grazing, farming, and burning of fossil fuels and forests, are also causing glacier retreat by Past 200 yr: CO2 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, 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 and Black Carbon •Aerosol: a colloidal suspension of particles five or six major ice ages in the past 3 billion years The Late dispersed in air or gas. reducing albedo. Ocean If glacier melted sea level would rise by: All of Greenland $(\overline{7.2m})$; West Antarctic Ice Sheet (3.2m). All of Antarctica (57m). •seal level has risen by 4 to 8 inches over the past century orate of rise over the past 20 years has been 0.13 inches (3.2 millimeters) a year Lith 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

melt, allowing water to be present. glaciers can move in even

recrystallized and have trapped air bubbles from previous time xygen Isotopes •2 common isotopes O¹6 and O¹8 •Water w/ 16O is lighter, water with 18O is heavier; 16 tends to evaporate and 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. Info from Ice Cores •Accumulation rate - The thickess 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 - It is possible to discern past air temperatures years Ice areas where sediments are deposited; glaciers are an example of

when the ice melts •Till-like mixtures of material with a wide range of particle sizes, called "diamicton" •Reflect a complex bglacial • Most difficult to observe. Rely history of deposition Si on ice cores and down-hole cameras eglaciers 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 river and lake deposits also occur Proglacial • even more dynamic than the subaglacial one eglacial 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 wate Include materials sorted by water or wind, river sediment (called outwash), lake sediment, windblown sand, and windblown silt

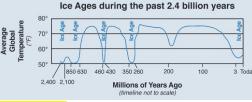
called loess Milankovitch Cycles describe the collective effects of changes in the Earth's movements on its climate over thousands of years. variations in eccentricity, axial tilt, and precession of the Earth's orbit resulted in cyclical variation in the solar radiation

Glacial Basics Aerosol: a colloidal suspension of particles reaching the Earth, and that this orbital forcing strongly influenced dispersed in air or gas. Firn; the intermediate state between snow climatic patterns on Earth. Eccentricity: refers to the earths orbit and glacial ice Accumulation: Accumulation is when glaciers gain and its shift from being circular to more elliptical over time; more mass through snowfall, windblown snow, avalanches, etc. Azial Tilt (Obliquity). Tilt of earths axis of rotation. A greater tilt Ablation: Ablation is when glaciers loose mass through surface means more drastic seasons; The angle varies between 22.1° melt, surface meltwater runoff, sublimation, avalanching and and 24.5°, over a cycle of about 41,000 years. The current windblown snow.

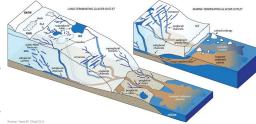
Global Connections

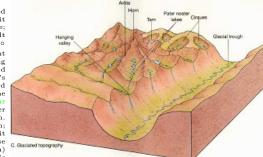
Atmosphere** Past 200 yrs: till is 23.44°. We are currently on a downward trend, meaning the properties of the control of the control of the control of the current of the curr warmer climates. Axial Precession: is a gravity-induced, slow, and Past 200 yr: CO2 went up by 40% and Methane by 200% - 300%; warmer chimates. ALIGH FICESSION. IS A STATIS, INCACON, SIGNAL CONTINUOUS change in the orientation of an astronomical body's Glaciers Reflect heat from the sun; increased dust and soot from rotational axis. The cycle is relative to fixed starts, with a period of 25771.5 vrs 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; are also causing glacier retreat (albedo) •layers of dust and soot The semi-major axis is a constant, therefore when the earth orbit are darkening the color of glaciers and snowpacks, causing them becomes more eccentric, the semi-minor axis shortens. Increase to absorb more solar heat and melt more quickly, and earlier in solar irradiation: at closest approach to the Sun (perihelion) spring. •Albedo, or "whiteness," is a scientific term meaning compared to the irradiation at the furthest distance (aphelion) is slightly larger than four times the eccentricity. Milutin Milankovi Serbian geophysicsicts and astronomer. • how long: 100,000 year glaciers •90% of Himalayan Glacier Melting Caused by Aerosols long cycle. History of Ice on Earth Recent History There have been

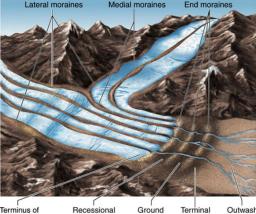
Cenozoic Ice Age began 34 million years ago, its latest phase being the Quaternary glaciation, in progress since 2.58 million Neoproterozoic Snowball on Earth Snowball earth around vears ago. 650 mya-biological activity in the ocean surface collapsed for millions of years; Ended when volcanic outgassing raised CO2 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 Pale: •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 land and ice. pressure from the weight of the ice reduces the be less extreme than once thought Eocene Oligocene Transition melting point at the base of the glacier which allows the ice to the impact of opening oceanic seaways • Marked by large scale extinction • Most affected organisms were marine or aquatic in the coldest of climates. Ice Cores a core sample drilled from nature •Major cooling on land and in ocean •Causes include the accumulation of snow and ice over many years that have volcanic activity + meteorite impacts + decrease in atmospheric CO2 •Sea level changes mark transition- in NE Italy, sea level periods, the composition of which can be used to reconstruct past fell 20 m and then 50-60 m in the Oligocene Isotope Event climates and climate change; typically removed from an ice sheet •Extinctions could have been caused by volcanic explosions or meteorites . Extinction caused by climate change and major fall in Terminus of easier, causing 18 accumulate in oceans and 16 to end up in water reorganization and relocation of species associations and may have enhanced species turnover •Changes in CO2 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 Formation Glacial Ice: Glacier formation - snow in same temperatures. Melt layers are formed when the surface snow area year long and accumulates into masses of ice; ; after the melts, releasing water to percolate down through the snow pack. first winter this is known as neve; after two winters (one melt They form bubble-free ice layers, visible in the ice core •Past air season), snow turns into firn; the ice increases in density over Crystal Structure: Commonly takes the shape of sheets from ice cores. This can be related directly to concentrations of or planes of oxygen atoms joined in a series of open hexagonal carbon dioxide, methane and other greenhouse gasses preserved rings; ice can form 18 different crystalline phases; tacked in a in the ice. Sedimentary Sequences Sedimentary environments are 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 this Supraglacial (ice marginal) • Readily be observed along glacial attached to different oxygen atoms Properties of Ice: The albedo margins •A dark, dirty-ice zone is not uncommon at a glacier's is 0.5 to 0.9 for snow, 0.3 to 0.65 for firm, and 0.15 to 0.35 for leading edge •The supraglacial environment is a very unstable glacier ice Albedo: lowers the melting point of the glacier due to place because material deposited on top of ice is going to move hydrostatic pressure, where deeper parts of the glacier are colder

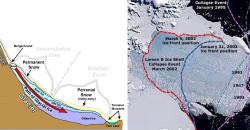






Types of Glaciers





ce 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 balance, just add the two figures Equatorian Education; The lower the a glacier where accumulation is equal to ablation; The lower the thousands of years, and dates how long the sediment has been thousands of years, and dates how long the sediment has been the gradient, the faster the floor of the glacier; Glaciers steeper of Earth's surface where water is in solid form including sea ice, in maritime climates and temperate latitudes then in continental lake ice. river ice, snow cover, glaciers, ice caps, ice sheets, and

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 iers 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. <u>Ice Rise</u> 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

oility 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 Sup raglacial (surface) water on a glacier is formed by the ice melting during the summer. <u>Ablation</u>: 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 $Englacial\ Hydrology\ ullet$ 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 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 neight 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 nuch 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. iocarbon 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 adiocarbon (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 Luc

sand. The radiation emanates from radioactive grains within

the radiation accumulated in quartz or feldspar grains within

west antarctic ice sheet Post-Glacial Landscape Erosional Features:

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 walls and causes them to collapse. Medial a ridge of a moraine it. Where are glaciers found? •Antarctica: •Greenland: 1,784,000 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 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 skers 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

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 ves, 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° F(22°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 conti

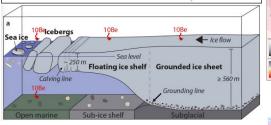
frozen ground (which includes permafrost). Larsen Ice Shelf a long nents to be arranged such that warm water flow from the equator Antartican Glaciers Has many outlet glaciers, valley glaciers ice shelf in the northwest part of the Weddell Sea, extending to the poles is blocked or reduced, ice sheets may arise and set cirque glaciers, tidewater glaciers and ice streams e.g. Pine Island along the east coast of the Antarctic Peninsula from Cape Long- another ice age in motion. •Today's ice age most likely began Glacier. Quick Facts: Fresh Water has 69 percent of the world's ing to Smith Peninsula •The collapse of Larsen B has revealed a when the land bridge between North and South America (Isthmus supply in glaciers Number of glaciers in Alaska is over 100,000 thriving chemotrophic ecosystem 800 m (half a mile) below the of Panama) formed and ended the exchange of tropical water Glacier and ice sheet all melted = a sea level rise of over 300 feet sea. •31 January 2002 - March 2002 Larsen B sector partially between the Atlantic and Pacific Oceans, significantly altering Speed of glaciers is as high as moving 150 feet per day A single sea. •o1 January 2002 - March 2002 Earsen B was stable for 10,000 ocean currents. How does ice build up? •Throughout the Quaternary glacier ice crystal can grow to the size of a baseball Figures. years, but due to warm currents eating away the underside of the period, high latitude winters have been cold enough to allow snow shelf it collapsed. •3.250-square-kilometer (1.255-square-mile) to accumulate. It is when the summers are cold. (i.e., summers section collapsed (size of Rhode island) Kilimanjaro • Kilimanjaro's that occur when the sun is at its farthest point in Earth's orbit) shrinking northern glaciers, thought to be 10.000 years old, could that the snows of previous winters do not melt completely. When disappear by 2030 The northern ice field, which holds most of this process continues for centuries, ice sheets begin to form. the remaining glacial ice, lost more than 140 million cubic feet of Finally, the shape of Earth's orbit also changes. At one extreme, ice in the past 13 years • Approximately 29% of the volume and the orbit is more circular, so that each season receives about the 32% of the surface area of the ice sheet has been lost since 2000. same amount of insolation. At the other extreme, the orbital •No real reason is known, with possible links to global warming ellipse is stretched longer, exaggerating the differences between and less snowfall Amundsen Sea Embayment •is located off of west seasons. The eccentricity of Earth's orbit also proceeds through Antarctica and the ice that drains into it is roughly 3 km thick a long cycle, which takes 100,000 years. Major glacial events •Recently, this sheet has significantly thinned because of shifts in the Quaternary have coincided when the phases of axial tilt. in wind patterns that allow warmer water to flow under the ice, precession of equinoxes and eccentricity of orbit are all lined and is already melting enough to raise the global sea level by 0.2 up to give the northern hemisphere the least amount of summer mm per year. •Two of Antarctica's largest glaciers drain into insolation. Glacial History of Quaternary The Quaternary System this basin and if they were to melt, the sea level could increase is that lasted from the present to approximately 2.588 million by up to 3 yards. •The weak underbelly of the West Antarctic years ago with the Neogene system before the Quaternary. The Ice Sheet, and if it were to collapse, could destabilize the entire 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 Cirques a bowl shaped basin formed when a glacier erodes under continents were formed to their present shape. As glaciers formed the bergschrund(a crevasse at or near the head of a glacier) and later retreated, thousands of lakes and rivers were created which opens in the early summer, exposing the rock underneath all over the world. As the glaciers retreated the sea level rose to frost action and causes upper rock to avalanche and scour and the amount of biological diversity in the oceans increased Glacier Fluctuations •In 1930 Milutin Milankovitch proposed that variations in three parameters of the earth's orbit caused glacial

at first by crosion and weathering of the ground surrounding it. fluctuations: •1. Orbital eccentricity - the orbit of the earth Valley happen when valley glaciers advance, eroded a around the sun is not a circle, but is elliptical and also varies. u-shaped depression in the land, and then recede, leaving this This eccentricity is a minor cause for seasons. •2. Tilt variations U-shaped valleys and mountains behind. Hanging Valley as a in the axis of rotation (obliquity) - the tilt of the earth's rotasmaller glacier at a higher elevation joins a lower, but larger tional axis varies with time. A tilted axis is the primary cause valley glacier, and they recede, the u shaped valley created by the of seasons. This varies between 22.1 and 24.5 in a 40,000 year smaller glaciers opens up onto the lower depression formed by the cycle •3. Precession - the earth's axis of rotation wobbles which larger glacier. Aretes a sharp, crested ridge that separates the results in minor fluctuations in the amount of solar radiation we heads of two opposing cirques where glaciers used to reside and receive. •Milankovitch pacing seems to best explain glaciation carved this thin ridge. Hornswhen glaciers erode three or more events with periodicity of 100k, 40k, and 20k years. This pattern aretes, ending with sharp, vertical peak. Stritations/Grooves are seems to fit the info on climate change found in oxygen isotope carved into bedrock as glaciers pass over it. Rôche moutonnée cores. However, there are some problems with the Milankovitch occurs when a glacier claws itself up a hill, it damages the surface, theories. •100,000 year Problem eccentricity variations have leaving jagged and irregular on that side, but as it slides down, a significantly smaller impact on solar forcing than precession or it polishes the surface, leaving the other side of the same rock obliquity and may be expected to produce the weakest effects. smooth and even. Tarn a lake left in a bowl shaped depression The greatest observed response is at the 100k year timescale, by a receding cirque glacier. <u>Depositional Features:</u> Moraines are while the theoretical forcing is smaller at this scale, in regard to rocks or sediment deposited by a glacier, typically at its edges. During the last 1 million years, the strongest climate End/Terminal a moraine that forms at the leading edge of a signal is the 100k year cycle. ●400,000 year Problem (aka stage glacier marking its furthest advance, formed by debris pushed to 11 problem) eccentricity variations have a strong 400k year cycle. the front of a glacier. Recessional a series of ridges formed paral. That cycle is only clearly present in climate records older than lel to the terminal moraine and form when a glacier temporarily the last million years. •Stage 5 problem refers to the timing stops receding. Lateral a series of parallel ridges deposited along of the penultimate interglacial that appears to have begun 10k the sides of a glacier that form when frost shatters the valley years in advance of the solar forcing hypothesized to have caused

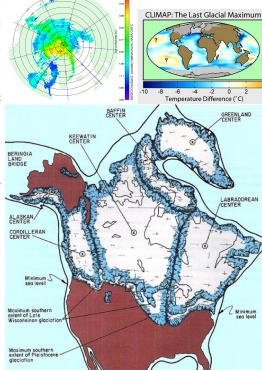
•Canada: 200,000 •Central Asia: 109,000 •Russia: 82,000 ●United States: 75,000 (including Alaska) ●China and Tibet: 33,000 •South America: 25,000 •Iceland: 11,260 •Scandinavia: 2,909 •Alps: 2,900 •New Zealand: 1,159 •Mexico: 11 •Indonesia: into sediment, and subsequently melts, the hole it leaves behind 7.5 • Africa: 10 Current Glacier Records: Top Five Longest Non-Polar

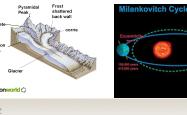
Fedchenko Glacier in Tajikistan at 77 km Siachen Glacier, in the Karakorum range, border between India and Pakistan - 76 km Biafo Glacier in Pakistan also by the border - 67 km Brugger Glacier in Chile - 66 km Baltoro Glacier in Pakistan at the border - 63 km. Longest per continent: Lambert Glacier(Biggest 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 Kilimaniaro'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 created in a glacier by waater within it. Category? Ice ages •An retreat in the globe Hubbard Glacier in N.A. (largest tidewater glacier my far). 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 Iztaccibuatl, 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

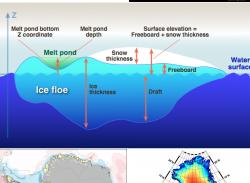
Riiser-Larsen Fimbul Larsen C Ronne-Filchner 422,420 km Wilkins Shackleton Abbott 4 27.000 km Ross

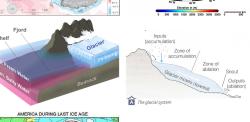


Arctic Sea Ice Thickness - March 2014

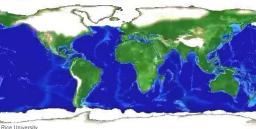


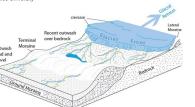












The area of a glacier where light and dark on a glacier; usually found below steep narrow ice- ice gets on top of rock in the seabed, these happen to ice shelves, result of enhanced rainfall during an ice age. (Example: Lake Bo falls and thought to be the result of different flow and ablation they are usually dome shaped •Ice sheet: a dome-shaped mass neville in Utah) •Polar glacier: nore glacier mass is lost than gained Ablation Hollows: allel grooves on the face of a large melting ice crystal Geyser: 50,000 square kilometers (12 million acres), the Greenland and summer or near the bed; polar glaciers are found only in Fountain that develops when water from a conduit is forced up Antarctic ice sheets) • Ice Shelves: ice sheet attached to land, ex-regions of the globe or at high altitudes • Pothol ation zone of a glacier: the rock has been plucked from the to the surface of a glacier; also called a negative mill Glacial tends over sea, floats on water ce stream; (1) a current of ice cal channel in ice that is formed by flowing water; usually four ountainside by the moving glacier and is melting out on the ice when a mountain glacier's terminus extends farther in an ice sheet or ice cap that flows faster than the surrounding after a relatively flat section of glacier in a region of trans urface Ablation Season: Period during which glaciers lose more downvalley than before; occurs when a glacier flows downvalley ice (2) sometimes refers to the confluent sections of a branched-crevasses; also called a mouline Push moraine they gain; usually coincides with summer Ablati faster than the rate of ablation at its terminus Glacial Erratic: valley glacier (3) obsolete synonym of valley glaciers Lee Tongue; ahead of an advancing glacier Quarternary; Area or zone of a glacier where snow and ice ablaa boulder swept from its place of origin by glacier advance or rea long and narrow sheet of ice projecting out from the coast- the late Cenozoic c. two million years ago to the present. ceed accumulation Abrasian: rocks within the ice acttreat and deposited elsewhere as the glacier melted; after glacial line to the ocean. •Ice-cemented glacier; a rock glacier that has name refers to the fourth interval of earth time, according ng like sandpaper to smooth and polish the surface below: pulmelt, the boulder might be stranded in a field or forest where no interstitial ice a meter or so below the surface • Ice-cored glacier; early geologists. • Randkluft; a fissure that separates verized rock produced is called rock flour; glacial striations; other rocks of its type or size exist Glacial Formation: 1) Loose a rock glacier that has a buried core of ice Icefall: part of glacier from its headwall rock; like a bergschrund Rec ce at the bottom of a glacier contains large rock fragments. snow (90% air), 2) granular snow (50% air), 3) firm (25% air), a glacier with rapid flow and a chaotic crevassed surface; occurs glacier: a glacier that is reconstructed or reconstituted nd long scratches and grooves; give clues to direction of travel 4) fine-grained ice (<20% air), 5) coarse grained ice (<20% air) where the glacier bed steepens or narrows • Ice field: a mass of other glacier material; usually formed by seracs falling from Area of a glacier where more mass is grooves or gouges cut into the bedrock by glacier ice; similar to an ice cap, and usually smaller and lacking a hanging glacier then re-adhering; also called reconstructed glaci rained than lost Accumulation Season: Period during which gravel and rocks carried by glacial ice and meltwater; also called dome-like shape; somewhat controlled by terrain on Interglacial: A regenerated glacier, or glacier remainie Reconstructed g glacier gains more mass than it loses usually coincides with accumulation Zone: Area of a glacier where more mass is where the ice surrounds debris so the debris starts to move with outburst flood that usually occurs when a glacially dammed lake material; usually formed by seracs falling from a hanging glaci tends farther down valley than before; glacial advance occur continent rises back up after an overlying continental ice sheet, a glacier Kame an irregularly shaped hill or mound composed of glacier, or glacier remainie Regelation en a glacier flows down valley faster than the rate of ablation melts away and the weight of the ice is removed. Takes thou- sand gravel and till that accumulates in a depression on a retreat- through ice by melting and freezing that is caused by press s terminus Alpine Glacier: A glacier that is confined by sursands of years •Glacial retreat: when the position of a mountain ing glacier, and is then deposited on the land surface with further differences; this process allows a glacier to slide past small nding mountain terrain: also called a mountain glacier •Arête glacier's terminus is farther upvalley than before; occurs when melting of the glacier. •Kettle Hole: A circular depression in the stacles on its bed•Regenerated glacier: Sharp, narrow ridge formed as a result of glacial erosion from a glacier ablates more material at its terminus than it transports ground made when a block of ice calves off the toe of a glacier, constructed or reconstituted out of other glacier material; up ooth sides •Band Ogives: Alternate bands of light and dark on a into that region Glacial striations: grooves or gouges cut into the becomes buried by till, and later melts. •Kettles: irregular till ally formed by seracs falling from a hanging glacier then placier: usually found below steep narrow icefalls and thought to bedrock by gravel and rocks carried by glacial ice and meltwater; thickness and depressions where large blocks of ice melted within adhering; also called reconstituted or reconstructed glacier. the result of different flow and ablation rates between summer also called glacial grooves Glacial Subsidence: The sinking of the the till •Knife Edged Ridges/ ridges between glacier remainie. Retreat: and winter Basal Sliding: The sliding of a glacier over bedrock: surface of a continent caused by the weight of an overlying glacial, widening u-shaped glacial valleys that become parrower until they, doesn't extend as far downvalley as it previously did; or nelting point of ice decreases with pressure. •Bergschrund: (Ri Crevasse that separates flowing ice from stagnant ice at mixtures of clay, silt, sand, gravel, and boulders; the usual com- a ridge-shaped moraine deposited at the side of a glacier and whose terminus is increasingly retreating upvalley position of a moraine Glacial Toe: The leading edge or margin of composed of material eroded from the valley walls by the moving its previous position due to a higher level of ablation compa r more tributary glaciers that flow into it: distinguished simple valley glacier that has only a single tributary past by any form of glacier is said to be glaciated • Glacial Polished ing the Pleistocene Epoch • Leeward Side: Side of a natural or of silt- and clay-sized particles that a glacier cree urface: A polished rock surface created by the glacial abrasion man made elements that does not receive wind \(\bullet \) Loess: wind- laden ice scrapes over bedrock; usually flushed out in meltwi of the underlying substrate. • Glacier: a mass of ice that orig. blown silt deposits blown away from the floodplains and bars of streams, causing water to look powdery gray; lakes and occ inates on land, usually having an area larger than one-tenth of the outwash streams that built up as sand dunes and a frosting that fill with glacier flour may develop a banded appearance. a square kilometer; many believe that a glacier must show some of fine silt •Luis Agassiz; Proposed that ice ages occurred in the glacier; looks like a mountain glacier and has active flow; u type of movement; others believe that a glacier can show evidence past •Marginal crevasse: a crevasse near the side of a glacier ally includes a poorly sorted mess of rocks and fine materia ating, but not enough to stop ablation • Calving of past or present movement Glacier cave: a cave of ice, usually formed as the glacier moves past stationary valley walls; usually may include: (1) interstitial ice a meter or so below the which a block of a glacier breaks off and falls into the sea to form underneath a glacier and formed by meltwater; cave entrances are oriented about 45 degrees up-glacier from the side wall Mass Bal- ("ice-cemented"), (2) a buried core of ice ("ice-cemented"), A semi permanent mass of firm often enlarged near a glacier terminus by warm winds; most com- ance: the difference between accumulation levels and ablation (3) rock debris from avalanching snow and rock Roge ormed by drifted snow behind obstructions or in the ground; also a ridge-shaped moraine in the middle of a A Rogen moraine (also called ribbed moraine) is a subglace called a snowdrift glacier or a drift glacier • Chattermarks: in which strong reflection of the sun on an icy surface causes a glacier originating from a rock outcrop, nunatak, or the converg- (i.e. under a glacier or ice sheet) formed type of moraine land tions or marks left on the surface of exposed bedrock caused by he advance and retreat of glacier ice Cirque: Bowl shaped or purst of water released by a glacier Glacier flour: a fine pow-duit: a channel within, underneath, on top of, or near the side Canada. They cover large areas that have been aphitheater usually sculpted out of the mountain terrain by a der of silt- and clay-sized particles that a glacier creates as its of a glacier that drains meltwater out of the glacier; usually kept and occur mostly in what is believed to que glacier Cirque Glacier: Glacier that resides in basins o rock-laden ice scrapes over bedrock; usually flushed out in melt- open by the frictional heating of flowing water that melts the ice eas of the ice sheets •Sastrugi: ater streams and causes water to look powdery gray; lakes and walls of the conduit. a mound, ridge, or other distinct by winds on the surface of hard snow, especially in teristic circular shape, with their width as wide or wider than oceans that fill with glacier flour may develop a banded appear- accumulation of glacial till. Moraine shoal: glacial moraine that Sedimentary ogives: alternating bands of light and dark at the length • Cold Glacier: Glacier in which most of the ice is bewell-bonded ice crystals has formed a shallow place in water●Moulin: a nearly vertical firm limit of a glacier; the light bands are usually young and light the pressure melting point; nonetheless the glacier's surface compacted from snow with a bulk density greater than 860 kilo- channel in ice that is formed by flowing water; usually found af- est at the highest level un-glacier, becoming increasingly of susceptible to melt due to incoming solar radiation, and grams per cubic meter (55 pounds per cubic-foot) Glacier mill: ter a relatively flat section of glacier in a region of transverse and darker as they progress down-glacier Sera the ice at the rock/ice interface may be warmed as a result of the a nearly vertical channel in ice that is formed by flowing wa- crevasses; also called a pothole Mountain glacier: a glacier that block of ice that is formed where the glacier surface atural (geothermal) heat from the earth's surface Compression ter: usually found after a relatively flat section of glacier in a re- is confined by surrounding mountain terrain; also called an alpine Sichelwannen- curved grooves formed by water under Flow that occurs when glacier motion is decelerating gion of transverse crevasses Glacier pothole: potholes formed at glacier Negative a geyser: a fountain that develops when pressure at the base of a glacier Sintering own-slope Constructive Metamorphism: Snow metamorphism the bottom of glaciers through erosion caused by sand and gravel water from a conduit hat adds molecules to sharpen the corners and edges of an ice vstal Continental Glacier: A glacier that covers much of a connent or large island • Corrie: A hollow containing a small glacier hat is armchair shaped •Cordilleran Ice Sheet: vered much of the mountains in the northwestern part of North falling from a hanging glacier, then re-adhering; also called recon- on a glacier surface; Dark= summer, Light=winter. They kind of Drift: Sediment laid down by glaial meltwater (lass stals that develop by sublimation in glacial crevasses and in lowest end of a glacier; also called glacier terminus or toe Glacier faster than the sides Outburst flood: any catastrophic flood- and temperate: usually predominantly below freezing, but cou the bottom of the ice of a glacier Glacier table: a rock ing from a glacier; may originate from trapped water in cavities experience extensive summer melt Surging hich water vapor can accumulate; physical origin is similar to that resides on a pedestal of ice; formed by differential ablation, inside a glacier or at the margins of glaciers or from lakes that experiences a dramatic increase in flow rate, 10 to 100 times fast Any part of a glacier which has ceased between the rock-covered ice and surrounding bare ice • Glacier ter- are dammed by flowing glaciers • Outlet glacier: a valley glacier than its normal rate; usually surge events last less than one; flow: dead ice is usually covered with moraine Dirt Cone: the lowest end of a glacier; also called glacier snout or which drains an inland ice sheet or ice cap and flows through a and occur periodically, between 15 and 100 years. e-shaped formation of ice that is covered by dirt: a dirt cone toe Glacier toe: the lowest end of a glacier; also called glacier gap in peripheral mountains Outwash Plain: Formed when sand summer months when the glacier is melting there will caused by a differential pattern of ablation between the dirtsnout or terminus Glacier trough: u-shaped valleys transformed is eroded, transported and deposited by meltwater streams from sunspots Tarn; a small mountain lake or pool; a mountain lake or pool; ered surface and bare ice Drain Channel: Preferred path for from v-shaped stream valleys due to erosion caused by passing the glaciers snout and nearby till deposits to areas in front of formed in a circue excavated by a glacier. A moraine may form ltwater to flow from the surface through a snow cover•Drif A semi-permanent mass of firn formed by drifted snow laid at present by a glacier is said to be covered; the alternative cal geometries displayed across the ground surface in relation to also called the glacier toe or glacier snout. obstructions or in the ground; also called a catchment snowdrift glacier Drumlin: Remnant elongated hills continuous layer of till near the edge or underneath a steadily re-result of surface disturbances caused by thermal anomalies and glacier. Tidewater glacier: rmed by historical glacial action; it is not clear exactly how they treating glacier Grooves: larger striations, created when larger freeze processes such as frost heave. Frost heave will disturb the the ocean Till: formed and why they form only in some glaciated regions • D rocks scape bedrock beneath a glacier • Halocene: 10,000 years frost layer as ice lenses accumulate and protrude, causing unsta- Tor: A high rock, a high rocky hill, or pile of rocks. A glacier so cold that its base remains frozen ago-present day Hanging glacier; a glacier that terminates at ble soil conditions. Can be polygons, circles, stripes, nets, and a projection of the ice edge up to several km in length caused the substrate, also called a polar glacier. Occur in regions or near the top of a cliff. Hanging valley: a valley formed by steps. Paternoster lakes: a series of tarns connected by a sin- wind and current; usually forms when a valley glacier moves ye here atmospheric temperatures stay so cold all year long that the a small glacier that has a valley bottom relatively higher than gle stream or a braided stream system Periglacial, relating to quickly into a lake or ocean Tributary glaci lacial ice remains below melting. Mars also has polar glaciers. nearby valleys formed by larger glaciers Headwall; a steep cliff, or denoting an area adjacent to a glacier or ice sheet or other- that flows into a larger glacier Valley glacier A mound or layer of moraine formed along usually the uppermost part of a circue. Horn: a peak or pinnacle wise subject to repeated freezing and thawing Piedmont glacier: whose flow is confined by valley walls. Varye: he edge of a glacier by rocks that fall off the ice; sometimes thinned and eroded by three or more glacial cirques Hummock large ice lobe spread out over surrounding terrain, associated deposited during a single year. One layer consists of silt broug called a ground moraine End Moraine: An arch-shaped ridge moraine found near the end of a glacier • Equilibrium Line boundary between the zone of accumulation and the zone Zone of a glacier in which the ablation Fauilibrium Zone mount of precipitation that falls is equal to the amount that elts the following summer Esker: A sinuous ridge of sedimenry material (typically gravel or sand) deposited by streams that under or through the glacier ice Erratics: cave entrances are often enlarged near a glacier terminus by warm m. grains within the formation change shape slowly, new grains which the glacier slides, also called a temperate glacier. vered: grow where old ones disappear. This allows the glacier to move, in regions where atmospheric temperatures become elerating down-slope False ogives: bands of light and land overlaid at present by a glacier is said to be covered; the Plucking the glacier freezing onto masses of rock, and glacier for glacial ice to be at or near its melting point. glacier that were formed by rock avalanching Fjord glacial troughs that fill with seawater Foliation: layering in that has distinctive crystal sizes and/or bubbles: foliice surface with parabolic ago. The Last Ice Age. • Glaciers moving sed- a glacier where there is more ablation than accumulation • ation is usually caused by stress and deformation that a glacier surface; located in accumulation zone •Ice quake: a shaking of iment because of the water in, on and under the glacier •Pluvial operiences as it flows over complex terrain, but can also origi-