What's so interesting about Old Ice?

John Matthews
Professor of Physics, U. of New Mexico

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Beginning around 3 million years ago, Earth cooled and entered an era marked by successive ice ages and interglacial periods, emerging from the last glaciation around 11,700 years ago.

How interesting. How can we learn about it?

Fortunately, glacial ice can be used to learn about Earth's past history.

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Old ice, particularly in the form of ice cores drilled from glaciers and ice sheets, is interesting because it acts as a unique archive of Earth's past climate and atmospheric conditions.

Ice patches, particularly paleo-ice patches (ancient ones), are interesting because they are repositories of history and environmental information, offering unique insights into the past.

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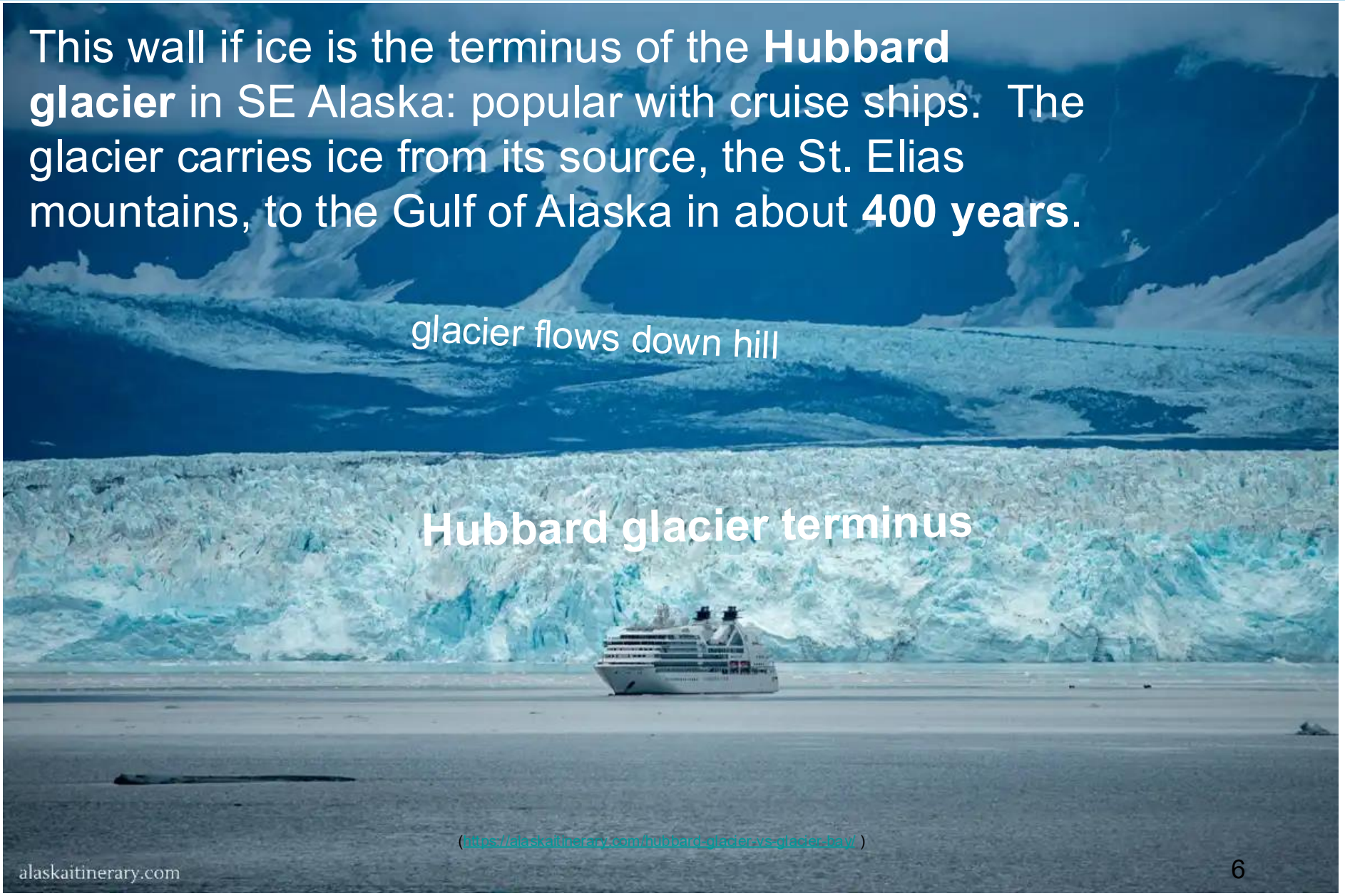
What exactly is “old ice”?

Over time, snowfall after snowfall, snow compresses to ice

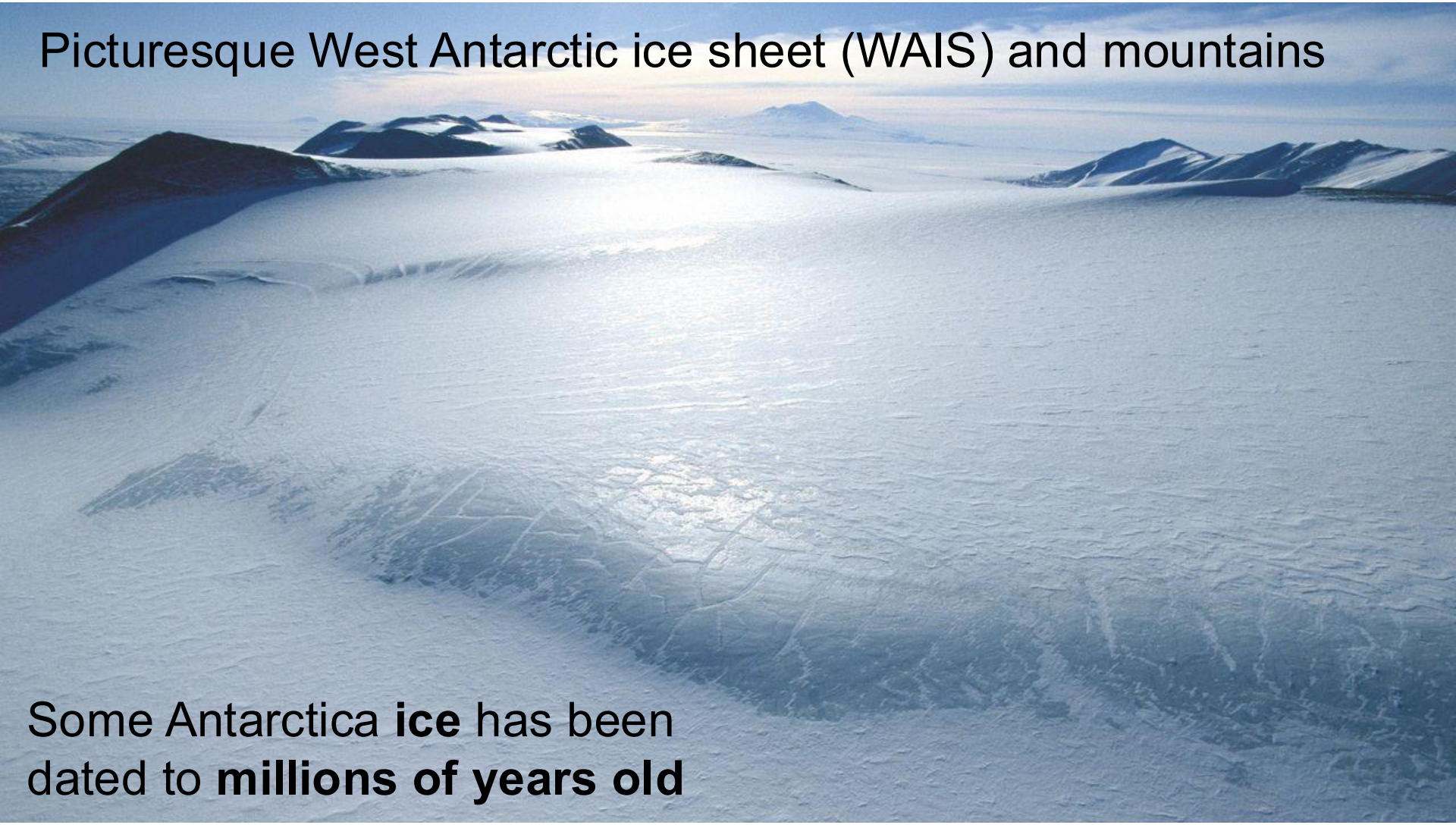
Glaciers move quite quickly, so their ice is generally young



Fortuitously some mountain ice is thousands of years old

(https://secretsoftheice.com/how-old/)

Earth's oldest ice is found two places: Antarctica & Greenland



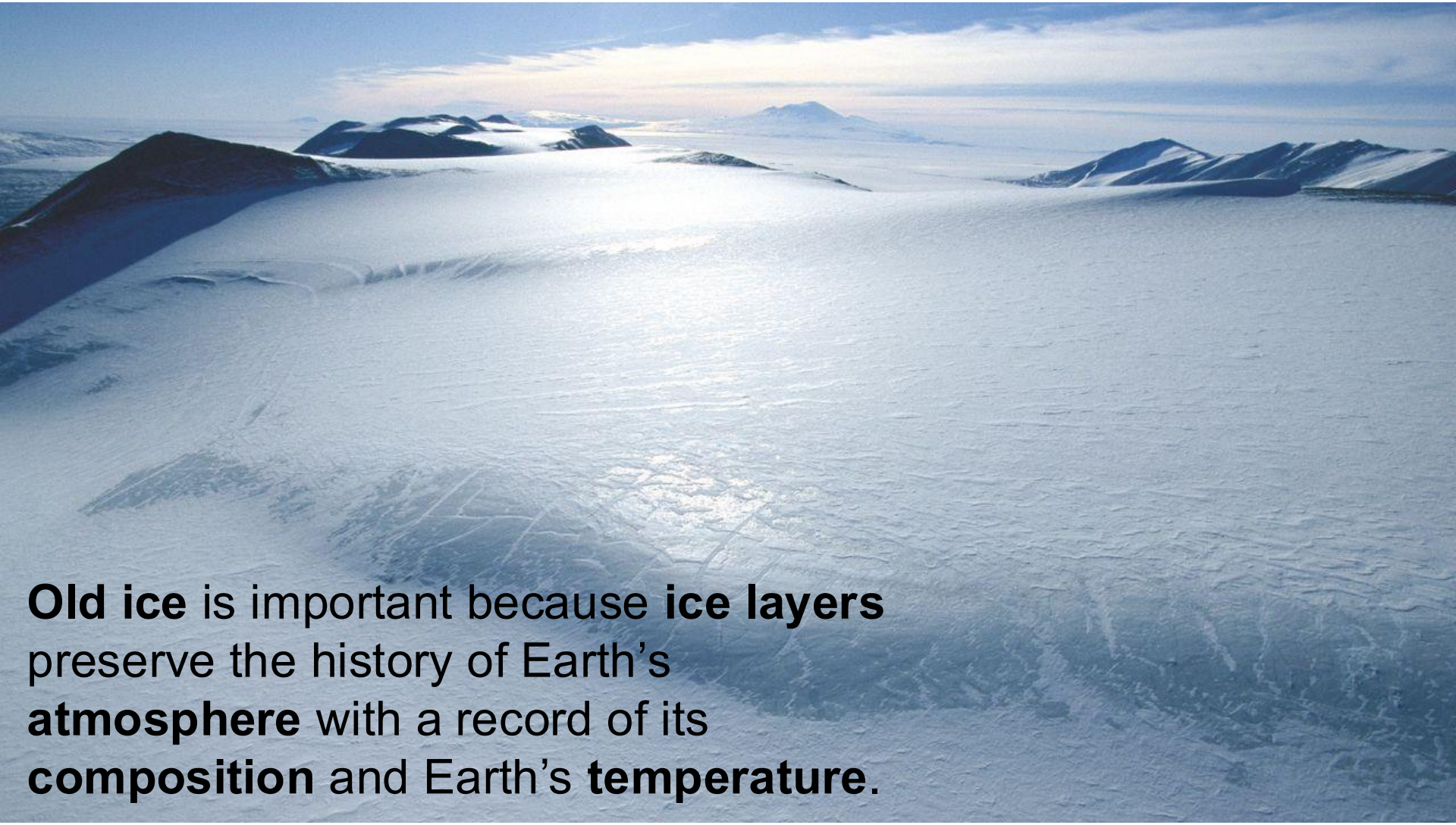
(https://www.nationalgeographic.co.uk/environment/2019/03/hunt-answers-beneath-antarcticas-ice)

Different ice depths and snowfall, different “look back times”

Ice core drilling stations in Antarctica (L) and Greenland (R)

Most ice cores are drilled in Antarctica and Greenland. The oldest continuous ice core record extends to 130,000 years in Greenland and 800,000 years in Antarctica. The deepest are over 3 km (2 miles) in depth.

So far, Antarctica provides the oldest ice

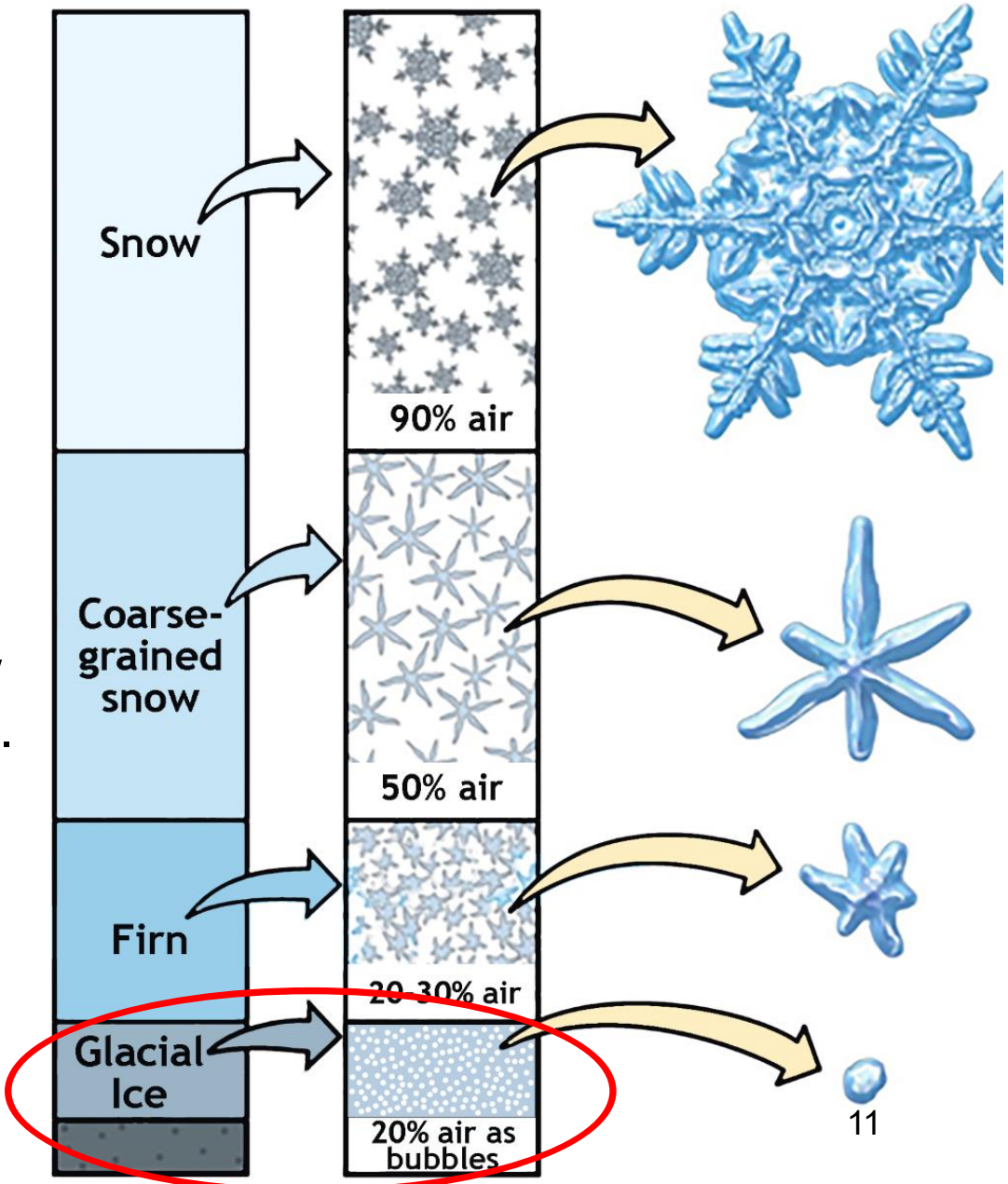


Old ice is important because **ice layers** preserve the history of Earth's **atmosphere** with a record of its **composition** and Earth's **temperature**.

(https://www.nationalgeographic.co.uk/environment/2019/03/hunt-answers-beneath-antarcticas-ice)

Years of snowfall compact to a record of Earth's atmosphere

- Each year, new layers of snow **bury** and **compress** the previous layers.
- Gradually the grains grow larger and the air pockets between the grains get smaller.
- After about a year the snow turns into **firn**, snow that now **survives** the "**summer melt**".
- After perhaps a hundred years the firn crystals have merged to a solid: air is now **bubbles** of **air** in the **glacial ice**.



(https://nsidc.org/learn/parts-cryosphere/glaciers)

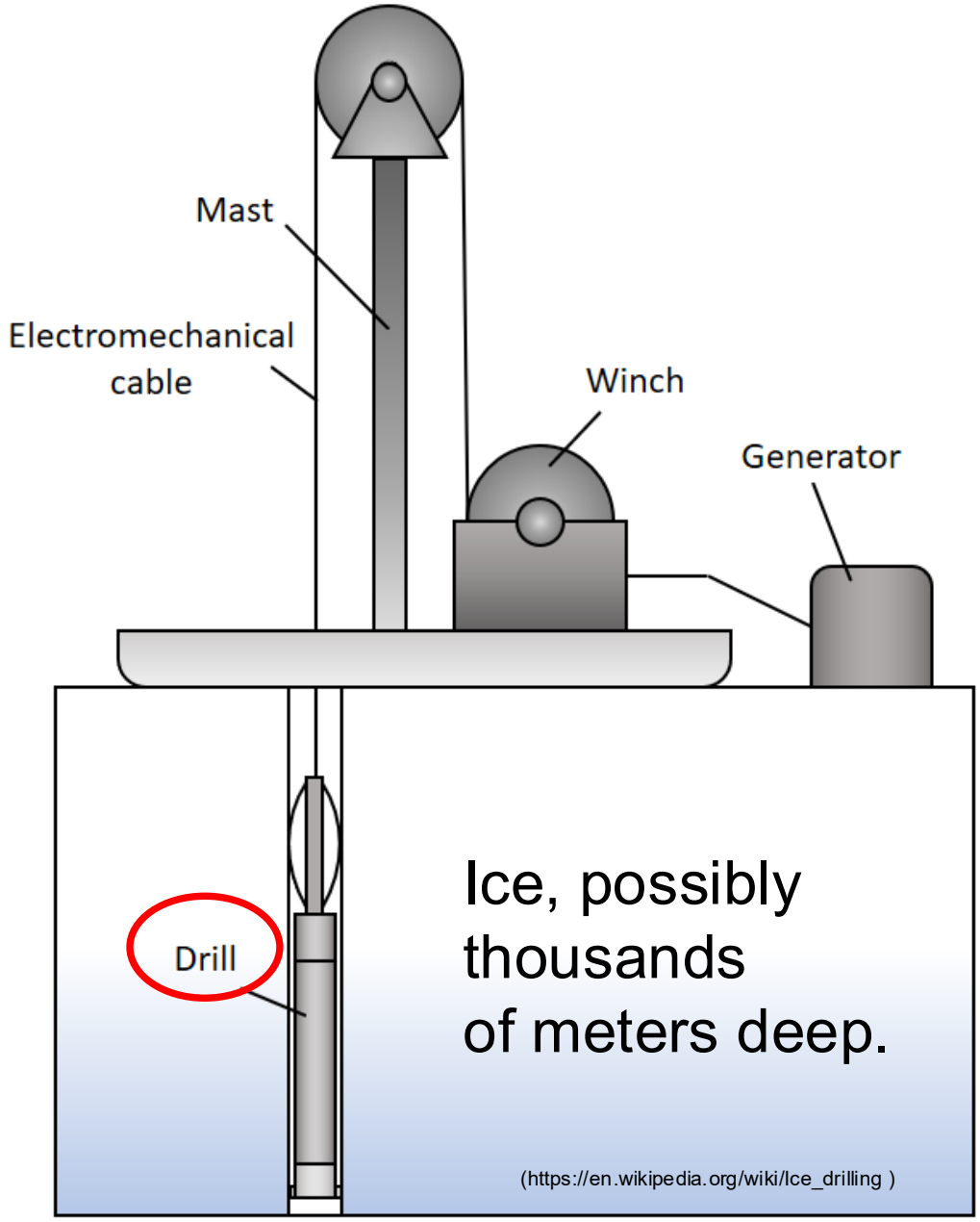
Like coring an apple, scientists core down into the glacial ice

(https://climate.nasa.gov/news/2616/core-questions-an-introduction-to-ice-cores/)

Ice cores from near the surface are done by hand

(https://www.britannica.com/science/ice-core)

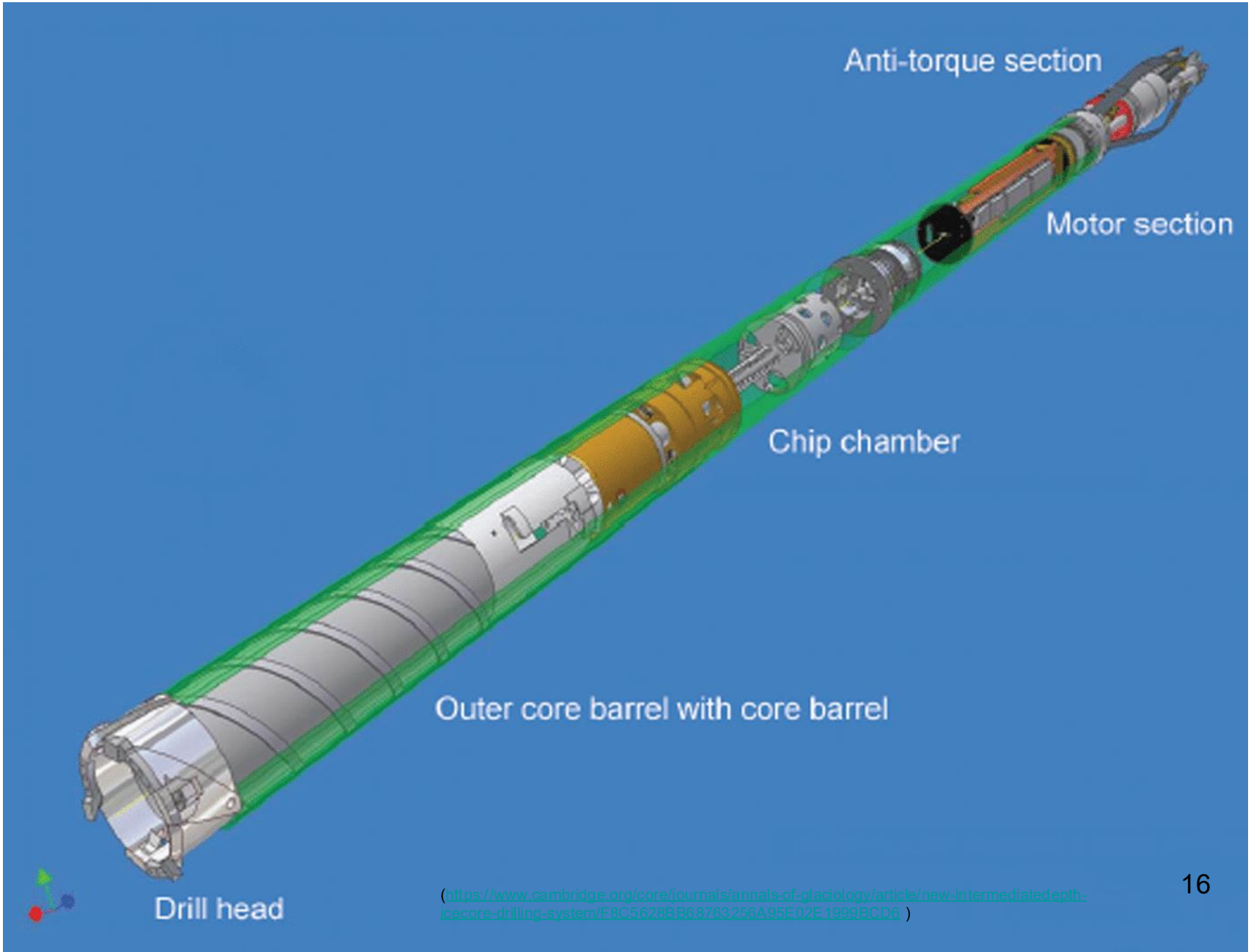
In most cases coring-drill is lowered on a long cable



Example of a coring-drill in operation at Allan Hills site

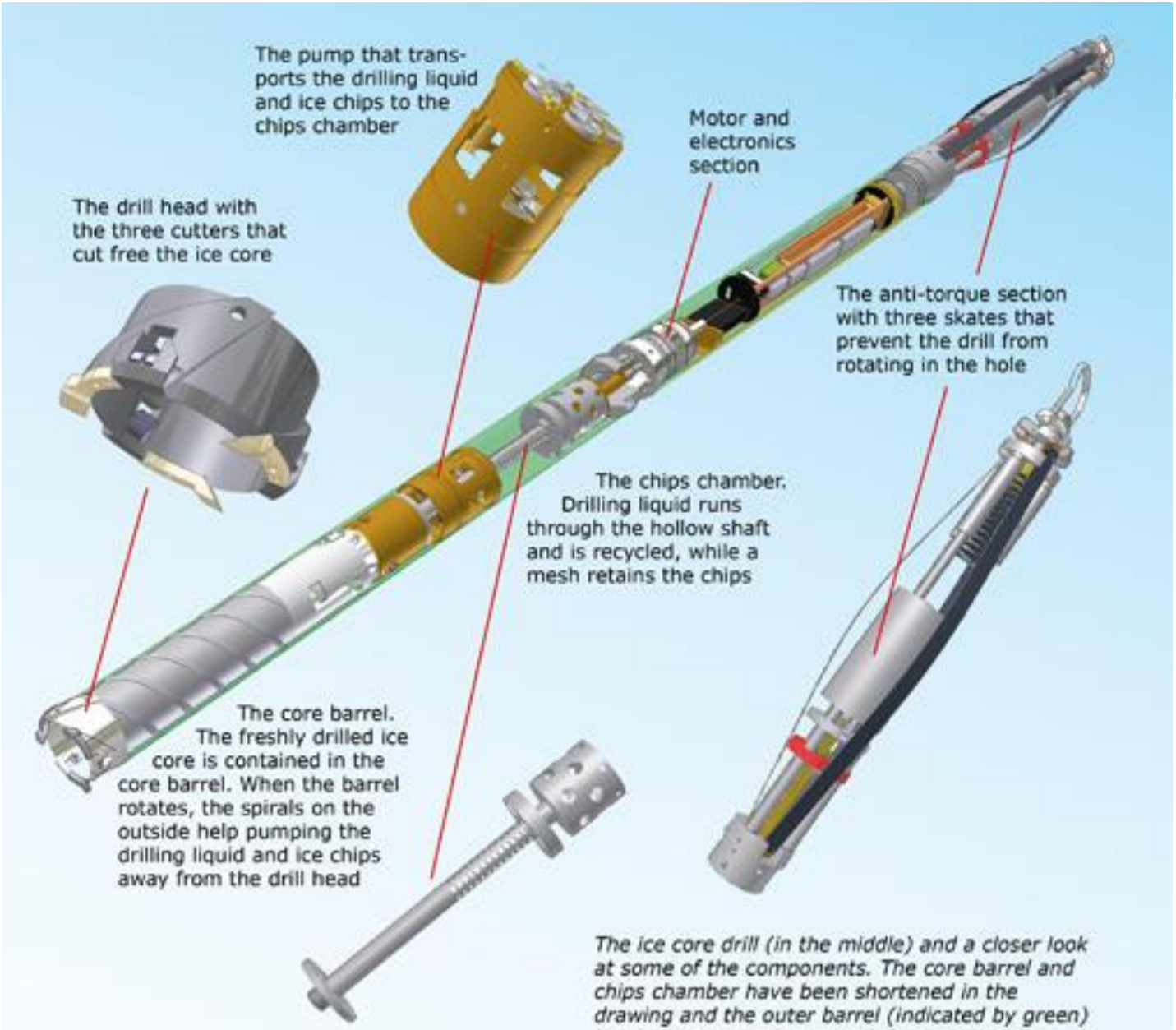
(https://icedrill.org/equipment/badger-eclipse-drill)

Coring-drills are high-tech with several components



(https://www.cambridge.org/core/journals/annals-of-glaciology/article/new-intermediatedepth-icecore-drilling-system/F8C5628BB68763256A95E02E1999BCD6)

Each drill component has a specific job to do



The ice core drill (in the middle) and a closer look at some of the components. The core barrel and chips chamber have been shortened in the drawing and the outer barrel (indicated by green) has been removed to reveal the parts inside

(https://neem.dk/about_neem/drillingicecores/)

Mast and coring-drill are tilted to get access to ice core

(https://discoveringantarctica.org.uk/oceans-atmosphere-landscape/atmosphere-weather-and-climate/climate-change-past-and-future/)

Earth's past atmosphere is then studied using the ice-cores

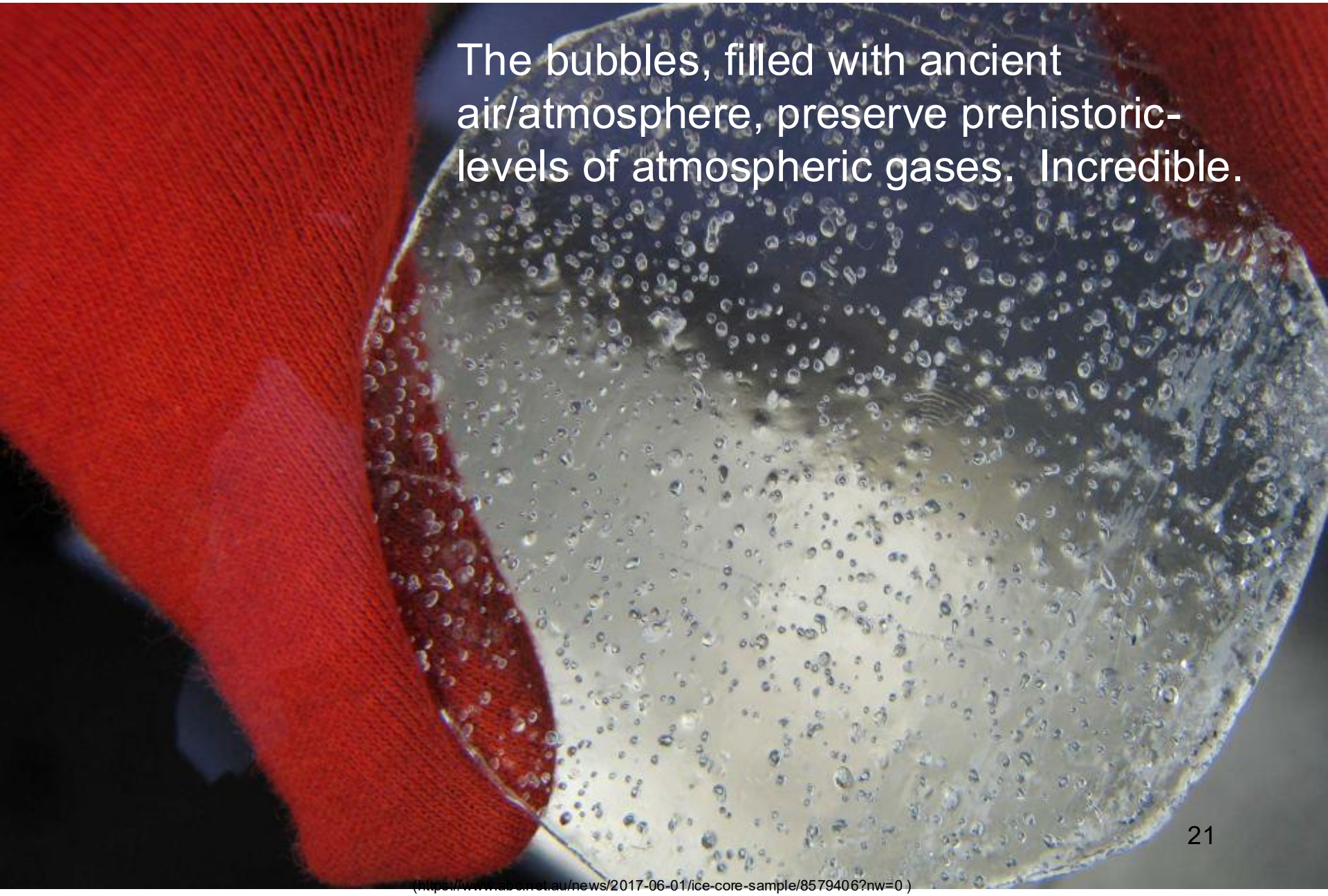
Ice-core sample being removed from coring-drill

(https://en.wikipedia.org/wiki/Ice_core)

The ice-cores look “cloudy” or like “frosted glass”

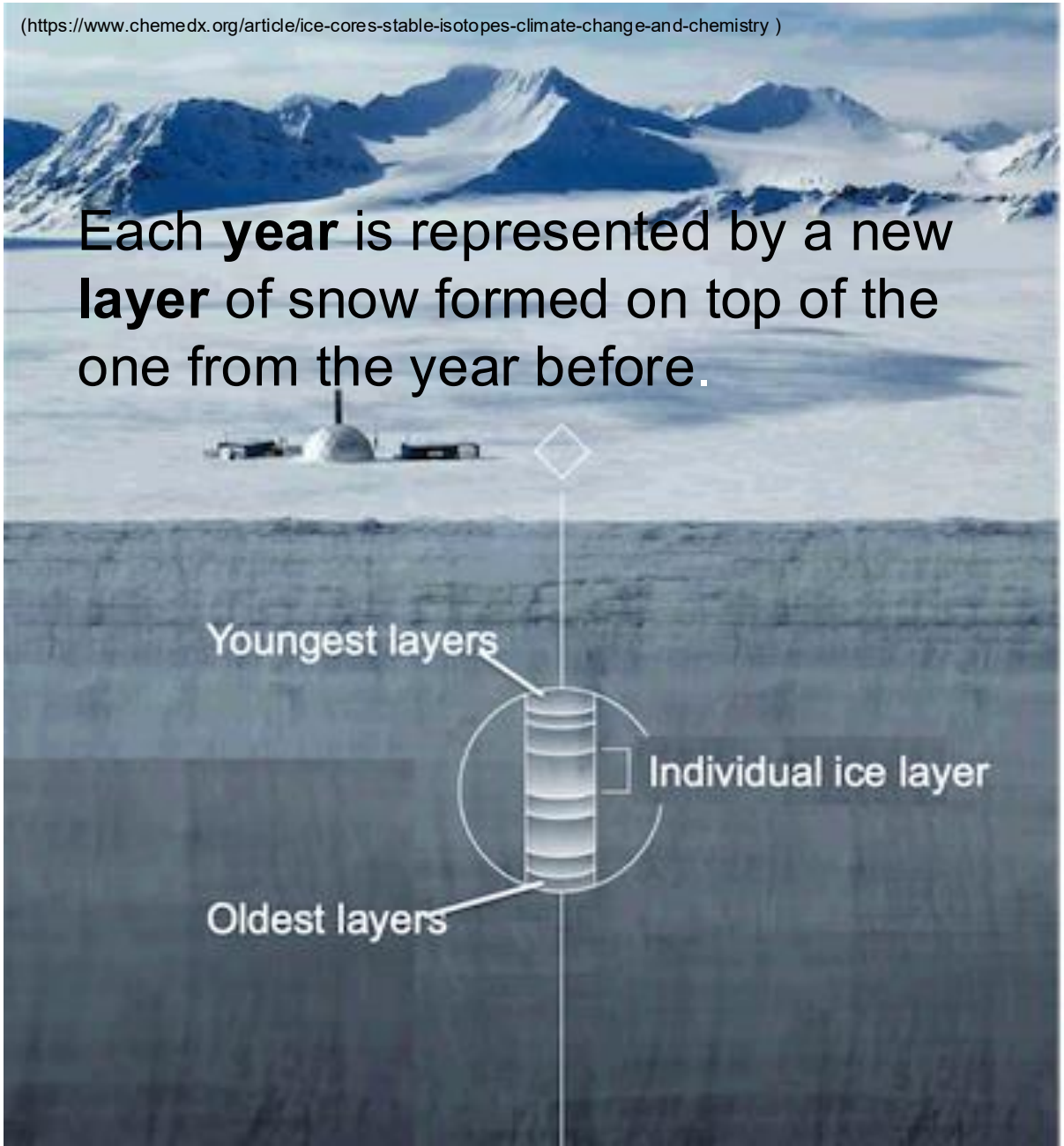
(https://climate.nasa.gov/news/2616/core-questions-an-introduction-to-ice-cores/)

A slice of the ice-core shows the mottled pattern of air bubbles



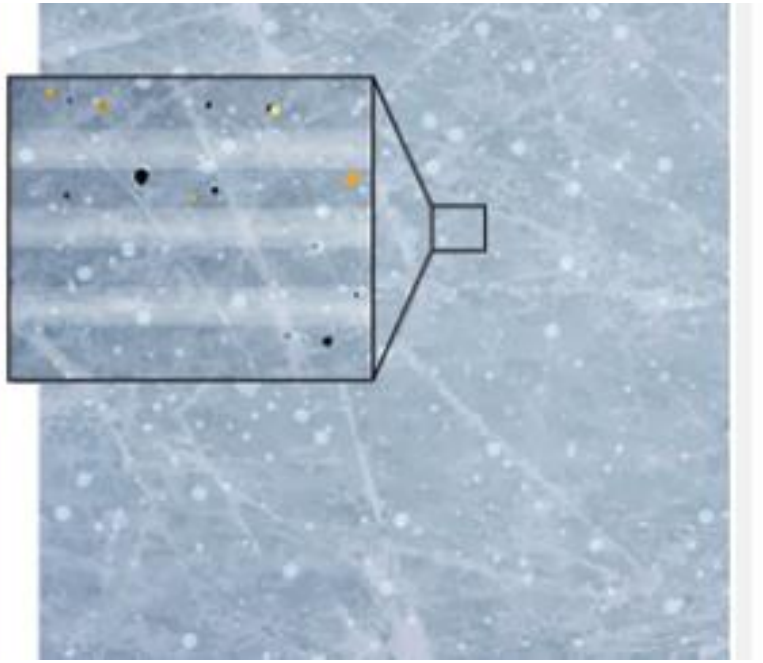
(https://www.abc.net.au/news/2017-06-01/ice-core-sample/8579406?nw=0)

Just to be clear: snow becomes ice and ice builds up over time



Typical structure of a column of ice

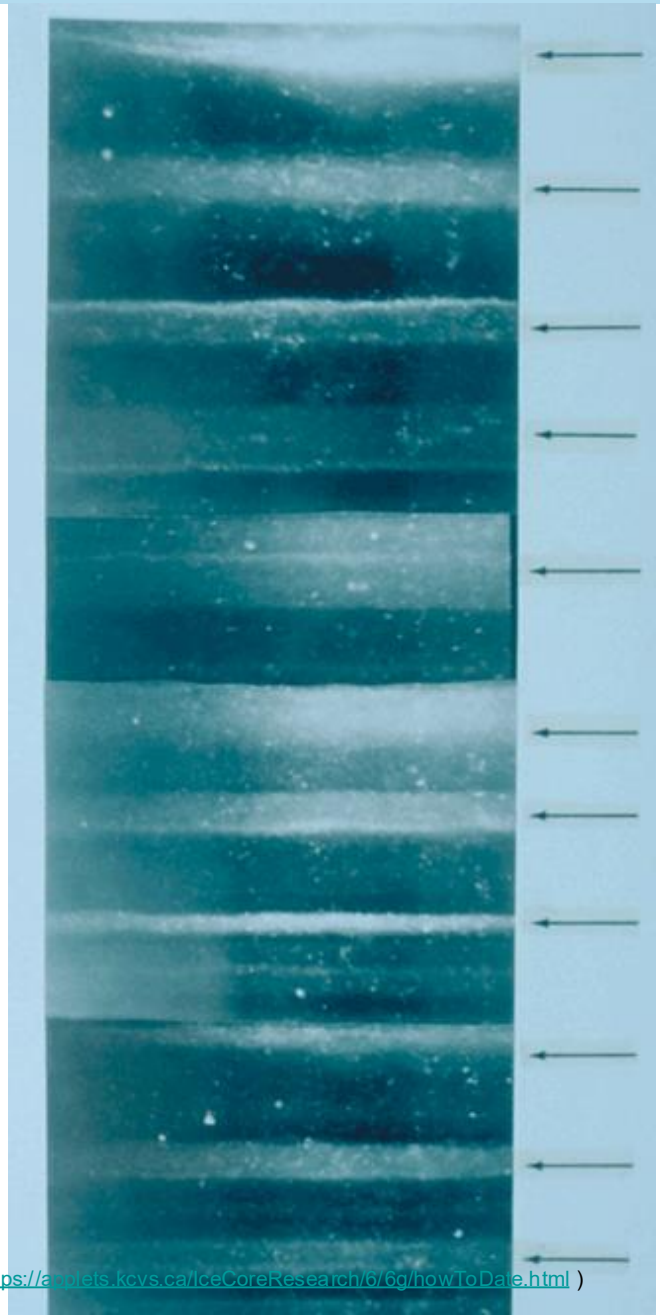
Compacted ice: Dark and light ice layers correspond to summer and winter snows.



(https://cen.acs.org/environment/climate-change/race-preserve-Earths-historical-climate/98/i23)

Dark and light layers “tick off” one year at a time

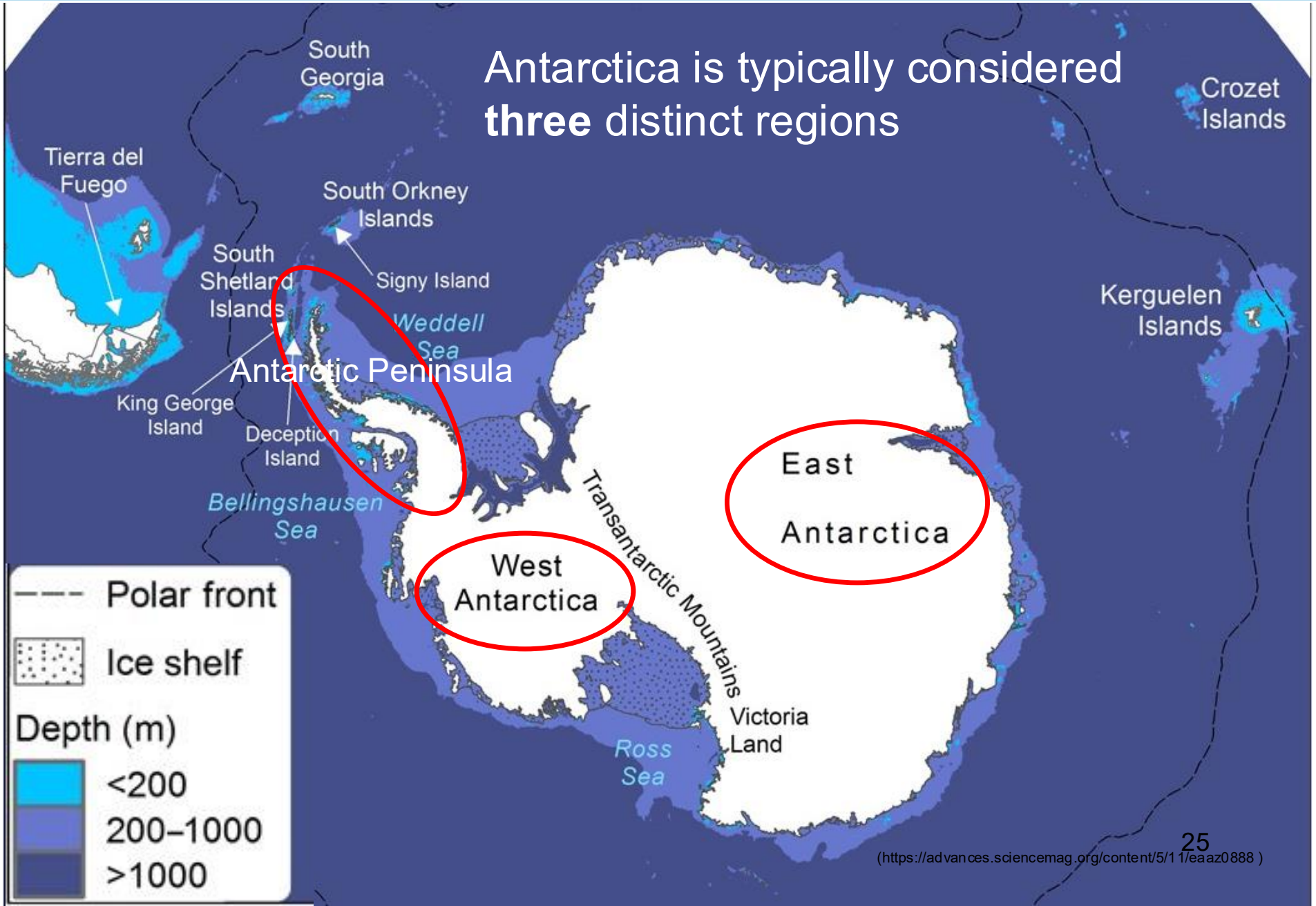
In practice scientists use a number of techniques to determine the **relative** and the **absolute ages** of the ice.



This pattern is clearest for shallower, younger ice

(https://applets.kcvs.ca/IceCoreResearch/6/6g/howToDate.html)

Antarctica is vast. Where is best for finding the oldest-ice?

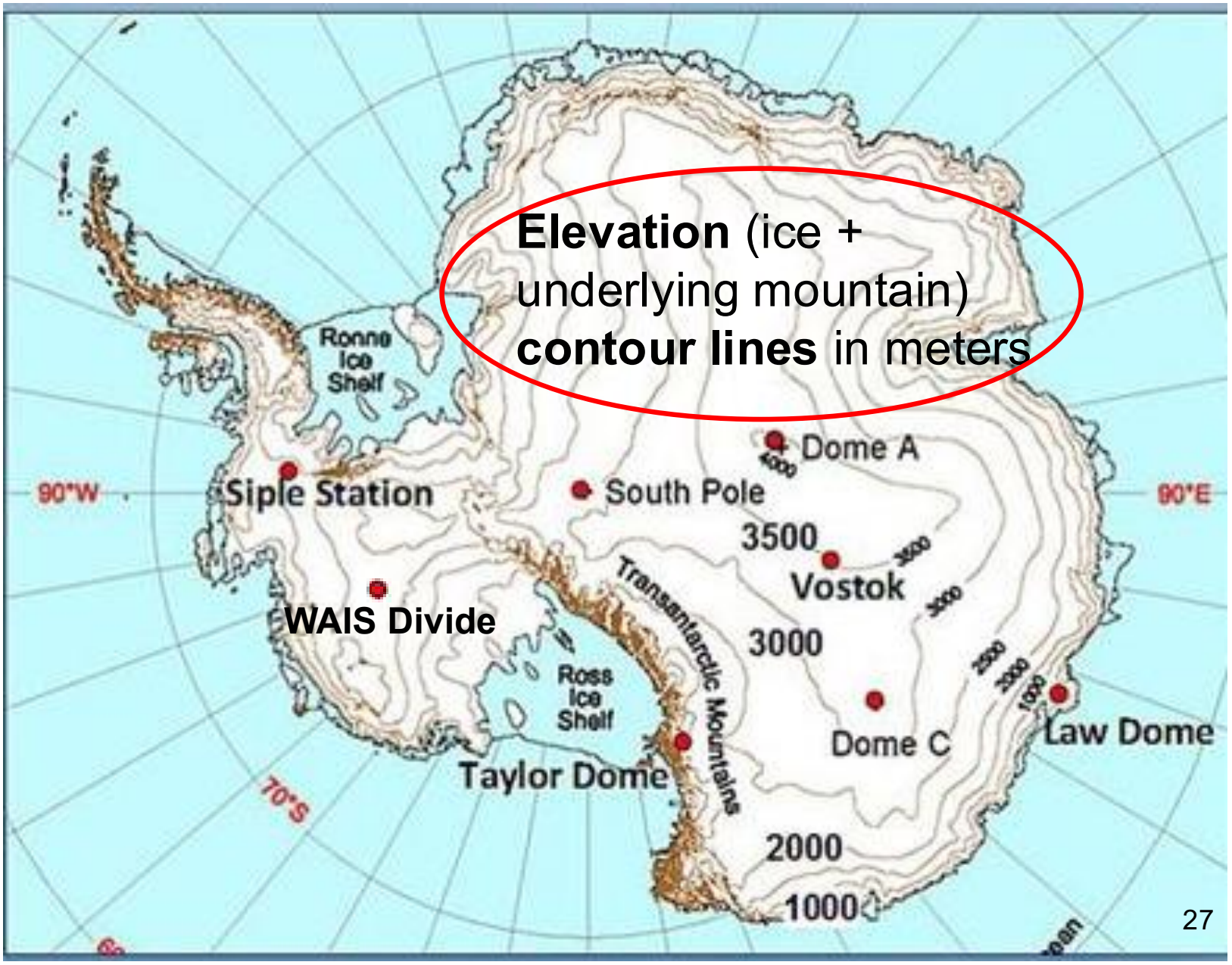


(https://advances.sciencemag.org/content/5/11/eaaz0888)

East Antarctica stores the most history in its thick ice

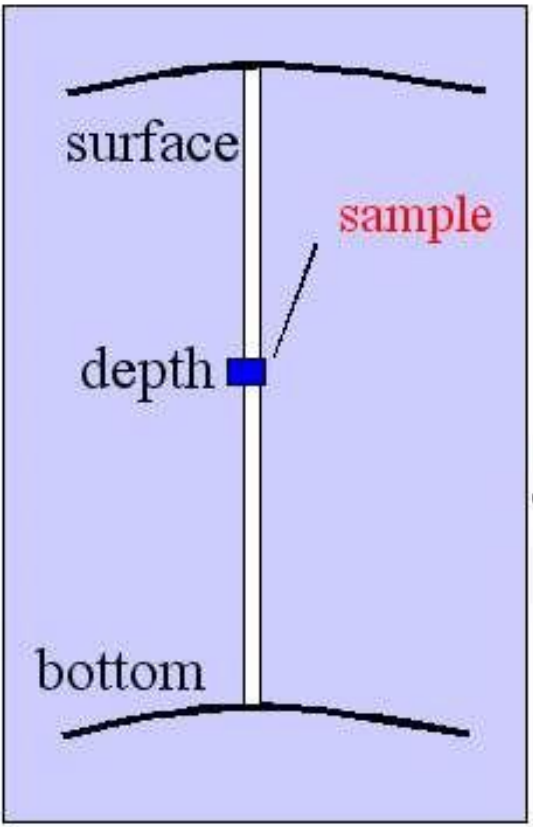
(https://www.ldeo.columbia.edu/res/pi/gambit/AntarcticInfo.html)

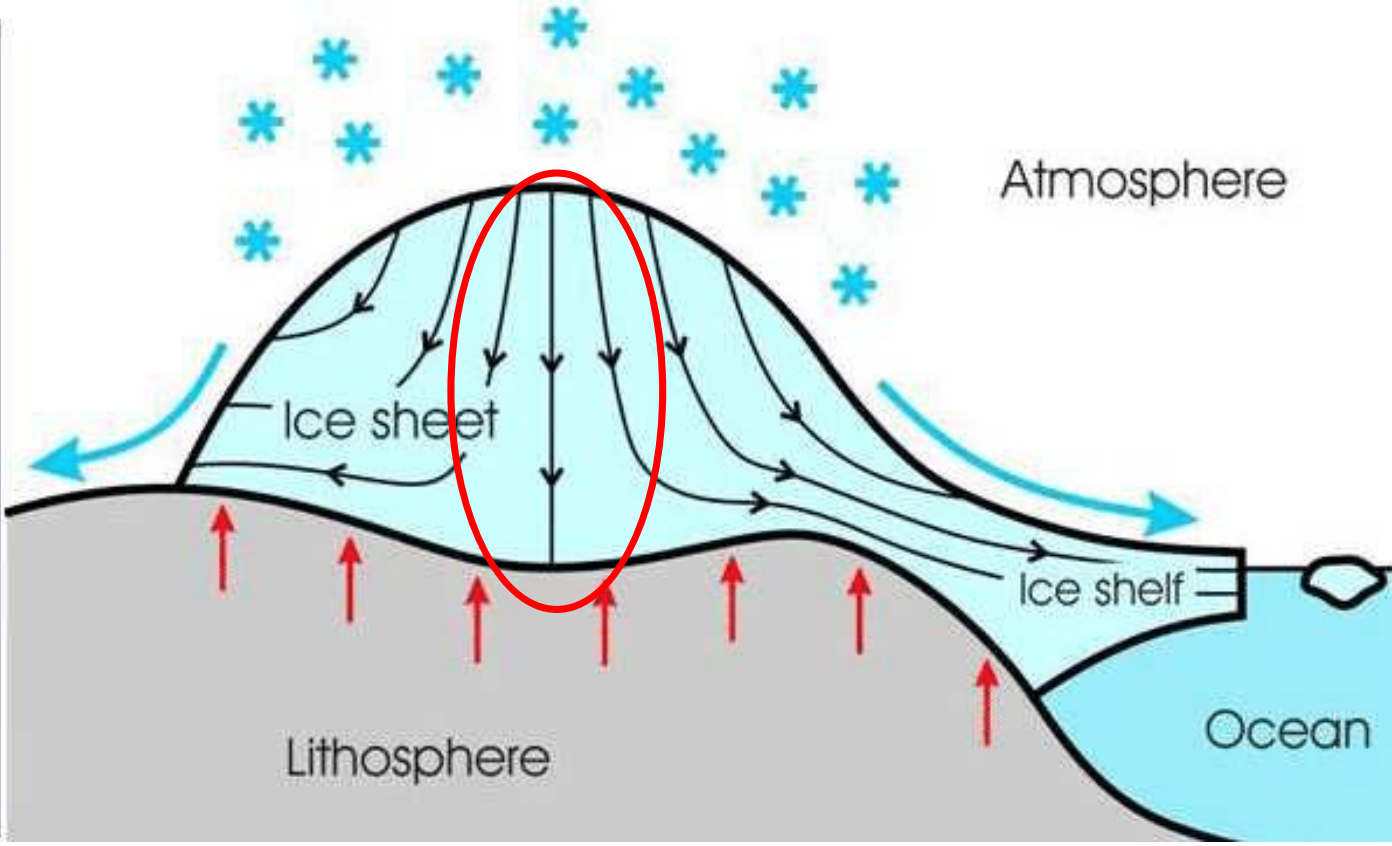
Ice at many locations is over 3000m (9850 ft) thick



(https://slideplayer.com/slide/16568631/)

Ice trajectories over time. Vertical lines are the best drill sites

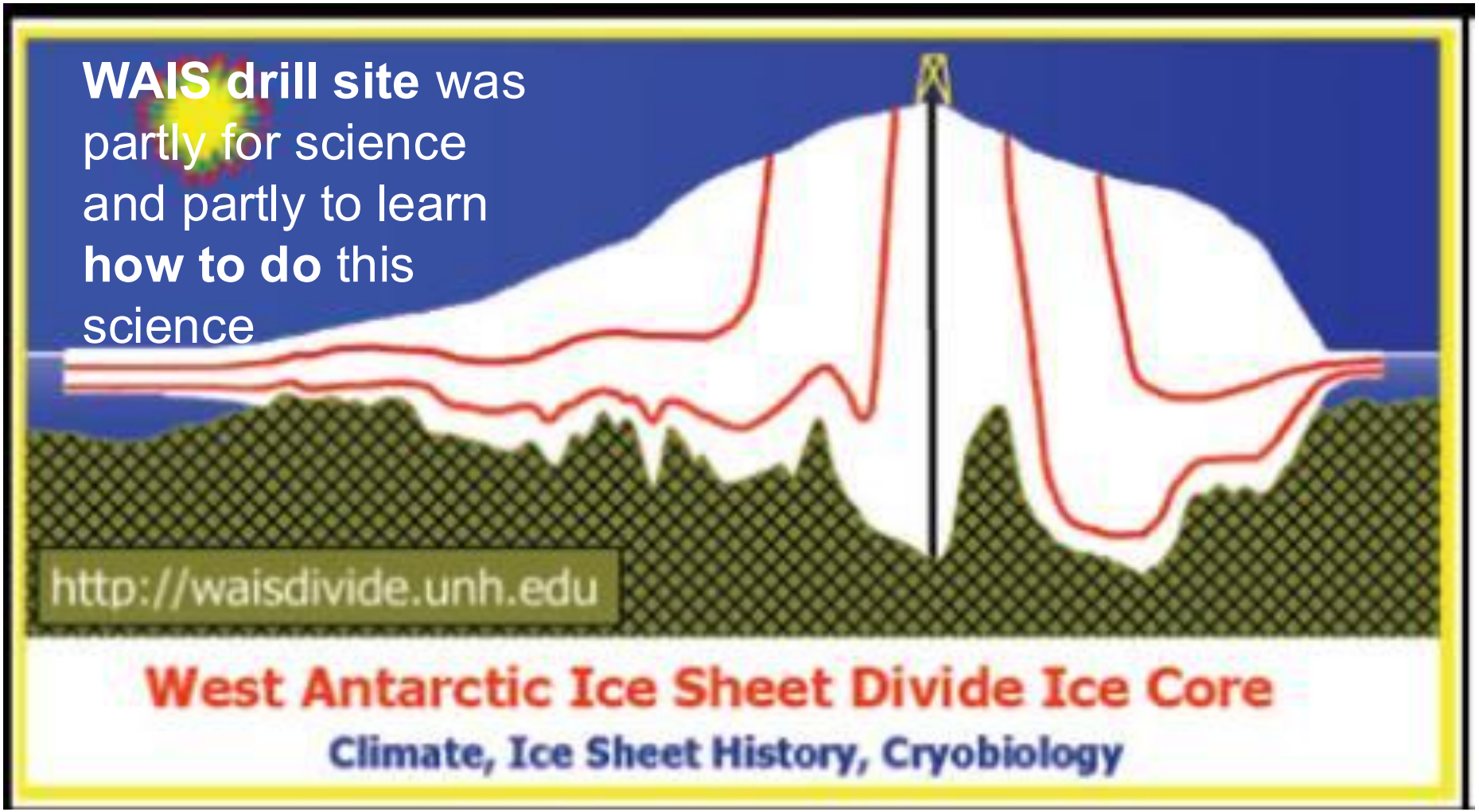




Ice **weight** causes ice sheets to **flow** to their peripheries

(https://www.researchgate.net/figure/a-Ice-specimen-at-a-certain-depth-of-an-ice-core-b-Ice-sheet-and-ice-shelf-bounded_fig2_267023538)

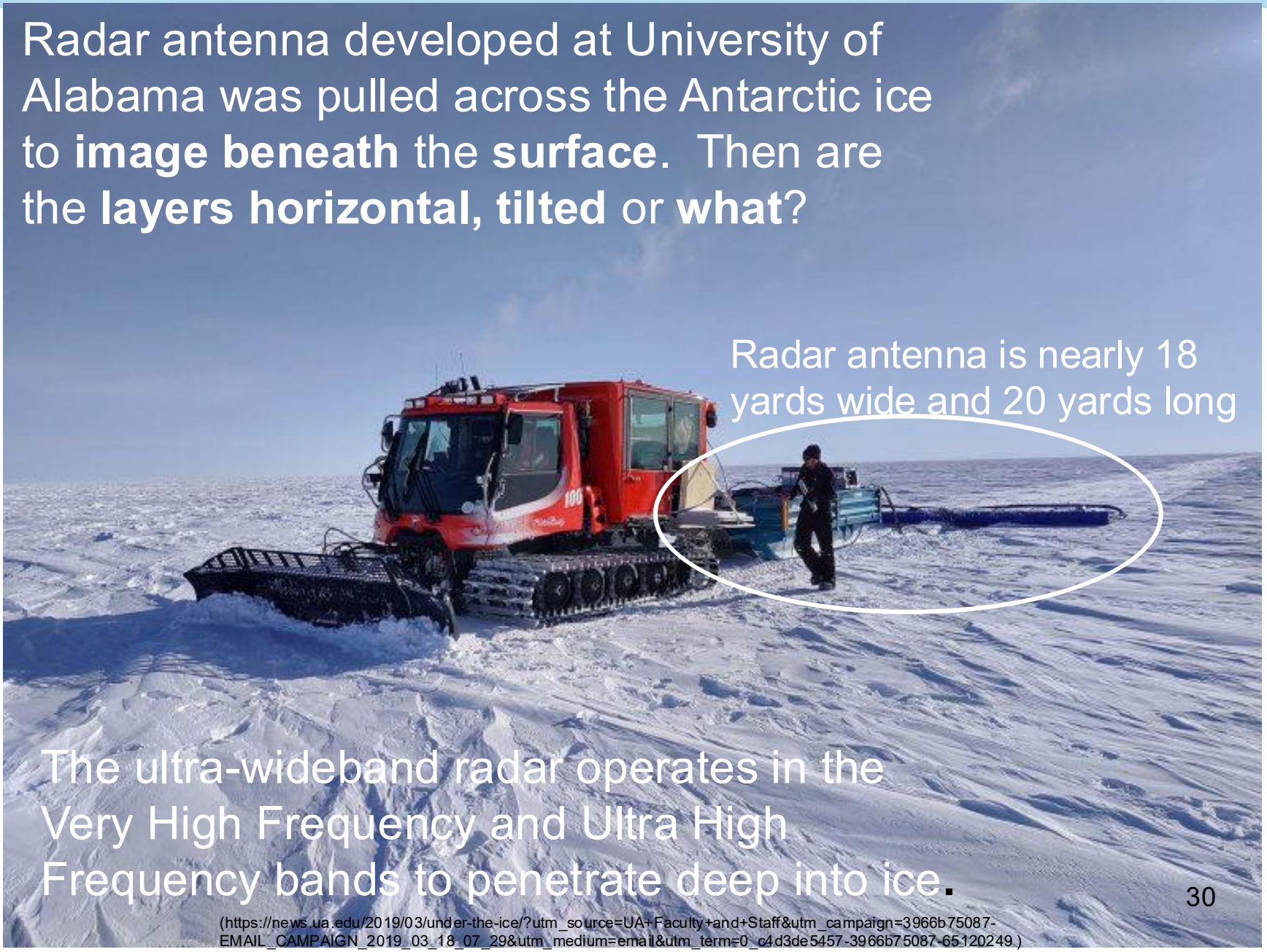
Drilling sites are selected for uniformity of ice-layers



(https://antarcticfudgesicles.wordpress.com/2011/01/19/why-wais-divide-part-1/)

Scientists have developed radar to map the ice

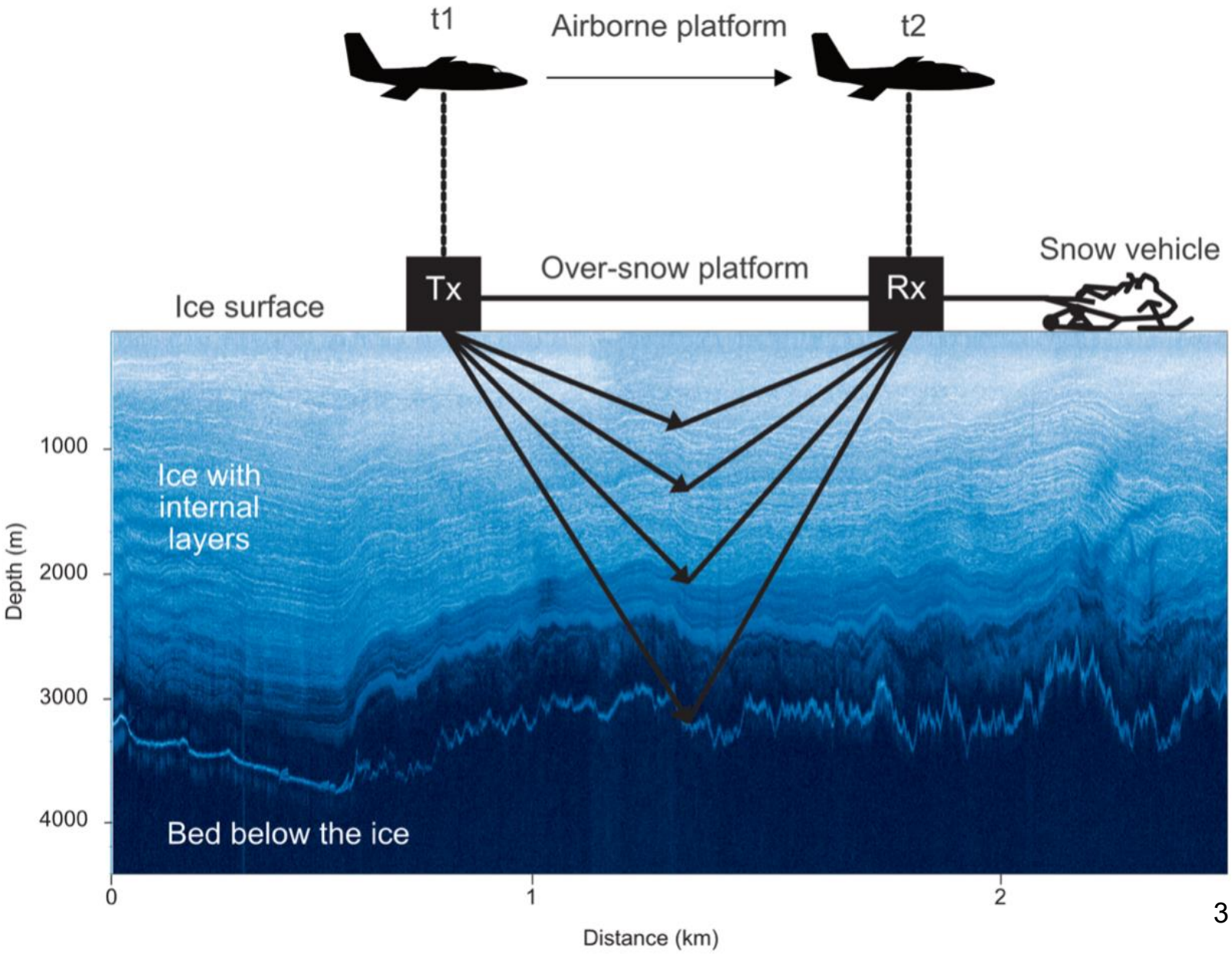
Radar antenna developed at University of Alabama was pulled across the Antarctic ice to **image beneath** the **surface**. Then are the **layers horizontal, tilted** or **what**?



The ultra-wideband radar operates in the Very High Frequency and Ultra High Frequency bands to penetrate deep into ice.

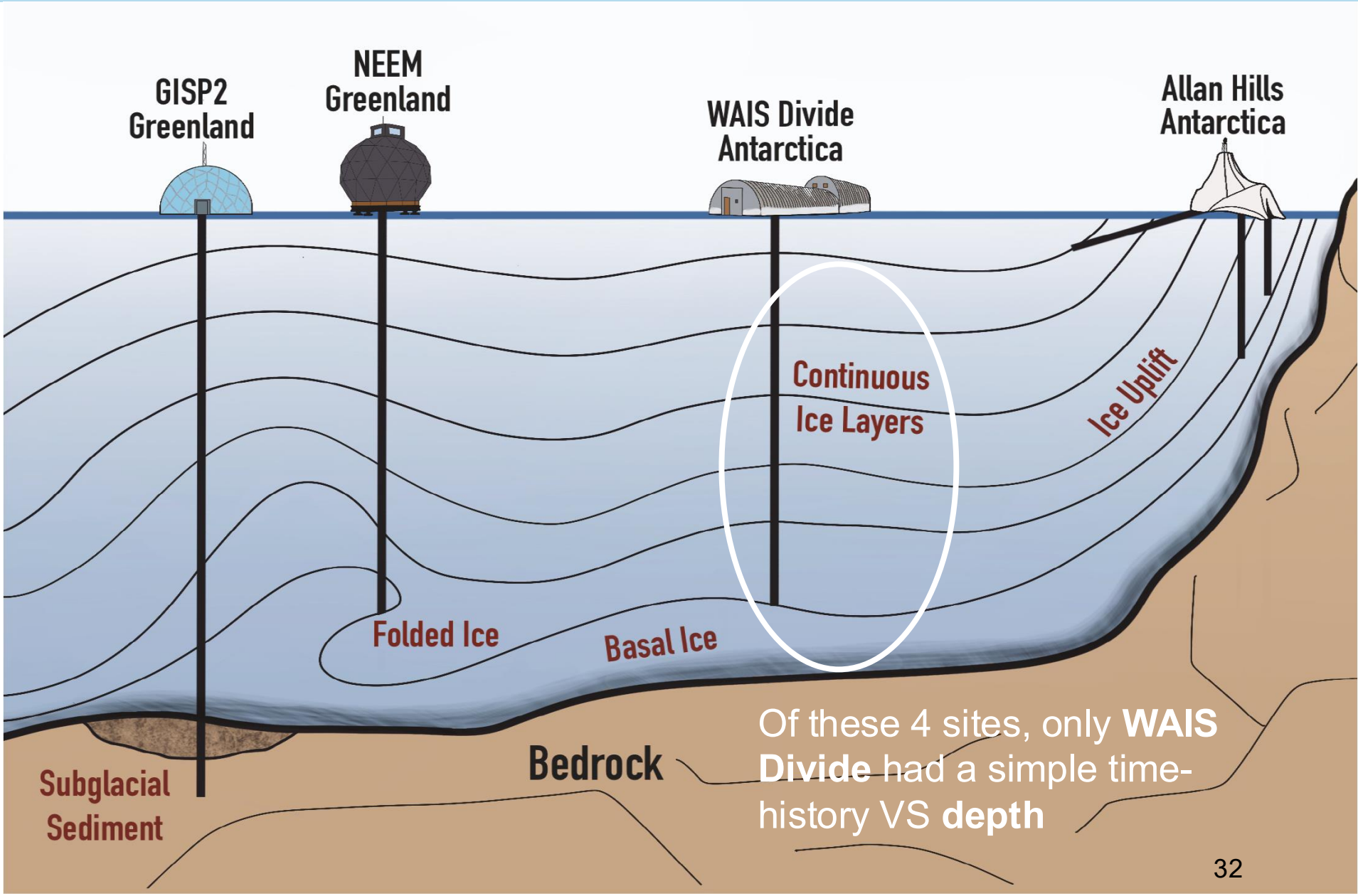
(https://news.ua.edu/2019/03/under-the-ice/?utm_source=UA+Faculty+and+Staff&utm_campaign=3966b75087-EMAIL_CAMPAIGN_2019_03_18_07_29&utm_medium=email&utm_term=0_c4d3de5457-3966b75087-65120249)

Airborne or ground-based radar map ice and bedrock



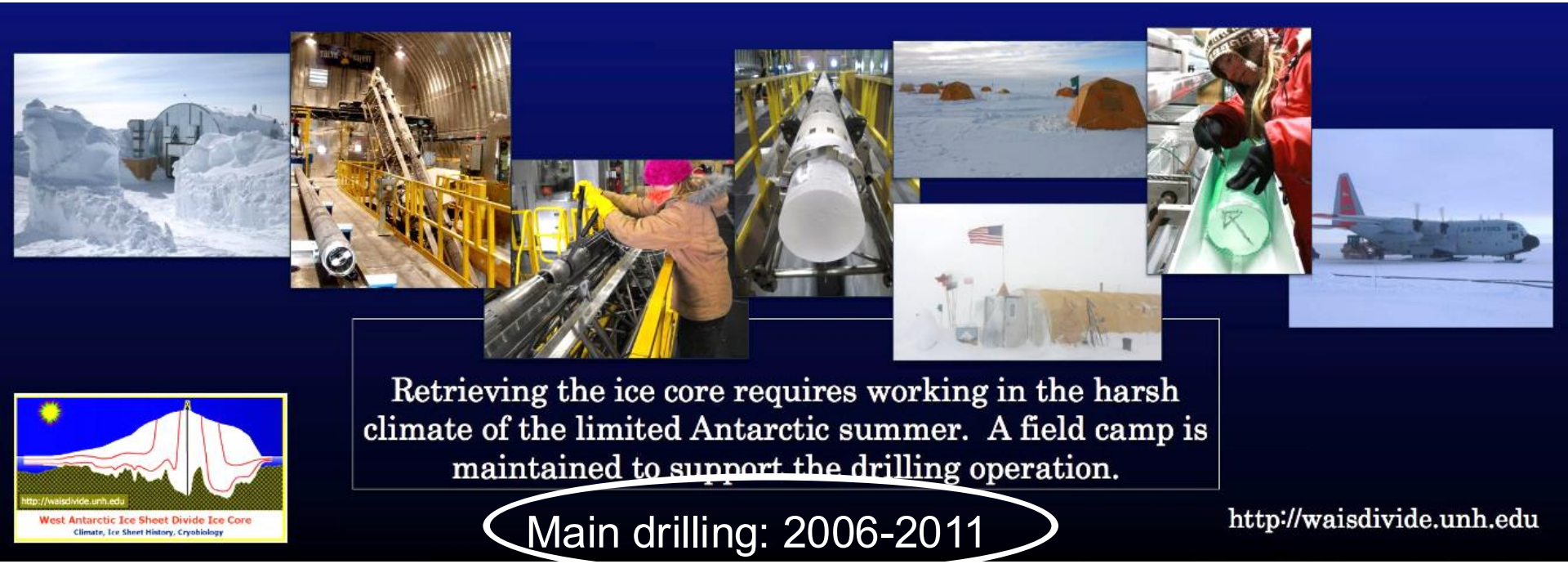
(https://www.antarcticglaciers.org/glaciers-and-climate/observing-and-monitoring-glaciers-and-ice-sheets/mapping-the-glacier-bed/)

The age of the ice is not necessarily simply related with depth



(https://pastglobalchanges.org/publications/pages-magazines/pages-magazine/129558)

Once started, the ice-core drilling extends over many years



The ice-core drilling effort, and logistics, are almost unimaginable.

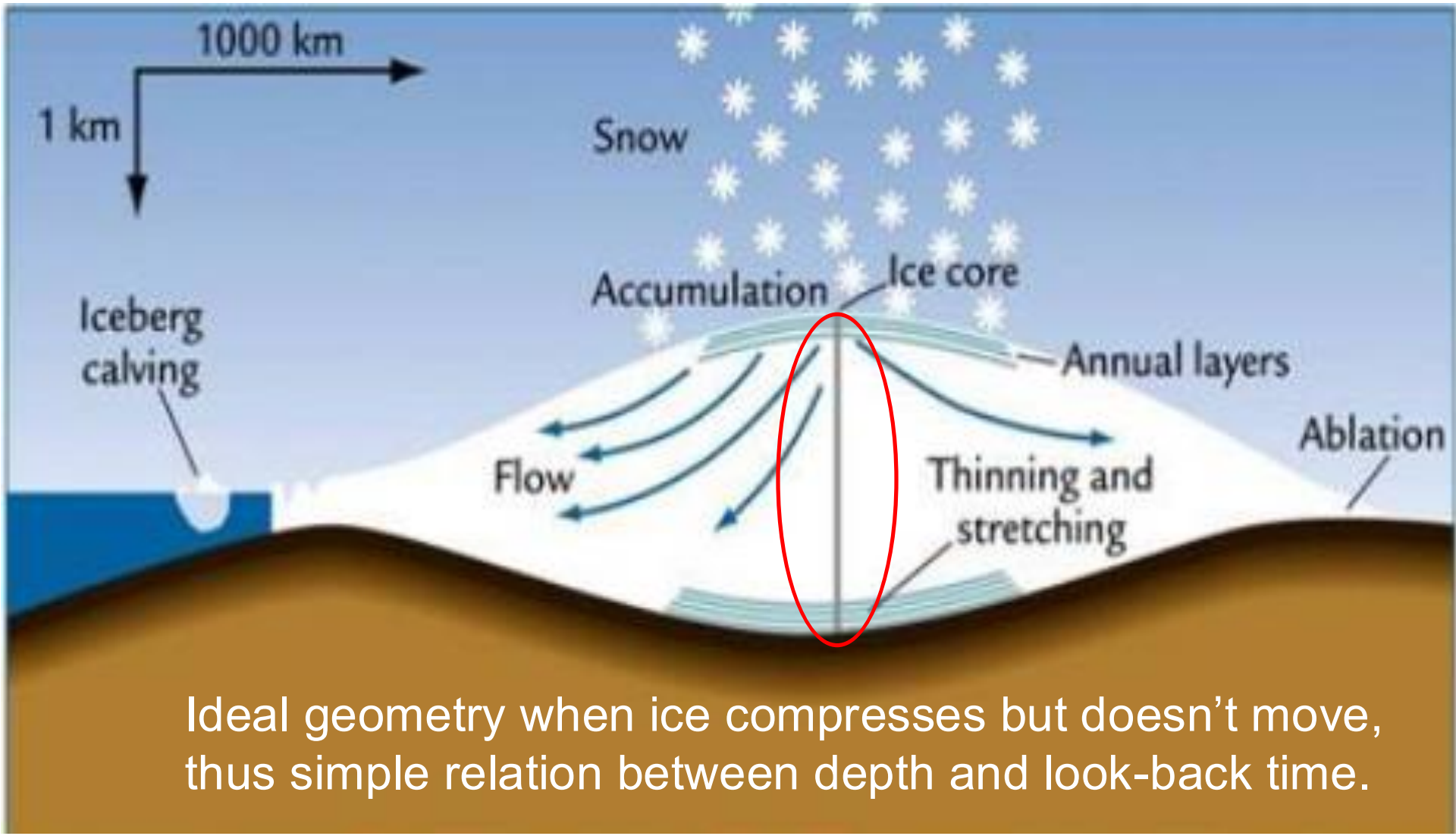
The **WAIS Divide** project reached its final depth goal of 3,405 meters (2.116 miles) on December 31, 2011

(https://waisdivide.unh.edu/posters/)

Ultimately, ice-cores are stored at -36°C (-32.8°F) for analysis

(https://icecores.org/)

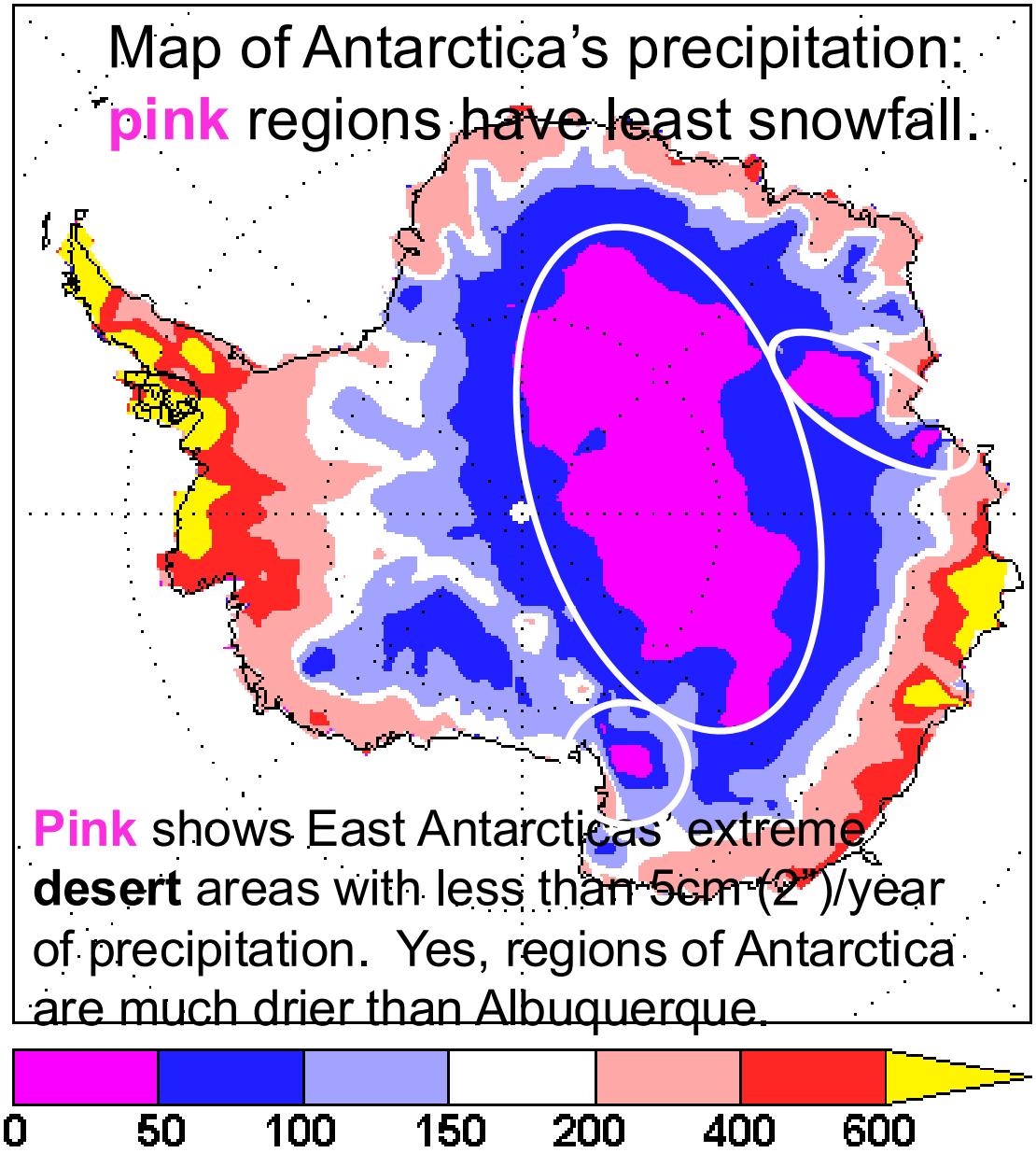
For longest ice-history, sites with most ice-layers are best



Ideal geometry when ice compresses but doesn't move, thus simple relation between depth and look-back time.

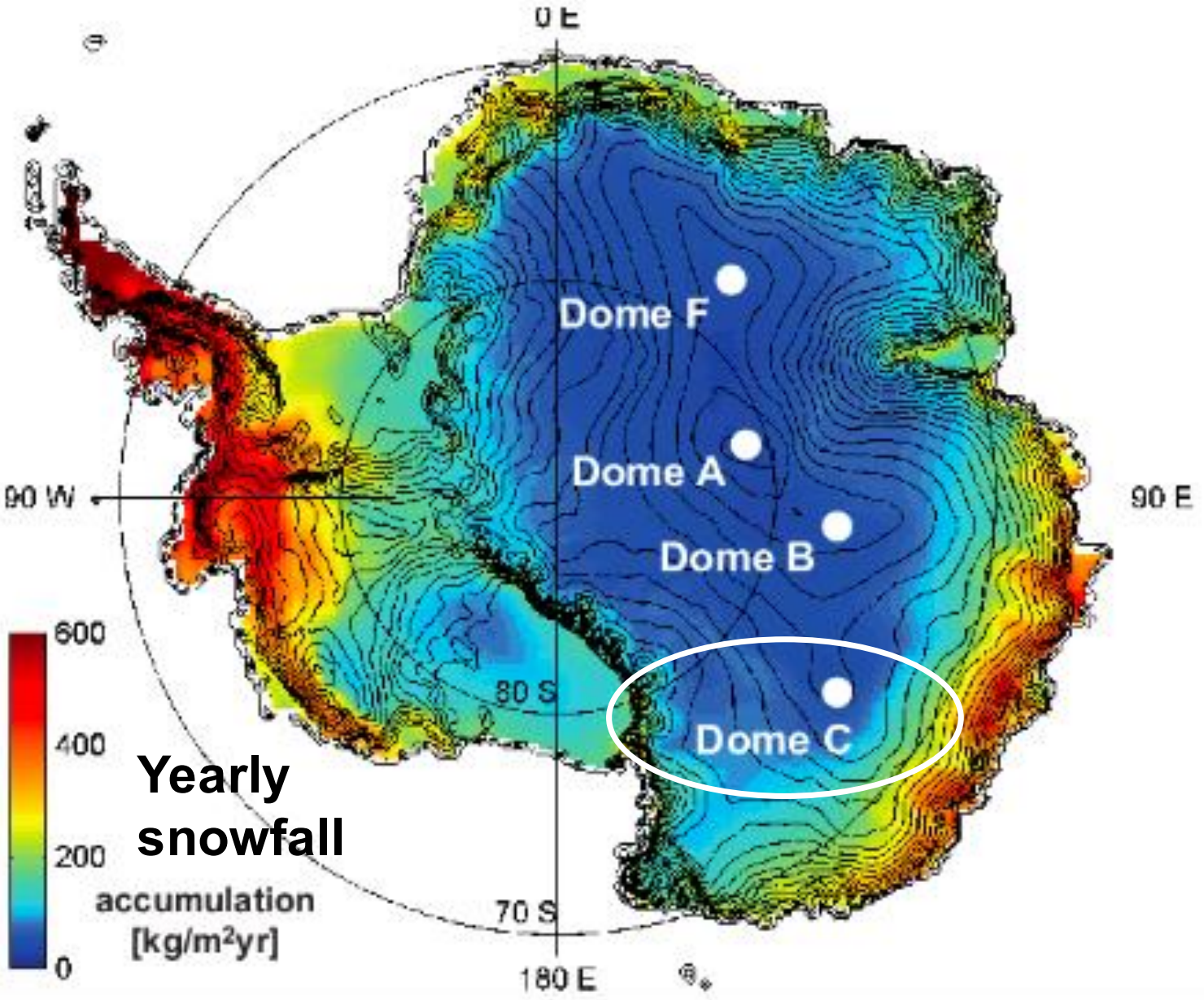
(https://globalchange.umich.edu/globalchange1/current/labs/Lab10_Vostok/Vostok.htm)

As yearly snowfall becomes a layer, minimum snowfall is best



(https://en.wikipedia.org/wiki/Climate_of_Antarctica)

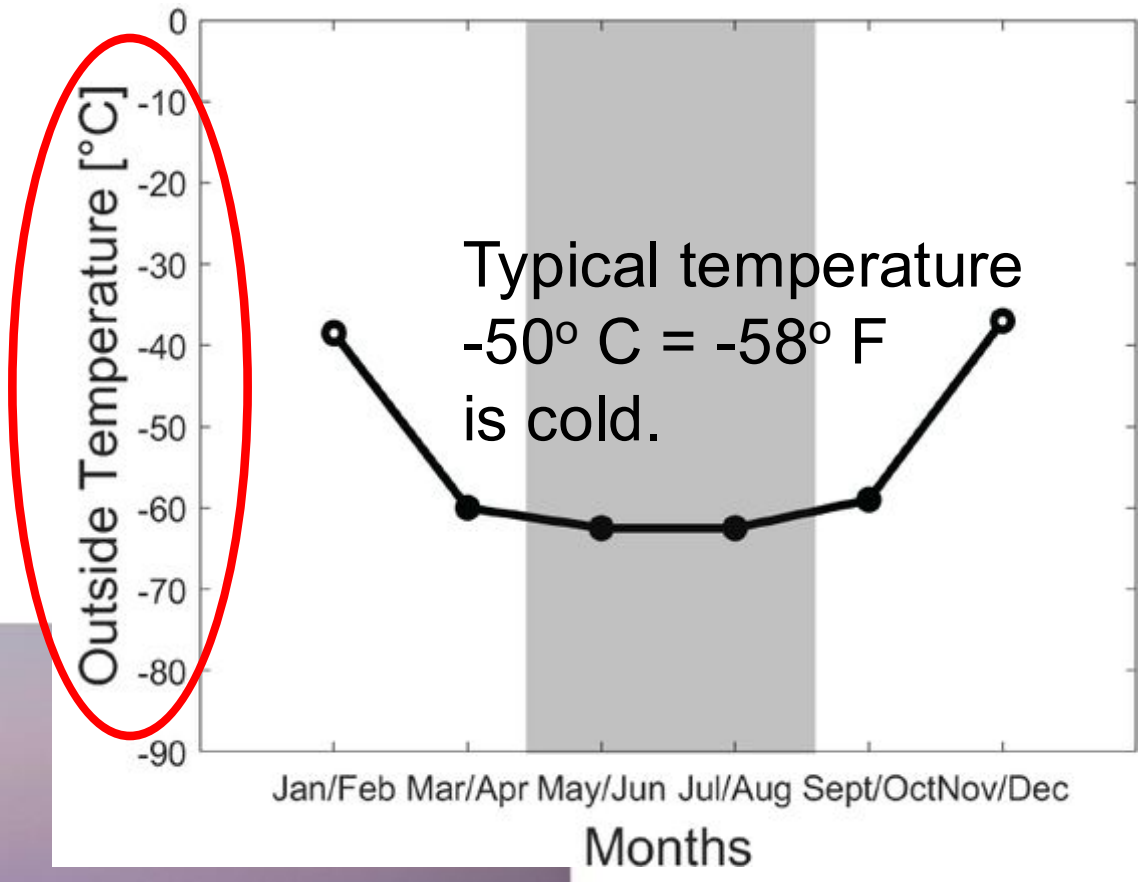
Several good drilling sites: high points with minimal snowfall



(https://www.semanticscholar.org/paper/Where-to-find-1.5-million-yr-old-ice-for-the-IPICS-Fischer-Severinghaus/4832d62dfcb2bb5e3c9b2ecc711b18379c85ea25/figure/3)

Concordia is the research station at Dome C

East Antarctic drill sites are all high and cold



Concordia: **3** floors of **laboratory** and **living** structures

(https://www.biorxiv.org/content/10.1101/516567v1.full)

Concordia Research Station is operated by France and Italy

(https://alchetron.com/Dome-C)

Concordia/Dome C are far inland: supplies are pulled on sleds

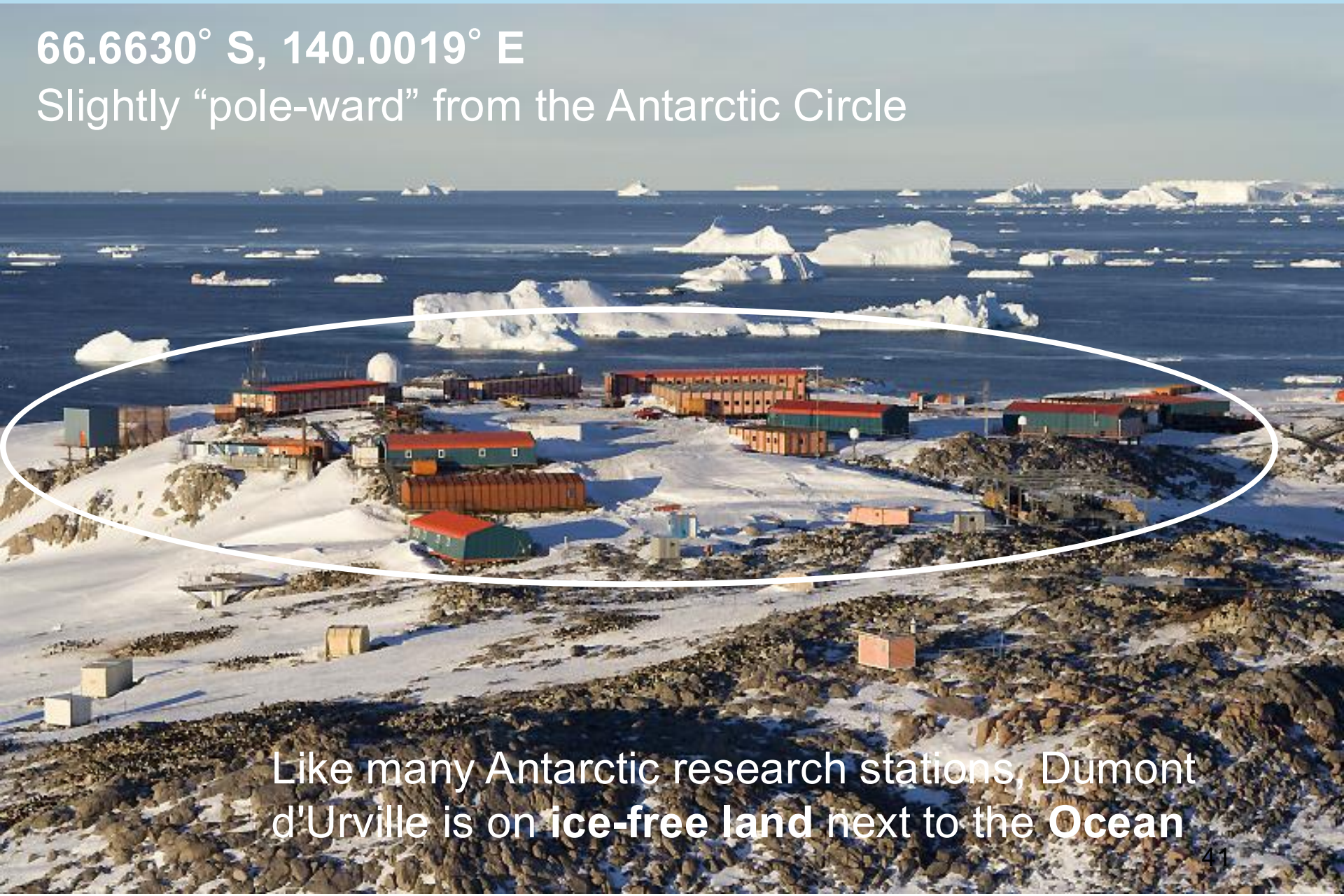
Most of the cargo is **moved** to Dome C by ***traverse*** from **Dumont d'Urville Station** in 7 to 12 days depending on weather conditions.

(https://www.livescience.com/65188-antarctica-drilling-oldest-ice.html)

France's Dumont d'Urville Station is next to the Ocean

66.6630° S, 140.0019° E

Slightly "pole-ward" from the Antarctic Circle



Like many Antarctic research stations, Dumont d'Urville is on **ice-free land** next to the **Ocean**

(https://ultima0thule.blogspot.com/2014/05/antarctic-base-dumont-durville-bit-of.html)

Ocean location is pivotal for base/research-mission supplies

Icebreaker makes up to 5 round-trip voyages to the Antarctic base during the November to February period.

(https://www.reddit.com/r/antarctica/comments/7axm6o/base_dumontdurville_france_antarctique_5184x3456/)

French Icebreaker L'Astrolab unloading supplies

Ship transports personnel and cargo between **Hobart**, Tasmania and the **Dumont d'Urville** base.

Curious **penguins** monitor the progress

(https://tridentnewspaper.com/ltn-moors-embarks-on-antarctic-voyage-aboard-lastrolabe/)

Cargo is loaded onto sleds that are pulled by tractors

(https://www.patricegodonpolarengineering.eu/ground-supply-traverses/)

Antarctica has little snow but frequently a lot of wind

Stiff katabatic-winds drive drifting snow across the “road” to Concordia. This path was cleared **two days earlier** by plows on the supply traverse.

(https://www.wunderground.com/cat6/Taste-Traverse-How-Cross-Antarctica-without-Plane)

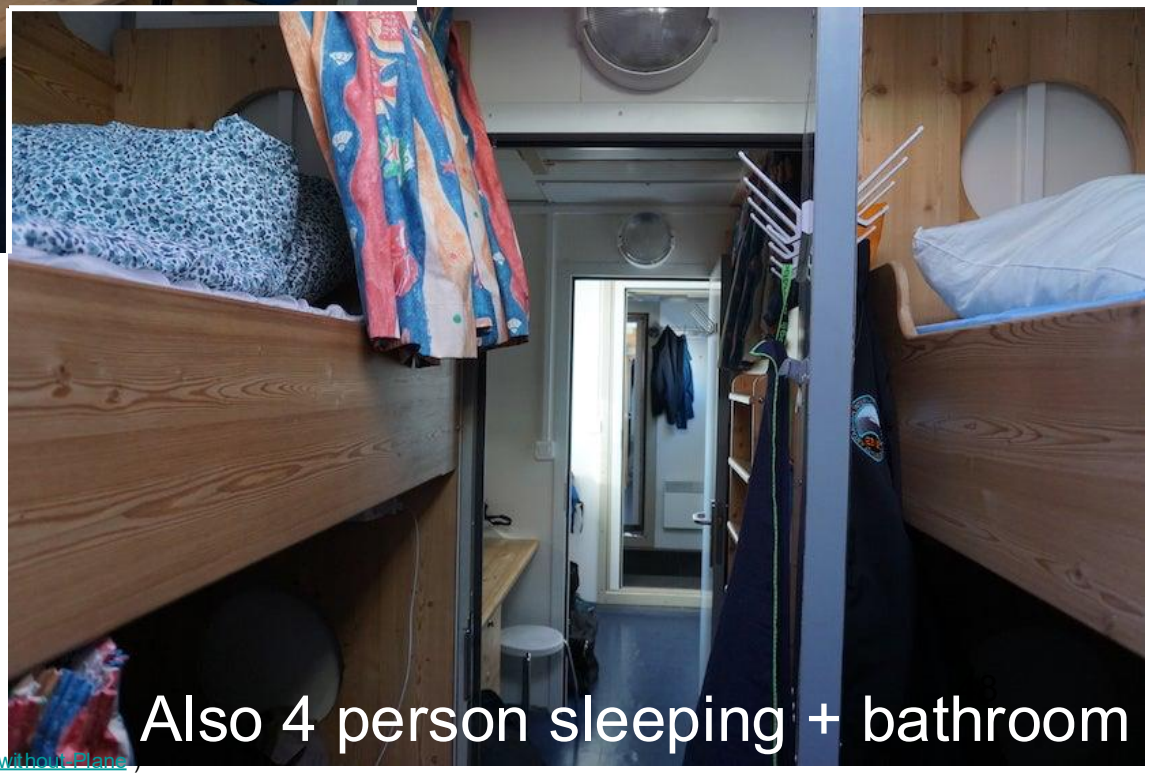
Summer Sun never sets and is never high in the sky

(https://www.wunderground.com/cat6/Taste-Traverse-How-Cross-Antarctica-without-Plane)

Convoy includes shipping containers refurbished as living quarters

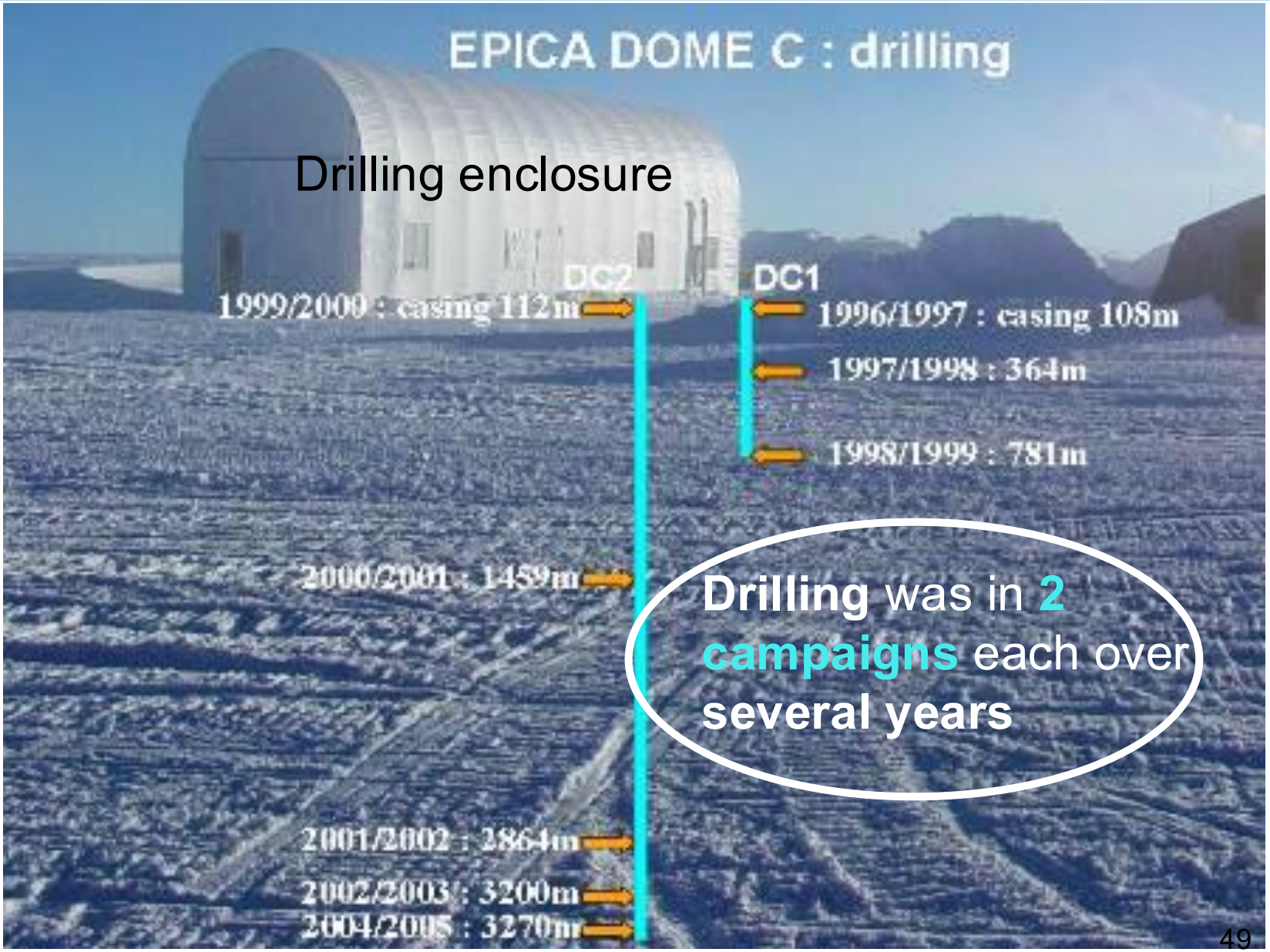
(https://www.wunderground.com/cat6/Taste-Traverse-How-Cross-Antarctica-without-Plane)

Living quarters for the 7 to 12 day trip to Concordia Station



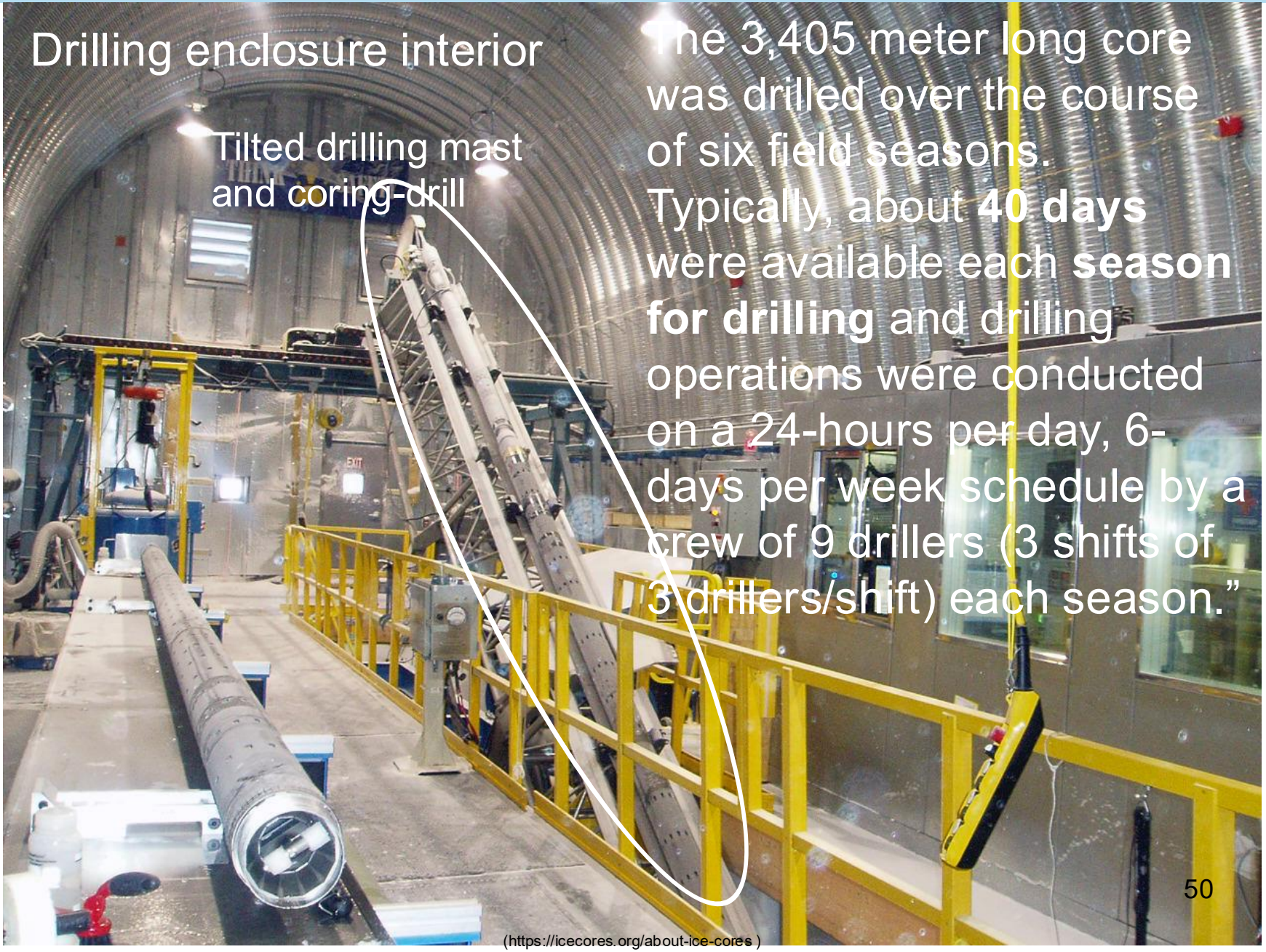
(https://www.wunderground.com/cat6/Taste-Traverse-How-Cross-Antarctica-without-Plane)

European Project ice coring at Dome C has significant history



(http://archives.esf.org/coordinating-research/research-networking-programmes/life-earth-and-environmental-sciences-lee/completed-esf-research-networking-programmes-in-life-earth-and-environmental-sciences/european-project-for-ice-coring-in-antarctica-epica-page-1.html)

Major installation needed to drill very deep/very old ice cores



(https://icecores.org/about-ice-cores)

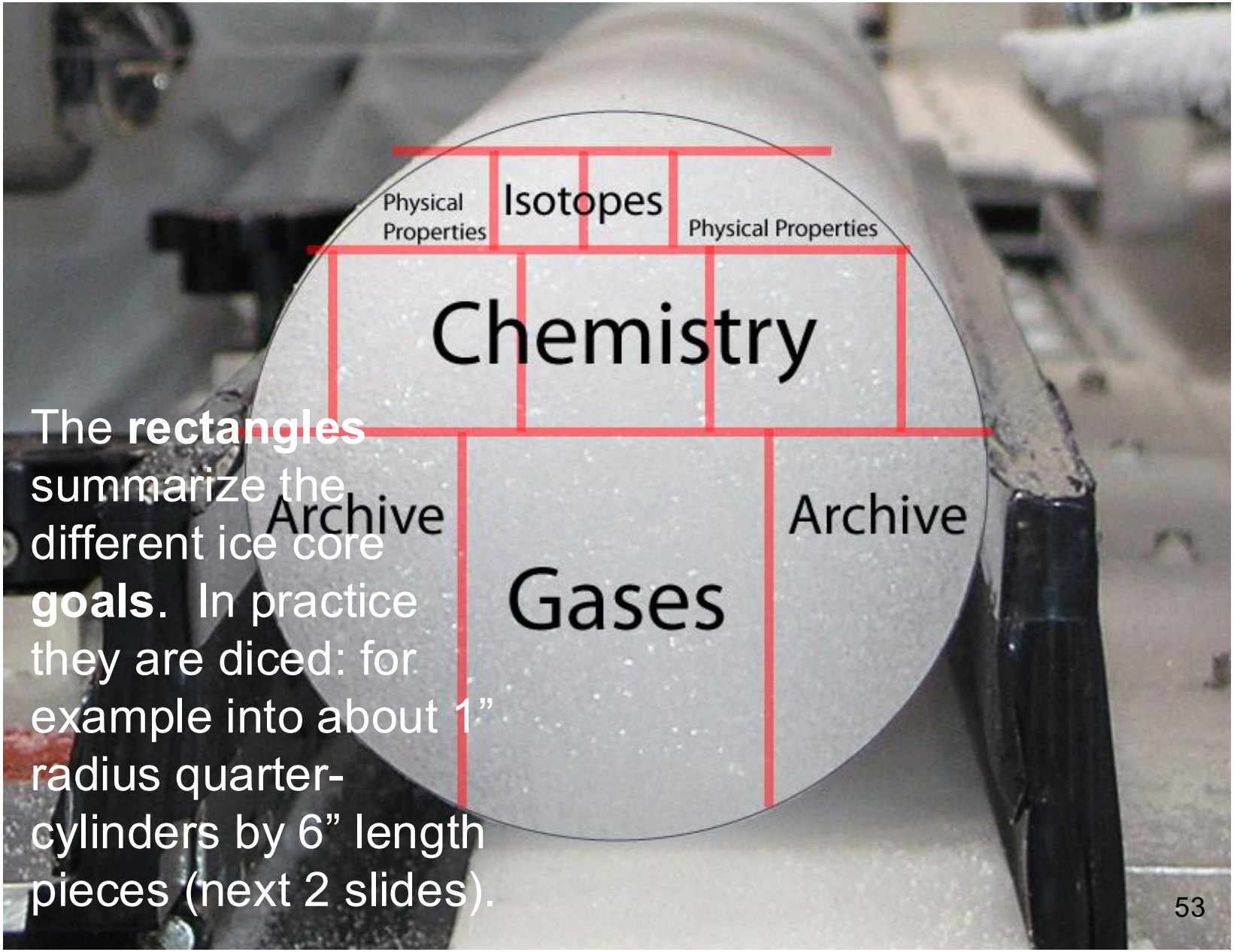
Some supplies and ice-core removal are by plane

(https://www.nature.com/articles/d41586-018-07588-3?utm_source=fbk_nnc&utm_medium=social&utm_campaign=naturenews&sf210131985=1)

Incoming supplies / outgoing ice-cores

(http://www.antarcticglaciers.org/glaciers-and-climate/ice-cores/ice-core-drilling/)

How do scientists “analyze” the ice cores?



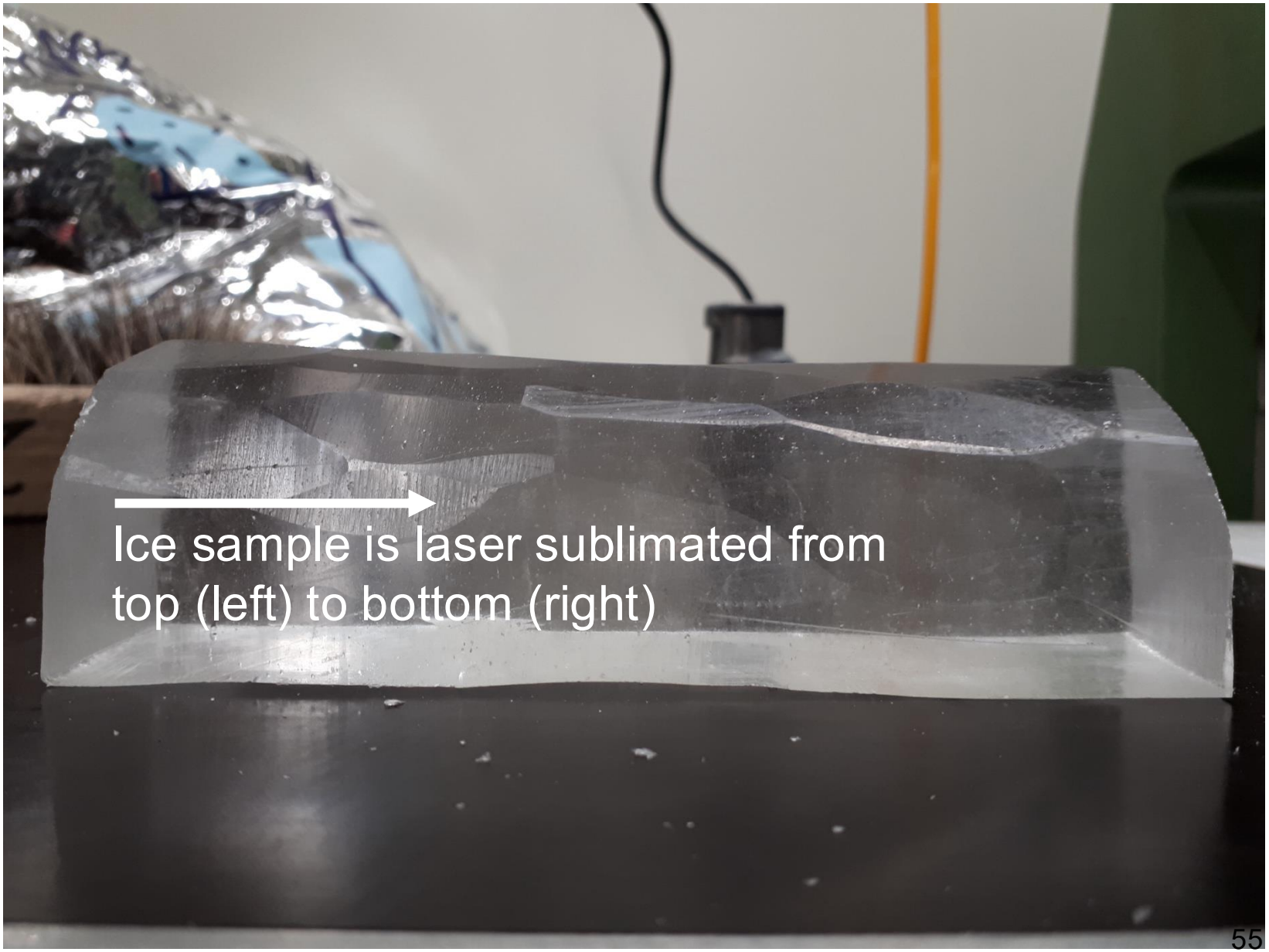
The **rectangles** summarize the different ice core **goals**. In practice they are diced: for example into about 1” radius quarter-cylinders by 6” length pieces (next 2 slides).

(https://www.antarcticglaciers.org/question/how-are-ice-cores-dated/)

Prepare sample for analysis: first cut and trim the ice core

(https://worldoceanreview.com/en/wor-6/climate-change-impacts-in-the-polar-regions/the-pathways-of-heat/ice-cores-how-researchers-read-the-climate-record/)

Ice sample is now ready for precision melting/analysis

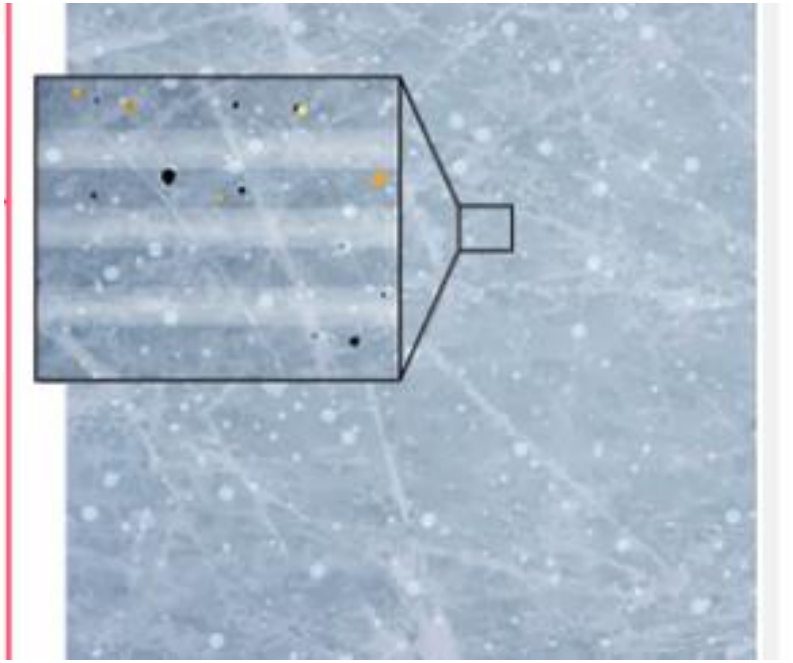


(https://mediarelations.unibe.ch/media_releases/2023/media_releases_2023/new_technology_revolutionizes_the_analysis_of_old_ice/index_eng.html)

Spectroscopic analysis: which molecules and their fractions?

(https://www.jahresbericht.unibe.ch/key_areas/sustainability/ocean_temperature/index_eng.html)

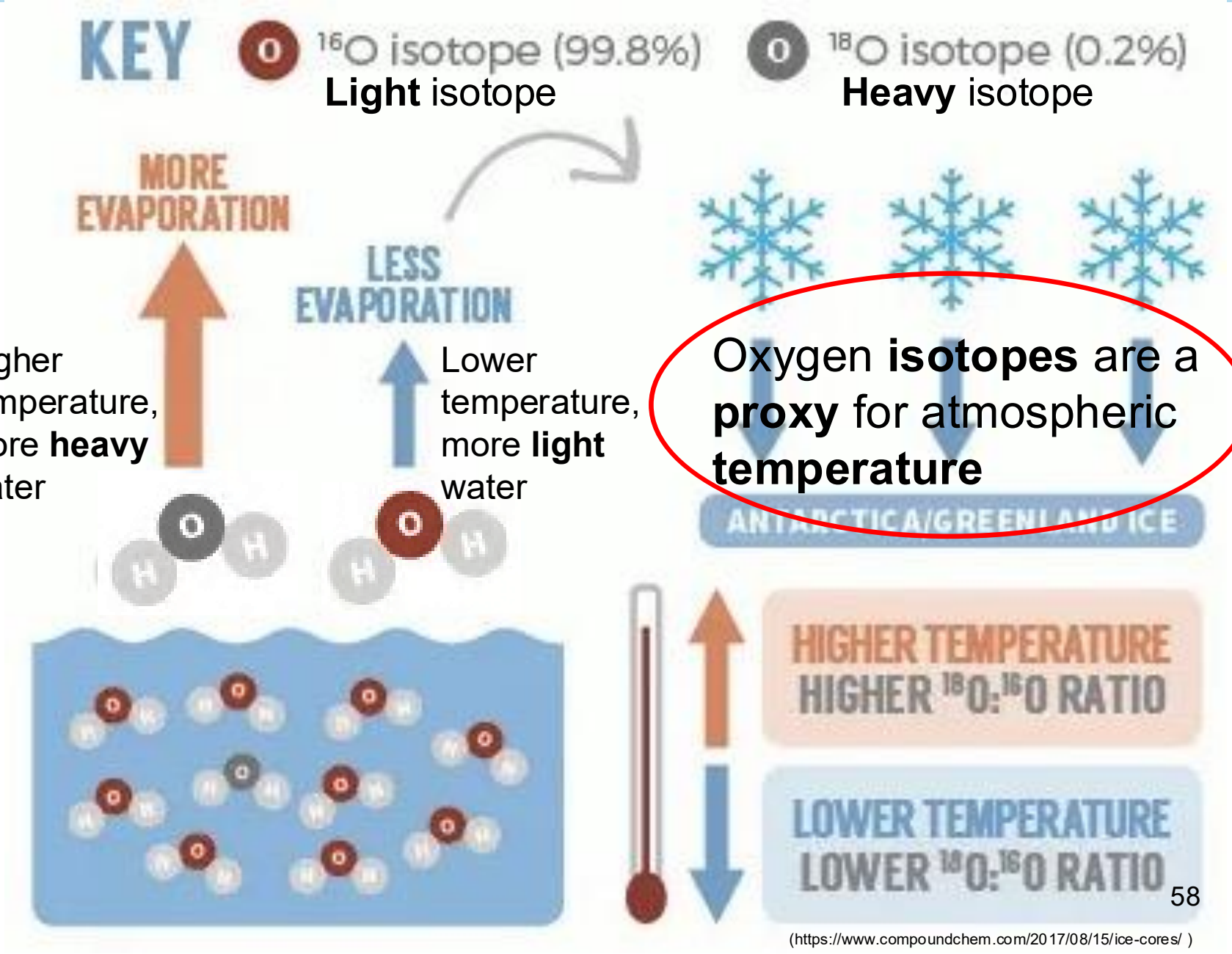
Water molecule isotopic abundance monitors temperature



Oxygen isotope ratios in the H_2O molecules indicate average temperatures and chart Earth's climate history.

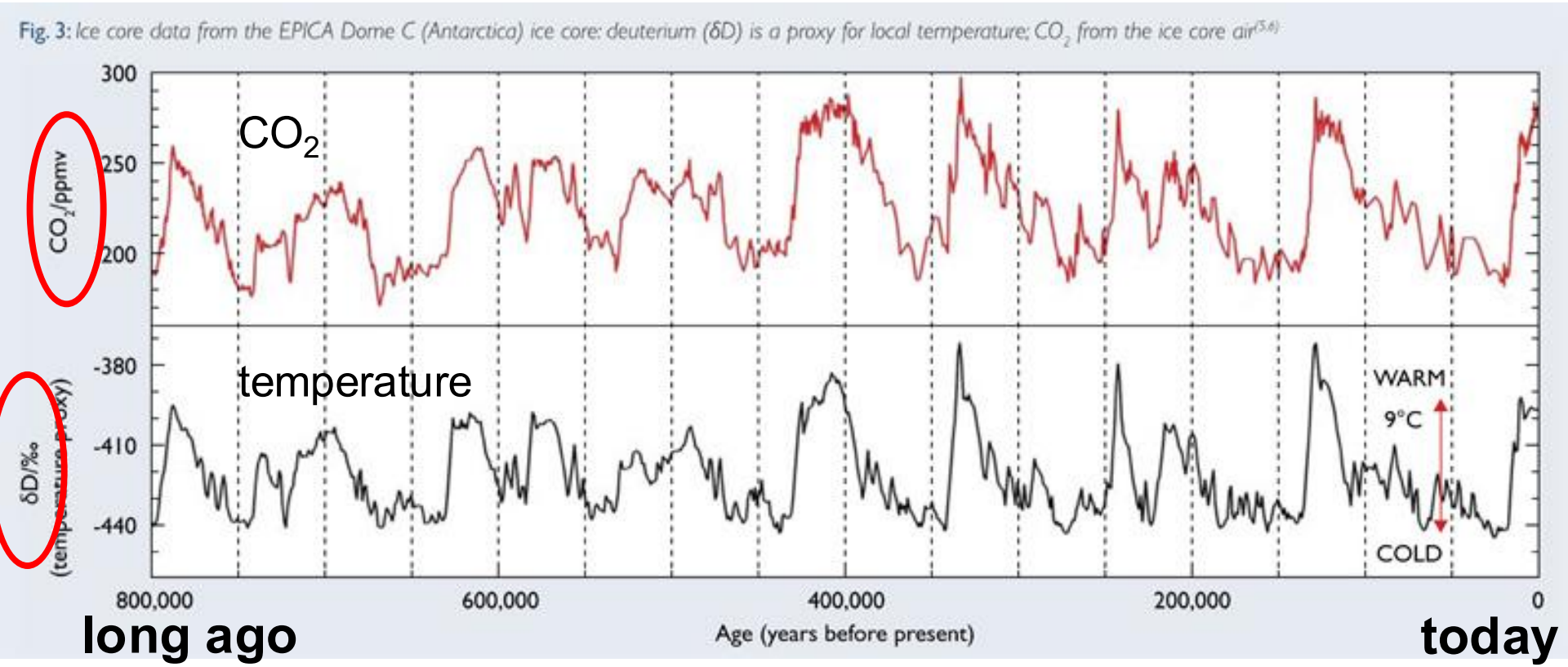
(https://cen.acs.org/environment/climate-change/race-preserve-Earths-historical-climate/98/i23)

Temperature sensitivity from relative isotope abundances



(https://www.compoundchem.com/2017/08/15/ice-cores/)

Ice-core data from EPICA Dome C go back 800,000 years



(top) **CO_2** fraction from the ice core air bubbles

(bottom) heavy water deuterium (δ**D**) is a **proxy** for **temperature**

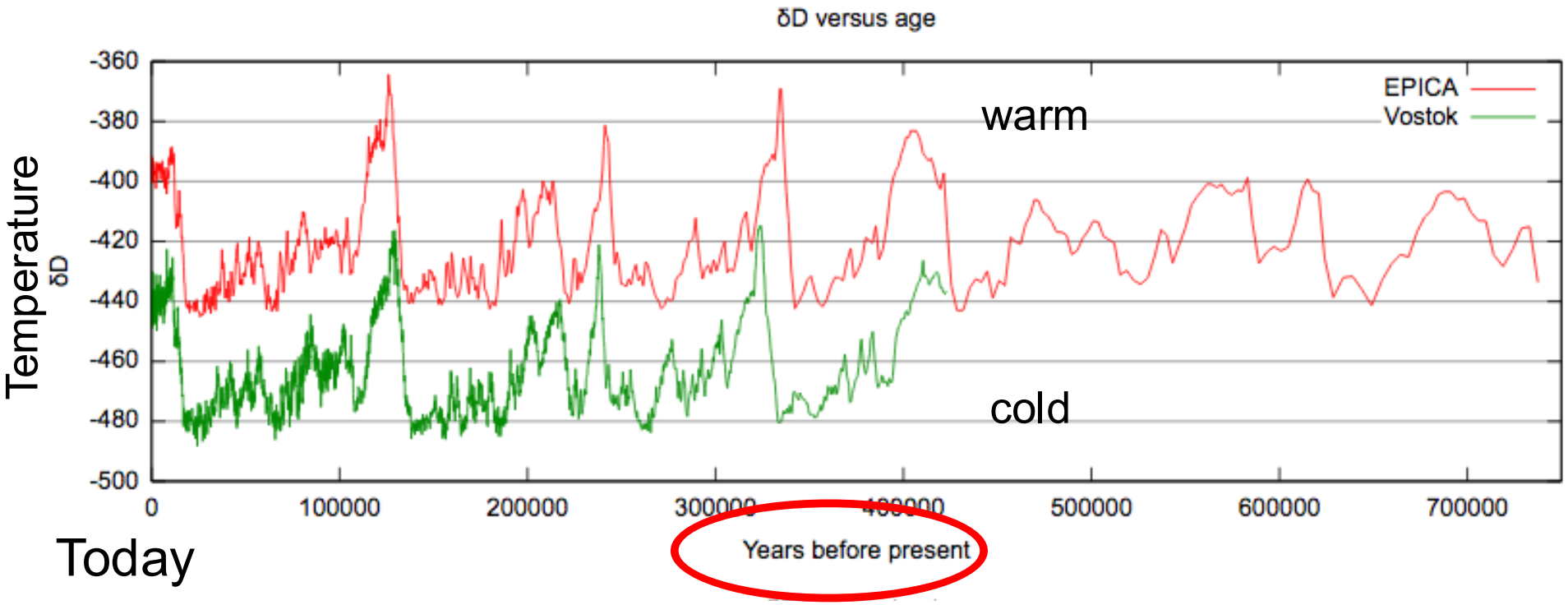
(https://www.bas.ac.uk/data/our-data/publication/ice-cores-and-climate-change/)

Two drilling sites: do the different ice-core results agree?

(https://cdiac.ess-dive.lbl.gov/trends/co2/ice_core_co2.html)

Vostok and Dome C comparison shows similar patterns

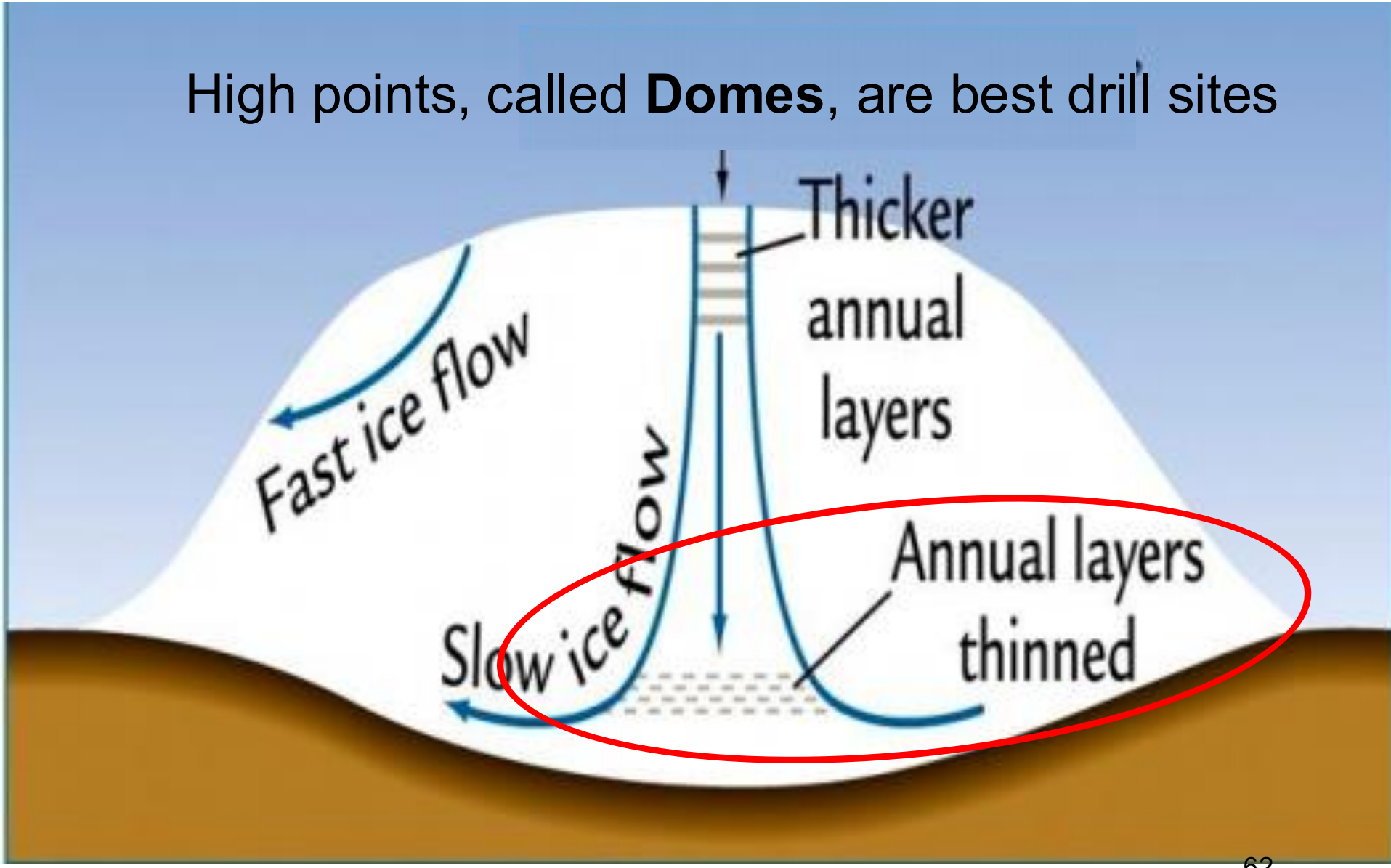
deuterium (δ**D**) is a **proxy** for **temperature**



Dome C (in **red**) oldest ice is much **older**

(https://en.wikipedia.org/wiki/European_Project_for_Ice_Coring_in_Antarctica)

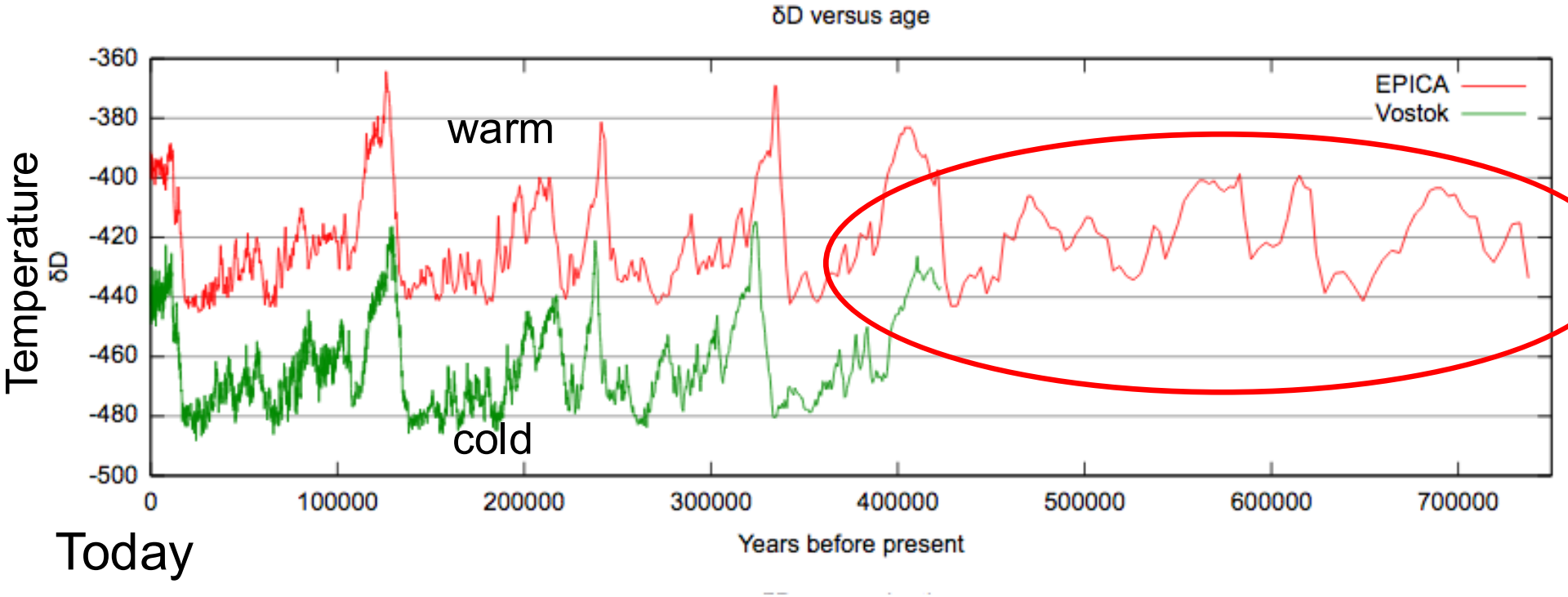
Deep ice layers become thinned at great depth



(http://sappho.eps.mcgill.ca/~olivia/GG/Presentations/2016/Mitchell_May-Ice-Core.pdf)

Dome C accesses much older ice but with degraded resolution

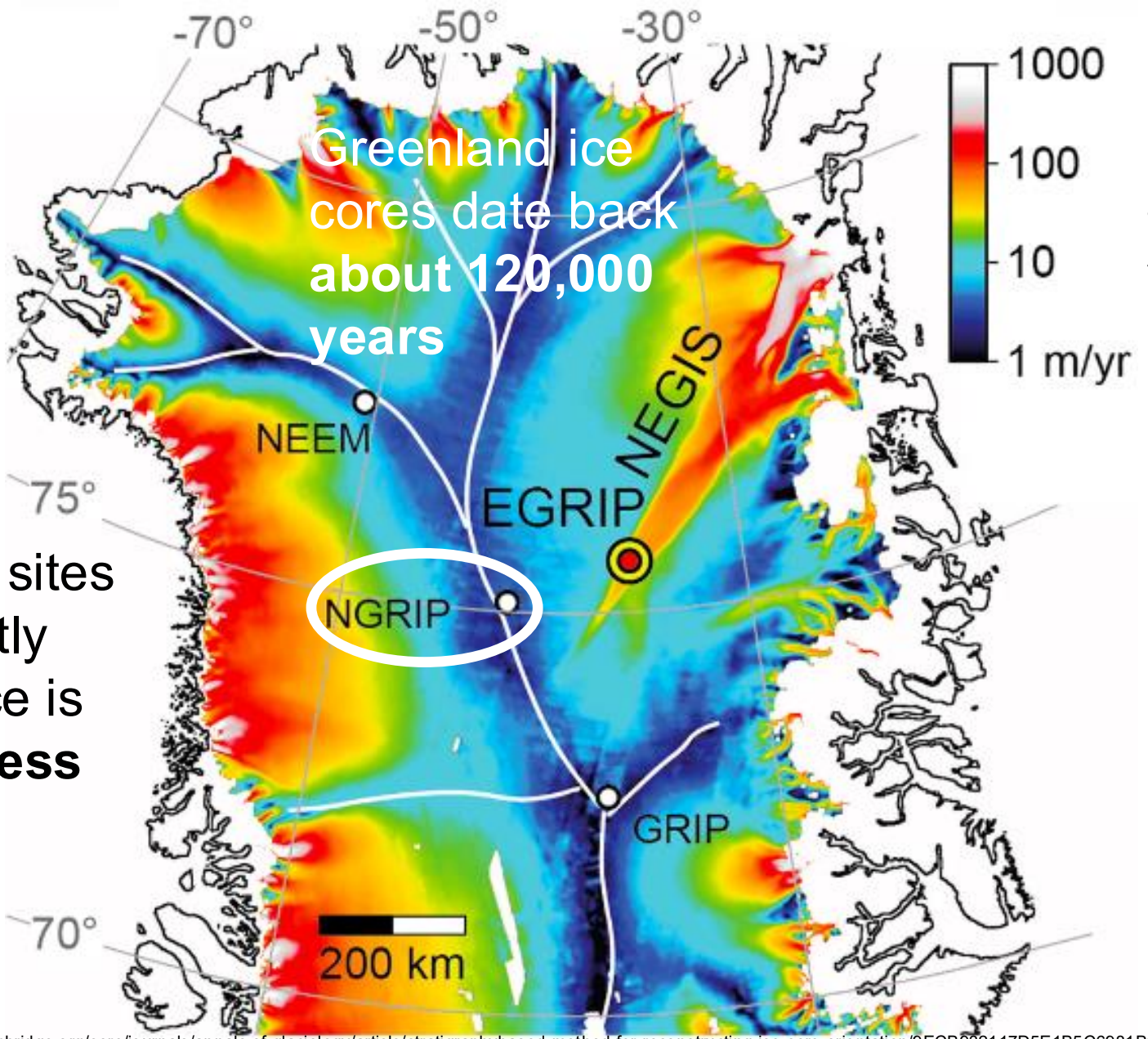
deuterium (δ**D**) is a **proxy** for **temperature**



Dome C (in **red**) ice is **older** but with somewhat **degraded temporal resolution** from layer thinning at **large depths**

(https://en.wikipedia.org/wiki/European_Project_for_Ice_Coring_in_Antarctica)

Do Greenland and Antarctic ice cores tell the same story?



Ice motion per year and **small** is **best**

Ice core sites are mostly where ice is **motionless**

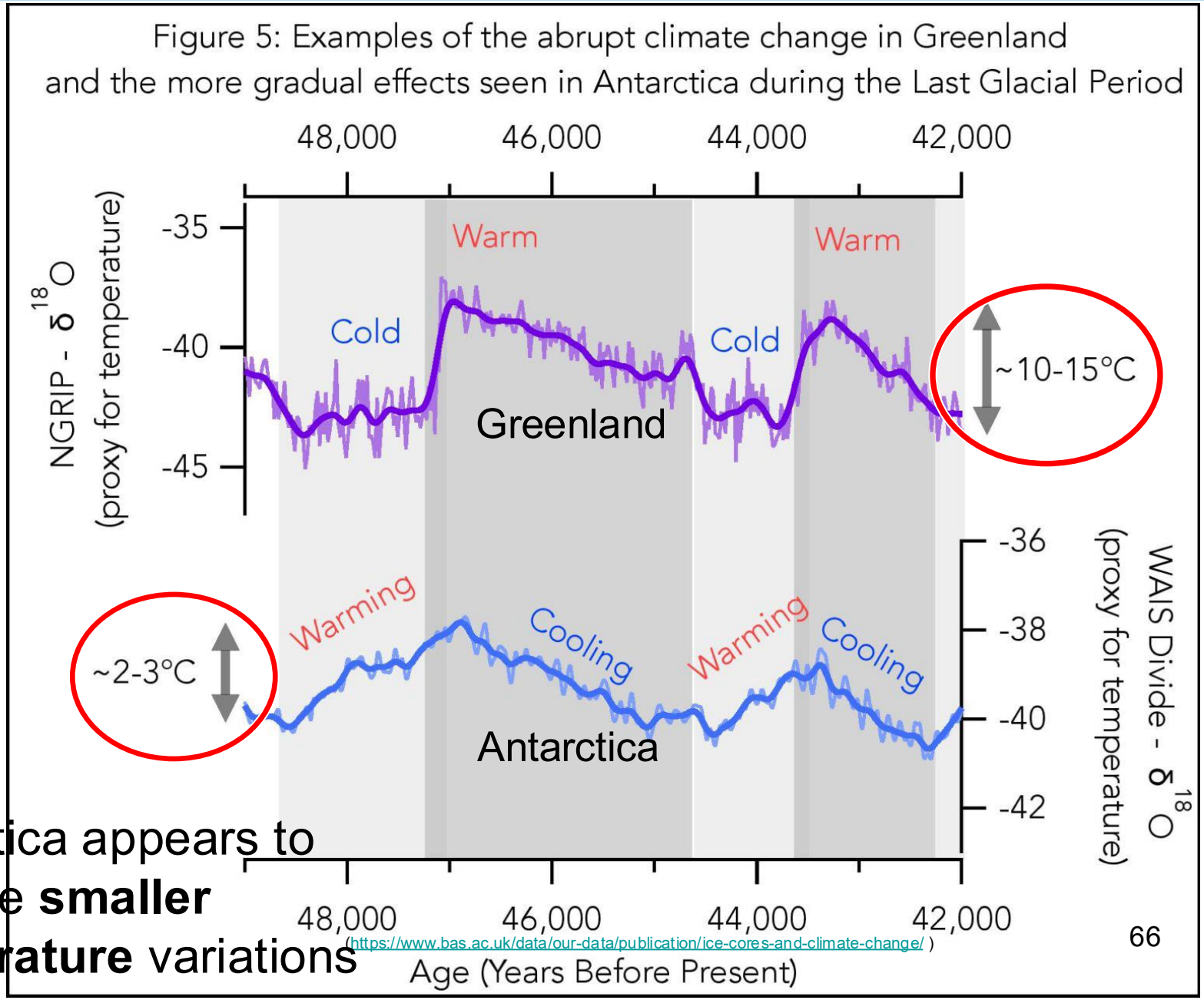
(https://www.cambridge.org/core/journals/annals-of-glaciology/article/stratigraphybased-method-for-reconstructing-ice-core-orientation/9ECB932117D5E1B5C6981B69A86A5932)

NGRIP drilling camp on the summit of the Greenland ice sheet

(https://www.semanticscholar.org/paper/Formal-definition-and-dating-of-the-GSSP-(Global-of-Rasmussen/f7759494e79bd507fe21e2c627c8abfb1e89816e)

The large structure is the camp main building (Main Dome); the two other domes are the workshop and storage buildings. The **flags** and **pipes** in the foreground mark the location of the **subsurface drill** and **science trenches**.

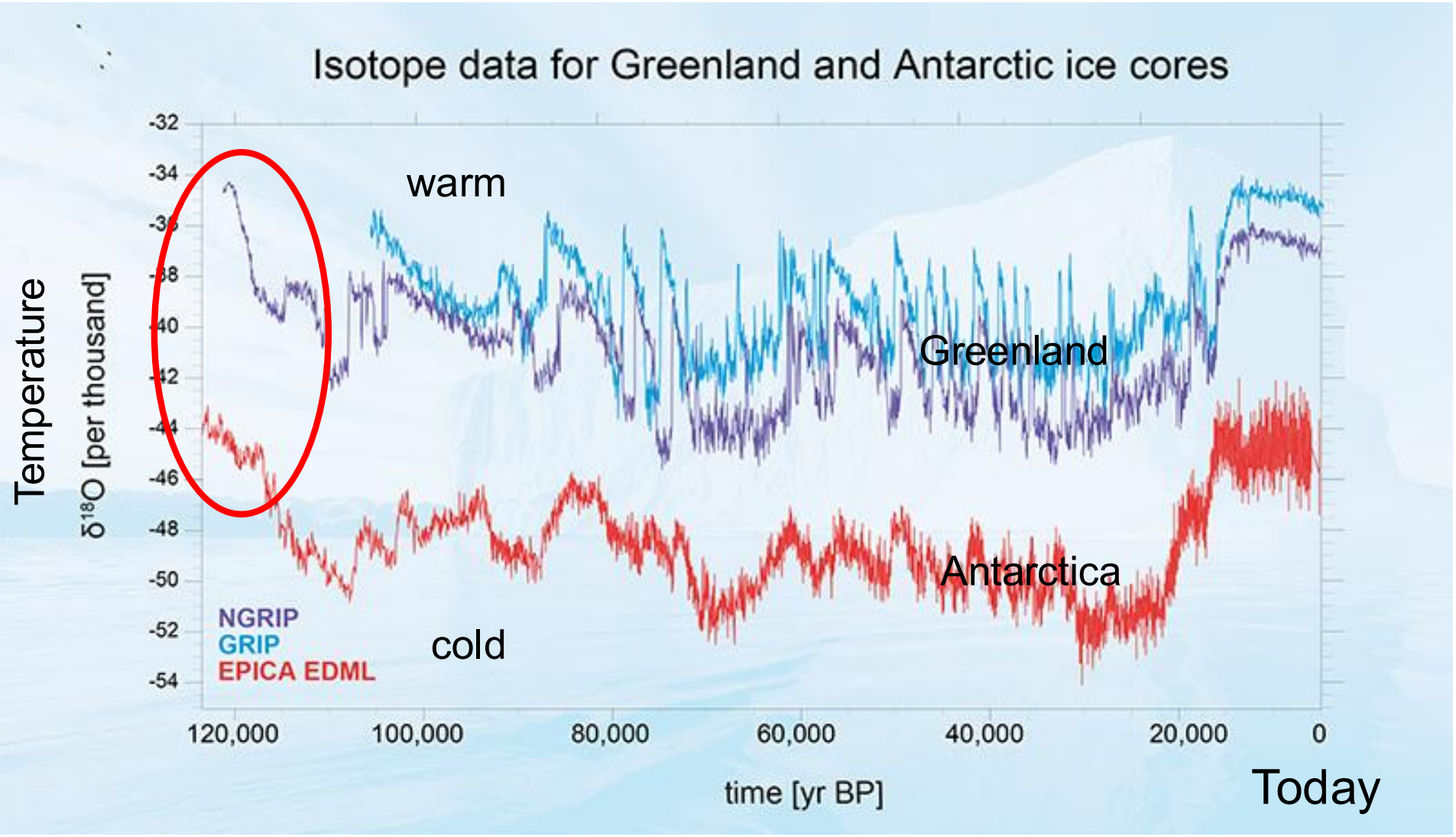
Greenland and Antarctica data show some similar trends



(https://www.bas.ac.uk/data/our-data/publication/ice-cores-and-climate-change/)

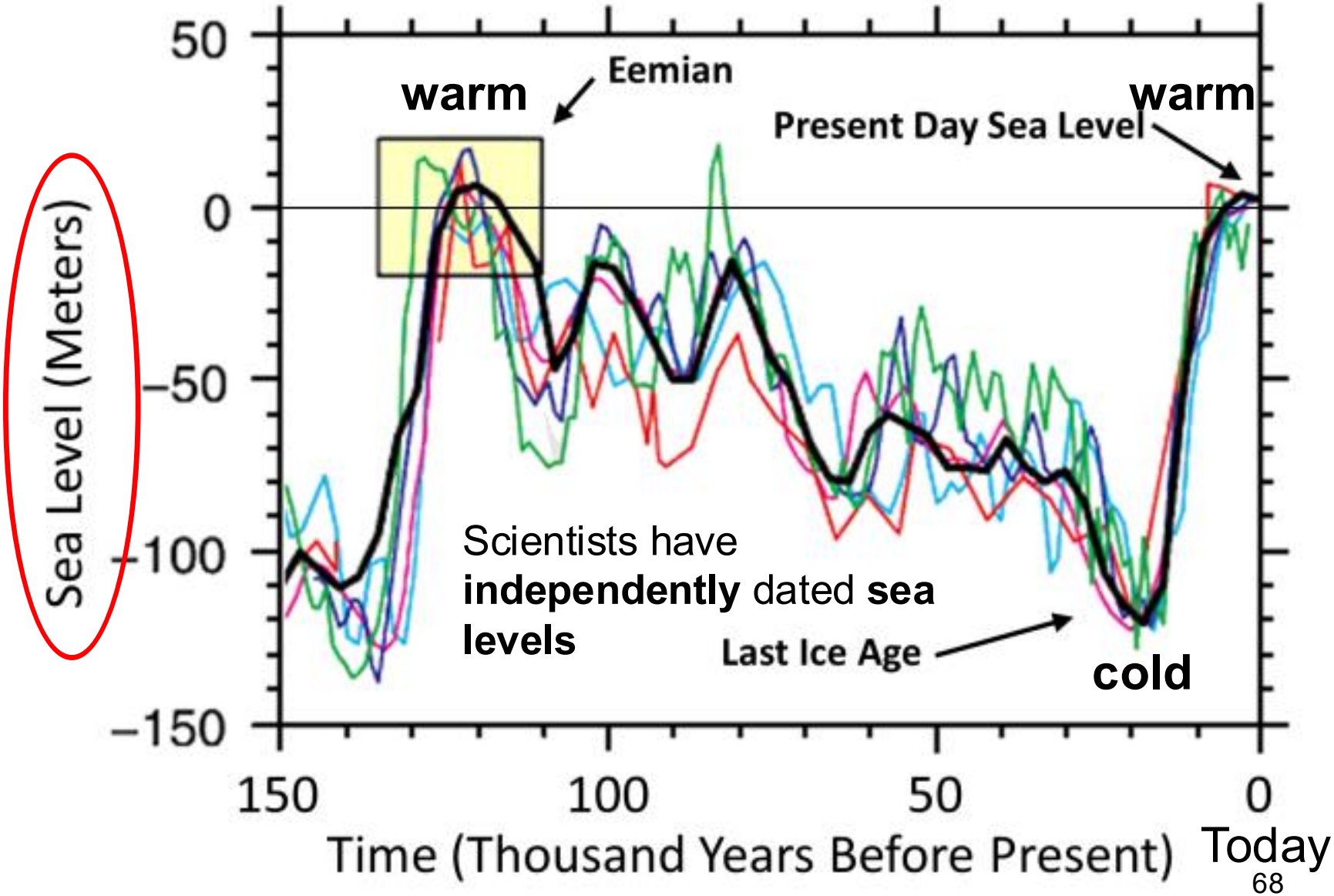
Antarctica appears to observe **smaller temperature** variations

Greenland and Antarctica both find warming 120,000 years ago



(https://eos.org/science-updates/comprehensive-earth-system-models-of-the-last-glacial-cycle)

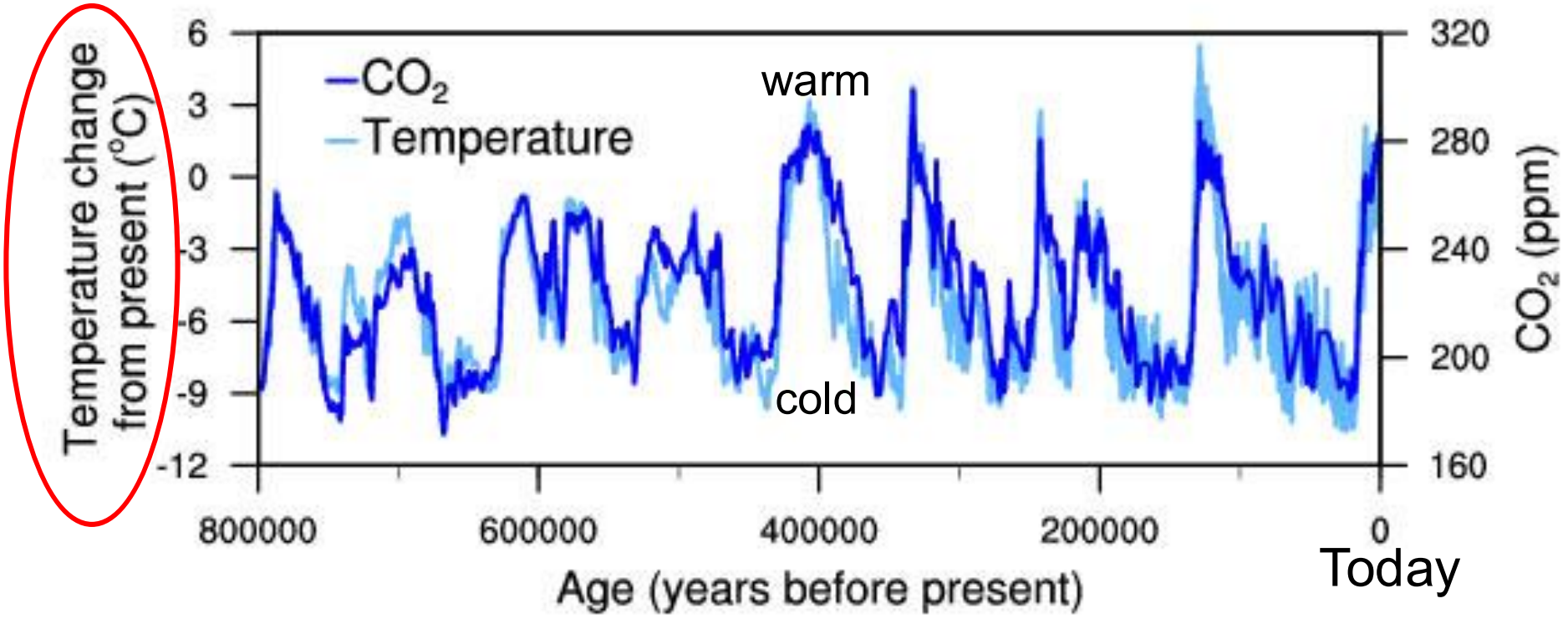
Independent sea-level data show similar trends



(https://www.forbes.com/sites/uhenergy/2018/07/30/how-much-sea-level-rise-is-actually-locked-in/)

Why do we care? Apparently Earth is not always the same.

For the last 800,000 years, Earth's temperature has varied with typically short warm periods followed by **long**, cold **glacial-periods**. Earth changes: these studies help tell us why and how.

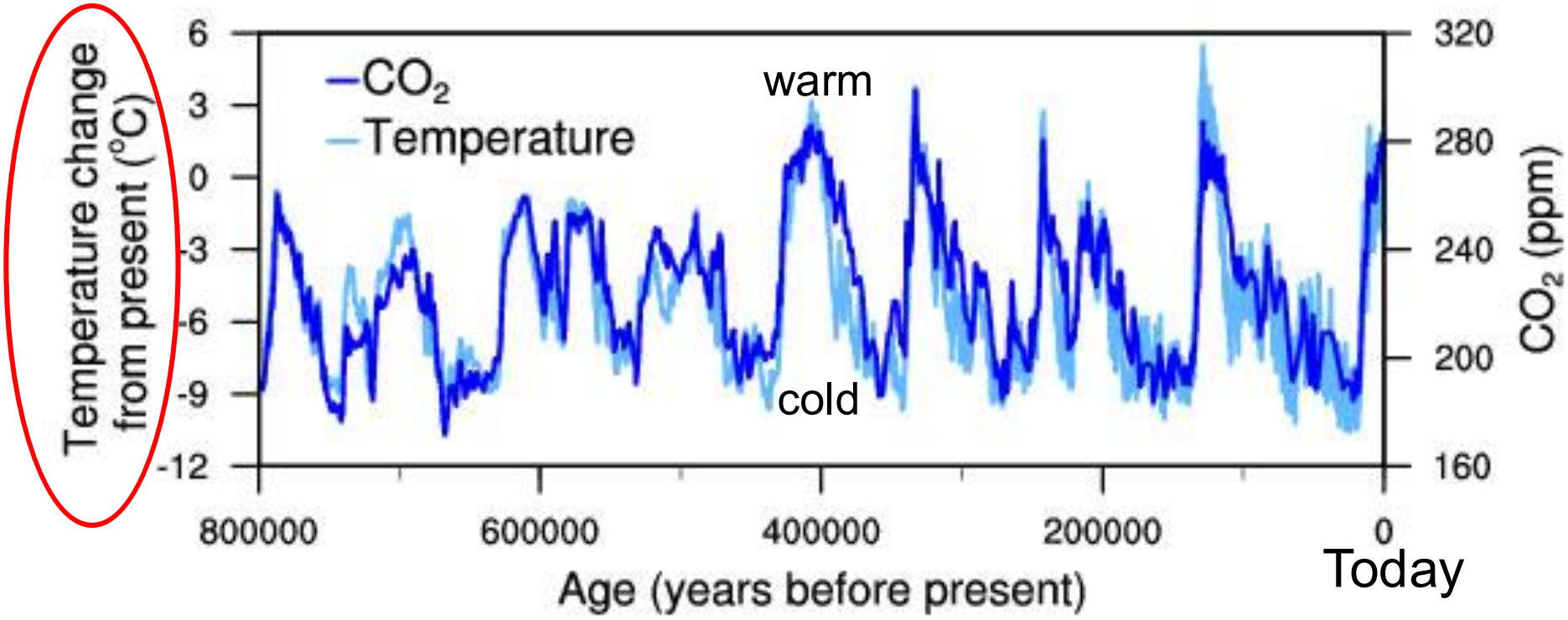


EPICA Dome C ice core results from Antarctica.
Both **CO_2** and **temperature** appear to have **periodic variations**.

(https://www.ncdc.noaa.gov/global-warming/temperature-change)

Data appear to show a 100,000 year *heartbeat*

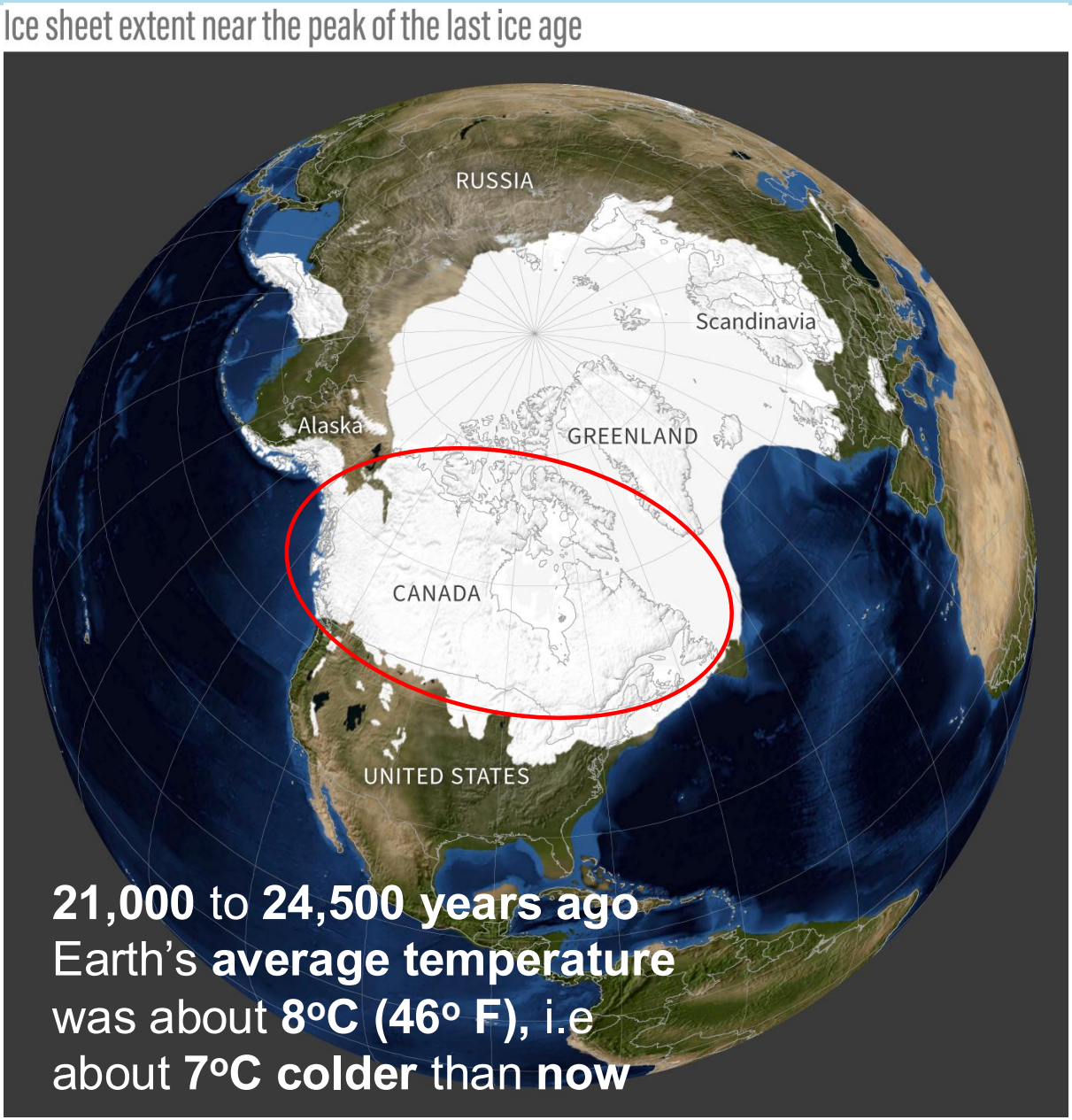
The pattern has a **periodicity** of about **100,000 years**. It's called the *100,000 year problem.* What's special about the last 800,000 years? (This motivates the **Beyond Epica:Oldest Ice project** (in a few slides)).



EPICA Dome C ice core results from Antarctica

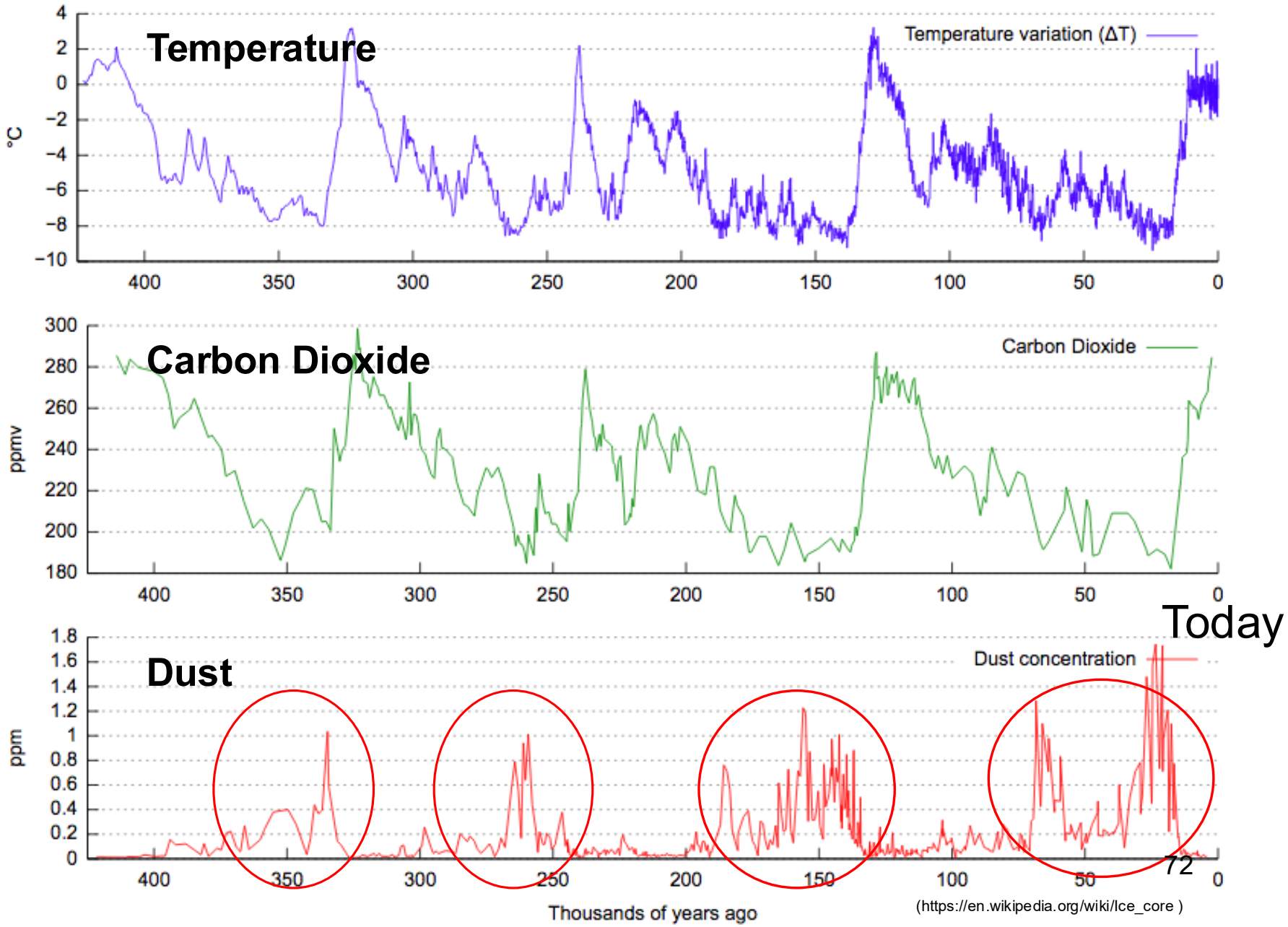
(https://www.ncdc.noaa.gov/global-warming/temperature-change)

Last glacial period meant that e.g. Canada was ice-bound



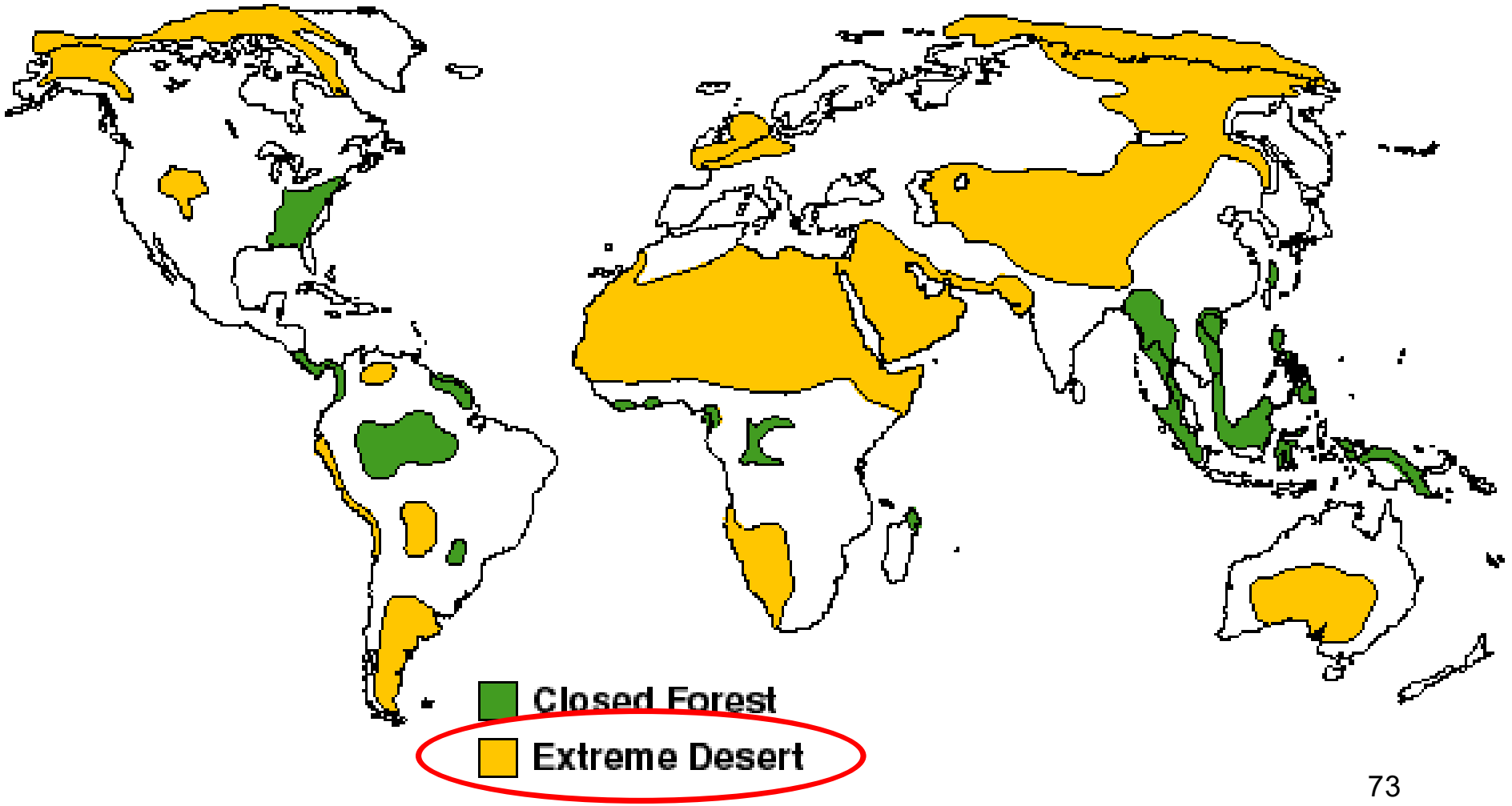
(https://www.climate.gov/media/11951)

Vostok data show dust *peaks* near the end of glacial periods



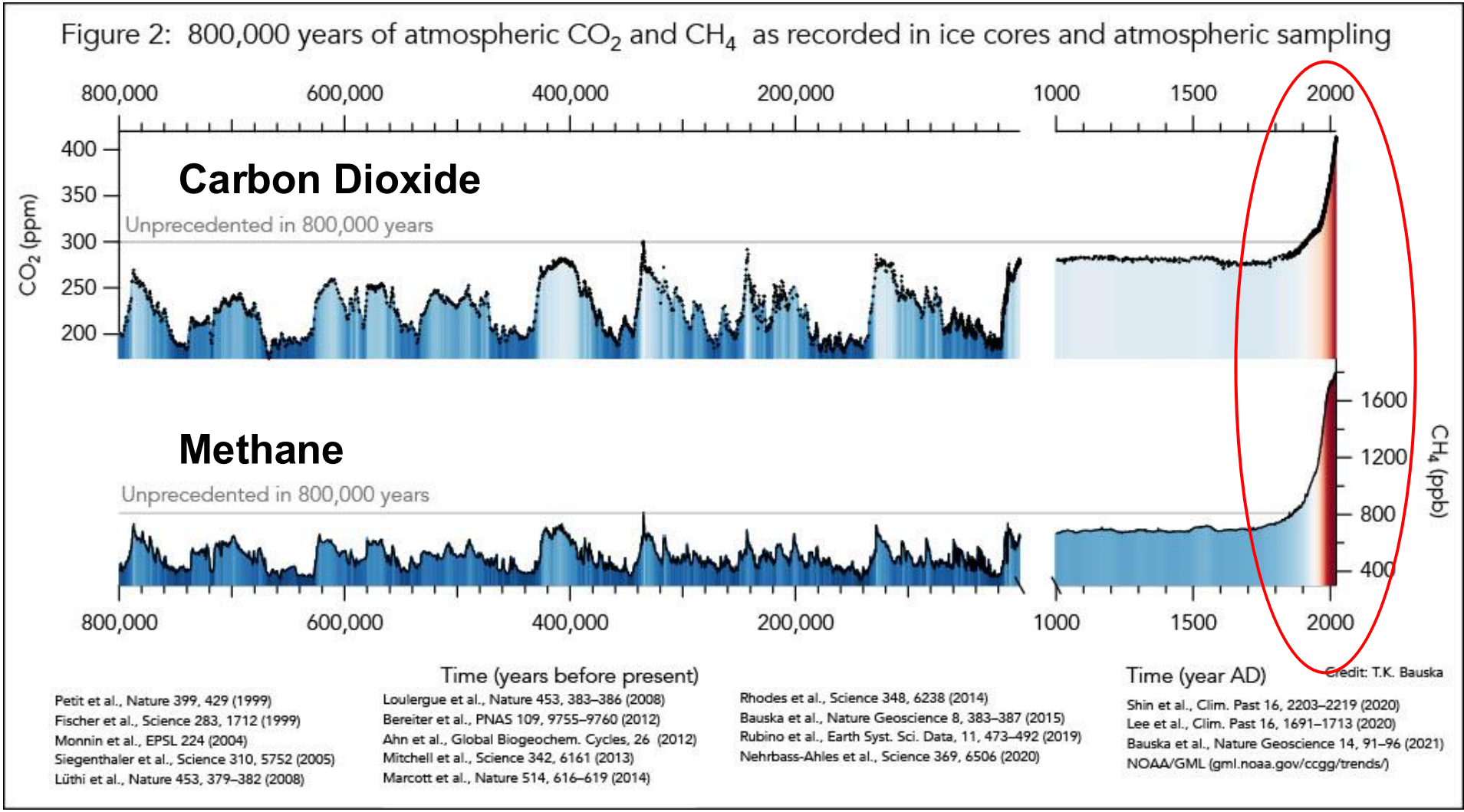
(https://en.wikipedia.org/wiki/Ice_core)

Dust from vast deserts may darken ice sheets to end ice ages



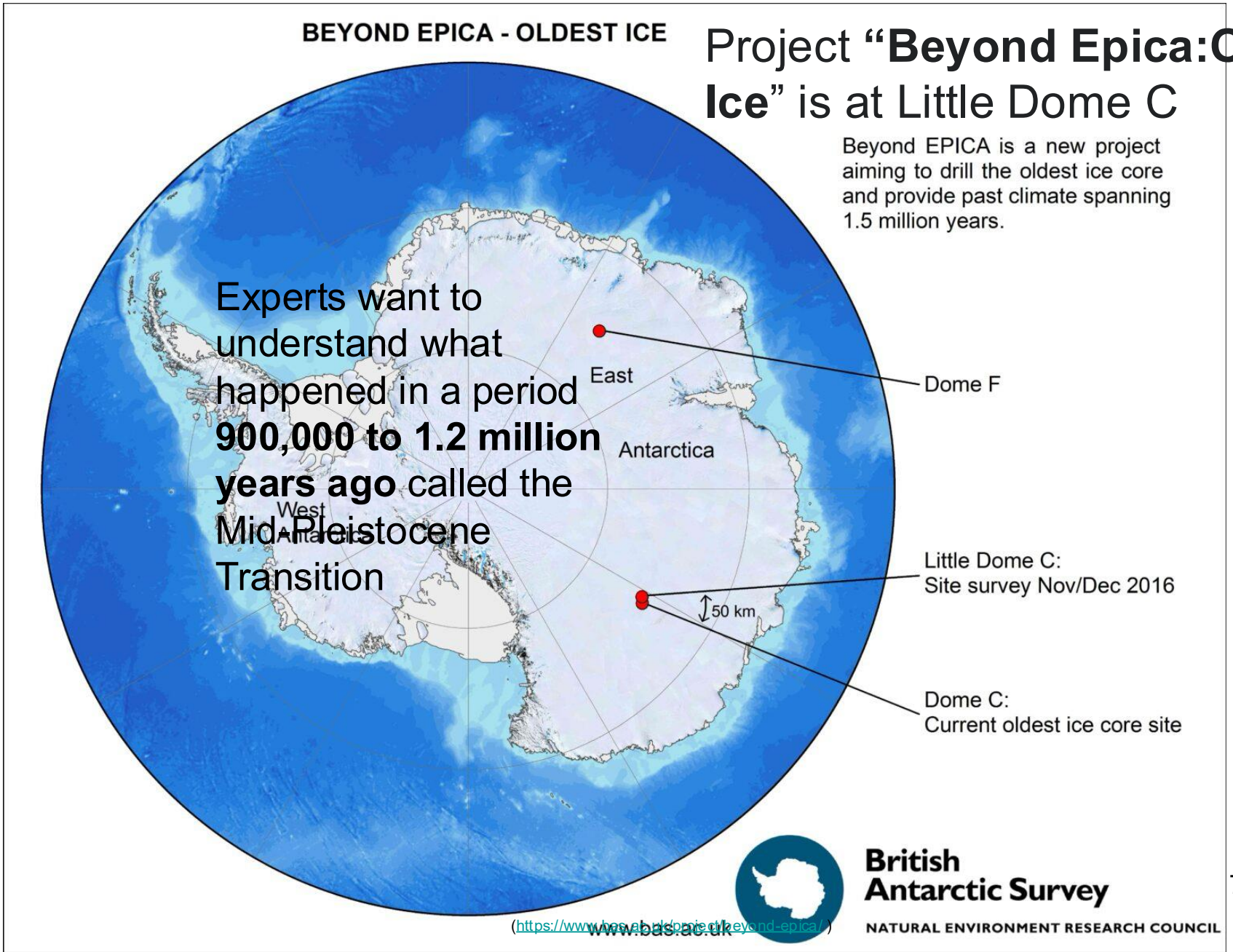
(https://wileyearthpages.wordpress.com/2017/01/13/amazonian-forest-through-the-last-glacial-maximum/)

Another story from Old Ice: CO_2 and CH_4 today are unusual



(https://www.bas.ac.uk/data/our-data/publication/ice-cores-and-climate-change/)

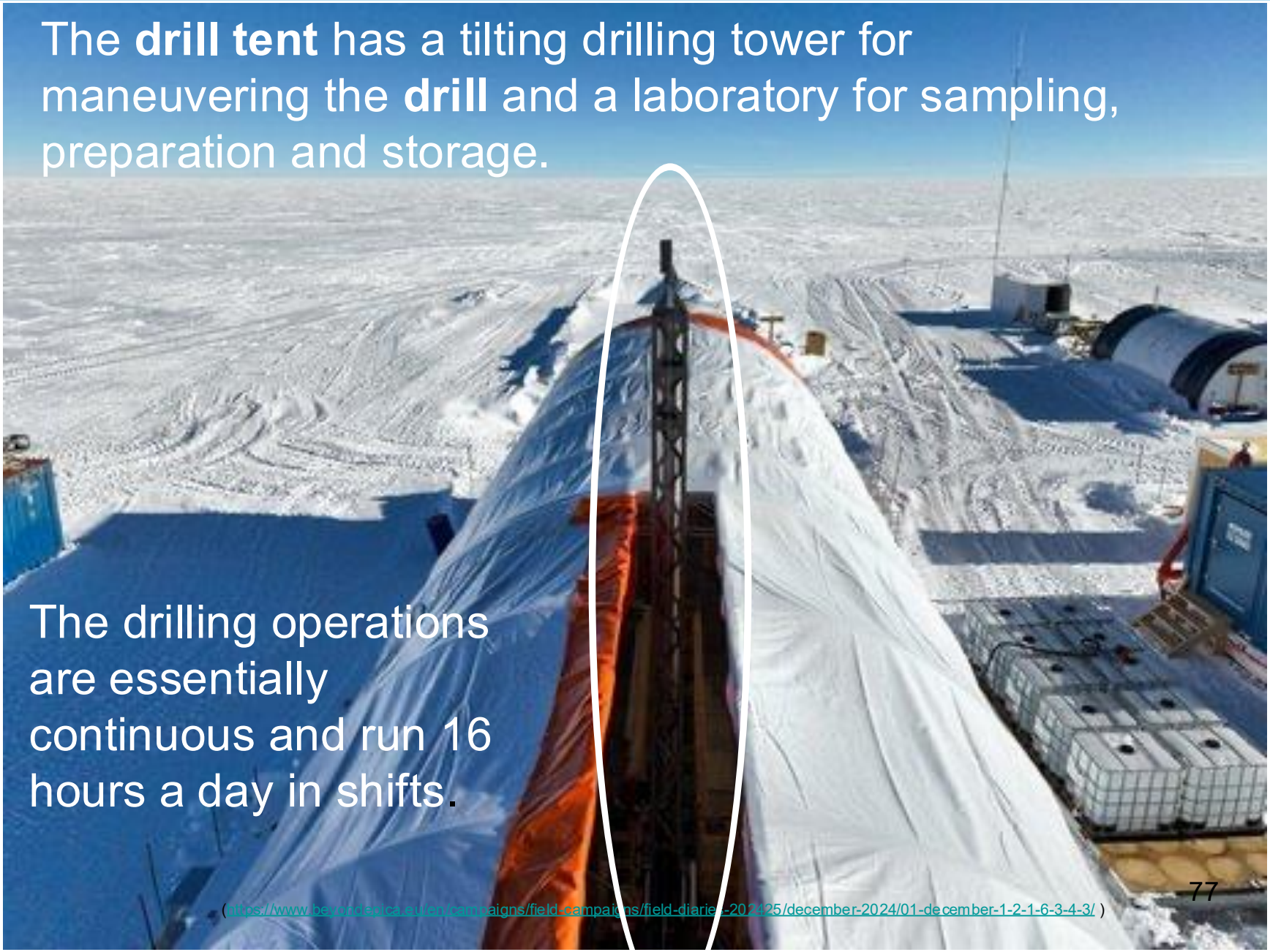
Can we look back further in time: maybe to 1.2 M years ago?



Beyond Epica:Oldest Ice at the Little Dome C drilling camp

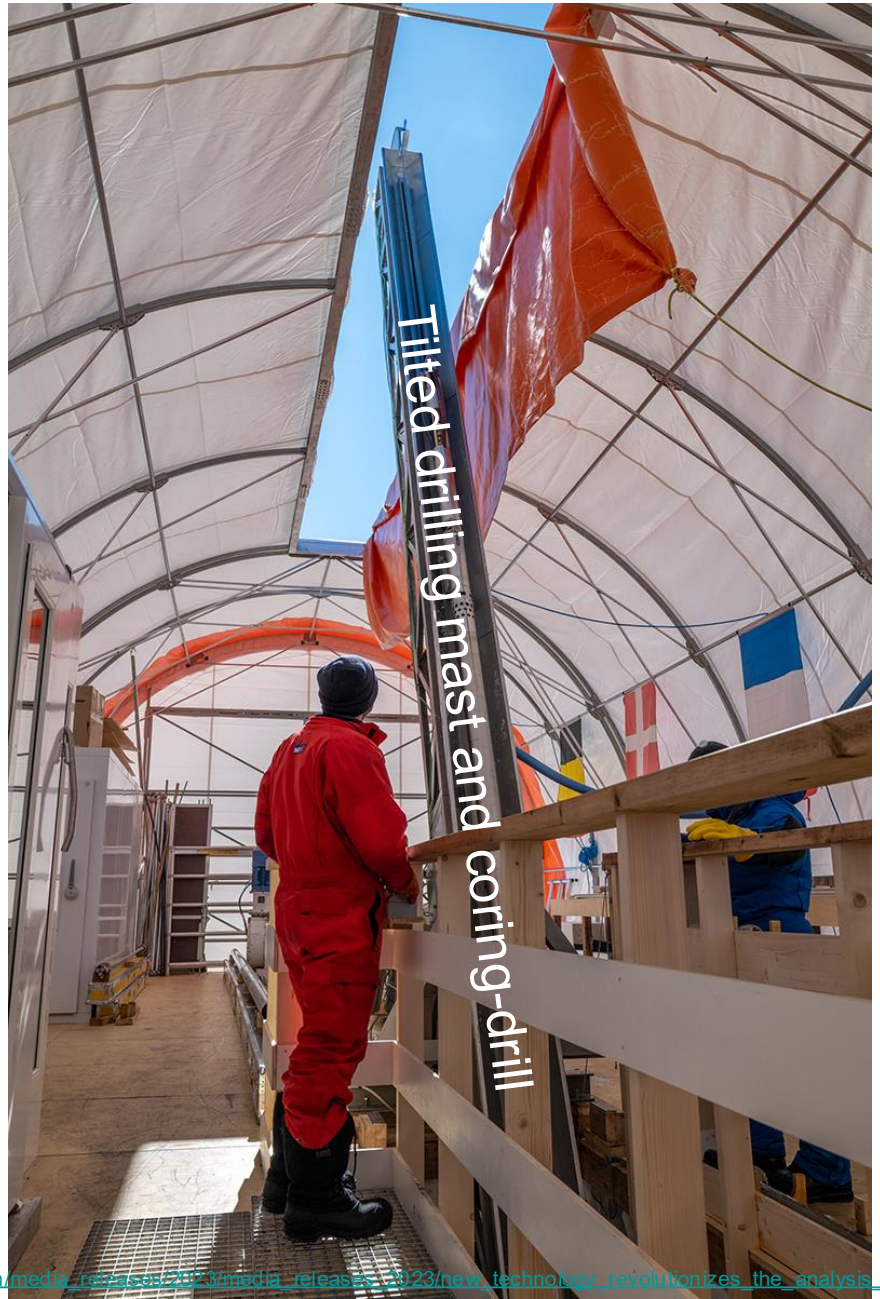
(https://www.media.enea.it/en/press-releases-and-news/years-archive/year-2022/antarctica-working-for-2-months-at-40-c-to-complete-the-little-dome-c-camp-of-beyond-epica-oldest-ice-project.html)

Beyond Epica:Oldest Ice: drill extends through drill tent



(https://www.beyondepica.eu/en/campaigns/field-campaigns/field-diaries-2024-25/december-2024/01-december-1-2-1-6-3-4-3/)

View from inside the drill tent

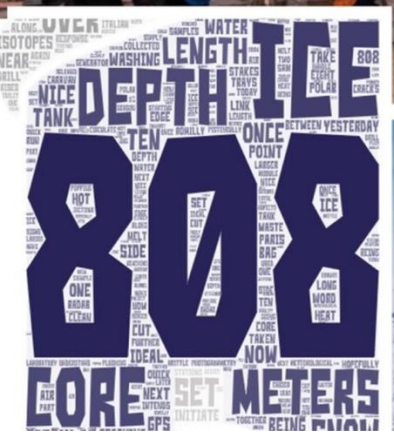


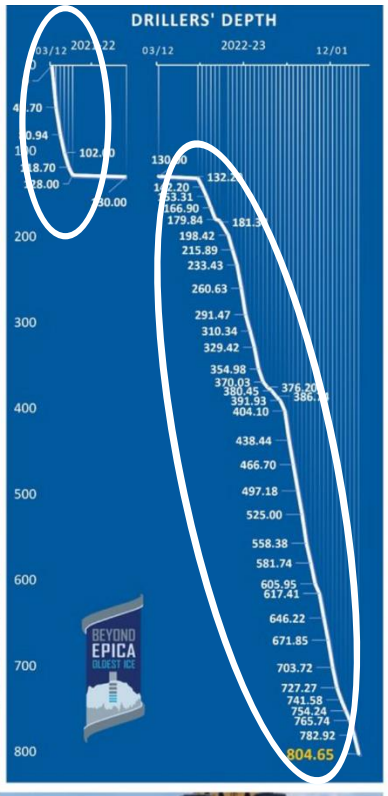
(https://mediarelations.unibe.ch/media_releases/2023/media_releases_2023/new_technology_revolutionizes_the_analysis_of_old_ice/index_eng.html)

Beyond Epica:Oldest Ice: typical ice core

(https://www.myscience.ch/news/wie_neue_technology_revolutionizes_the_analysis_of_old_ice-2023-empa)

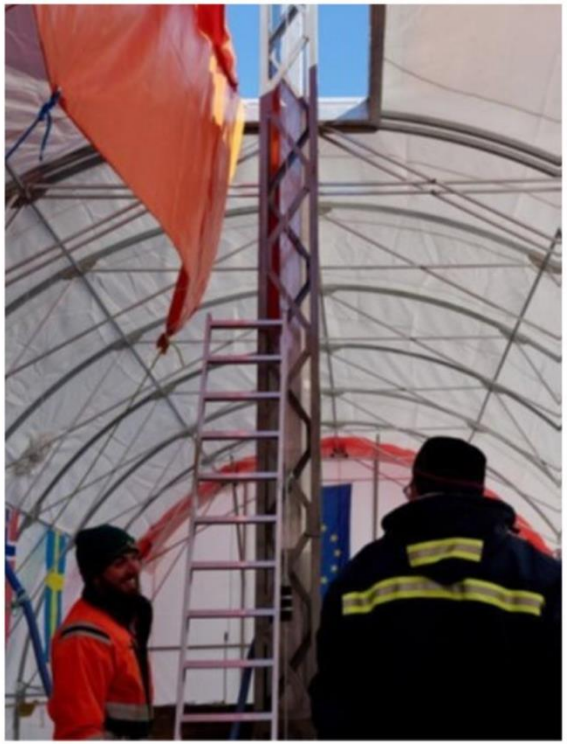
Beyond Epica:Oldest Ice: drilling only during Austral summer

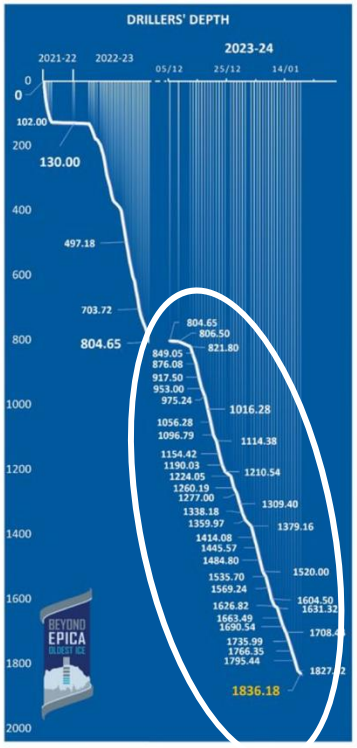


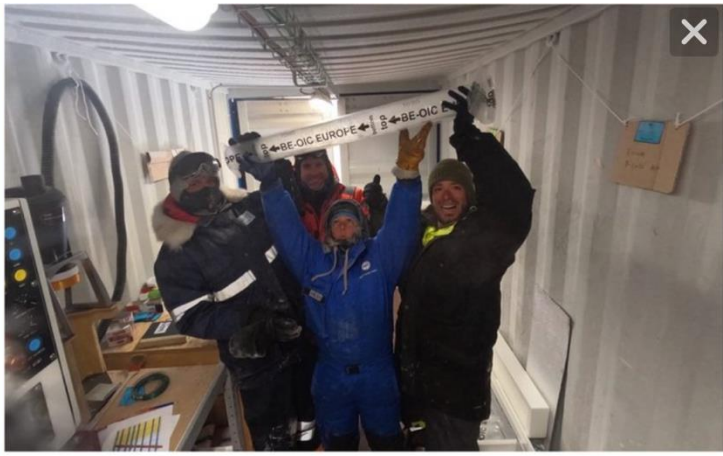


(https://www.beyondepica.eu/en/)

Beyond Epica:Oldest Ice: season 2023/2024 to 1836.18m

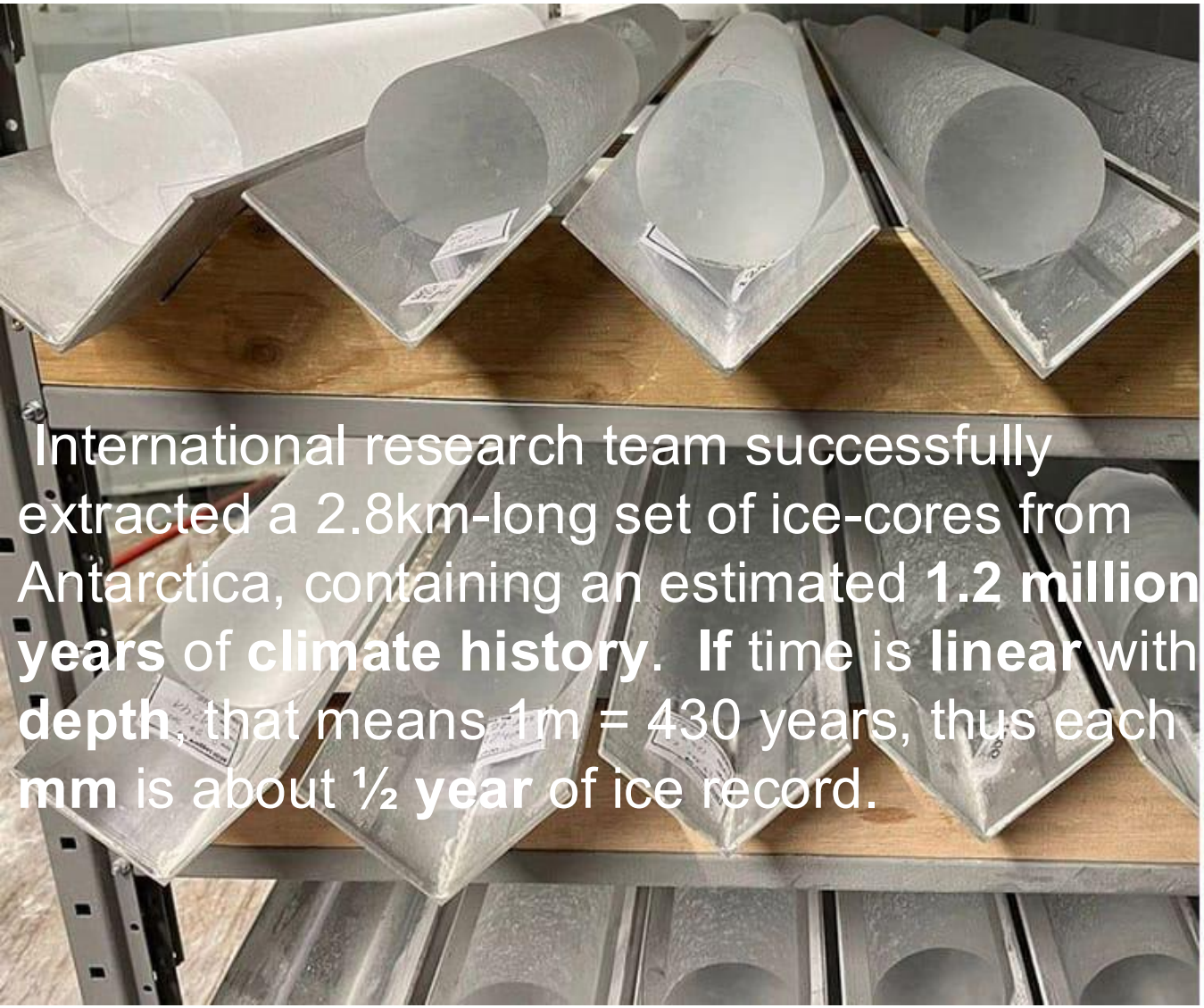




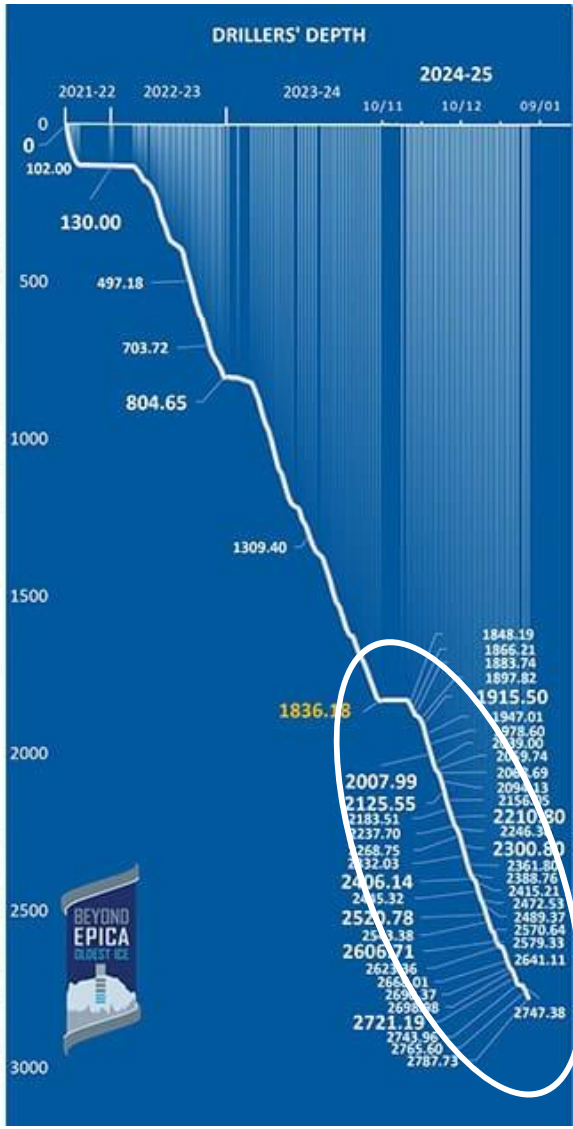


(https://www.beyondepica.eu/en/)

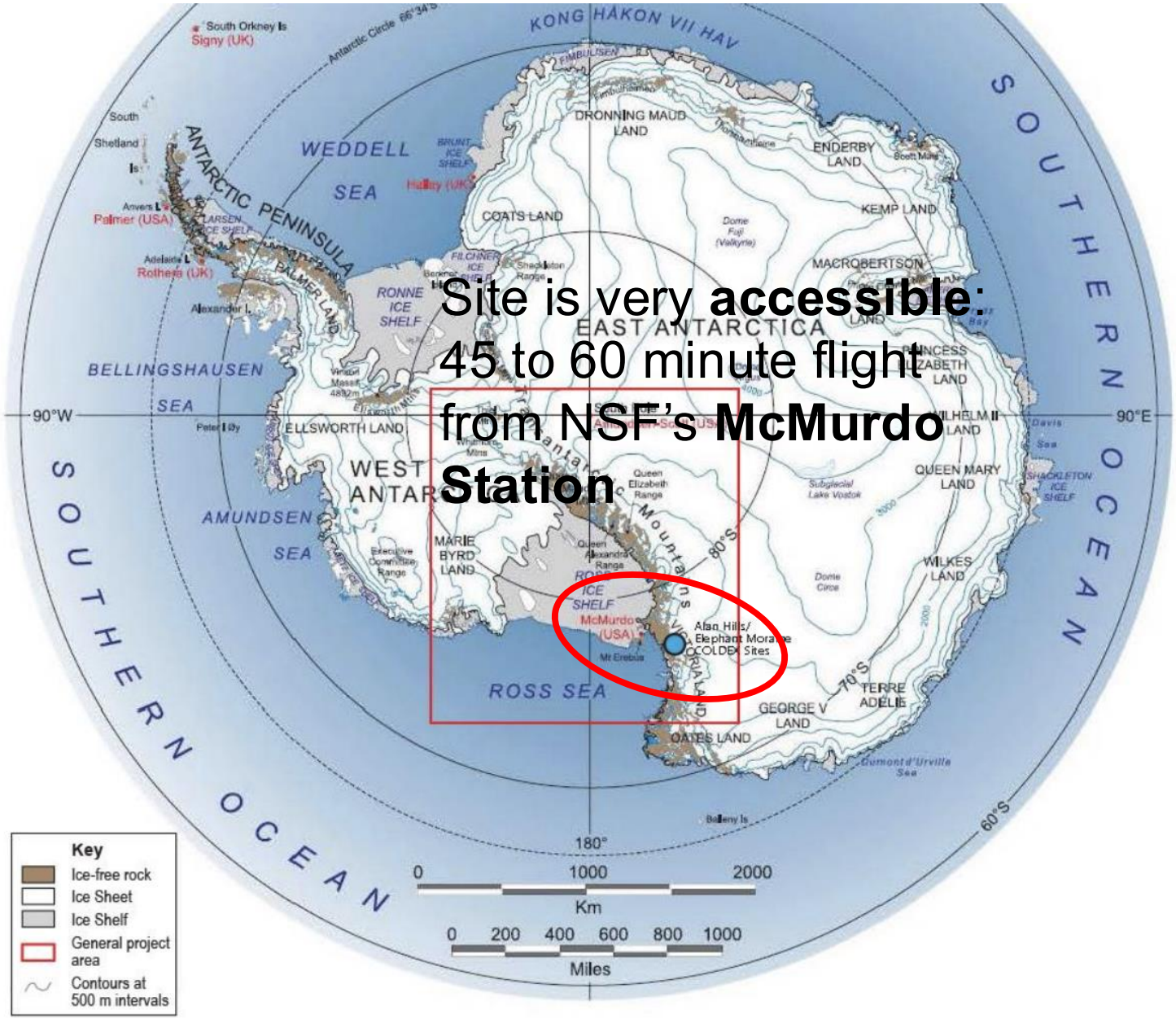
Beyond Epica:Oldest Ice: January 9, 2025 stop at 2727.38m



International research team successfully extracted a 2.8km-long set of ice-cores from Antarctica, containing an estimated **1.2 million years** of **climate history**. **If** time is **linear** with **depth**, that means 1m = 430 years, thus each **mm** is about ½ **year** of ice record.



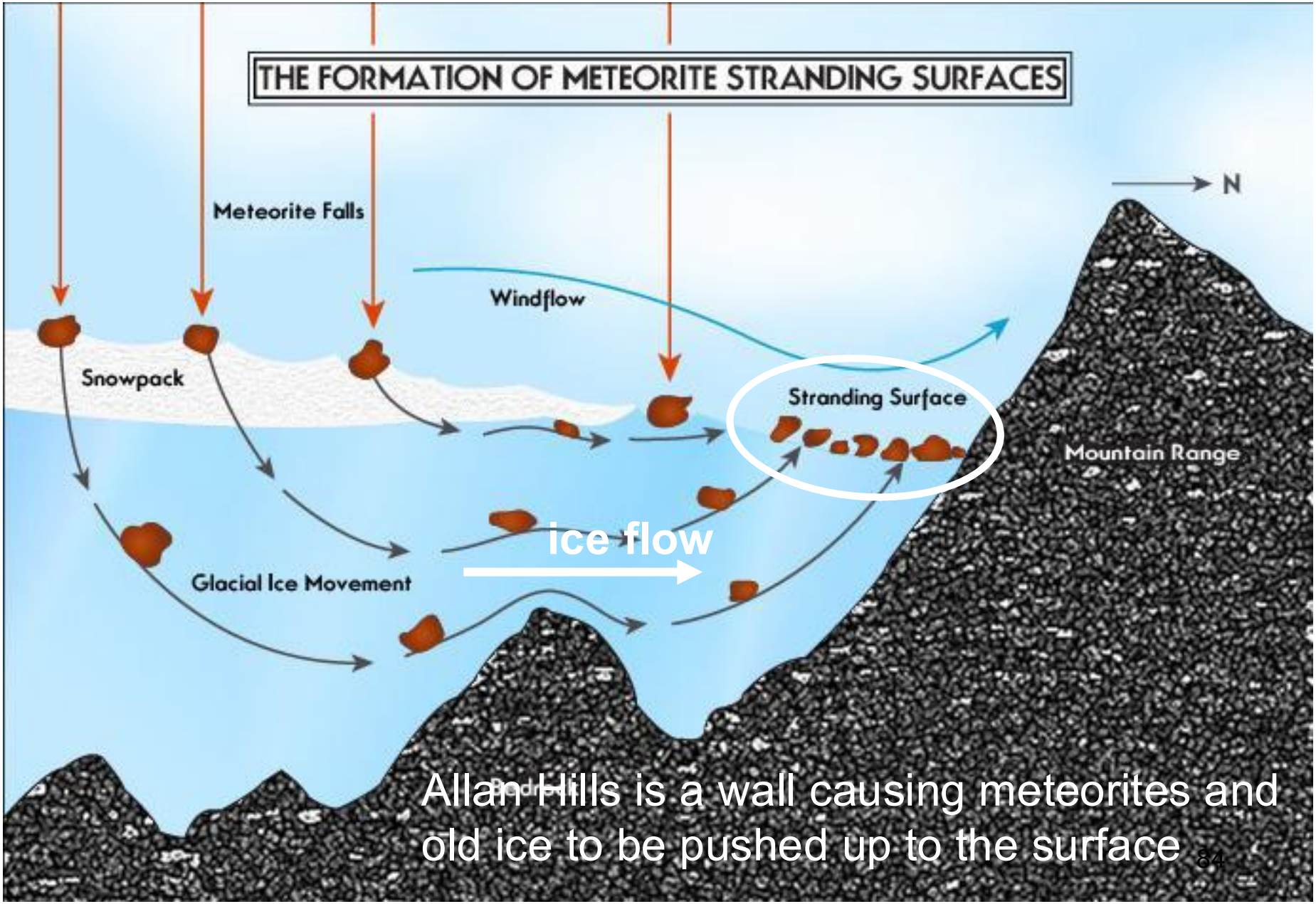
But oldest ice is serendipitously from nearby Allan Hills



Landsat Image Mosaic of Antarctica (LIMA) Project

(https://documents.ats.aq/EIES/EIA/02450enUSAP%20COLDEX_Final%20IEE_11-17-22_Signed.pdf)

This story starts with ice flow concentrating meteorites



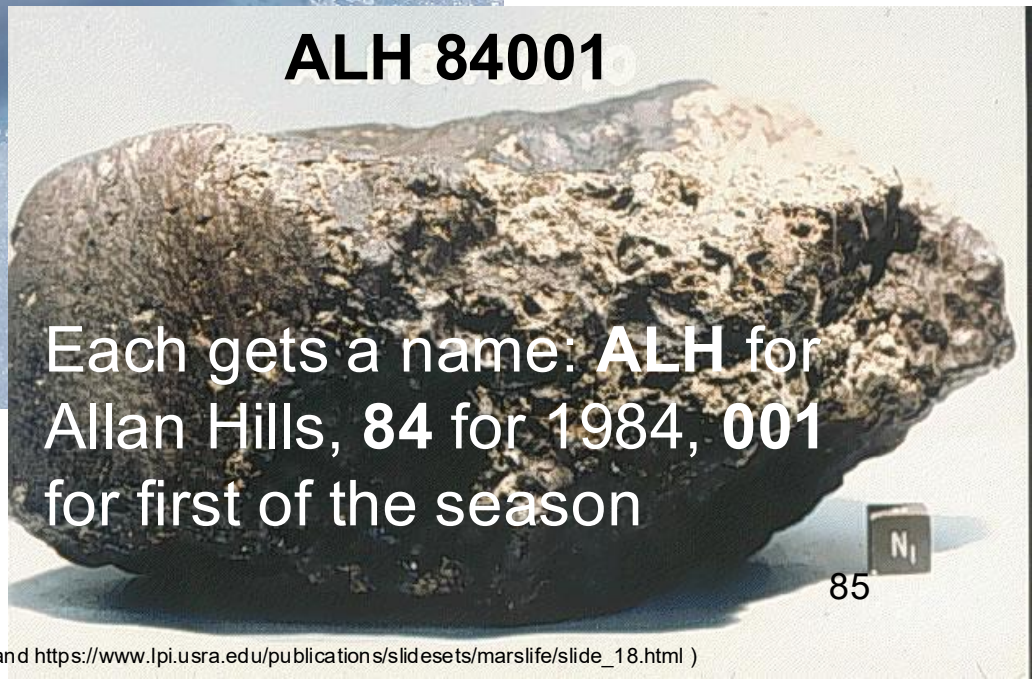
Allan Hills is a wall causing meteorites and old ice to be pushed up to the surface

(https://expeditions.fieldmuseum.org/antarctic-meteorites/blog/6-meteorite-spotting-practice-sessions)

Strong winds mean no (or minimal) snow cover

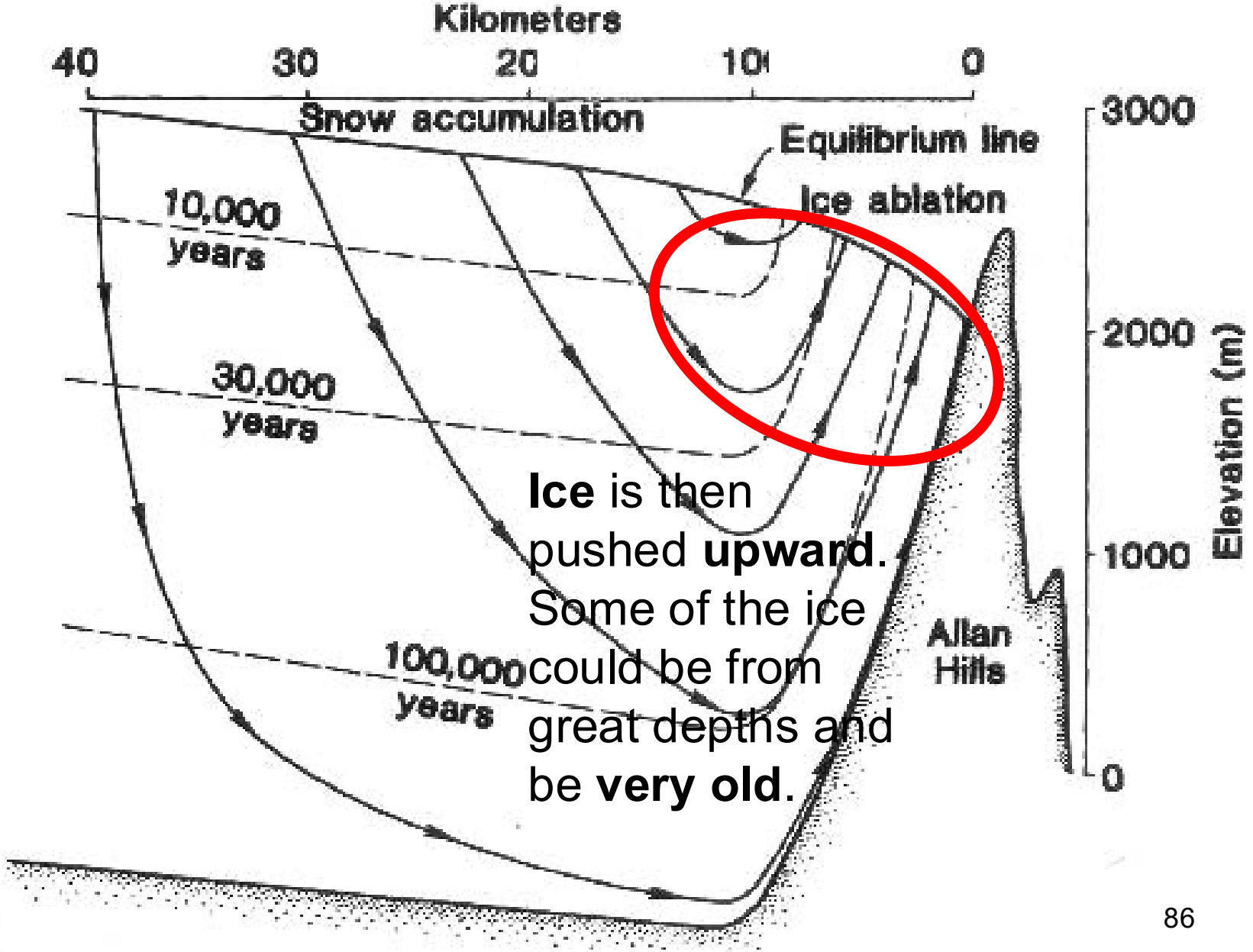
Meteorites are obvious:
rocks sitting on an icy field.

Interesting. Might this also bring deep, old ice to the surface?



(https://en.wikipedia.org/wiki/Blue-ice_area and https://www.lpi.usra.edu/publications/slidesets/marslife/slide_18.html)

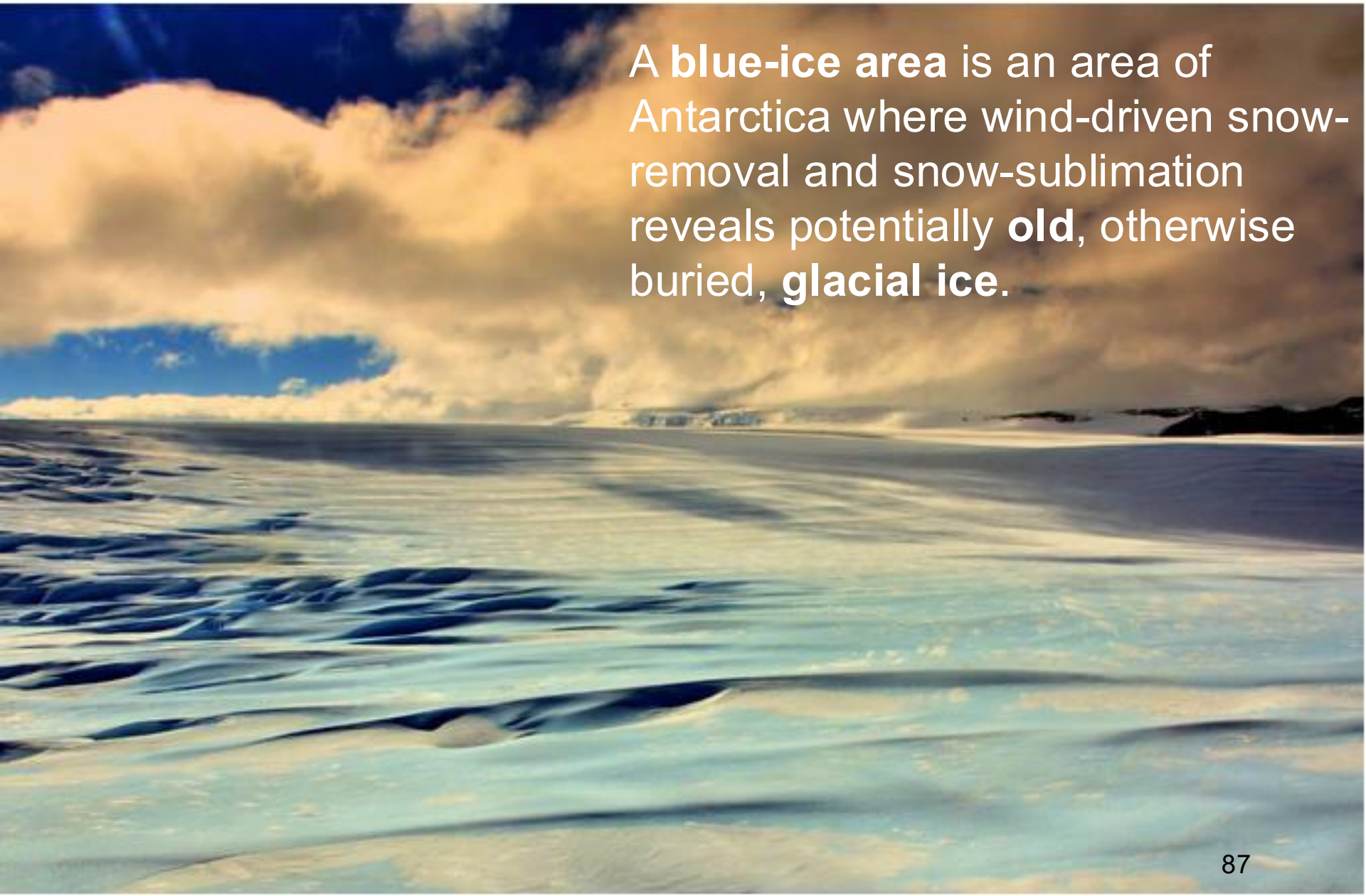
Ice flows from high elevations until blocked by coast mountain



Ice is then pushed **upward**. Some of the ice could be from great depths and be **very old**.

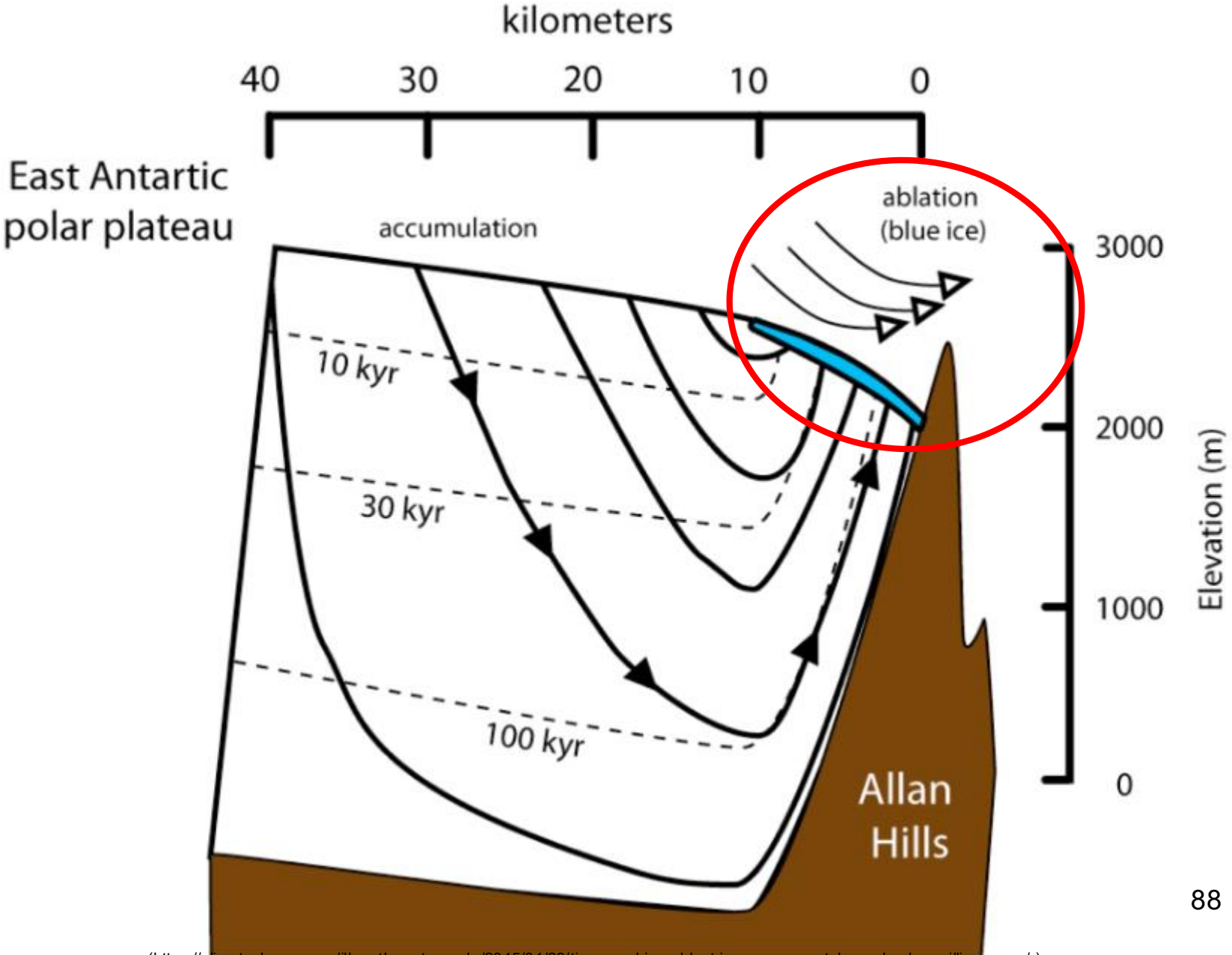
(http://www2.umaine.edu/climatechange/Research/projects/blueice.html#:~:text=Typically%2C%20blue%20ice%20areas%20form,over%20older%20and%20older%20ice.)

Strong winds remove recent snow revealing ancient blue-ice



(https://umaine.edu/news/blog/2019/11/26/cci-teams-with-princeton-to-analyze-2-million-year-old-ice-cores/ /)

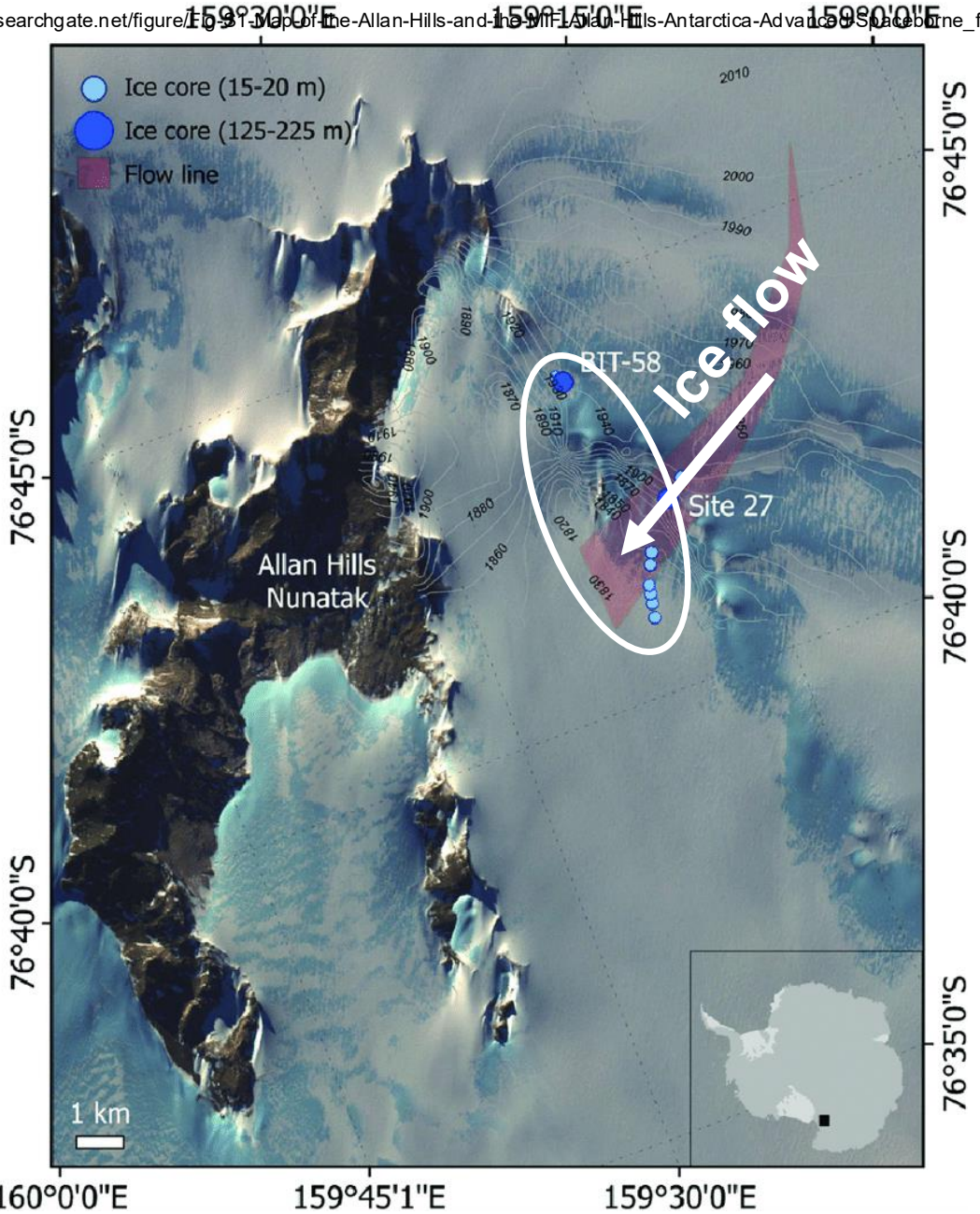
The question: has very-old-ice also “surfaced” in the blue-ice?



(https://climatechange.medill.northwestern.edu/2015/01/29/time-machine-oldest-ice-cores-now-take-us-back-a-million-years/)

Allan Hills showing ice core drilling areas (blue/green dots)

(https://www.researchgate.net/figure/Fig-S1-Map-of-the-Allan-Hills-and-the-MIF-Allan-Hills-Antarctica-Advanced-Spaceborne_fig2_276209358)



Teams drill at several locations in the blue-ice area

(https://antarcticsun.usap.gov/science/4416/)

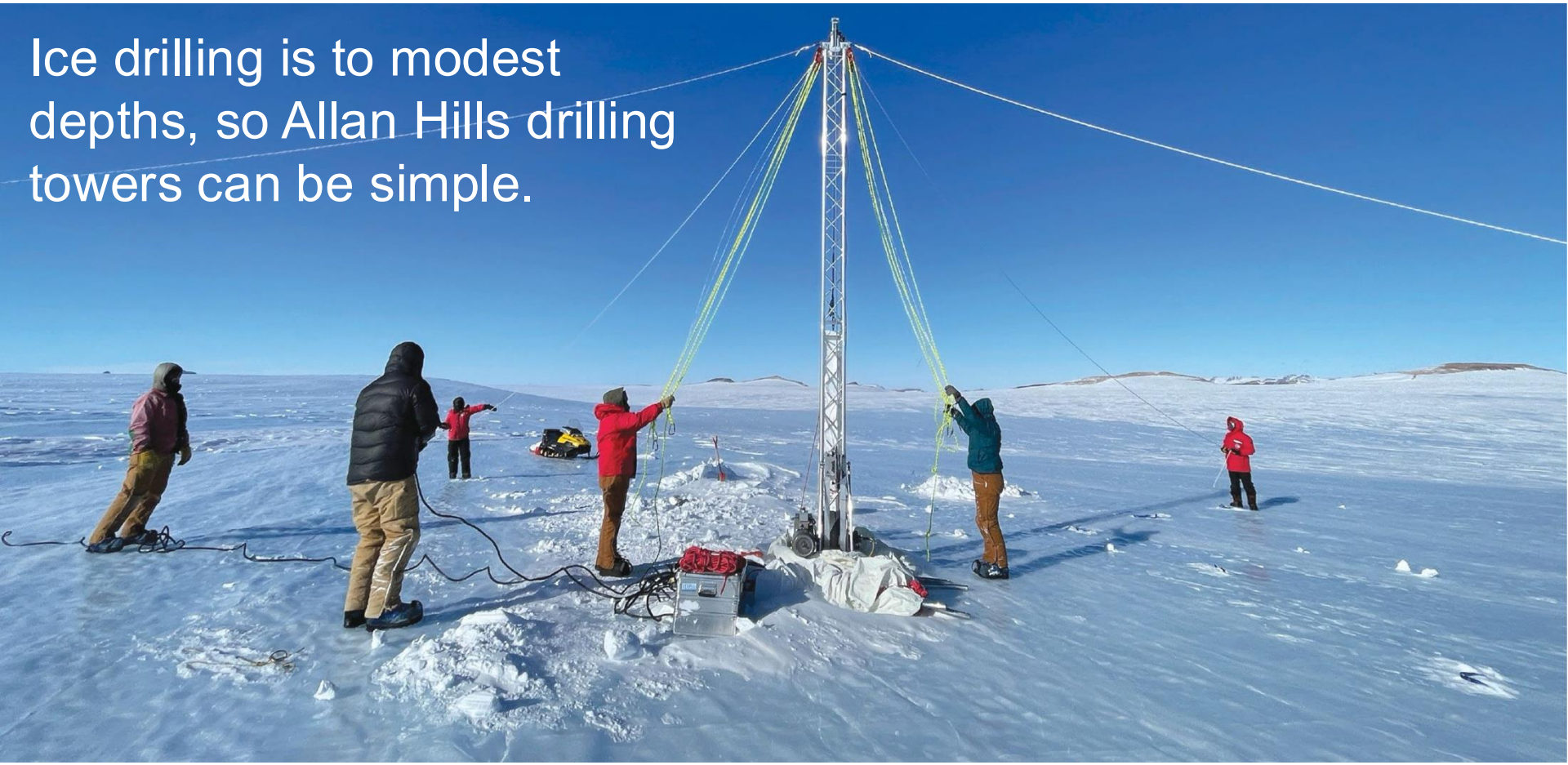
Unlike Dome C, scientists *enjoy* no infrastructure

(https://www.princeton.edu/news/2019/11/21/two-million-year-old-ice-cores-provide-first-direct-observations-ancient-climate)

Graduate student “selfie” to send home

(https://earthsciences.dartmouth.edu/news/2024/12/pictures-searching-earths-oldest-ice)

“Old ice” is now potentially not at great depths



(https://pubs.aip.org/physicstoday/article/76/4/18/2879453/Scientists-drill-for-oldest-ice-to-reveal-secrets)

Drill-tent provides essential protection from Allan Hills' winds

(https://www.princeton.edu/news/2019/11/21/two-million-year-old-ice-cores-provide-first-direct-observations-ancient-climate)

Then several records for oldest ice core

Water isotopes are proxies for Earth's past temperature.

Bubbles in the ice contain greenhouse gases from Earth's atmosphere at a **time** when Earth's **recent cycles** of **glacial advance** and **retreat** were likely just **beginning**.

(https://www.sciencemag.org/news/2017/08/record-shattering-27-million-year-old-ice-core-reveals-start-ice-ages#:~:text=Scientists%20announced%20today%20that%20a,than%20the%20previous%20record%2Dholder.)

Complex glacial ice motion makes dating tricky (but doable)

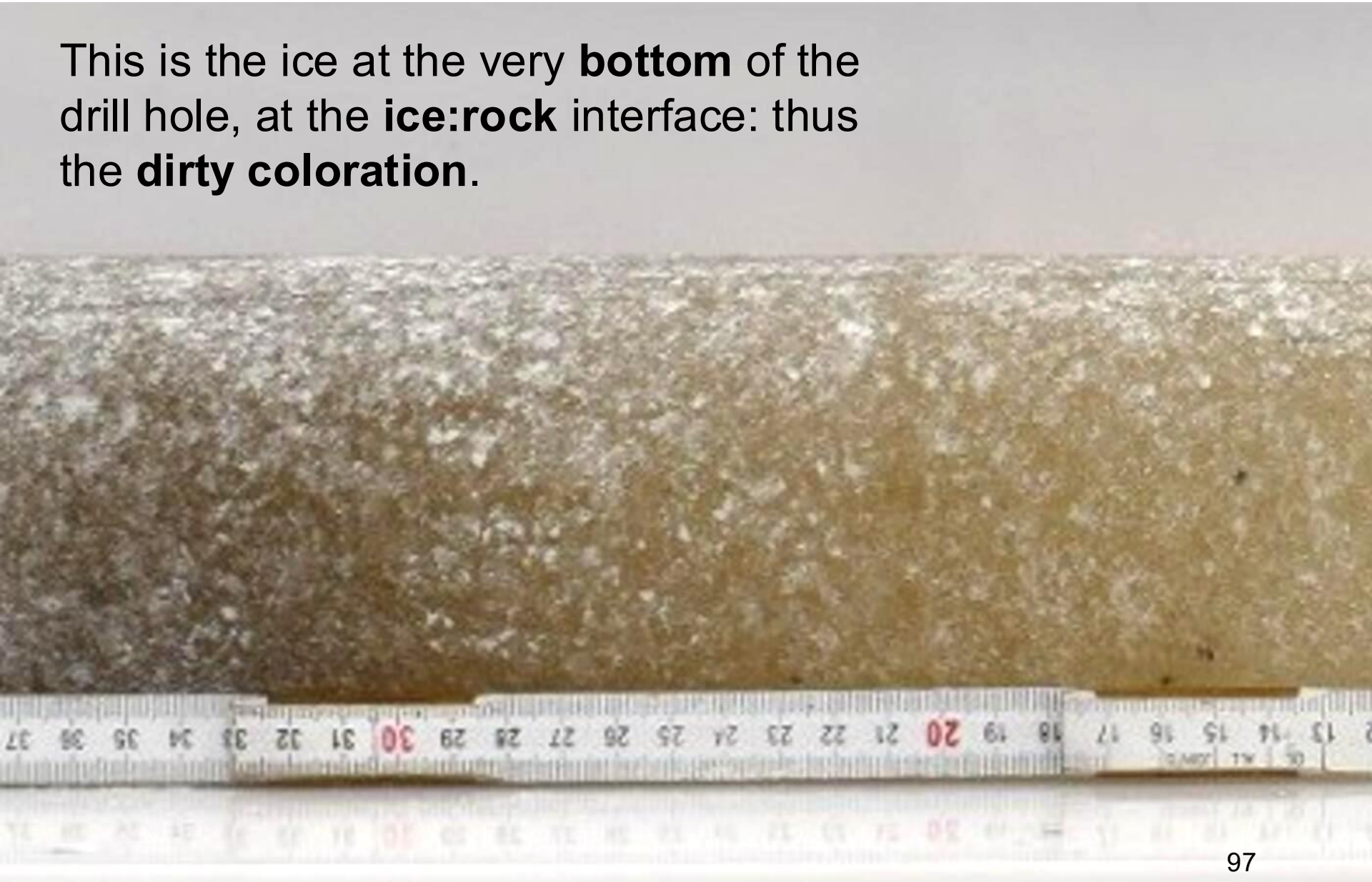
Chunks of ice are dated from trace amounts of **argon** gases they contain.

Although not as precise as other dating methods, the technique can date ice to within 100,000 years or so.

(https://www.innovations-report.com/earth-sciences/a-thermometer-for-the-oceans//)

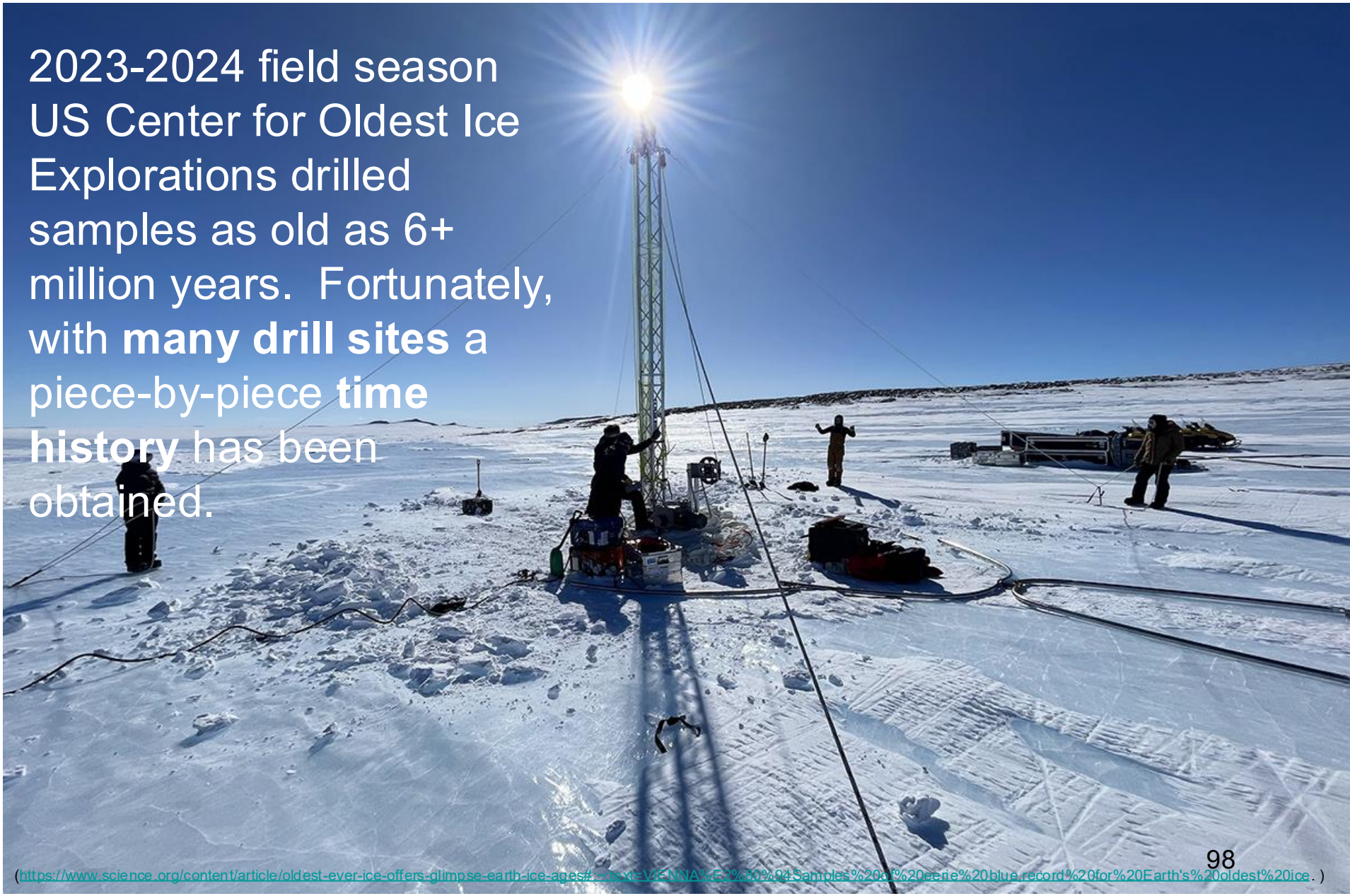
Allan Hills oldest ice core: this one is over 6 million years old

This is the ice at the very **bottom** of the drill hole, at the **ice:rock** interface: thus the **dirty coloration**.



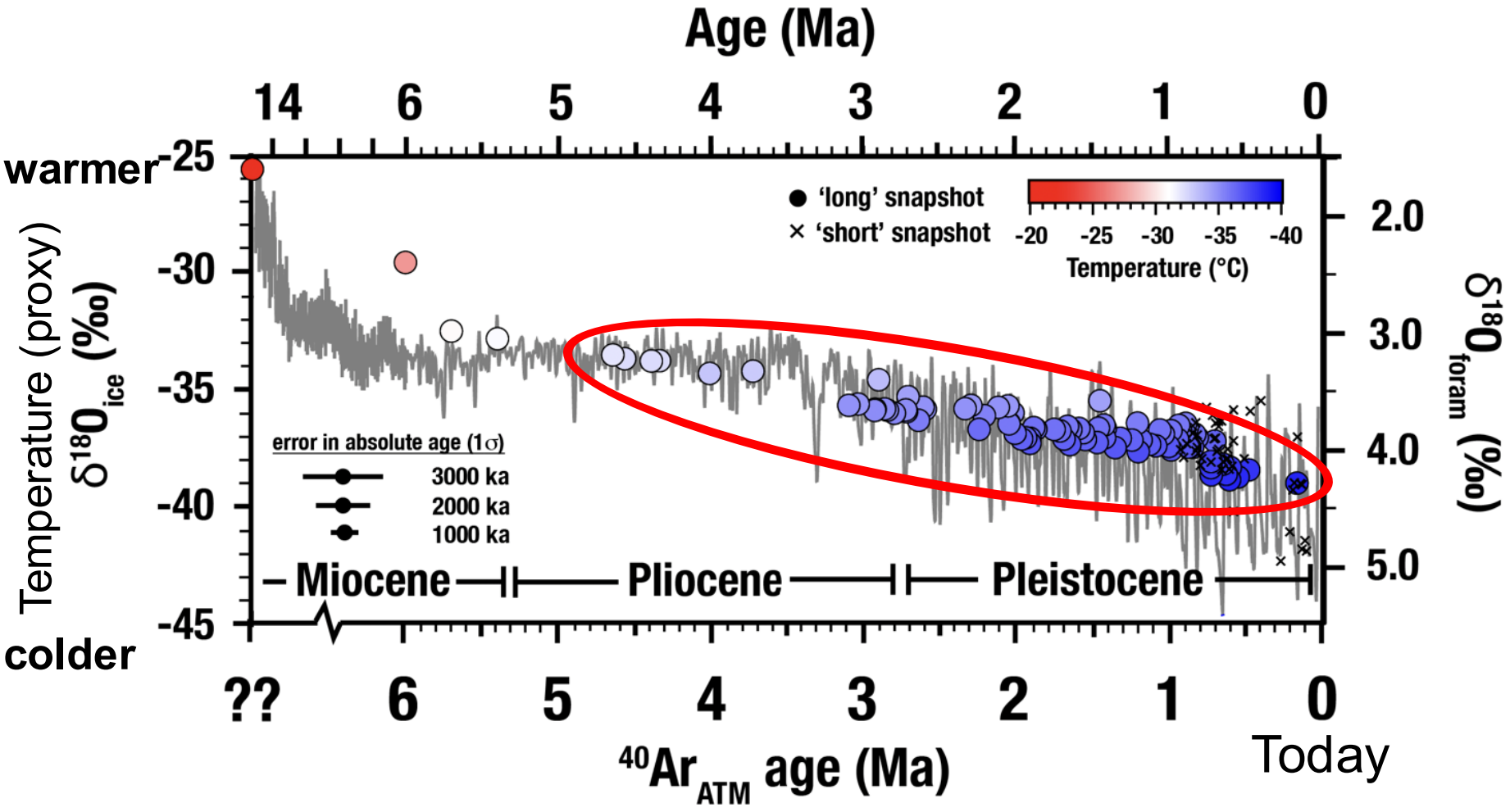
(https://news.oregonstate.edu/news/six-million-year-old-ice-discovered-antarctica-offers-unprecedented-window-warmer-earth)

While a new record, “old” is not the same as a “time history”



(https://www.science.org/content/article/oldest-ever-ice-offers-glimpse-earth-ice-ages#:~:text=VIENNA%E2%80%94Samples%20of%20eerie%20blue,record%20for%20Earth's%20oldest%20ice.)

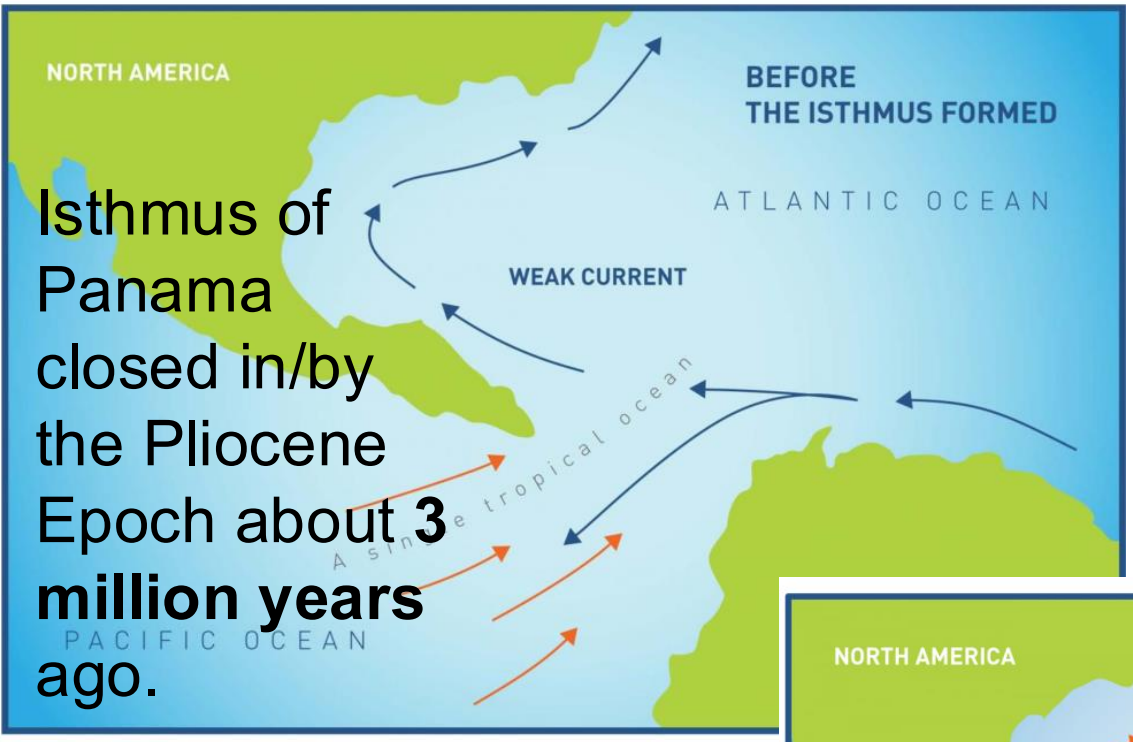
Allan Hills data (in color) is in good agreement with ocean sediment cores



Curiously **Earth** has **cooled** by **several ºC** over the last **3 to 4 million years**. This is likely a consequence of plate tectonics, e.g. Isthmus of Panama closed about 3 million years ago.

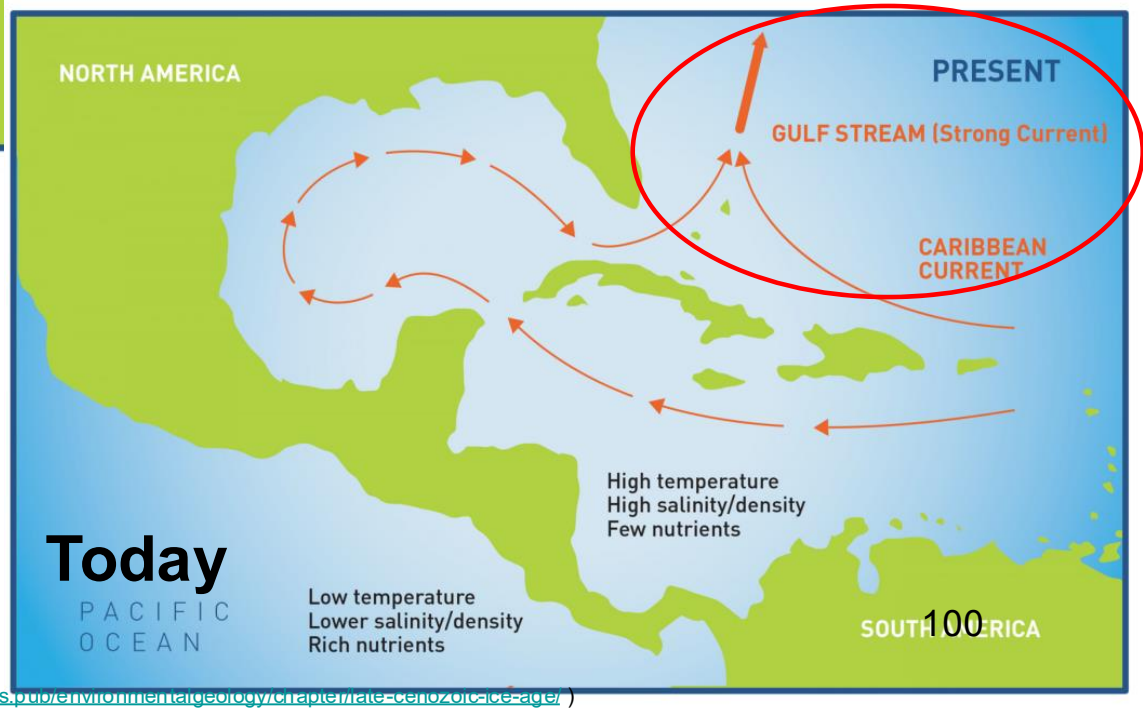
(https://essopenarchive.org/users/533092/articles/1265697-miocene-and-pliocene-ice-and-air-from-the-allan-hills-blue-ice-area-east-antarctica)

Long term temperature changes likely from plate tectonics



Isthmus of Panama closed in/by the Pliocene Epoch about **3 million years** ago.

The Caribbean became warmer and saltier. This created a strong **Gulf Stream** current that now **transports heat** into the North Atlantic.



(https://minnstate.pressbooks.pub/enVironmentalgeology/chapter/late-cenozoic-ice-age/)

In contrast, ice patches reveal Earth's fairly-recent history

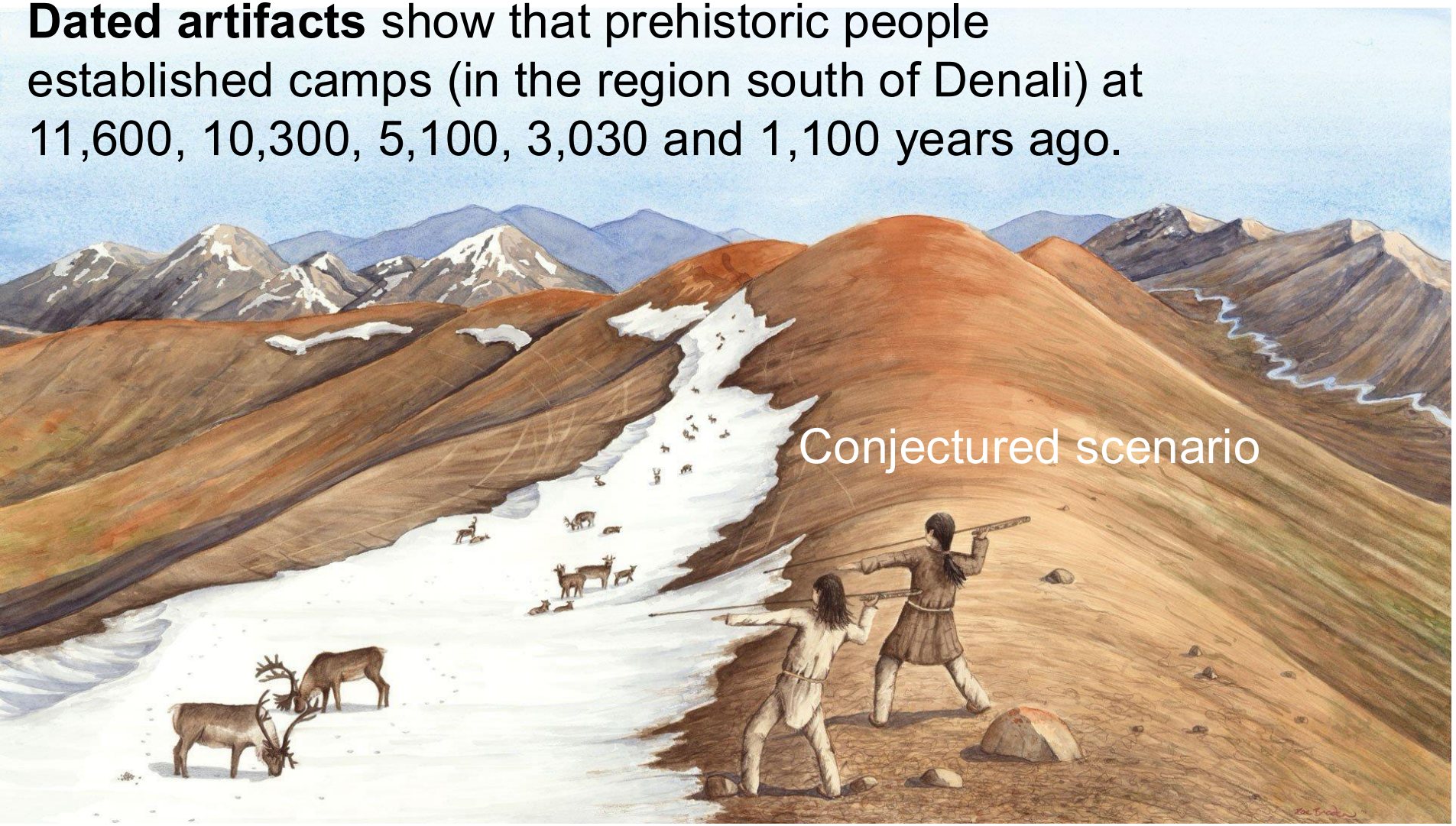
(https://www.nps.gov/articles/denali-ice-patch-archeology.htm)

In recent years, this patch has shrunk and thinned significantly

(https://www.nps.gov/articles/denali-ice-patch-archeology.htm)

Ice patch artifacts document passage of prehistoric people

Dated artifacts show that prehistoric people established camps (in the region south of Denali) at 11,600, 10,300, 5,100, 3,030 and 1,100 years ago.



(https://dnr.alaska.gov/parks/oha/projects/tanglelakes.htm)

Flaked-stone dart/spear points

(https://dnr.alaska.gov/parks/oha/projects/tanglelakes.htm)

Thickest Glacier NP ice patches are over 6,000 years-old

Retreating ice in Mount Edziza Provincial Park, B.C. Canada

One of nine ice patches that released objects from as old as **6,200–5,300 years** ago

(https://www.atlasobscura.com/articles/artifacts-found-ice-canada)

A 2,000-year-old bark-container with visible stitching

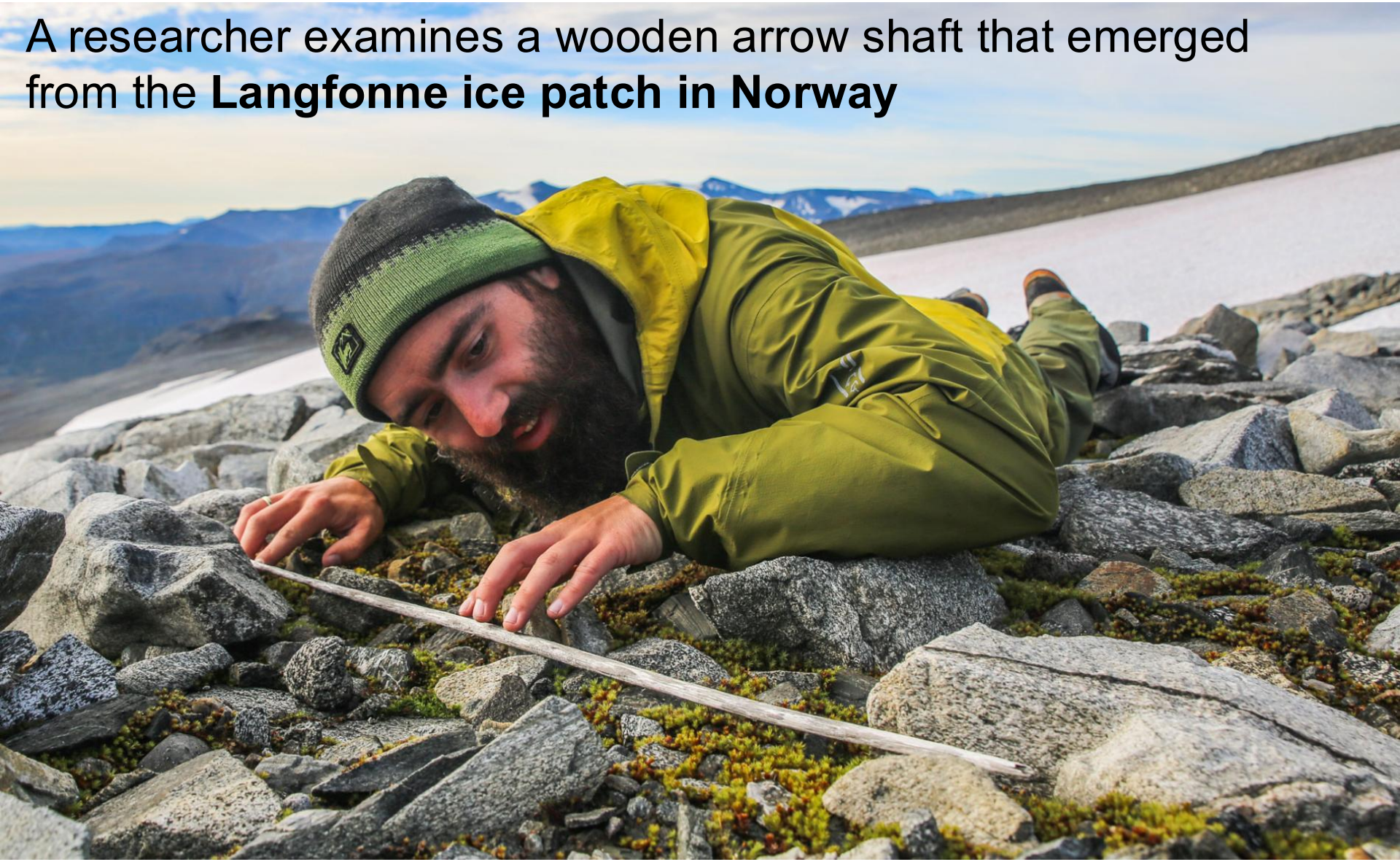
(https://www.atlasobscura.com/articles/artifacts-found-ice-canada)

This ice patch has melted back in time to Norway's stone age

(https://www.treehugger.com/ancient-artifacts-are-emerging-norways-melting-ice-4869687)

(One of two) 1,300-year-old skis from ice in southern Norway

68 complete and partial arrows, some dating back 6,000 years



(https://www.nationalgeographic.com/science/2020/11/6000-years-arrows-emerge-melting-norway-ice-patch/)

2nd arrow found in Norwegian Jotunheimen mountains

(https://www.heritagedaily.com/2022/08/glacial-archaeologists-find-arrow-in-melting-ice/144475)

With rapid warming, it's a race against time

A wooden **arrow** about 3,000 years old and in unusually fine condition was found recently in the mountains of Norway.

(https://www.nytimes.com/2023/09/23/climate/arrow-glacier-melting-norway.html)

Horseshoe dating back to Viking times

Ancient cairns marked the mountain pass at Lendbreen

(https://news.artnet.com/art-world/melting-ice-reveals-ancient-viking-trade-route-1841139#:~:text=A%20trove%20of%20about%20800,a%20result%20of%20global%20warming.&text=In%20a%20melted%20ice%20patch,woolen%20mitten%2C%20and%20a%20tunic.)

Each year more ice melts. Then one day the artifact is visible.

Iron age horse snowshoe, Lendbreen Norway, around BCE300

(https://www.theguardian.com/science/2020/nov/01/secrets-of-the-ice-unlocking-a-melting-time-capsule-archaeology-glaciers)

Summary: what do the ice-cores tell us?

Water isotopes are proxies for Earth's past temperature.

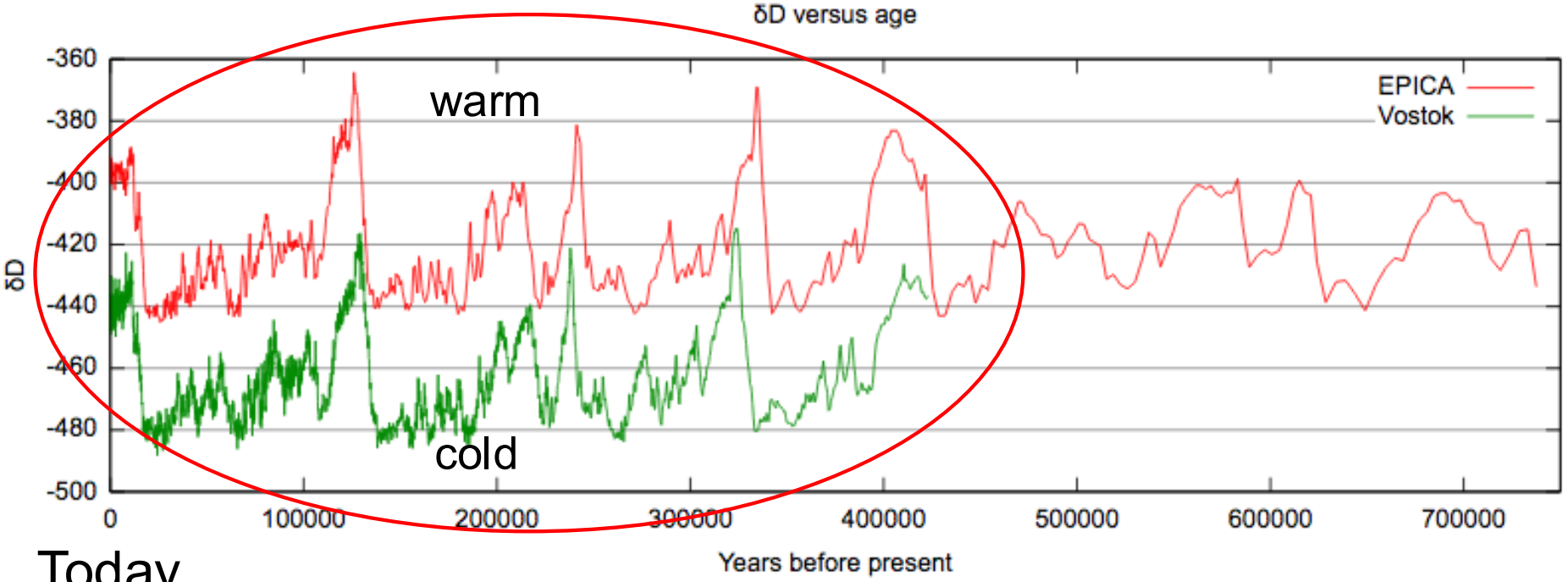
Bubbles in the ice contain e.g. greenhouse gases from Earth's atmosphere.

Both date further back in time the deeper the ice core.

(https://www.sciencemag.org/news/2017/08/record-shattering-27-million-year-old-ice-core-reveals-start-ice-ages#:~:text=Scientists%20announced%20today%20that%20a,than%20the%20previous%20record%2Dholder.)

Summary: independent measurements show results reliable

Independent measurements show **good agreement**
deuterium (δ**D**) is a proxy for **temperature.**



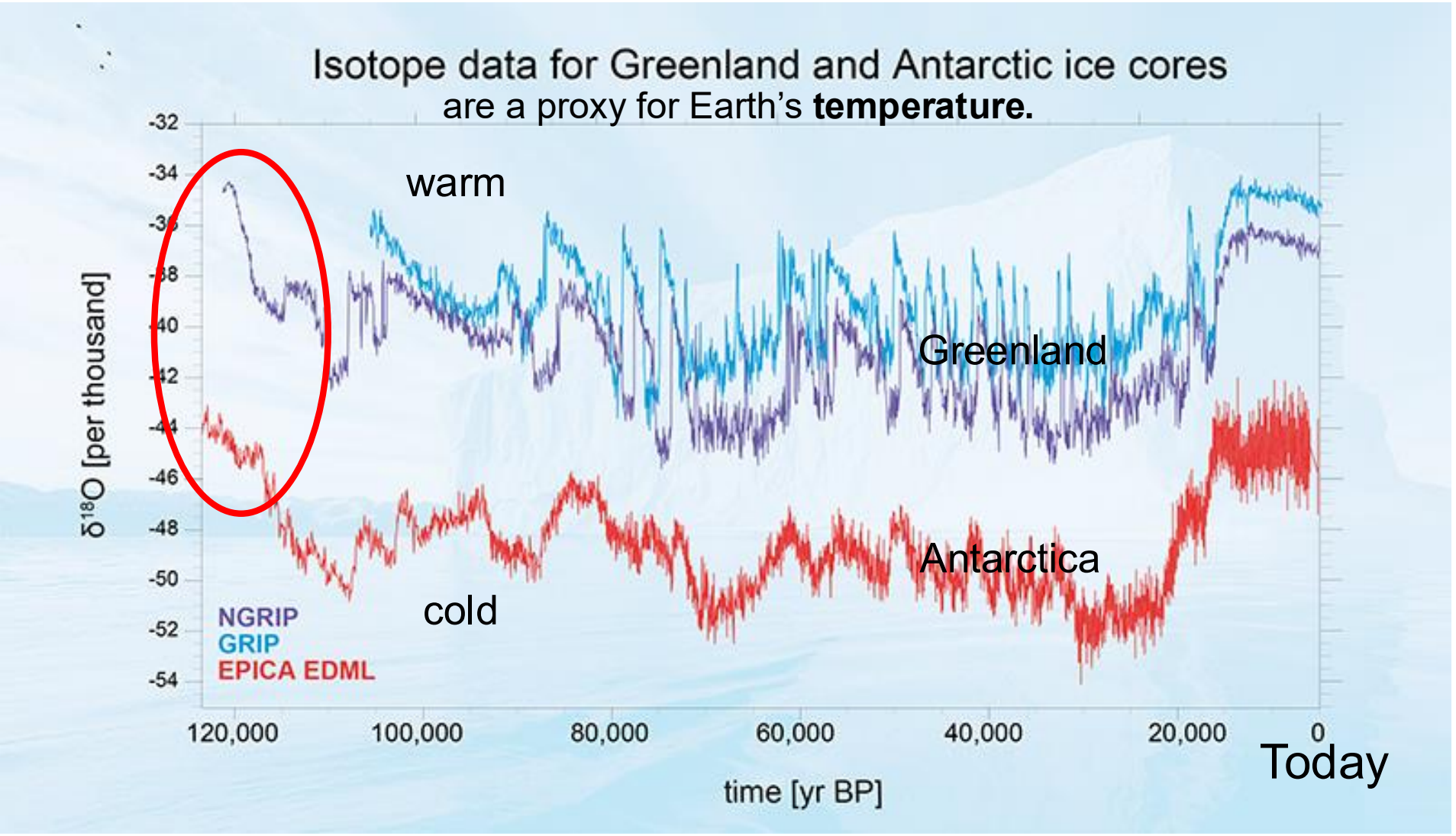
Today

Antarctica **Vostok** and **Dome C** comparison:

Dome C ice is **older** but with **degraded temporal resolution** from layer thinning at **large depths.**

(https://en.wikipedia.org/wiki/European_Project_for_Ice_Coring_in_Antarctica)

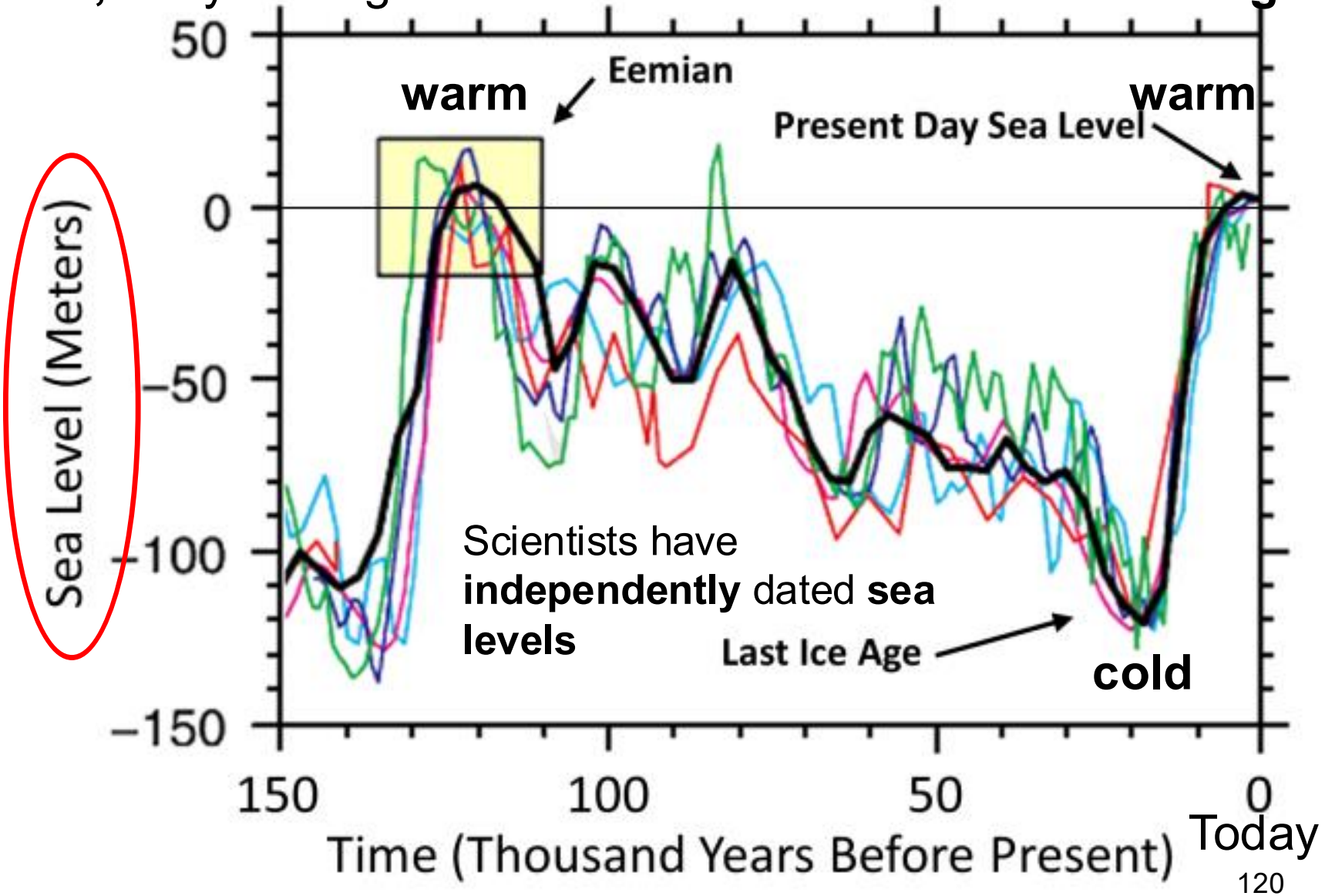
Summary: Greenland and Antarctica both find warming 120,000 years ago



(https://eos.org/science-updates/comprehensive-earth-system-models-of-the-last-glacial-cycle)

Summary: ice-core and sea-level measurements also agree

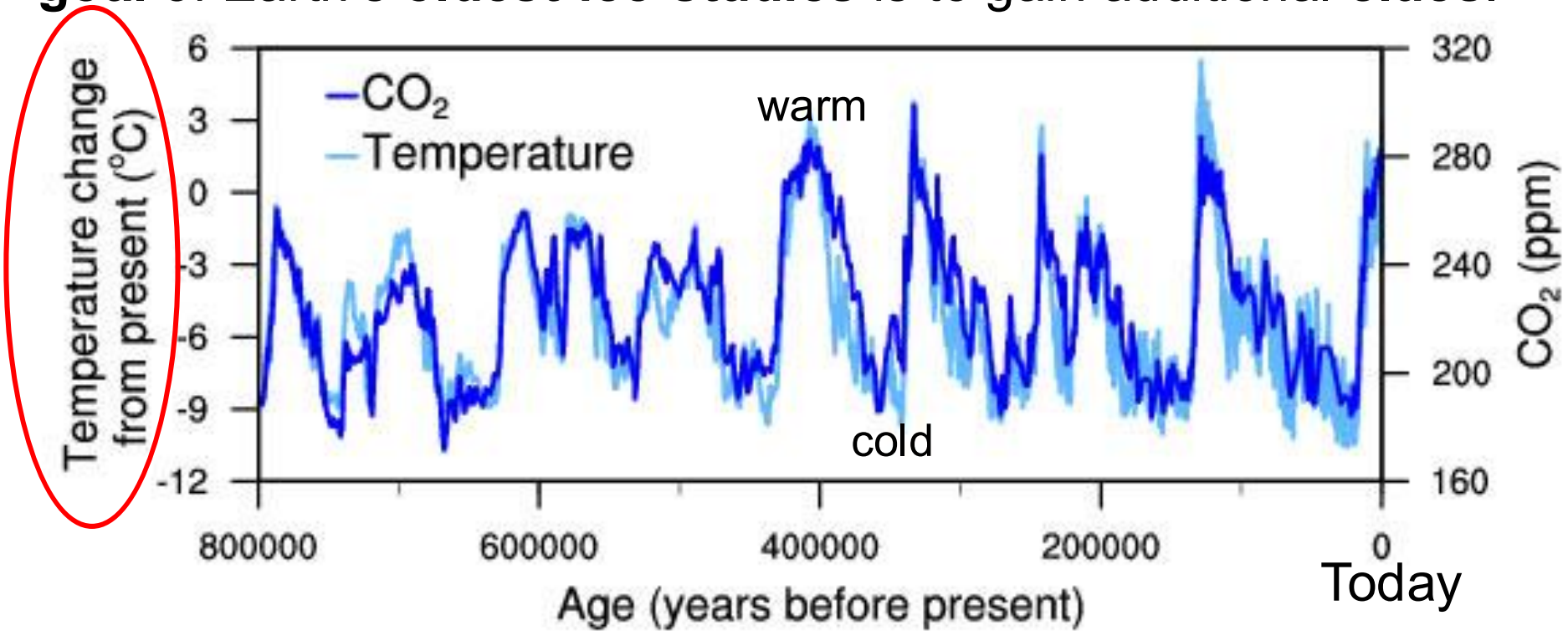
120,000 years ago Earth was "**warmer**" and **sea level higher**



(https://www.forbes.com/sites/uhenergy/2018/07/30/how-much-sea-level-rise-is-actually-locked-in/)

Why do we care? Because Earth is not always the same.

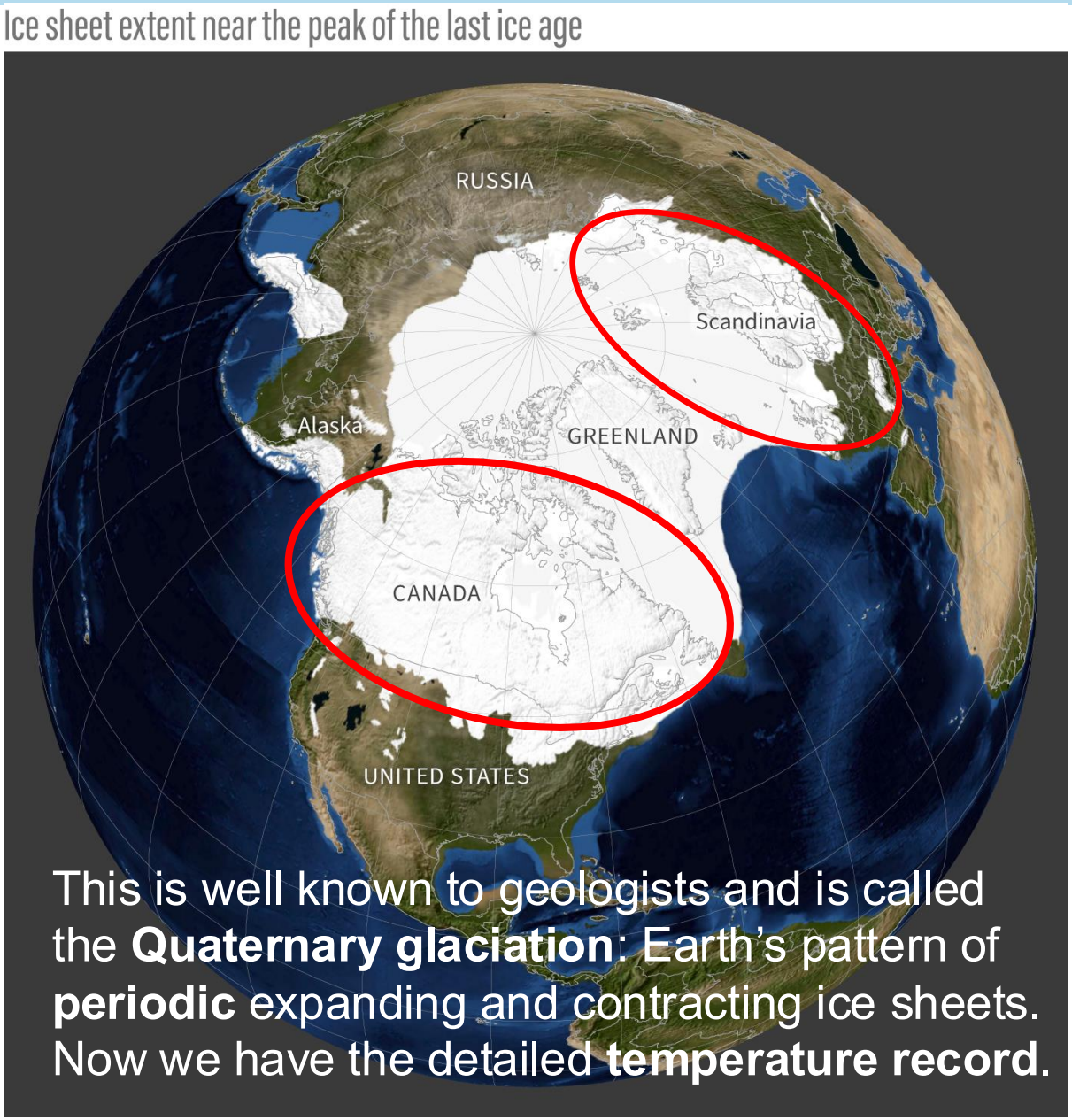
Recently Earth's temperature changes with typically short warm periods followed by **long**, cold **glacial periods**. This pattern has a periodicity of about a 100,000 years. While mostly the result of Earth's periodic orbit/axis variations, why impactful recently? The **goal** of Earth's **oldest-ice-studies** is to gain additional **clues**.



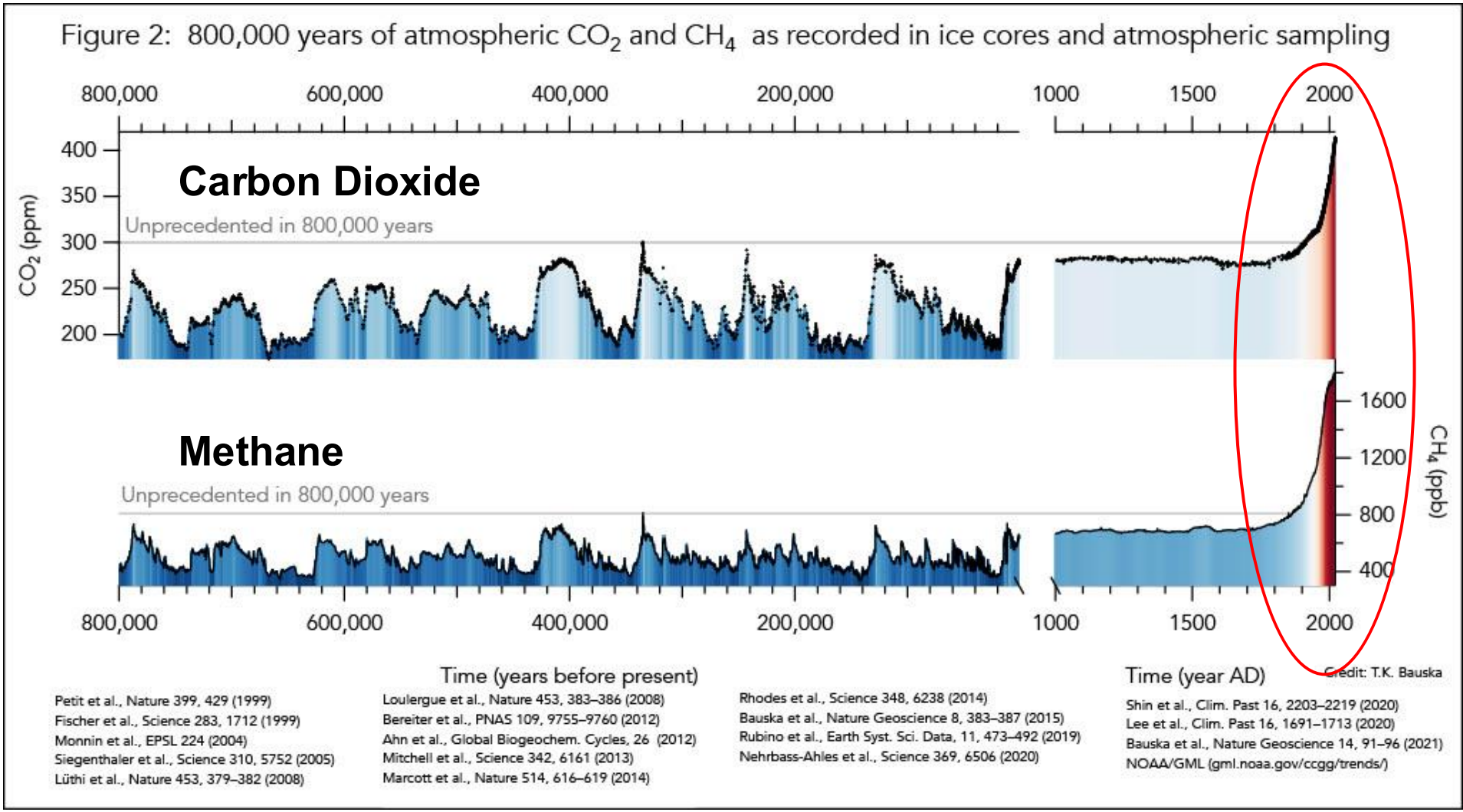
EPICA Dome C ice core results from Antarctica

(https://www.ncdc.noaa.gov/global-warming/temperature-change)

Glacial periods mean that e.g. Canada/Scandinavia can be ice-bound



Another story from Old Ice: CO_2 and CH_4 today are unusual

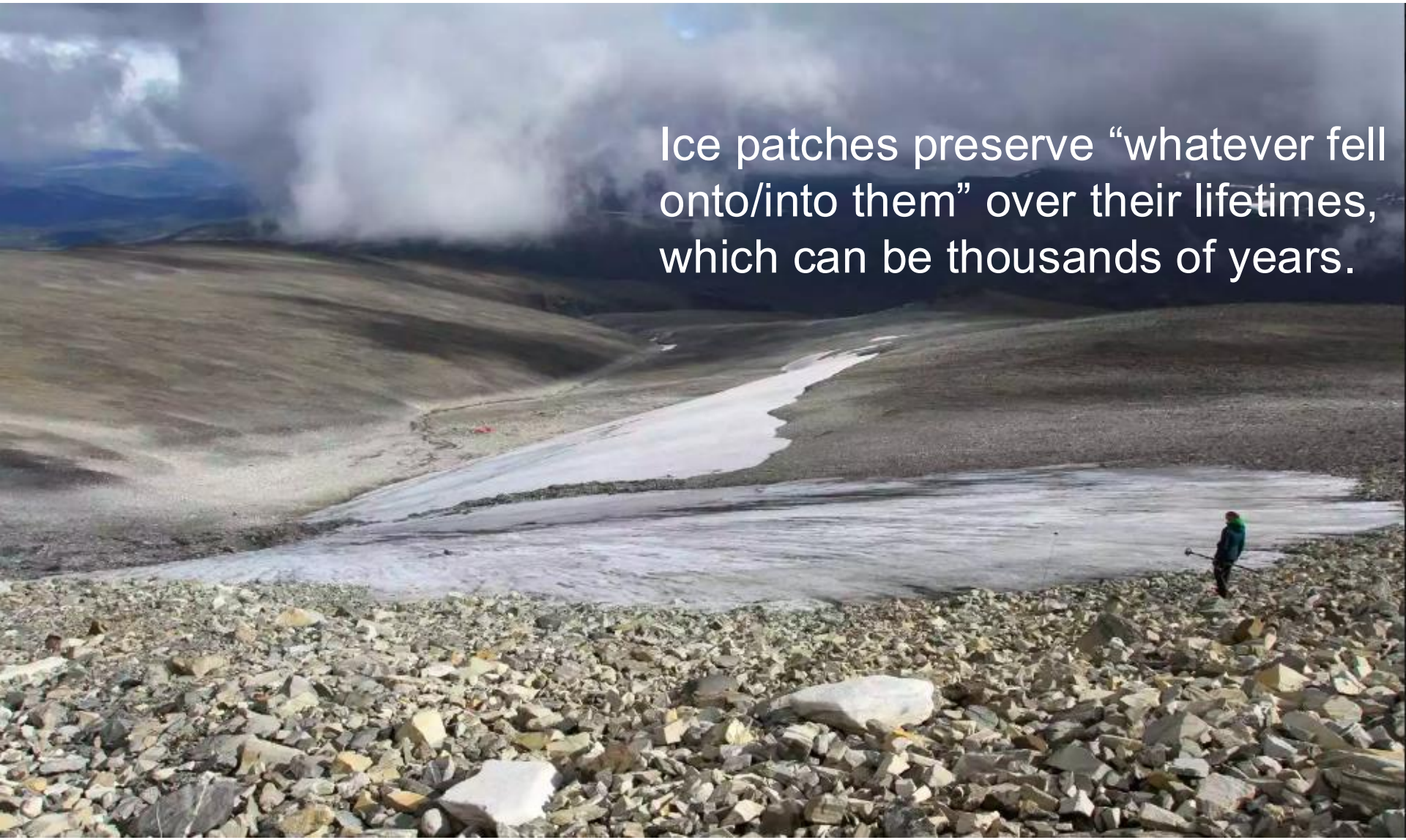


(https://www.bas.ac.uk/data/our-data/publication/ice-cores-and-climate-change/)

Summary: recent, often-human history, is in “ice patches”

(https://www.nps.gov/articles/denali-ice-patch-archeology.htm)

Summary: retreating ice patches go back to iron, bronze and stone ages



(https://www.treehugger.com/ancient-artifacts-are-emerging-norways-melting-ice-4869687)

Summary: each year more ice melts, one day the artifact is visible

Historic treasures from melting ice patches: iron age sandal

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Historic treasures from melting ice patches: Viking sword

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Historic treasures from melting ice patches: Viking age mitten

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Historic treasures from melting ice patches: arrowhead

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Historic treasures from melting ice patches: iron age skis

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Historic treasures from melting ice patches: iron age tunic

(https://www.livescience.com/archaeology/25-things-found-frozen-in-europes-mountain-ice)

Summary: here's to "old ice" and likely lots more to teach us

(http://www.imaginature.nl/pages/antarctica3.html)

Thank you

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What's so interesting about Old Ice?