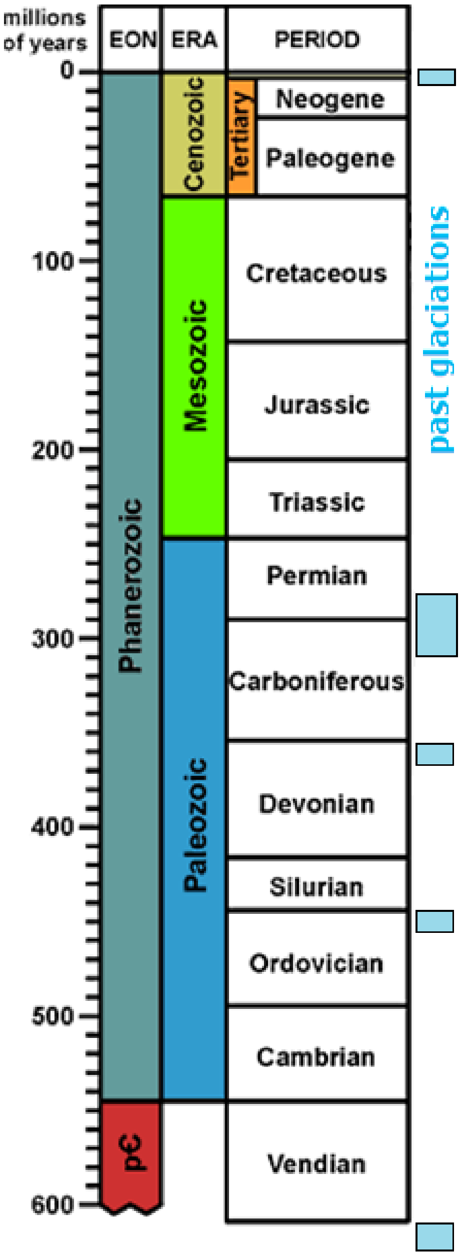
Glaciation and surficial deposits

E1) Past glaciations

For most of the last 3.5 billion years of the earth's history (and possibly for a quite a bit longer) the temperature has stayed at a level that is moderate and suitable for life to flourish. The present global mean annual temperature (MAT) is 15° C, which is probably a few degrees cooler than the average MAT over geological time. We have evidence that past temperatures have been as much as 10° C warmer than this for extended periods (tens to hundreds of millions of years). There is also abundant evidence that it has been colder for shorter periods (millions of years) and that the earth has been glaciated to varying degrees many times in the past.



The most recent glacial period, known as the Pleistocene glaciation, has lasted for about the past 2 m.y., and while we are not in a deep glaciation right now, we are still within this glacial period and it is quite likely that more intense glacial conditions will return within the next few tens of thousands of years. (The Pleistocene glaciation is covered in greater depth below.)

As we'll discuss later, in the context of Plate Tectonics, there was a significant glaciation during the Permian and Carboniferous. At that time most of the earth's land masses were all part of one continent (known as Pangea) situated near to the South Pole, and large parts of Africa, South America, India, Australia and Antarctica were glaciated. This appears to be one of the most enduring glaciations in the geological record, lasting as long as about 40 m.y.

There was also a less extensive and less well understood glaciation in the latter part of the Devonian. Again, most of the evidence for glaciation at this time is in rocks of the land masses that were south of the equator at the time. It appears that another glacial event took place near to the end of the Ordovician.

In addition to these Phanerozoic glaciations, geological evidence from ancient rocks show that some of the most intense glaciations took place in pre-Cambrian times—at 635 m.y. and at 750 m.y., and also at 2200 m.y. ago. These glaciations, accompanied by global MATs as cold as -50° C, appear to have been so intense that the entire oceans froze over—a so-called "snowball earth"—for millions of years. It is proposed that the conditions that allowed such intense glaciation to develop included:

- a concentration of landmass near to the equator,
- continental breakup that would have led to enhanced weathering of rocks and hence consumption of atmospheric CO_2, and
- a powerful positive feedback effect as the build-up of ice led to increased albedo (reflectivity) of the earth, which led to more cooling and more ice and so on.

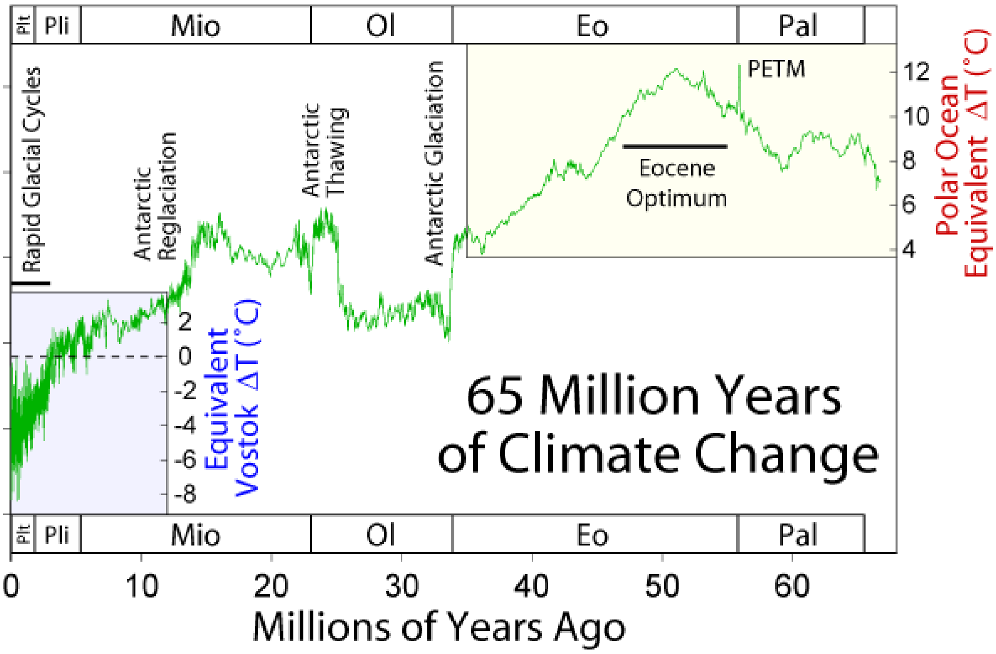
There is abundant geological evidence for snowball earth episodes. In numerous locations rocks have been found that show that glaciation existed in equatorial regions at sea level. (Even during the most intense parts of the Pleistocene glaciation sea-level glaciation was restricted to areas north of 40° N and south of 60° S.) There are also some unique sediments that were deposited on the sea floor during and immediately after snowball-earth conditions, and these are preserved in many different parts of the world.

An important question to ask is: what would have to happen to bring the earth out of a snowball phase? This is interesting because with the oceans and much of the land completely covered in reflective snow and ice, the earth's albedo would be so high that most of the sun's energy would be reflected directly back into space and not converted to heat. In this situation a very high level of atmospheric CO_2 would be necessary to trap enough heat to melt the ice. Energy balance calculations have shown that it would take about 10 m.y. of volcanism for the CO_2 level to get high enough (about 120,000 ppm, or over 300 times the current level!) to overcome the cooling effect of that bright white surface.

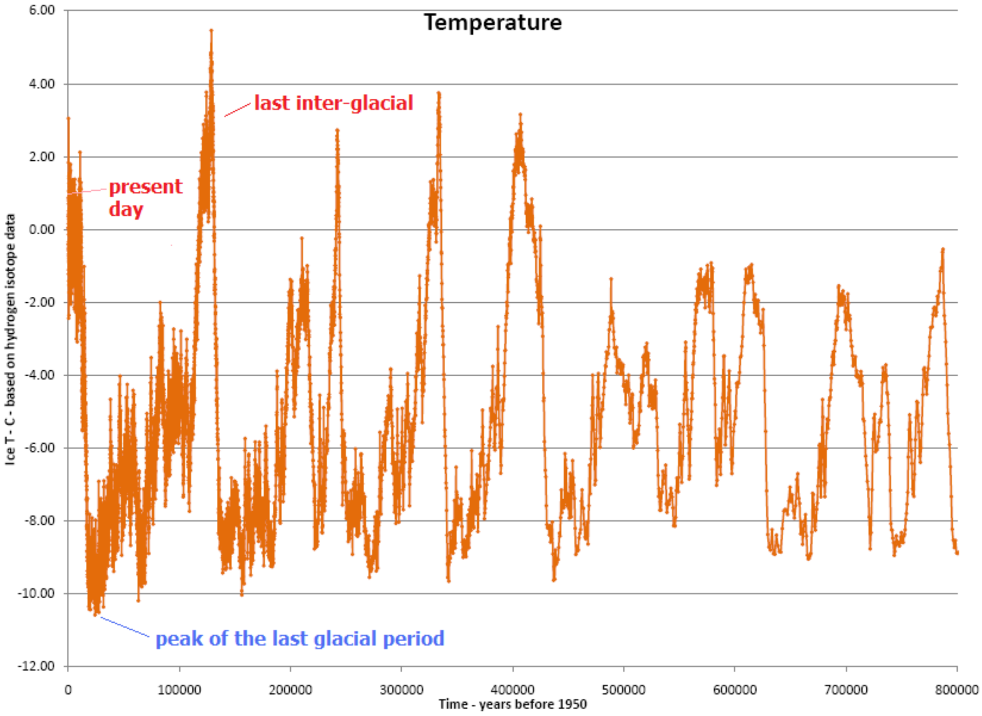
There is lots of information about Snowball Earth at http://snowballearth.org/, and in many other places on the internet. [Snowball Earth is also discussed on p. 459 of the text.]

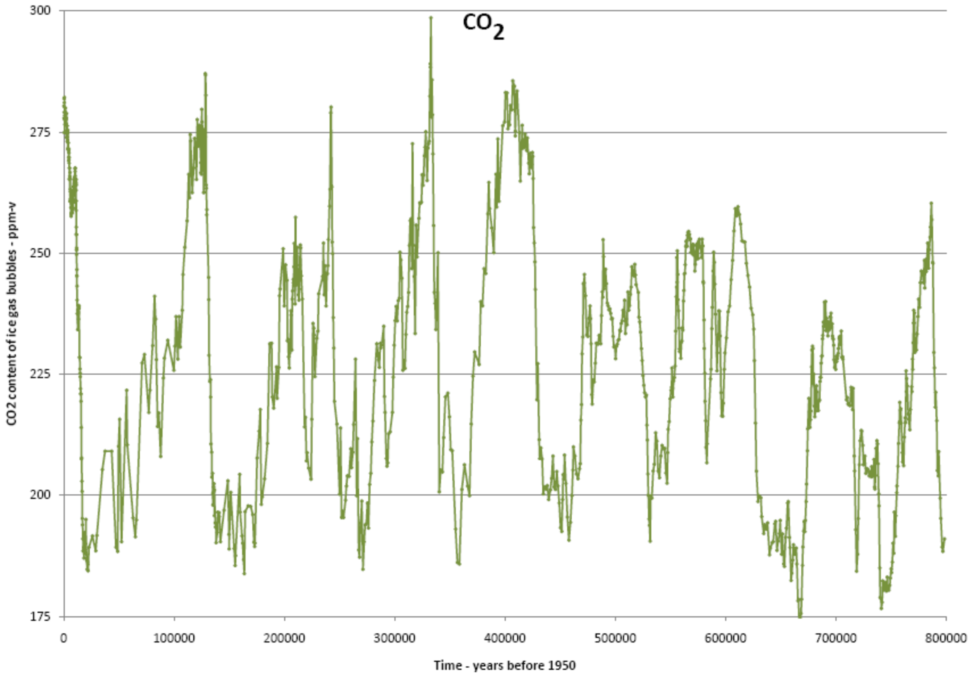
E2) The Pleistocene Glaciation

The earth's climate was consistently warm during the Mesozoic era (i.e., during the Triassic, Jurassic and Cretaceous from 250 m.y to 65 m.y. ago), and as shown on the diagram to the right, that warmth continued up until about 50 m.y. ago. For a variety of reasons—the main ones being tectonic collisions and the formation of mountain chains like the Himalayas—CO_2 levels and temperatures have dropped consistently over the past 50 m.y. As shown on the diagram to the right, the earth's first glaciations in over 200 m.y. took place in Antarctica around 30 m.y. ago and again around 10 m.y. ago. Antarctica has remained glaciated since 10 m.y. ago, and by 2 m.y. ago the earth had cooled sufficiently for glaciation to take hold in the northern hemisphere as well. This glaciation is what we call the Pleistocene glaciation, although as noted above, it continues into the Holocene (which began 12,000



years ago). We know much more about the Pleistocene glaciation than any of the older ones because we still have the remnants of glacial ice in polar and alpine regions, we can see the direct effects of the glacial erosion and deposition on the land around us and we have the means to estimate temperatures and atmospheric characteristics by studying ice cores and other records.





The two diagrams to the right, which are based on data from ice cores drilled in Antarctica, show variations in temperature (relative to the present day) and in atmospheric carbon dioxide levels over the past 800,000 years, or about one-third of the Pleistocene glaciation. (Note that time runs from right to left in these diagrams, the present day is at time=0, on the left). The main thing to observe here is that the Pleistocene glaciation has been highly cyclical in nature. On a fairly regular basis, with a period of around 100,000 years, global temperatures have varied by as much as 14° C. These variations are now known to be caused by minor variations in the earth's orbit around the sun (eccentricity, tilt etc.) – which are referred to as Milankovitch cycles. [See p. 470-471.]

As temperatures fluctuated during the Pleistocene so did the composition of the atmosphere. Carbon dioxide levels ranged from a low of 175 ppm during glacials to a high of nearly 300 ppm during inter-glacials[1].

At the height of the Pleistocene glaciations there was ice in Antarctica and Greenland (as there is still today) and also in northern Europe and over most of northern North America [See Figure 17.29]. The

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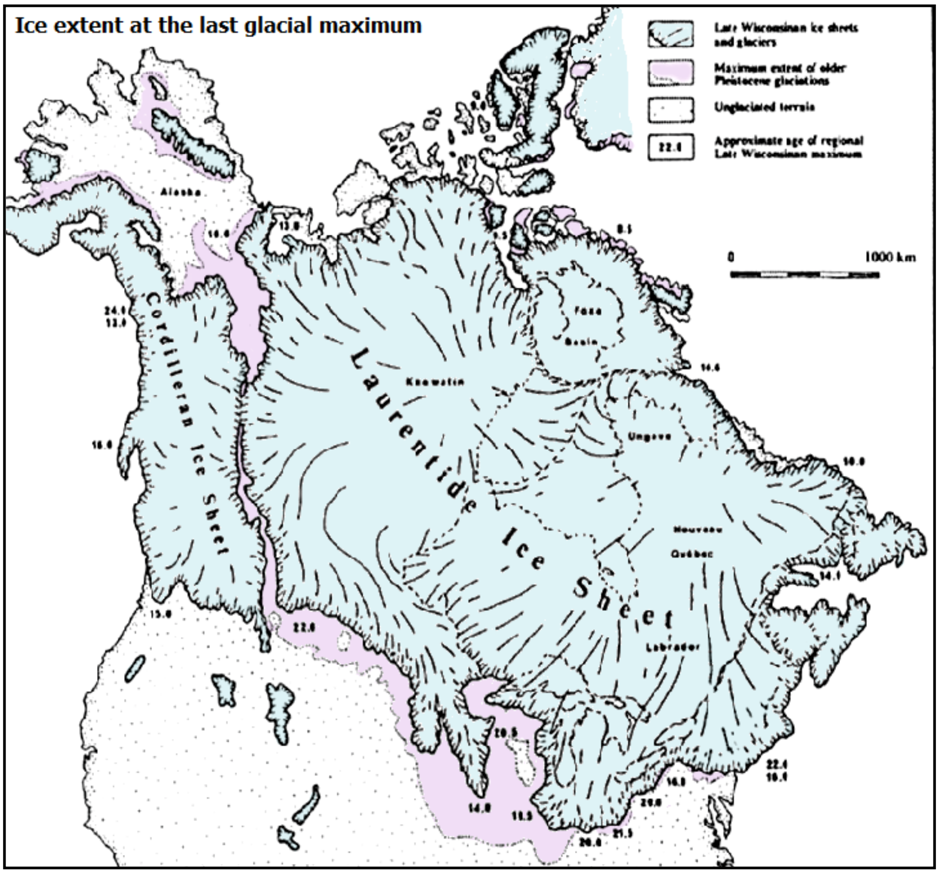
[1] The atmospheric CO_2 level is currently 380 ppm, but this elevated level is mostly due to our impact on the environment, especially the destruction of forests and burning of fossil fuels.



major North American ice mass was the Laurentide Ice Sheet, and it covered virtually of central and eastern Canada and the northern part of the eastern US. At the last glacial maximum the Cordilleran Ice Sheet covered virtually all of BC (including almost all of Vancouver Island) plus parts of Alaska and the Yukon, and it extended into Washington State, as far south as the southern end of Puget Sound (near to Tacoma).

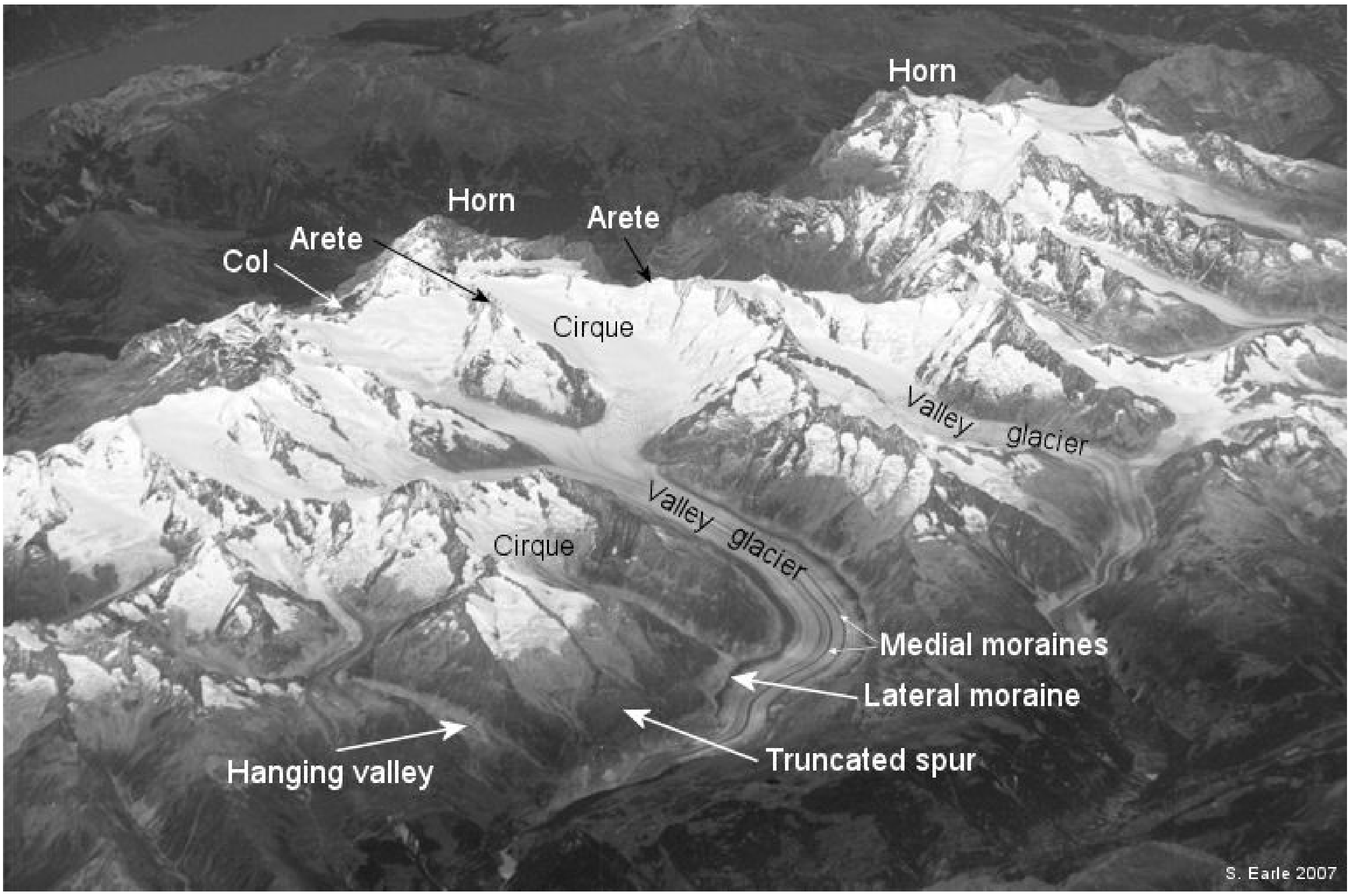
Like the ice in Greenland and Antarctica, these were continental glaciers. They covered millions of square kilometres and flowed outward from areas of accumulation, where the ice would have been thousands of metres thick. Continental glaciers contributed to the erosion of the land surface, in some cases to flat plains, and they also left behind glacial deposits and landforms, including features like eskers and drumlins. [See figure 17.27.]

Eskers are a product of deposition of glacio-fluvial sediments (sand and gravel) from water flowing within a tunnel at the base of an ice sheet.

Drumlins are very common in some areas of continental glaciation. They form beneath the ice and are mostly comprised of glacial till.

At present most glaciers in North America are confined to mountainous regions and we call these “alpine glaciers”. Some alpine glaciers are small and are present only at high elevations near to mountain peaks; others flow for tens of kilometres within steep-sided valleys. In northern areas some even reach the ocean.

Erosion caused by alpine glaciers produces spectacular scenery and many unique landforms, some of which are visible on the photograph below of part of the Swiss Alps. Alpine glaciers carve steep-sided u-shaped valleys with bowl-shaped cirques at their upper ends. The high ground between two adjacent valleys may be carved into a steep ridge known as an arête. Where a tributary glacier meets a larger main-valley glacier that has been eroded more deeply, a hanging valley is created. [For more on glacial erosion features see Fig. 17.13 in the text]



E3 Glacial and non-glacial surficial deposits

Geological deposits that are unconsolidated (have not been turned into rock) are known as *surficial deposits* or *drift*, and can include materials such as clay, silt, sand and gravel. Almost all of the sedimentary deposits produced by recently active processes, including virtually all river, shoreline, and desert deposits, and the deposits of the Pleistocene glaciations, have not been buried deep enough or long enough to become lithified, and hence are surficial deposits. Both continental and alpine glaciers produce several types of surficial deposits, including materials that are moved by the ice itself, and those that are moved by glacial melt water and are deposited in glacial streams or lakes or the ocean. It is important to be aware that glaciers are always producing meltwater, even when they are advancing.

Material moved directly by glacial ice is known as glacial till. It does not get sorted and layered in the same way as material moved by water. It tends to be relatively rich in silt- and clay-sized fragments, but also contains clasts ranging up to boulder size. Most glacial till forms beneath ice sheets, and it gets compressed by the weight of the ice. As shown on the photo below, till can be very strong and hard even though it is not lithified. (Ancient glacial till that has been lithified is known as tillite.) [See Fig. 17.21 for more pictures of till.]

Glacial till at the front of a glacier in Iceland. Note absence of layering and sorting, and angular shape of many of the clasts. This material is rich in clay and is quite strong.

Glacio-fluvial sediments at a gravel pit near to Nanaimo. Note the layering and sorting (some layers are coarser than others) and the rounded clasts.

Sediments deposited by rivers flowing out of glaciers are known as glacio-fluvial sediments. They are commonly quite coarse-grained (as shown in the photo above) and, unlike glacial till, they tend to be well bedded and sorted. If glacial meltwater flows into a lake or the ocean the fine material will be deposited as glacio-lacustrine or glacio-marine sediments.

Even though glacial sediments are very common in our region, there are also non-glacial deposits all around us. These include river sediments, lake sediments and gravity deposits. Although rare in British Columbia, wind-blown (aeolian) deposits are common in some other parts of the world.

Fluvial sediments

Gravity deposits

Wind-blown (aeolian) deposits

Fluvial sediments are common in river valleys, and like glacio-fluvial sediments, they tend to be bedded and well sorted, with well-rounded clasts. Lake sediments are typically very fine (silt and clay) and in many cases show well defined lamination (fine bedding). In most cases the sediments within lakes cannot be easily observed because they are still under water, but where the lake level has dropped in the recent geological past the lake old sediments might be exposed around the shoreline. A good example of this is Okanagan Lake, the level of which was much higher shortly after the last glaciation.

Gravity deposits accumulate at the bases of steep cliffs in areas of rapid mechanical erosion (typically as a result of freezing and thawing). Such deposits are known as *scree* or *talus*, and they comprise clasts that are almost exclusively angular because they have not been moved far or by water. The fragments that make up a talus slope are commonly comprised of only one type of rock because most of them have simply fallen down from the cliffs above. Gravity deposits also include the material moved during major rock slides (such as the Hope Slide – see photo to the right) or other slope failures.

Aeolian deposits accumulate in areas where winds are quite strong and there isn't enough vegetation to stabilize the sandy material. Most of the grains are sand-sized, and it is quite typical for them to be dominated by quartz.

Questions

1. How many glacial periods (that we know of) have taken place during the Phanerozoic eon?
2. Explain how a snowball earth glaciation is thought to have been initiated.
3. What is the connection between planetary albedo and glaciation?
4. What is the connection between atmospheric carbon dioxide levels and glaciation?
5. What has been the dominant period of climate variability during the past 500,000 years of the Pleistocene glaciation, and what is the origin of those variations?
6. What are the names given to the two major ice sheets that covered parts of North America during the most recent glacial period?
7. How does an esker form?
8. What is the difference between continental and alpine glaciation?
9. Identify some of the glacial erosion features visible in the photo to the right.
10. What are some of the differences between glacial till and glacio-fluvial gravel?
11. What would you look for in order to distinguish between glacial till and gravity deposits related to freezing and thawing?