26th April 2024

When your host hands you a disappointingly **weak** ***gin*** and ***tonic*** it's impossible to know [for sure] whether they've been deliberately **miserly** with the ***gin*** **or** accidentally **generous** with the ***tonic***.

Furthermore:

It's possible your **miserly** host mixed two glasses of **2** parts ***gin*** - **4** parts ***tonic*** but then **added** lots of ***watery ice*** to **your** half empty glass so it contains **1** part ***gin*** - **2** parts ***tonic*** - **3** parts ***watery ice***.

In this situation a well trained ***expert*** analysing the contents of both glasses will conclude your host is a **perfect gentleman** because both glasses contain exactly the same **1:2 ratio** of ***gin*** to ***tonic***.

Similarly:

When you encounter a curiously different series of **$\delta^{18}O$** values it's **impossible to know** whether ***Mother Nature*** was **miserly** with the **^{18}O** **or** over **generous** with the **^{16}O** **or** **added** some extra **^{17}O**.

That's because **$\delta^{18}O$** values only report the **ratio** of **^{18}O** to **^{16}O** and **ignore** the **^{17}O** content.

In essence they're **pretending** a *three body problem* is only a *two body problem*.

Isotopes of $_8O$	Abundance %	Half-Life
^{16}O	99.76	stable
^{17}O	0.038	stable
^{18}O	0.200	stable

Tropospheric Transport of Water Vapour
Harald Sodemann - 2006
https://www.amazon.com/dp/3832513841/

… **$\delta^{18}O$** … **ratio** of stable isotopes **oxygen-18 (^{18}O)** and **oxygen-16 (^{16}O)**.

Wikipedia - $\delta^{18}O$
https://en.wikipedia.org/wiki/Delta_18O

The earliest reference I've found to the *abundance of oxygen isotopes* dates back to the era of the **Manhattan Project** and **heavy water** so there may [or may **not**] be reasons for *cooking the books*.

Of very great importance is the discovery that ordinary oxygen actually consists of three isotopes, of which the atomic masses, mass numbers, and relative abundance are as follows:[1]

M	A	Relative abundance (per cent)
16.00000	16	99.76
17.00450	17	0.04
18.0049	18	0.20

Fundamentals of Atomic Physics - Saul Dushman - 1951

For some of the isotopes Bethe's values are very slightly different from those given by R. T. Birge in **1941**, which are quoted in Appendix 2.
…
O = 16.004357 (from abundance **O16:018:017** = **506:1:0.204**)

Fundamentals of Atomic Physics - Saul Dushman - 1951
https://archive.org/details/fundamentalsofat0000saul/page/190/mode/1up

The **Manhattan Project** was a program of research and development undertaken during World War II to produce the first nuclear weapons.
…
On 9 October **1941**, President Roosevelt approved the **atomic program** after he convened a meeting with Vannevar Bush and Vice President Henry A. Wallace
…
Although DuPont's preferred designs for the nuclear reactors were helium cooled and used graphite as a moderator, DuPont still expressed an interest in using **heavy water** …

Wikipedia - Manhattan Project
https://en.wikipedia.org/wiki/Manhatten_project

Either way:

In the land of the *two body problem* they've made it **far** more confusing because **$\delta^{18}O$** values now represent the **deviation** of a sample's **^{18}O** to **^{16}O ratio** **from** an approved **standard** **^{18}O** to **^{16}O ratio**.

$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{\text{sample}}}{\left(\frac{^{18}O}{^{16}O}\right)_{\text{standard}}} - 1 \right) \times 1000 ‰$$

… defined as the **deviation** … between a **sample** and a **standard** … where the standard has a known isotopic composition, such as **Vienna Standard Mean Ocean Water** (VSMOW).

Wikipedia - $\delta^{18}O$
https://en.wikipedia.org/wiki/Delta_18O

The approved **VSMOW standard** was first published in 1968.

Parts Oxygen	16O ppm	16O Percent	17O ppm	17O Percent	18O ppm	18O Percent	18O/16O	VSMOW Delta 18O
1,000,000.0000	**997,614.9000**	99.76%	**379.9000**	0.04%	**2,005.2000**	0.20%	-997.9900	0.0000

The isotopic composition of **VSMOW water** is … expressed as **parts per million** (ppm).
…
^{18}O / **^{16}O** = **2005.20** ±0.43 **ppm** [1 in 498.7 oxygen atoms]
^{17}O / **^{16}O** = **379.9** ±1.6 **ppm** [1 in 2632 oxygen atoms]

Wikipedia - Vienna Standard Mean Ocean Water - 06:03 21 July 2006
https://en.wikipedia.org/w/index.php?title=Vienna_Standard_Mean_Ocean_Water&oldid=64988384

Vienna Standard Mean Ocean Water (VSMOW) is an **isotopic standard for water**
… whose proportions of different isotopes of hydrogen and oxygen are accurately known.
Published … by the Vienna-based International Atomic Energy Agency in **1968** ...
…
In December 1996, because of a dwindling supply of VSMOW, the IAEA decided to create a replacement standard, **VSMOW2**. Published in 1999, it contains a nearly identical isotopic mixture. About 300 liters was prepared from a **mixture of distilled waters**, from **Lake Bracciano** in Italy, the **Sea of Galilee** in Israel, and a **well** in Egypt**,** in proportions chosen to reach VSMOW isotopic ratios.
…
The VSMOW–SLAP scale is **recommended** … for measurement of … **^{18}O** concentrations in any substance. For **^{18}O**, a scale based on **Vienna Pee Dee Belemnite** **can** also **be used.**

Wikipedia - Vienna Standard Mean Ocean Water
https://en.wikipedia.org/wiki/Vienna_Standard_Mean_Ocean_Water

The **Peedee Formation** is a geologic formation in North and South Carolina.
A **marine deposit**, named for exposures along the Great Peedee River, it preserves belemnites and foraminifera fossils dating to the Late Cretaceous (Maastrichtian).

The formation is **notable for its occurrence of Belemnitella americana**, known as the **Pee Dee Belemnite (PDB)**, a long-standing **standard in stable** carbon **isotope research**.

Wikipedia - Peedee Formation
https://en.wikipedia.org/wiki/Peedee_Formation

Belemnitella americana
Rutgers Geology Museum - Wikimedia: Skye McDavid

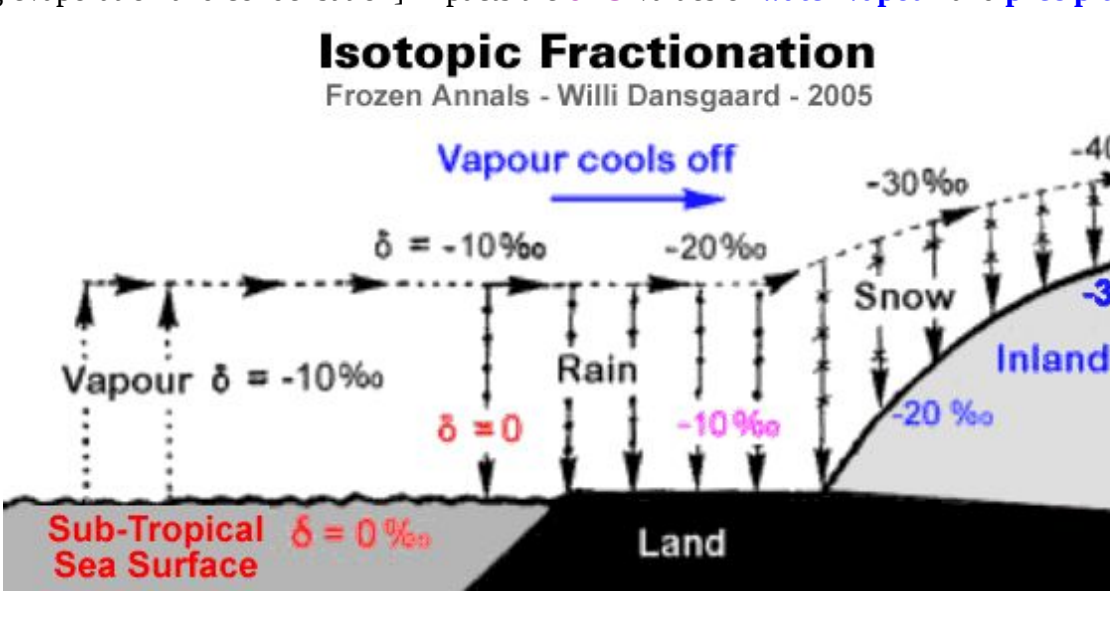
Belemnitella is a genus of belemnite from the **Late Cretaceous** of Europe and North America. Belemnitella was a **squidlike animal**, probably related to the ancestors of modern squids and cuttlefish. The shell was internal.
…
Belemnitella americana, is the **source of the Pee Dee Belemnite**, **reference standard** …

Wikipedia - Belemnitella
https://en.wikipedia.org/wiki/Belemnitella

In 2005 Willi Dansgaard published a wonderful diagram that depicts the journey of **water vapour** from it's origin in sub-tropical surface **sea water** to it's ultimate fate as falling **snow** over Greenland.

The journey to Greenland includes a series of annotations that reveal how **Isotopic Fractionation** [during evaporation and condensation] impacts the **$\delta^{18}O$** values of **water vapour** and **precipitation**.

Isotopic Fractionation
Frozen Annals - Willi Dansgaard - 2005



In Fig. 1.4 the primary **evaporation takes place from a sub-tropical ocean** surface to the left, and the horizontal arrows follow the humid air mass toward north while cooling to the dew point, when the first rain is formed (with **δ = 0 ‰**).

During **the proceeding cooling**, when the air mass crosses a continent, or flows **over the inland ice** (to the right in the figure), or ascent along a warm front, it **gives off precipitation** and **acquires steadily decreasing δ's** for both the vapour and the precipitation.

Frozen Annals - Willi Dansgaard - 2005
http://www.iceandclimate.nbi.ku.dk/publications/FrozenAnnals.pdf

Isotope fractionation describes fractionation processes that affect the relative abundance of isotopes, phenomena which are **taken advantage of** in isotope geochemistry and other fields.
…
Isotope fractionation **occurs during a phase transition**, when the ratio of light to heavy isotopes in the involved molecules changes.

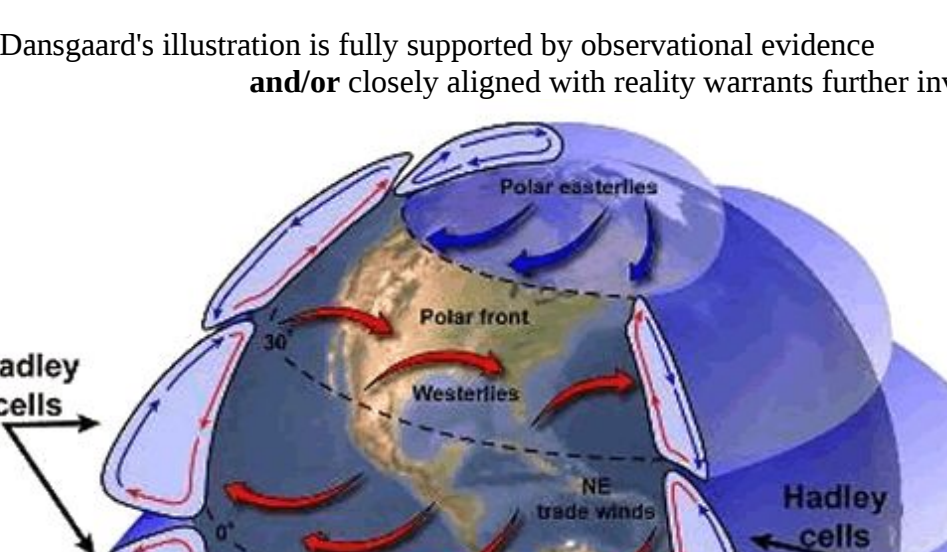
When **water vapor condenses** (an equilibrium fractionation),
the **heavier water isotopes** (**^{18}O** and **^{2}H**) **become enriched in the liquid phase** while
the **lighter** **isotopes** (**^{16}O** and **^{1}H**) **tend toward the vapor phase**.

Wikipedia - Isotope Fractionation - 15:56 17 October 2023
https://en.wikipedia.org/w/index.php?title=Isotope_fractionation&oldid=1180588130

$\delta^{18}O$ also reflects local evaporation and freshwater input, as **rainwater is ^{16}O-enriched** — a result of **the preferential evaporation of the lighter ^{16}O from seawater**.

Wikipedia - δ18O - 03:32 10 February 2024
https://en.wikipedia.org/w/index.php?title=%CE%9418O&oldid=1205638079

Whether Willi Dansgaard's illustration is fully supported by observational evidence
and/or closely aligned with reality warrants further investigation.



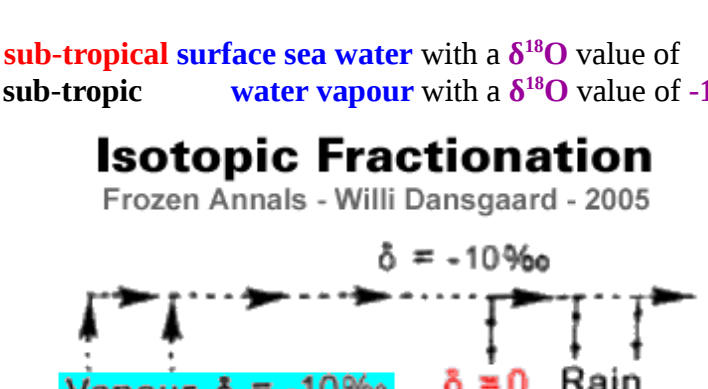
When I started studying weather and climate it was believed there were three cells: the *Polar*, *Ferrel*, and *Hadley*. **Then it was argued that the *Ferrel Cell* did not exist**, and air movement between the Polar and Hadley Cells was extremely complicated. Dr. Tim Ball.

Malaga Bay - Taylor-Couette Circulation
https://malagabay.wordpress.com/2015/02/03/taylor-couette-circulation/

Beginning at the beginning:

Willi Dansgaard turns **sub-tropical surface sea water** with a **$\delta^{18}O$** value of **0 ‰**
into **sub-tropic** **water vapour** with a **$\delta^{18}O$** value of **-10 ‰**.

Isotopic Fractionation
Frozen Annals - Willi Dansgaard - 2005



Reverse engineering this transformation reveals:

Evaporating **16.764%** of the **^{16}O water molecules**
along with **100.000%** of the **^{18}O water molecules** from a **sample** with a **$\delta^{18}O$** value of **0 ‰**
will create **water vapour** with a **$\delta^{18}O$** value of **-10 ‰**.

Parts Oxygen	16O ppm	16O Percent	17O ppm	17O Percent	18O ppm	18O Percent	18O/16O	VSMOW Delta 18O
1,000,000.0000	**997,614.9000**	99.76%	**379.9000**	0.04%	**2,005.2000**	0.20%	-997.9900	0.0000
169,467.1551	167,240.1618	98.69%	221.7932	0.13%	2,005.2000	1.18%	-988.0101	**-10.0000**

This truly **remarkable** example of the **"preferential evaporation of the lighter ^{16}O"** leaves the **sample incapable** of producing any additional **water vapour** with a **$\delta^{18}O$** value of **-10 ‰**.

Furthermore:

Parts Oxygen	16O ppm	16O Percent	17O ppm	17O Percent	18O ppm	18O Percent	18O/16O	VSMOW Delta 18O
1,000,000.0000	**997,614.9000**	99.76%	**379.9000**	0.04%	**2,005.2000**	0.20%	-997.9900	0.0000
169,467.1551	167,240.1618	98.69%	221.7932	0.13%	2,005.2000	1.18%	-988.0101	-10.0000
830,532.8449	830,374.7382	99.98%	158.1068	0.02%	0.0000	0.00%	-1,000.0000	**2.0140**

This truly **remarkable** example of the **"preferential evaporation of the lighter ^{16}O"** leaves the **sample** with an enhanced level of **^{16}O** that is reflected in it's residual **$\delta^{18}O$** value of **+2.014 ‰**.

Unsurprisingly:

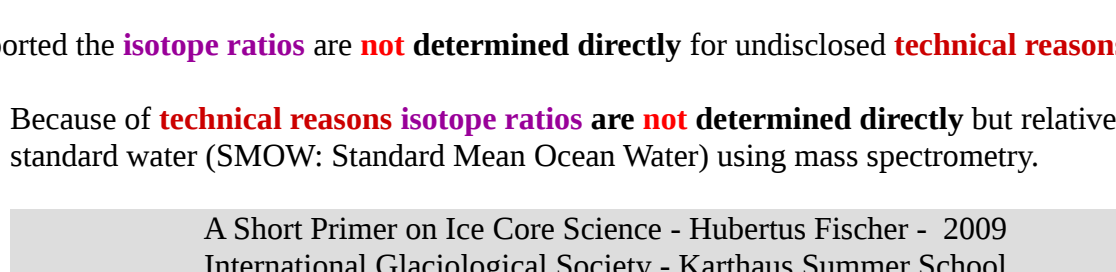
It's reported the **isotope ratios** are **not determined directly** for undisclosed **technical reasons**.

Because of **technical reasons isotope ratios are not determined directly** but relative to a standard water (SMOW: Standard Mean Ocean Water) using mass spectrometry.

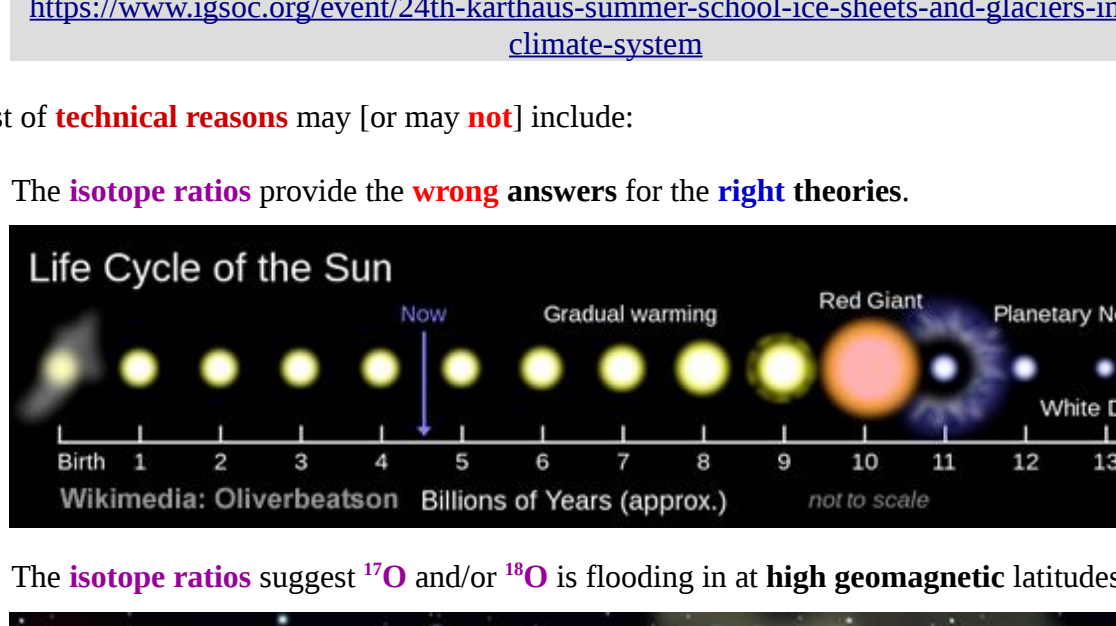
A Short Primer on Ice Core Science - Hubertus Fischer - 2009
International Glaciological Society - Karthaus Summer School
https://www.igsoc.org/event/24th-karthaus-summer-school-ice-sheets-and-glaciers-in-the-climate-system

The list of **technical reasons** may [or may **not**] include:

► The **isotope ratios** provide the **wrong answers** for the **right theories**.



► The **isotope ratios** suggest **^{17}O** and/or **^{18}O** is flooding in at **high geomagnetic** latitudes.



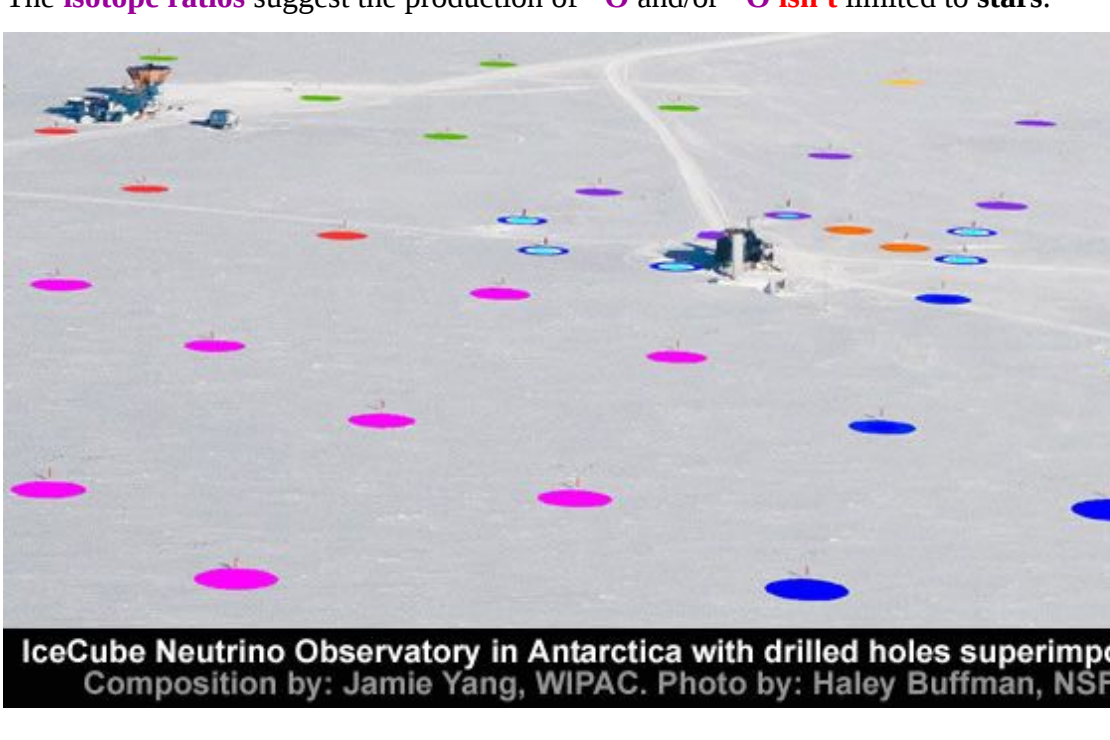
Earth's magnetopause … **allows solar wind particles to enter**.

Wikipedia - Magnetosphere
https://en.wikipedia.org/wiki/Magnetosphere

The **solar wind is a stream of charged particles** released from the upper atmosphere of the Sun, called the corona. This plasma mostly consists of electrons, protons and alpha particles with kinetic energy between 0.5 and 10 keV. The composition of the solar wind plasma **also includes** a mixture of materials found in the solar plasma: trace amounts of heavy ions and atomic nuclei of elements such as C, N, **O**, Ne, Mg, Si, S, and Fe. There are also rarer traces of some other nuclei and isotopes such as P, Ti, Cr, and ^{58}Ni, ^{60}Ni, and ^{62}Ni.

Wikipedia - Solar Wind
https://en.wikipedia.org/wiki/Solar_wind

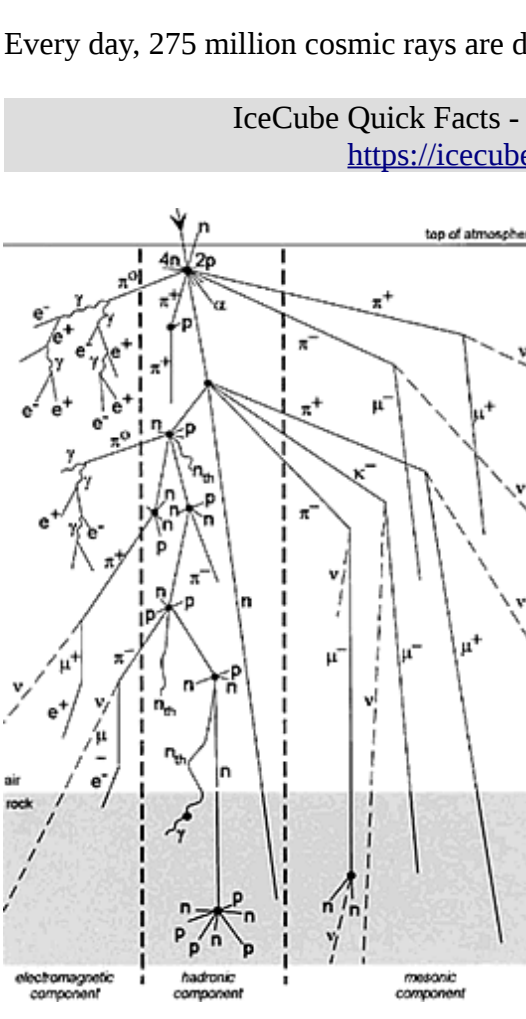
► The **isotope ratios** suggest the production of **^{17}O** and/or **^{18}O** **isn't** limited to **stars**.



IceCube Neutrino Observatory in Antarctica with drilled holes superimposed
Composition by: Jamie Yang, WIPAC. Photo by: Haley Buffman, NSF

Every day, 275 million cosmic rays are detected by IceCube.

IceCube Quick Facts - University of Wisconsin–Madison
https://icecube.wisc.edu/about-us/facts/



The major components of a cosmic-ray extensive air shower (cascade), showing secondary particle production in the atmosphere and rock

Modified from:
Allkofer and Grieder - 1984
Clay and Dawson - 1997

Terrestrial in Situ Cosmogenic Nuclides: Theory and Application
J C Gosse and F M Phillips
Quaternary Science Reviews 20 - 2001

Terrestrial in Situ Cosmogenic Nuclides: Theory and Application
J C Gosse and F M Phillips - Quaternary Science Reviews 20 - 2001
http://quebec.hwr.arizona.edu/classes/hwr696t/gosse01-cosmogenic-nuclide-review.pdf

Malaga Bay - Cosmic Ray Blues
https://malagabay.wordpress.com/category/cosmic-ray-blues/

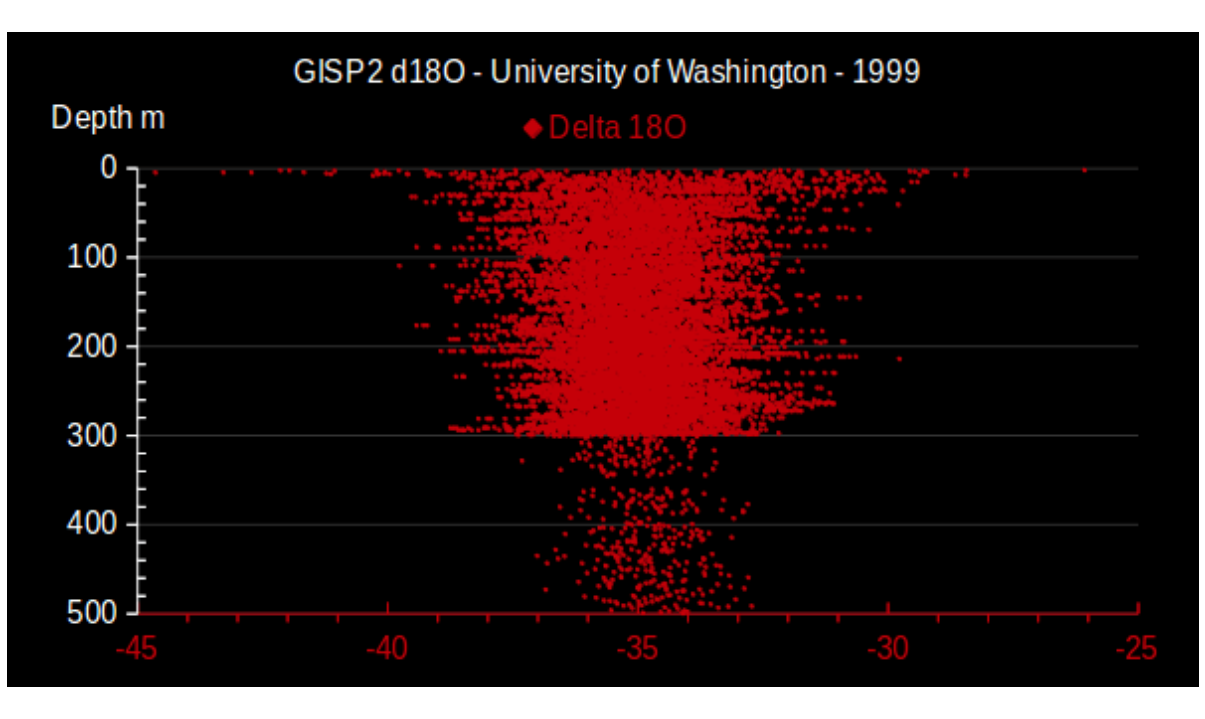
The relative and absolute abundance of **^{16}O** is high because it is a principal product of stellar evolution and because it is a primary isotope, meaning it can be made by stars that were initially made exclusively of hydrogen.
…
^{17}O is primarily made by the burning of hydrogen into helium during the CNO cycle, making it a common isotope **in the hydrogen burning zones of stars**.

Most **^{18}O is produced** when ^{14}N (made abundant from CNO burning) captures a ^{4}He nucleus, making ^{18}O common **in the helium-rich zones of stars**.

Wikipedia - Isotopes of Oxygen - 15:00 2 December 2008
https://en.wikipedia.org/w/index.php?title=Isotopes_of_oxygen&oldid=255426010

Whatever the reasons may be:

The most likely explanation for the sudden symmetrical squeeze in the **δ18O** value range in the **GISP2** **ice core** below 300 metres is that the sea temperatures around Greenland were consistently higher [with a consistently narrower range of **δ18O** values] during the period of continuous winter **snow** that was triggered by the Southern Hemisphere being continuously tilted towards the Sun.



Below 300 metres the **GISP2** **ice core** **δ18O** values experience a remarkable *regime change*.

Malaga Bay - Depths of Dating
https://malagabay.wordpress.com/2024/04/12/depths-of-dating/

In paleosciences, **^{18}O:^{16}O** **data from** … **ice cores** are used as a **proxy** for **temperature**.
…
Based on the simplifying assumption that the signal can be attributed to temperature change alone, with the effects of salinity and ice volume change ignored, Epstein et al. (**1953**) estimated that **a** **δ18O** **increase** of 0.22‰ **is equivalent to** a **cooling** of 1 °C (or 1.8 °F).

Wikipedia - δ18O
https://en.wikipedia.org/wiki/Delta_18O

The sudden disappearance of the **Cryoconite** layers at depth in the **Greenland Ice Sheet** is totally consistent with a period of continuous **snowing** from about **850** to **1350** **CE** that was triggered by the Southern Hemisphere being continuously tilted towards the Sun.

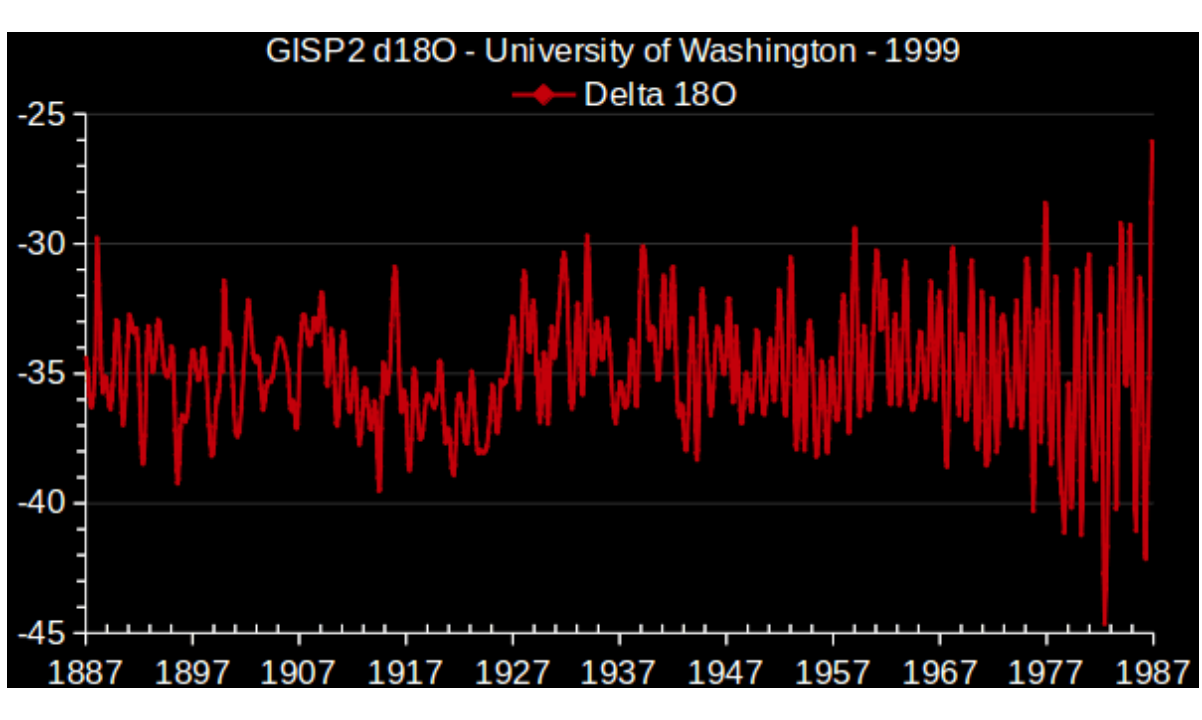
More specifically:

A period of continuous **snowing** would explain why the airborne constituents of **cryoconite** are distributed throughout the “transparent” section of the **ice core** as “micro-particles”.

Malaga Bay - Depths of Dating
https://malagabay.wordpress.com/2024/04/12/depths-of-dating/

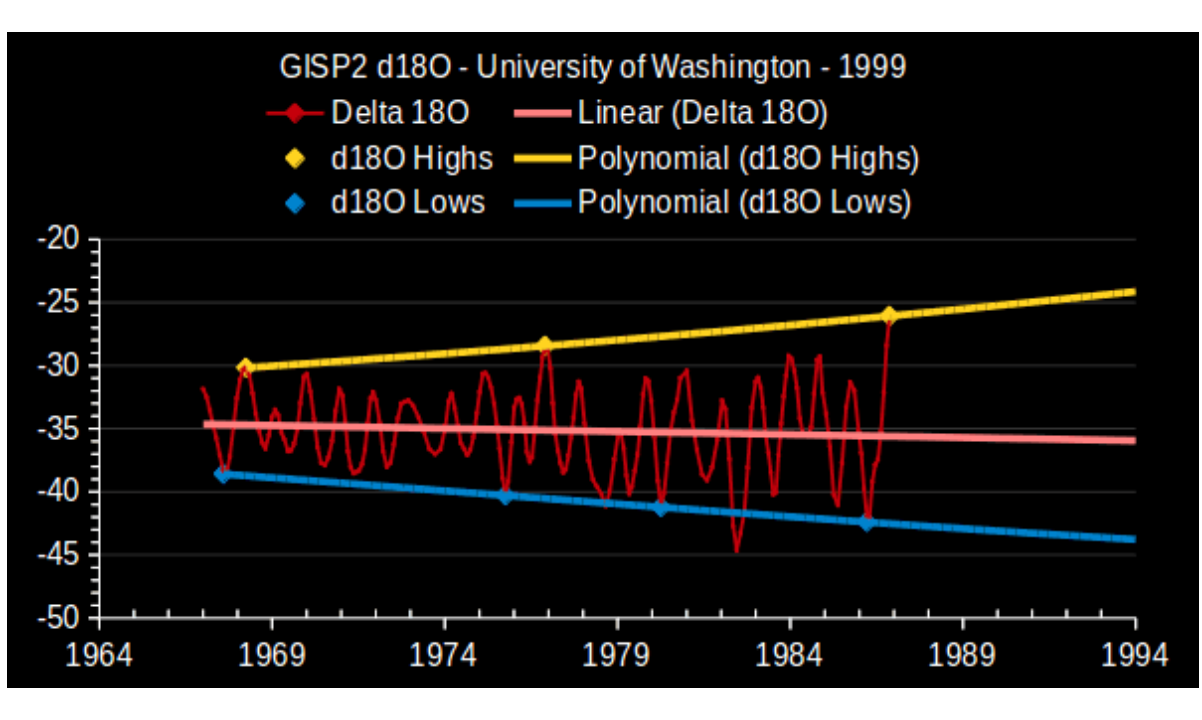
However:

It's more difficult finding a viable explanation for the gradual symmetrical squeeze in the **δ18O** value range found in the uppermost layers of the **GISP2** **ice core**.

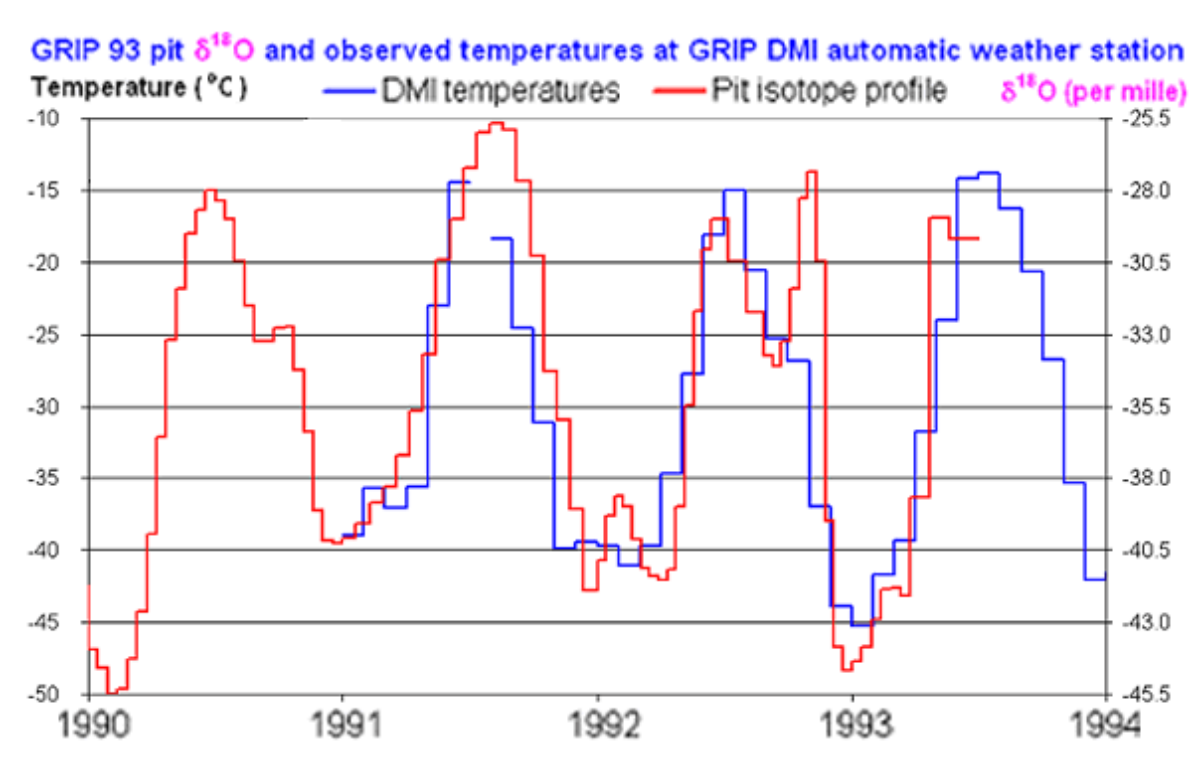


The entire continuous GISP2 delta 18O sample data set (excluding the silty ice samples)
University of Washington's Quaternary Isotope Laboratory - 5 March 1999
https://web.archive.org/web/20060517193048/http://depts.washington.edu/qil/datasets/gisp2_silty_ice.txt

The gradual symmetrical squeeze in the **δ18O** value range it most apparent in the first 20 years.

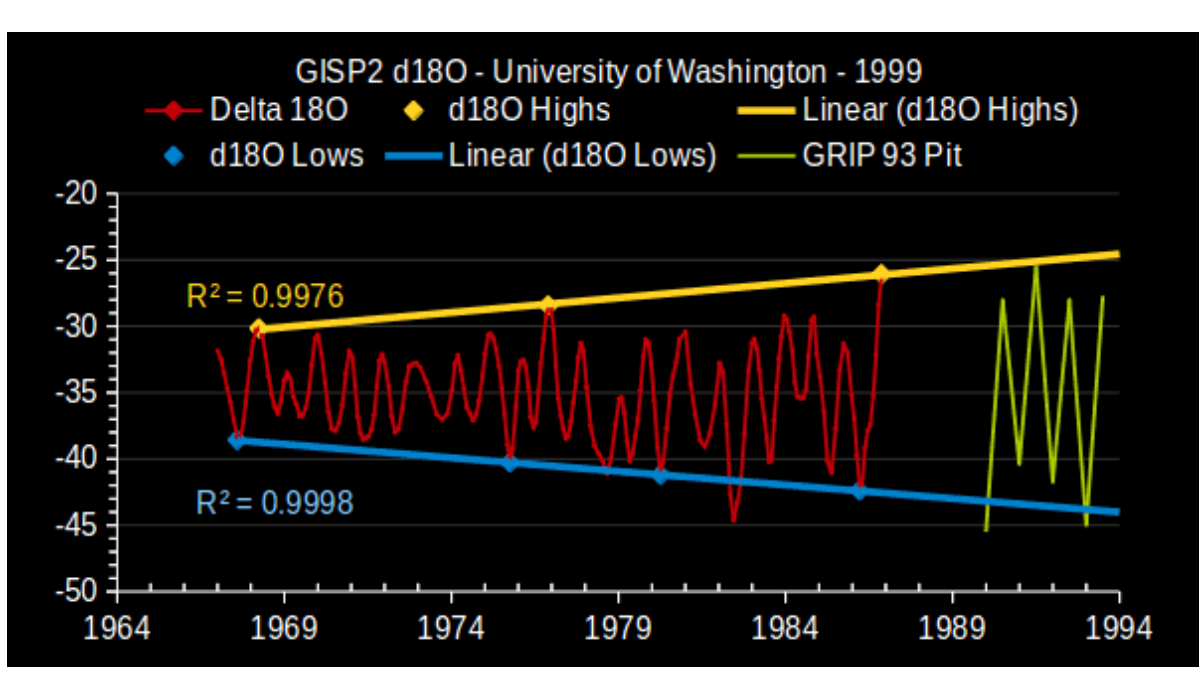


The impact of the gradual symmetrical squeeze at the top of the **GISP2** **ice core** can be better understood by including surface **δ18O** data from the nearest drill site on the **Greenland Ice Sheet**.



Greenland and North Atlantic climatic conditions during the Holocene
Bo Møllesøe Vinther - Ph.D. Dissertation - University of Copenhagen - 2006
https://web.archive.org/web/20130625080014/http://www.iceandclimate.nbi.ku.dk/publications/theses/PhD_Afhandling_Bo_Vinther_ny.pdf/

The **GRIP** data suggests the **GISP2** **Summer Highs** were **cooler** by [about] **10º C** in 1967
while the **GISP2** **Winter Lows** were **warmer** by [about] **10º C.**



The mainstream explanation for this **strong smoothing** primarily focuses upon **diffusion.**

Another complication for seasonal changes arises from **diffusion** of water molecules in the ice lattice and in the open pore space of the firn column. This **leads to a strong smoothing of the δ-record** which is most pronounced for low accumulation sites.

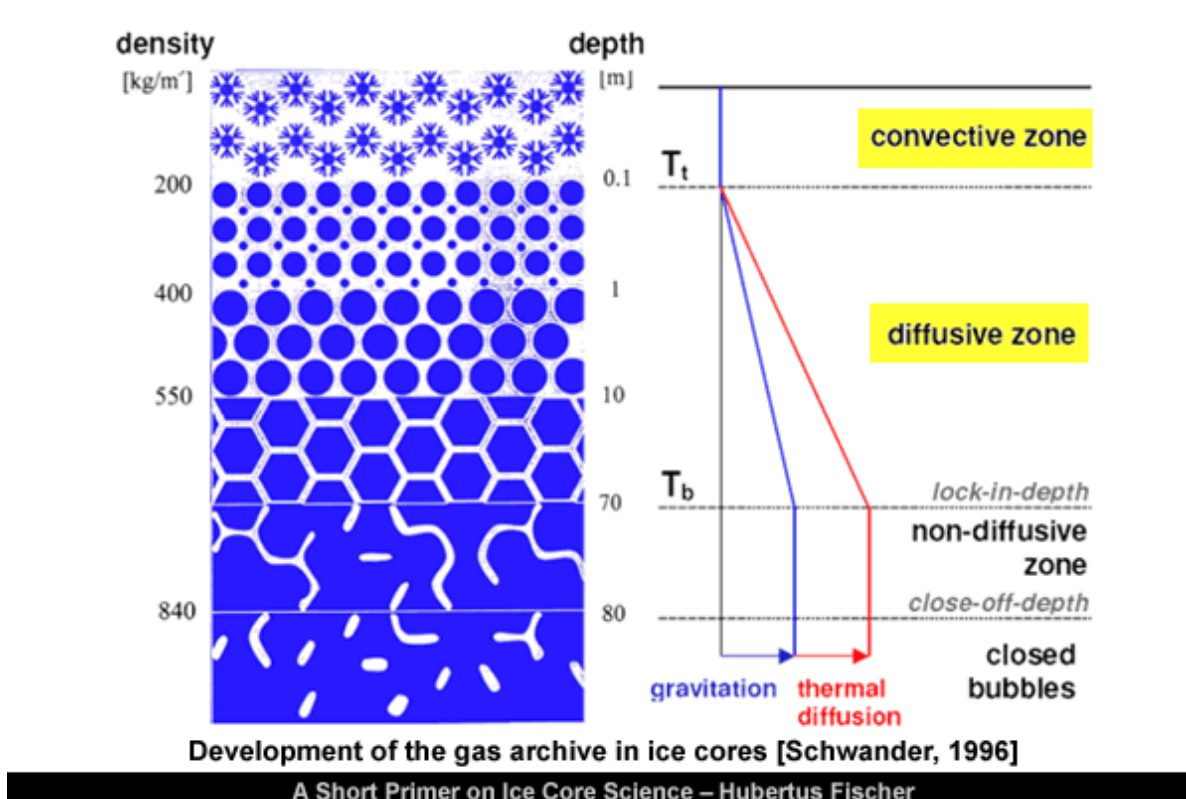
A Short Primer on Ice Core Science - Hubertus Fischer - 2009
International Glaciological Society - Karthaus Summer School
https://www.igsoc.org/event/24th-karthaus-summer-school-ice-sheets-and-glaciers-in-the-climate-system

Diffusion is the **net movement** of anything generally **from** a region of **higher concentration** **to** a region of **lower concentration.**

Wikipedia - Diffusion

On the one hand:

The mainstream asserts **δ18O** **smoothing** **stops** at a depth of between **60** and **80 metres**.



Development of the gas archive in ice cores [Schwander, 1996]
A Short Primer on Ice Core Science – Hubertus Fischer

A Short Primer on Ice Core Science - Hubertus Fischer - 2009
International Glaciological Society - Karthaus Summer School
https://www.igsoc.org/event/24th-karthaus-summer-school-ice-sheets-and-glaciers-in-the-climate-system

… **Greenland** ice core **δ18O** data is **smoothed** by **diffusional processes** in the **top 60 meter of the ice sheet** [Johnsen 1977a, Johnsen et al., 2000].

As the **diffusion** **dampens the annual oscillations in the** **δ18O** data, creating artificial trends in summer and winter season time series of **δ18O**, it is crucial that the **δ18O** data are corrected for diffusion before any interpretation is pursued.

Greenland and North Atlantic climatic conditions during the Holocene
Bo Møllesøe Vinther - Ph.D. Dissertation - University of Copenhagen - 2006
https://web.archive.org/web/20130625080014/http://www.iceandclimate.nbi.ku.dk/publications/theses/PhD_Afhandling_Bo_Vinther_ny.pdf/

The firn-ice transition or **pore close-off** density at **GISP2** was reached at **75-77 m** …

Physical and structural properties of the Greenland Ice Sheet Project 2 ice core: A review
A J Gow, D A Meese, R B Alley, J J Fitzpatrick, S Anandakrishnan, G A Woods, B C Elder
Journal of Geophysical Research - Volume 102 - Number C12 - 30 November 1997
https://agupubs.onlinelibrary.wiley.com/doi/10.1029/97JC00165

Below the convective zone is the **diffusive zone**, where the main gas transport mechanism is molecular diffusion.

At the base of the **diffusive zone** **is the** **non-diffusive** **or** **lock-in zone** **(LIZ)** characterized by layers of firn, some of which are permeable and some are not. At the start of the LIZ is the **lock-in depth** (LID), the depth at which **the first impermeable horizontal layers** of firn impede vertical gas exchange with the atmosphere.

The LIZ ends at the **close-off depth** beyond which **all pores are closed-off** from one another both vertically and horizontally and no gas transport exists.

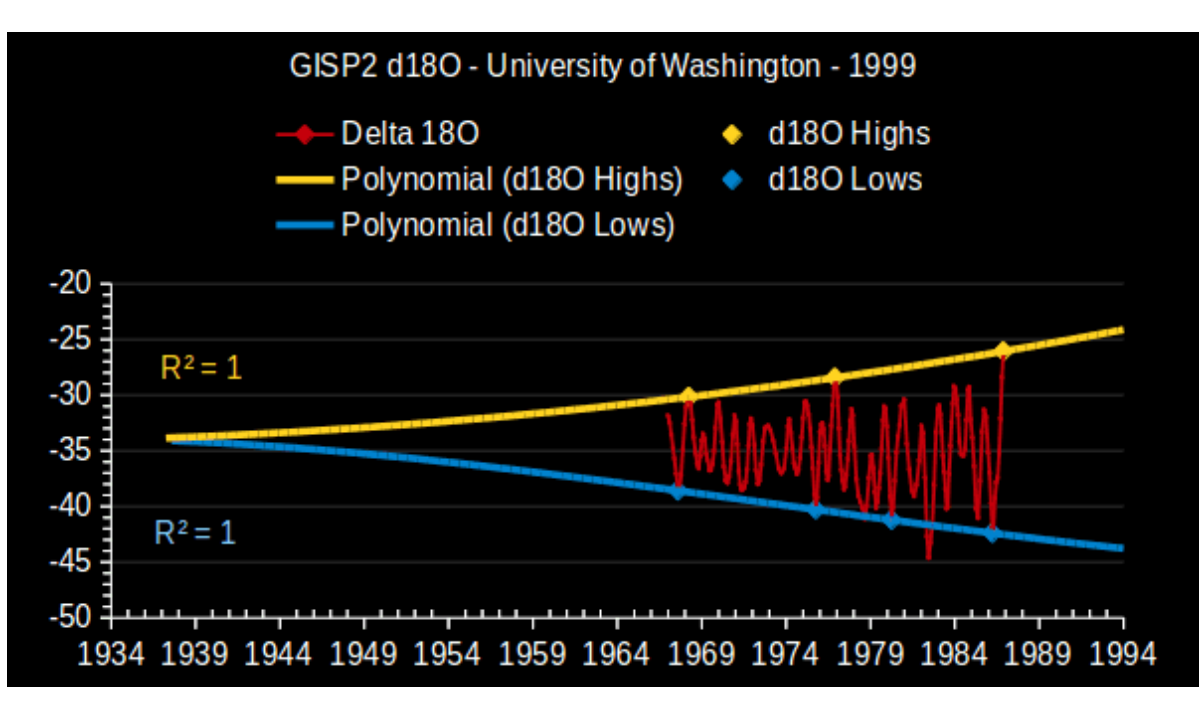
Impact of physical properties and accumulation rate on pore close-off in layered firn
S A Gregory, M R Albert, and I Baker
The Cryosphere Discussions - 7 - 2533–2566 - 2013
https://tc.copernicus.org/preprints/7/2533/2013/tcd-7-2533-2013.pdf

On the other hand:

The **δ18O** symmetrical squeeze in the **GISP2** **ice core** **stops** at a depth of about **12 metres**.

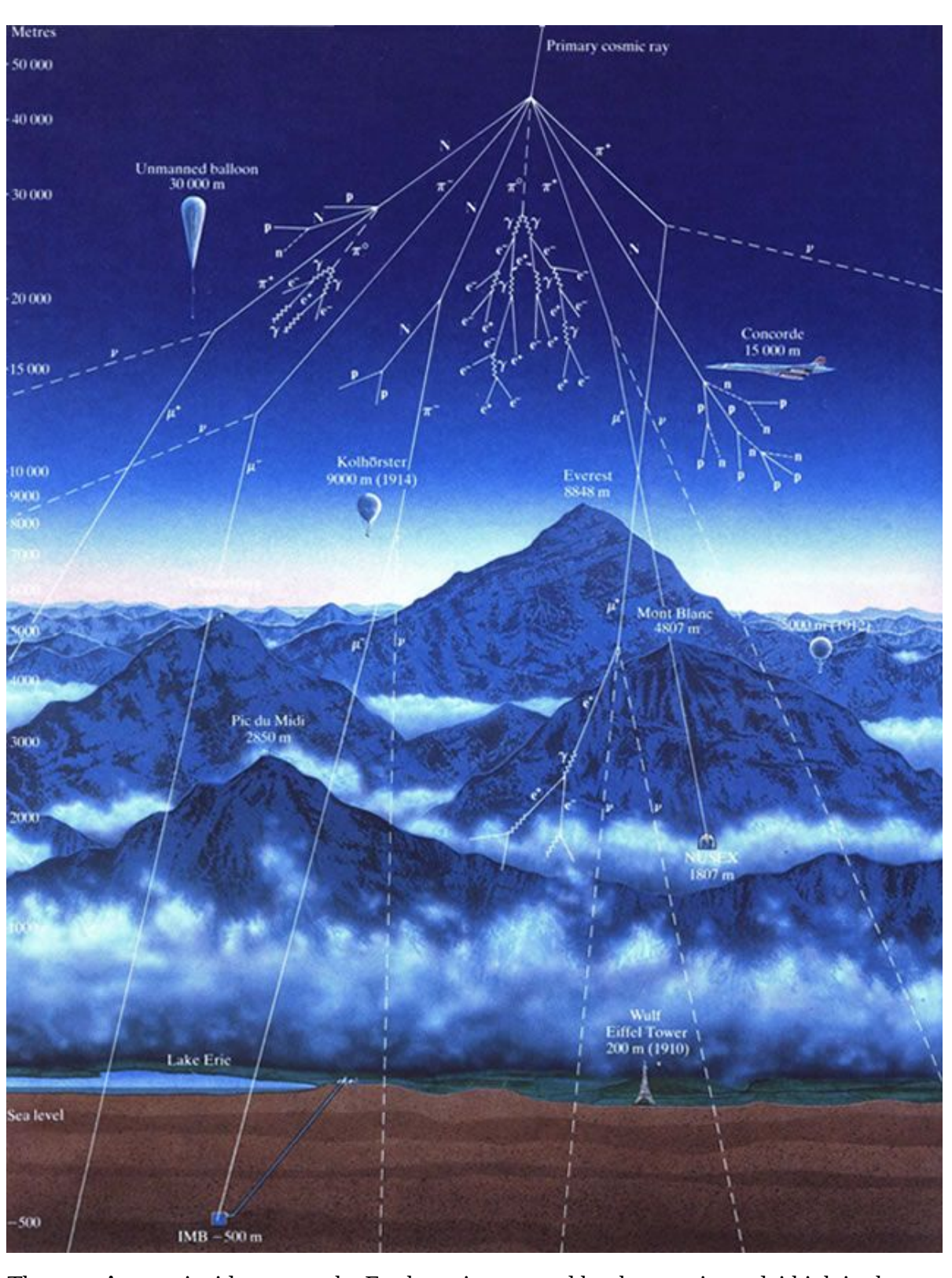
Furthermore:

If the **δ18O** symmetrical squeeze had continued then the **δ18O** would ***flat line*** below **24 metres**.



Therefore:

It appears likely **^{17}O** is produced by ***cosmic rays*** in the atmosphere and the **GISP2** **ice core** down to depth of 12 metres and this *in situ* creation of **^{17}O** ***waters down*** the concentrations of **^{18}O** and **^{16}O**.



The **cosmic rays** incident upon the Earth are intercepted by the atomic nuclei high in the atmosphere. The "blanket" of air surrounding the Earth acts as a very thick (equivalent to about 3 meters of concrete) radiation shield.

As soon as a cosmic particle reaches the atmosphere of the Earth it **collides with atmospheric nuclei (oxygen or nitrogen).** The products of this collision collide again and so on, thus producing a particle cascade, or air shower.

The more energy a primary cosmic particle possesses, the larger number of secondary particles are produced. Many of these particles reach the sea level and can be detected.

Particles originating from a single primary cosmic ray arrive at sea-level almost simultaneously.

While developing the cascade, the secondaries are spread over a large area.

This area raises along with energy of the primary cosmic ray.

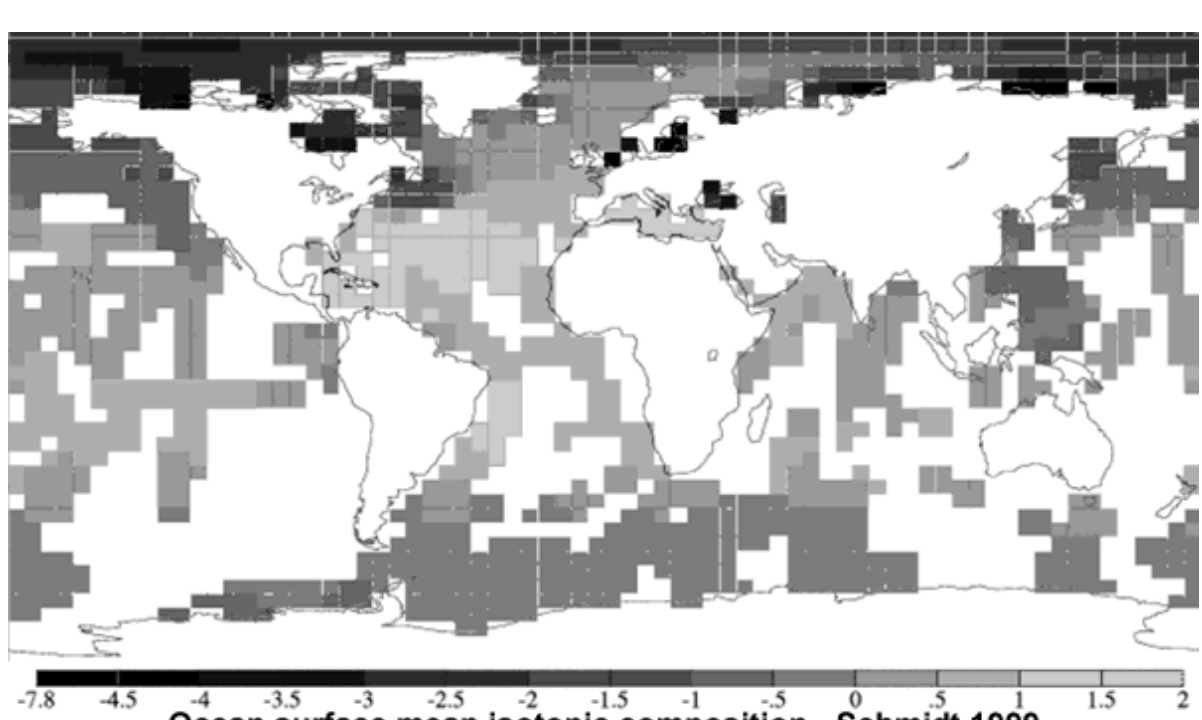
Cosmic Ray Study using Air Shower Time Coincidence Arrays
G A Chelkov, M A Demichev, and A S Zhemchugov
Dzhelepov Laboratory of Nuclear Problems
http://uc.jinr.ru/images/pdf/projects/shelkov.pdf

"Shower of Knowledge"
JINR University Centre - Moscow Region
http://uc.jinr.ru/en/shower-of-knowledge

Malaga Bay - Cosmic Ray Blues
https://malagabay.wordpress.com/category/cosmic-ray-blues/

The ***watering down*** process is enhanced by density separation [aka buoyancy aka gravity]
whereby: unconstrained **^{16}O** tends to rise above **^{17}O**
and unconstrained **^{17}O** tends to rise above **^{18}O**.

The combined effect is best demonstrated by the remarkably narrow range of **δ18O** values found in the **surface waters** **of the oceans** **except** for the **polar regions** that have “more **depleted** ratios”.



Ocean surface mean isotopic composition - Schmidt 1999
Tropospheric Transport of Water Vapour - Harald Sodemann - 2006

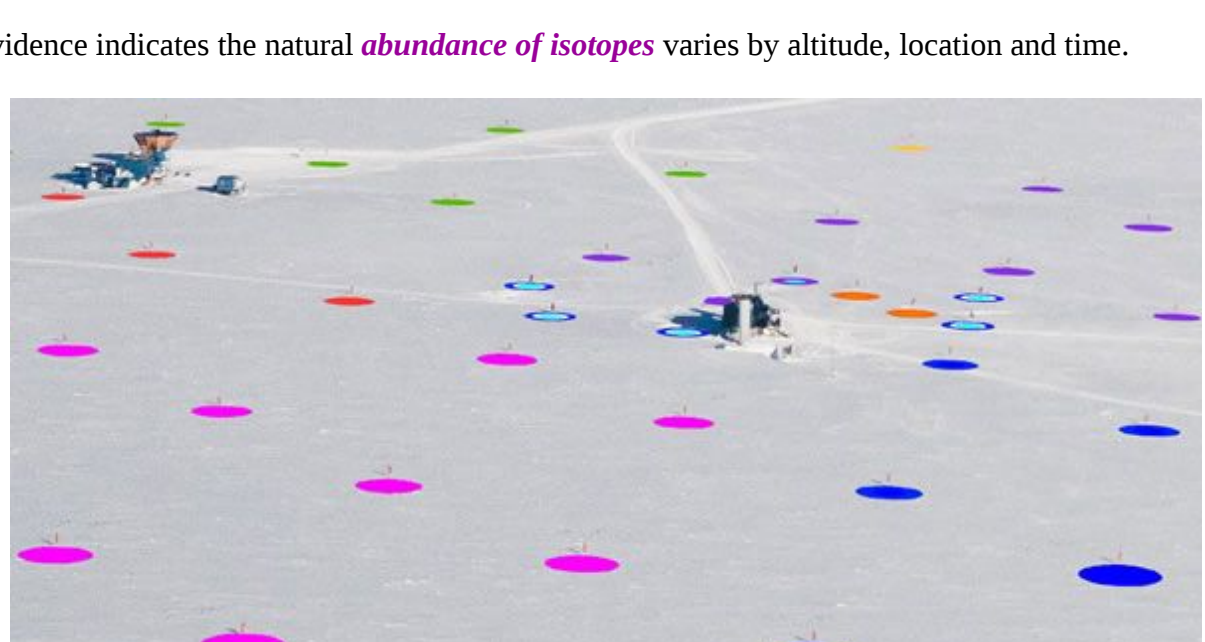
… **by definition** the mean isotopic composition of **ocean water is δ(D, ^{18}O)$_{V\text{-}SMOW}$ = 0** … **observations** of ocean **surface waters** can show isotope ratios **ranging between −6 to +3** (Schmidt 1999).

A map of the global mean distribution of **δ18O** in ocean surface waters compiled from all available data (uncorrected for season) shows **more** **depleted** **ratios towards the poles**.

Tropospheric Transport of Water Vapour
Harald Sodemann - 2006
https://www.amazon.com/dp/3832513841/

Overall:

The evidence indicates the natural ***abundance of isotopes*** varies by altitude, location and time.



IceCube Neutrino Observatory in Antarctica with drilled holes superimposed
Composition by: Jamie Yang, WIPAC. Photo by: Haley Buffman, NSF

Every day, 275 million cosmic rays are detected by IceCube.

IceCube Quick Facts - University of Wisconsin–Madison
https://icecube.wisc.edu/about-us/facts/

The same can be said about a ***gin*** and ***tonic***.

Cheers!

As always:

Review the evidence and draw your own conclusions.