EESA06 – Introduction to Planet Earth
University of Toronto Scarborough, Winter 2019

Introduction to Planet Earth

Brackish - mixture of salt/freshwater - organisms hate the brackish water because they evolve to adapt a specific type of water
Subsurface - "a big sponge", below the surface (sediments, etc. have porous spaces).
Base flow - supplies water to rivers by springs that enables water to keep flowing despite no rain
Brackish base flow - still causes salinity even during summer (when no road salt)
Pangea -> Pan (All) Gea (Earth) - Pangea means all the earth
250M years ago - Pangea
1B years ago - Rodina
Future - Pangea 2
Continents are moving 3.7cm per year
Convection - hot rock (not molten, like a plastic) rises, cools once it nears the surface, then it sinks, forming spreading centers. As it goes up, it undergoes decompression melting (magma melts), and it spreads (because new molten magma intrudes into rocks).
This convection and expansion of sea level is why expansion happens.
When the oceanic crust gets too heavy, it subducts (pushed under) another level - a lot of friction happens when it **subducts** underneath either other oceanic crusts.
The older oceanic crusts are heavier - they are subducted underneath newer ones.
Basalt is formed here, dark heavy rock. It is about 2.9 grams per cubic cm.
When oceanic crust is subducted, it is re-melted. If Basalt is melted with sea water, other minerals, we get **granite** - 2.7ccm (lighter).
The destruction of oceanic crust drives the creation of **continental** crust.
This process will stop eventually because of radioactive decay of uranium in the mantle.
Edges of the plate are not coastline, they're at **spreading centers.**
Rate of plate movement depends on the **production/material of spreading centers**.
Orogenic belts - mountain belts, meaning to build relief (the reliefs on the big mountains) in Latin.
Orogenic activity resulting from plate collisions.
Orogeny - specific mountain-building events
Canadian Shield - exposed rock, granite, different topography -- really old rock. This was created by a series of orogenic events.
Megathrust earthquakes - large thrust subduction, the coastline can be jacked up 11 meters. Top rocks are older than the bottom
A lot of eastern North America (Canada) is parts of Africa left behind when Atlantic ocean opened.
Living Document - subject to change as new data comes in. A geological timescale is an example of one of these.
Uniformitarianism - To understand ancient rocks, we need to study the modern environment of rocks
Province - an area where the geology was fairly similar. Sleve province is where most diamonds are produced.
CNBBZ - an ancient fault, produces small earthquakes
Anak Crakatoa - sulphurous volcanoes collapsed and created a huge tidal wave
Continential drift and pangea -> First proposed **by Alfred Wegner** - an meteorologist in 1915. Was intriguied that you can fit continents together
In the 16th century, lots of global trade. Detailed world maps appear. **Francis Bacon** noticed that you can **fit coastlines** together (late 1500s).
"The Origin of Continents and Oceans" (Wegener) in 1915 talked about putting continents together to form Pangea.
Wegner reconstructed pangea by identifying rocks of same age and looked at their origins. They formed belts, which looked like they formed around a Pangean equator.
Fossil records for old animals that couldn't swim was more evidence for lands being connected at one time.
Ice sheets and ice caps, debris, and striations also give evidence that how they moved across Pangea.
Fixists/permanentists -> opponents of continential drift
1960s -> the ocean floor gets mapped (through stuff like Echo sounders). Subsurface layering of ocean started to be developed thorugh hydrophones and sidescans.

Interesting developments such as fracture lines and lines of volcanoes arose.
Harold Hess (navy man) -> introduced the idea of **sea floor spreading** (called Geopoetry).
Edward Bullard -> Computer reconstruction of fit of modern continents

Also measuring the magnetic properties using magnetometers - towed behind a boat. Measuring the subtle differences of magnetic properties of rocks.
Magnetic stripes started to be discovered.
Vine-Matthews-Morely hypothesis - poles are always reversing. Stromboli mountain produces lots of magma. The magma's iron particles align with magnetic north, but as it **cools, they are fixed.**
This hypothesis confirmed sea floor spreading and pole reversing.
Iceland is an island that is expanding/**torn apart** - eastwards and westwards due to **spreading centers**.
Plate Tectonics - **Tulso Wilson** (1960s) was a geophysicist
Epicenter - where the earthquake happens. Epicenters are systematically arranged in belts. (On the earth's surface)
Focus - can be kilometers underground.
Depth of the earthquake tracks the depth of the plate as it moves downwards. These occur at subduction zones. Shallow earthquakes are at midocean ridges
Passive margins - where the plates meet each other (little earthquakes)
Active margins - where plates are subducting under each other or sliding past each other (huge events)
Subduction zones are faults
Why are volcanoes sometimes in the middle of plates? Due to **plumes**, as Tuzo discovered in Hawaii. These are tubes of red-hot magma, it physically moves the volcano away from the plumes. These creates "**hotspot trails**"
Dead volcanoes are called **Guyots** which are left by a hotspot trail.
The ridges on the world map is called **transform faults**. These allow spreading centers to be sinuous.
Shallow earthquakes happen when the sinuous movement causes **plates parallel to each other to go in different direction**s.
Nowhere on the earth's surface is completely stable - always moving, uplifted, or pushed down.
Seismology -> The study of earthquakes
Fault Scarp - a cliff that is produced by a block going down and another block going up.
3 Types of Faults: There is a hanging wall block and a footwall block.

- **Compression** - plates moving together, plates are pushed together. In the case of a reverse fault, the hanging wall block goes UP.
- **Extension** - in a normal fault, where plates move away from each other, the hanging wall block goes DOWN.
- **Transform** - kind of a horizontal sort of fault.

The fault dynamics can tell us which way the plates were moving.
Richter scale - size of deflection on a seismograph (M1 to M10) [this is a rock and paper and pen]
Seismogram is the paper copy of the actual movement of pen on the paper.
Moment magnitude - based on energy released, with each scale being 32x increase in power of earthquake.
Marcelli scale - a scale that determines how much damage was done by an earthquake and where the epicenter is.
2 Major types of Seismic waves:

- **Body** waves - can go through interior of planet
- **Surface** waves - are kept to the surface of the earth (do the most dmg, but also not too important)

Primary waves and Secondary Waves go through the body of the planet
Primary waves - 4-7km/second velocity, extremely fast. They are the first to arrive at a location away from earthquake.
Secondary waves - up to 4km/second.
Last to arrive are surface waves, but show up the most on seismograms.
We can use the difference in times for the waves to estimate how far away the focus is.
The earthquakes pick out plates, but also transform faults.
P-waves can move through solid and liquids. They create P-wave shadow zones (due to refraction in core)
S-waves are more limited can only move through solids. They create S-wave shadow zones (due to inability to move through core)
Using earthquakes to map inside of planet is not simple because infrequent. We can make our own P/S waves using 'Dancing Elephants', 4-wheel drives using vibrating jacks.

Local gravity fields reflect density of underlying structures (using gravitometer on a plane). Denser is greater gravitational attraction.
Ore - rock that contains sufficient metal to be worth mining
The giant **ice sheets are pushing the continents down**. The last ice sheet was the Laurentide ice sheet.

Post-glacial Rebound - when the continent rebounds from the mantle after the ice sheet melts. Mantle material flows back under the continent.
Equilibrate -> coming back to the default state before disturbance. The rebounding can take tens of thousands of years.
Isostasy - Ups and downs of the earth's crust reflected in the flow of the mantle below continents.
Differentiated planet - layered at depth, changing (increased) densities and physical properties as we go deeper.
Existence of very weak layer called **Asthenosphere** where the **Lithosphere** moves around on.
DIVERGENT plate boundaries - Mid-ocean ridges, continental rifts
CONVERGENT plate boundaries - Oceanic crust, subduction zones, obduction zones (continential slams)
TRANSFORM plate boundaries - Plates slide past each other
Plate movement is dictated by how much magma arises.
Continental crust cannot be subducted because it is too light (compared to oceanic crust).
Continental crust amount is **always increasing**. At subduction zones oceanic crust is recycled as continental crust.
Gneiss - typical of lower continental crust.
Heat flow suggests there isn't much change from 300km and 100km. There's more complex than onion skin model due to Seismic tomography.
New model - almost lava lamp. large plumes come from d double prime layer to fuel lava plumes. Green areas are subduction zones.
Wilson Cycle - organizing principle for earth history
Igneous (of fire) at convergent margins, they are acidic (water and silica-rich) e.g. granite (continential crust)
Igneous at divergent margins, they are dry (iron-rich, silica poor), basalt (oceanic crust)
Viscosity - high viscosity silicia-rich magmas and low viscosity silicia-poor magmas
Magma contains gas - thats how we have oxygenated atmosphere, because of volcanoes.
Low viscosity magma releases gas, **high viscosity magma blows up volcanoes**.
Mantle is not fluid, its plastic (hot rock). It only becomes fluid when rises to surface and melts.
Wilson Cycle -> Embroynic, mature, dying
The **Mohorovicic discontinuity** defines base of crust, not plate
Lithosphere includes crust (cont/oceanic) and weak upper part of mantle.
When we talk about plate tectonics, we are talking about movement below **Mohorovicic**, not about crust.
When oceanic meets oceanic meets, then **the older oceanic plate subducts.**
Divergent - plate moves apart, spreading centers, continental rifts, mid-ocean ridges. Produces silica poor like basalt and gabbro
Convergent - subduction zones. Combines with seawater to produce silica rich like andesite, diorite and granite
Rock cycle - igneous is eroded by precipitation, washed into lakes/oceans as sediments. Lithification (cementification, by carbonate or silica) resulting in sedimentary rock. Pressurization creates metamorphic rocks.
Decompression melting - as hot mantle rock rises, pressure is taken off, rock starts to melt, only occurs in deep mantle rocks which are silica-poor.
Silica poor magmas flow easily, silicia rich magmas don't flow, so they explode easier.
Some magma never rises to surface, called **granitic magma**. Stiffens as it loses pressure, can never reach surface.
Igneous Rocks
Extrusive: Low viscosity, low silica. `Flood Basalts` because they flow so well.
Intrusive/**Plutonic**: Rocks that never make it to the surface, igneous magma creates dikes throughout base rock.
Apahnitic - fine grained crystals in rocks due to rapid cooling
Phaneric - larger minerals visible in rock, cooled slower.
The more basic the rock, the darker it is (less silica = less color)
Silica is probably most common mineral on the planet.
More silicia rich magmas have a lot more complex tetrahedra structures. This means it becomes stiffer and **less viscous.**
Shield volcanoes - low sloped volcanoes this means fluid and low viscosity magma. This occurs at divergent margins
Caldera - a giant crater after the volcano explodes due to inability for magma escaping.
Decompression thickening - as magma rises and they cant melt, they thicken into dikes or intrusive rocks. This happens to rocks w/water

Decompression melting - melting pt decreases as it approaches surface, melts. Happens to dry rocks.
Plume - column of hot rock (basaltic magma) that rises upwards.
When **doming** happens (plumes from the bottom) Triple junctions occur and only two will develop, the third will become a **failed rift**. Also called **Aulacogens**.
Mississippi and Niger and Amazon are all flowing along failed rifts (that couldn't develop into Oceans). Lots of sediments and enormous oil deposits.
Canada west is subduction zone earthquakes. Canada north is due to ice sheets. East of Canada is intraplate. Earthquakes that occur in middle of plates are failed rifts. Intraplate earthquakes are failed rifts in NA plate.
Horsts (highs) and Grabens (low) is where continential crust is being stretched.
Erte Ale Shield volcano - **shield** volcano, very low due to very low visciosity means it flows easily.
Pahoehoe lava - extremely fluid lava creeps over the land surface
Ropey lava - looks like coiled rope
AA lava - rough lava, crust forms on magma that gets broken
Stratovolcano - balsaltic magma comes up through continential crust, contaminated by silica. Creates multiple ash layers due to eruption.

Modules
1598 - The first modern Atlas of the earth was published by Abraham Ortelius. Speculation that SAf and SAm were once joined by fit.
1683 - First Europeans see Niagara Gorge, missionary Louis Hennepin
1842 - Niagara gorge is key to proving estimations of earth's age. Shown by Charles Lyell that it was formed by gradual recession of Niagara Falls from escarpment. Recession of 1m/year, figures about 5000-54000 years to get into current position.
Lyell also laid out the philosophy of uniformitarianism in "Principles of Geology"
1795 - James Hutton published "Theory of the Earth" on geological record. Great insights on the enormity of geologic time.
1846 - Robert Mallet proposes that earthquakes are generated by crustal movements/faults. Termed the ideas of "seismic" and "epicenter". Studied the Great Neopolitan earthquake of 1857.
1858 - Antonio Pelligrini noted that plants fossils which are unable to travel over oceans existed in Eu/Am, thus Americas and Europe and Africa must have once been connected
1862 - Kelvin estimated the age of the earth to be 100M.
1872 - HMS Challenger discovered a rise on the floor of the Atlantic, named the Mid Atlantic Ridge (16000km long chain of volcanoes). Deepest point named Challenger Deep in honor of this expedition
1895 - Mapping of the ocean floor by Sounding. "Bathymetrical Chart of the Oceans Showing the Deeps" written by John Murray.
1905 - Nuclear Decay is discovered, proposition that half-life can be used to date rocks.
1906 - Jean Bruhnes discovered that mineralized magnetite lock in place and indicate records of pole reversals
1906 - Seismology stations were created that could locate epicenters of earthquakes with ease. Can also measure intensity. Cool things discovered include liquid inside mantle and solid core at center.
1910 - Frank Taylor suggests that mountains grow due to continental movement. Incorrect, but important due to association of submarine trenches and mountain belts - these are now subduction zones.
1911 - Radiometric dating, Arthur Holmes published "The Assocation of lead with uranium in rock/minerals and its application to the measurement of geological time". Uses ur-238 and pb-206 decay series to date very old rocks.
1912 - Alfred Wegener proposes continential drift. "Origin of continents and oceans". He terms Pangea and Panthalassa (all the land/sea). Lots of evidence but still cant explain physical component.
1928 - Arthur Holmes proposes continential drift can be explained by convection currents in the mantle.
1939 - World war 2 triggers use of sonar to map sea floor. Harold Hess discovers flat-topped volcanic mountains called guyots when observing sea-floor.
1955 - Hugo Benioff discovers pacific earthquakes occur along a dipping plane - a benioff zone. These are later discovered as subduction zones
1958 - Cold War forces US to up seismic stations, creating the World-Wide Standarized Sismographic Network (WWSSN)
1959 - Maurice Ewing, Marie Tharp, Bruce Heezen start to create detailed map of the seafloor.
1961 - Sea floor spreading was coined by Robert Dietz and Harold Hess, magma erupts and plates move in two opposite directios.
1963 - Tuzo Wilson explains hotspot tracks, which helps determine why volcanoes occur away from plate boundaries. Also helps explain guyots.
1965 - Sea floor striping, discovered by Vines-Matthews-Morely. Confirms Sea floor spreading due to reversing polarities.

1965 - computational power allows simulation of fitting SAm and Africa geometrically.
1965 - Tuzo Wilson describes transform margins, allowing plates to slip past each other without removal or addition of new material (San Andreas Fault).
1965 - National Geodetic satellite programme, satellite laser ranging helps to give accurate geodetic measurements.
1966 - The Wilson Cycle describes the growth and decay of supercontinents.
1976 - Launch of LAGEOS, laser geodynamic satellite that helps measure shape of geoid and speed and direction of earth's crustal movements.
1978 - the GPS is launched by the US department of defense.
1985 - NASA uses SLR to directly observe tectonic plate motions.

Earth -> Spheroid of concentric layers with diff phys and chem properties.
We live on the lithosphere.
Earth formed from coalescence of interstellar dust and asteroids 4.6B years ago. Heavy elements collected towards center, lighter elements rose. This created layers with diff chem and mechanical properties.
Layers -> Solid, Liquid, Plastic, chemical and compositional properties
Crust is the silica rich low density rocks that form thin outer rind of earth. There is continential crust and oceanic crust, with different compositions and densities.
These two crusts make up, with the uppermost mantle, the lithosphere.
Geology -> investigating and studying rocks exposed at or near surface. Works at finding natural resources, predicting hazards, etc.
Drilling can provide insights but even deepest project (Kola superdeep borehole) only went 12.3km.
Geodesy (geodetics) is the science of location. GPS is used for location, but can also be used to track small movements of tectonic plates. Calculates using time it takes for signal to be transmitted from satellite (3) to receiver.
Geophysics is using seismic, gravitational and magnetic properties to discover more about subsurface. Examples are seismic reflection surveys. Pulses of energy are sent and reflected back to receivers, and speed of return tells image of subsurface.
Gravimetry is the measurement of strength of magnetic field. Uses gravimeter. Varies by +/-0.5% by heterogeneties below surface. It can be used to indicate dense or light regions, quantify atmospheric mass variations, tides, groundwater variations, and soil moisture variations.
Heat flow - energy lost from one medium to another. Temperature gradient with depth is geotherm and is 25C/km. Continential crust insulates the earth. Heat is also produced in c.crust by radioactive minerals releasing energy. Heat flow from deep earth to oceanic crust drives many Earth processes.
Geomagnetism studies earth's magnetic field using magnetometer to assess strength of anomalies in magnetic field, changing due to concerntrations of minerals buried deep underground. Fossilzed magnetism helps figure out location of continents in the past.
Lithosphere is broken into dozen tectonic plates that slide over plastic asthenosphere and interact at boundaries.
Stationary mantle plumes help track absolute plate motion because they leave chains of volcanic islands.
Mantle is made of ferromagnesian silicate minerals - more rich in iron and magnesium than crustal rocks. They are Ultramafic (rich in mag, iron) makes up 67% of earths mass and 84% of volume. Solid rock, but convects over long time scales.
Heat transferred from interior of earth to surface called Mantle Convection
Cold lithospheric plates descend into mantle at subduction zones, pools at core mantle boundary
This displaces hot mantle rock at D" layer which upwells in mantle plumes
Mantle plumes undergo decompression melting at surface, causing magna eruption through crust
The Core is mainly Nickle and Iron. Solid inner core and liquid outer core. 15% of vol, 33% mass.
Impossible to sample, but geologists think its similar to metallic meteorites that fall on Earth's surface, cores of other worlds.
Seismology is study of earthquakes and seismic waves. Uses Surface and Body waves. P/S waves (P faster, goes through liquid), S slower, goes through solid. Used this to determine that core is solid and there is liquid around it.
Earth's magnetic field is a geodynamo generated by convection of molten iron and nickle in fluid outer core. Grains of magnetite in lava flow align and solidify, giving insight to continents shifting over time.

Divergent boundaries - tectonic plates are pulled apart, new lithosphere being created.
Continents breaking aparts create embroynic rift basins, juvenile ocean basins, and mature ocean basins.
Embroynic Ocean basins

Continential extension happens when mantle plumes heat continential crust. It domes upwards (doming) and splits, three linear arms of a triple junction.
Each arm is a rift basic where crust subside along normal faults.
East African Rift - example of embroynic ocean basin. Center of rift basin is volcanic, margins are elevated due to underneath heating. Ol Doinyo Lengai is a volcano.
Afar Triangle - triangle depression in center of Afar triple junction (Africa, Somalia, Arabian plates).
Oceanic crust being produced at midoceanic ridges and Gulf of Arden pushing Arabian plate N.
Basaltic magma erupts in great volumes, creating shield volcanoes. Erte Ale is one of the Afar triangle ones.
Caldera - the crater of the volcano. Erte Ale has lava in the caldera.
Juvenile Ocean

Basins tend to produce basalt in the basin center, pushing continents apart. Oceanic crust sits at lower elevation compared to continential crust
Regions elevated during embroynic stage subside, waters flood into narrow basin creating seaways. red sea, gulf of arden, california
Almost entirely or partially cut off from ocean. Sediment washing off cliffs trapped and form shelves along coastline. Prone to evaporation leaving salt and minerals behind.
Mature ocean basins

Oceanic crust continues to be produced, margins of continents become passive margins where sediments from erosion of continents accumulate. Atlantic ocean.
Offset in ridge axis - transform faults where the crusts slide uneventfully, byproduct of stretching ridged crust across a spherical surface.
Iceland is an ocean made from doming of midatlantic ridge above mantle plumes. Rare example of midocean ridge above sea level. NW lineation are faults that run along mid ocean ridges.
Thingvellir - in Iceland, you can see cracks of midocean ridges. Walls are rows of basalt lava flows.
Hydrothermal circulation - seawater filters into crust through faults, heated and expelled back up to surface.

Convergent boundaries
> Tectonic plates collide at convergent plate boundaries
> Denser of two oceanic plates subducts
> Desnity is related to age
> Oceanic crust cools and thickens, metamorphosed by hydrothermal fluids increasing density
> As oceanic crust descends, triggers melting and magma production
> Forms volcanic arc in overriding plate above (ex. Mariana Trench and Arc)

Mariana Trench
> Deepest feature on planet earth
> Pacific and phillipines plates meet
> Crust of pacific plate has been travelling for 170M
> rate of subduction is so great it pulls Phillipine plate forwards, causing tension and SFS in behind the volcanic arc (back arc)
> arcuate chain of volcanoes (volcanic arc) scar the seafloor

Oceanic-continential convergence
> Oceanic crust is less buoyant than continential, so it subducts under continential
> Oceans shrink
> Crust melts and creates magma production as it descends
> Creates volcanoes in magmatic arcs Ring of Fire, Cascadia Subduction zone

Benioff zones
> Subducting slabs in ocean/ocean and ocean/continential convergence zones creates seismic energy in forms of earthquakes as they descend
> By tracking earthquake foci they can track the subducting slab.
> 700km+, rocks begin to deform plastically instead of fracturing or breaking and tend to not produce earthquakes

Pacific Ring of Fire
> Pacific ocean is being encroached as Atlantic continues to open

> Subduction creates the Ring of Fire - intense region of earthquakes and volcanic activity
> Earthquakes occur on plate margins
> Divergent and transform margins experience shallow earthquakes
> Deeper earthquakes in the direction plate is sinking -> benioff zones

Continential-continential convergence
> Both plates crumple together and weld into large mountain belts called orogenies
> Himalayas, Alps, Appalachian, Grenville Orogen

Mediterranean
Tethys ocean seperated Europe from Africa. Shrinking due to subduction. Forming Alpine orogeny,
> Terranes are smaller continential slivers are made of adesitic volcanic material, too buoyant to subduct
> Opening of red sea causes african/arabian plate to swing northwards and many close Mediterranean entirely

Matterhorn
> Matterhorn of Alps has triangular shaped peak.
> Greyish colors are African crust that has been thrusted onto Eurasian palte
> Reddish-streaking looking rocks are deformed ophiolotic rocks, slice of ocean floor obducted northwards as Italy collided with Europe

Lava flow -> magma flow is dictated by silicia content. Mid-ocean ridge basalts are low in silicia (mafic), subduction zones have wider range of silica content. Most eruptions are felsic or intermediate, making magma viscous and explosive due to gases trapped. Rock from crystallized intermediate magma is andesite, rock forms from felsic magma is rhyolite
Lateral blast > volcanic eruptions triggered by decrease in overpressure allows magma to be released explosively. Pressure wave that devastates enormous areas (1980s Mt. St. Helen)
Ash fallout > magma explodes to produce volcanic ash - tephra, harmful for respiratory damage but can break things under layer of ash, dmg vegetation, cause famine
Airborne Particulate ash > can enter airplane engiens to melt moving parts, damage windshields, etc. coming out of andesitic volcanoes
Pyroclastic flow > Nuee ardente, flow of hot ash, rock and gas. Generated by rising ash cloud collapses under its own weight downslope 40kph temperatures of 700C hugging the ground.
Lahar > mudflow found in volcanic regions where water mixes with ash that makes slurry like wet concrete. Further than pyroclastic flows. From indonesia.
Volcanic gasses > magma contains gasses like water vapor, carbon dioxide, sulfur oxide, etc. Can pose rsisks by accumulating in hollows and suffocate animals/vegetation.
Acid rain > gassesous compounds are produced by volcanoes alongside aerosols to produce hydrochloric, hydrofluoric, suphuric acids and damaging to vegetation over wide area.
Fault creep > faults move without causing major disruption, slow movement of faults is caleld fault creep because it causes damage to infrastucture. Hayward Fault in California is notorious for causing structure damage
Earthquakes > Seismic activty due to slippage along a fault, but fault scarps can be seen where land is displaced. Shaking is seismic waves intersecting the surface. Causes fire, structure damage, landslides, liquifaction, and tsunamis.
Megathrust earthquakes > Low seismicity zones are risky because they are locked and building up tectonic stress (Cascadia SZ). Stress will overcome Juan de Fuca from subducting, causing a giant earthquake of > 9.3
Aftershock > Affects areas around main earthquakes Can reach magnitudes similar to main shock but affect areas that have been weakened. 17 days onwards can happen!
Liquefaction > sediment loses strength and acts liquid than solid. Shaking grains of sediments through earthquakes causes them to flow. They can sink and cause damage - major is over 1964 Niigata earthquake, apartments fell over

Tsunami > Large waves generaetd by sudden disturbance of seafloor like submarine earthquake/landslide/volcanim eruption/fault motion. If it reaches a coastline it can flood coastal regions and water can pile onto itself

Landslide > can occur anywhere with relief, convergent margins are particularly prone to this instability. Volcanic/magmatic arcs and wedges are under stress and weakened coasted in soft sediment prone to failure. Seismicity can trigger, or heavy orogenic rainfall events by clouds hitting barrier.