Dynamic Planet B/C

Science Olympiad
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Dynamic Planet

This year the topic is climate change with a focus on the geological record for climate change

- The primary focuses of the test will be on the geologic evidence for past climates
  - surface landforms
  - sedimentation history
  - geochemical evidence - stable isotopic data (competition C)

resources available

Check the Science Olympiad website which links you to NASA, USGS and NOAA webpages

- https://www.noaa.gov/resource-collections/2019-science-olympiad-glaciers-glaciation-and-long-term-climate-change

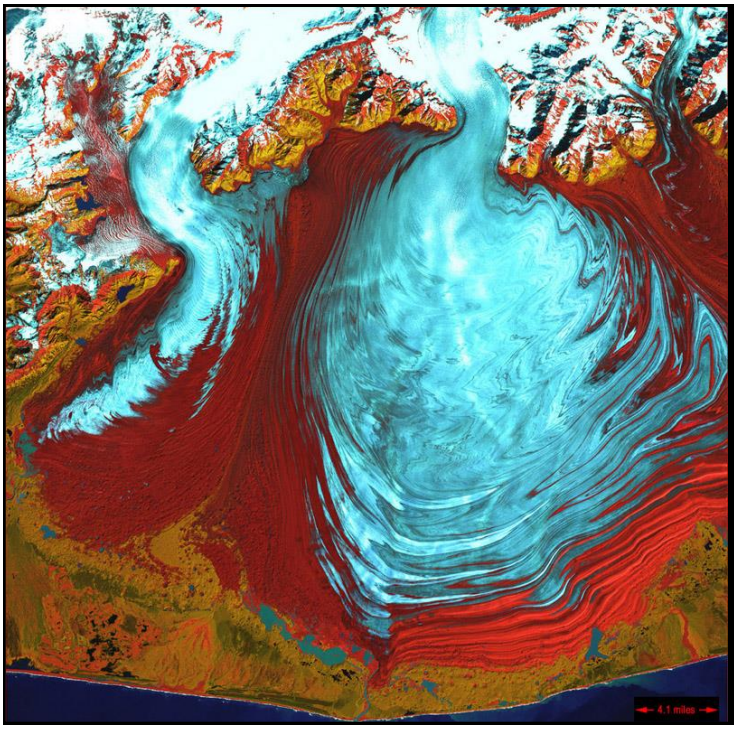
Importance of reading maps for the tests

- The student competitors will be required to examine portions of maps (USGS topographic quadrangles)
- Identify glacial features from both alpine and continental glaciated environments
  - includes depositional as well as erosional geomorphic features
- Understand and be able to describe the processes/mechanisms involved with their formation

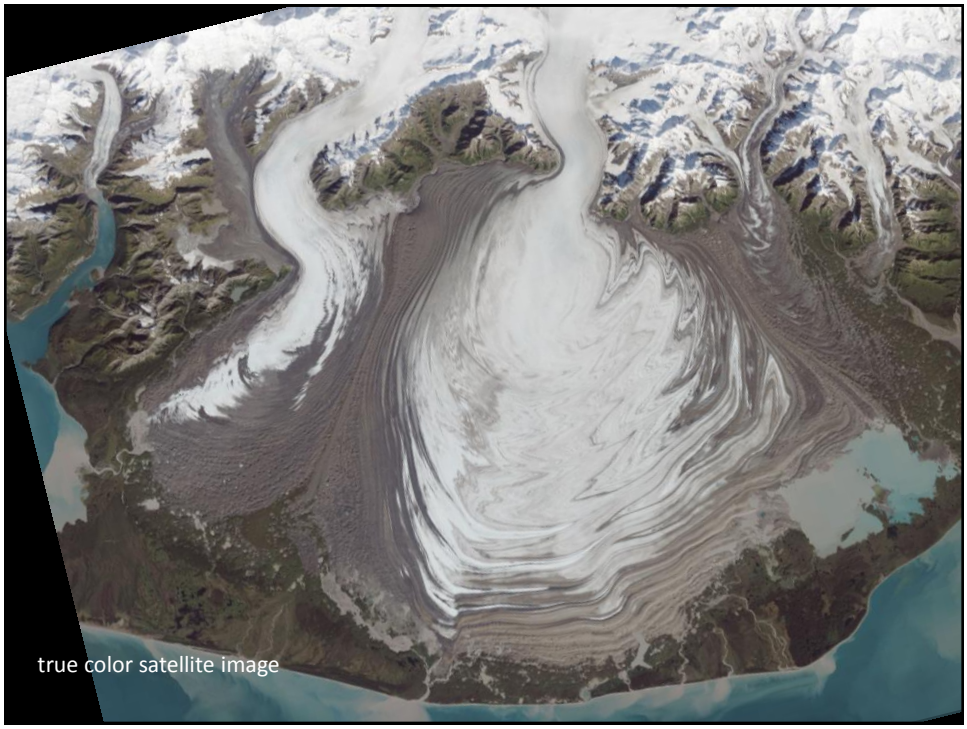
Resources: Most introductory geology laboratory manuals (university-level intro geology) have a chapter on glaciers and using topographic maps.

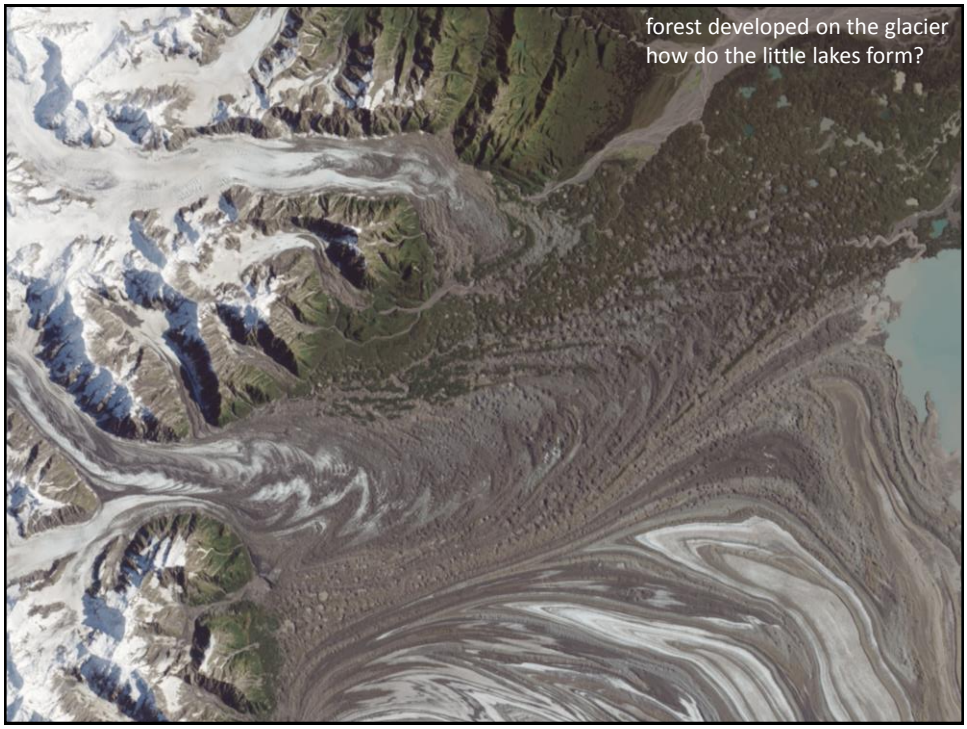
Remote sensing of glaciers

- Landsat images - what do the colors refer to?
- Digital Elevation Models (DEM) - what is this data and how is it generated? What is it used for relative to climate studies?

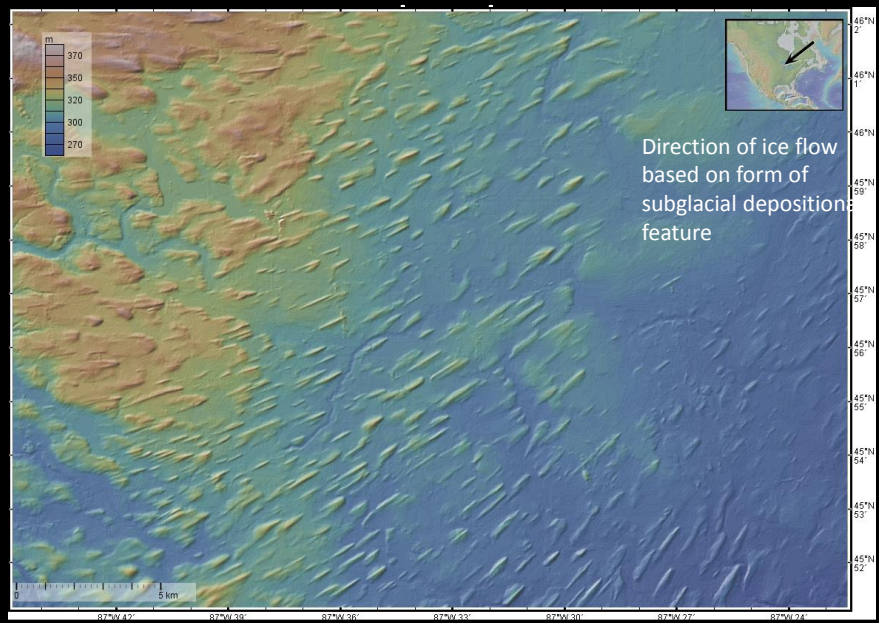


What produces the wavy patterns?


true color satellite image

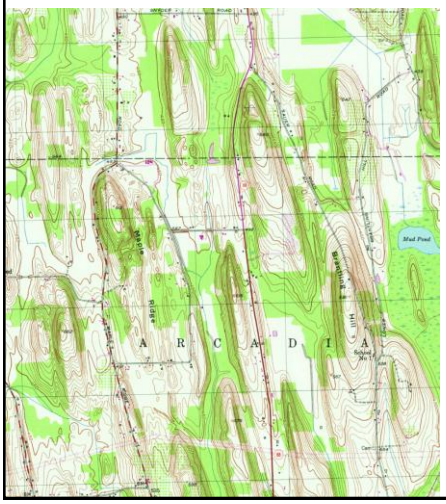

forest developed on the glacier
how do the little lakes form?

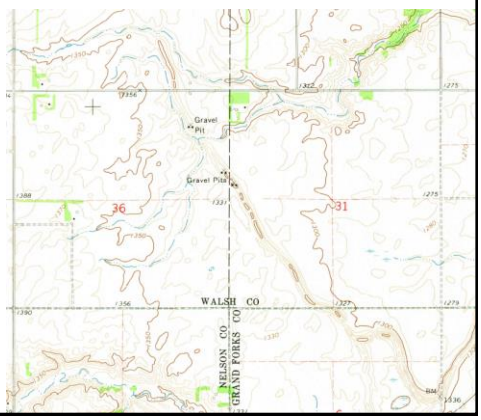
http://www.geomapapp.org/MSInstall

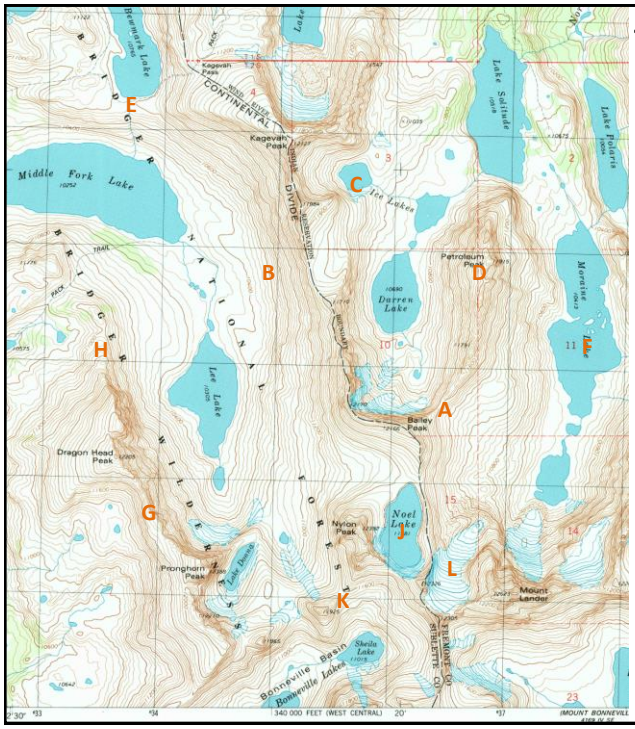


topographic maps

depositional features from continental glaciation







topographic maps

Erosional features identify:

- col
- arête
- cirque
- etc.

Depositional features

- end moraines
- lateral moraines
- medial moraines
- outwash plain
- etc.

Water features related to glaciation

- tarn
- swale
- paternoster lake
- etc.

Rate of glacier retreat or advance

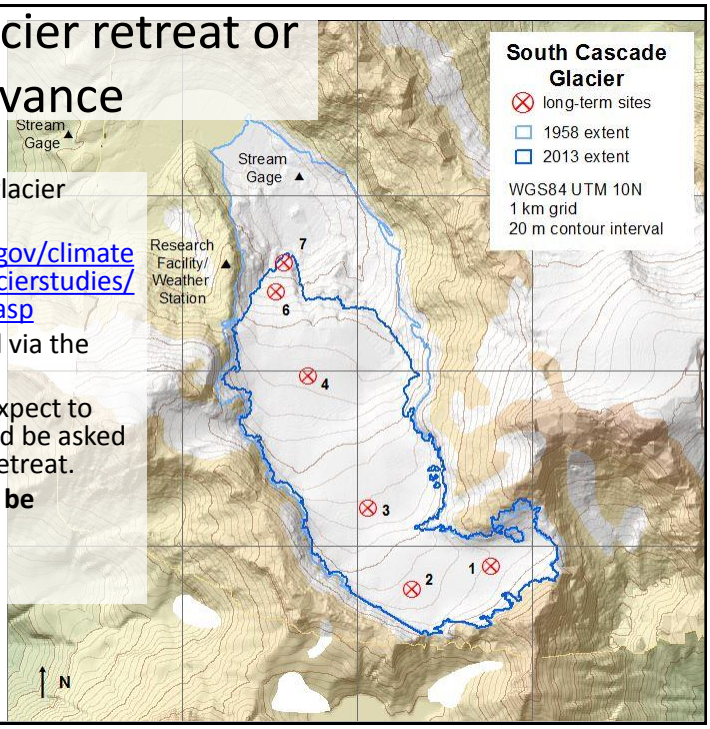
The USGS provides glacier monitoring data at:

https://www2.usgs.gov/climate_landuse/clu_rd/glacierstudies/benchmarkGlaciers.asp

This can be accessed via the previous weblink.

Competitors could expect to see a similar map and be asked to calculate rate of retreat.

Unit conversion will be required.



Sedimentation

What does the sedimentary record indicate about the earth's past climate?

- What is the *direct* evidence for glaciation in the earth's past based on sedimentary rocks?
- What is the *indirect* evidence for climate variations in the sedimentary record?

Rock types and climate

Certain rocks types are indicative of climatic conditions

- In New Mexico many Cretaceous-aged (110-50Ma) rocks shows evidence for climatic conditions:
  coal/peat = swamps = hot and/or humid
- Other rocks show indications of climate via fossil evidence - marine fossils such as warm water faunas
- soils (paleosols) develop in temperate to tropical climates
- Certain rocks/deposits form only during glaciation events:
  - tillite (morainal material)
  - diamictite (very poorly sorted marine/lake sediment that may contain stones dropped ("drop stones")from floating ice)

Bechstadt et al. (2018)

diamictite - very poorly sorted sediment with a fine grained matrix

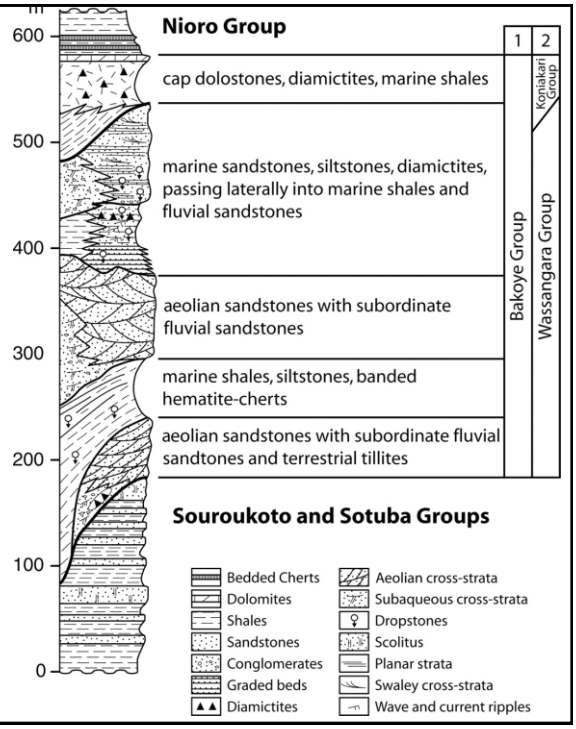
Bechstadt et al. (2018)

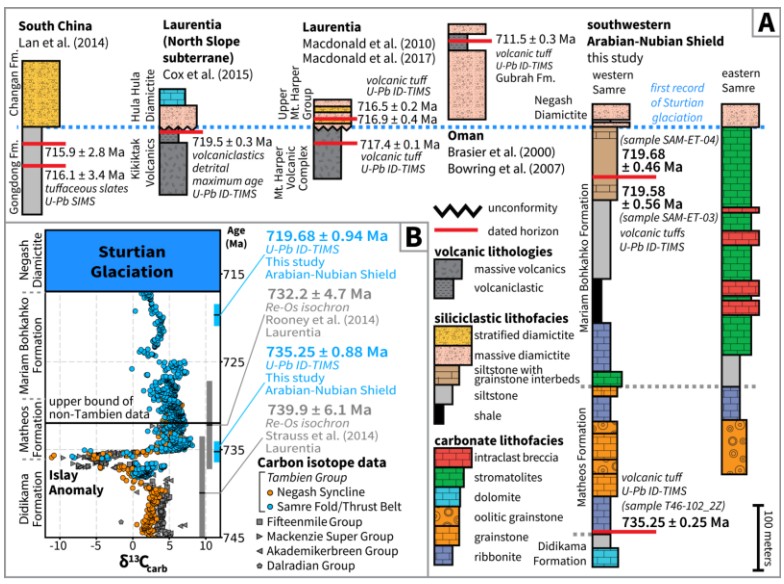
“drop stones” in diamictite - soft sediment laminations under larger clasts were indented/deformed during impact of stones falling through the water column

stratigraphic columns

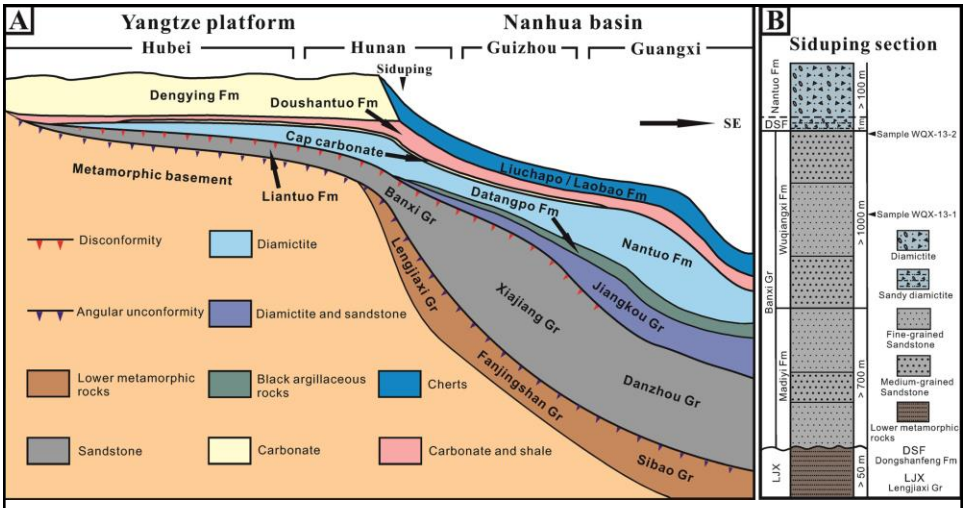
Stratigraphic columns are used to show the types of rocks found in a region or site and their stratigraphic (timing) relationship to each other

- The key to understanding such diagrams is knowing lithology terms, especially those that are related to glacial events:
  - tillite,
  - diamictite,
  - "dropstone",
  - "cap carbonates"
- Other rock types could also be related to glaciation but are NOT diagnostic
- How are different rock types related to climate: coal, fossiliferous rocks





The important considerations here are the meaning of the "lithofacies" terms and how these may, or may not, be related to climate change



This diagram shows the stratigraphic relationships of different packages of rocks in different parts of China that are synchronous. The thickness and change of sediment type indicates differences in sedimentation style and carbonate and diamictite are the effects of climate variations over time in different depositional environments.

Isotopic evidence

A significant component in Test C

- What are stable isotopes?
- Can the student understand the expression of isotopic data?
- Which stable isotopic systems are used for climate studies?
- What is an isotopic excursion, and how is it useful for indicating climate variations?

Resources: many explanations of stable isotopic systems are freely available on the internet.

delta notation

Delta notation (δ) is a way of expressing small isotopic variations measured against a standard

- Every stable isotopic system has its own delta notation

$$\delta = (R_{sample}/R_{std}-1)x1000$$

$$\delta^{18}O_{SMOW} = \left(\frac{^{18}O/16Osample}{^{18}O/16OSMOW} - 1\right) \times 1000$$

$$\delta D_{SMOW} = \left(\frac{^{2}H/^{1}H_{sample}}{^{2}H/^{1}H_{SMOW}} - 1\right) \times 1000$$

$$\delta^{13}C_{PDB} = \left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{PDB}} - 1\right) \times 1000$$

- $+\delta$ means that the analyzed sample is enriched in the heavy isotope relative to the standard
- $-\delta$ means that the analyzed sample is depleted relative to the standard

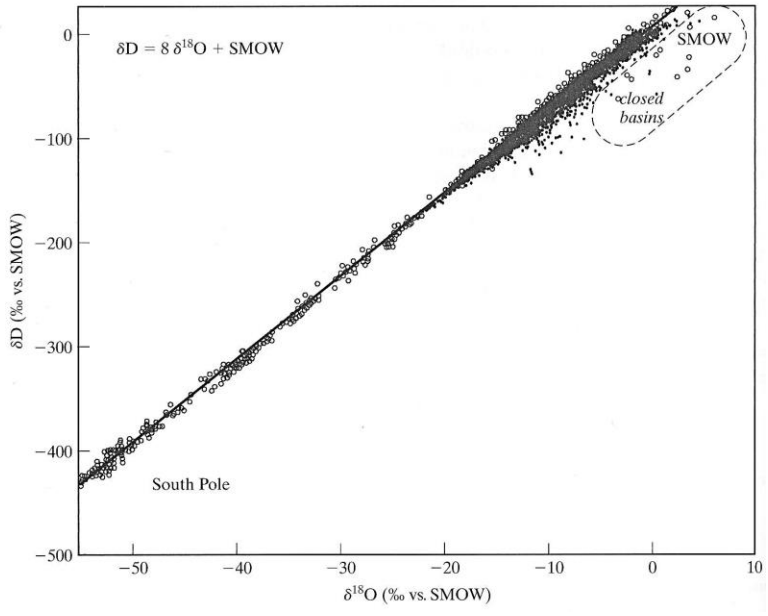
For H and O, $+\delta$ means the sample is isotopically enriched in the heavy isotope relative to SMOW

stable isotopic systems in climate studies

- Oxygen and hydrogen each have multiple isotopes and are chemically part of many compounds, including minerals and water
- These isotopes fractionate during chemical processes, akin to partition of elements between different compounds or phases of compounds
- The fractionation process is strongly temperature dependent, which is why they provide information (not usually direct) on temperature

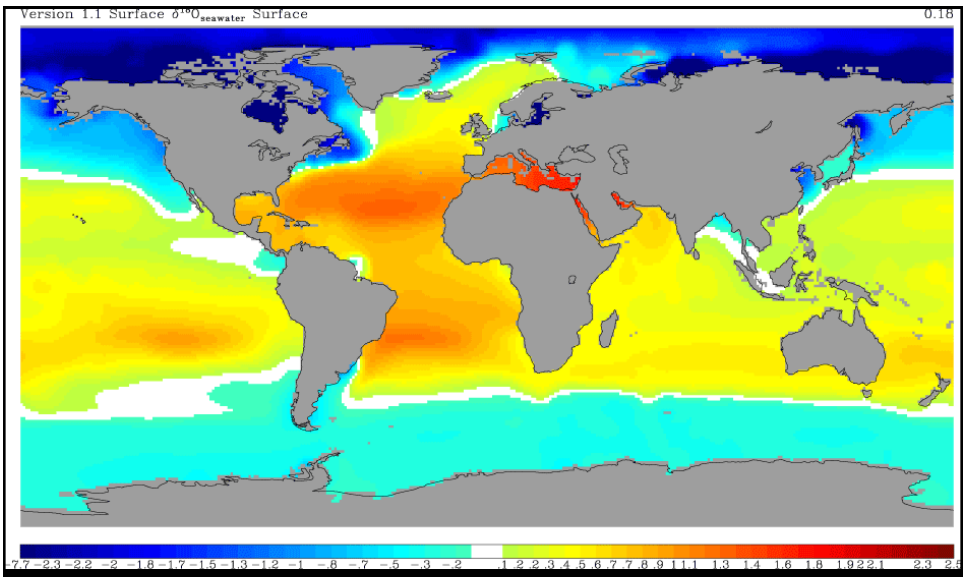
The most important fractionation processes for O and H are related to evaporation and condensation of H_2O.

- evaporation leads to isotopically light H_2O in the water vapor relative to the liquid source
- condensation tends to partition the heavier isotopic H_2O into the liquid, or solid phase (snow) - the magnitude is strongly temperature dependent
- The result of this fractionation on resulting precipitation is the *meteoric water line*



Sharp (2007)

- On a local level, if the water is precipitation is isotopically heavy, it is a function of warmer T
- Snow and ice record the isotopic composition of condensed H_2O at the time of condensation
- This fact has been used as a proxy for global temperatures from glacial ice cores

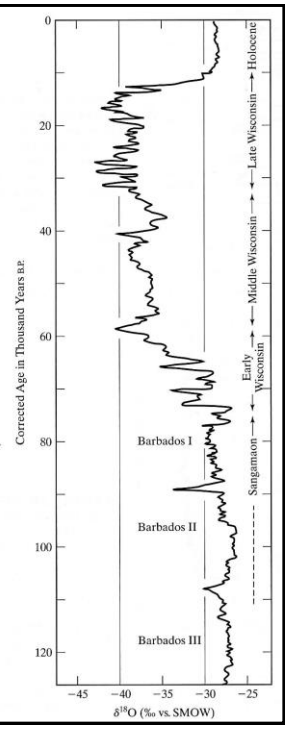


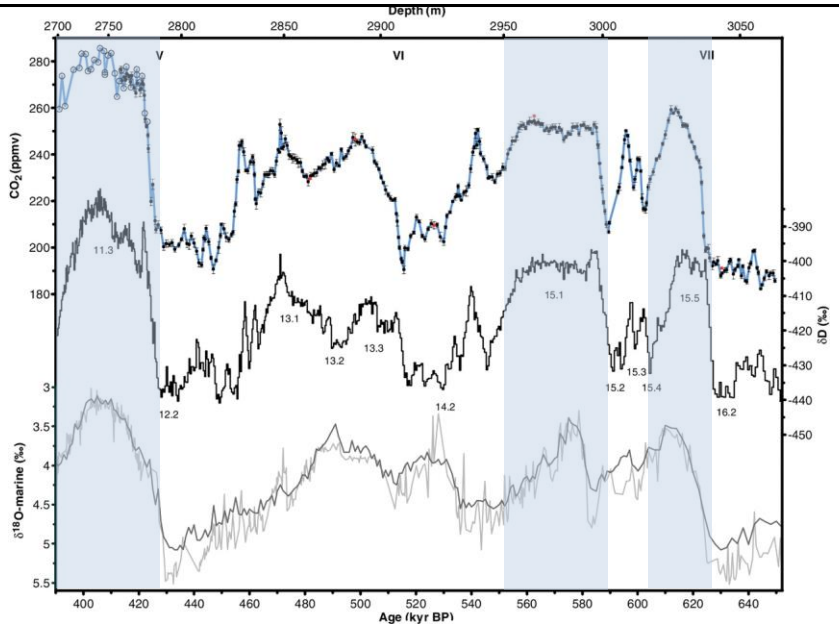
variations in $\delta^{18}O$ a function of ambient T and source of water (e.g., glacial meltwater mixing)

NASA

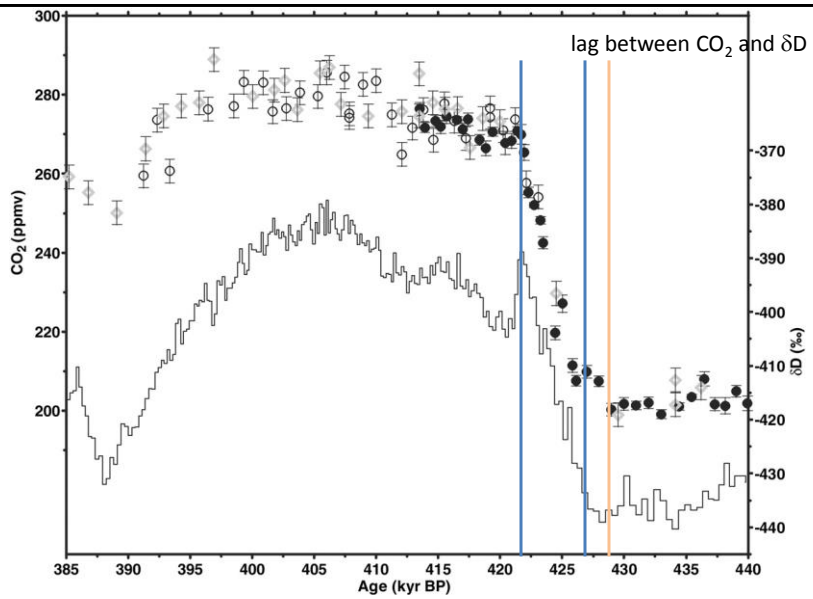
Glacial ice

- ice contains H and O - either can be used for T proxies
- The idea is to evaluate excursions in the isotopic record which could indicate large climatic changes
- Present $\delta^{18}O$ of ice is similar over the last 10k yrs
- Prior to that there is a large "negative excursion" which means the precipitation was isotopically lighter - usually attributed to cooler temperatures, all other things being equal (e.g., circulation patterns)

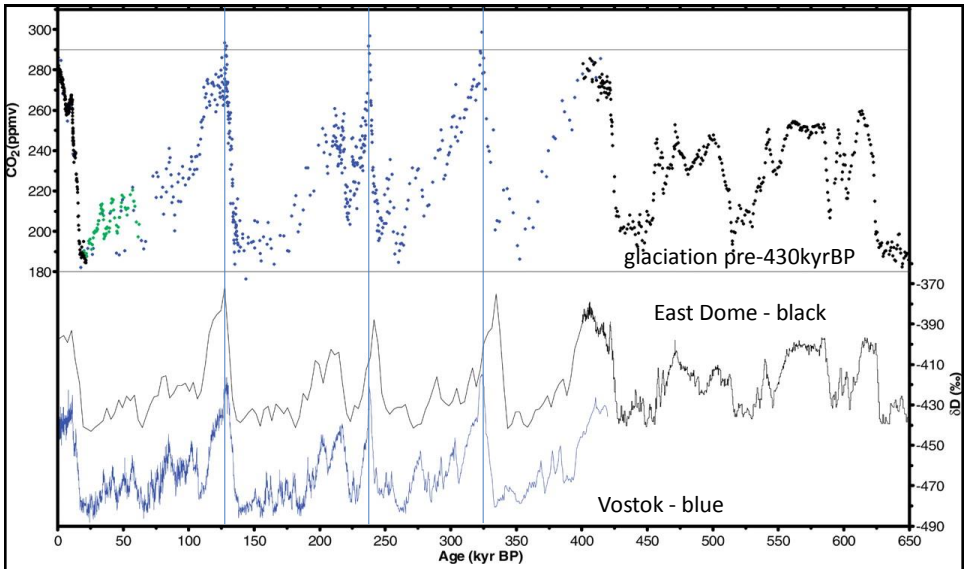




Ice-core stable isotope data from East Antarctica measuring δD, compared to CO_2 extracted from bubbles in ice core and $\delta^{18}O$ of carbonate tests of foraminifera - δD is the "proxy for global ice volume" or "Antarctic temerpature"- when it is low, ice extent is high. Sampling resolution is 731 years (Siegenthaler et al., 2005)



High resolution CO_2-δD record from (Seigenthaler et al., 2005). Error bars in 1σ. Vertical lines show the period of shift toward isotopically lighter values (lower δD). This means that the precipitation falling was more strongly fractionated than before, to more negative values.



- Combined isotopic data and CO_2 from several Antarctic ice cores
- The cycles are interpreted to be major glacial cycles

paleo T from marine sediments

Glacial information goes back less than 1Ma

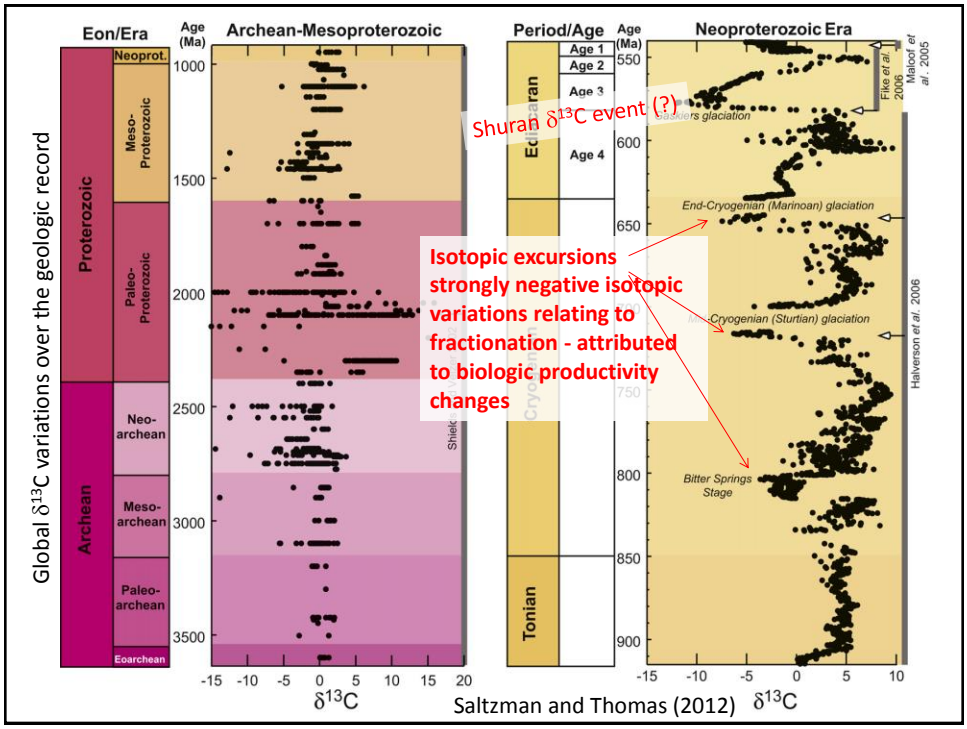
The sedimentary record contains isotopic information that sheds light on climate changes

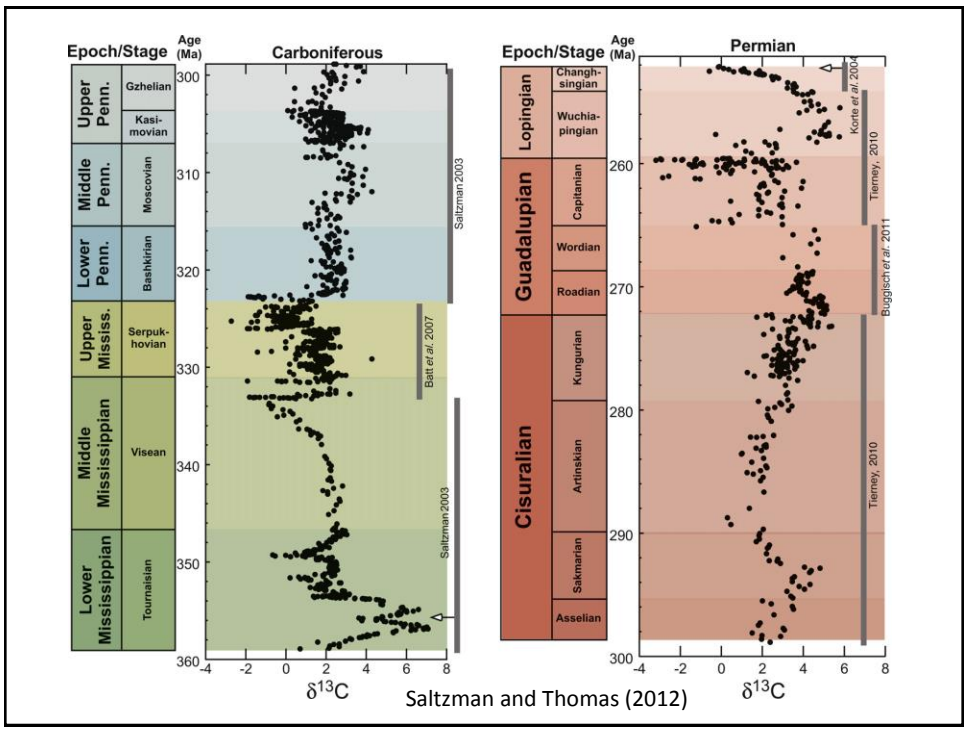
- Presumably the sediments precipitated (chemical precipitates) from sea water will have a isotopic character controlled by the T and isotopic character of the seawater
- Direct chemical precipitation of calcite ($CaCO_3$) and SiO_2 from seawater records the ambient T
- Microorganisms precipitate tests (shells) where the isotopic composition of their test is related to the ambient T - this is related to T (stress) and productivity

How this is applied to paleoclimate studies may require several simplifying assumptions.

C-isotopes in the geologic record

- C-isotopes are less influenced by local T, unlike O and H
- C-isotope fractionation is strongly related to biological "productivity" - where biological activity is high, there is less fractionation of C (more positive $\delta^{13}C$)
- Where biological activity is low, the fractionation is more extreme, with more negative $\delta^{13}C$ recorded in the rocks


Global δ13C variations over the geologic record
Eon/Era
Proterozoic
Archean
Neoprot.
Meso-Proterozoic
Paleo-Proterozoic
Neo-archean
Meso-archean
Paleo-archean
Eoarchean
Age (Ma)
Archean-Mesoproterozoic
1000
1500
2000
2500
3000
3500
-15 -10 -5 0 5 10 15 20
δ13C
Period/Age
Ediacaran
Age 1
Age 2
Age 3
Age 4
Tonian
Neoproterozoic Era
550
600
650
750
800
850
900
Shuran δ13C event (?)
Isotopic excursions strongly negative isotopic variations relating to fractionation - attributed to biologic productivity changes
Fike et al. 2006
Kaufman et al. 2005
End-Cryogenian (Marinoan) glaciation
Cryogenian (Sturtian) glaciation
Halverson et al. 2006
Bitter Springs Stage
-15 -10 -5 0 5 10
δ13C
Saltzman and Thomas (2012)


Epoch/Stage
Upper Penn.
Gzhelian
Kasi-movian
Middle Penn.
Moscovian
Lower Penn.
Bashkirian
Upper Mississ.
Serpuk-hovian
Middle Mississippian
Visean
Lower Mississippian
Tournaisian
Age (Ma)
Carboniferous
300
310
320
330
340
350
360
Saltzman 2003
Batt et al. 2007
Saltzman 2003
-4 -2 0 2 4 6 8
δ13C
Epoch/Stage
Lopingian
Changh-singian
Wuchia-pingian
Guadalupian
Capitanian
Wordian
Roadian
Cisuralian
Kungurian
Artinskian
Sakmarian
Asselian
Age (Ma)
Permian
260
270
280
290
300
Korte et al. 2004
Tierney, 2010
Bugglisch et al. 2011
Tierney, 2010
-4 -2 0 2 4 6 8
δ13C
Saltzman and Thomas (2012)

Additional topics

- The guides for Dynamic Planet B/C present some important additional topics that the competitors should be aware of such as:
  - How does a glacier form?
  - What factors affect glacier gain and loss?
  - What explains the cyclicity of recent and deep past glaciations? (E.g., Milankovitch cycles, supercontinent formation, orogenic effects, galactic passage of the solar system)