GEOL100
5-3-10
Continental glaciers and Ice ages

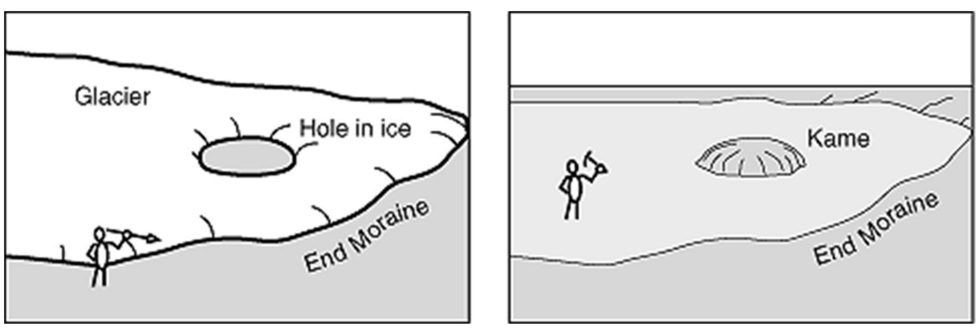
Climate change as a reality of nature: By the 18th century, literate people recognized that climate conditions described by Classical and Medieval authors were often different from those that they witnessed. Today we note that the canals of the low countries are no longer the reliable winter highways for skaters depicted by Peter Brueghel or described in *Hans Brinker, or the Silver Skates.* It is apparent that climate changes over time. As the science of geology arose, the attention of geologists was drawn to ancient climates for which no eye-witness accounts existed.

Louis Agassiz: (1807 - 1873) Swiss geologist, paleontologist, paleoclimatologist. Investigated reports of glacial erratics (glacier-transported boulders) in places where contemporary glaciers couldn't possibly transport them, such as the Jura Mts. of France and Switzerland. In 1840, published *Etudes sur les glaciers* (*Study of Glaciers*), proposing that the prehistoric Earth had experienced an **ice age** in which a continental glacier similar to that of Greenland had covered the Alps and had lapped against the Juras. As more information rolled in, it became clear that the the ice age glaciations had occurred at high elevations throughout the world and throughout high latitudes.

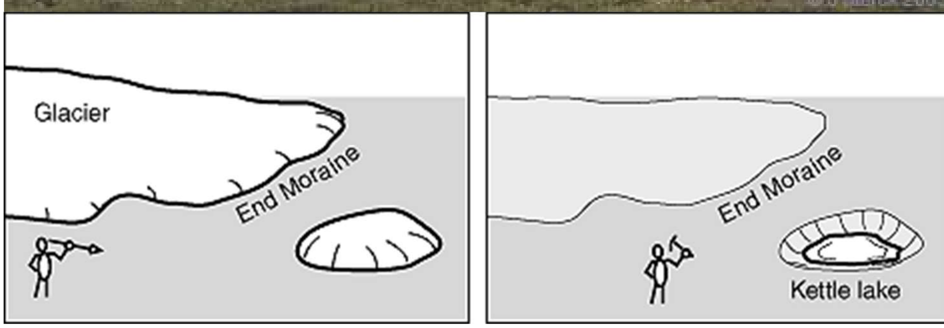
To know what kind of landforms led to this conclusion, one needs to understand the deposition of continental glaciers today:

Land forms resulting from continental glaciers: Continental scale glaciation creates interesting opportunities for ice to interact with large volumes of sediment. Results include:

- **Drumlin**: Hills made of reshaped glacial till (not bedrock like a roche moutonee.
  - The steep end is on the side of the ice's approach
  - The shallow end points in the direction of ice movement



- **Kame** [Scots"comb." Pronounced like English "came"]: Hills of stratified drift that form when a stream deposits sediment in a hole in the glacial ice.



- **Kettle lake**: This is essentially the opposite of a kame. When a block of glacial ice is stranded by a retreating glacier, it prevents sediments from being deposited. When if finally melts, a depression is left that fills with water. Think of Minnesota - the land of 1000 lakes. these lakes are mostly kettles formed during the retreat of a continental ice sheet.

- **Esker** [Irish Eiscir - "ridge"]: Long sinuous ridge of stratified drift. Results from sediment deposited in the point bars of under-glacier stream.

Periglacial features: Beyond features created by glacial ice, itself, the regions adjacent to continental glaciers display characteristic features owing to:

- **Permafrost** in subsurface.
- **Intense freeze-thaw cycles** at surface

Resulting land-forms reflect interaction of regolith and ice:

- **Patterned ground** - Polygons formed by ice wedges. extending into the soil.

- **Pingoes** - Bodies of ice that rise up through the regolith in response to burial pressure.

Ice ages:

So what has the global distribution and age of the glacial and periglacial features taught us?

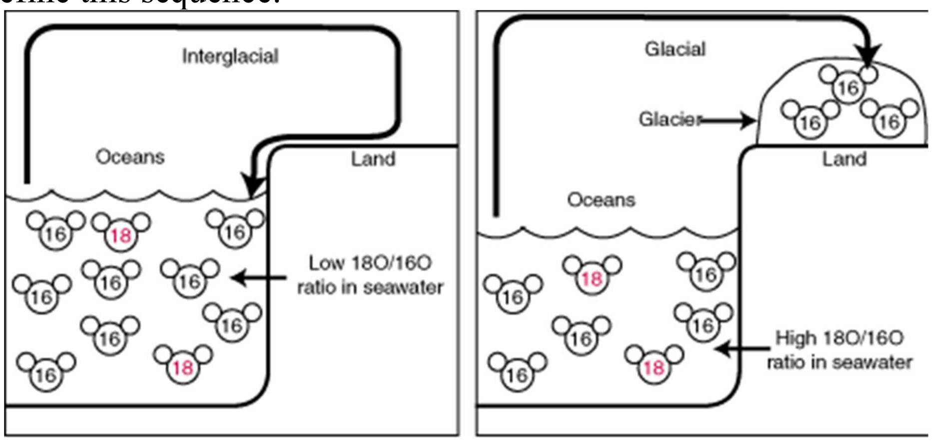
The Cretaceous and early Paleogene was a **greenhouse world**. From the Late Plaeogene onward, we have been in an **ice house conditions** occurred during that interval. During last 2 million years (the Quaternary Period), the situation has become extreme, an **ice age** with major continental **glaciations** alternating with **interglacials**. The interval from 2 mya to 10,000 years ago is called the **Pleistocene Epoch**. The last interglacial of the Quaternary Period (the one we are in) is the **Holocene Epoch**.

Pleistocene temperature and "proxy data": The first reliable thermometers went into use in Italy in the late 17th century. The first continuous records of daily temperature didn't begin until the early 19th century in England, so how do we know about ancient temperatures? We infer them indirectly through **proxy data**:

- **Glacial landforms**: document the presence of glaciers, but are a very blunt instrument. The problem with glaciers is that they don't record temperature precisely and that new ones bulldoze away the traces of older ones. As a result, ancient moraines and such only tell us so much about the history of glacial intervals.

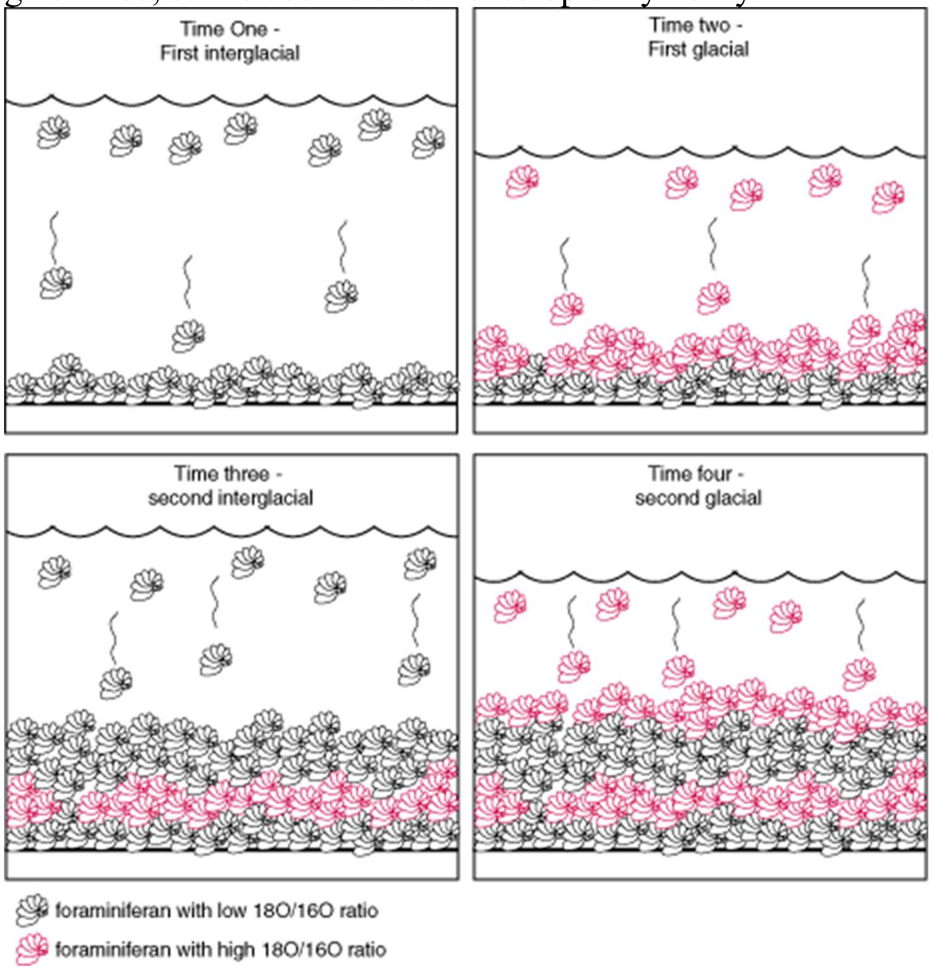
- **Geochemical data** gives a clearer picture.

The Oxygen isotope record: During the late 20th century, a new technique allowed us to refine this sequence.

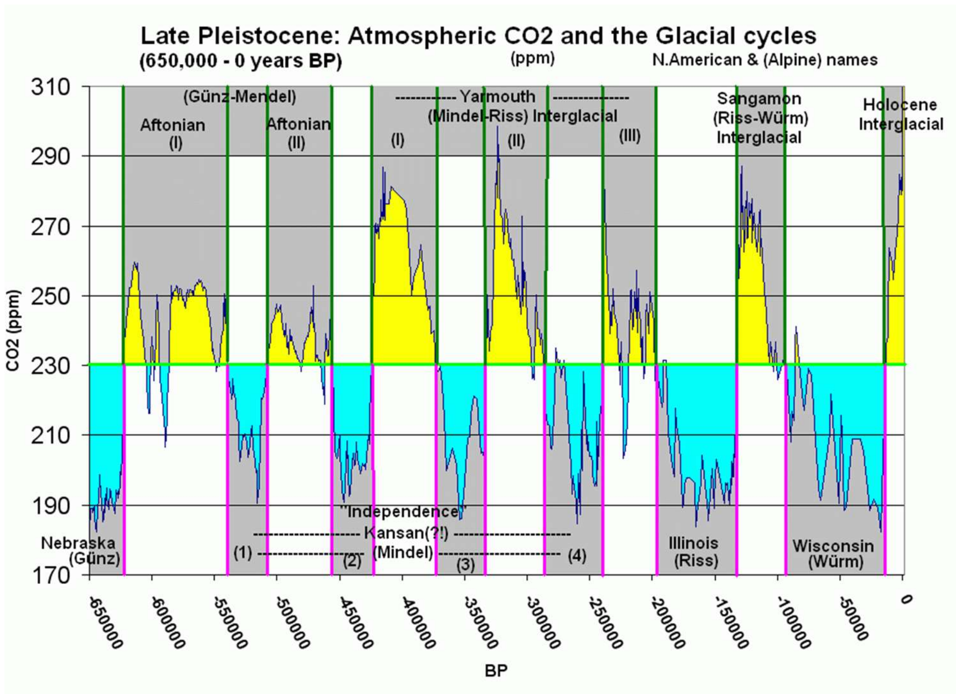


- **The method**:
  - There are several stable (i.e. non-radioactive) isotopes of oxygen. The most importatn are ^{16}O and ^{18}O.
  - When ocean water evaporates, molecules containing the lighter isotope of oxygen, ^{16}O, are more likely to "take off."
  - Normally, this wouldn't cause any permanent change in the oceans' isotopic chemistry because the molecules would return tot he ocean soon enough as rain. During an ice age, however, the water is locked up in

glacial ice, so the oceans become isotopically heavy.



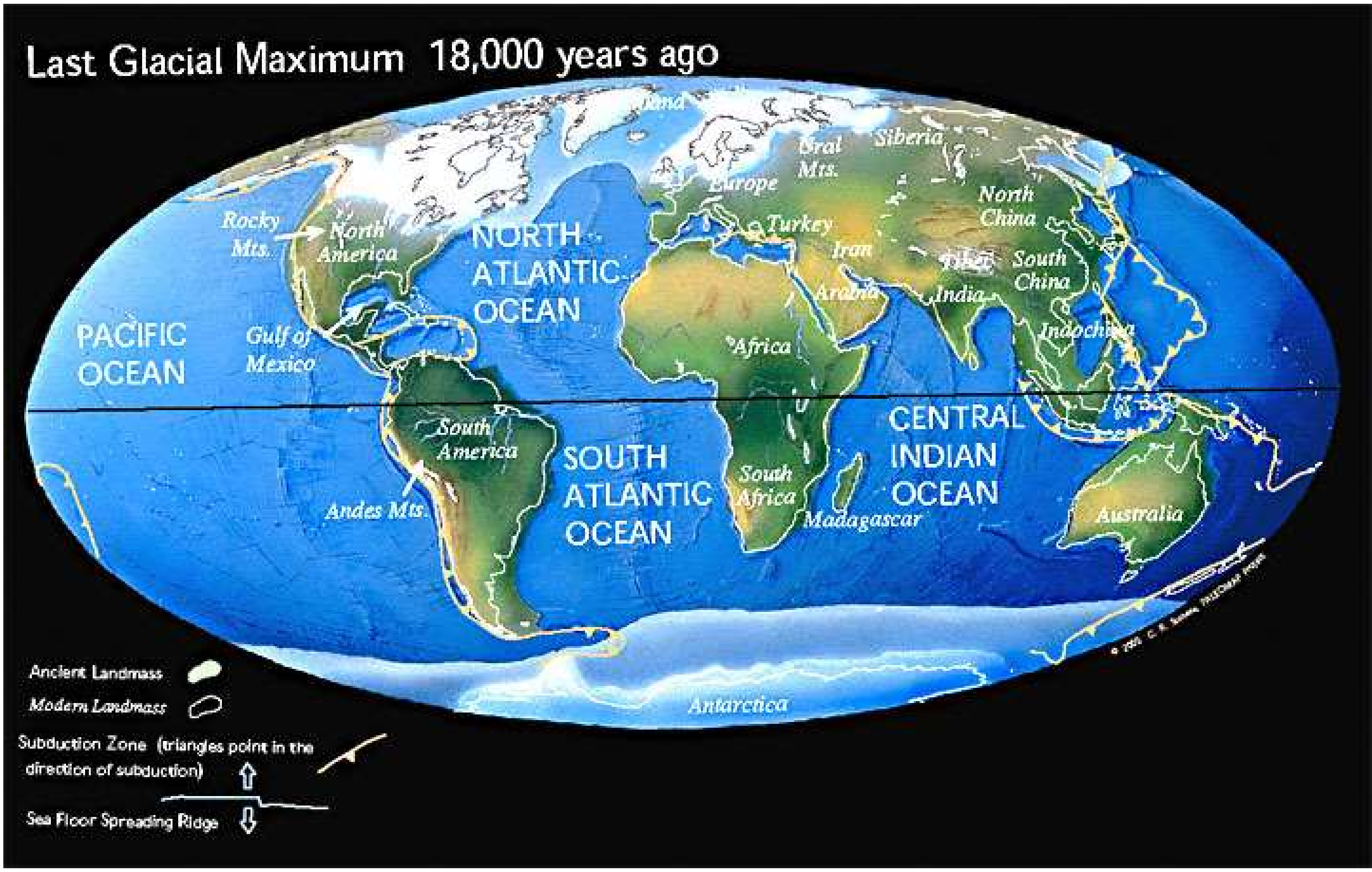
- Now the magic: Critters like foraminiferans are constantly sampling the oceans' oxygen by building it into their $CaCO_3$ shells. When they die and fall to the bottom, they create a record of oceanic oxygen isotopes during their lives.
- We can reconstruct the ocean's **isotopic history** by looking at the ratio of oxygen isotopes present in foraminiferan shells deposited at different times. **That ratio**, in turn, tells us how much water was locked up as continental ice.



- **The result**:

  Apparently there were closer to thirty distinct glacials and interglacials. On a longer time scale, we see that these cycles have gradually increased in severity.

Condition 18,000 years ago during the last glacial maximum:

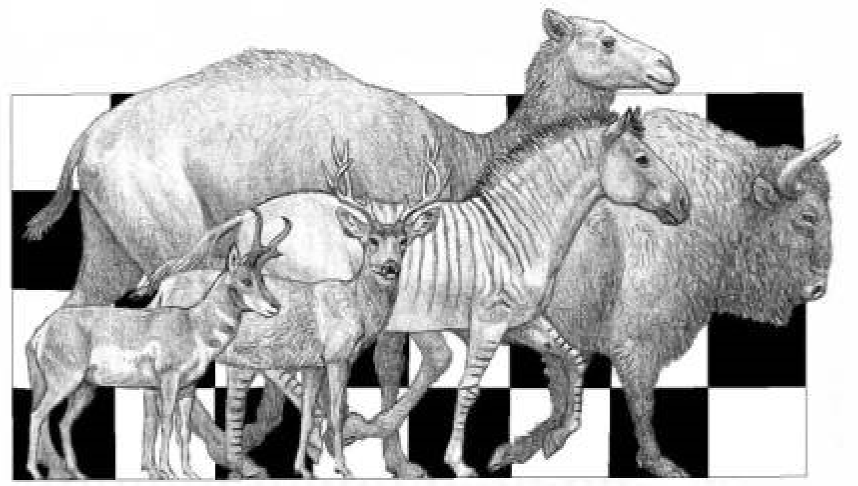


- Today's ice caps grew to 3x their current area and were up to 3 km thick
- Cold weather zones expanded and warm weather zones contracted into a thinner strip of warm tropical weather.
- Regions of highest rainfall shifted to higher latitudes, forming large, rain-fed **pluvial lakes**. (These can be mapped using ancient wave-cut platforms).
- The land **deformed isostatically** upon loading by the ice sheets. In some locations, the land is still responding isostatically to the removal of the ice. E.g. Scandinavia (1m / century), Ohio valley.
- As a consequence of isostatic deformation, the land buckled downward near the edge of the ice. Glacial meltwater pooled up at margins of glaciers forming large **meltwater lakes**. The Great Lakes are stranded remnants of such.
- At the climax of the last glaciation, **18,000 years ago**, accumulation of all that ice and snow - **sea level dropped 120 m.** Some of the major geographic differences from the modern Earth (besides the presence of so much continental ice):

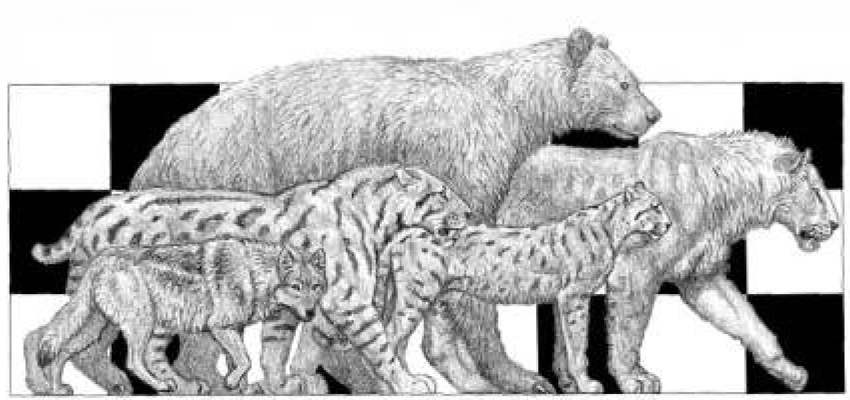
  - **Beringia** - the land bridge across the Bering straites
  - Australia, Tasmania, and New Guinea were one large land mass

- Many of the islands of Southeast Asia were part of the mainland.

• Last remnant of North American Ice sheets melted roughly **10,000 years ago**. At the end of the last ice age lots of North American animals went extinct - especially large plant-eating mammals and the predators that fed on them, including:



- Four species of elephants (e.g. North American Columbian mammoth)
- Native horses (right)
- Giant ground sloths
- Native camels (right)



- Two species of sabre-toothed cat (E.g. ***Smilodon*** (right)
- A native wolf, the **dire wolf** (right)
- A native **pantherine cat, *Panthera atrox*** (long considered to be a North American lion, but recent research suggests that it is closer to jaguars - right)
- A native **cheetah, *Miracinonyx inexpectatus*** (right)
- A native bear, the short-faced bear (right)

Was this due to:

- Changes in climate
- Loss of habitat
- Overhunting by humans? (So called "Pleistocene overkill")

An irrationally emotional debate rages. (Psst! Merck bets on the third option in most cases.)

The Ice-Age is still with us:

In this and many other lectures, we discuss various natural processes and patterns as if the Earth were at equilibrium. **The fact is that it isn't**. We can list ways in which equilibration is still occurring:

- Isostatic rebound is in progress, indicates non-equilibrium of shorelines and river longitudinal profiles. For example, the Ohio River has incised its old meander loops as the land beneath it rebounds.

- Eastern Canada and New England occasionally experience earthquakes caused by rebounding bedrock.
- Normal drainage patterns have still not been established for regions that were under the ice.
- Many species of trees are still adjusting their ranges following the melting of the ice.

- No one has a freaking clue what the equilibrium ecology of North American forests was like back when they were crawling with elephants. In Africa and Asia these creatures radically transform forests into open savannahs. This probably happened in North America as well. Some people speak of "old-growth" forests as if they were the pristine primeval state of this land, but they, too, are an invention of the Holocene.

None of this is surprising, given that environments had only had 10,000 years to adjust.

Key concepts and vocabulary:

- Climate change is real
- Louis Agassiz: discoverer of ice ages
- Continental glacial landforms
    - Drumlins
    - Kame
    - Kettle lake
    - Esker
- Periglacial features
    - Permafrost
    - Patterned ground
    - Pingoes
- Ice age
- Glacial
- Interglacial
- Pleistocene Epoch
- Holocene Epoch
- Stable isotope record
- ^{16}O
- ^{18}O
- Foraminiferan
- Pluvial lake
- Meltwater lake
- Isostatic rebound
- Sea-level lowstand - 120 m. below present
- Beringia
- "Greater Australia" including New Guinea and Tasmania
- Pleistocene Megafauna of North America
- Extinction of megafauna in North america between 11 and 10 ka.