent)
-Ultra-plinian eruptions are colossal (Ex: Lake Toba, Tambora)

Lecture 16: Eruptive Style and Landforms 2

Caldera-type Eruptions
-Mostly found in subduction zones and hotspots
-Magma composition: Andesitic and Rhyolitic
-High viscosity
-High volatile content
-Very large volume
-Largest explosive volcanic eruptions
-Calderas and central vents are both circles features that are associated with volcanoes, however explosions create central vents and calderas are collapsed features
-Two different phenomena:
1) Volcano collapse
>Collapse of existing stratovolcano into partially emptied magma chamber (Follows a Plinian-type eruption that opened void space below the volcano, Poston-like action of collapsing volcano cause very large volume of magma to flow outward as pumce-rich sheets)
>Ex: Crater Lake, Oregon
2) Cataclysmic explosion
>Explosion blows the existing volcano apart completely (Ex: Krakatoa, Santorini: date = 1883, Subduction of Australian plate under the Eurasian plate along west coast of Indonesia, had the deadliest Tsunami prior to 2004, explosion = 100 megatons and was heard on 1/3 of the Earth's surface)
>Santorini, Greece: Akrotiri (similar to the Krakatoa volcano), 1626 BC, early warning signs of volcanic activity so most people had evacuated 1-2 years before the explosion. First Tsunami waves hit ½ hour after the explosion in Crete (Immediate impact on society: people living near the shore were killed, damage to the harbor and fleet. Longer term: Loss of collective knowledge. Present day: Reborn volcano Nea Kameni

Eruptive Sequence
-Caution: a volcano cam change type through time (Ex: Vesuvius)
-Early phase: Vulcanian-type eruption (Formation of stratovolcano)
-Major phase: Plinian-type eruption (Continued development of the stratovolcano)

-Final Phase: Plinian-type eruption (Formation of lava dome) OR Caldera-type eruption (Formation of caldera)

Volcanism in Canada

-Canada has examples of several types of volcanoes, formed in many different tectonic environments

>Volcanoes <5Ma years of age are grouped in 6 volcanic belts in BC and the Yukin

>Many volcanoes are considered dormant

-Volcanoes are formed in a zone of crustal weakness due to the stretching of the crust (this is their spreading center)

>Ex: Stikine volcanic belt, northwest BC = Mount Edziza volcanic complex, BC has one large lava plateau, one shield volcano, and four stratovolcanoes with several isolated scoria cones

-Canadian subduction zone volcano: Mount Garibaldi, BC = Contains most explosive young volcanoes and is close to populated areas

-Canadian hot spot volcano: Anaheim volcanic belt, BC = 14Ma old, west = oldest eroded volcanoes, east = youngest

>Ex: Nazko scoria cone (most recent erption was 7200 years ago)

Volcanic Hazards

-50-60 eruptions worldwide each year (2-3 in North America)

- Volcanoes becomes hazardous when people are in close proximity

-Primary hazards occur during the eruptive phase (ie. Lava flows, volcanic gas etc.)

-Pyroclastic flows "Nuee ardente": Hot gases, ash and rock fragments moving down the sides of a volcano

>Direct effects: Responsible for the largest number of fatalities related to volcanism, highly destructive due to momentum, high temperataure, and great mobility

>Indirect effects: Fires

>Ex: Pompeii

-Volcanic gases come out of the melt and increase in volume during eruption. They are the main driving force of explosive eruptions. (Most abundant, CO_2, SO_2, H_2O)

>Concentrated near the vent, distribution is controlled by prevailing wind

>Direct effects: Suffocation

-Lava flows are hazardous due to the speed at which they advance (although most move slow enough to allow the evacuation of people)

>Controlling factors: Slope steepness, lava viscosity (Basaltic = km/hr and rhyolitic/andesititc = cm/h), Rate of lava production at the vent etc.

>Direct effects: Lava flows destroy everything in their path (bury, crush, and burn objects)

-Pyroclastic fall: Ballistic projectiles = >2mm, Volcanic ash = <2mm (hard, abrasive etc.) with direct effects including destroyed vegetation, contamination of surface water, respiratory health issues, structural damage to building etc.

Secondary Hazards

-Result from the environment that has been created by the volcano (can persist long after the eruptive phase)

-Ex: Lahars (Type of mudflow that originates on the slops of volcanoes when volcanic ash and debris become saturated with water and flow rapidly downslope, they spread over long distances with a speed of 1-40m/s, they almost always occur on stratovolcanoes, and their triggers include heavy rainfall and the melting of snow/ice), atmospheric dust (indirect effect of volcanic ash), floods (lava flows can dam rivers and modify drainage relationships)
-Teritary hazards result from the destabilizing long-term effects of the volcanic eruption on society and include famine (extensive crop damage and loss of farm animals), diseases (breakdown of sewage and water systems)
>Can be felt for several years or even decades after the initial eruption

Mitigation against volcanic hazards
-Low frequency, high magnitude = difficult to mitigate
-Exact timing of next event is difficult to predict
-Volcanic explosivity index (VEI): Metric established to quantify the hazards posed by volcanoes
>3 factors affect this scale including:
1) Volume of material extruded
2) Height of eruption column
3) Duration of major eruptive blast
-Classifications:
>Active: Volcano that has erupted in historical times
>Dormant: Volcano that has not erupted in historical time but is capable of erupting in the future
>Extinct: Volcano that is not expected to erupt again
(Subjective, not all volcanologists agree)

Lecture 17: Extreme Weather 1

Climate
-Meteorological elements and phenomena averaged over along period of time for a region of the Earth's surface (elements include: humidity, temperature, precipitations etc.) (Phenomena include hail, frost, fog etc.)
-Factors that influence Earth's climate includes long-term trends in heating and cooling the Earth's surface as well as the circulation of the atmosphere and oceans

Energy balance between the Sun and the Earth
-Balance must be maintained at a certain point in time (energy entering the Earth's atmosphere must equal the energy re-emitted into space otherwise global warming/cooling will occur)
-Irradiation: incoming solar energy
-Albedo: Amount of energy reflected back into space
-Greenhouse effect: Energy radiated (105%) by Earth's surface and reflected back (85%)
-50% of energy is absorbed into the Earth's surface, 20% into the Earth's atmosphere, 30% goes into the hydrologic cycle
>+50%-105%+85%-30% = 0

-Energy absorbed by the Earth's surface is mostly stored in the oceans, which cover 70% of Earth's surface. This is because water has an exceptionally high heat capacity
-Irridation (penetrates deep through the water) is distributed unequally as equatorial regions receive more and Polar Regions have a deficit (this is because there is a stronger albedo due to white snow cover)

Energy Redistribution
-Circulation of heat from the equator to the poles in an effort to restore the thermal equilibrium via the oceans and the atmosphere
-Process for exchanging the largest quantity of heat: deep ocean currents
-Quickest process exchanging heat: Global circulation of winds
-Surface oceanic currents are also important to note

Circulation of Winds
-Major trends: hot air flows towards the poles, cold air flows towards the equator
-Influence on the Earth's rotation
>Centrifugal varies with altitude (highest at the equator, null at the poles). This causes the Earth to be slightly deformed and not be a perfect sphere
>Coriolis effect: Masses of air moving across latitudes follow curved paths
-In the Northern hemisphere the paths veer to the right with respect to their direction of movement and the air moving south creates winds flowing NE-SW, whereas air moving north creates winds flowing SW-NE
-In the Southern hemisphere the paths veer to the left with respect to the direction of movement causing the air moving south to create wind flowing NW-SE, and air moving north to create wind flowing SE-NW
-The direction of trade winds are controlled by the coriolis effect

Circulation of surface Oceanic Water
- Coupled together, circulation of deep oceanic currents (depth >500m) and winds influence the circulation of surface oceanic water (depth < 500m)

Climate and Weather
-Climate: Long-term variations (30 years – several Ma), Influences the evolution of life
-Weather: Short-term variations (A few days to a few years)
-"Climate is what you expect, weather is what you get"

Weather: Meteorology 101
-Warm and cold air
-Warm air: Expands in volume (less dense, more pressure), rises, holds more humidity, and unstable molecules that move more
-Cold air: Contracts in volume (denser, high pressure), sinks, holds less humidity, more stable molecules that move less
-Wind: Horizontal movement of air from regions of high pressure to regions of low pressure (wind flows inward to fill low P region)
-Vertical movement of air from regions of high pressure at Earth's surface to regions of low pressure high in the atmosphere

-Air must overcome gravity (rising air looses energy and becomes cooler, while sinking air gains energy and becomes warmer)

Troposhere