Ankara University
Faculty of Languages and History-Geography
Department of Geography

Glacial Geomorphology

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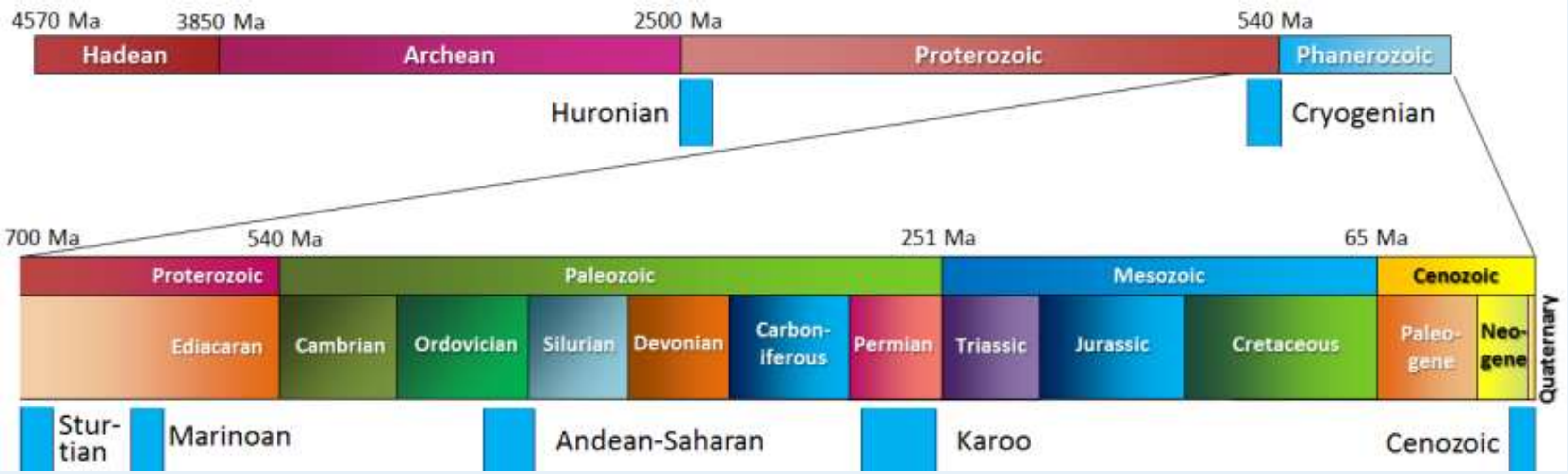
Lecture 6

Quaternary Climate Change – Quaternary Glaciations

- Major Ice Ages in Earth's History:



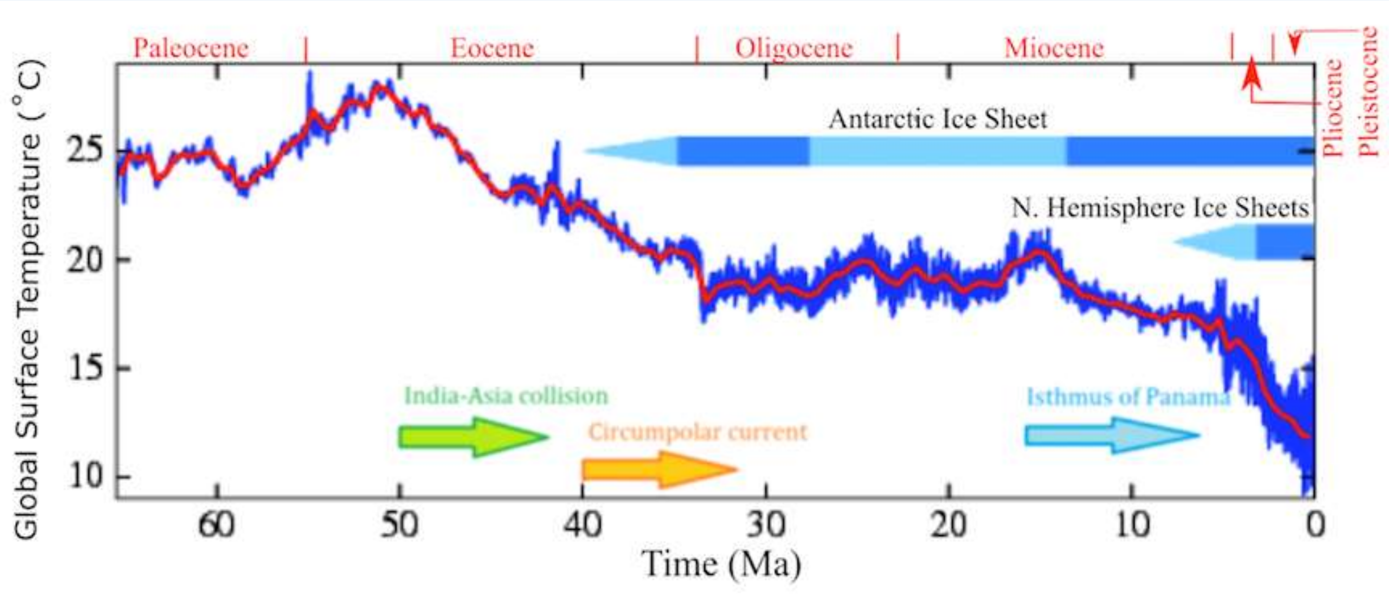
https://opentextbc.ca/geology/wp-content/uploads/sites/110/2015/07/major-past-glaciations.png

- **Huronian Glaciation** (~2.4–2.1 billion years ago): Glacial deposits from the area around Lake Huron in Ontario and elsewhere
- **Cryogenian** Period (~720–635 million years ago): Known for the "**Snowball Earth**" hypothesis, where ice may have extended to the equator. The Snowball Earth hypothesis suggests that, during the Neoproterozoic era, from around 720 to 630 million years ago, the Earth underwent a prolonged freezing period. During this time, thick ice sheets covered the oceans, effectively isolating the Earth's atmosphere from the ocean below. There were two main glacial periods within the Cryogenian, each lasting for about 20 million years: the **Sturtian** at around 700 Ma and the **Marinoan** at 650 Ma.
- **Phanerozoic** (the past 540 million years)
  - Andean/Saharan (Ordovician): recorded in rocks of South America and Africa
  - Karoo (Permian): named for rocks in southern Africa. The Karoo was the longest of the Phanerozoic glaciations, persisting for much of the time that the supercontinent Gondwana was situated over the South Pole (~360 to 260 Ma). Glaciers covered large parts of Africa, South America, Australia, and Antarctica.
  - Cenozoic glaciations

Quaternary Climate Change – Quaternary Glaciations

- Ice Age (Glacial Period)

- The Ice Age refers to a long-term period in Earth's history when global temperatures were significantly lower than today, leading to the expansion of massive ice sheets and glaciers over continents and polar regions.
- These cold periods are part of Earth's natural climate cycles and are interspersed with warmer intervals known as interglacial periods.
- The Swiss geologist and naturalist Louis Agassiz is credited with formally proposing the idea of an "Ice Age" (or "Glacial Period") in a lecture to the Swiss Society of Natural Sciences in 1837.
- According to Agassiz large parts of Europe had once been covered by thick glaciers, presenting evidence such as glacial moraines and erratics. His findings were inspired by earlier studies of modern glaciers in the Swiss Alps.
- Agassiz's groundbreaking book, Études sur les Glaciers (1840), expanded the theory and applied it to larger parts of Europe and North America.



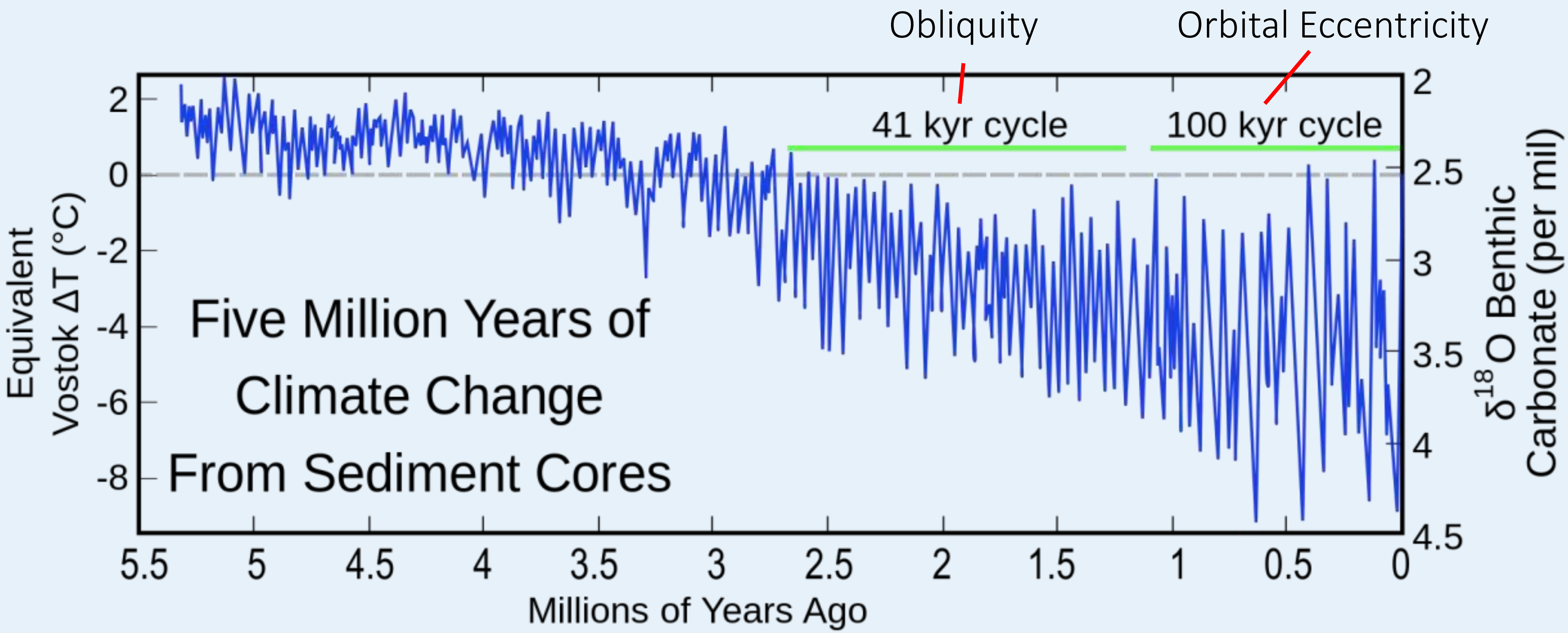
https://opentextbc.ca/physicalgeologyearle/wp-content/uploads/sites/145/2016/03/cenozoic-t-2.png

Quaternary Climate Change – Quaternary Glaciations

- Ice Age (Glacial Period)

Throughout the Pleistocene, global temperatures fluctuated significantly, with changes of nearly 10°C occurring over periods ranging from 40,000 to 100,000 years. These fluctuations led to the cyclical expansion and contraction of ice sheets and are primarily attributed to subtle shifts in Earth's orbital parameters, known as Milankovitch cycles. Over the last million years, these glacial cycles have occurred approximately every 100,000 years.

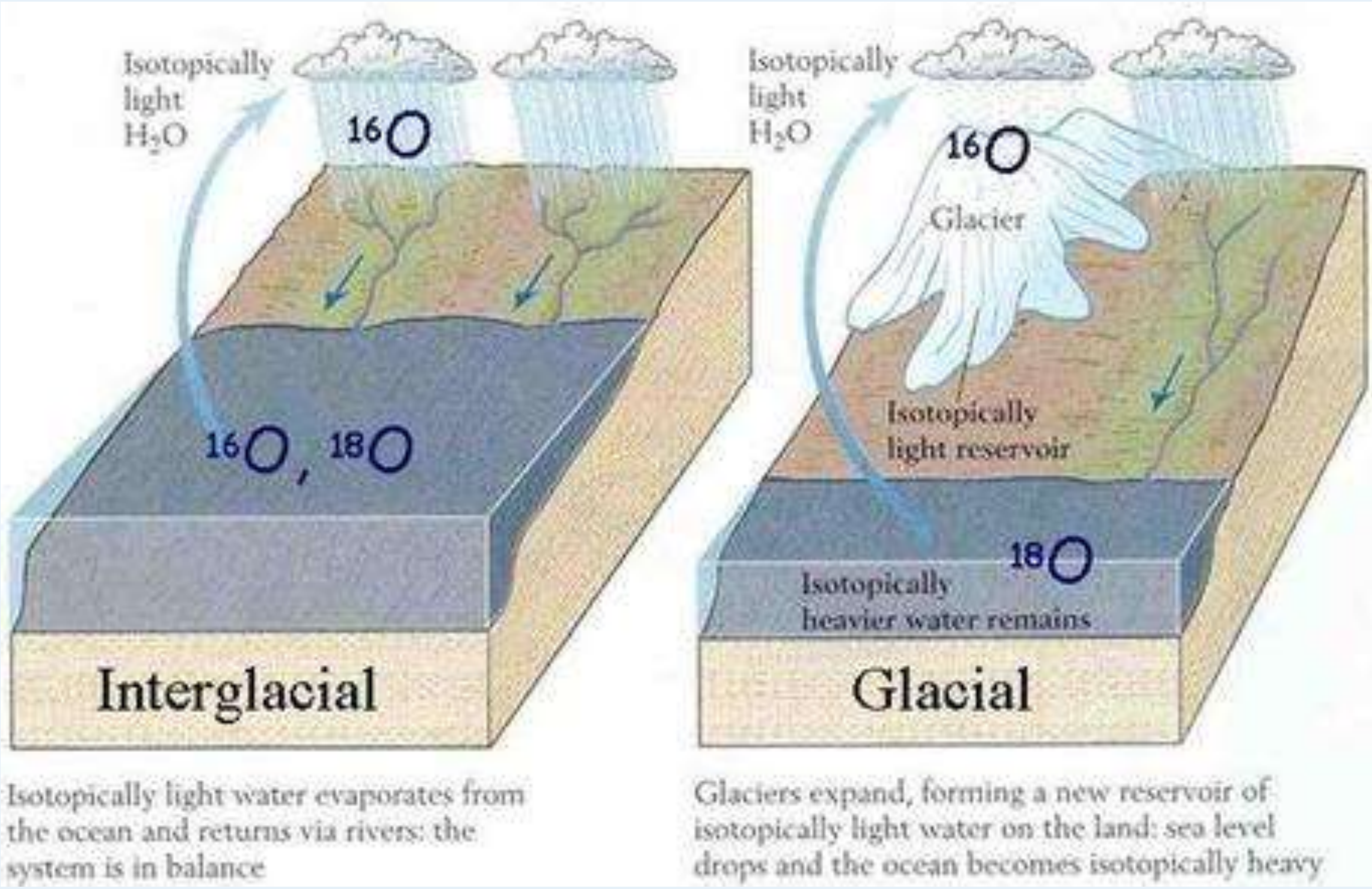
Milutin Milanković hypothesized that glacial cycles were driven by changes in summer insolation at high latitudes, modulated by orbital cycles.



https://www.epj-conferences.org/articles/epjconf/abs/2015/17/epjconf_eps-sif_02001/epjconf_eps-sif_02001.html

Quaternary Climate Change – Quaternary Glaciations

- Ice Age (Glacial Period)

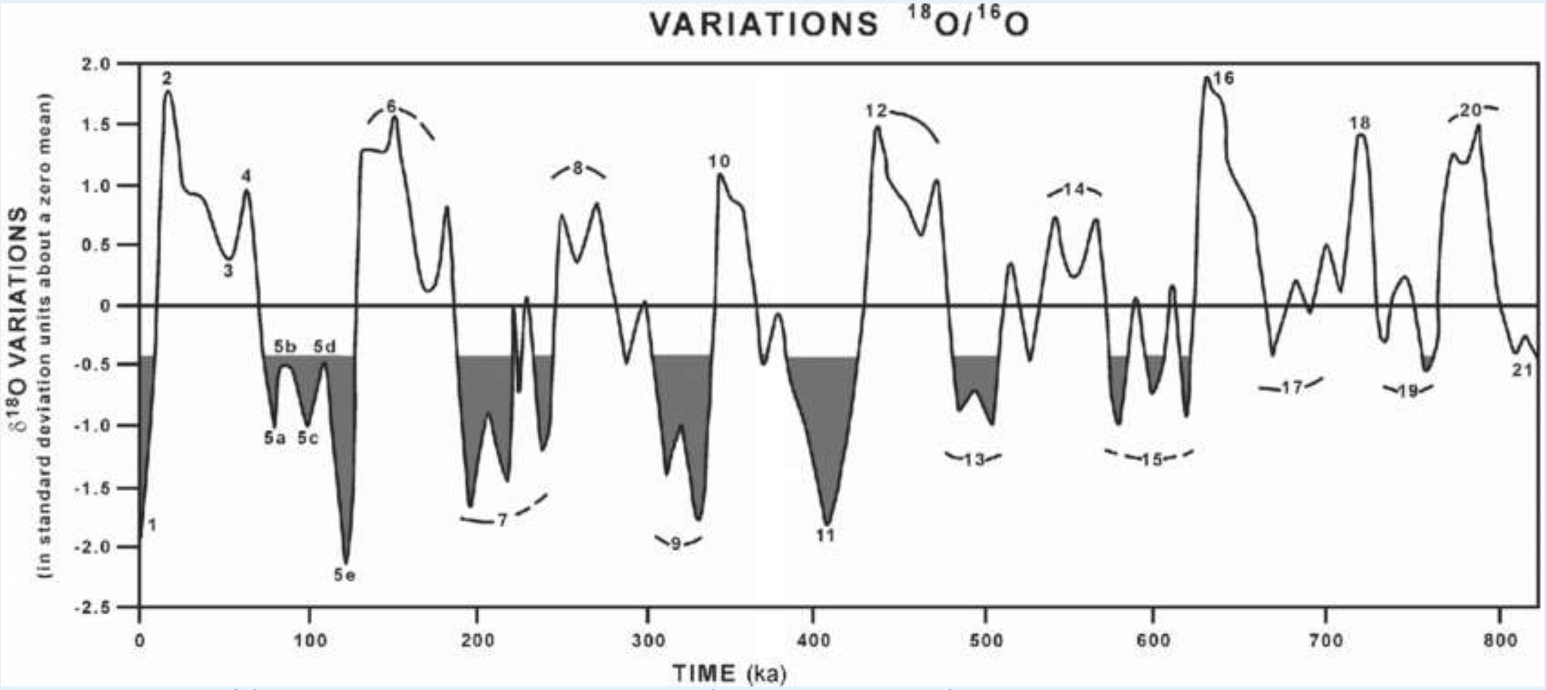


https://serc.carleton.edu/details/images/38316.html

Quaternary Climate Change – Quaternary Glaciations

Ice Age (Glacial Period)

- **Marine Isotope Stages (MIS)** are alternating warm and cool periods in Earth's paleoclimate, deduced from oxygen isotope data derived from deep-sea sediment cores. These stages are identified based on the ratio of heavy oxygen isotopes (^18O) to light oxygen isotopes (^16O) in the calcium carbonate shells of foraminifera, microscopic marine organisms.
- During cold (glacial) periods, more ^16O is trapped in ice sheets, leading to a higher ratio of ^18O in seawater and marine sediments.
- During warm (interglacial) periods, ice sheets melt, returning ^16O to the oceans, lowering the ^18O ratio in marine records.
- Odd-numbered stages (e.g., MIS 1, 5) represent interglacial (warmer) periods.
- Even-numbered stages (e.g., MIS 2, 6) represent glacial (colder) periods.

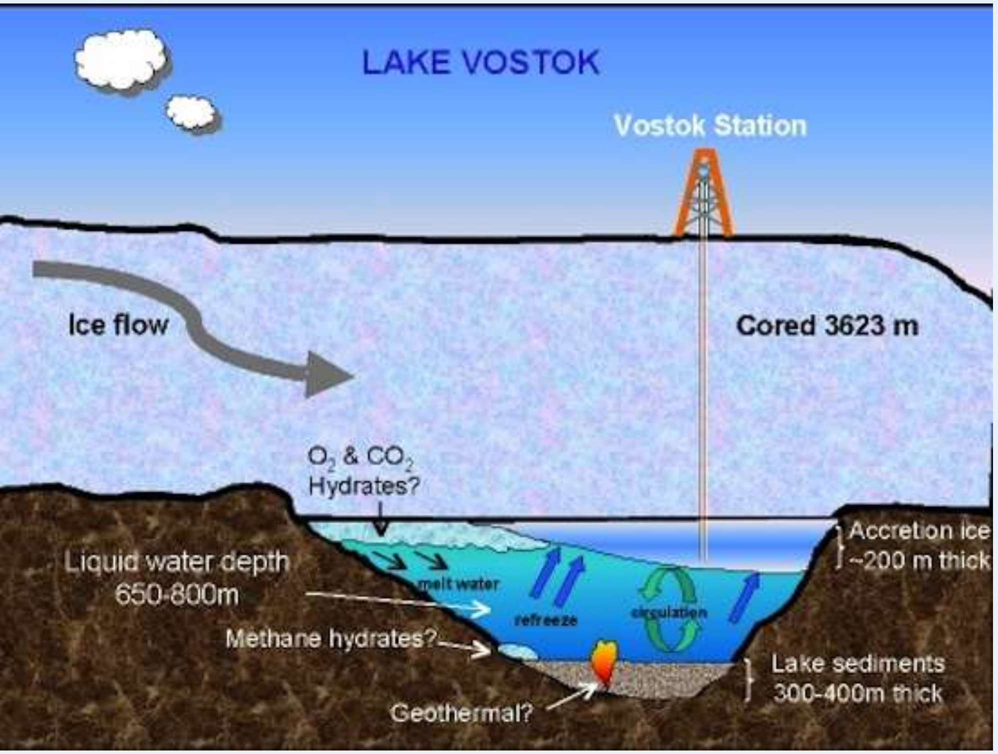


https://www.researchgate.net/publication/258486550_Walsh_T_J_Polenz_Michael_Logan_R_L_Lanphere_M_A_Sisson_T_W_2003_Pleistocene_tephrostratigraphy_and_paleogeography_of_southern_Puget_Sound_near_Olympia_Washington_In_Swanson_T_W_editor_Western_Cordille/figures?lo=1&utm_source=google&utm_medium=organic

Quaternary Climate Change – Quaternary Glaciations

Ice Age (Glacial Period)

- Ice Cores



https://theconversation.com/life-in-lake-vostok-the-link-between-antarctica-and-extra-terrestrials-5334

Quaternary Climate Change – Quaternary Glaciations

Distribution of Glaciers During Last Glacial Maximum

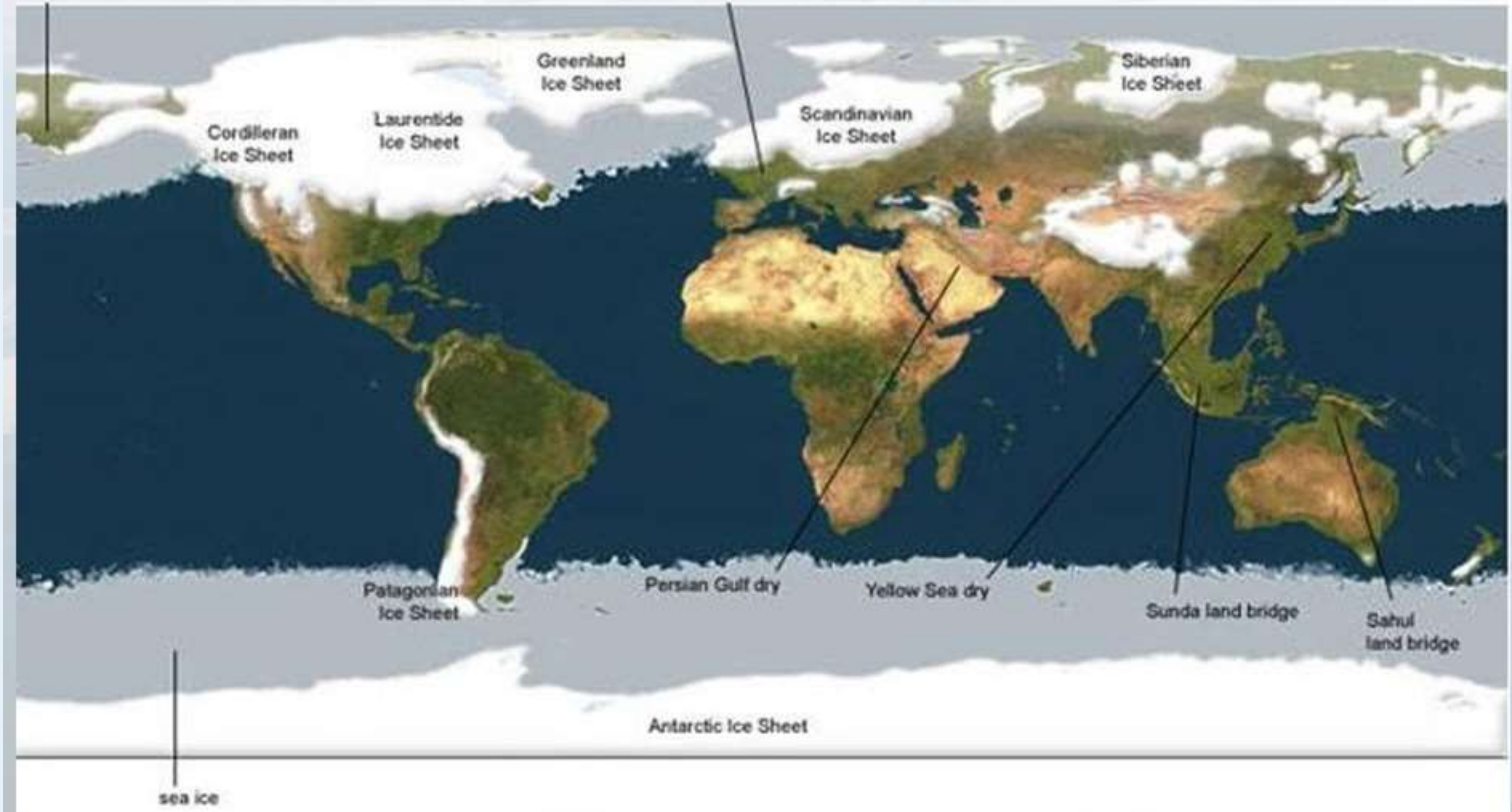


Image Source: http://www.humberriver.ca/globalice.html

Last Glacial Maximum

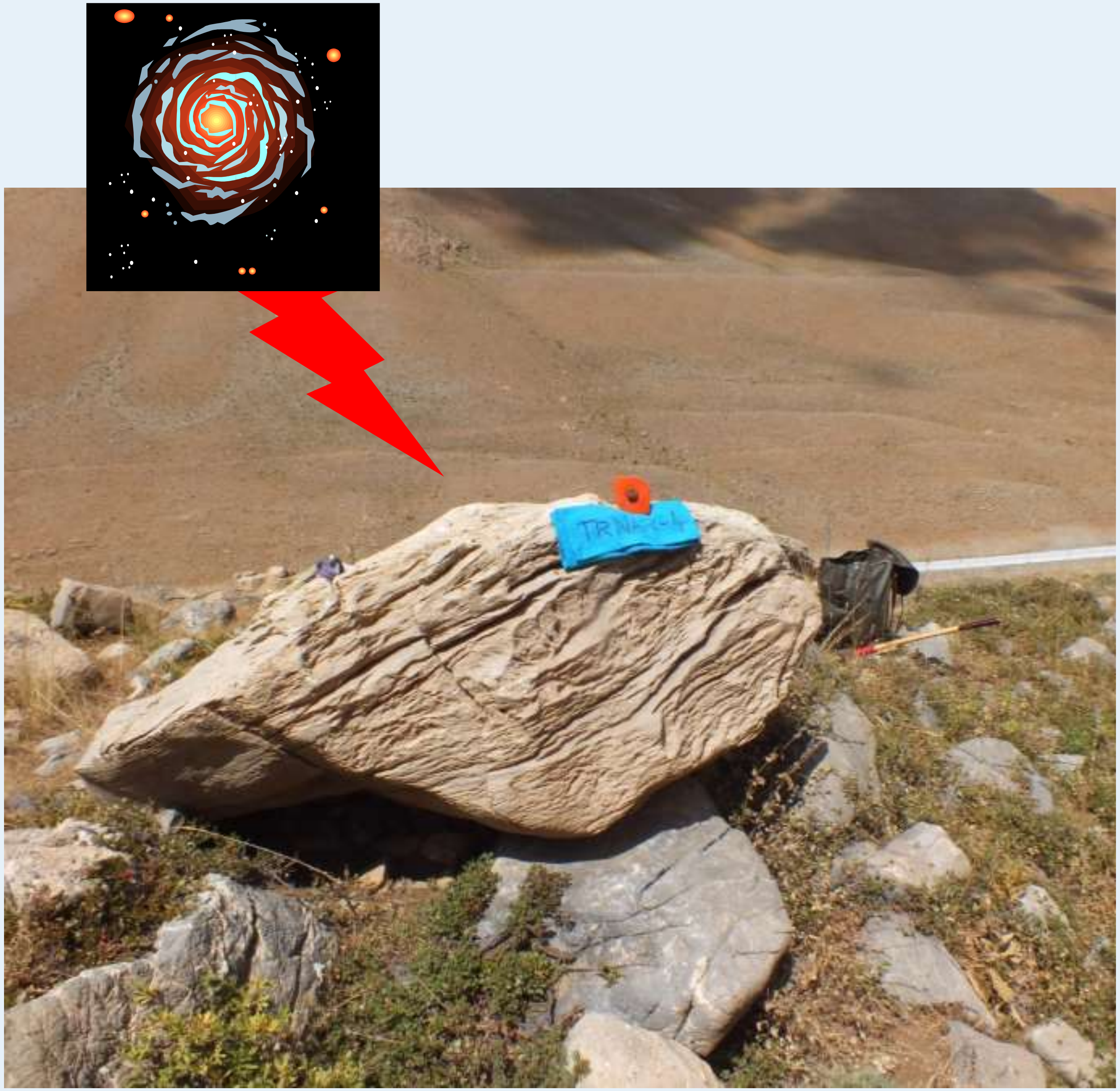
- Approximately 125,000 years ago, during the last interglacial period, the climate was similar to present-day conditions. However, starting from around 120,000 years ago, cooling trends began to occur
- Continental-scale ice sheets developed, covering northern North America and northern Eurasia.
- Mountain glaciers extended their ice tongues for kilometers along valleys.
- As water evaporated from the oceans and was transported via precipitation to accumulate in continental ice sheets, global sea levels dropped by tens of meters.
- Sea ice expanded in both the Northern and Southern Hemispheres, spreading toward lower latitudes.
- Global atmospheric circulation patterns and ocean currents underwent significant changes.
- Around 20,000–22,000 years ago, the Last Glacial Maximum (LGM) occurred.
- Global sea levels dropped by 125 meters compared to current levels.
- Regions outside the glaciated areas experienced average surface temperatures that were 5°C cooler than today.
- Cold-adapted plants and animals migrated to warmer regions, both horizontally and vertically.
- In Turkey's high mountains, hundreds of valley glaciers formed.
- In Central Anatolia, pluvial lakes developed, and the water levels of existing lakes rose.
- In contrast, lakes in Eastern Anatolia experienced declines in water levels.
- Approximately 11,700 years ago, the Last Glacial Period ended, giving way to a new interglacial period, the Holocene, which continues to this day.

https://slideplayer.com/slide/4529153/

Dating of Glacial Sediments by Surface Exposure Dating

- When rocks or other materials are exposed at the surface of the Earth, they are bombarded by high-energy cosmic rays (mostly protons) from outer space. These rays interact with the nuclei of atoms within the rock or surface material, producing rare isotopes, called cosmogenic nuclides. The concentration of these nuclides in the material can be measured to estimate the duration of surface exposure.
- Unlike other radiometric dating methods, this technique enables the determination of surface exposure ages without considering the formation age of the rock.
- Cosmic rays interact with minerals at the Earth's surface, producing cosmogenic nuclides via spallation (breaking of atomic nuclei), neutron capture, or muon capture.
- Rock or sediment samples are collected from a specific surface or landform (e.g., a moraine, erratic boulder, or landslide).
- The cosmogenic nuclide concentration is measured using Accelerator Mass Spectrometry (AMS).
- The concentration of the cosmogenic nuclide is used in combination with known production rates (which vary with latitude, elevation, and shielding) to calculate the exposure age.
- Depending on the minerals present in the rocks, new cosmogenic isotopes such as Beryllium-10 (^{10}Be; Half-life: 1.36 ± 0.07 million years), Chlorine-36 (^{36}Cl; Half-life: 301 ± 2 thousand years), Carbon-14 (^{14}C; Half-life: 5,730 ± 30 years), and Aluminum-26 (^{26}Al; Half-life: 708 ± 17 thousand years) can be formed.

Dating of Glacial Sediments by Surface Exposure Dating



- Location (Altitude & Latitude)
- Topographic shielding
- Air pressure
- Vegetation
- Snow coverage
- Local production rate
- Techtonic uplift
- Erosion
- Unknown factors

Dating of Glacial Sediments by Surface Exposure Dating

Sampling

Dating of Glacial Sediments by Surface Exposure Dating

Dating of Glacial Sediments by Surface Exposure Dating

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Labels	Alt (m)	Lat (DD.DD)	Long (DD.DD)	Depth (cm)	Thickness (m)	Shielding	Shielding_err	Conc (1e6 atoms Cl36/g rock)	err (1e6 atoms Cl36/g rock)	Cl (ppm)	err (ppm)	Inheritance (1e6 atoms Cl36/g rock)	Erosion (cm/kyr)	Density (g/cm3)	Assumed age (kyr)	O	H	C	Na	Mg Al
2	TRNAR-1	2512	38.15561	42.97560	1.25	4	0.99031	0	2.071	0.055	106.5	0.53	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	13.6
3	TRNAR-2	2524	38.15557	42.97678	1.25	4.5	0.99226	0	2.211	0.053	49.0	0.14	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	4.27
4	TRNAR-3	2523	38.15558	42.97680	1.25	5	0.99226	0	2.061	0.074	40.8	0.18	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	3.63
5	TRNAR-4	2520	38.15481	42.97514	1.25	3	0.99175	0	1.907	0.057	88.9	0.59	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	7.59
6	TRNAR-5	2523	38.15471	42.97503	1.25	5	0.99175	0	2.439	0.070	128.9	0.76	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	5.37
7	TRNAR-6	2528	38.15456	42.97498	1.25	5	0.99175	0	2.031	0.066	69.6	0.15	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	6.55
8	TRNAR-7	2547	38.15238	42.97390	1.25	4	0.99376	0	1.773	0.041	14.8	0.02	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	0.43
9	TRNAR-8	2618	38.14823	42.96878	1.25	3	0.97125	0	2.457	0.050	18.5	0.07	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	1.48
10	TRNAR-9	2600	38.14944	42.97078	1.25	4	0.98211	0	2.273	0.052	43.5	0.19	0	0.5	2.4	25	48.00000	0.00000	12.00000	0	3.11
11	TRNAR-10	2592	38.15007	42.97205	1.25	4	0.99068	0	1.716	0.035	12.2	0.04	0	0.5	2.4	25	47.93579	0.00000	11.99508	0	0.23
12		from geolo	from geology	from geology	from geol	from geolo	from geolo	from geology					from geology	from geolo	from geology						
13									from AMS	from AMS	from AMS	from AMS				you can put 10 in this column					
14																it is used for the calculation of concentration in the "output" sheet					
15																(one can then cross-check the age calculation)					

Dating of Glacial Sediments by Surface Exposure Dating

$$N = \frac{PC}{\lambda + \frac{\rho\varepsilon}{\Lambda}}\left(1 - e^{-\left(\lambda + \frac{\rho\varepsilon}{\Lambda}\right)T}\right) + N_o e^{-\lambda T}$$

- **N: Accumulated cosmogenic isotope concentration, (of SiO_2 for ^{10}Be and ^{26}Al)**
- **N_o Initial concentration of ^10Be in the material**
- **P Production rate of the isotope (in atoms/gram per yr)**
- **C Correction factor accounting for enhancements to production rates (e.g., shielding effects, atmospheric corrections).**
- **T Exposure time of the surface to cosmic rays (in yrs)**
- **λ Radioactive decay constant of the isotope (in 1/yr)**
- **ρ Density of the rock or soil (in g/cm^3)**
- **ε Erosion rate (in cm/yr)**
- **Λ Attenuation length, representing the penetration depth of cosmic rays into the material (in g/cm^2)**

Explanation of the Equation:

1. **First Term**: Represents the production of isotopes, considering radioactive decay and material loss due to erosion:

$$\frac{PC}{\lambda + \frac{\rho\epsilon}{\Lambda}}\left(1 - e^{-\left(\lambda + \frac{\rho\epsilon}{\Lambda}\right)T}\right)$$

   This term balances the production rate with decay and erosion processes.

2. **Second Term**: Represents the decay of the initial cosmogenic isotope concentration over time:

$$N_0 e^{-\lambda T}$$