Camp Century ice core basal sediments record the absence of the Greenland Ice Sheet within the last million years.

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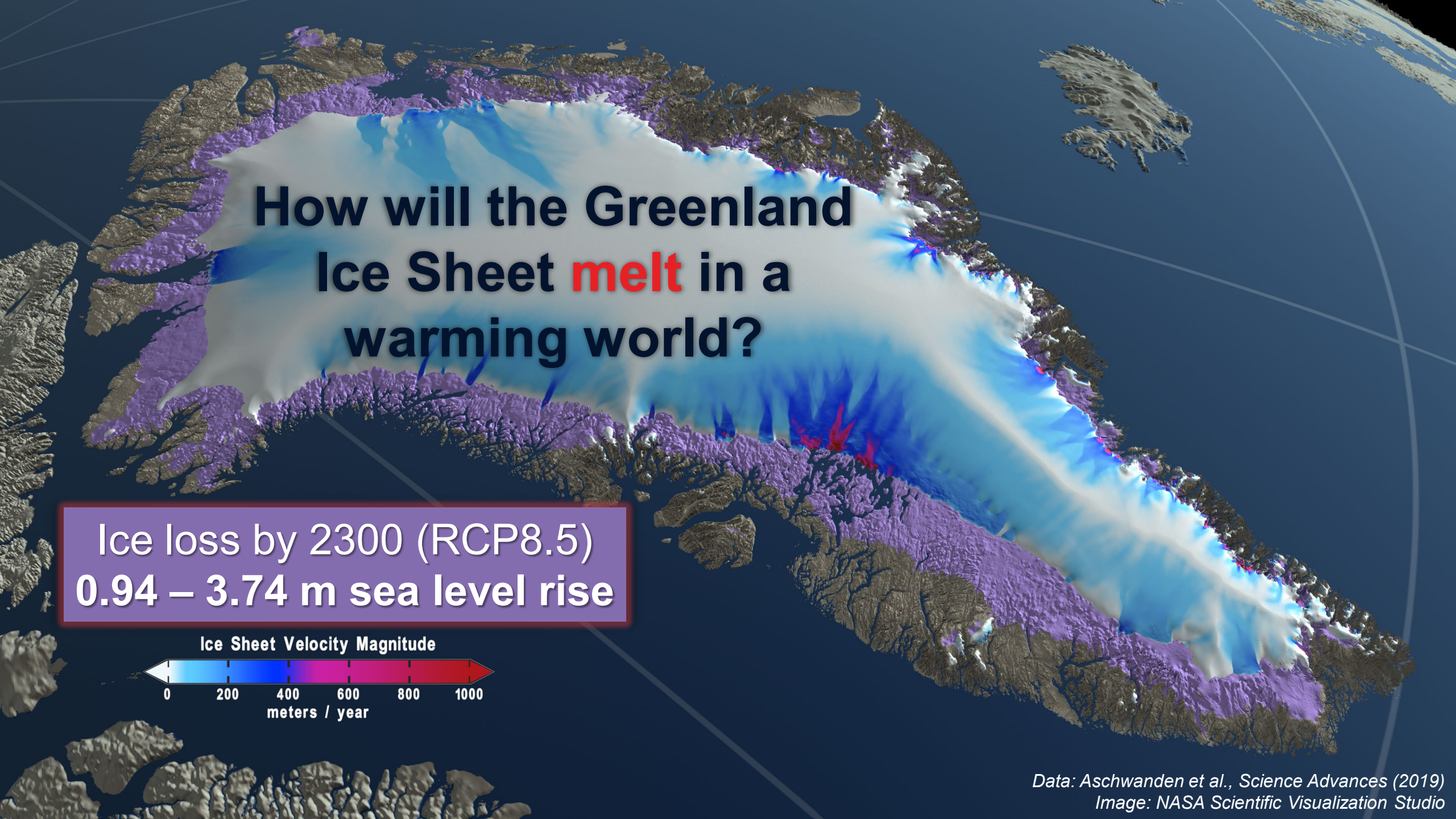
Camp Century, c. 1966, *CRREL, US Army*

EGU General Assembly 2020



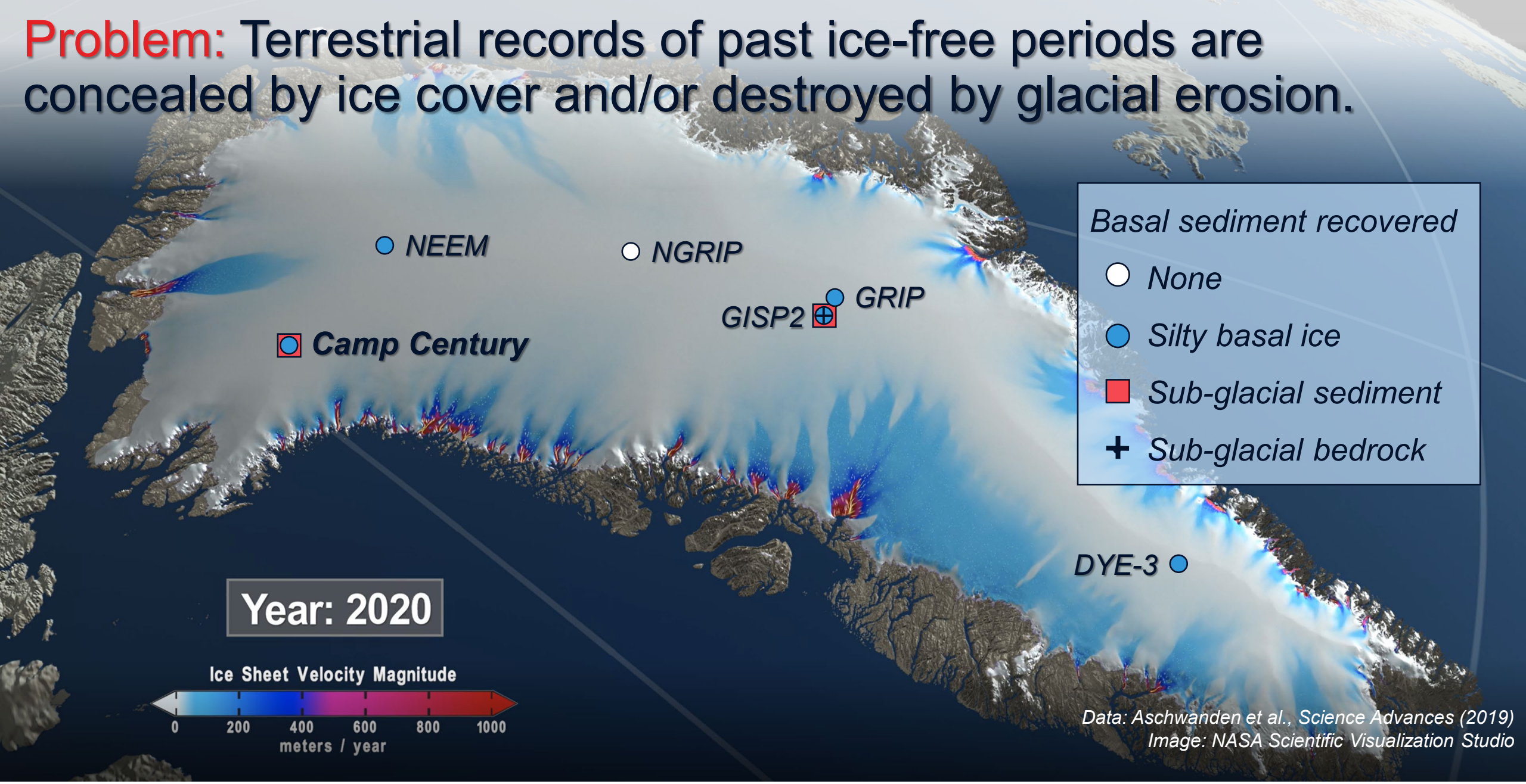
Data: Aschwanden et al., Science Advances (2019)
Image: NASA Scientific Visualization Studio

The big geological questions:

Where and when did parts of the Greenland Ice Sheet melt away in the past?

What were climate conditions like during these times in Greenland and globally?

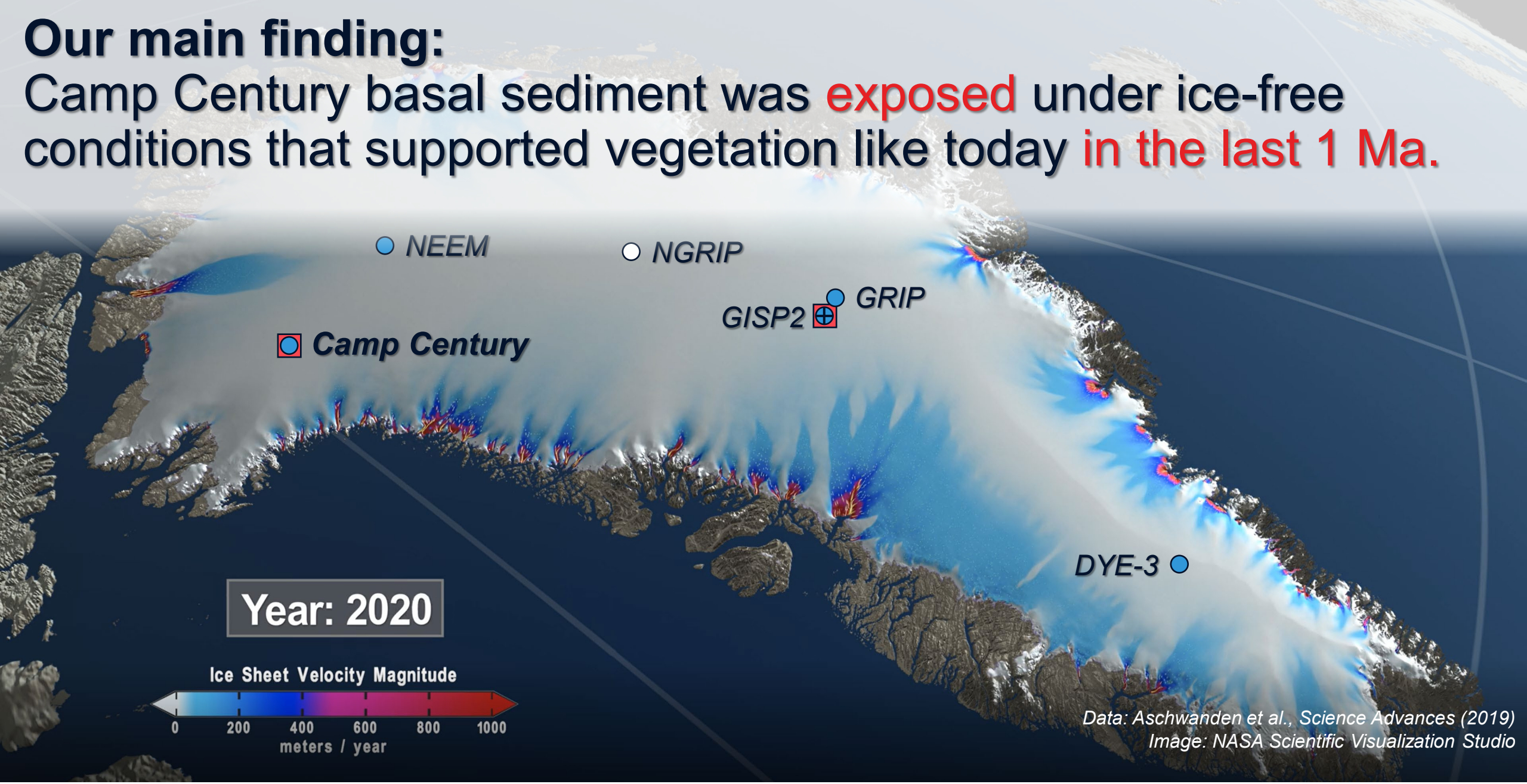
Problem: Terrestrial records of past ice-free periods are concealed by ice cover and/or destroyed by glacial erosion.



Basal materials from deep ice cores are critical, yet rare archives.

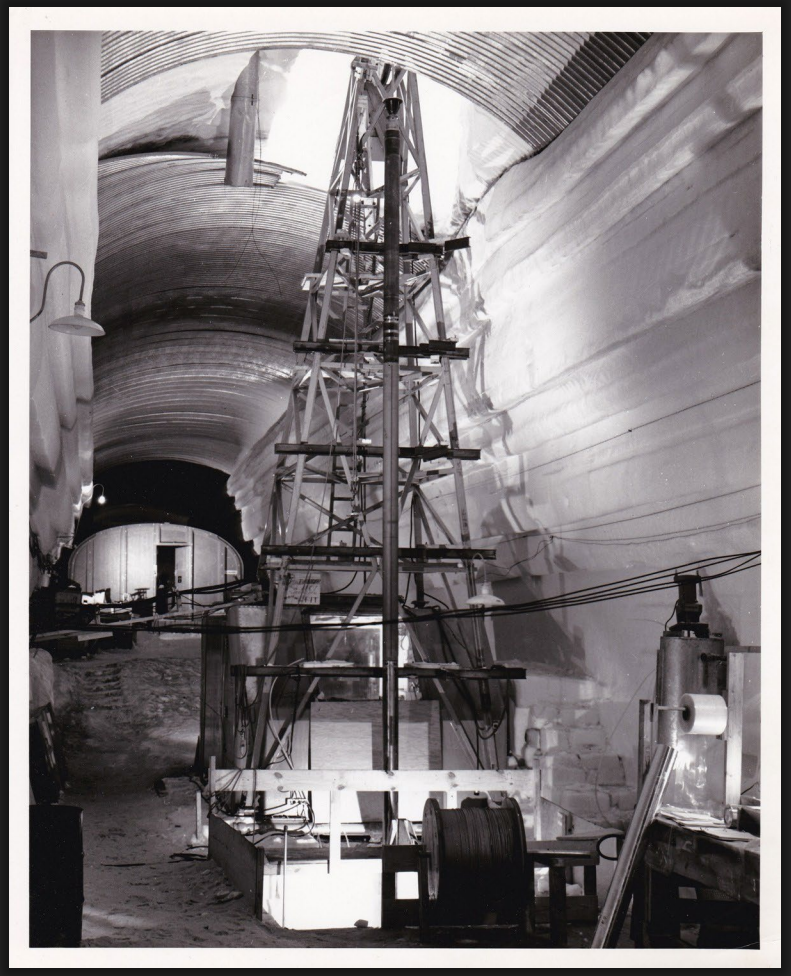
Our main finding:

Camp Century basal sediment was exposed under ice-free conditions that supported vegetation like today in the last 1 Ma.



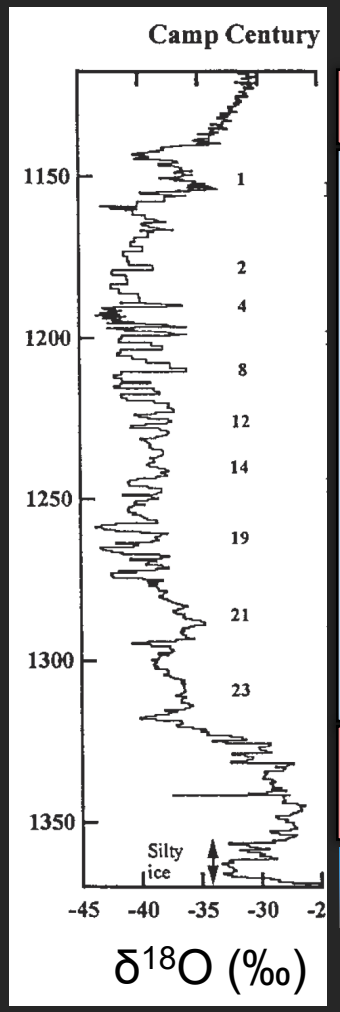
Remainder of this talk: how did we get to this initial conclusion?

Camp Century was the first ice core drilled to the base of an ice sheet and revolutionized our understanding of paleoclimate since 125 ka.



Ice core drill rig, c. 1966, CRREL, US Army

1387.5 m ice



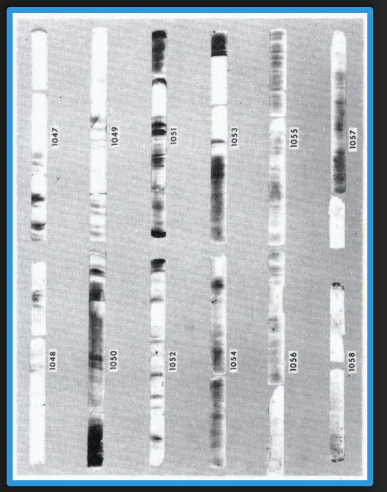
Johnsen et al., 2001

Holocene

Last Glacial

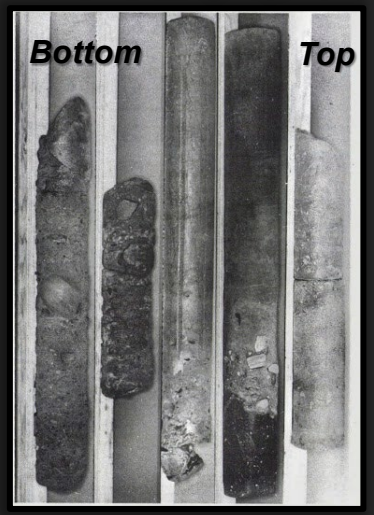
Last inter-glacial

Basal ice & sediment



Herron & Langway, 1979

15.7 m of debris-laden ice



Fountain et al., 1981

3.55 m of frozen diamict

The basal ice & sediment were incompletely studied and then *lost!*

Basal ice & sediment were re-described last summer. Two basal sediment samples were cut for this study.

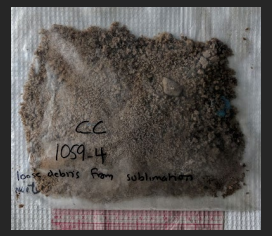
1059-4: 0-0.1 m

TOP

10 cm

9 cm

1059-4 loose sediment replicate analyses



1063-7: 3.38-3.51 m

TOP

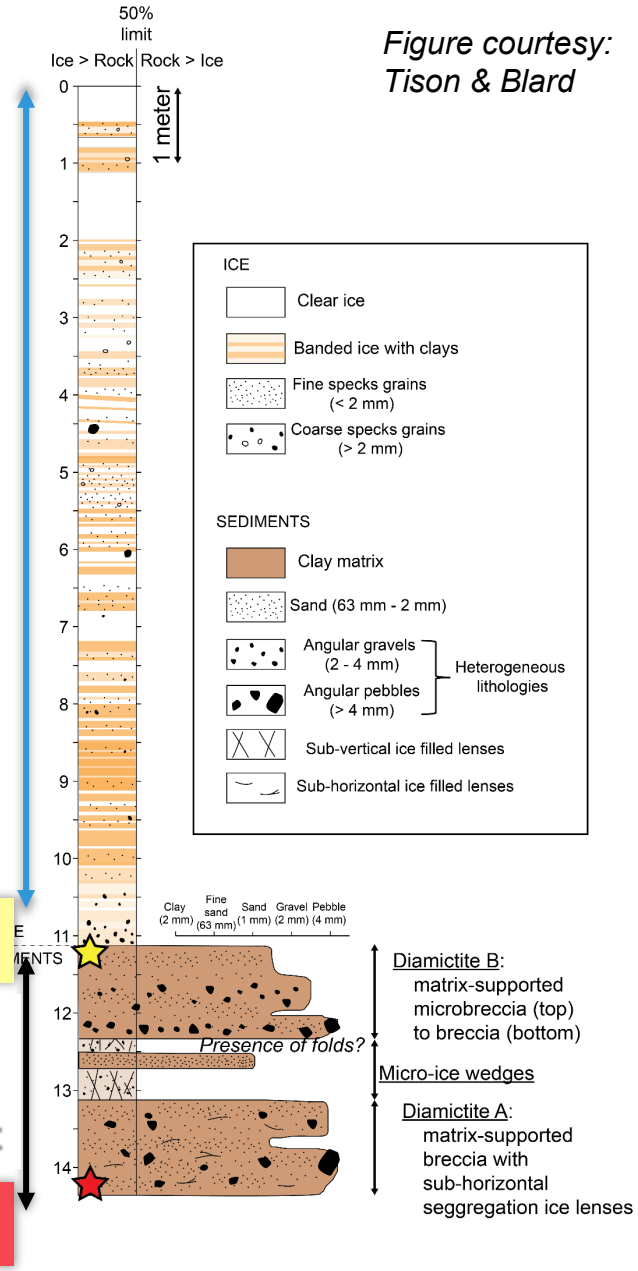
12.6 cm

9 cm

We analyzed the upper- and lower-most basal sediments.

Camp Century basal ice & sediment log

Figure courtesy: Tison & Blard



32 analyses, only ~750 g of sediment.

Paleoclimate

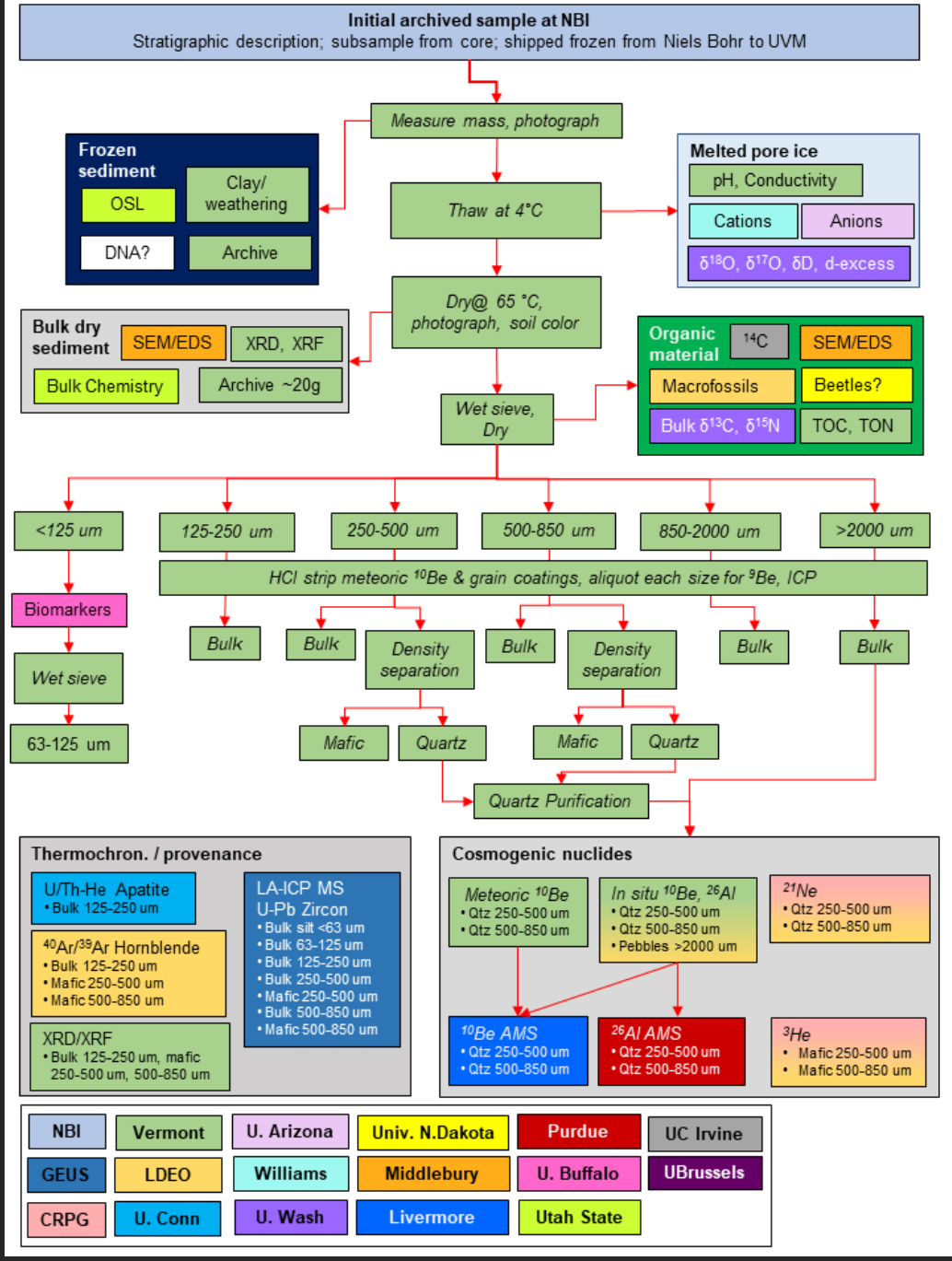
- Pore ice stable isotopes
  - $\delta^{18}O$, $\delta^{17}O$, δD, D-excess

Paleoenvironmental conditions

- Macrofossil assemblages
- $\delta^{13}C$, $\delta^{15}N$ – organic matter
- Lipid biomarkers

Exposure & burial history

- $\Delta^{14}C$ organics
- Cosmogenic nuclides
  - In situ $^{10}Be_{qtz}$, $^{26}Al_{qtz}$, $^{21}Ne_{qtz}$
- Optically stimulated luminescence



Sample processing workflow

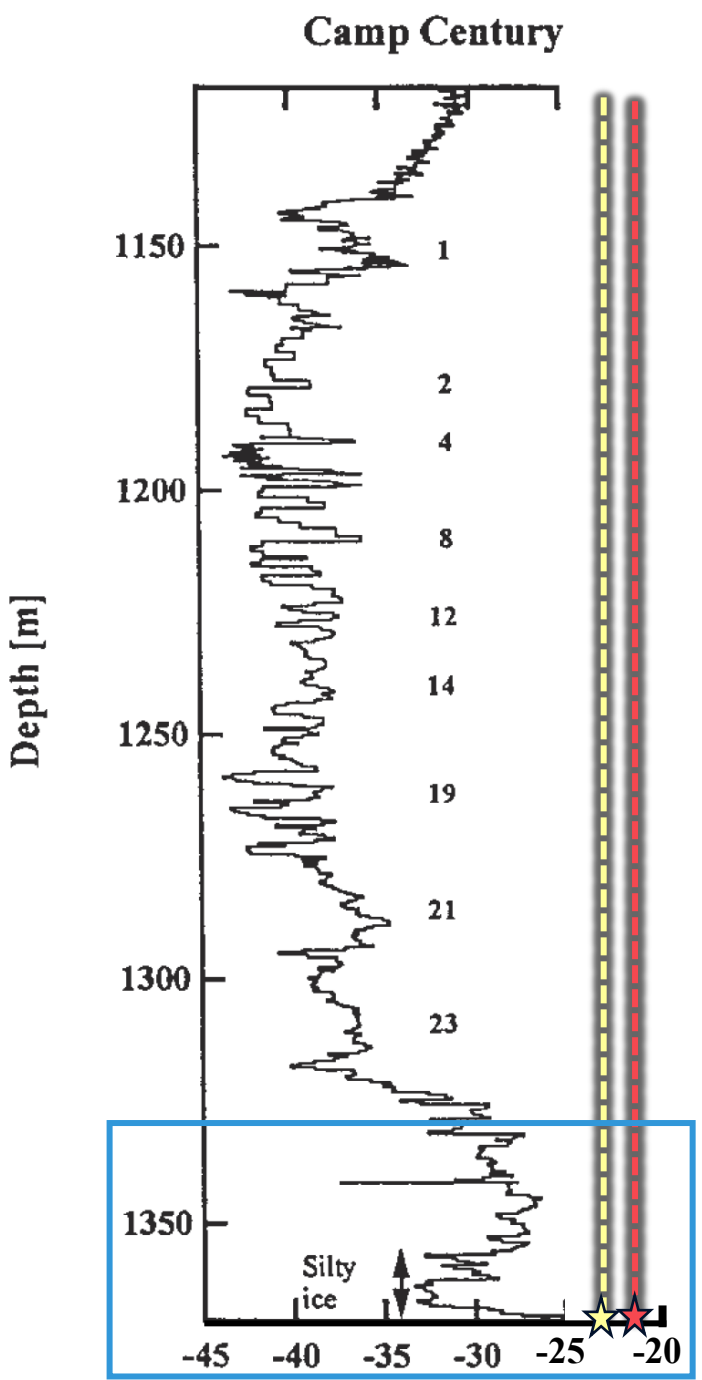
Results: stable isotopes of pore ice in sediment

Sample	$\delta^{18}O$ (‰)	^{17}O excess (per meg)	δD (‰)	D-excess (‰)
Upper 1059-4	-23.06 ± 0.08	35 ± 12	-180.14 ± 0.70	4.3 ± 0.8
Lower 1063-7	-21.49 ± 0.08	84 ± 16	-158.53 ± 0.36	13.4 ± 0.4

Analyses by E. Steig

- $\delta^{18}O$ values are enriched
- ^{17}O-excess resemble modern precipitation at NEEM & Camp Century
- δD similar to other cores
- D-excess in 1059 – evaporation and refreezing?

Johnsen et al., 2001

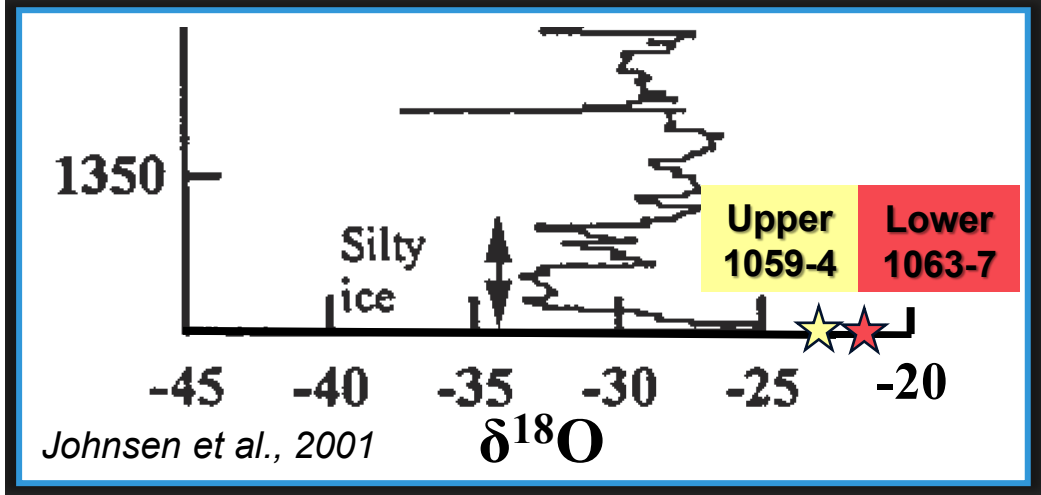


$\delta^{18}O$ of pore ice is enriched relative to all overlying glacier and silty ice (<-25 ‰).

- Mean $\delta^{18}O$ difference with today: +7‰
- ~~Interpreted as temperature:~~
  - ~~~10°C warmer than present.~~

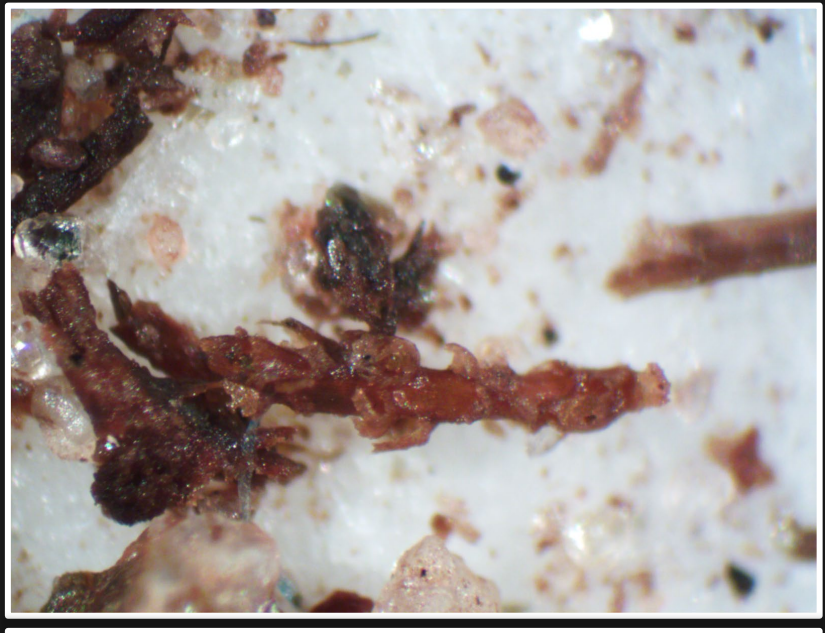
Too warm!

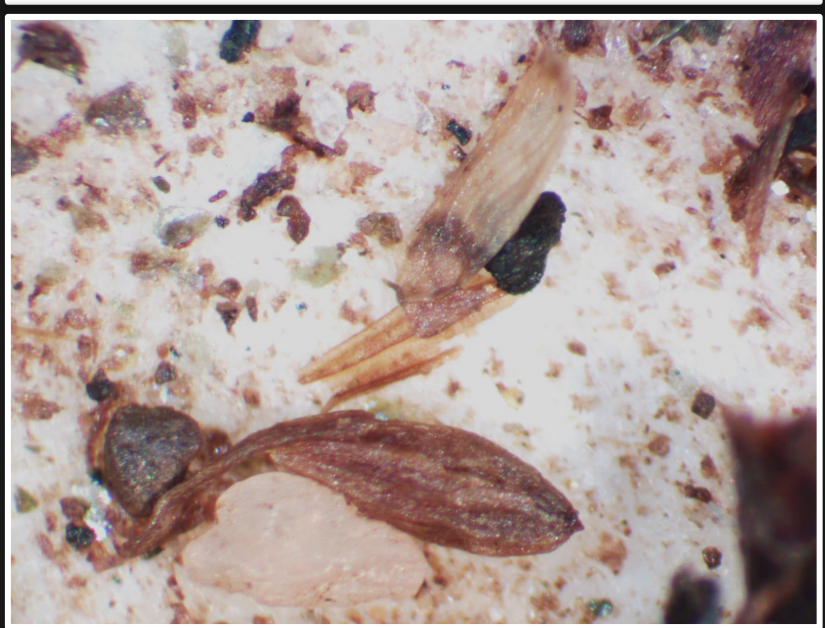
- Interpreted as elevation:
  - 1000-1600 m lower than present.
  - Ice thickness at Camp Century: 1388 m



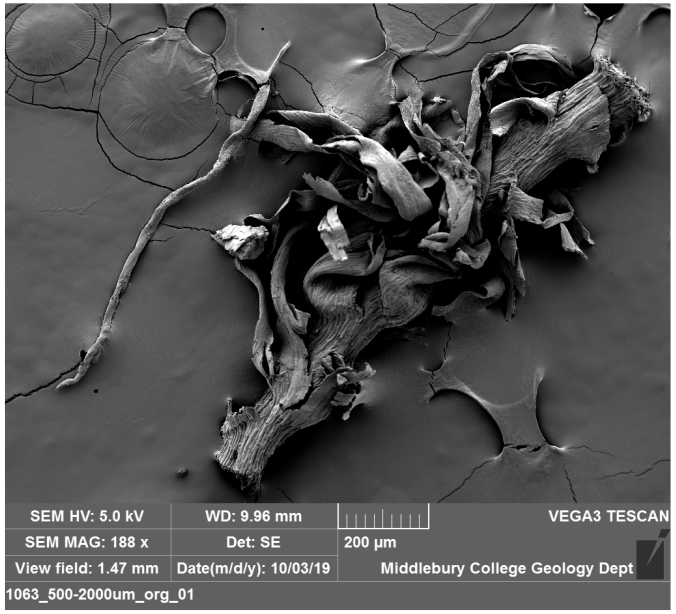
Significance: Pore ice $\delta^{18}O$ consistent with ice-free conditions

We started wet sieving…and found **macrofossils!**





Micrographs



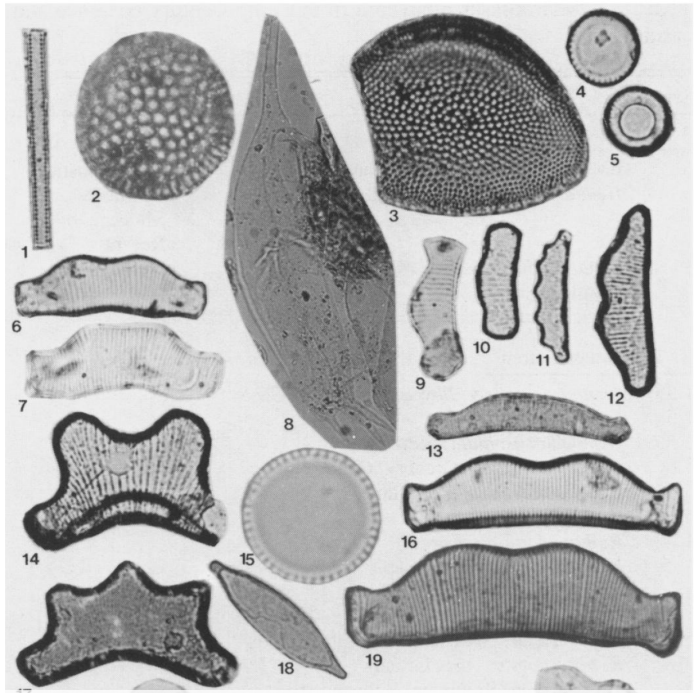
SEM images (Middlebury)

ARCTIC
VOL. 39, NO. 4 (DECEMBER 1986) P. 304-308

Do Diatoms beneath the Greenland Ice Sheet Indicate Interglacials Warmer than Present?[1]

DAVID M. HARWOOD[2]

(Received 2 July 1985; accepted in revised form 11 July 1986)

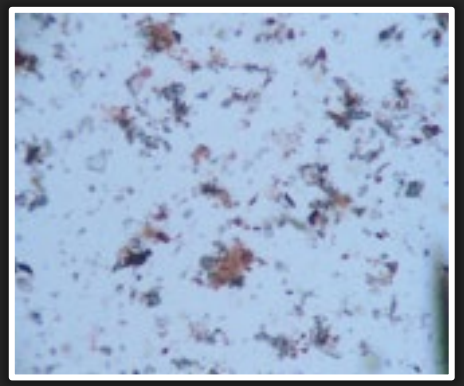


- Freshwater diatoms in silty ice & sediment from a shallow pond
- Windblown marine diatoms

Harwood, 1986

Pollen has been elusive, but we identified several macrofossils from a terrestrial ecosystem.

Cenococcum geophilum



Cenococcum geophilum

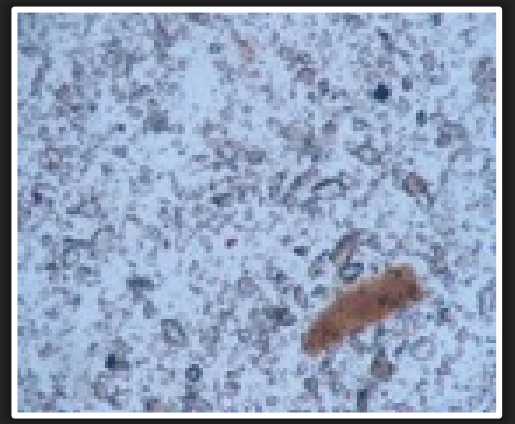
Tomenthypnum nitens?

Tomenthypnum nitens?

Tomenthypnum nitens (?)

Polytrichum juniperinum

Polytrichum juniperinum



Pollen stomate?

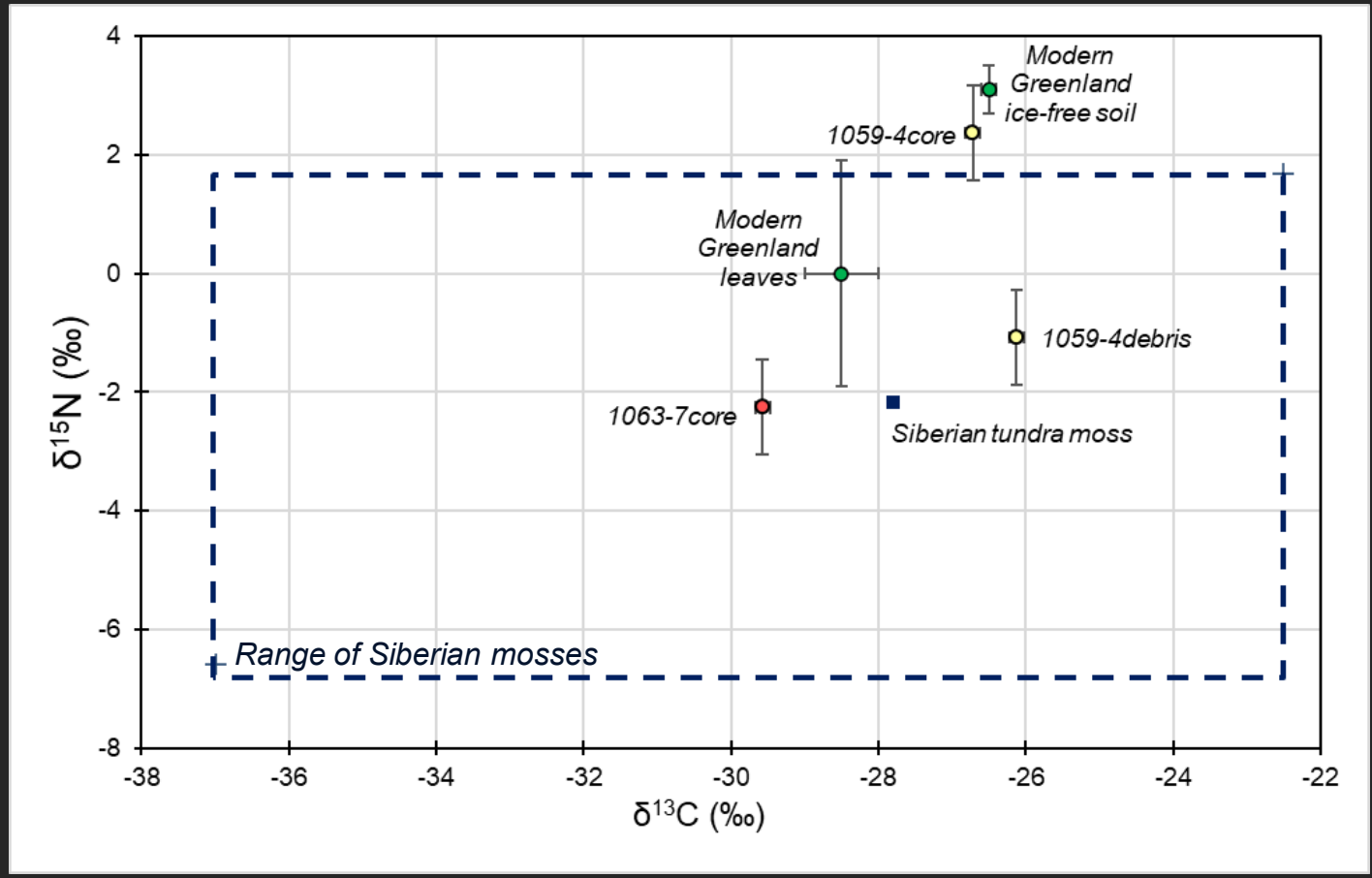
Photos courtesy D. Peteet

Identified macrofossils suggest a dry environment, possibly calciphile.

Organic material geochemically resembles modern Greenland and Arctic tundra vegetation.

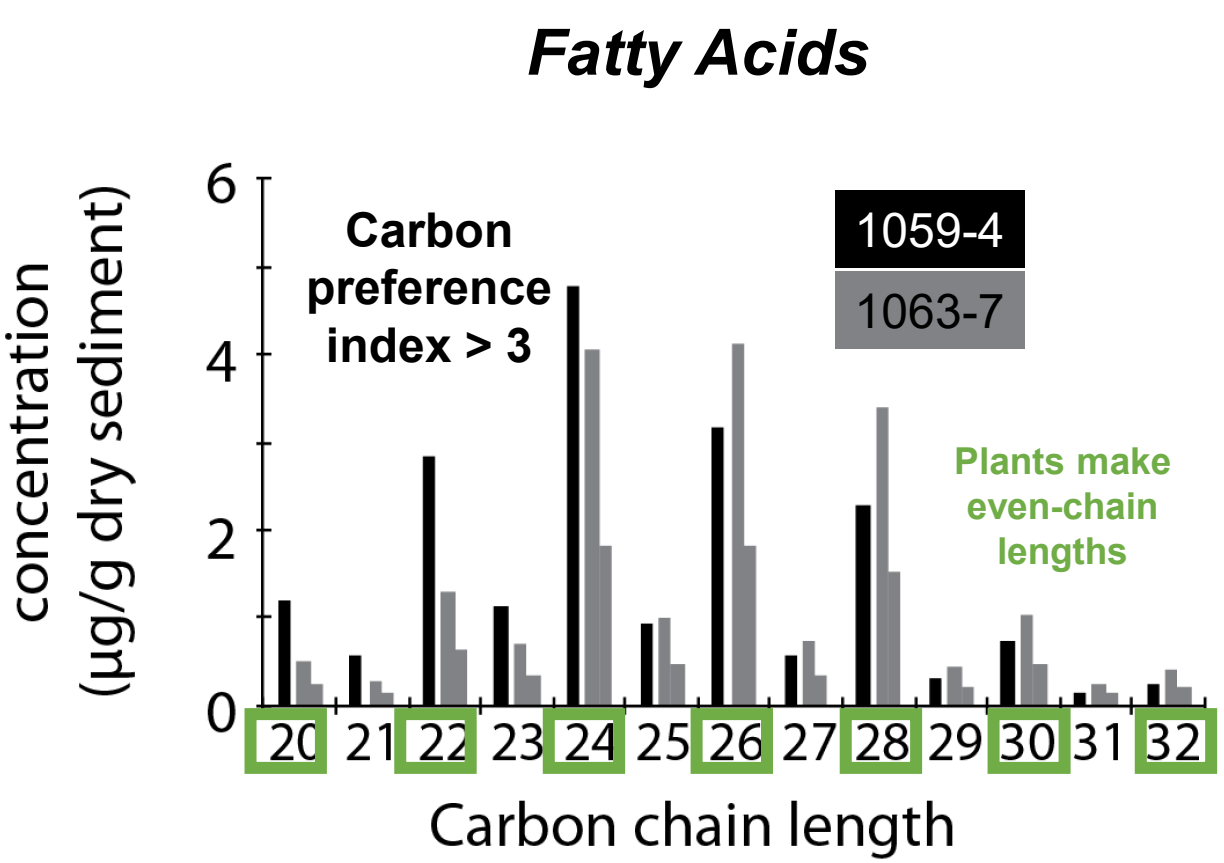
Sample	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±
1059-4 core	-26.7	0.1	2.4	0.8
1059-4 debris	-26.1	0.1	-1.1	0.8
1063-7core	-29.6	0.1	-2.3	0.8

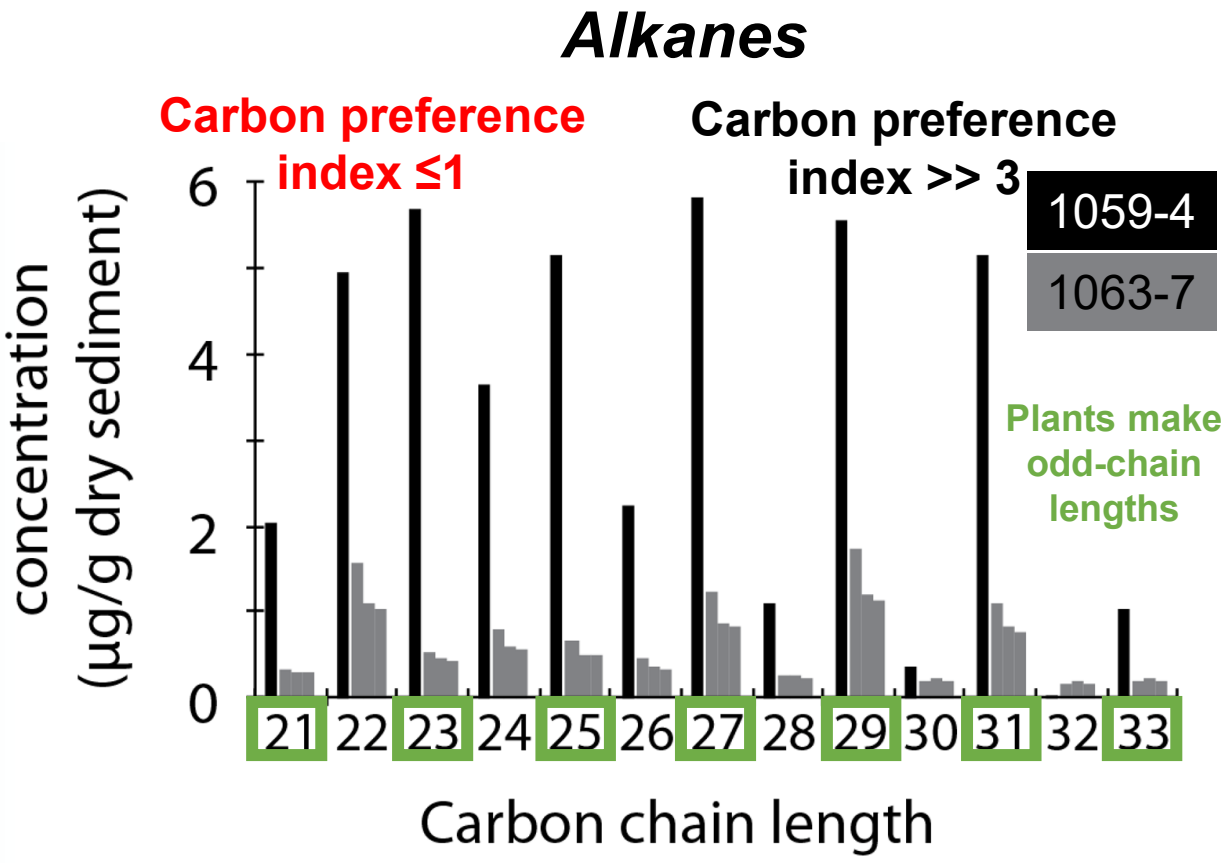
Sample	TOC (%)	TON (%)	C/N
1059-4 core	20.9	1.3	16.4
1059-4 debris	2.1	0.1	25.9
1063-7core	47.7	0.9	53.5



Greenland soil and leaves: Schaeffer et al., 2013
Siberian mosses: Zibulski et al., 2016

Biomarkers (leaf waxes) resemble modern Greenland vegetation.





Analyses & figures by E. Thomas & O. Cowling

Leaf wax concentrations are higher in the upper diamict than the lower diamict. Organic molecules are well preserved.

How old is the sub-glacial sediment?

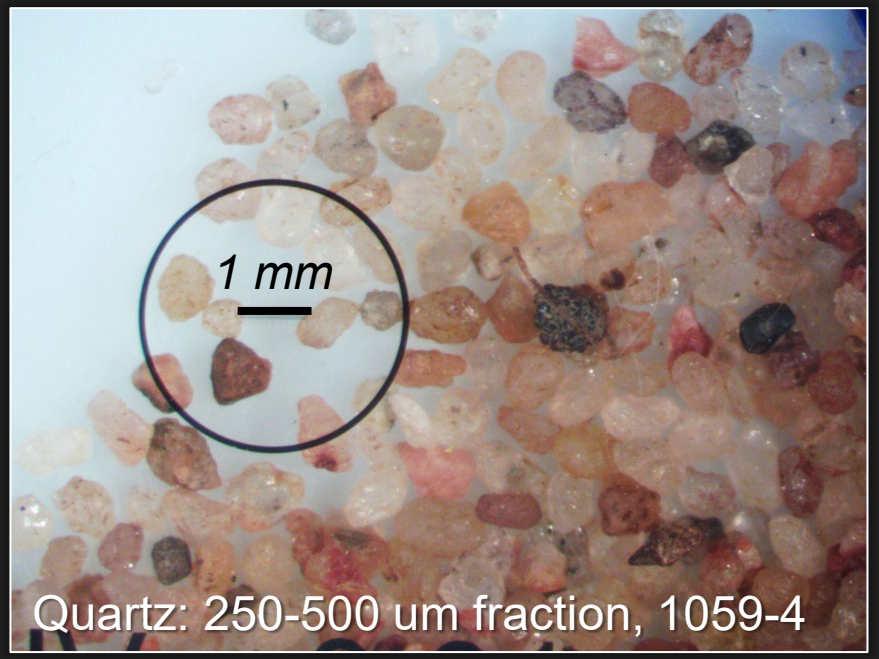
Radiocarbon dating

- Twig & woody tissue yield infinite ages.
- The sediment is >50 kyr BP

Organic material in 1059

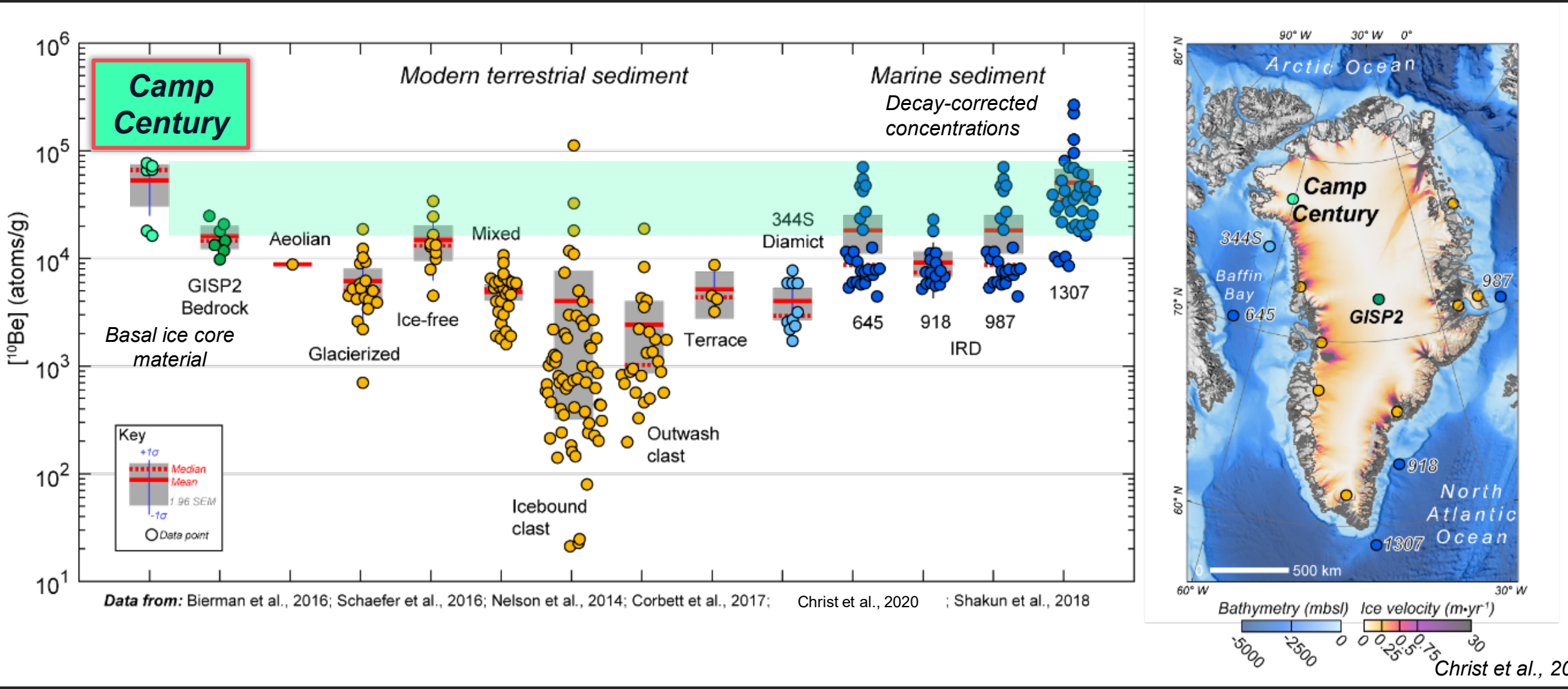
Exposure & burial history

- Optically stimulated luminescence
  - 1063 last exposed >600 kyr BP
- Cosmogenic nuclides
  - In situ $^{10}Be_{qtz}$, $^{26}Al_{qtz}$
    - $^{21}Ne_{qtz}$ in progress



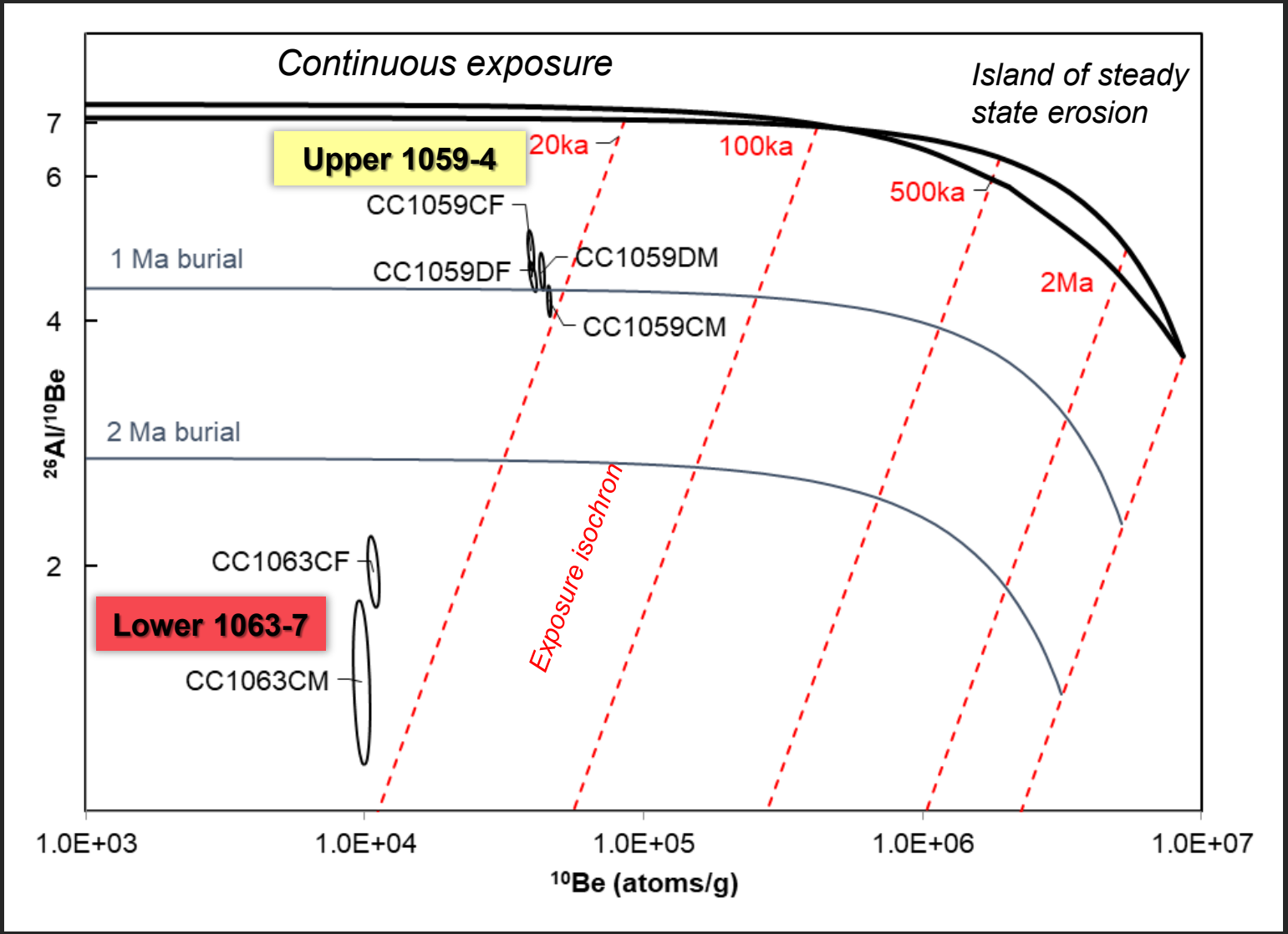
Quartz: 250-500 um fraction, 1059-4

Results: ^{10}Be concentrations are on the order of 10^4 atoms/g.



Comparable, but greater than GISP2 bedrock & older IRD in marine cores.
Greater than Pleistocene marine diamict and modern terrestrial sediment.

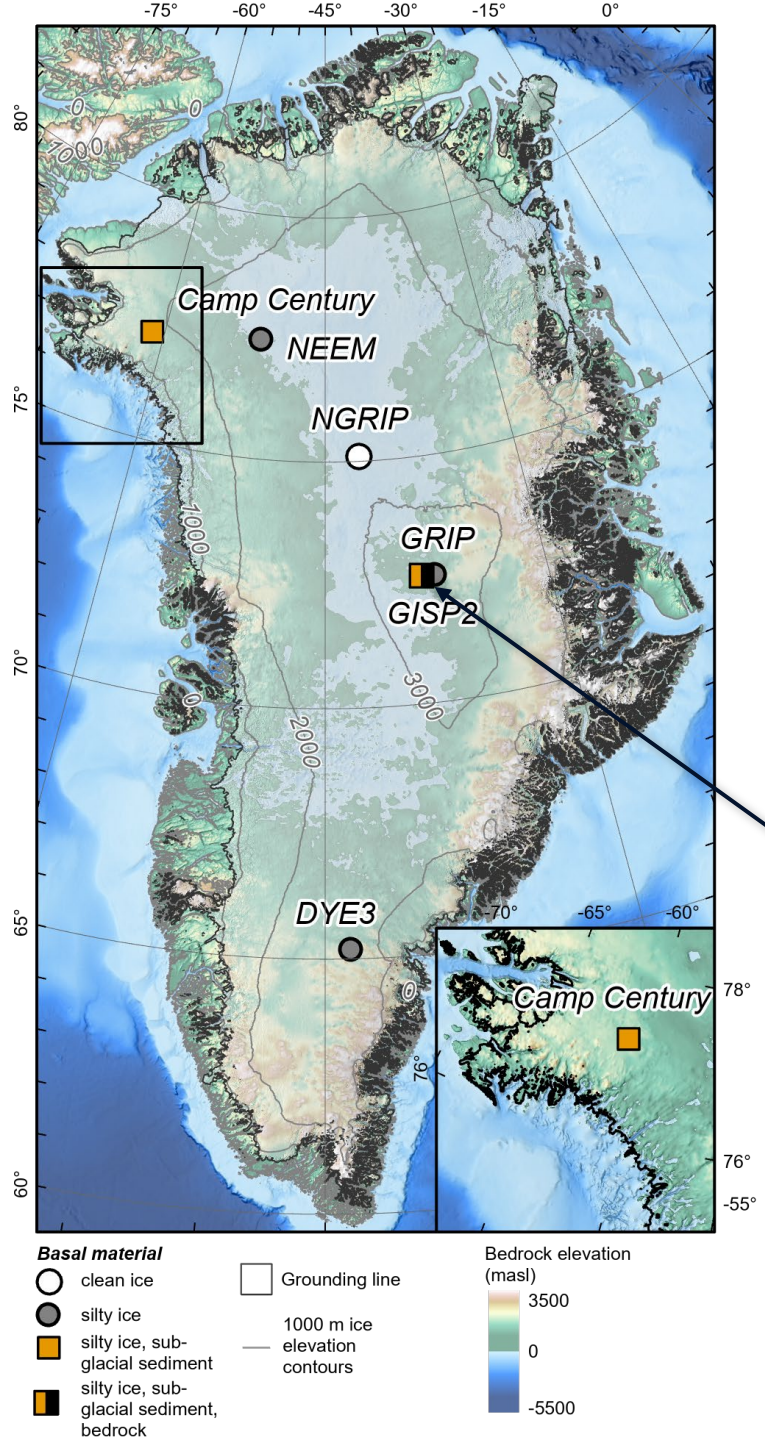
$^{26}Al/^{10}Be$ ratios indicate the upper and lower basal sediments have different and complex burial histories.



Upper sediment (1059-4)
- <20 kyr exposure
- <1 Myr burial

Lower sediment (1063-7)
- ~15 kyr exposure
- >2 Myr burial

Sediment in the upper diamict was exposed within the last million years.



Our main finding:

Camp Century was ice-free and supported vegetation like today within the last 1 Myr.

- Pore ice δ18O enriched relative to overlying ice
- Biomarkers and macrofossils resemble modern vegetation
- $^{26}Al/^{10}Be$ burial age indicate upper sediment exposed within last 1 Myr, lower sediment buried >2 Myr

LETTER *Schaefer et al., 2016*

doi:10.1038/nature20146

Greenland was nearly ice-free for extended periods during the Pleistocene

Joerg M. Schaefer[1,2], Robert C. Finkel[1,3], Greg Balco[4], Richard B. Alley[5], Marc W. Caffee[6], Jason P. Briner[7], Nicolas E. Young[1], Anthony J. Gow[8] & Roseanne Schwartz[1]

Corroborates findings from GISP2 sub-glacial bedrock

Implications:

The Greenland Ice Sheet was largely absent at some point in the last 1 Myr and dynamic despite Pleistocene [CO_2] <300 ppm.

Questions or comments?

Contact Andrew Christ

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Camp Century, c. 1966
CRREL, US Army