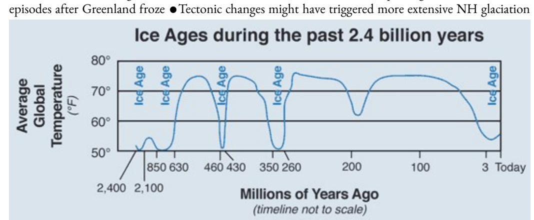
Glacial Basics *Aerosol:* a colloidal suspension of particles dispersed in air or gas. *Firn:* the intermediate state between snow and glacial ice *Accumulation:* Accumulation is when glaciers gain more mass through snowfall, windblown snow, avalanches, rime ice (freezing water vapor), refreezing meltwater. *Ablation:* Ablation is when glaciers loose mass through surface melt, surface meltwater runoff, sublimation, avalanching and windblown snow. **Glacier Movement** *acceleration:* caused by thinning of ice sheet due to ablation, increased heat form geothermal gradient, lubrication of basal sliding surface via meltwater. *Slow down:* caused by ice sheet thickens, freezes to basal bed surface, a reduction in the thermal gradient, change in elevation and slope. *Ice sheet mechanism for ice flow:* will transport ice via ice streams, where ice flows from central accumulation zones into fast flowing ice streams, which carve out deep channels-deeper, increased warmth, faster flow. Ex: Lambert Glacier, Antarctica. *Modern ice caps* found mostly in polar and subpolar regions (Greenland, Antarctica, North Pole, Himlayas) *Grounding line:* point at which ice sheet begins to float. *Instability of ice shelves:* Indicates that ice shelves are fairly unstable, and may have feedback mechanisms associated with them- ie ice collapses, the grounding line moves out (since shelves are not attached to the base of anything) and then increases the drawdown of the ice sheet- allowing further grounding line retreat. **Glacial Landforms** *Medial Moraines:* tell you two glaciers coexisted at same time and neither was higher than height of medial moraine. If they ask what direction you need drumlins!!! Order of how much underlying topography exerts influence: ice sheet, ice cap, ice field, valley glacier. You see asymmetrical profiles bc ice flow builds up sediment and material and on uphill side. Glacial retreat influences glacial sediment deposition by depositing fine grained sediment and material. It forms kames, eskers, and tors. ●Increased melting -> glacier moves faster from water lubrication. Liquid water found at bases from high pressure creating compression melting. Subglacial channels, makes, eskers, drumlins are evidence of water at base of glacier. Why are glaciers hazardous? They can dam lakes, rapidly melt, and release flood water. Subglacial lakes can generate large floods too. *Atmosphere redistributes heat* over surface of earth through thermal convection – hot air rises and then sinks to the poles. Sea level drops during ice age, to check this you can investigate changes in oxygen isotope composition (reflective of changes in global ice volume), or look for transgressive or regressive sedimentary sequences. *Why are there icebergs on coast of Newfoundland*, but not Norway(much more North)? The Norwegian current brings warm water up the coast of Europe, which warms the eastern side of the ocean basin. Newfoundland is adjacent to the source of formation for the North Atlantic Deep Water (NADW), and is cooled by air and water circulating down from the attic. Oceanic sediment core – ●Core w/ primarily fine grained muds, but every ten cm you see large 5cm clasts of a dark mafic rock. These are drop stones, eroded out under a glacier or ice sheet, which calved icebergs into the ocean, which drifted to the location of the core and melted. Epishelf: a floating ice shelf (the seaward extension of glaciers that terminate in the ocean) may block the mouth of a fjord, creating a unique type of lake called an "Epishelf Lake". Densities - New snow: 0.05 to 0.07 g/cm³ Damp new snow: 0.1 to 0.2 g/cm³ Settled snow: 0.2 to 0.3 g/cm³ Depth hoar: 0.1 to 0.3 g/cm³ Wind packed snow: 0.35 to 0.4 g/cm³ Firn: 0.4 to 0.83 g/cm³ Very wet snow and firn: 0.7 to 0.8 g/cm³ Glacier ice: 0.83 to 0.92 g/cm³ **Global Connections** *Glacial Buzzsaw hypothesis:* a hypothesis claiming erosion by warm-based glaciers is key to limit the height of mountains above certain threshold altitude.To this the hypothesis it adds that great mountain massifs are leveled towards the equilibrium line altitude (ELA), which would act as a "climatic base level"Starting from the hypothesis it has been predicted that local climate restricts the maximum height that mountain massifs can attain by effect of uplifting tectonic forces *Plucking* is glacial phenomenon that is responsible for the erosion and transportation of individual pieces of bedrock, and this results in a eroded headwall in most valley glaciers. In addition, this is a method that rocks are transported through a glacier *Thermohaline Circulation:* Is a part of the large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater fluxes. The biggest determiners are temperature and salinity. *Temperature-Salinity* As the Earth continues to warm and Arctic sea ice melts, the influx of freshwater from the melting ice is making seawater at high latitudes less salty and hence less dense. *Cooling of Europe!* Cooling in Western Europe! Currently the ocean currents carry warmth from the tropics up to the high latitudes. That warmth is lost to the atmosphere keeping the temperatures of places like England, Norway, and many other countries in northern Europe a bit milder than other places at the same latitude. If the Global Ocean Conveyor were to stop completely, the average temperature of Northern Europe would cool 5° to 10° Celsius, but even a slow down could lead to a measurable cooling. *North Atlantic Deep Water (NADW)* North Atlantic Deep Water (NADW) is a deep water mass formed in the North Atlantic Ocean. Thermohaline circulation (properly described as meridional overturning circulation) of the world's oceans involves the flow of warm surface waters from the southern hemisphere into the North Atlantic. It is actually a nutrient minima because it is formed from nutrient depleted surface layers that sunk. *Ozone Holes* Ozone holes form in the poles because they are surrounded by oceans which cause a whirlpool effect with CFC concentrated water and air. *Paleoclimate Proxy Information* ●climate proxies are preserved physical characteristics of the past that stand in for direct meteorological measurements[2] and enable scientists to reconstruct the climatic conditions over a longer fraction of the Earth's history. ●Reliable global records of climate only began in 1880s Examples of Proxies: include ice cores, tree rings, sub-fossil pollen, boreholes, corals, lake and ocean sediments, and carbonate speleothems. The character of deposition or rate of growth of the proxies' material has been influenced by the climatic conditions of the time in which they were laid down or grew. Chemical traces produced by climatic changes, such as quantities of particular isotopes, can be recovered from proxies. Some proxies, such as gas bubbles trapped in ice, enable traces of the ancient atmosphere to be recovered and measured directly to provide a history of fluctuations in the composition of the Earth's atmosphere. *Atmosphere* Past 200 yrs: Past 200 yr: CO_2 went up by 40% and Methane by 200% - 300%; Glaciers Reflect heat from the sun; increased dust and soot from grazing, farming, and burning of fossil fuels and forests, are also causing glacier retreat by ●Past 200 yr: CO_2 went up by 40% and Methane by 200% - 300%, which glaciers have the ability to combat ●Reflect heat from the sun, ●increased dust and soot from grazing, farming, and burning of fossil fuels and forests, are also causing glacier retreat (albedo) ●layers of dust and soot are darkening the color of glaciers and snowpacks, causing them to absorb more solar heat and melt more quickly, and earlier in spring. ●Albedo, or "whiteness," is a scientific term meaning reflectivity ●Cooking stoves (biomass stoves) darken snow and ice in mountainous regions. In The himalayas this is bad because the Yangtze, Yellow, Mekong, and Ganges rivers all feed from glaciers ●90% of Himalayan Glacier Melting Caused by Aerosols and Black Carbon ●Aerosol: a colloidal suspension of particles dispersed in air or gas. reducing albedo. *Ocean* If glacier melted sea level would rise by: All of Greenland (7.2m); West Antarctic Ice Sheet (3.2m). All of Antarctica (57m). ●sea level has risen by 4 to 8 inches over the past century ●rate of rise over the past 20 years has been 0.13 inches (3.2 millimeters) a year *Lithosphere* When glaciers erode the rock underneath them, they release carbon gases trapped in the lithosphere. Also, when ice sheets weigh down on the sea floor, the cause depression in the earth's lithosphere, and the edges are called fore bulges, which are massive hills that areas like America's east coast lie upon. When these sink, the depressions left rise, causing a reshuffling of the earth's lithosphere. This is called glacial isostatic adjustment. basal sliding. when the ice slides over the land with a layer of water acting as a lubricant and reducing the friction between land and ice. pressure from the weight of the ice reduces the melting point at the base of the glacier which allows the ice to melt, allowing water to be present. glaciers can move in even the coldest of climates. **Ice Cores** a core sample drilled from the accumulation of snow and ice over many years that have recrystallized and have trapped air bubbles from previous time periods, the composition of which can be used to reconstruct past climates and climate change; typically removed from an ice sheet *Warming and Cooling Periods* Oxygen primarily occurs in two isotopes, 18O and 16O ; water containing 18O is heavier, and thus condenses more readily ; water evaporates from the oceans near the equator and begins to move towards the poles, and condenses and precipitates along the way ; during cooler periods, condensation occurs even closer to the equator and the vapor that reaches the poles is more depleted in 18O ; during warmer periods, condensation occurs closer to the poles and the vapor that reaches the poles is richer in 18O. *Oxygen Isotopes* ●2 common isotopes O^{16} and O^{18} ●Water w/ 16O is lighter, water with 18O is heavier; 16 tends to evaporate easier, causing 18 accumulate in oceans and 16 to end up in ice ●During constant climatic conditions the 16O lost to evaporation returns to the oceans by rain and streams, so that the ratio of 18O to 16O (18O / 16O) is constant. ●But, during a glaciation, some of the 16O gets tied up in glacial ice and does not return to the oceans. Thus during glaciations the 18O / 16O ratio of sea water increases. ●During an interglaciation, on the other hand, the 16O that was tied up in glacial ice returns to the oceans causing a decrease in the 18O / 16O ratio of seawater. ●Thus, we expect that during glaciations the 18O / 16O ratio in seawater will be high, and during interglaciations the 18O /16O ratio in seawater will be low. *Densityof Ice for Air to be trapped:* Firn is not dense enough to prevent air from escaping; but at a density of about 830 kg/m3 it turns to ice, and the air within is sealed into bubbles that capture the composition of the atmosphere at the time the ice formed. *Info from Ice Cores* ●Accumulation rate - The thickness of the annual layers in ice cores can be used to derive a precipitation rate (after correcting for thinning by glacier flow). Past precipitation rates are an important palaeoenvironmental indicator, often correlated to climate change, and it's an essential parameter for many past climate studies or numerical glacier simulations. ●Melt Layers - Ice cores provide us with lots of information beyond bubbles of gas in the ice. For example, melt layers are related to summer temperatures. More melt layers indicate warmer summer air temperatures. Melt layers are formed when the surface snow melts, releasing water to percolate down through the snow pack. They form bubble-free ice layers, visible in the ice core ●Past air temperatures - It is possible to discern past air temperatures from ice cores. This can be related directly to concentrations of carbon dioxide, methane and other greenhouse gasses preserved in the ice. Rate of flow: Controlled by: 1. The severity of the slope 2. Basal water= wet bottom= faster flow 3. location within glacier=greater velocity in ice center *Brittle Ice* Over a depth range known as the brittle ice zone, bubbles of air are trapped in the ice under great pressure. When the core is brought to the surface, the bubbles can exert a stress that exceeds the tensile strength of the ice, resulting in cracks and spall. At greater depths, the air disappears into clathrates and the ice becomes stable again. At the WAIS Divide site, the brittle ice zone was from 520 m to 1340 m depth. *Isotopic Analysis:* The isotopic composition of the oxygen in a core can be used to model the temperature history of the ice sheet. Oxygen has three stable isotopes, 16O, 17O and 18O.[65] The ratio between 18O and 16O indicates the temperature when the snow fell.[66] Because 16O is lighter than 18O, water containing 16O is slightly more likely to turn into vapour, and water containing 18O is slightly more likely to condense from vapour into rain or snow crystals. At lower temperatures, the difference is more pronounced. The standard method of recording the 18O/16O ratio is to subtract the ratio in a standard known as standard mean ocean water (SMOW):

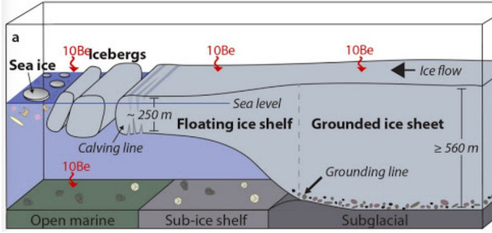
$$\delta^{18}O = \left(\frac{\left(\frac{18O}{16O}\right)sample}{\left(\frac{18O}{16O}\right)SMOW} - 1 \right) \times 1000 perthousand$$

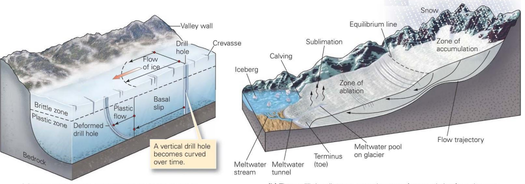
Ratios are defined as: ●2H/1H = 155.76 ppm ●3H/1H = 1.85×10^{-11} ●18O/16O = 2005.2 ppm ●17O/16O = 379.9 ppm *Radiocarbon Dating:* Radiocarbon dating can be used on the carbon in trapped CO_2. In the polar ice sheets there is about 15–20 µg of carbon in the form of CO_2 in each kilogram of ice, and there may also be carbonate particles from wind-blown dust (loess). The CO_2 can be isolated by subliming the ice in a vacuum, keeping the temperature low enough to avoid the loess giving up any carbon. The results have to be corrected for the presence of 14C produced directly in the ice by cosmic rays, and the amount of correction depends strongly on the location of the ice core. Corrections for 14C produced by nuclear testing have much less impact on the results.[43] Carbon in particulates can also be dated by separating and testing the water-insoluble organic components of dust. The very small quantities typically found require at least 300 g of ice to be used, limiting the ability of the technique to precisely assign an age to core depths **Methods of studying glaciers** ●The two main processes used to determine ablation or accumulation are probing and crevasse stratigraphy, which can give accurate measurements of snowpack thickness. *Probing:* researchers will place poles in the icepack at various points, at the beginning of the melt period or accumulation period. After a few months the researchers will return and look at the changes in levels of ice, by looking at the height of the ice along the pole. *Crevasse stratigraphy:* researchers will find crevasses, then observe the number of layers that formed. Based on the layers the researchers will be able to determine how much snow accumulated. The layers are almost like layers in a tree trunk. *Cosmogenic nuclide dating* is useful for directly dating rocks on the Earth's surface. It gives an Exposure Age: that is, how long the rock has been exposed to cosmic radiation. It is effective on timescales of several millions of years. It assumes that boulders have not been buried and then re-exposed at the Earth's surface. *Radiocarbon dating* dates the decay of Carbon-14 within organic matter. Organic matter needs to have been buried and preserved for this technique. It is effective for up to the last 40,000 years. It assumes that organic material is not contaminated with older radiocarbon (which, for example, is a common problem with organic material from marine sediment cores around Antarctica). *Amino Acid Racemisation* dates the decay and change in proteins in organisms such as shells. *Optically Stimulated Luminescence* dates the radiation accumulated in quartz or feldspar grains within sand. The radiation emanates from radioactive grains within the sediment, such as zircons. It is effective for hundreds of thousands of years, and dates how long the sediment has been buried. **Instruments** *Depth vs. Resolution* using higher frequency radio waves gives better resolution, but the radar is more strongly absorbed by ice so the pulses cannot travel as deeply into the ice; conversely using lower frequency waves results in lower resolution but the waves are not absorbed as strongly and thus penetrate more deeply. *Raymond Bumps* Ice rises situated in the ice-shelf belt around Antarctica have a spatially confined flow regime, which is decoupled from the surrounding ice shelves, and which contains local ice divides. Beneath the divides, ice stratigraphy often develops arches (Raymond Bumps) with amplitudes that record the divide's horizontal residence time as well as surface elevation changes. **Sedimentary Sequences** ●Sedimentary environments are areas where sediments are deposited; glaciers are an example of this *Supraglacial (ice marginal)* ●Readily be observed along glacial margins ●A dark, dirty-ice zone is not uncommon at a glacier's leading edge ●The supraglacial environment is a very unstable place because material deposited on top of ice is going to move when the ice melts ●Till-like mixtures of material with a wide range of particle sizes, called "diamicton" ●Reflect a complex history of deposition *Subglacial* ●Most difficult to observe. Rely on ice cores and down-hole cameras ●glaciers grind up and mix rock and soil debris in and beneath their base forming a mixture of material (rocks, sand, silt, and clay) that is called till ●Till is the most common subglacial deposit, but other deposits also occur *Proglacial* ●even more dynamic than the subglacial one ●glacial meltwater and summer rains carry debris away from the glacier or deposit it in lakes that come and go as the force of the water causes natural dams to give way and lakes to drain, sometimes catastrophically sweeping material away in the water ●Include materials sorted by water or wind, river sediment (called outwash), lake sediment, windblown sand, and windblown silt called loess **Chemistry of Ice** ●Polar and covalent bond within the molecule. Hydrogen bonds between molecules. ●Unusual properties: higher than usual melting point, density of ice relative to water (crystal structure from hydrogen bonds causing water molecules to be spaced farther apart from each other compared to the noncrystalline liquid state). ●Hexagonal structure, with four hydrogen bonds on each molecule. ●Hexagonal crystal family. ●Coordination number of Oxygen is 4 ●Another form of ice that is metastable is isometric with four 3 fold or 3 bar axes. **Milankovitch Cycles** describe the collective effects of changes in the Earth's movements on its climate over thousands of years. variations in *eccentricity*, *axial tilt*, and *precession* of the Earth's orbit resulted in cyclical variation in the solar radiation reaching the Earth, and that this *orbital forcing* strongly influenced climatic patterns on Earth. *Eccentricity:* refers to the earths orbit and its shift from being circular to more elliptical over time; *Axial Tilt (Obliquity):* Tilt of earths axis of rotation. A greater tilt means more drastic seasons; The angle varies between 22.1° and 24.5°, over a cycle of about 41,000 years. The current tilt is 23.44°. We are currently on a downward trend, meaning warmer climates. *Axial Precession:* is a gravity-induced, slow, and continuous change in the orientation of an astronomical body's rotational axis. The cycle is relative to fixed starts, with a period of 25771.5 yrs *Aspidal Precession:* changing of the line between the sun and the earth that changes. Tilt of the orbit itself. Solar Forcing: changes in these movements of the Earth, which alter the amount and location of solar radiation reaching the Earth. Perihelion: closest to the sun; Aphelion: farthest from the sun; The semi-major axis is a constant, therefore when the earth orbit becomes more eccentric, the semi-minor axis shortens. Increase in solar irradiation: at closest approach to the Sun (perihelion) compared to the irradiation at the furthest distance (aphelion) is slightly larger than four times the eccentricity. Milutin Milankovic Serbian geophysicsicts and astronomer. ●*how long:* 100,000 year long cycle. **History of Ice on Earth** *Recent History* There have been five or six major ice ages in the past 3 billion years The Late Cenozoic Ice Age began 34 million years ago, its latest phase being the Quaternary glaciation, in progress since 2.58 million years ago. *Neoproterozoic Snowball on Earth* Snowball earth around 650 mya–biological activity in the ocean surface collapsed for millions of years; Ended when volcanic outgassing raised CO_2 to 350x modern level; Ocean was virtually covered by thin sea ice + continents were covered in patchy ice due to hydrologic cycle; Sir Douglas Mawson proposed this. *Late Palezoic Ice Ages* ●Conventional view: paleozoic ice age was a long ice age for 10 million years w/ some internal waning + waving of glaciers ●Recent research: series of shorter glacial events separated by periods of warmth ●Expanded from South America to southern Africa to Australia ●The ending constitutes turnover to greenhouse state ●Sea level response (glacio eustatic) to ice age may be less extreme than once thought *Eocene Oligocene Transition* and the impact of opening oceanic seaways ●Marked by large scale extinction ●Most affected organisms were marine or aquatic in nature ●Major cooling on land and in ocean ●Causes include volcanic activity + meteorite impacts + decrease in atmospheric CO_2 ●Sea level changes mark transition– in NE Italy, sea level fell 20 m and then 50-60 m in the Oligocene Isotope Event ●Extinctions could have been caused by volcanic explosions or meteorites ●Extinction caused by climate change and major fall in sea levels *Pleistocene onset of Northern Hemisphere glaciation* ●lead to reorganization and relocation of species associations and may have enhanced species turnover ●Changes in CO_2 could have helped to lead to glaciation ●Began a unique period in Earth's history where both poles have remained ice locked ●Between 10 and 6 Ma but did not gain momentum until 3.5-3 Ma ●Northern Hemisphere glaciation occurred in episodes after Greenland froze ●Tectonic changes might have triggered more extensive NH glaciation



Glacial periods are characterized with large ice sheets and are normally known as ice ages. The periods between these are known as interglacial periods and currently we are in the Holocene interglacial period. The last glacial period was between 120,000 to 11,500 years ago and was during the Pleistocene Epoch. ●Glacial periods are times in the Earth's history where average global temperatures were approximately 6 C lower and glaciers covered much of the planets surface. The last of these periods ended approximately 10,000 years ago. There are 6 main factors that contribute to global climate and can cause glacial periods: solar variability, insulation, dust, atmospheric composition, ocean current circulation, sea ice, and atmospheric circulation. All of these are natural processes and the only one that is affected by humans is atmospheric composition. ●Interglacial periods are caused by shifts in the Earth's orbit and this causes a change in the amount of solar radiation that hits the Earth. When the amount of solar radiation increases, this is when the Earth shifts from a glacial to interglacial period. The Quaternary has had multiple shifts between glacial and inter-glacial periods and in the middle of this period, the change cycle between glacial and interglacial changed every 100,000 years. ●Antarctica is a great indicator if Earth is in a glacial or interglacial period because the amount of ice and snow on it indicates the amount of solar radiation that is hitting the Earth as well as the average temperature of the Earth. ●CO_2 is also an indicator of the changing from a glacial to interglacial period or vice versa. As the CO_2 levels increase the Earth's average temperature will increase and it will move into an interglacial period whereas if the CO_2 levels were to fall, the average temperature would fall and the Earth would change to a glacial period. **Glacial Formation** *Glacial Ice:* Glacier formation - snow in same area year long and accumulates into masses of ice; ; after the first winter this is known as neve; after two winters (one melt season), snow turns into firn; the ice increases in density over years *Ice Crystal Structure:* Commonly takes the shape of sheets or planes of oxygen atoms joined in a series of open hexagonal rings; ice can form 18 different crystalline phases; tacked in a laminar structure that occasionally deforms by gliding; When this gliding deformation occurs, the bonds between the layers break, and the hydrogen atoms involved in those bonds must become attached to different oxygen atoms *Properties of Ice:* The albedo is 0.5 to 0.9 for snow, 0.3 to 0.65 for firn, and 0.15 to 0.35 for glacier ice Albedo: lowers the melting point of the glacier due to hydrostatic pressure, where deeper parts of the glacier are colder *Moraine:* Material a glacier picks up or pushes as it moves forms moraines along the surface and sides of the glacier. As a glacier retreats, the ice literally melts away from underneath the moraines, so they leave long, narrow ridges that show where the glacier used to be. Glaciers do not always leave moraines behind, however, because sometimes the glacier's own meltwater washes the material away. *Drumlins:* long, tear-drop-shaped sedimentary formations. What caused drumlins to form is poorly understood, but scientists believe that they were created subglacially as the ice sheets moved across the landscape during the various ice ages. Theories suggest that drumlins might have been formed as glaciers scraped up sediment from the underlying ground surface, or from erosion or deposition of sediment by glacial meltwater, or some combination of these processes. Because the till, sand, and gravel that form drumlins are deposited and shaped by glacier movement, all drumlins created by a particular glacier face the same direction, running parallel to the glacier's flow. Often, hundreds to thousands of drumlins are found in one place, looking very much like whale backs when seen from above *Structure:* The region near the head of the glacier where snow is converted to firn and then ice is called the zone of accumulation. The region near the foot of the glacier is called the zone of ablation; this is where ice is lost by melting, evaporation or calving (to make icebergs). Separating the accumulation zone from the ablation zone is the equilibrium line. The equilibrium line is located at the equilibrium line altitude (ELA). **Mass-balance and Flow** *Ablation and Accumulation Zones:* Accumulation Zones are the part of the glacier that has more accumulation than ablation Ablation Zones are the part of the glacier that has more ablation than accumulation, and the calculate mass balance, just add the two figures *Equilibrium Lines* The point across a glacier where accumulation is equal to ablation; The lower the altitude of this line, the faster the glacier advances, and vice versa *Relation of flow to elevation and gradient:* Gradient - the higher the gradient, the faster the floor of the glacier; Glaciers steeper in maritime climates and temperate latitudes then in continental climates and polar latitudes. Elevation -Lower the altitude, the less likely it is to find a glacier; So, the lower altitude causes glaciers to be valley or piedmont glaciers rather then cirque, and more active. **Glacier Types and Forms** *Ice Caps* have an area less than 50,000 square km *Ice Sheets* have an area greater than this; only extant ice sheets are in Antarctica and Greenland *Alpine Glaciers* Begin high in the mountains from cirques and then valley, then piedmont Cirque Glaciers glacial ice collected in bowl shaped depression high in the mountains Hanging Glaciers A hanging glacier originates high on the wall of a glacial valley and descends only part of the way to the surface of the main glacier and abruptly stops, typically at a cliff. Piedmont Glaciers valley glaciers that spread out onto a flat lowland Tidewater Glaciers glaciers that flow to the sea Valley Glaciers a thin stream of ice that takes up a valley and originates from one or many cirques Apron Glaciers Glaciers that cling to steep mountainsides and are very avalanche prone. **Glacial Features** *Ice Stream* section of fast flow within a glacier that make up most o the way that a glacier discharges ice and sediment. *Ice Shelves* a suspended section of ice connected to a landmass that forms when a glacier flows down to the ocean's surface. *Ice Rise* an obvious dome shaped bump in the ice of a glacier formed when the seabed under a glacier has a similar bump, located with valley glaciers. *Ice Stream* a long, narrow sheet of ice that extends out over the ocean that forms when a valley glacier moves very rapidly onto the ocean. *Nunatak* an exposed, often rocky element of a ridge, mountain, or peak not covered with ice or snow within an ice field or glacier; also called glacial islands. *Crevasses* deep cracks in glacier ice caused by the stress of the ice moving over rocky terrain underneath, indicate that glacier is under different types of stress as it flows. If crevasses close up, it shows that a glacier is flowing over an area of less gradient. *Ogives* alternating bands of light and dark ice that forms ridges arcs of ice bending downstream. This shows that a glacier is moving faster in the center, creating these arched bands, or is moving over steeper terrain. *Ice Falls* glaciers flow over an steep drop or squeeze through an narrow place characterized by rapid flow and a crevassed surface. Happens when a glacier flows over a steep surface or narrows. **Hydrology** ●Glacier hydrology is the study of the flow of water through glaciers ●Glacier ice is permeable, with a network of microscopic veins and lenses of water. *Glacier Permeability* ●The rate at which water percolates through the glacier is dependent on salinity, pressure and temperature. ●The rate at which ice seeps through the ice, however, is so slow, that for practical reasons ice can generally be considered impermeable *Supraglacial (surface) water* on a glacier is formed by the ice melting during the summer. *Ablation*: Surface melt; occurs in hard packed snow (firn: the transistional state between snow and ice) *Swamp zone* If a firn becomes saturated all the way to the surface it becomes a 'swamp zone'; Swamp zone moved up glacier as the melt season progresses. ●Much of the meltwater runoff in Antarctica is restricted to coastal areas and ice shelves during the summer seasons *Englacial Hydrology* ●Moulins are vertical shafts cut by the water. ●Water cascades down these into the ice sheet. Despite the pressures within the ice sheet, moulins remain open by constant melting by the water *Subglacial Hydrology* ●Basal meltwater flowing through large subglacial networks impact glacial erosion and ice velocity. *Proglacial Drainage* ●Abundant meltwater can form large braided river plains, or sandur ●Runoff is less in Antarctica, and meltwater in the northern Antarctic Peninsula tends to be restricted to small braided streams ●These streams redeposit glacial sediments and rework glacial landforms **Laurentide Ice Sheet** ●The mass of ice in the Greenland Ice Sheet has begun to decline. From 1979 to 2006, summer melt on the ice sheet increased by 30 percent, reaching a new record in 2007 ●Antartica has not shown noticeable changes. ●Antartic peninsula has seen changes which is the part that sticks out of the continent

Recent Records of Cryospheric Change Cryosphere: portions of Earth's surface where water is in solid form including sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground (which includes permafrost). *Larsen Ice Shelf* a long ice shelf in the northwest part of the Weddell Sea, extending along the east coast of the Antarctic Peninsula from Cape Longing to Smith Peninsula ●The collapse of Larsen B has revealed a thriving chemotrophic ecosystem 800 m (half a mile) below the sea. ●31 January 2002 - March 2002 Larsen B sector partially collapsed and parts broke up. ●Larsen B was stable for 10,000 years, but due to warm currents eating away the underside of the shelf it collapsed. ●3,250-square-kilometer (1,255-square-mile) section collapsed (size of Rhode island) *Kilimanjaro* ●Kilimanjaro's shrinking northern glaciers, thought to be 10,000 years old, could disappear by 2030 ●The northern ice field, which holds most of the remaining glacial ice, lost more than 140 million cubic feet of ice in the past 13 years ●Approximately 29% of the volume and 32% of the surface area of the ice sheet has been lost since 2000. ●No real reason is known, with possible links to global warming and less snowfall *Amundsen Sea Embayment* ●is located off of west Antarctica and the ice that drains into it is roughly 3 km thick ●Recently, this sheet has significantly thinned because of shifts in wind patterns that allow warmer water to flow under the ice, and is already melting enough to raise the global sea level by 0.2 mm per year. ●Two of Antarctica's largest glaciers drain into this basin and if they were to melt, the sea level could increase by up to 3 yards. ●The weak underbelly of the West Antarctic Ice Sheet, and if it were to collapse, could destabilize the entire west antarctic ice sheet **Post-Glacial Landscape** *Erosional Features:* Cirques a bowl shaped basin formed when a glacier erodes under the bergschrund(a crevasse at or near the head of a glacier) which opens in the early summer, exposing the rock underneath to frost action and causes upper rock to avalanche and scour the floor beneath in the bowl shape, or the bowl left behind from a cirque glacier. Tor a free-standing rock outcropping that abruptly rises from the surrounding environment, formed at first by erosion and weathering of the ground surrounding it. U-Shaped Valley happen when valley glaciers advance, eroded a u-shaped depression in the land, and then recede, leaving this U-shaped valleys and mountains behind. Hanging Valley as a smaller glacier at a higher elevation joins a lower, but larger valley glacier, and they recede, the u shaped valley created by the smaller glaciers opens up onto the lower depression formed by the larger glacier. Aretes a sharp, crested ridge that separates the heads of two opposing cirques where glaciers used to reside and carved this thin ridge. Hornswhen glaciers erode three or more aretes, ending with sharp, vertical peak. Stritations/Grooves are carved into bedrock as glaciers pass over it. Rôche moutonnée occurs when a glacier claws itself up a hill, it damages the surface, leaving jagged and irregular on that side, but as it slides down, it polishes the surface, leaving the other side of the same rock smooth and even. Tarn a lake left in a bowl shaped depression by a receding cirque glacier. *Depositional Features:* Moraines are rocks or sediment deposited by a glacier, typically at its edges. End/Terminal a moraine that forms at the leading edge of a glacier marking its furthest advance, formed by debris pushed to the front of a glacier. Recessional a series of ridges formed parallel to the terminal moraine and form when a glacier temporarily stops receding. Lateral a series of parallel ridges deposited along the sides of a glacier that form when frost shatters the valley walls and causes them to collapse. Medial a ridge of a moraine that forms in the center of a valley. It forms when two glaciers meet and the debris on the edges of the adjacent valley sides join and are carried on top of the enlarged glacier. Ground an irregular blanket of sediment most often deposited by continental glaciers Kettles when a block of ice calves and is submerged into sediment, and subsequently melts, the hole it leaves behind is called a kettle. Kames a hill of sand, sediment and till that forms on top of a retreating glacier then is deposited on the land underneath as the glacier further melts. Drumlins an elongated hill shaped like a inverted spoon aligned with the ice flow that forms under the glacier bed and a left when the glacier retreats. Eskers a long ridge composed of sediment and gravel formed under a glacier when subglacial rivers in ice walled tunnels left sediment underneath then and when the retaining walls of ice melted away Erratics pieces of rocks that are foreign to their surroundings regarding their size and type. They are transported by glaciers for thousands of miles. Moulins are vertical shafts created in a glacier by waater within it. **History of Ice Ages** *Ice ages* ●An ice age is a long interval of time (millions to tens of millions of years) when global temperatures are relatively cold and large areas of the Earth are covered by continental ice sheets and alpine glaciers. Within an ice age are multiple shorter-term periods of warmer temperatures when glaciers retreat (called interglacials or interglacial cycles) and colder temperatures when glaciers advance (called glacials or glacial cycles). ●At least five major ice ages have occurred throughout Earth's history: the earliest was over 2 billion years ago, and the most recent one began approximately 3 million years ago and continues today (yes, we live in an ice age!). ●Currently, we are in a warm interglacial that began about 11,000 years ago. The last period of glaciation, which is often informally called the "Ice Age," peaked about 20,000 years ago. At that time, the world was on average probably about $10^\circ F (5^\circ C)$ colder than today, and locally as much as $40^\circ F (22^\circ C)$ colder. *What causes ice ages?* ●Many factors contribute to climate variations, including changes in ocean and atmosphere circulation patterns, varying concentrations of atmospheric carbon dioxide, and even volcanic eruptions. The following discusses key factors in (1) initiating ice ages and (2) the timing of glacial-interglacial cycles. ●One significant trigger in initiating ice ages is the changing positions of Earth's ever-moving continents, which affect ocean and atmospheric circulation patterns. When plate-tectonic movement causes continents to be arranged such that warm water flow from the equator to the poles is blocked or reduced, ice sheets may arise and set another ice age in motion. ●Today's ice age most likely began when the land bridge between North and South America (Isthmus of Panama) formed and ended the exchange of tropical water between the Atlantic and Pacific Oceans, significantly altering ocean currents. *How does ice build up?* ●Throughout the Quaternary period, high latitude winters have been cold enough to allow snow to accumulate. It is when the summers are cold, (i.e., summers that occur when the sun is at its farthest point in Earth's orbit), that the snows of previous winters do not melt completely. When this process continues for centuries, ice sheets begin to form. Finally, the shape of Earth's orbit also changes. At one extreme, the orbit is more circular, so that each season receives about the same amount of insolation. At the other extreme, the orbital ellipse is stretched longer, exaggerating the differences between seasons. The eccentricity of Earth's orbit also proceeds through a long cycle, which takes 100,000 years. Major glacial events in the Quaternary have coincided when the phases of axial tilt, precession of equinoxes and eccentricity of orbit are all lined up to give the northern hemisphere the least amount of summer insolation. *Karoo Ice Age* Major Late Paleozoic ice age caused by ocean current disruption and named after a South African basin *Glacial History of Quaternary* The Quaternary System is that lasted from the present to approximately 2.588 million years ago with the Neogene system before the Quaternary. The Quaternary System contains two series: the Holocene and the Pleistocene with the Holocene being the present. In this period, ice sheets were able to form in Greenland and Antarctica and the continents were formed to their present shape. As glaciers formed and later retreated, thousands of lakes and rivers were created all over the world. As the glaciers retreated the sea level rose and the amount of biological diversity in the oceans increased *Wisconsin* This Wisconsin glaciation left widespread impacts on the North American landscape. The Great Lakes and the Finger Lakes were carved by ice deepening old valleys. Most of the lakes in Minnesota and Wisconsin were gouged out by glaciers and later filled with glacial meltwaters. The old Teays River drainage system was radically altered and largely reshaped into the Ohio River drainage system. Other rivers were dammed and diverted to new channels, such as Niagara Falls, which formed a dramatic waterfall and gorge, when the waterflow encountered a limestone escarpment. Another similar waterfall, at the present Clark Reservation State Park near Syracuse, New York, is now dry. *History of Events:* *Glacial Buzzsaw Hypothesis* This is the theory that the maximum height of mountain ranges is controlled by the erosion by glaciers. Evidence for: mountains are higher closer to the tropics where there is less glaciation, many mountain complexes are oriented towards the ELA line. Evidence against: modern studies of erosion rates do not correlate, cirques do not totally flatten the landscape. *Indicative of glacial advance:* moraine, horn, arête, cirque, erratic (think erosional features); indicative of retreat – moraine, tor, kame Sedimentary Deposits Rhythmites - are deposits of sedimentary rock that occur with periodicity and cyclicity. Can be indicative of events occurring on annual or 9longer scales (i.e. rise and fall of sea level, sediments pulsing out to ocean, etc). *Cooling of Antarctica -* The opening of the Drake Passage and formation of the antarctic circumpolar current. 50 mya onset of glaciation around 3 mya - Closure of the Panama Isthmus, therefore increasing the intensity of North Atlantic Deep Water formation thereby cooling higher latitudes. Uplift of the Tibetan plateau (increased silicate weathering leading to CO_2 drawdown and cooling) . Deepening of the Bering Strait allowing more cold Arctic water to flow through. *Younger Dryas Event* This was an abrupt cooling that occurred in the middle of the current warming period 24-26ka. Cooling is thought to be linked to changes in ocean circulation, with temperature drops of 2-6 degrees Celsius. It is often correlated to the onset of agriculture in human civilization. *Snowball Earth:* 2.4 to 2.1 billion years ago ●The Huronian glaciation is the oldest ice age we know about. The Earth was just over 2 billion years old, and home only to unicellular life-forms The early stages of the Huronian, from 2.4 to 2.3 billion years ago, seem to have been particularly severe, with the entire planet frozen over in the first "snowball Earth". This may have been triggered by a 250-million-year lull in volcanic activity, which would have meant less carbon dioxide being pumped into the atmosphere, and a reduced greenhouse effect. *Evidence for Snowball Earth:* ●Glacial deposits found at tropical latitudes, very extensive and thick glacial deposits, negative carbon isotope excursions, banded iron formations. After the event we would expect to find cap carbonates, that would have formed as a result of rapidly changing ocean chemistry and the quick precipitation of calcium carbonate. Cyclothems = sea level periodically rises and falls. *Evidence Against Snowball Earth:* (1) Pulses of continental drift formed large, tropical plateaus, supporting glaciation; (2) Earth's axial tilt was naturally very high during the Proterozoic, supporting mid-latitude and tropical glaciation (for more information, see the Zipper rift hypothesis, high-obliquity hypothesis, and polar wander) *Zipper Rift Hypothesis* The "Zipper rift" hypothesis proposes two pulses of continental "unzipping"—first, the breakup of the supercontinent Rodinia, forming the proto-Pacific Ocean; then the splitting of the continent Baltica from Laurentia, forming the proto-Atlantic—coincided with the glaciated periods. *Deep Freeze:* 850 to 630 million years ago ●During the 200 million years of the Cryogenian period, the Earth was plunged into some of the deepest cold it has ever experienced – and the emergence of complex life may have caused it. ●One theory is that the glaciation was triggered by the evolution of large cells, and possibly also multicellular organisms, that sank to the seabed after dying. This would have sucked CO_2 out of the atmosphere, weakening the greenhouse effect and thus lowering global temperatures ●There seem to have been two distinct Cryogenian ice ages: the so-called Sturtian glaciation between 750 and 700 million years ago, followed by the Varanger (or Marinoan) glaciation, 660 to 635 million years ago. There's some evidence that Earth became a snowball at times during the big freezes, but researchers are still trying to work out exactly what happened. *Mass Extinction:* 460 to 430 million years ago ●Straddling the late Ordovician period and the early Silurian period, the Andean-Saharan ice age was marked by a mass extinction, the second most severe in Earth's history. ●The die-off was surpassed only by the gargantuan Permian extinction 250 million years ago. But as the ecosystem recovered after the freeze, it expanded, with land plants becoming common over the course of the Silurian period. And those plants may have caused the next great ice age. *Plants Invade the Land:* 360 to 260 million years ago: ●Like the Cryogenian glaciation, the Karoo ice age featured two peaks in ice cover that may well have been distinct ice ages. They took place in the Mississipian period, 359 to 318 million years ago, and again in the Pennsylvanian 318 to 299 million years ago. ●These ice ages may have been the result of the expansion of land plants that followed the Cryogenian. As plants spread over the planet, they absorbed CO_2 from the atmosphere and released oxygen. As a result CO_2 levels fell and the greenhouse effect weakened, triggering an ice age. ●There is some evidence that the ice came and went in regular cycles, driven by changes in Earth's orbit. If true, this would mean that the Karoo ice age operated in much the same way as the current one *Antartica Freezes Over:* 14 million years ago ●Antarctica wasn't always frozen. It wasn't until around 34 million years ago that the first small glaciers formed on the tops of Antarctica's mountains. And it was 20 million years later, when world-wide temperatures dropped by $8^\circ C$, that the glaciers' ice froze onto the rock, and the southern ice sheet was born. ●This temperature drop was triggered by the rise of the Himalayas. As they grew higher they were exposed to increased weathering, which sucked CO_2 out of the atmosphere and reduced the greenhouse effect. ●The northern hemisphere remained relatively ice-free for longer, with Greenland and the Arctic becoming heavily glaciated only around 3.2 million years ago. *Our Ice Age:* ●First, the chilly "Older Dryas" of 14,700 to 13,400 years ago transformed most of Europe from forest to tundra, like modern-day Siberia. After a brief respite, the Younger Dryas, between 12,800 to 11,500 years ago, froze Europe solid within a matter of months – probably as a result of meltwater from retreating glaciers shutting down the Atlantic Ocean's "conveyor-belt" current, although a cometary impact has also been blamed. ●Twelve thousand years ago, the great ice sheets retreated at the beginning of the latest interglacial – the Flandrian – allowing humans to return to northern latitudes. This period has been relatively warm, and the climate relatively stable, although it has been slightly colder than the last interglacial, the Eemian, and sea levels are currently at least 3 metres lower – differences that are being closely scrutinised by researchers keen to understand how our climate will develop. *Glacier Fluctuations* ●In 1930 Milutin Milankovitch proposed that variations in three parameters of the earth's orbit caused glacial fluctuations: ●1. Orbital eccentricity - the orbit of the earth around the sun is not a circle, but is elliptical and also varies. This eccentricity is a minor cause for seasons. ●2. Tilt variations in the axis of rotation (obliquity) - the tilt of the earth's rotational axis varies with time. A tilted axis is the primary cause of seasons. This varies between 22.1 and 24.5 in a 40,000 year cycle ●3. Precession - the earth's axis of rotation wobbles which results in minor fluctuations in the amount of solar radiation we receive. ●Milankovitch pacing seems to best explain glaciation events with periodicity of (Eccentricity) 100k, (Obliquity) 41,000, and (Axial Precession) 25,771.5 years. This pattern seems to fit the info on climate change found in oxygen isotope cores. However, there are some problems with the Milankovitch theories. ●100,000 year Problem eccentricity variations have a significantly smaller impact on solar forcing than precession or obliquity and may be expected to produce the weakest effects. The greatest observed response is at the 100k year timescale, while the theoretical forcing is smaller at this scale, in regard to the ice ages. During the last 1 million years, the strongest climate signal is the 100k year cycle. ●400,000 year Problem (aka stage 11 problem) eccentricity variations have a strong 400k year cycle. That cycle is only clearly present in climate records older than the last million years. ●Stage 5 problem refers to the timing of the penultimate interglacial that appears to have begun 10k years in advance of the solar forcing hypothesized to have caused it. *Where are glaciers found?* ●Antarctica ●Greenland: 1,784,000 ●Canada: 200,000 ●Central Asia: 109,000 ●Russia: 82,000 ●United States: 75,000 (including Alaska) ●China and Tibet: 33,000 ●South America: 25,000 ●Iceland: 11,260 ●Scandinavia: 2,909 ●Alps: 2,900 ●New Zealand: 1,159 ●Mexico: 11 ●Indonesia: 7.5 ●Africa: 10 *Famous Scientists* Louis Agassiz – He developed Continental Glaciation, and his hypothesis was that much of the continent of North America was covered by glacial ice that was 2 miles thick and which extended over much of the midwest. In 1840, Agassiz published a two-volume work entitled Études sur les glaciers. First to scientifically propose the existence of past ice ages. Milankovic – he explained the Earth's long term climate changes caused by changes in the position of the Earth in comparison to the Sun, now known as Milankovitch Cycles. This explained the ice ages occurring in the geological past of the Earth, as well as the climate changes on the Earth which can be expected in the future. Jens Esmark – extension of past glaciations James David Forbes – concluded that glaciers were viscous Louis Lilboutry - Formation of penitentes, surveyed Andean glaciers Mark Meier - Expert on sea level rise due to melting glaciers; Director of the Institute of Arctic and Alpine Research (INSTAAR) from 1985 to 1994. Louis Rendu - Theorized on glacier motion Valter Schytt - Studied Storglaciären in northern Sweden Wilhelm Sievers – documented south American ice ages John Tyndall - studied glacier motion Ignaz Venetz – suggested the existence of past ice ages *Current Glacier Records:* *Top Five Longest Non-Polar* Fedchenko Glacier in Tajikistan at 77 km Siachen Glacier, in the Karakorum range, border between India and Pakistan - 76 km Biafo Glacier in Pakistan also by the border - 67 km Bruggen Glacier in Chile - 66 km Baltoro Glacier in Pakistan at the border - 63 km. *Longest per continent:* Lambert Glacier(Biggest in the world) in Antarctica(320 mi long, 40 mi wide) Heard Island Glacier in Australia(which cover 67 percent of heard island proper) Siachen Glacier in Asia with 3 trillion cubic tons of ice Kilimanjaro's glaciers in Africa(which are retreating alarmingly) Vatnojokull Glacier of Europe (Iceland –> covers 8 percent) Perito Moreno Glacier in S.A. which is thriving despite trend of retreat in the globe Hubbard Glacier in N.A. (largest tidewater glacier my far). *Fastest Surge:* The Kutiah Glacier in Pakistan has the record for the fastest glacier surge. In 1953, it moved more than 12km in three months. *Largest Glacier:* The largest glacier in the world is the Lambert-Fisher Glacier in Antarctica. At 400 kilometers (250 miles) long, and up to 100 kilometers (60 miles) wide, this ice stream alone drains about 8% of the Antarctic Ice Sheet. LGM During the maximum point of the last ice age, glaciers covered about 32% of the total land area. ●The word "glacier" comes from the French language and the name is derived from the Latin word glacies meaning "ice". Death: In 1985, a volcano in Colombia that was covered in glaciers erupted, instantly melting the glaciers. Two hours later, a 100 ft deep flood of rock and water traveling 39 feet per second leveled an entire nearby village, killing 20,000 out of its 29,000 residents Greenland rising: Greenland is rising 1 inch per year as glaciers melt, alleviating the land of its weight. Europe Glaciers found in the Alps, Caucasus and the Scandinavian Mountains and Iceland. Most of Europe's large glaciers are in Norway, with the exception of the biggest, which is in Iceland, called the Vatnojokull Glacier. N.A. Glaciers Glaciers are in 9 of America's states, in Mexico and of course in Canada. Southernmost in the states is the Lilliput in California. Glaciers in Mexico are in the Pico de Orizaba (Citlaltépetl), Popocatépetl and Iztaccíhuatl, the three tallest mountains in the country. S.A. Glaciers S.A. glacier exclusively on the Andes. Apart from this there is a wide range of latitudes on which glaciers develop from 5000 m in the Altiplano mountains and volcanoes to reaching sea level as San Rafael Lagoon (45° S) and southwards. South America hosts two large ice fields, the Northern and Southern Patagonian Ice Fields. Oceania Glaciers No glaciers remain on the Australia mainland or Tasmania.Heard Island glaciers are located in the territory of Heard Island and McDonald Islands. New Guinea has the Puncak Jaya glacier. New Zealand contains many glaciers, located near the Main Divide of the Southern Alps in the South Island. They are classed as mid-latitude mountain glaciers. There are eighteen small glaciers in the North Island on Mount Ruapehu. Africa Glaciers Only all-season glaciers exsist on Kilimanjaro, Mount Kenya, and the Rwenzori, but seasonally occur in the Drakensberg Range of South Africa, the Stormberg Mountains, and the Atlas Mountains in Morocco. Antartican Glaciers Has many outlet glaciers, valley glaciers, cirque glaciers, tidewater glaciers and ice streams e.g. Pine Island Glacier. *Quick Facts:* Fresh Water has 69 percent of the world's supply in glaciers Number of glaciers in Alaska is over 100,000 Glacier and ice sheet all melted = a sea level rise of over 300 feet Speed of glaciers is as high as moving 150 feet per day A single glacier ice crystal can grow to the size of a baseball ●Glaciers most often occur at high latitudes and elevations ●Glacier ice is blue because when the snow transitions to firn and glacier ice, ●the air bubbles are squeezed out and the natural color shows ●Glacier ice is formed by the snow not melting and slowly compressing over the years ●The equilibrium line is also called the firn limit ●The order of glacial ice formation is as follows - Snow > granular ice > firn ice > glacial ice *Radom Answers* ●Glacial movement by internal flow is not very fast. ●Ice in the upper central part of a valley glacier moves faster than ice at the sides. ●Strain rate for ice creep is not usually uniform. ●Snow from the previous season can recrystallize and form firn ice. ●The superimposed ice zone is usually near the snow line. ●If glacial ice starts to internally deform, plastic flow will start to dominate. ●The peaks of a nunatak are usually free of glacial ice. ●About half of all insolation received by the upper atmosphere is absorbed by land and oceans, while the remaining half is either reflected or absorbed by the lower atmosphere. ●If all the sea ice in the Arctic Ocean were to melt, the average sea level will not change. ●Increased orbital eccentricity will increase seasonal contrast. ●The Last Glacial Maximum lasted from around 25,000-15,000 years ago. ●Meltwater from the Laurentide Ice Sheet formed the massive Lake Agassiz. ●Rapid, quasi-periodic climatic fluctuations occurring about 25 times during the last glacial period = Dansgaard-Oeschger events. ●Two general methods by which glacier can flow = Basal Sliding and Internal Flow. *Formation of Pangea* The forming of supercontinents and their breaking up appears to have been cyclical through Earth's history. There may have been several others before Pangaea. The fourth-last supercontinent, called Columbia or Nuna, appears to have assembled in the period 2.0–1.8 Ga.[15][16] Columbia/Nuna broke up and the next supercontinent, Rodinia, formed from the accretion and assembly of its fragments. Rodinia lasted from about 1.1 billion years ago (Ga) until about 750 million years ago, but its exact configuration and geodynamic history are not nearly as well understood as those of the later supercontinents, Pannotia and Pangaea. When Rodinia broke up, it split into three pieces: the supercontinent of Proto-Laurasia, the supercontinent of Proto-Gondwana, and the smaller Congo craton. Proto-Laurasia and Proto-Gondwana were separated by the Proto-Tethys Ocean. Next Proto-Laurasia itself split apart to form the continents of Laurentia, Siberia and Baltica. Baltica moved to the east of Laurentia, and Siberia moved northeast of Laurentia. The splitting also created two new oceans, the Iapetus Ocean and Paleoasian Ocean. Most of the above masses coalesced again to form the relatively short-lived supercontinent of Pannotia. This supercontinent included large amounts of land near the poles and, near the equator, only a relatively small strip connecting the polar masses. Pannotia lasted until 540 Ma, near the beginning of the Cambrian period and then broke up, giving rise to the continents of Laurentia, Baltica, and the southern supercontinent of Gondwana. In the Cambrian period, the continent of Laurentia, which would later become North America, sat on the equator, with three bordering oceans: the Panthalassic Ocean to the north and west, the Iapetus Ocean to the south and the Khanty Ocean to the east. In the Earliest Ordovician, around 480 Ma, the microcontinent of Avalonia – a landmass incorporating fragments of what would become eastern Newfoundland, the southern British Isles, and parts of Belgium, northern France, Nova Scotia, New England, South Iberia and northwest Africa – broke free from Gondwana and began its journey to Laurentia.[17] Baltica, Laurentia, and Avalonia all came together by the end of the Ordovician to form a minor supercontinent called Euramerica or Laurussia, closing the Iapetus Ocean. The collision also resulted in the formation of the northern Appalachians. Siberia sat near Euramerica, with the Khanty Ocean between the two continents. While all this was happening, Gondwana drifted slowly towards the South Pole. This was the first step of the formation of Pangaea.[18] The second step in the formation of Pangaea was the collision of Gondwana with Euramerica. By the Silurian, 440 Ma, Baltica had already collided with Laurentia, forming Euramerica. Avalonia had not yet collided with Laurentia, but as Avalonia inched towards Laurentia, the seaway between them, a remnant of the Iapetus Ocean, was slowly shrinking. Meanwhile, southern Europe broke off from Gondwana and began to move towards Euramerica across the newly formed Rheic Ocean. It collided with southern Baltica in the Devonian, though this microcontinent was an underwater plate. The Iapetus Ocean's sister ocean, the Khanty Ocean, shrank as an island arc from Siberia collided with eastern Baltica (now part of Euramerica). Behind this island arc was a new ocean, the Ural Ocean. By the late Silurian, North and South China split from Gondwana and started to head northward, shrinking the Proto-Tethys Ocean in their path and opening the new Paleo-Tethys Ocean to their south. In the Devonian Period, Gondwana itself headed towards Euramerica, causing the Rheic Ocean to shrink. In the Early Carboniferous, northwest Africa had touched the southeastern coast of Euramerica, creating the southern portion of the Appalachian Mountains, the Meseta Mountains and the Mauritanide Mountains. South America moved northward to southern Euramerica, while the eastern portion of Gondwana (India, Antarctica and Australia) headed toward the South Pole from the equator. North and South China were on independent continents. The Kazakhstania microcontinent had collided with Siberia. (Siberia had been a separate continent for millions of years since the deformation of the supercontinent Pannotia in the Middle Carboniferous.) Western Kazakhstania collided with Baltica in the Late Carboniferous, closing the Ural Ocean between them and the western Proto-Tethys in them (Uralian orogeny), causing the formation of not only the Ural Mountains but also the supercontinent of Laurasia. This was the last step of the formation of Pangaea. Meanwhile, South America had collided with southern Laurentia, closing the Rheic Ocean and forming the southernmost part of the Appalachians and Ouachita Mountains. By this time, Gondwana was positioned near the South Pole and glaciers were forming in Antarctica, India, Australia, southern Africa and South America. The North China block collided with Siberia by the Late Carboniferous, completely closing the Proto-Tethys Ocean. By the early Permian, the Cimmerian plate split from Gondwana and headed towards Laurasia, thus closing the Paleo-Tethys Ocean, but forming a new ocean, the Tethys Ocean, in its southern end. Most of the landmasses were all in one. By the Triassic Period, Pangaea rotated a little and the Cimmerian plate was still travelling across the shrinking Paleo-Tethys, until the Middle Jurassic. The Paleo-Tethys had closed from west to east, creating the Cimmerian Orogeny. Pangaea, which looked like a C, with the new Tethys Ocean inside the C, had rifted by the Middle Jurassic, and its deformation is explained below. *History 3 major ice sheets* present in North America at various times: Cordilleran, Laurentide and Innutitian or Franklin ice sheets. Presence of ice sheet would have pushed circulation patterns south, resulting in increased precipitation in the southern portion of the US. Minnesota/Nebraska had lobate ice flow over multiple times, leaving rolling hills, drumlins, eskers. Wisconsin had multiple phases of glacial outburst floods from the Columbia Gorge and Glacial Lake Missoula, leaving rough "scabland" topography. *Lake Agassiz* – large glacial lake extending from Saskatchewan to Minnesota. The Great Lakes are a remnant of this large inland seaway. Why do plains states grow crops well? Glaciers and ice sheets leave behind till and fine nutrient-rich glacial flour. Much of the soil in the Midwest was blown in from Canada. Causes of glaciation at end of Ordovician - CO_2 drop (decrease in global temperatures), rapid sea level change (drop = more land for ice), shifts in circulation (bringing cold air further north) shifts in orbital parameters, continental configuration (allowed for growth of ice sheets) *Background* The major glacial stages of the current ice age in North America are the Illinoian, Eemian and Wisconsin glaciation. The use of the Nebraskan, Afton, Kansan, and Yarmouthian stages to subdivide the ice age in North America has been discontinued by Quaternary geologists and geomorphologists. These stages have all been merged into the Pre-Illinoian in the 1980s *Wisconsin* This Wisconsin glaciation left widespread impacts on the North American landscape. The Great Lakes and the Finger Lakes were carved by ice deepening old valleys. Most of the lakes in Minnesota and Wisconsin were gouged out by glaciers and later filled with glacial meltwaters. The old Teays River drainage system was radically altered and largely reshaped into the Ohio River drainage system. Other rivers were dammed and diverted to new channels, such as Niagara Falls, which formed a dramatic waterfall and gorge, when the waterflow encountered a limestone escarpment. Another similar waterfall, at the present Clark Reservation State Park near Syracuse, New York, is now dry. *Glacial Till in NA* The area from Long Island to Nantucket, Massachusetts was formed from glacial till, and the plethora of lakes on the Canadian Shield in northern Canada can be almost entirely attributed to the action of the ice. As the ice retreated and the rock dust dried, winds carried the material hundreds of miles, forming beds of loess many dozens of feet thick in the Missouri Valley. Post-glacial rebound continues to reshape the Great Lakes and other areas formerly under the weight of the ice sheets. *Late Glacial Climate Warming* ●Climate amelioration began to occur rapidly throughout Western Europe and the North European Plain c. 16,000-15,000 years ago. The environmental landscape became increasingly boreal, except in the far north, where conditions remained arctic. Sites of human occupation reappeared in northern France, Belgium, northwest Germany, and southern Britain between 15,500 and 14,000 years ago. Many of these sites are classified as Magdalenian, though other industries containing distinctive curved back and tanged points appeared as well. As the Fennoscandian ice sheet continued to shrink, plants and people began to repopulate the freshly deglaciated areas of southern Scandinavia. ●Between 12,000 and 10,000 years ago, the western coast of Norway and southern Sweden to latitude 65° north became occupied by sites belonging to the Fosna-Hensbacka complex. They are defined by the appearance of tanged points and other artifacts similar to those found earlier in Northwest Germany. Komsa sites, dated to about 7,000 years ago, are found along Norway's Finnmark county above 70° north and further east on the Kola Peninsula. They are defined by surface finds of tanged points, burins, scrapers, and adzes. The primary game of Magdalenian hunters appears to have been reindeer, though evidence of bird and shellfish consumption persist, as well. *Pleistocene Glaciations* ●Japan glaciation During the Pleistocene Epoch Ice Age, beginning about 2.5 million years ago, virtually all of southwestern Canada was repeatedly glaciated by ice sheets that also covered much of Alaska, northern Washington, Idaho, Montana, and the rest of northern United States. In North America, the most recent glacial event is the Wisconsin glaciation, which began about 80,000 years ago and ended around 10,000 years ago. [Source: U.S. National Park Service Website, Ice Age Floods, 2002] ●During the Great Ice Age, or Pleistocene Epoch, which began about 2 million years ago, large portions of Canada and the Northern United States were blanketed by the continental ice sheet. Much of the rich soil of the Midwest is glacial in origin, and the drainage patterns of the Ohio River and the position of the Great Lakes were influenced by the ice. The effects of the glaciers can be seen in the stony soil of some areas, the hilly land surfaces dotted with lakes, the scratched and grooved bedrock surfaces, and the long, low ridges composed of sand and gravel which formed at the front of the ice sheet. [Source: Schlee, Our Changing Continent: USGS General Interest Publication, Online, January 2001 ●Increased rainfall in the area south of the continental ice sheet formed large lakes in Utah, Nevada, and California. Remnants of these ancient lakes still exist today as the Great Salt Lake, Pyramid Lake, Winnemucca, and many others. Ancient shorelines for these old lakes can be found along the sides of mountains, as for example, near Provo, Utah. ●The tremendous size of the ice sheet further influenced paleogeography by lowering sea level about 450 feet below the present level; the water contained in the ice and snow came from the oceans. The continental shelves around our continent, as well as the other continents of the world, were above water and, as a result, some States such as Florida were much larger than they are today. The shoreline deposits and shells at the edge of the Continental Shelf, in waters to 450 feet deep, are evidence of this marked drop in sea level during the Pleistocene. ●During the Pleistocene Epoch Ice Age, beginning about 2.5 million years ago, virtually all of southwestern Canada was repeatedly glaciated by ice sheets that also covered much of Alaska, northern Washington, Idaho, Montana, and the rest of northern United States. In North America, the most recent glacial event is the Wisconsin glaciation, which began about 80,000 years ago and ended around 10,000 years ago. *Fraser Glaciation* ●Antarctic Ice Age glaciation During the Fraser (Late Wisconsin) Glaciation, the Cordilleran ice sheet advanced southward from source areas in British Columbia and terminated in the United States between the Pacific Ocean and the Continental Divide. The ice sheet extended farthest along major south-trending valleys and lowlands that traverse the international boundary; it formed several composite lobes segregated by highlands and mountain ranges. Each lobe dammed sizable lakes that drained generally southward or westward along ice margins and across divides. ●During the Fraser Glaciation the Cordilleran ice sheet occupied parts of the Fraser and Puget lowland and Strait of Juan de Fuca between about 18,000 and 13,000 B.P., after the maximum stand of nearby alpine glaciers. At its maximum extent about 14,500 to 14,000 years B.P., the ice-sheet surface sloped from about altitude 1,000 meters at the international boundary to between 0 and 300 meters at the ice terminus on the continental shelf and in the southern Puget lowland. Drainage from deglaciated alpine valleys in the Cascade Range and Olympic Mountains flowed southward along both ice margins and coalesced into meltwater streams that built broad outwash trains southward and westward to the Pacific Ocean. In the North Cascades Range, Cordilleran ice overrode high divides and inundated major drainage basins. The ice-sheet surface descended from above 2,600 meters near the international boundary to 270 meters in the Columbia River valley. ●East of the Cascade Range, the Okanogan lobe extended southward as a broad lobe that dammed the Columbia River valley to form glacial Lake Columbia. The lake discharged along the course of the Grand Coulee, whose tandem gorges developed by recession of great cataracts beneath catastrophic floods from glacial Lake Missoula. ●The Columbia River lobe dammed the Spokane valley to form a shallow glacial Lake Spokane. The Pend Oreille River sublobe, and eastern appendage of the Columbia River lobe, was less extensive than formerly inferred. The Priest River valley remained unglaciated except for a distributary of the Purcell Trench lobe that dammed the valley mouth. ●The Purcell Trench lobe dammed the 2,000-cubic-kilometer glacial Lake Missoula, which successively discharged as huge jökulhlaups that flowed to Spokane along the Rathdrum valley and from upper Pend Oreille River valley. From Spokane the great floods swept across the Channeled Scabland and down the Columbia River valley. *The West Kootenai* and East Kootenai glaciers flowed across a high-relief landscape, terminating within a general upland. The Flathead lobe was more extensive than formerly inferred. Both the Flathead lobe and nearby alpine glaciers reached near-maximum positions during high stands of Lake Missoula and thus during the maximum stand of the Purcell Trench lobe. Topographic lows trending south from southern British Columbia fed each of the major lobes of the Cordilleran ice sheet east and west of the Cascade Range, but the secondary lobation of the ice margins was determined by the configuration of local valleys. ●*As the Puget lobe* retreated northward, ice-marginal streams and proglacial lakes progressively expanded northward. Glacial Lake Russell drained southward during initial retreat; glacial Lake Bretz later drained northward. Calving into seawater, the Juan de Fuca lobe retreated rapidly and perhaps thereby caused the northwestern part of the Puget lobe to stagnate. Continued ice retreat permitted the sea to enter Puget Sound, and a glaciomarine interval ensued from 13,500 to 11,500 years B.P. Stillstands or readvances of the ice margin occurred during and near the end of the glaciomarine interval. In the northeastern Cascade Range and Waterville Plateau, deglaciation occurred by progressive downwasting and backwasting of ice whose margins frequently stagnated. Most lobes east of the Cascade Range built one or more small recessional moraines. As ice tongues retreated, glacial Lakes Columbia and Missoula fell to successively lower levels as they grew northward behind retreating ice. At length the early lakes were succeeded by glacial Lakes Brewster, Clark, and Kootenay. ●The apparent absence of the Glacier Peak layer-G tephra within the northern part of its projected fallout area along with the occurrence of several jökulhlaups from glacial Lake Missoula after the Mount St. Helens set-S airfall suggest that much of the glaciated terrain east of the Cascade Range remained glaciated until about 13,000 years ago. In the North Cascade Range, erratics transported by the ice sheet up valleys to cirque floors indicate that, as the ice sheet disappeared, alpine glaciers did not rejuvenate much below the limits of modern glaciers. Although ice lobes both east and west of the Cascade Range generally retreated from terminal positions to the international boundary during the interval 14,000 to 11,000 years B.P., the lobes were not exactly in phase with each other. Particular stillstands and retreats were influenced by local conditions such as topography or seawater that did not affect all lobes equally. *Wisconsin Glaciation* ●During the Pleistocene Epoch Ice Age, beginning about 2.5 million years ago, virtually all of southwestern Canada was repeatedly glaciated by ice sheets that also covered much of Alaska, northern Washington, Idaho, Montana, and the rest of northern United States. In North America, the most recent glacial event is the Wisconsin glaciation, which began about 80,000 years ago and ended around 10,000 years ago. [Source: U.S. National Park Service Website, Ice Age Floods, 2002 ●A mere 15,000 years ago, during the Ice Age, most of northern America lay under the grip of colossal ice sheets. The effects of the advancing and retreating glaciers can be seen in the headlands of Cape Cod, the Finger Lakes of New York, and the hills of Michigan, but nowhere is the glacier's mark upon the land more impressive than in Wisconsin. Indeed, the state has lent its name to the most recent series of glacial advances and retreats – the Wisconsin Glaciation lasting from about 100,000 to 10,000 years ago. *Antarctica* ●list 4 animals from Antarctica and a fact about each: orca: some will stay w/ their mothers their whole life humpback whale: males are slightly smaller than females southern elephant seals: sounds males make from their long noses can be heard from 7 miles away chinstrap penguins: most abundant penguin in the penguin population ●describe the geography of Antarctica including plant species examples and reasons why there is little vegetation there: 98% ice and is divided in half by the transantarctic mountains reasons are little vegetation are poor soil, lack of sunlight, cold temperatures, and lack of moisture examples of plants are lichens, moss, algae, and fungi ●why is Antarctica considered a desert?: a desert must have less than 10 inches of rainfall per year and Antarctica has 4 inches per year ●what is threatening krill in Antarctica?: they are being captured by Asian countries who consider them a delicacy ●what is threatening penguins in Antarctica?: hole in the ozone layer has lead to high exposure to UV rays which causes damages the penguin's eyes ●what is threatening oil and other materials in Antarctica?: Antarctica holds a great deal of oils and countries are attempting to overturn the Antarctic Treaty in order to get these resources ●what is threatening the ozone layer in Antarctica?: excess use of chemicals by humans is causing a hole in the ozone layers ●what is threatening the glaciers in Antarctica?: the glaciers are melting due to global warming which causes the rise of sea level ●what are 2 mountain ranges in Antarctica? what is the highest peak?: the transantarctic mountains and the Ellsworth mountains are two mountain ranges of Antarctica Vision Massif in the Ellsworth mountains is the highest peak ●why is It colder in Antarctica than the Arctic?: Antarctica has a higher elevation ocean currents move toward the Arctic which warms the Arctic ●was Antarctica connected to any land masses? what evidence suggests this?: Antarctica broke off of South of America, Africa, and Australia fossils of marsupials show interlinking connection to Australia ●*Largest Lake* Largest subglacial lake in Antarctica, named after a nearby Russian research station Lake Vostok

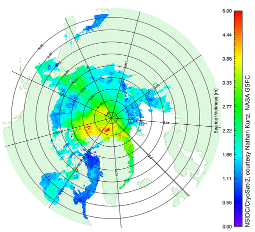


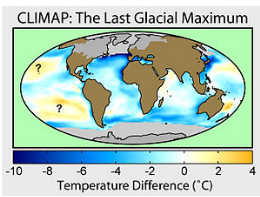


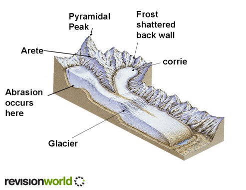
(a) Different parts of a glacier flow at different velocities, due to friction with the substrate. The top and center regions flow fastest.

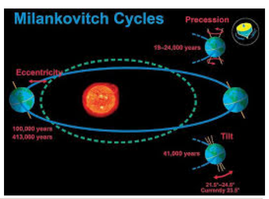
(b) The equilibrium line separates the zone of accumulation from the zone of ablation. As indicated by arrows, ice flows down in the zone of accumulation and up in the zone of ablation.

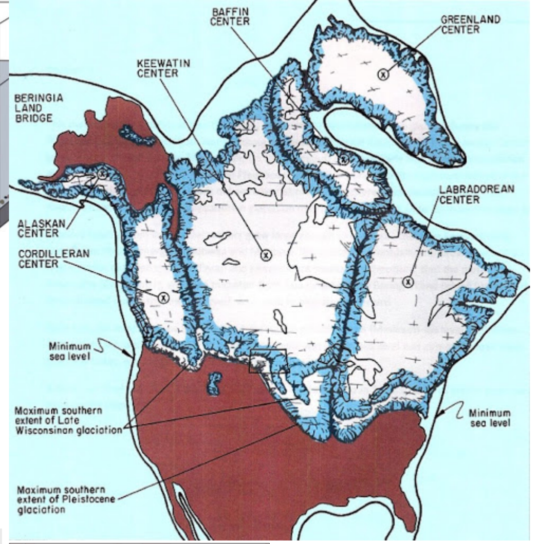
Arctic Sea Ice Thickness - March 2014

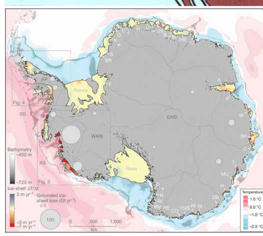


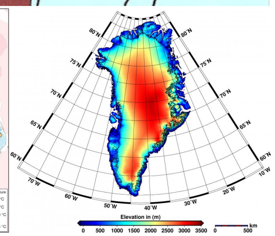


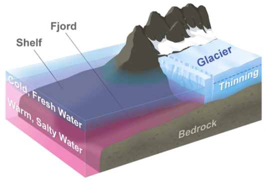


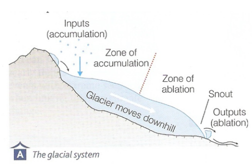


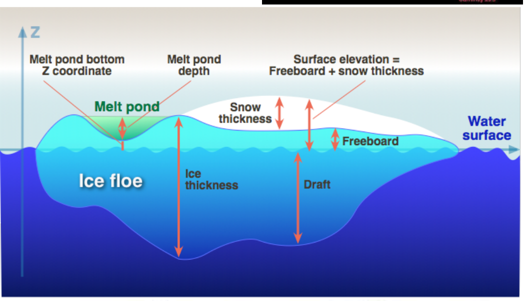


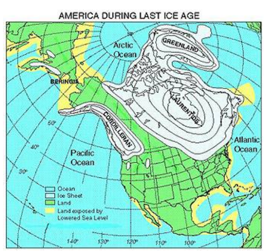


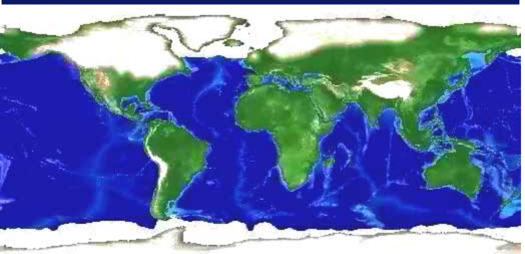


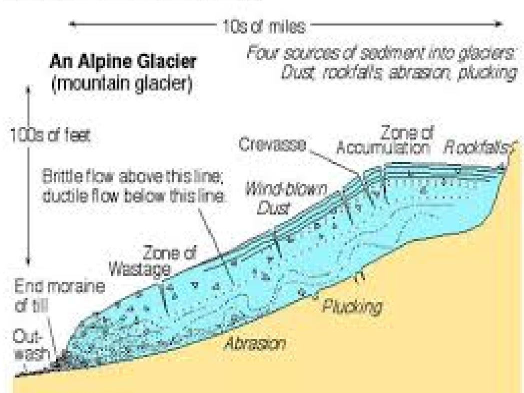


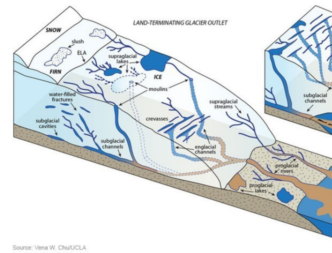


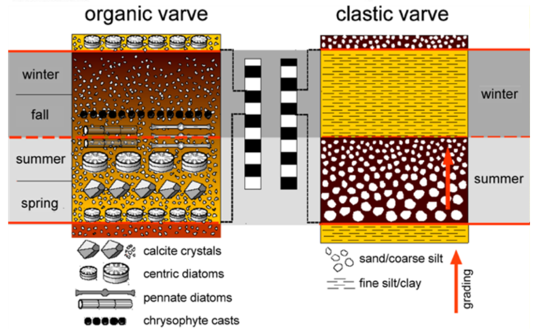


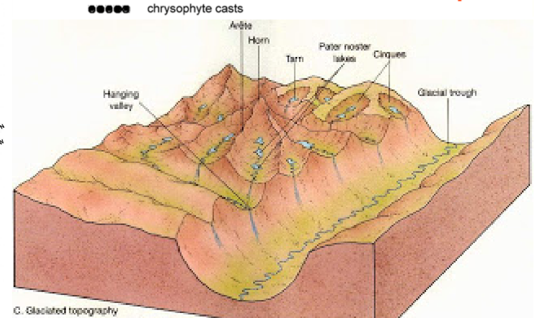


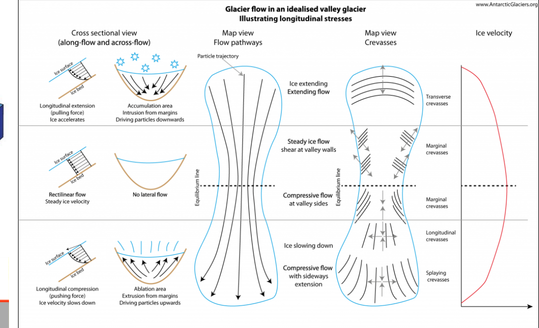


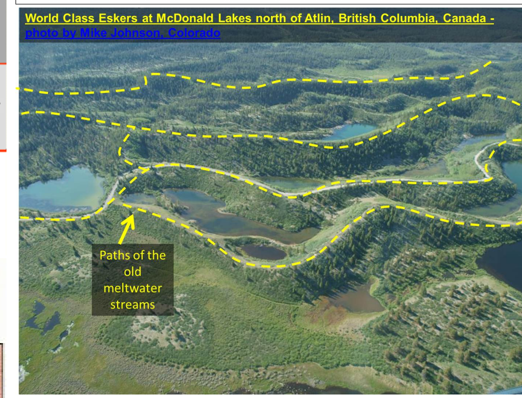


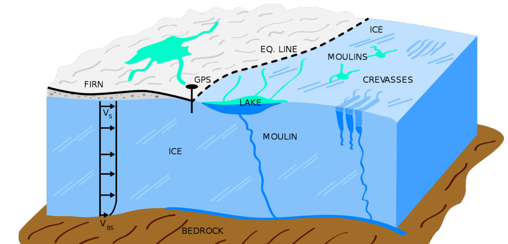


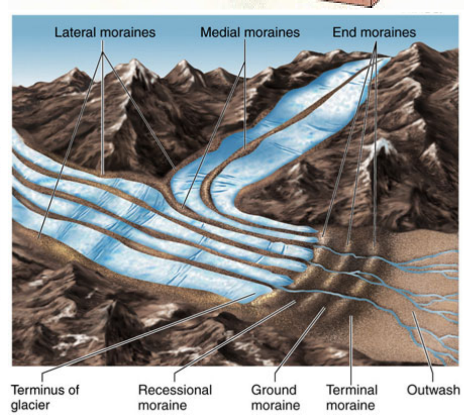


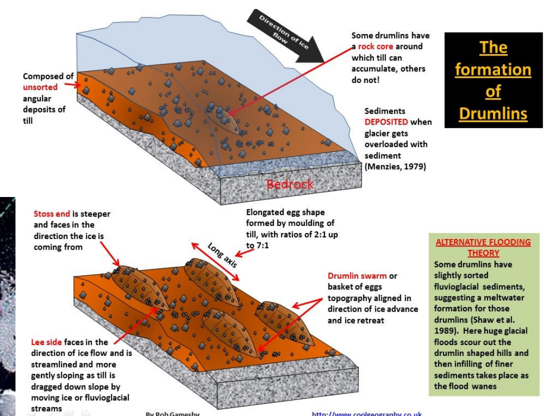


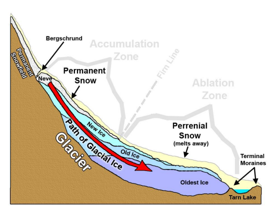


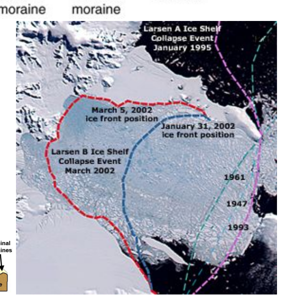


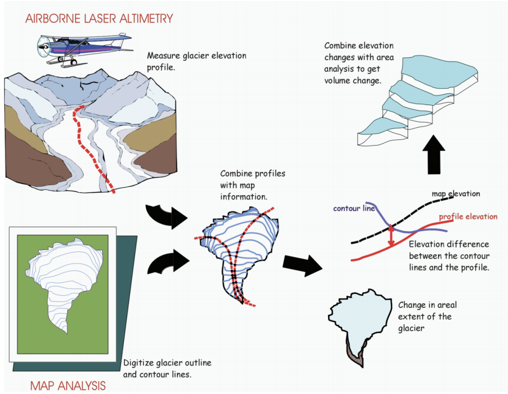


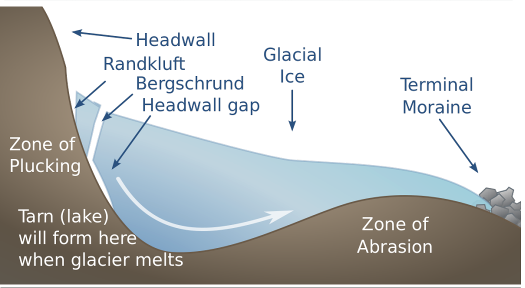


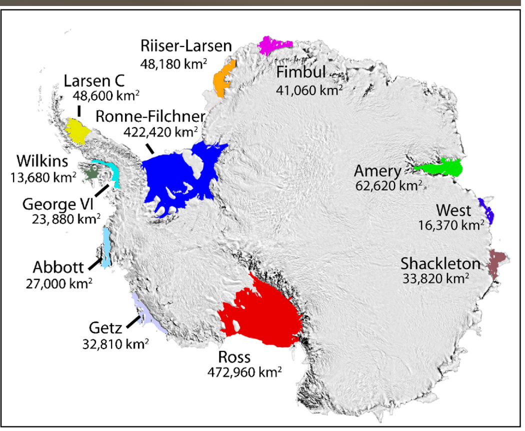


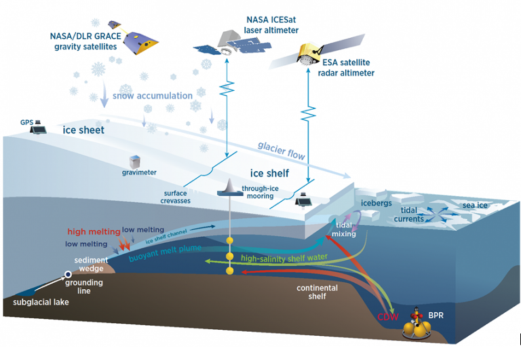


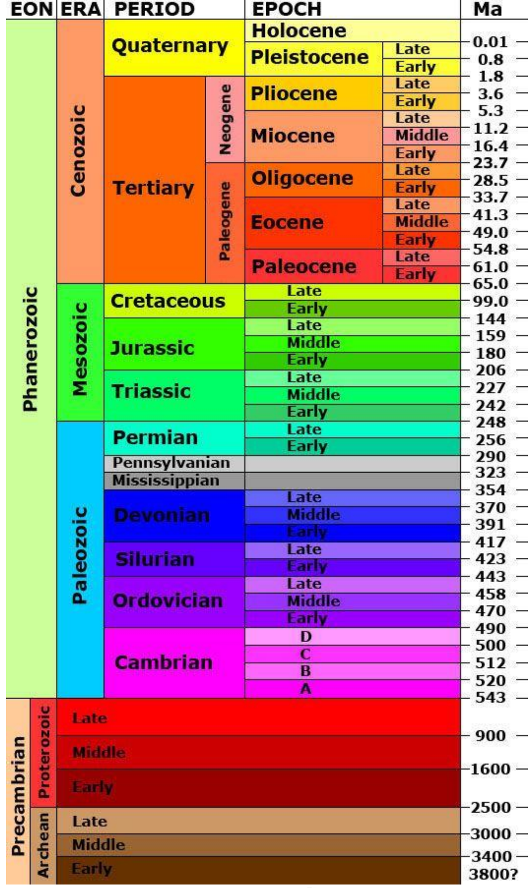


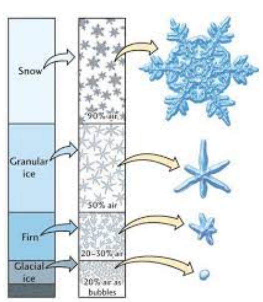


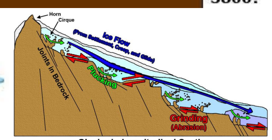




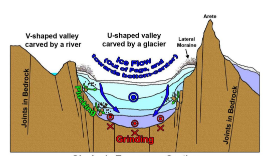




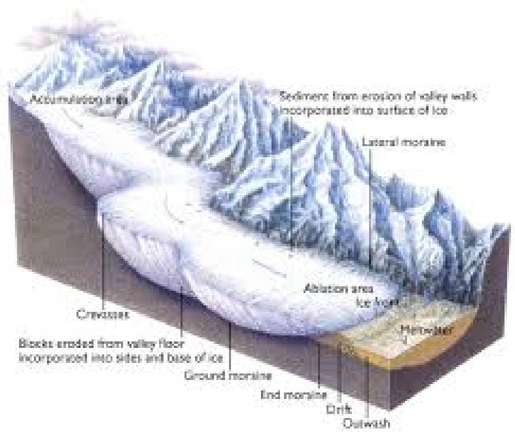


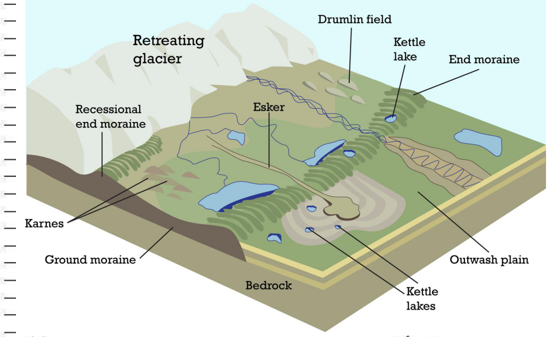


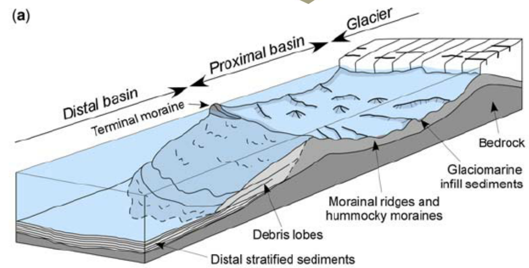
Glacier in Longitudinal Section

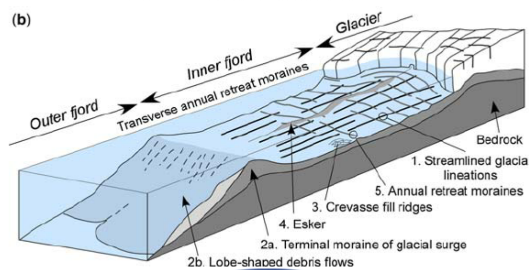


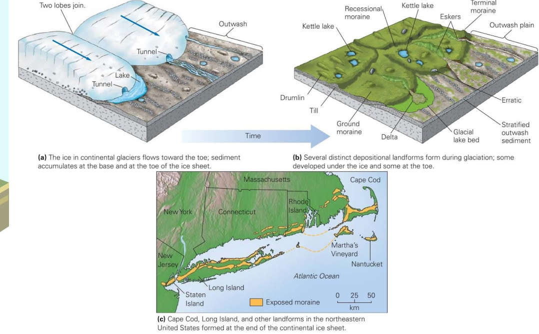
Glacier in Transverse Section

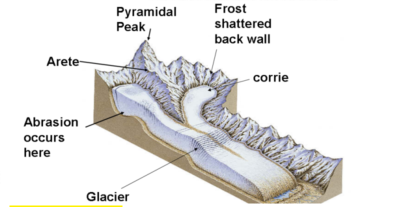






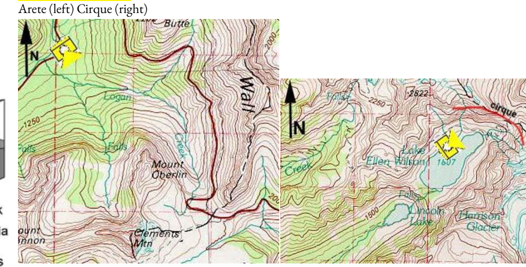




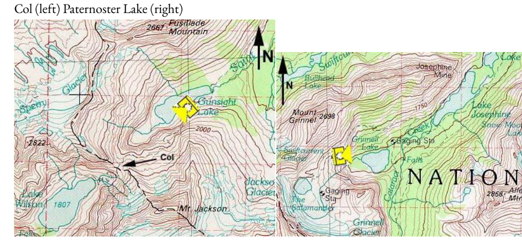


Topographic Images Do not look at yellow marker. Label is on top of image

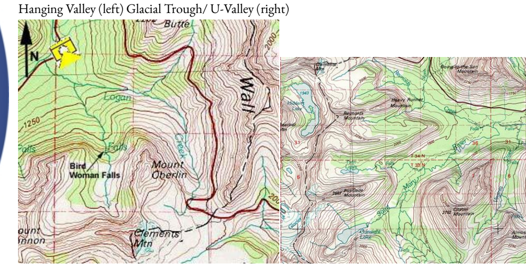
Arete (left) Cirque (right)



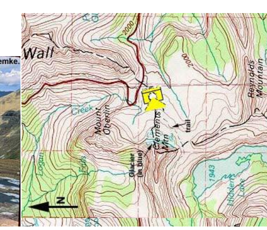
Col (left) Paternoster Lake (right)



Hanging Valley (left) Glacial Trough/ U-Valley (right)



Grooves (Left) Horn (right)



Ablation Hollows: Depressions in the snow surface caused by the sun or warm, gusty wind **Ablation Moraine:** Mound or layer of moraine in the ablation zone of a glacier; the rock has been plucked from the mountainside by the moving glacier and is melting out on the ice surface **Ablation Season:** Period during which glaciers lose more mass than they gain; usually coincides with summer **Ablation Zone:** Area or zone of a glacier where snow and ice ablation exceed accumulation **Abrasian:** rocks within the ice acting like sandpaper to smooth and polish the surface below; pulverized rock produced is called rock flour; glacial striations: ice at the bottom of a glacier contains large rock fragments, and long scratches and grooves; give clues to direction of travel **Accommodation Space Equation:** represents a simple volume balance, with the terms on the left controlling the amount of space that can be occupied by sediments and water and the terms on the right describing how much water or sediment fills the accommodation space **Accumulation Area:** Area of a glacier where more mass is gained than lost **Accumulation Season:** Period during which a glacier gains more mass than it loses usually coincides with winter **Accumulation Zone:** Area of a glacier where more mass is gained than lost **Advance:** When a mountain glacier's terminus extends farther down valley than before; glacial advance occurs when a glacier flows down valley faster than the rate of ablation at its terminus **Advancing glacier:** When accumulation exceeds ablation and the glacier advances **Albatross:** the largest sea bird in Antarctica **Alluvium:** Sediment eroded from adjacent areas and deposited by running water in and along rivers and streams. sorted. **Alpine Glacier:** A glacier that is confined by surrounding mountain terrain; also called a mountain glacier **Altithermal:** A period of time in the mid-Holocene when climate was generally warmer. Also called the hypsithermal and/or climatic optimum **Amundsen and Scott:** 2 explorers that raced to be the first to the South Pole **Antarctica:** the coldest, highest, and driest continent **Antarctic Peninsula:** the peninsula that juts out on the northwestern part of Antarctica **Arête:** Sharp, narrow ridge formed as a result of glacial erosion from both sides **Avalanche:** A great mass of ice, earth, or snow mixed with rocks sliding down a mountain **Band Ogives:** Alternate bands of light and dark on a glacier; usually found below steep narrow icefalls and thought to be the result of different flow and ablation rates between summer and winter **Basal Sliding:** The sliding of a glacier over bedrock; melting point of ice decreases with pressure. **Bergschrund:** (Rimaye) Crevasse that separates flowing ice from stagnant ice at the head of a glacier **bergy bits:** A large chunk of glacial ice (or a very small iceberg) which floats in the sea. **bottom bergs:** Icebergs which originate from near the base of a glacier. They are usually black from trapped rock material or dark blue because of old, coarse, bubble-free ice and sit low in the water due to the weight of embedded rocks. **Branched-Valley Glacier:** Glacier that has one or more tributary glaciers that flow into it; distinguished from a simple valley glacier that has only a single tributary glacier **Brittle Zone:** The upper 50 meters of a glacier that breaks as the ice moves **Bubble Rock:** Name of this one erratic in Acadia national park. **Budget of Glacier:** as terminus, or bottom of glacier, retreats, zone of wastage decreases ⟶ new balance will be reached eventually between accumulation and wastage, and ice front will become stationary; no matter how margin is moving ice within the glacier continues to flow forward; even if glacier is retreating, but not enough to stop ablation **Buttressing:** This is due to "iceshelf buttressing," the term used to describe the resistive forces imparted to the ice sheet by its ice shelves **Calving:** process by which a block of a glacier breaks off and falls into the sea to form an iceberg **Catchment Glacier:** A semi permanent mass of firn formed by drifted snow behind obstructions or in the ground; also called a snowdrift glacier or a drift glacier **Chanelled Scablands:** Land after a giant flood. **Chattermarks:** Striations or marks left on the surface of exposed bedrock caused by the advance and retreat of glacier ice **Chattermarks:** Striations or marks left on the postglacial exposed bedrock caused by the striking of englacial debris against the bedrock surface during glacial movement. **Cirque:** a bowl-shaped depression at the head of a glacial valley **Cirque:** Bowl shaped or amphitheater usually sculpted out of the mountain terrain by a cirque glacier **Cirque Glacier:** Glacier that resides in basins or amphitheaters near ridge crests; most cirque glaciers have a characteristic circular shape, with their width as wide or wider than their length **Clay:** Plate minerals with water **Col:** Ridge between 2 cirques **Col:** the lowest point of a ridge or saddle between two peaks, typically affording a pass from one side of a mountain range to another. **Cold Glacier:** Glacier in which most of the ice is below the pressure melting point; nonetheless the glacier's surface may be susceptible to melt due to incoming solar radiation, and the ice at the rock/ice interface may be warmed as a result of the natural (geothermal) heat from the earth's surface **Compression Flow:** Flow that occurs when glacier motion is decelerating down-slope **Constructive Metamorphism:** Snow metamorphism that adds molecules to sharpen the corners and edges of an ice crystal **Continental Glacier:** A glacier that covers much of a continent or large island **Continental glaciers:** Continents covered in ice (Antarctica and Greenland) **Cordilleran Ice Sheet:** The ice cap that covered much of the mountains in the northwestern part of North America during the Pleistocene Epoch. **Corrie:** A hollow containing a small glacier that is armchair shaped **Crag and Tail:** Rocky hill followed by a tale of till **Crayocinite:** Depression in a glacier formed when a rock on the surface is heated and melts the surrounding snow. **Crevasse:** A deep crack or fissure in the ice of a glacier. **Crevasse Hoar:** A kind of hoarfrost; ice crystals that develop by sublimation in glacial crevasses and in other cavities with cooled space and calm, still conditions under which water vapor can accumulate; physical origin is similar to depth hoar **Cuesta:** A ridge with a gentle slope on one side and a steep slope on the other, often resulting from the movement of a glacier over a rock outcrop. Cuestas are large scale features analogous to rock knobs (roche moutonnée). **Cwm:** same thing as a cirque. **Dead Ice:** Any part of a glacier which has ceased to flow; dead ice is usually covered with moraine **De geer moraine:** underwater moraine; parallel ridges like ripple marks. Only a few 100 ft apart. **depth hoar:** In snow, relatively large (1 to several mm diameter), cohesionless, coarse, faceted snow crystals resulting from the presence of steep temperature gradients within the snowpack. **Diamicton:** Diamicton is a general term used to describe a non-sorted or poorly sorted, sometimes non-calcareous, terrigenous or marine sediment containing a wide range of particle sizes derived from a broad provenance **Dirt Cone:** A cone-shaped formation of ice that is covered by dirt; a dirt cone is caused by a differential pattern of ablation between the dirt-covered surface and bare ice **Discharge:** The total volume of ice passing through a specified cross section of the glacier during a particular unit of time/ **Draft:** The depth below the water level, usually sea level, to whichthe base (or keel) of an iceberg penetrates is called its draft. **Drain Channel:** Preferred path for meltwater to flow from the surface through a snow cover **Drift:** Any material carried and deposited by a glacier. **Drift Glacier:** A semi-permanent mass of firn formed by drifted snow behind obstructions or in the ground; also called a catchment glacier or a snowdrift glacier **Dropstone:** A rock that was carried elsewhere by a glacier or iceberg and deposited when the ice melts, the rock sinks to the bottom of the body of water and becomes part of a sedimentary rock. **Drumlin:** Remnant elongated hills formed by historical glacial action; it is not clear exactly how they are formed and why they form only in some glaciated regions **Drumlin:** Tear drop shaped hill made of reworked glacial moraines **Dry Bottom Glacier:** A glacier so cold that its base remains frozen to the substrate, also called a polar glacier. Occur in regions where atmospheric temperatures stay so cold all year long that the glacial ice remains below melting. Mars also has polar glaciers. **Dump Moraine:** A mound or layer of moraine formed along the edge of a glacier by rocks that fall off the ice; sometimes called a ground moraine **emperor penguin:** the largest of the 6 types of penguins found in Antarctica **End Moraine:** An arch-shaped ridge of moraine found near the end of a glacier **Englacial:** All the glacial environments which occur within the ice itself are called englacial environments. **Equilibrium Line:** the boundary between the zone of accumulation and the zone of ablation **Equilibrium Zone:** Zone of a glacier in which the amount of precipitation that falls is equal to the amount that melts the following summer **Erratics:** Large pieces of rock that have been transported away from their source areas by moving glacier sheets **Esker:** A sinuous ridge of sedimentary material (typically gravel or sand) deposited by streams that cut channels under or through the glacier ice **Extending flow:** when glacier motion is accelerating down-slope **fabric:** In tills which have been oriented by flowing water, fabric indicates the preferred orientation of the grains. Sedimentologists would refer to this as "imbrication." **False ogives:** bands of light and dark on a glacier that were formed by rock avalanching **Felsenmeers:** A large area blanketed with angular debris from outcrops which have suffered repeated cycles of freezing and thawing. **Fern and Neve:** Snow under pressure. When granules of ice are put under pressure, the granules weld together **Fjord:** glacial troughs that fill with seawater **flutes:** Long grooves gouged by englacial debris on subglacial pavement parallel to direction of glacial movement. **Foliation:** layering in glacier ice that has distinctive crystal sizes and/or bubbles; foliation is usually caused by stress and deformation that a glacier experiences as it flows over complex terrain, but can also originate as a sedimentary feature **Forbes bands:** alternate bands of light and dark on a glacier; usually found below steep narrow icefalls and thought to be the result of different flow and ablation rates between summer and winter **foredeepening topography:** The ground below an ice sheet may be bowl-shaped with the inner part being deeper than the ground around the edges because glaciers erode preglacial material and subsidence due to the weight of the ice. **Forel stripes:** shallow, parallel grooves on the face of a large melting ice crystal **Frazil Ice:** Disorganized, slushy ice crystals in the water column, usually near the water surface. Frazil ice is the first stage in the formation of sea ice. **Furrow:** Long grooves in subglacial till or pavement gouged by englacial debris. (see flutes) **Gargantuan steps:** Giant terraces in a u shaped valley formed by glacial plucking **Gendarmes:** Ice towers such as seracs and penitantes. **Geyser:** Fountain that develops when water from a conduit is forced up to the surface of a glacier; also called a negative mill **Glacial advance:** when a mountain glacier's terminus extends farther downvalley than before; occurs when a glacier flows downvalley faster than the rate of ablation at its terminus **Glacial Erratic:** a boulder swept from its place of origin by glacier advance or retreat and deposited elsewhere as the glacier melted; after glacial melt, the boulder might be stranded in a field or forest where no other rocks of its type or size exist **Glacial Formation:** 1)Loose snow (90% air), 2) granular snow (50% air), 3) firn (25% air), 4) fine-grained ice (<20% air), 5) coarse grained ice (<20% air) **Glacial grooves:** grooves or gouges cut into the bedrock by gravel and rocks carried by glacial ice and meltwater; also called glacial striations **Glacial Incorporation:** A form of glacial erosion where the ice surrounds debris so the debris starts to move with the ice. **Glacial moraine:** Materials carried and deposited by glaciers **Glacial Polished Surface:** A polished rock surface created by the glacial abrasion of the underlying substrate. **Glacial Rebound:** The process by which the surface of a continent rises back up after an overlying continental ice sheet melts away and the weight of the ice is removed. Takes thousands of years **Glacial retreat:** when the position of a mountain glacier's terminus is farther upvalley than before; occurs when a glacier ablates more material at its terminus than it transports into that region **Glacial striations:** grooves or gouges cut into the bedrock by gravel and rocks carried by glacial ice and meltwater; also called glacial grooves **Glacial Subsidence:** The sinking of the surface of a continent caused by the weight of an overlying glacial ice sheet. **Glacial till:** accumulations of unsorted, unstratified mixtures of clay, silt, sand, gravel, and boulders; the usual composition of a moraine **Glacial Toe:** The leading edge or margin of a glacier **Glacial trough:** a large u-shaped valley formed from a v-shaped valley by glacial erosion **Glaciated:** land covered in the past by any form of glacier is said to be glaciated **Glacier:** A river of ice that erodes, transports material, and carves earth's surface. They are formed by years of accumulation of snow that hardens and becomes a glacier. **Glacier:** a mass of ice that originates on land, usually having an area larger than one-tenth of a square kilometer; many believe that a glacier must show some type of movement; others believe that a glacier can show evidence of past or present movement **Glacier cave:** a cave of ice, usually underneath a glacier and formed by meltwater; cave entrances are often enlarged near a glacier terminus by warm winds; most common on stagnant portions of glaciers **Glacieret:** a very small glacier **Glacier fire:** a phenomenon in which strong reflection of the sun on an icy surface causes a glacier to look like it is on fire **Glacier flood:** a sudden outburst of water released by a glacier **Glacier flour:** a fine powder of silt- and clay-sized particles that a glacier creates as its rock-laden ice scrapes over bedrock; usually flushed out in meltwater streams and causes water to look powdery gray; lakes and oceans that fill with glacier flour may develop a banded appearance; also called rock flour **Glacier ice:** well-bonded ice crystals compacted from snow with a bulk density greater than 860 kilograms per cubic meter (55 pounds per cubic-foot) **Glacierized:** land overlaid at present by a glacier is said to be covered; the alternative term glacierized has not found general favour **Glacier Milk:** Flour that has been mixed with water to create milky appearance. **Glacier mill:** a nearly vertical channel in ice that is formed by flowing water; usually found after a relatively flat section of glacier in a region of transverse crevasses **Glacier pothole:** potholes formed at the bottom of glaciers through erosion caused by sand and gravel in melt-water; melt-water seeps through crevasses in the glaciers, sometimes forming whirlpools; at the bottom of the glacier, the water is under very high pressure, leading to erosion of underlying rocks **Glacier remainie:** a glacier that is reconstructed or reconstituted out of other glacier material; usually formed by seracs falling from a hanging glacier, then re-adhering; also called reconstituted, reconstructed or regenerated glacier **Glacier snout:** the lowest end of a glacier; also called glacier terminus or toe **Glacier sole:** the bottom of the ice of a glacier **Glacier table:** a rock that resides on a pedestal of ice; formed by differential ablation between the rock-covered ice and surrounding bare ice **Glacier terminus:** the lowest end of a glacier; also called glacier snout or toe **Glacier toe:** the lowest end of a glacier; also called glacier snout or terminus **Glacier trough:** u-shaped valleys transformed from v-shaped stream valleys due to erosion caused by passing glaciers **glaciofluvial:** Geomorphic feature whose origin is related to the processes associated with glacial meltwater. **Gleization:** A soil formation process that occurs in poorly drained environments. Results in the development of extensive soil organic layer over a layer of chemically reduced clay that takes on a blue color. **Gneiss:** Striped, metamorphic rock formed deep underground **Graupel:** Variations in temperature, migration of liquid and vapor water, and pressure of snow cover may result in rounded snow pellets from 2 to 5 mm diameter. Graupel is visually similar to hail, but lacks the banded outward growth pattern of hail. **Grooves:** larger striations, created when larger rocks scape bedrock beneath a glacier **Gros ventre:** Reverse fault **Ground moraine:** continuous layer of till near the edge or underneath a steadily retreating glacier **Halocene:** 10,000 years ago-present day **Hanging glacier:** a glacier that terminates at or near the top of a cliff **Hanging valley:** a valley formed by a small glacier that has a valley bottom relatively higher than nearby valleys formed by larger glaciers **Headwall:** a steep cliff, usually the uppermost part of a cirque **Hinge fault:** A fault where the foot wall or hanging wall is slanted **Hoarfrost:** a deposit of interlocking ice crystals (hoar crystals) formed by direct sublimation on objects, usually those of small diameter freely exposed to the air, such as tree branches, plant stems and leaf edges, wires, poles, etc.; the surfaces of these objects are sufficiently cooled, mostly by nocturnal radiation, to cause the direct sublimation of the water vapor contained in the ambient air. **Horn:** a peak or pinnacle thinned and eroded by three or more glacial cirques **Hummock:** Small area of raised ground which is formed as a glacier slowly retreats, leaving behind ground moraine. **Hypisthermal:** A period of time in the mid-Holocene when climate was generally warmer. Also called the altithermal. **Ice apron:** a mass of ice adhering to a mountainside **ice breccia:** Large angular ice fragments embedded in finer ice or snow record abrupt changes. **Ice cap:** a dome-shaped mass of glacier ice that spreads out in all directions; an ice cap is usually larger than an icefield but less than 50,000 square kilometers (12 million acres) **Ice Cap Glacier:** Mounds of ice that submerge peaks and ridges at the crest of a mountain range **Ice cave:** a cave of ice, usually underneath a glacier and formed by meltwater; cave entrances are often enlarged near a glacier terminus by warm winds; most common on stagnant portions of glaciers **Ice-cemented glacier:** a rock glacier that has interstitial ice a meter or so below the surface **Ice-cored glacier:** a rock glacier that has a buried core of ice **Ice covered:** land overlaid at present by a glacier is said to be covered; the alternative term glacierized has not found general favor **Ice Cubic:** Cubic ice is a solid form of water that has been proposed to form in high clouds. metastable. **Ice divide:** the boundary separating opposing flow directions of ice on a glacier or ice sheet **Ice Dome:** ice surface with parabolic surface; located in accumulation zone **Icefall:** part of a glacier with rapid flow and a chaotic crevassed surface; occurs where the glacier bed steepens or narrows **Ice falls:** happen when glaciers flow over a steep drop or squeeze through narrow places **Ice field:** a mass of glacier ice; similar to an ice cap, and usually smaller and lacking a dome-like shape; somewhat controlled by terrain **Ice Hexagonal:** (ice Ih) is the form of all natural snow and ice on Earth as evidenced in the six-fold symmetry in ice crystals grown from water vapor (that is, snowflakes). **Ice quake:** a shaking of ice caused by crevasse formation or jerky motion **Ice rise:** when ice gets on top of rock in the seabed, these happen to ice shelves, they are usually dome shaped **Ice sheet:** a dome-shaped mass of glacier ice that covers surrounding terrain and is greater than 50,000 square kilometers (12 million acres), the Greenland and Antarctic ice sheets) **Ice Shelves:** ice sheet attached to land, extends over sea, floats on water **Ice stream:** (1) a current of ice in an ice sheet or ice cap that flows faster than the surrounding ice (2) sometimes refers to the confluent sections of a branched-valley glacier (3) obsolete synonym of valley glaciers **Ice Tongue:** a long and narrow sheet of ice projecting out from the coastline to the ocean. **ice-wedge casts:** A vertical structure that results from cracks in frozen ground (by means of ice wedging) which are later filled by sediment. They are similar to infilled mudcracks in drying lakes, but usually larger. **Igneous dike:** magma forced into a vertical cracks **Illinoian:** 300,000-125,000 years ago; North American glaciation related to European Riss glaciation. **Indian Ocean, Atlantic Ocean, Pacific Ocean:** the oceans that are all part of the Southern Ocean **Interglacial:** A period of time between two glaciations **interglacial periods:** Times between recognized advances of the ice. Sea level can be hundreds of feet higher in interglacials than in glacial periods. The present time is the latest interglacial period. **Isostatic rebound adjustment:** Up or down warping of the Earth's lithosphere to accommodate for mass being added or removed. Northern Ontario, Canada is rebounding in adjustment to the last glacial retreat 10,000 years ago. **James Cook:** the early explorer that was the first to cross the Antarctic Circle **Jokulhlaup:** (1) a large outburst flood that usually occurs when a glacially dammed lake drains catastrophically (2) any catastrophic release of water from a glacier **Kame:** an irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier, and is then deposited on the land surface with further melting of the glacier. **Kame:** Rounded hill of sand and gravel deposited by meltwater within or at the base of the glacier. **Kansan:** North American glaciation related to European Mindel glaciation. **katabatic wind:** A wind that flows from a glacier, caused by air cooled by the ice becoming heavier than surrounding air, then draining down-valley. **Kettle:** A depression formed by melting glacial ice **Kettle Hole:** A circular depression in the ground made when a block of ice calves off the toe of a glacier, becomes buried by till, and later melts. **Kettles:** irregular till thickness and depressions where large blocks of ice melted within the till **kinematic waves:** These ice waves move downglacier and are propagated by increasing glacial thickness. Kinematic waves may move two to six times the velocity of surrounding, thinner ice. **Knife Edged Ridges/ Pointe D Peaks:** ridges between widening u-shaped glacial valleys that become narrower until they rise steeply to narrow, aretes/pointy pyramids **krill:** the animal that is the most abundant in the Southern Ocean **lacustrine:** Pertaining to lakes. Lacustrine proglacial deposits usually show confined sorting of fine sized sedimentary particles. They may have dropstones if icebergs once floated in the lake. Other lakes associated with glaciers are supraglacial lakes and kettle lakes. **Lambert Glacier:** the largest glacier in the world **Lateral moraine:** a ridge-shaped moraine deposited at the side of a glacier and composed of material eroded from the valley walls by the moving glacier **Lateral moraine:** moraine that forms along the side of a glacier **Laurentide Ice Sheet:** The continental glacier that covered eastern Canada and parts of the northeastern United States during the Pleistocene Epoch **leads:** Long, narrow openings or fractures in sea ice. **Leeward Side:** Side of a natural or man made elements that does not receive wind **lens/lenticular:** A thick-in-the-middle/thin-at-the-edges geologic deposit in which the surfaces converge together. **Loess:** wind-blown silt deposits blown away from the floodplains and bars of the outwash streams that built up as sand dunes and a frosting of fine silt **loesskinder:** Calcarous concretions found in loess deposits. Called "children of the loess" by the Germans who were the first to describe them because the concretions often take pentacular or homunucular proportions. **Luis Agassiz:** Proposed that ice ages occurred in the past **Marginal crevasse:** a crevasse near the side of a glacier formed as the glacier moves past stationary valley walls; usually oriented about 45 degrees up-glacier from the side wall **Mass Balance:** the difference between accumulation levels and ablation **Mc Murdo Station:** the largest research station in Antarctica **Medial moraine:** A moraine formed when two lateral moraines merged together **Meltwater conduit:** a channel within, underneath, on top of, or near the side of a glacier that drains meltwater out of the glacier; usually kept open by the frictional heating of flowing water that melts the ice walls of the conduit **Metastable:** theoretically unstable but so long-lived as to be stable for practical purposes. **Mindel:** European glaciation related to North American Kansan glaciation. **Moraine:** a mound, ridge, or other distinct accumulation of glacial till **Moraine shoal:** glacial moraine that has formed a shallow place in water **Moulin:** a nearly vertical channel in ice that is formed by flowing water; usually found after a relatively flat section of glacier in a region of transverse crevasses; also called a pothole **Mountain glacier:** a glacier that is confined by surrounding mountain terrain; also called an alpine glacier **NADW (North Atlantic Deep Water):** The deep portion of the thermohaline circulation in the northern Atlantic Ocean. **Nebraskan:** the earliest Pleistocene glaciation for which there is ample evidence for, it occurred about 650,000 years ago before the Kansan glaciations. North American glaciation related to European Gunz glaciation. **Negative mill:** a geyser; a fountain that develops when water from a conduit is forced up to the surface of a glacier **Neve:** The upper area of accumulation in a glacier where firn is found. **Niche glacier:** very small glacier that occupies gullies and hollows on north-facing slopes (northern hemisphere); may develop into cirque glacier if conditions are favorable **Normal Stress:** normal stress = density * height * g * cos(angle) **Nunatak:** a rocky crag or small mountain projecting from and surrounded by a glacier or ice sheet **Ogives:** alternate bands of light and dark ice seen on a glacier surface; Dark= summer, Light=winter. They kind of bend towards the middle. indicates the middle of the glacier flows faster than the sides **Outburst flood:** any catastrophic flooding from a glacier; may originate from trapped water in cavities inside a glacier or at the margins of glaciers or from lakes that are dammed by flowing glaciers **Outlet glacier:** a valley glacier which drains an inland ice sheet or ice cap and flows through a gap in peripheral mountains **outlet glaciers:** Valley glaciers which permit ice to move from accumulation areas through mountainous terrain to the sea. **Outwash:** material deposited by meltwater from a glacier **Outwash Plain:** Formed when sand is eroded, transported and deposited by meltwater streams from the glaciers snout and nearby till deposits to areas in front of the glacier. **paleosol:** An ancient or buried soil, often used as a stratigraphic marker for interglacial periods. **pancake ice:** Coherent plates of ice that can reach a few meters across and grow from thickened grease ice and resembles pancakes or lily pads. **Paternoster lakes:** a series of tarns connected by a single stream or a braided stream system **Patterned grounds:** consists of mostly symmetrical geometries displayed across the ground surface in relation to local frost action and cryogenic processes. Patterns emerge as a result of surface disturbances caused by thermal anomalies and freeze processes such as frost heave. Frost heave will disturb the frost layer as ice lenses accumulate and protrude, causing unstable soil conditions. Can be polygons, circles, stripes, nets, and steps. **Periglacial:** relating to or denoting an area adjacent to a glacier or ice sheet or otherwise subject to repeated freezing and thawing **periglacial:** The area around a glacier often characterized by harsh climate. **Piedmont glacier:** large ice lobe spread out over surrounding terrain, associated with the terminus of a large mountain valley glacier **Pingo:** Large mounds of earth-covered ice which form in a permafrost environment which are found in Alaska, Greenland and Antarctica. Pingos may be up to 70 meters tall and 600 meters diameter. The word was borrowed from the Inuit in 1938 by A.E. Porsild after whom Porsild Pingo in Tuktoyaktuk was named. Pingos have an average life-time of about 1,000 years. **Pingo:** also called hydrolaccolith or bulgunniakh, is a mound of earth-covered ice found in the Arctic and subarctic that can reach up to 70 metres in height and up to 600 m in diameter. **pitch:** In climbing, a unit of measure approximately equal to the length of your rope, or the distance between fixed anchor positions. To go secured from pitch 3 to pitch 4 of a glacier means that you would be protected by a rope and safety gear during that part of the ascent. "Unprotected pitches" include many icefalls and crevasse fields. **Plastic Deformation:** When a sufficient load is applied to a material, it will cause the material to change shape. Ice deforms below 60 m, grains within the formation change shape slowly, new grains grow where old ones disappear. This allows the glacier to move. **Plastic Flow:** slow movement of a glacier in which ice crystals slip over each other **Plastic Zone:** place where cracks cannot form in the glacier **Plestocene:** 1.8 million years ago to 11,000 years ago. The Last Ice Age. **Plucking the glacier freezing onto masses of rock, and glacier flow causing this mass being pulled and broken off, and carried by the glacier:** **Pluvial Lake:** A lake formed to the south of a continental glacier as a result of enhanced rainfall during an ice age. (Example: Lake Bonneville in Utah) **Pluvial Processes:** Glaciers moving sediment because of the water in, on and under the glacier **Polar glacier:** a glacier entirely below freezing, except possibly for a thin layer of melt near the surface during summer or near the bed; polar glaciers are found only in polar regions of the globe or at high altitudes **Polar plateau:** The relatively flat, elevated central region of the East Antarctic Ice Sheet. **polynya:** The open seawater between pack-ice and the land or the edge of a glacier. **Pothole:** a nearly vertical channel in ice that is formed by flowing water; usually found after a relatively flat section of glacier in a region of transverse crevasses; also called a moulin **Proglacial lake:** Lake that forms in front of a glacier **Push moraine:** moraine built out ahead of an advancing glacier **Quarternary:** geologic period of the late Cenozoic c. two million years ago to the present. The name refers to the fourth interval of earth time, according to early geologists. **Randkluft:** a fissure that separates a moving glacier from its headwall rock; like a bergschrund **Raymond Bump:** Beneath ice sheet divides ice stratigraphy often develops arches (Raymond Bump) with amplitudes that record the divide's horizontal residence time. **Rcessional Moraine:** Terminal moraine after it has come back and moved forward again. **Receding glacier:** When ablation exceeds accumulation and the glacier recedes **recessional moraine:** Ground moraine deposited as glacier recedes. It usually forms perpendicular to the glacier **Reconstituted glacier:** a glacier that is reconstructed or reconstituted out of other glacier material; usually formed by seracs falling from a hanging glacier then re-adhering; also called reconstructed glacier, regenerated glacier, or glacier remainie **Reconstructed glacier:** a glacier that is reconstructed or reconstituted out of other glacier material; usually formed by seracs falling from a hanging glacier then re-adhering; also called reconstituted glacier, regenerated glacier, or glacier remainie **Regelation:** motion of an object through ice by melting and freezing that is caused by pressure differences; this process allows a glacier to slide past small obstacles on its bed **Regenerated glacier:** a glacier that is reconstructed or reconstituted out of other glacier material; usually formed by seracs falling from a hanging glacier then re-adhering; also called reconstituted or reconstructed glacier, or glacier remainie **relative humidity:** Relative humidity is actual humidity of a packet of air divided by maximum possible humidity that air can hold. In glaciers, if the relative humidity of a packet of air is high enough that the air reaches the dew point as it cools in contact with the snow or ice, condensation occurs, releasing +AH4- 680 calories/gram of latent heat. **relief:** The vertical difference between the surface in valleys and hilltops or the vertical between the base of a glacier and its top. **Retreat:** when a mountain glacier's terminus doesn't extend as far downvalley as it previously did; occurs when ablation surpasses accumulation **Retreating glacier:** a glacier whose terminus is increasingly retreating upvalley compared to its previous position due to a higher level of ablation compared to accumulation **rheology:** The study of flow behavior and characteristics. **Ribbon Lake Long:** thin lakes that form after a glacier retreats that form in hollow **Richard Byrd:** The explorer to first fly over the South Pole **Rigid zone:** Upper part of a glacier in which there is no plastic flow. **rime:** Ice deposits formed when supercooled water droplets freeze on contact with an object (deposition). **Riss:** European glaciation related to North American Illinoian glaciation. **Roche Mountain:** Rock drumlin. **Rock flour:** a fine powder of silt- and clay-sized particles that a glacier creates as its rock-laden ice scrapes over bedrock; usually flushed out in meltwater streams, causing water to look powdery gray; lakes and oceans that fill with glacier flour may develop a banded appearance **Rock glacier:** looks like a mountain glacier and has active flow; usually includes a poorly sorted mess of rocks and fine material; may include: (1) interstitial ice a meter or so below the surface ("ice-cemented"), (2) a buried core of ice ("ice-cored"), and/or (3) rock debris from avalanching snow and rock **Rogen Moraine:** (also called ribbed moraine) is a subglacially (i.e. under a glacier or ice sheet) formed type of moraine landform, that mainly occurs in Fennoscandia, Scotland, Ireland and Canada. Landform assemblage of numerous, parallel, closely-spaced ridges consisting of glacial drift, usually TILL. The ridges are formed transverse to ice flow in a subglacial position and are usually found in the central portions of former ice sheets. believed to have been the central areas of the ice sheets. Formation linked closely to Drumlins. **Sandar:** Flat outwash plains caused by glacial melting feature braided streams and sinous sand and gravel bars. **Sastrugi:** parallel wave-like ridges caused by winds on the surface of hard snow, especially in polar regions. **Sedimentary ogives:** alternating bands of light and dark at the firn limit of a glacier; the light bands are usually young and lightest at the highest level up-glacier, becoming increasingly older and darker as they progress down-glacier **Serac:** an isolated block of ice that is formed where the glacier surface is fractured **shear stress:** shear stress = density * height * g * sin(angle) **Sichelwannen- curved grooves formed by water under immense pressure at the base of a glacier:** **Sintering:** the bonding together of ice crystals **Snowdrift glacier:** a semipermanent mass of firn formed by drifted snow behind obstructions or in the ground; also called a catchment glacier or a drift glacier **Snowline:** The end of the zone of accumulation and start of the zone of melting **snow line:** The elevation above which snow remains all year long **Solifluction:** A slow, viscous, downslope flow of saturated sediment and rock debris especially in areas underlain by frozen ground. **Southern Ocean:** the ocean that surrounds Antarctica **South Pole:** the important place located in Antarctica **Splay crevasse:** a crevasse pattern that forms where ice slowly spreads out sideways; commonly found near a glacier terminus **Stratified Drift:** Sediment laid down by glaial meltwater (lasagna) **Striation:** Grooves in bedrock gouged in by moving glaciers **Subglacial Volcano:** is a volcanic form produced by subglacial eruptions or eruptions beneath the surface of a glacier or ice sheet which is then melted into a lake by the rising lava. The more distinctly flat-topped, steep-sided subglacial volcanoes are called tuyas, named after Tuya Butte in northern British Columbia by Canadian geologist Bill Mathews in 1947. Often cause Jokulhlaups. **Sub polar glacier:** a glacier whose temperature regime is between polar and temperate; usually predominantly below freezing, but could experience extensive summer melt **Sun cup:** Ablation hollow that develops, during intense sunshine. **Surface Hoar:** Deposition of ice crystals on a surface which occurs when the temperature of the surface is colder than the air above and colder than the frost point of that air. **Surges:** in the summer months when the glacier is melting there will be quick sunspots **Surging glacier:** a glacier that experiences a dramatic increase in flow rate, 10 to 100 times faster than its normal rate; usually surge events last less than one year and occur periodically, between 15 and 100 years **Tabular:** Thinner in one direction than the other **Tarn:** a small mountain lake or pool; a mountain lake formed in a cirque excavated by a glacier. A moraine may form a natural dam below a tarn **temperature-gradient metamorphism:** Process of firnification when large temperature gradients exist within the snowpack, such as within adjacent layers of snow. When all snow is fully converted to ice, the density is about 830-840 kg/cubic meter. **terminal/end moraine:** Moraine deposited at the end of a glacier **Terminus:** End of glacier **Terminus:** the lowest end of a glacier, also called the glacier toe or glacier snout **Teton blockfault:** One side bound by a normal fault on one side **Teton Fault:** Normal fault **thermohaline circulation:** is a part of the large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater fluxes. **Thomson crystal:** a large ice crystal found in deep, stagnant water-filled cavities of a glacier **Tidewater glacier:** mountain glacier that terminates in the ocean **Till:** Any kind of glacial deposit **Till:** The sediments deposited directly by a glacier; **Tongue:** a projection of the ice edge up to several km in length caused by wind and current; usually forms when a valley glacier moves very quickly into a lake or ocean **Tor:** A high rock, a high rocky hill, or pile of rocks. **Trans antarctic mountains:** the natural border between East and West Antarctica **Tributary glacier:** a small glacier that flows into a larger glacier **Tuya:** Volcanos which erupted beneath glaciers, melts through the ice above and finishes with a subaerial lava flow are called "tuyas" after the type locality, Tuya Butte, Stikine Belt, Northwest British Columbia, Canada. Also called "table mountains," the typical flat-top is created by the explosive interaction of hot magmas and lavas with water and ice. Tuyas reveal the height of the ice at the time of eruption and may be used as part of correlative dating. Similar volcanic structures, called "guyots" or "sea mounts," are created under the oceans when magma hits ocean water. **U-shaped valley:** The shape of a valley formed by the erosion of a glacier **Valley glacier:** a mountain glacier whose flow is confined by valley walls **Varve:** A pair of thin layers deposited during a single year in a lake. One layer consists of silt brought in during spring floods and the other of clay deposited in winter when the lake's surface freezes over and the water is still. **Ventifact:** A faceted or triangular-shaped stone formed by sandblasting in strong winds, often highly polished. **Vienna Standard Mean Ocean Water (VSMOW):** is a water standard defining the isotopic composition of fresh water. **Vinson Massif:** highest mountain peak in Antarctica **Wave ogives:** ogives that show some vertical relief on a glacier; usually the dark bands are in the hollows and the light bands are in the ridges; form at the base of steep, narrow ice falls **Weathered ice:** glacier ice that has been exposed to sun or warm wind so that the boundaries between ice crystals are partly disintegrated **Weddell Sea:** the sea that is north of Antarctica **Wet Bottom Glacier:** A glacier with a thin layer of water at its base, over which the glacier slides, also called a temperate glacier. Occur in regions where atmospheric temperatures become warm enough for glacial ice to be at or near its melting point. **whale:** animal at the top of the Antarctic food web **Whaleback:** similar to a roche moutonnée, but on a larger scale. **Where do you find trees and why?:** You find trees at glacial moraines because it has clay, which retains water **White-Out:** A weather condition in which the horizon cannot be identified and there are no shadows. White snow blends everywhere. All you see is white. (I've been there before, it's scary. Michaelene Cutro) **Wurm:** European glaciation related to North American Wisconsinan glaciation. **Zone of Ablation:** In the lower part of a glacier where there is more ablation than accumulation **Zone of Accumulation:** In the upper part of the glacier where there is more accumulation than ablation **zone of accumulation:** The part of a glacial system where snow and ice are accumulating faster than they are melting away. **Zone of Fracture:** The upper 50 meters of glacial ice is brittle and is carried by the ice below it. **Zone of plastic flow:** The lower part of the glacier that has the ability to flow due to pressure **Zone of Wastage:** below the snow line, where snow melting exceeds snow accumulation