Ice core drilling at a temperate glacier site: Combatant Col Mt. Waddington, BC, Canada (2006, 2010, 2023)

Peter Neff, Eric Steig, Brian Menounos, Julia Andreasen, Bridget Hall, Doug Clark, Elizabeth Morton, Jess Ackermann, Jim Koehler, Bella Bergeron

Hakai
Science on the Coastal Margin

NSF 2002441, 2001961, 0902392, 0902240, 0902734, 0903124

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Ice core drilling at a temperate glacier site: Combatant Col Mt. Waddington, BC, Canada (2006, 2010, 2023)


A Hawkins photo

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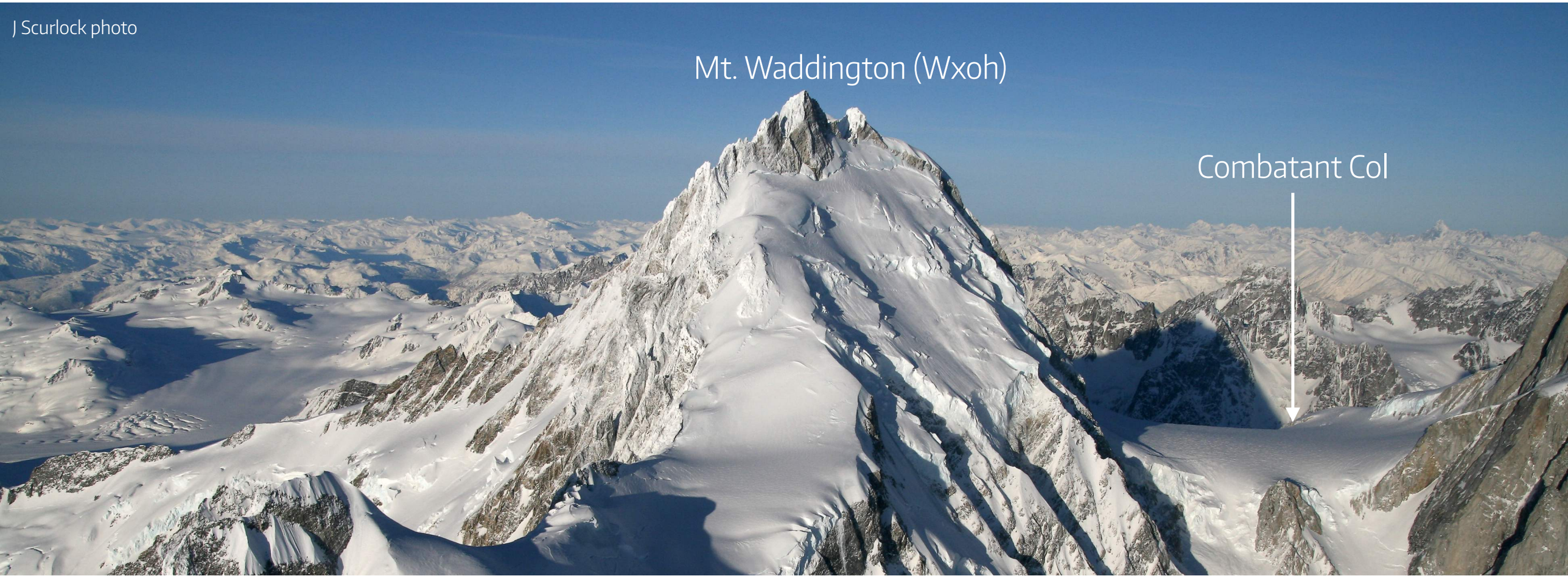

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3000 m a.s.l. | ~240 m thick | 0.5 km²

~ -5ºC mean annual temp

4–7 m/yr ice-equiv. snow accumulation

Firn aquifer at ~50 m firn-ice transition

2006
NSF SGER

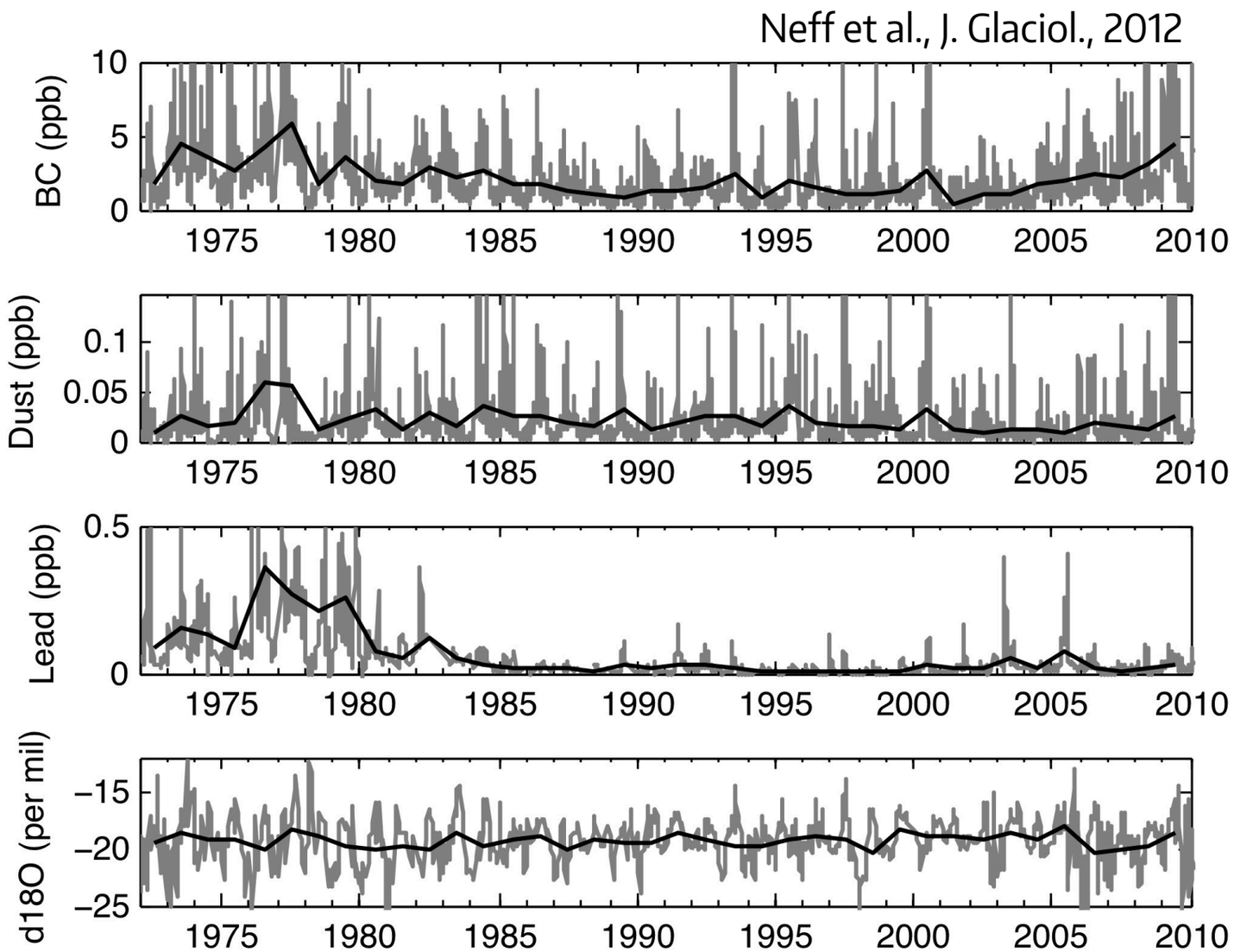
65 m

Site exploration led by Eric Steig & others since 2005

2010
NSF P2C2

141 m

2010 core

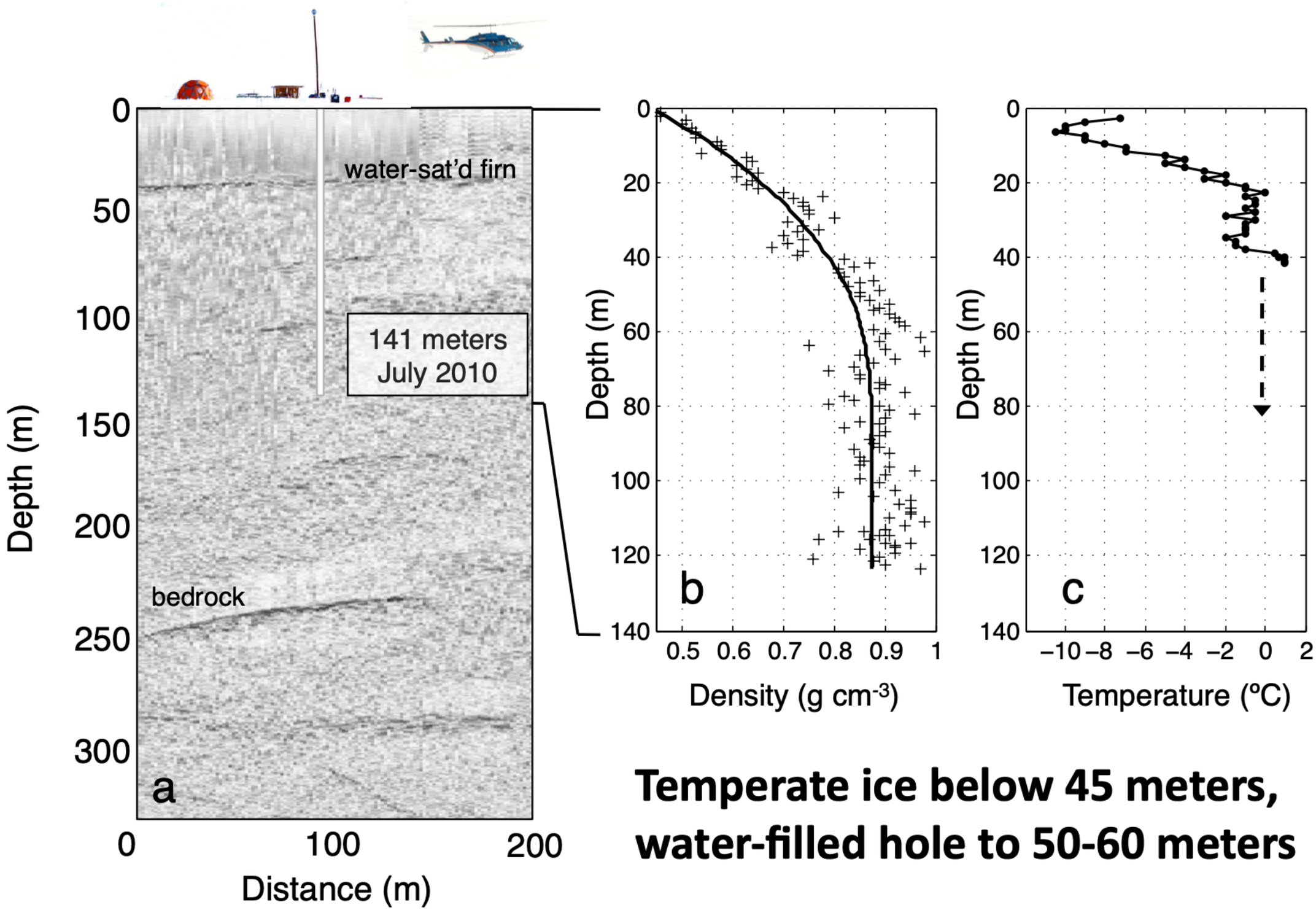


141 m core dated 1973-2010

(It is VERY snowy...)

2010 Thermal Coring

Deep drilling difficult due to **temperate ice, water-filled borehole**

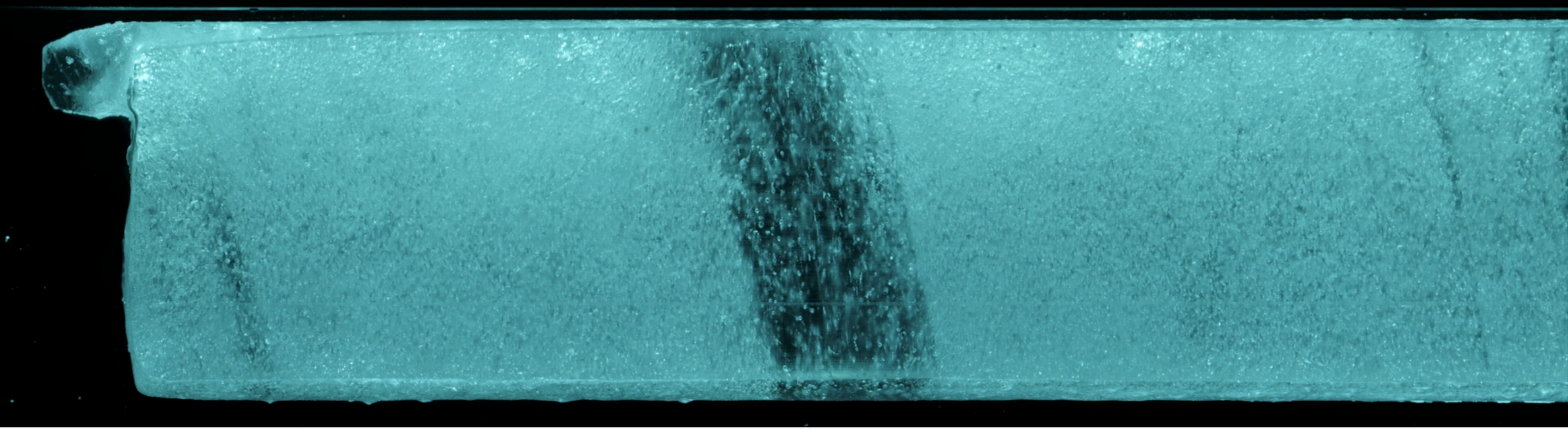


Temperate ice below 45 meters, water-filled hole to 50-60 meters

2010 Thermal Coring

80-100m deep, borehole water refreezes if left overnight or during storms
Powering on the drill led to deviations and shows refrozen bubble-free annulus

Mt. Waddington depth-age



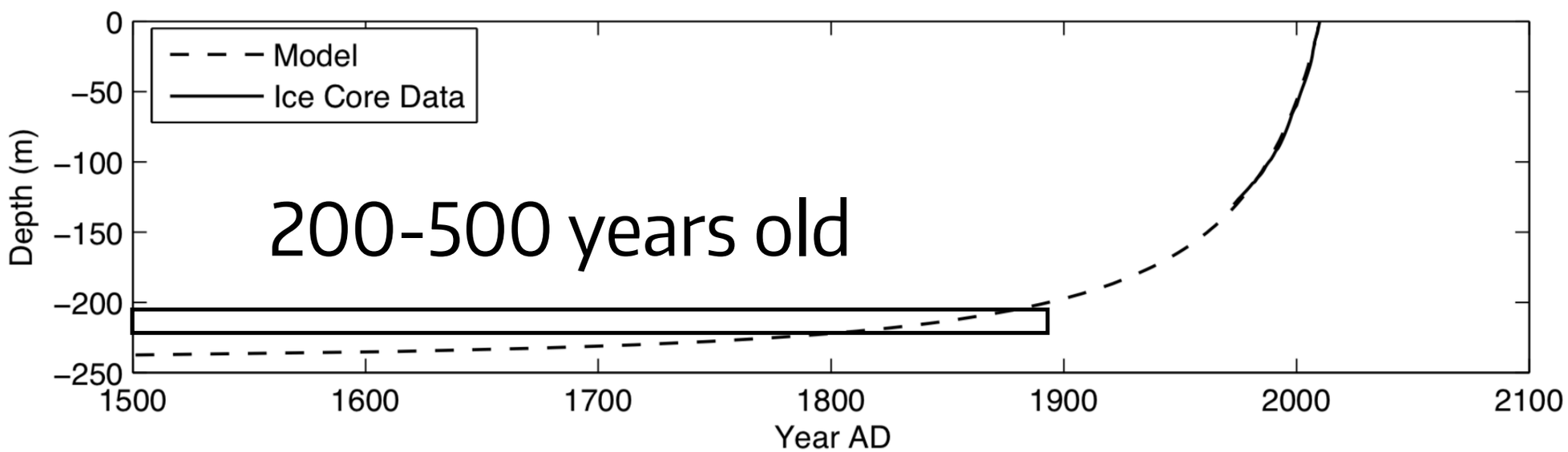


Figure 3. Measured (solid line) and modeled (dashed line) ice core depth-age relationships, assuming no basal sliding, 7 m/year ice-equivalent snow accumulation, a conservative 240 m ice thickness, and Dansgaard-Johnsen flow-model kink-height h = 0.65 (fractional height above the bed where horizontal velocity begins to linearly decrease to zero; see details in Neff et al., 2012).

Neff et al., 2012

NSF funding awarded 2020 for eventual 2023 return

2002441, 2001961

Mike King

Chief Pilot/Owner

Patrick King

Maintenance Manager/Engineer

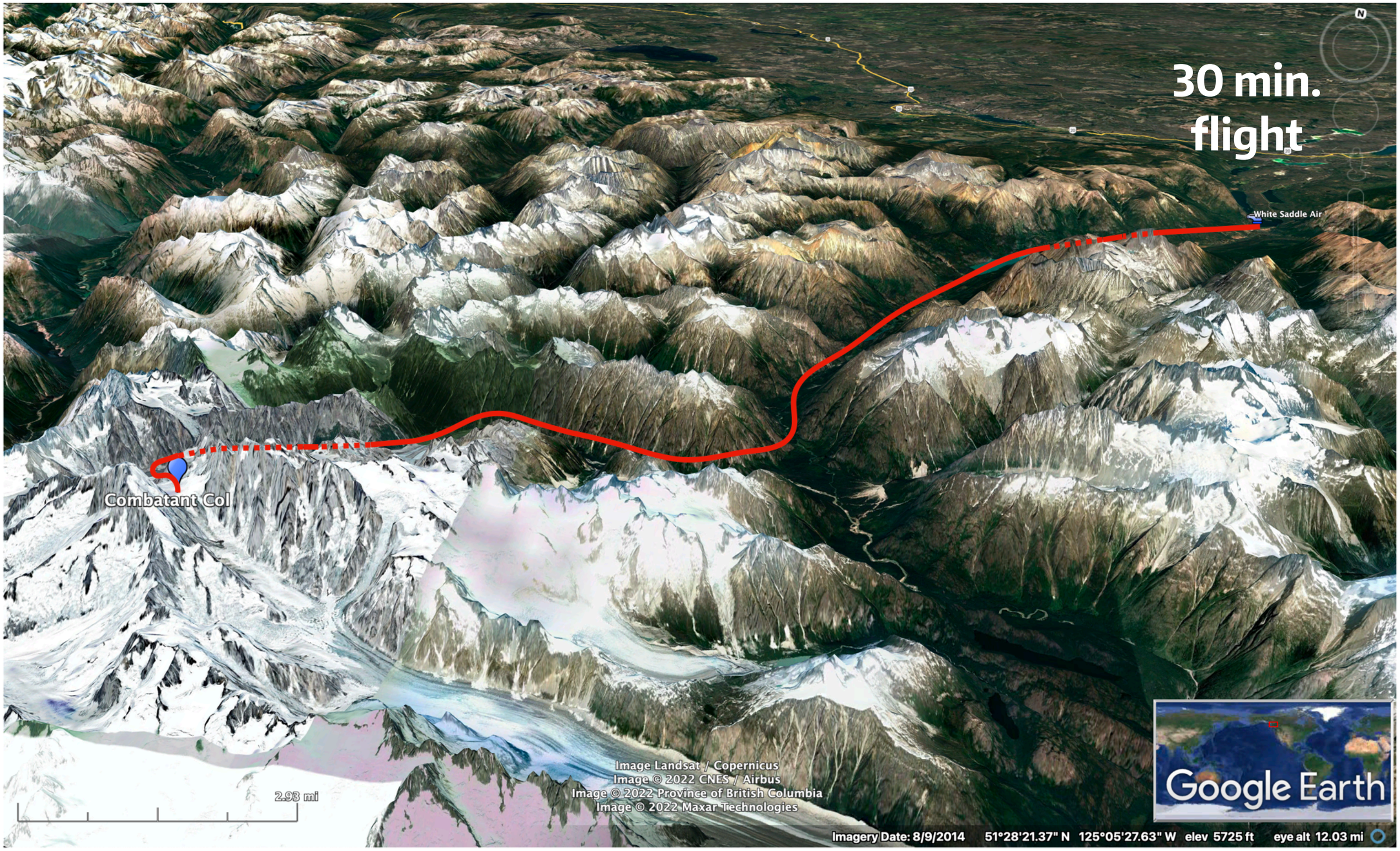
Audrey King

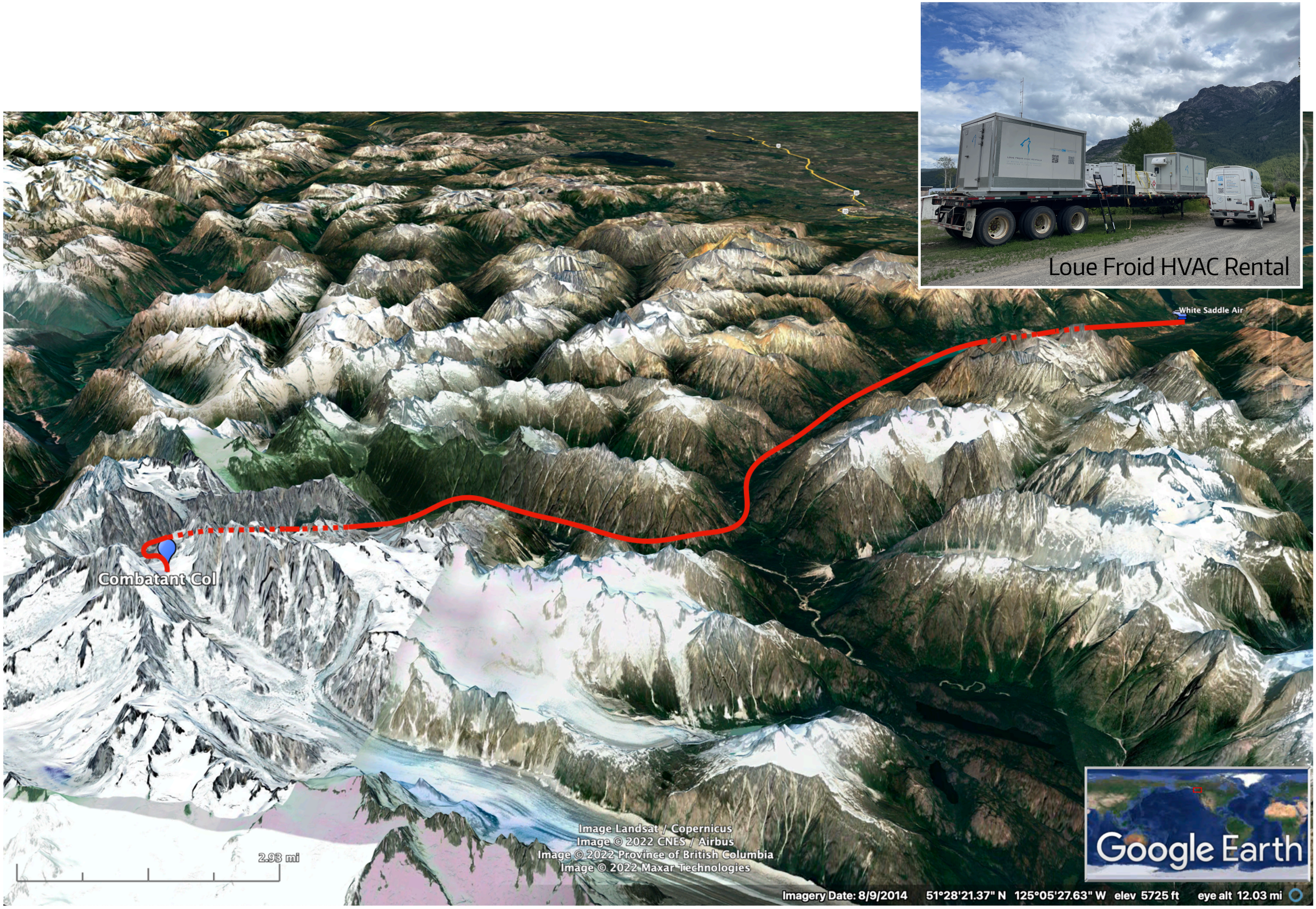
General Manager

White Saddle

AIR SERVICES LTD.

Bell 407GXi


30 min.
flight
White Saddle Air
Combatant Col
2.93 mi
Image Landsat / Copernicus
Image © 2022 CNES / Airbus
Image © 2022 Province of British Columbia
Image © 2022 Maxar Technologies
Google Earth
Imagery Date: 8/9/2014 51°28'21.37" N 125°05'27.63" W elev 5725 ft eye alt 12.03 mi


Loue Froid HVAC Rental
White Saddle Air
Combatant Col
2.93 mi
Image Landsat / Copernicus
Image © 2022 CNES / Airbus
Image © 2022 Province of British Columbia
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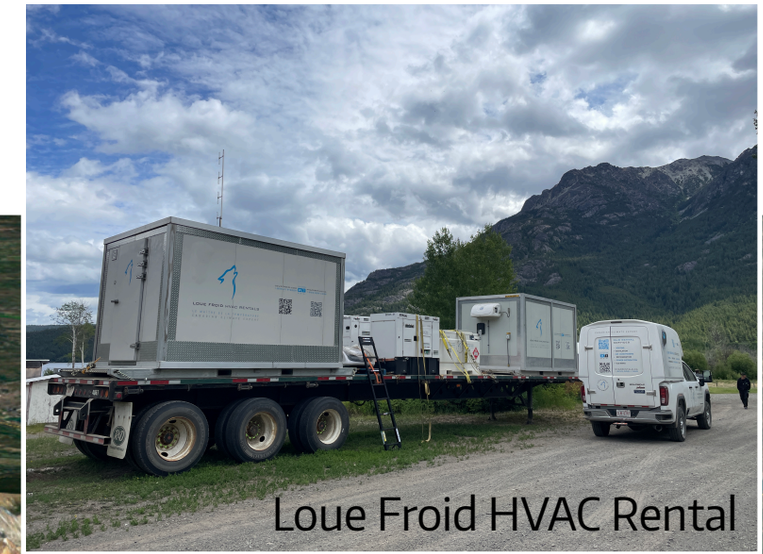
C-GKWS


Loue Froid HVAC Rental


White Saddle Air
Combatant Col
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Image Landsat / Copernicus
Image © 2022 CNES / Airbus
Image © 2022 Province of British Columbia
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Frankie Carino

2023 Thermal Coring

NSF US Ice Drilling Program 3” Thermal Drill

Pro: can drill in water-filled borehole; no ice cuttings to transport

Con: can’t clear debris from melt face w/o magnet or vacuum tool

Initial Obstacle - 209 m

NSF US Ice Drilling Program
3” Thermal Drill

Pro: can drill in water-filled borehole; no ice cuttings to transport

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~209 m

Initial Obstacle - 209 m

NSF US Ice Drilling Program
3” Thermal Drill

Pro: can drill in water-filled borehole; no ice cuttings to transport

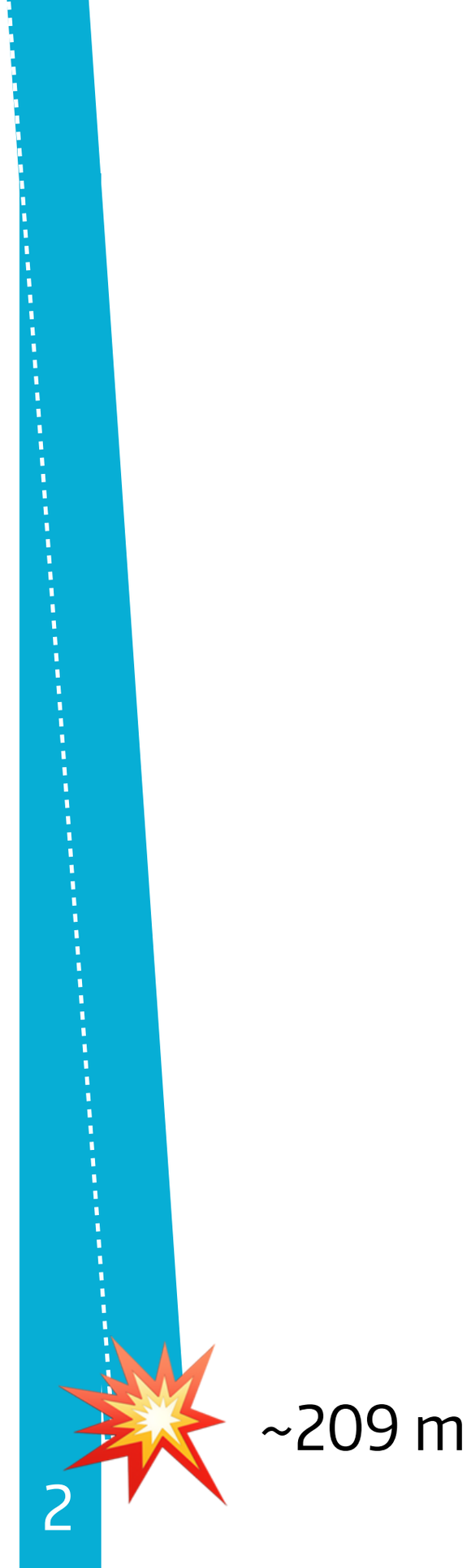
Con: can’t clear debris from melt face w/o magnet or vacuum tool

~209 m

Borehole Deviation

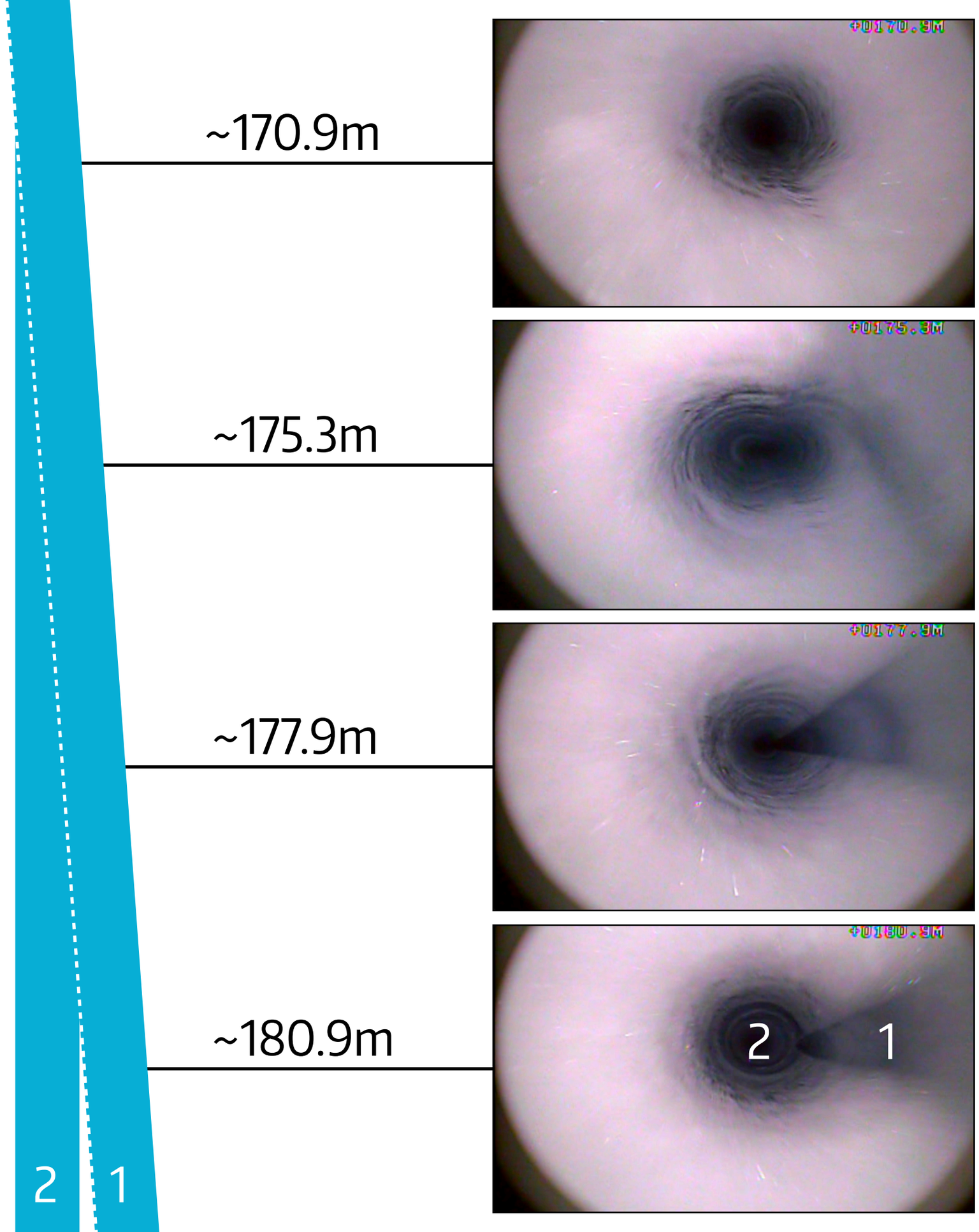
Ice core boreholes aren't perfectly vertical

One opportunity to use gravity to carve deviation



Borehole Deviation

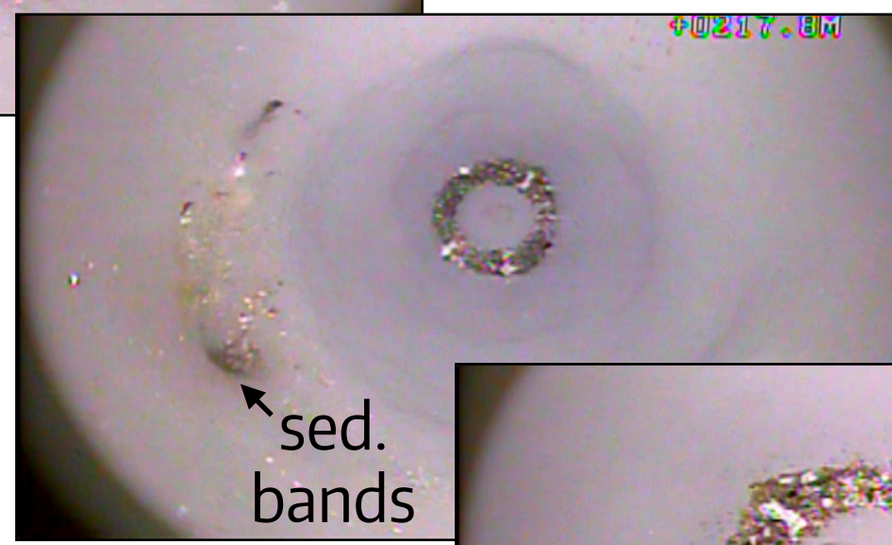
Deviation at ~170 m to divert around 209 m sediment accumulation

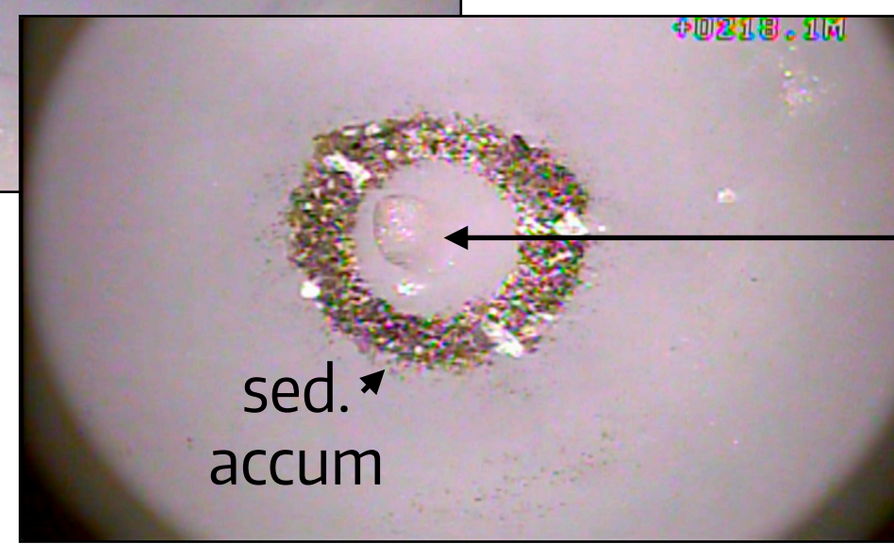


Sediment accumulation - 219 m

Increased sediment bands below 200 m

Sediment accumulation - 219 m



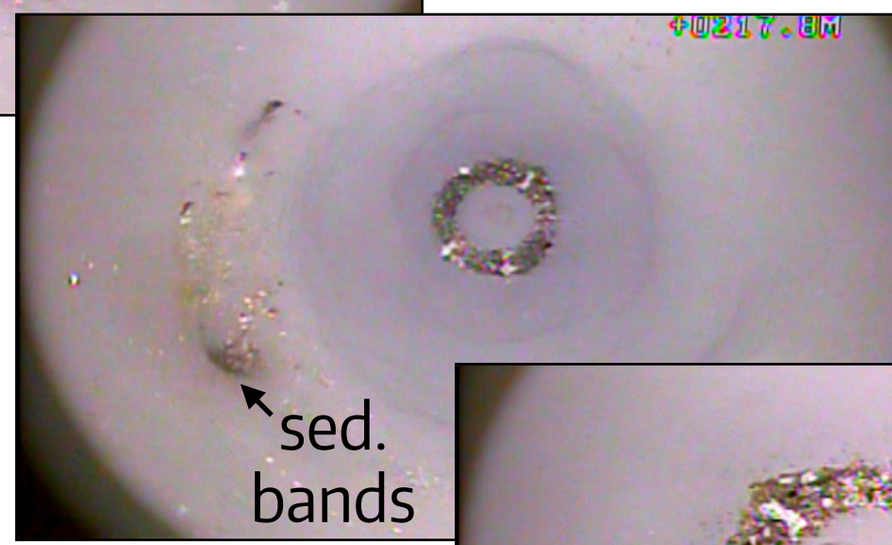


Increased sediment bands below 200 m

Sediment accumulation in melt annulus

final melted "carrot" of ice core

Sediment accumulation - 219 m



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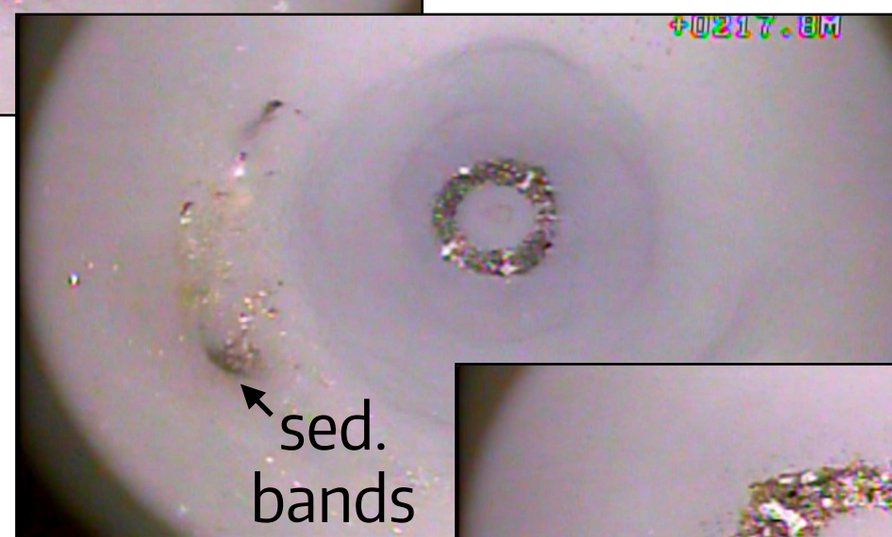
Sediment accumulation - 219 m



Increased sediment bands below 200 m

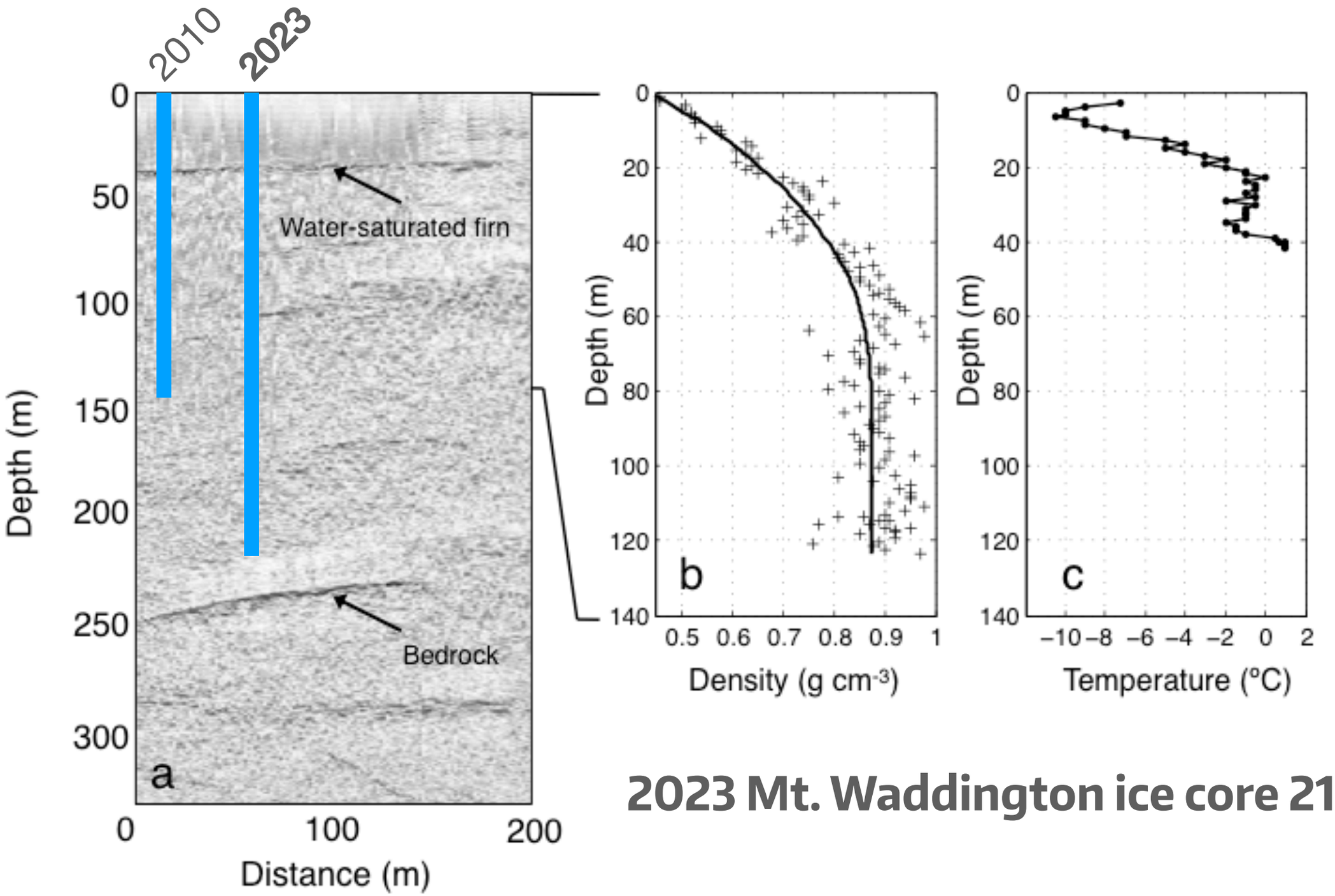
final melted "carrot" of ice core

Sediment accumulation in melt annulus

Drilling concluded,

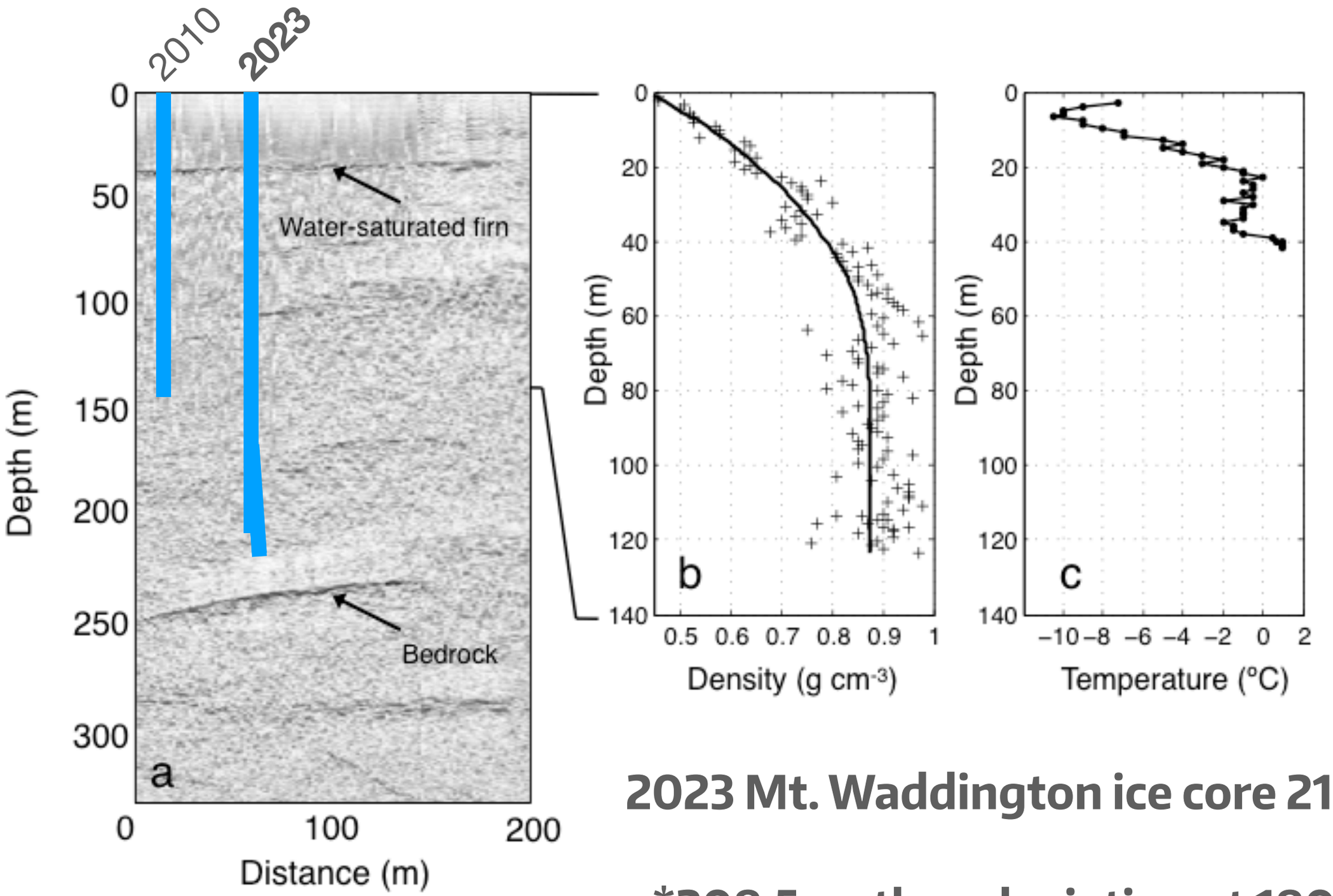
219 m assumed near bedrock

July 12, 2023



2023 Mt. Waddington ice core 219 m

Neff et al., *J. Glaciology*, 2012



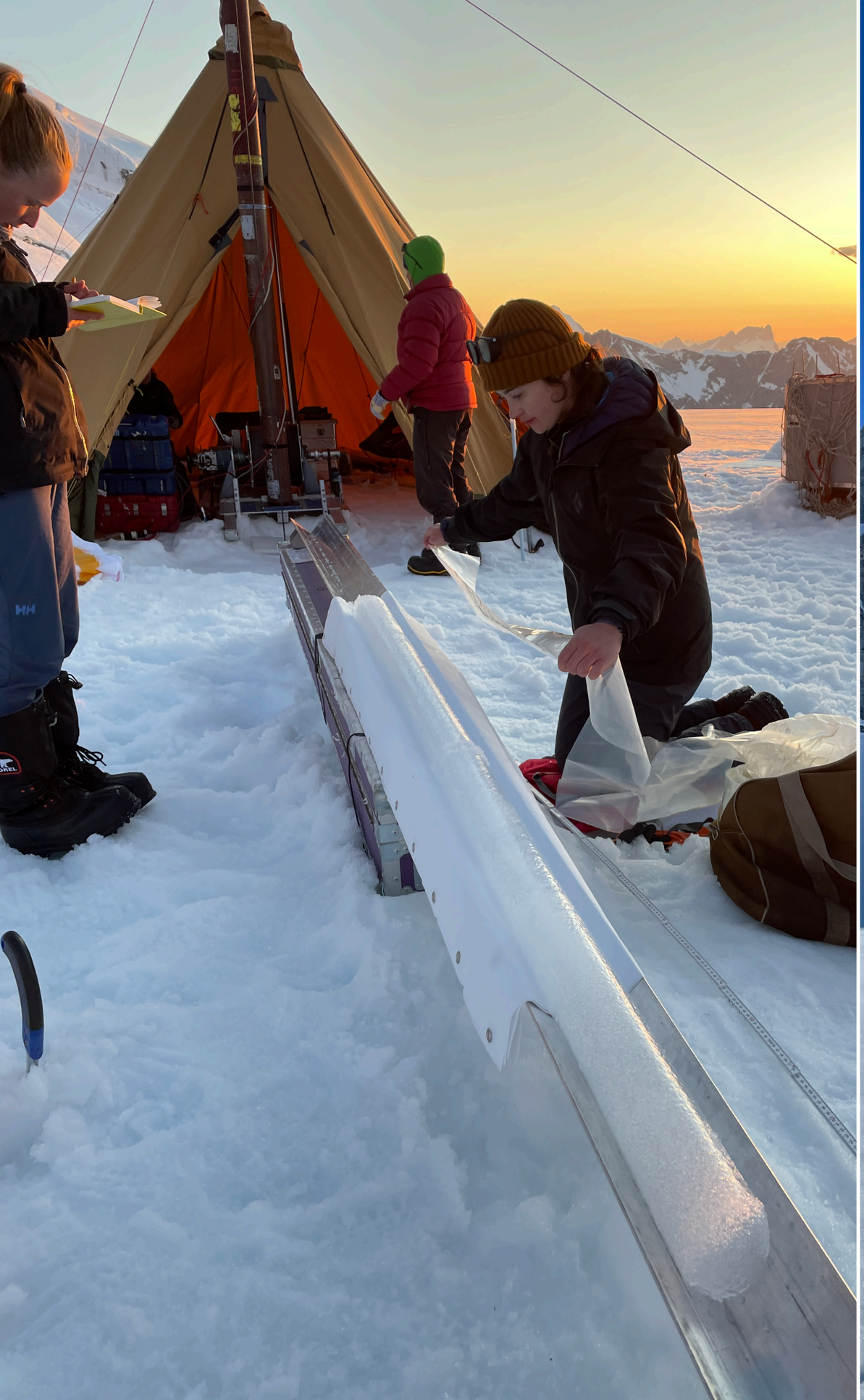
2023 Mt. Waddington ice core 219 m

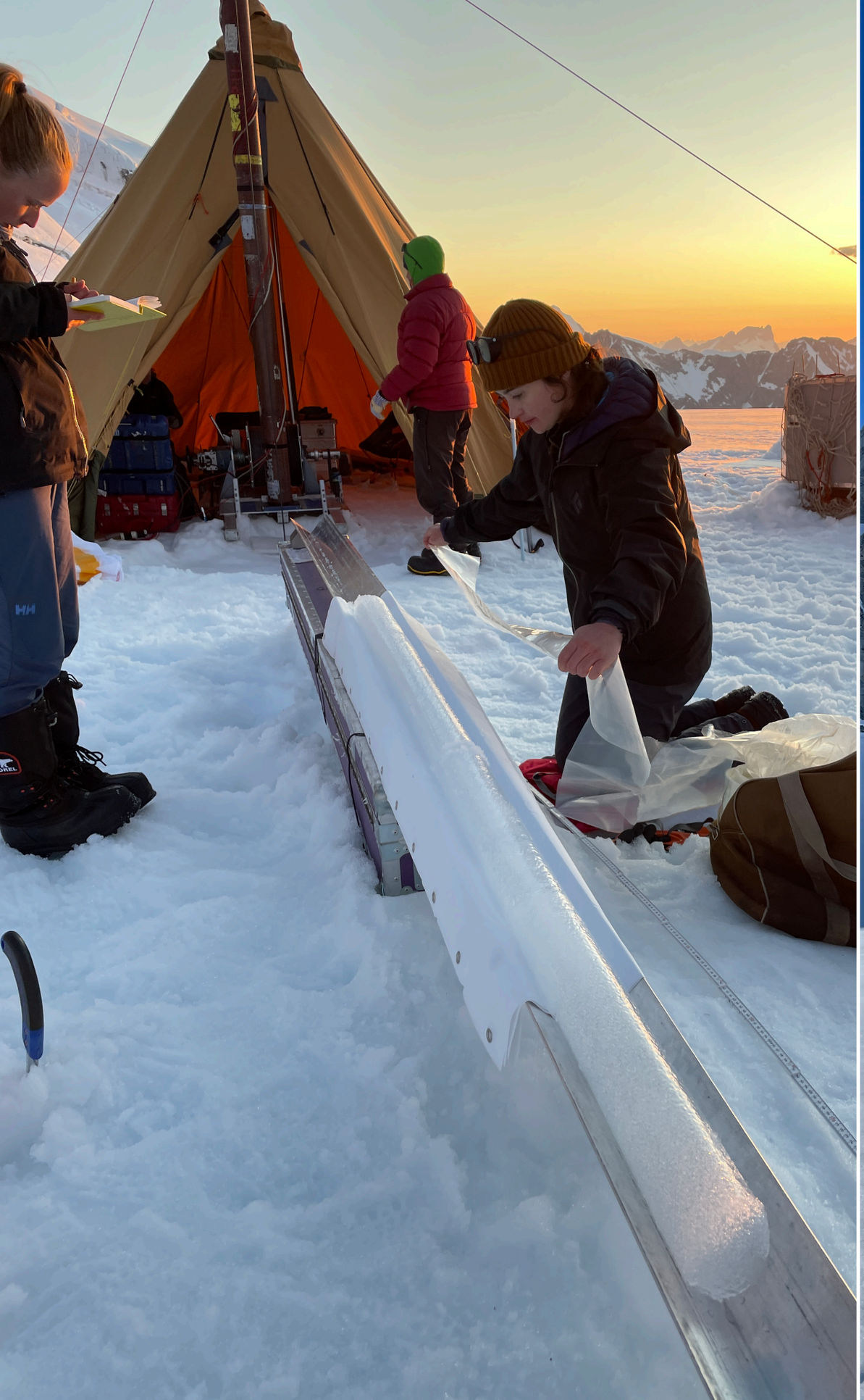
***208.5 m, then deviation at 180 m extending to 219 m**

Neff et al., *J. Glaciology*, 2012

Several meter-long sections of bubble-free ice

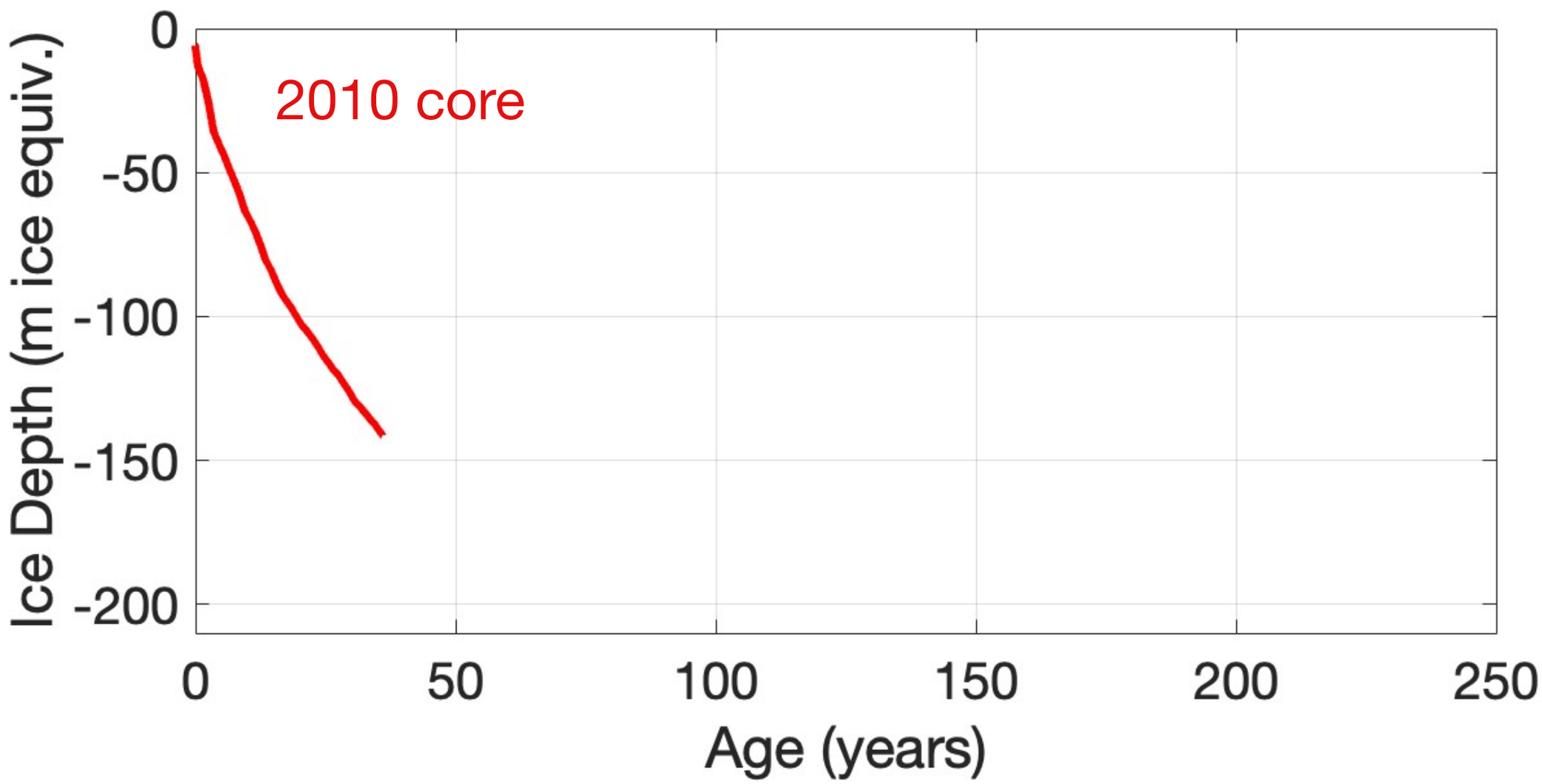
Water stable isotopes relatively unaffected in these zones...





How old is the ice core?

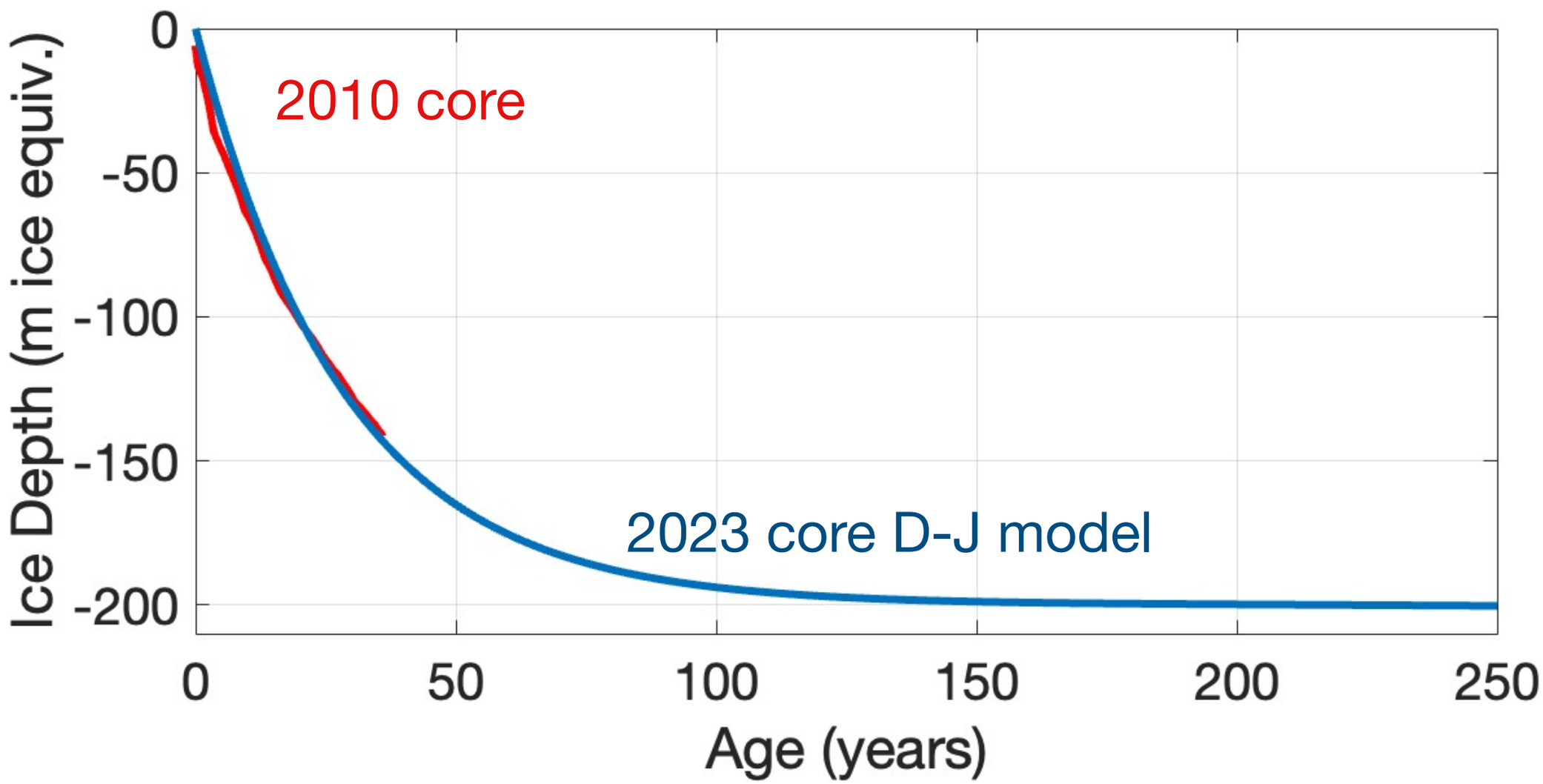
Preliminary Depth-Age



Preliminary Depth-Age

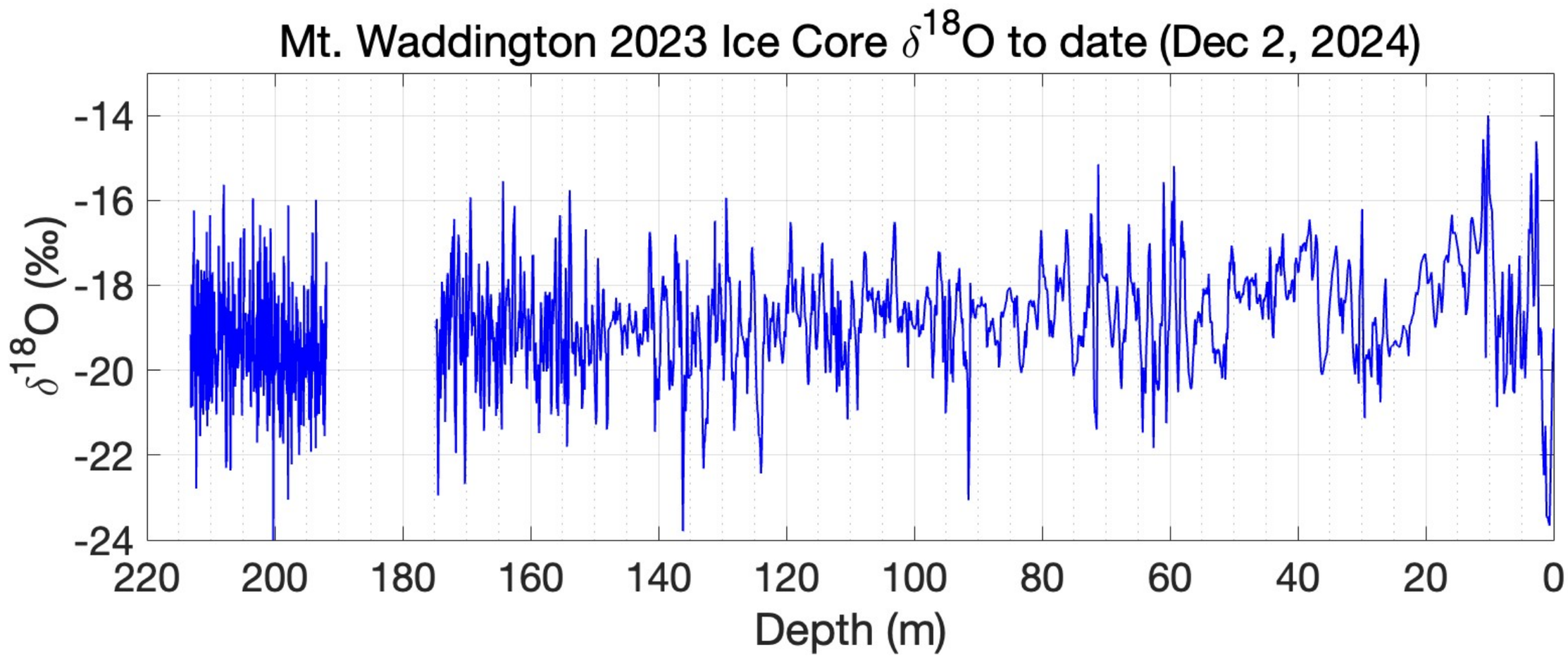
Calculate reasonable D-J ice flow model for 219 m core

(7 m/yr, 1 cm/yr basal melt, divide flow)



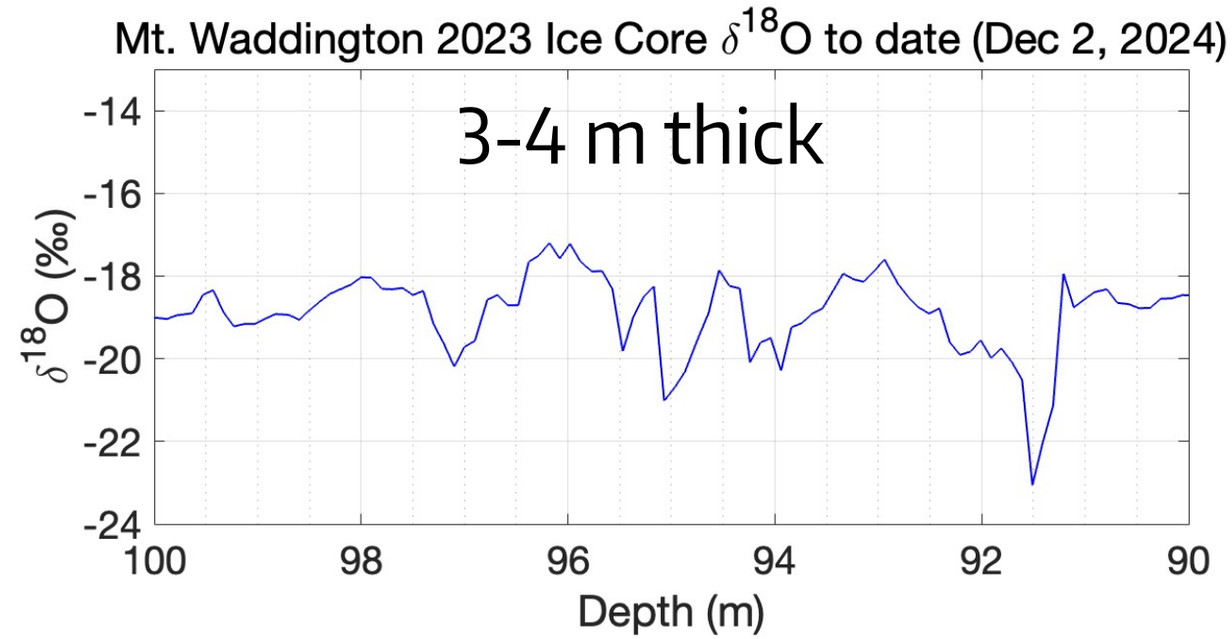
Dansgaard, W., & Johnsen, S. J. (1969). Journal of Glaciology, 8(53), 215-223.

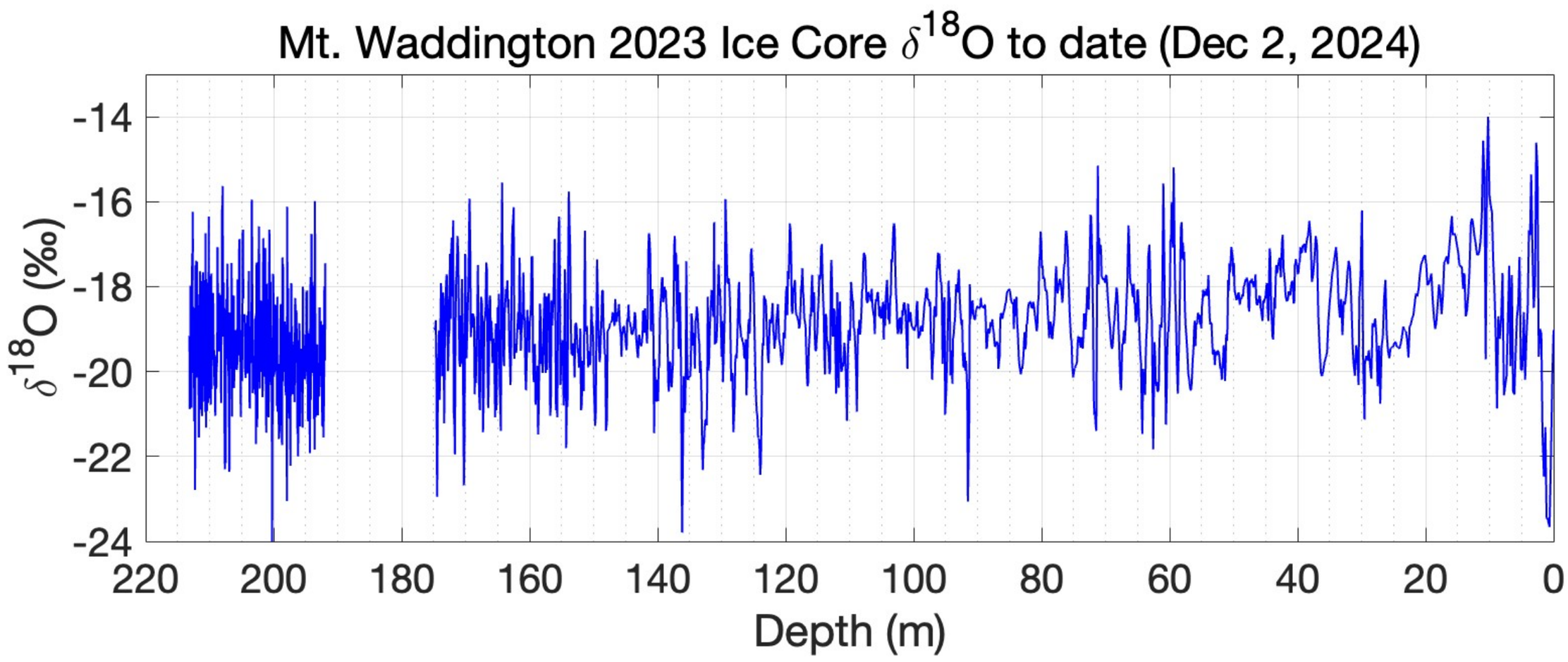
Water Stable Isotopes - Preliminary Data



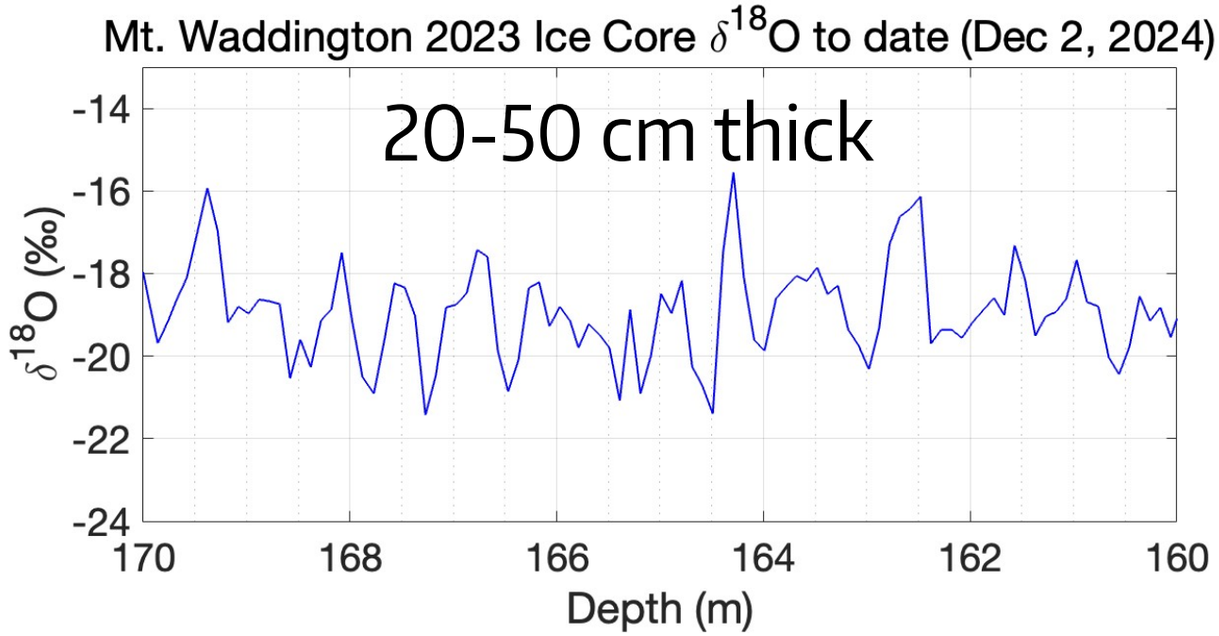
Bottom	Top
Old	Young
Thin	Thick

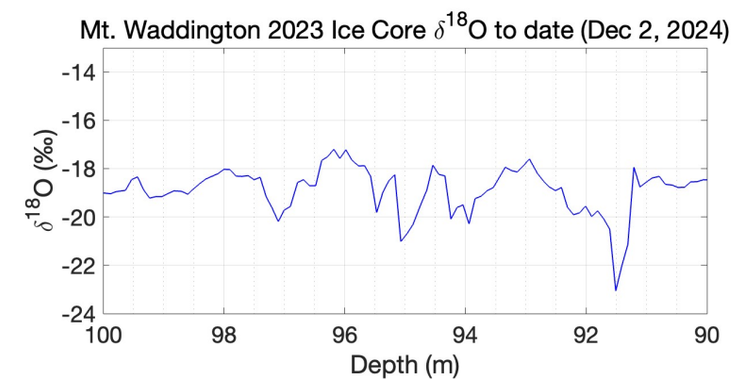
Water Stable Isotopes - Preliminary Data

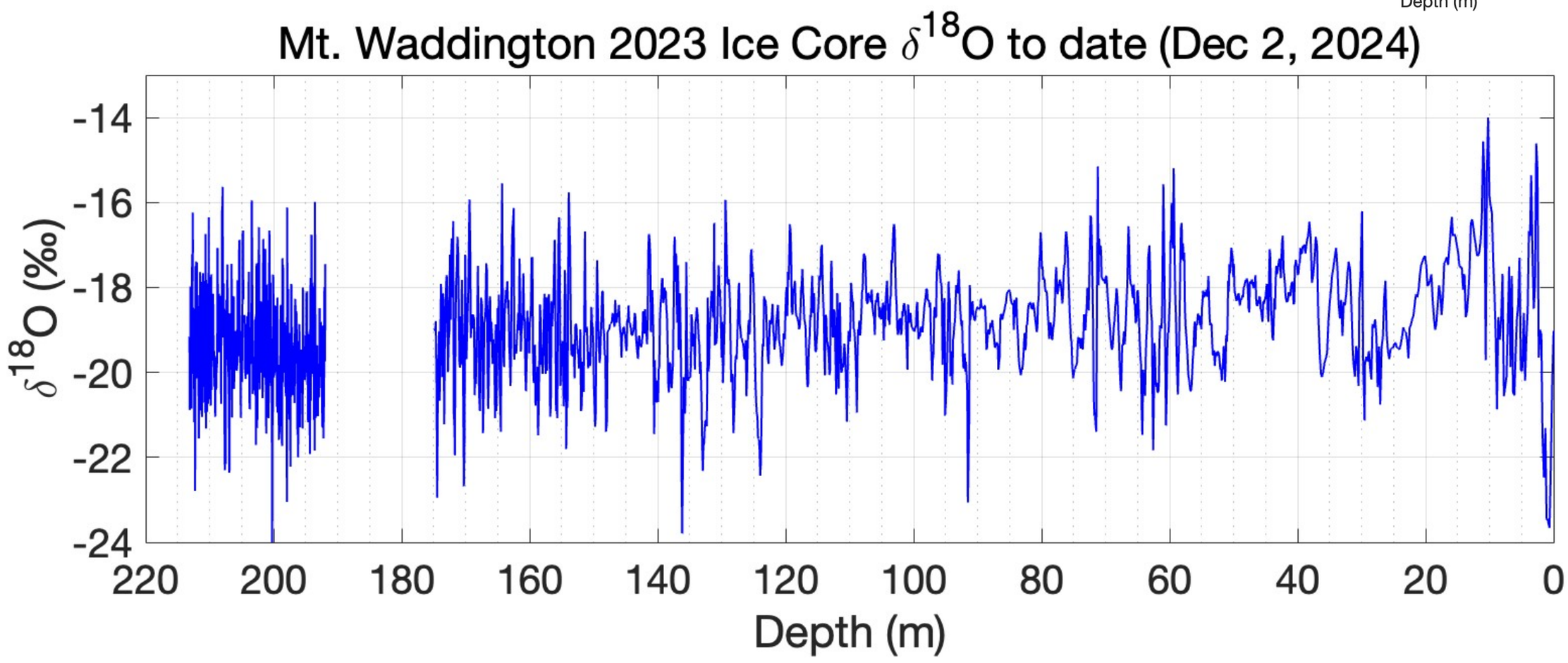




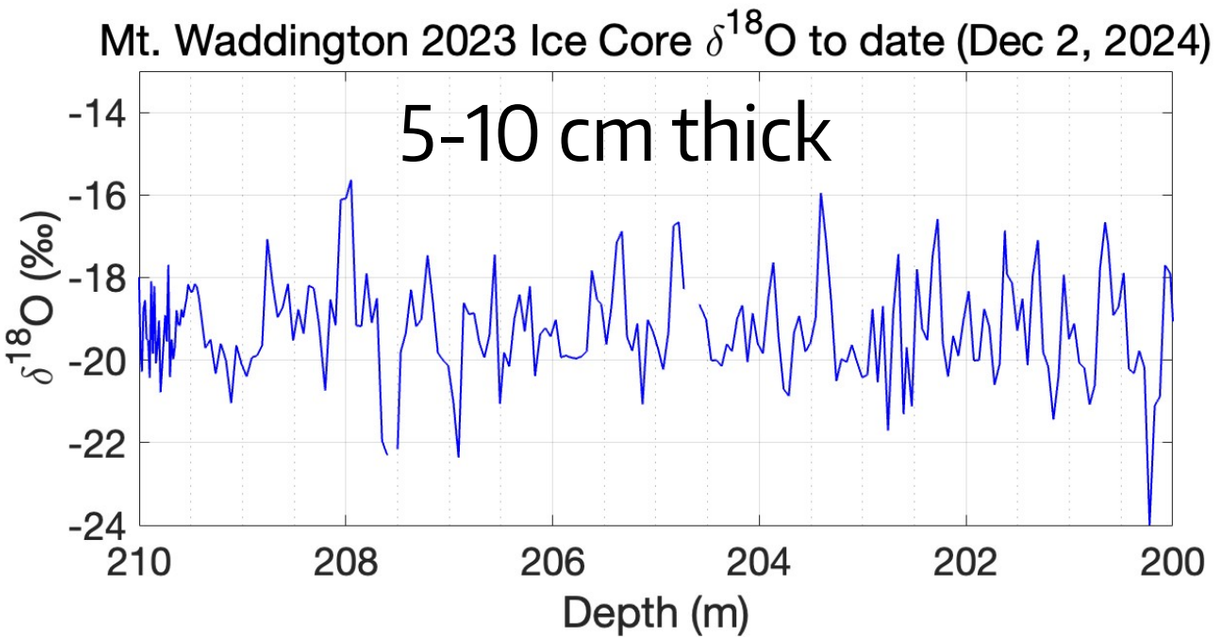
Water Stable Isotopes - Preliminary Data

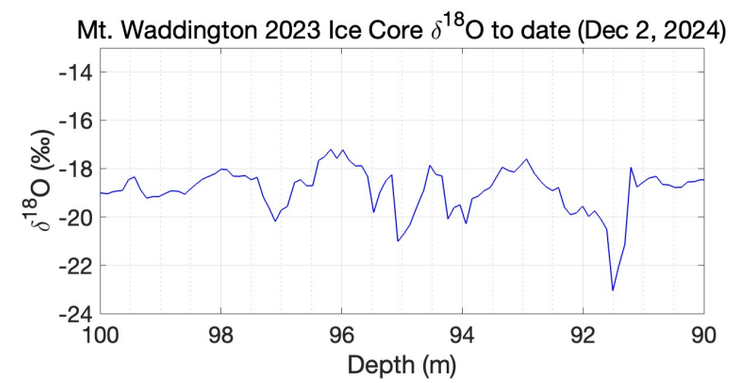


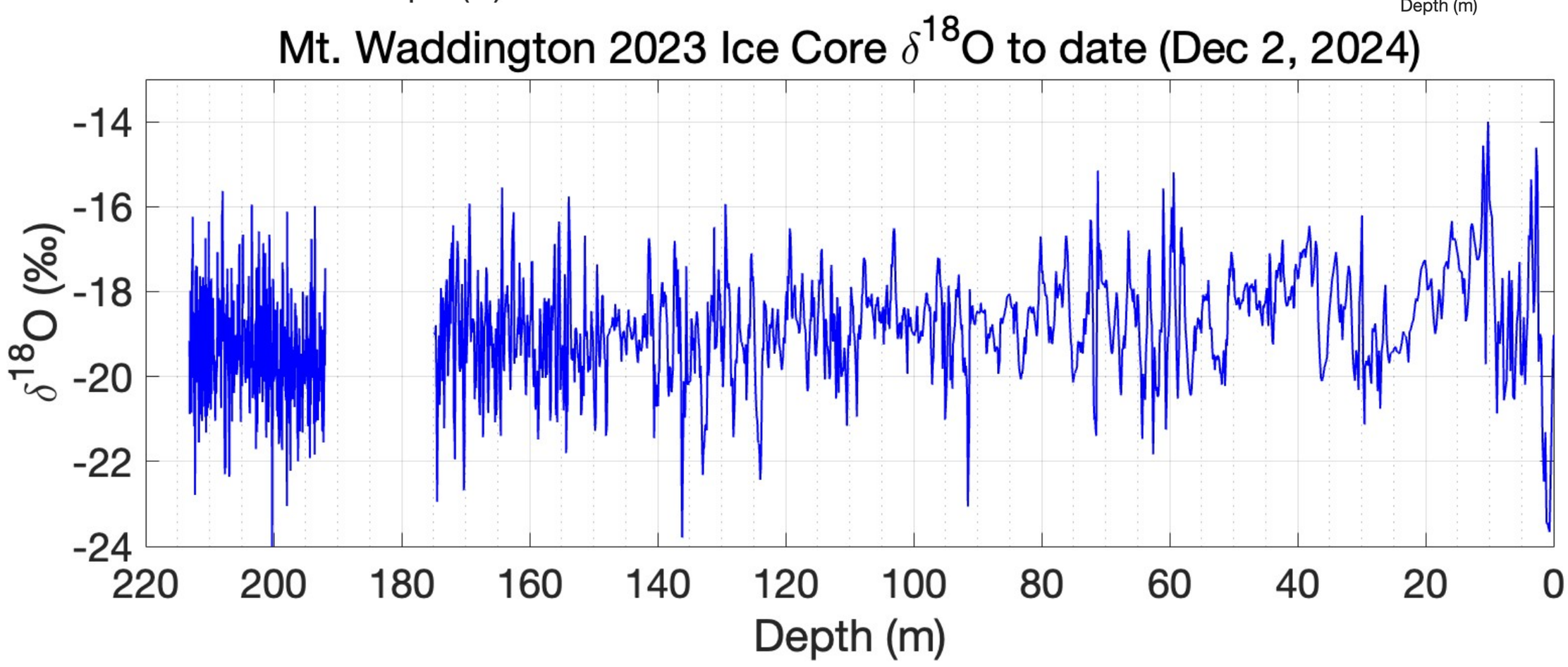




Water Stable Isotopes - Preliminary Data

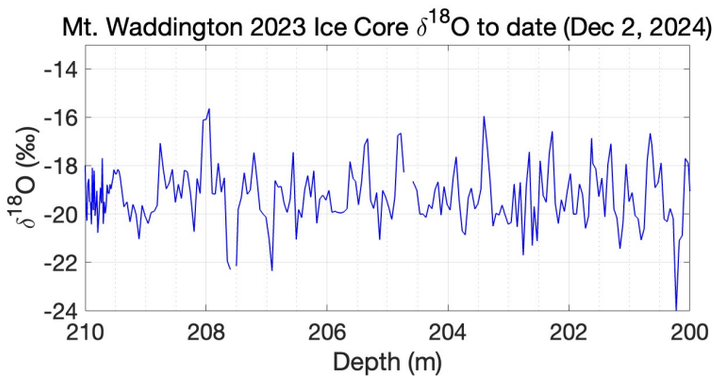




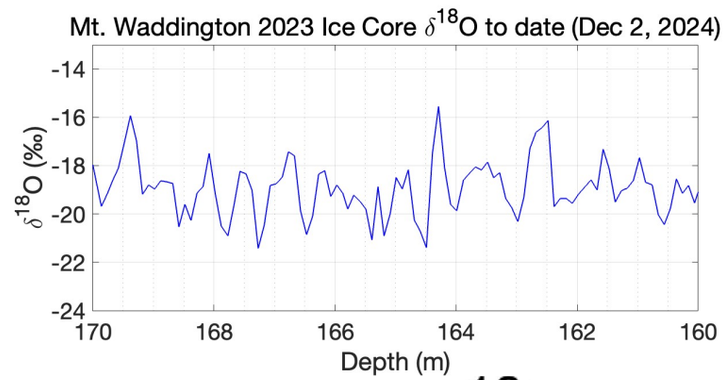


Water Stable Isotopes - Preliminary Data

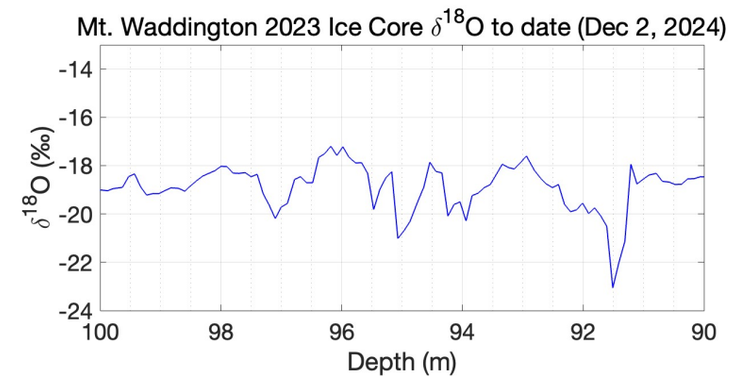
5-10 cm thick

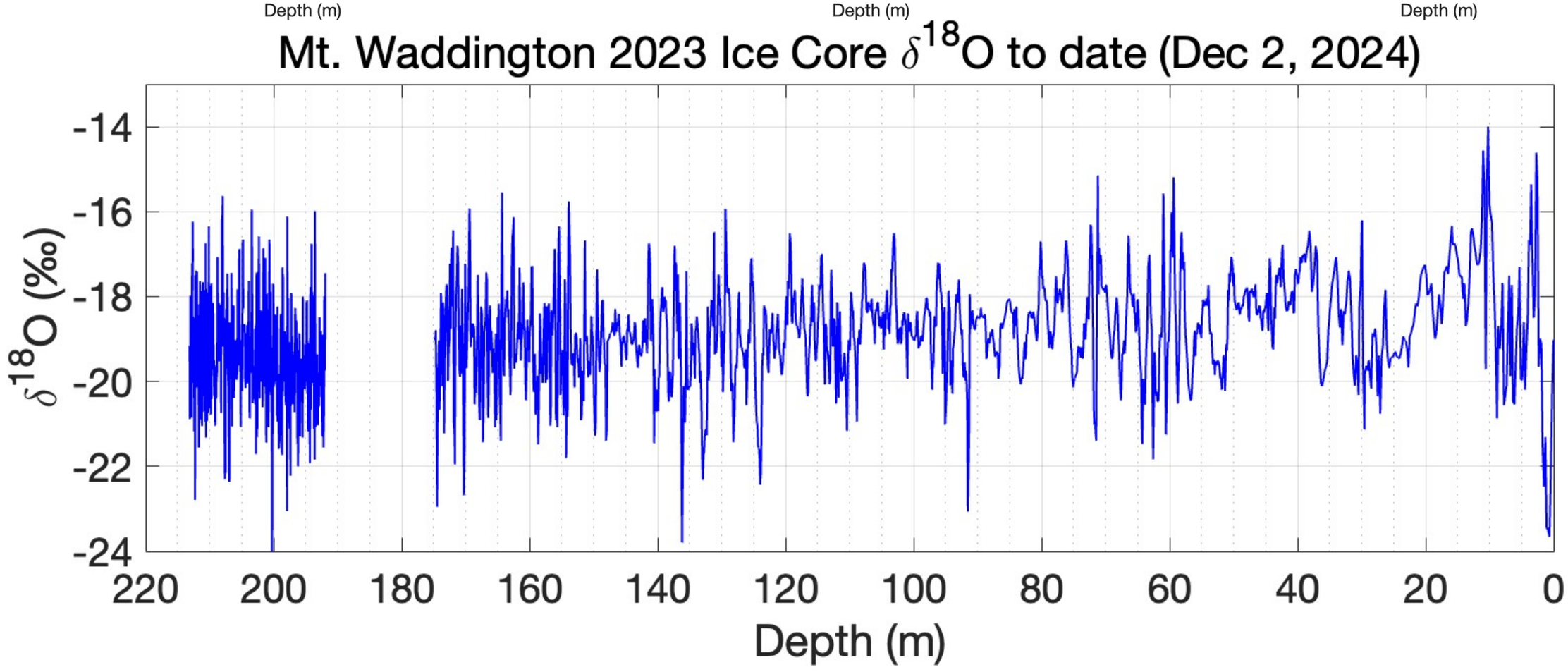


20-50 cm thick



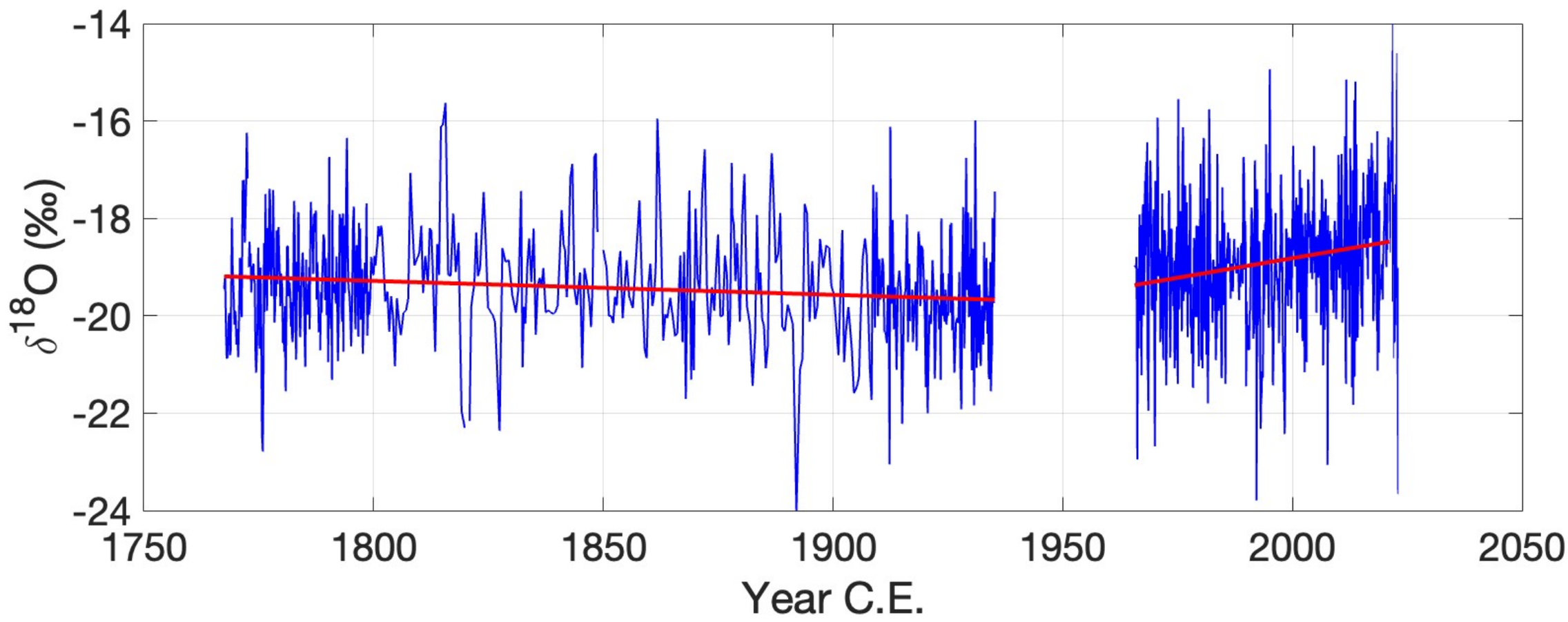
3-4 m thick





Water Stable Isotopes - Preliminary Timeseries

Oxygen isotopes on estimated ice-flow age scale

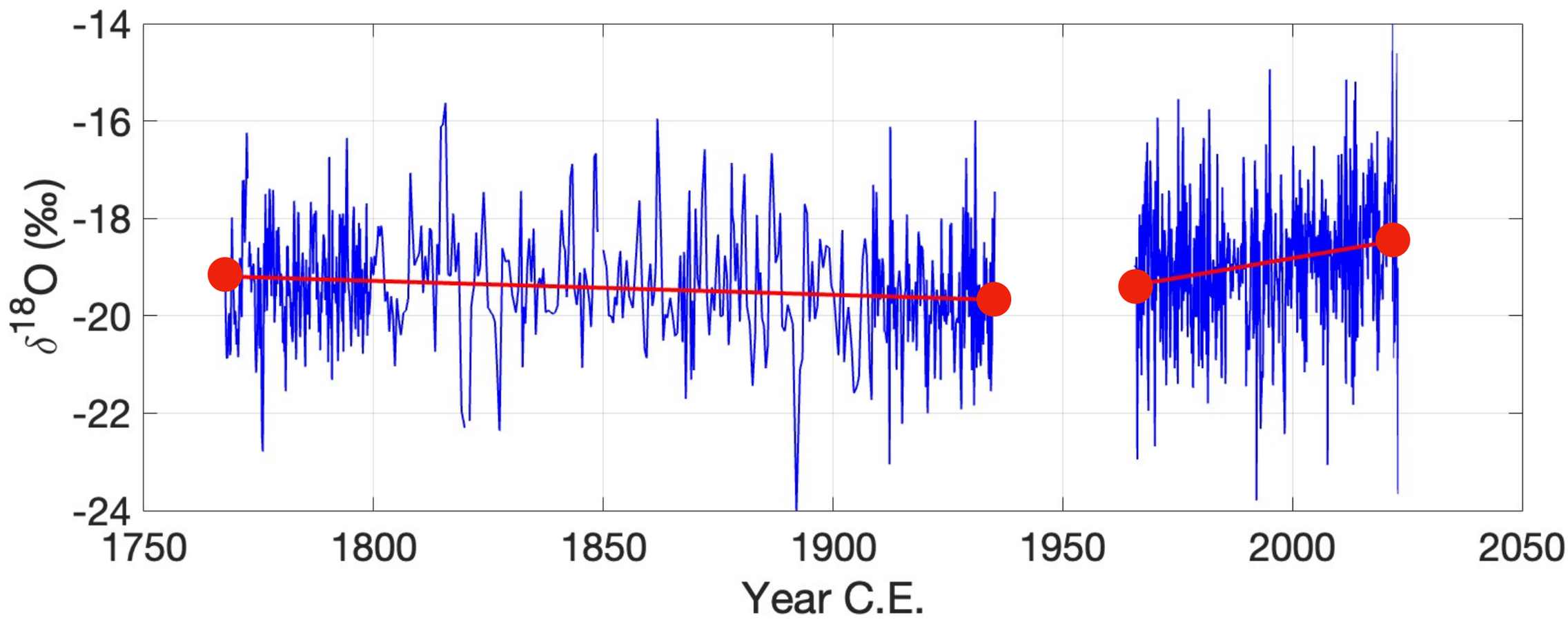


Jouzel, J., Alley, R. B., Cuffey, K. M., Dansgaard, W., Grootes, P., Hoffmann, G., ... & White, J. (1997)
Journal of Geophysical Research: Oceans, 102(C12), 26471-26487.

Water Stable Isotopes - Preliminary Timeseries

~1770: -19.2‰ **~1968: -19.4‰**

~1935: -19.7‰ **~2022: -18.5‰**



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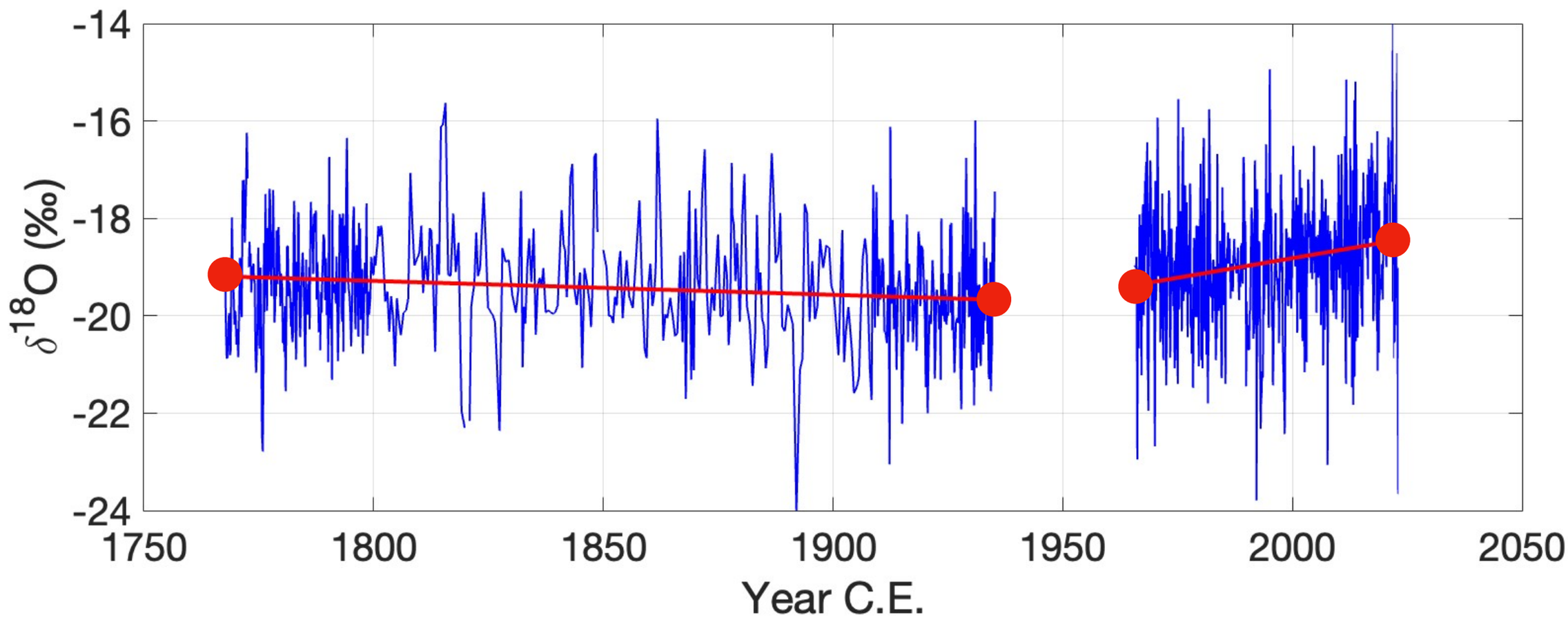
Water Stable Isotopes - Preliminary Timeseries

~1770: -19.2‰ **~1968: -19.4‰**

~1935: -19.7‰ **~2022: -18.5‰**

Reasonable to assume 0.7‰/°C

(e.g. Jouzel et al., 1997)



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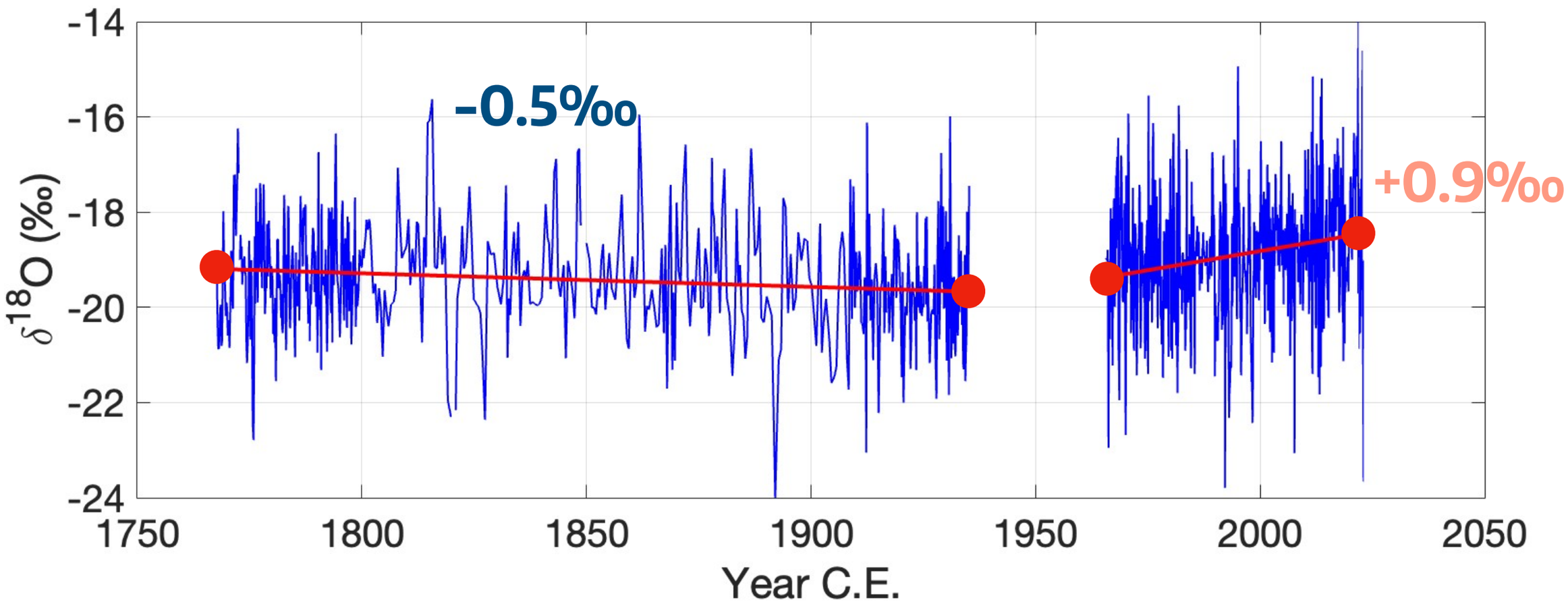
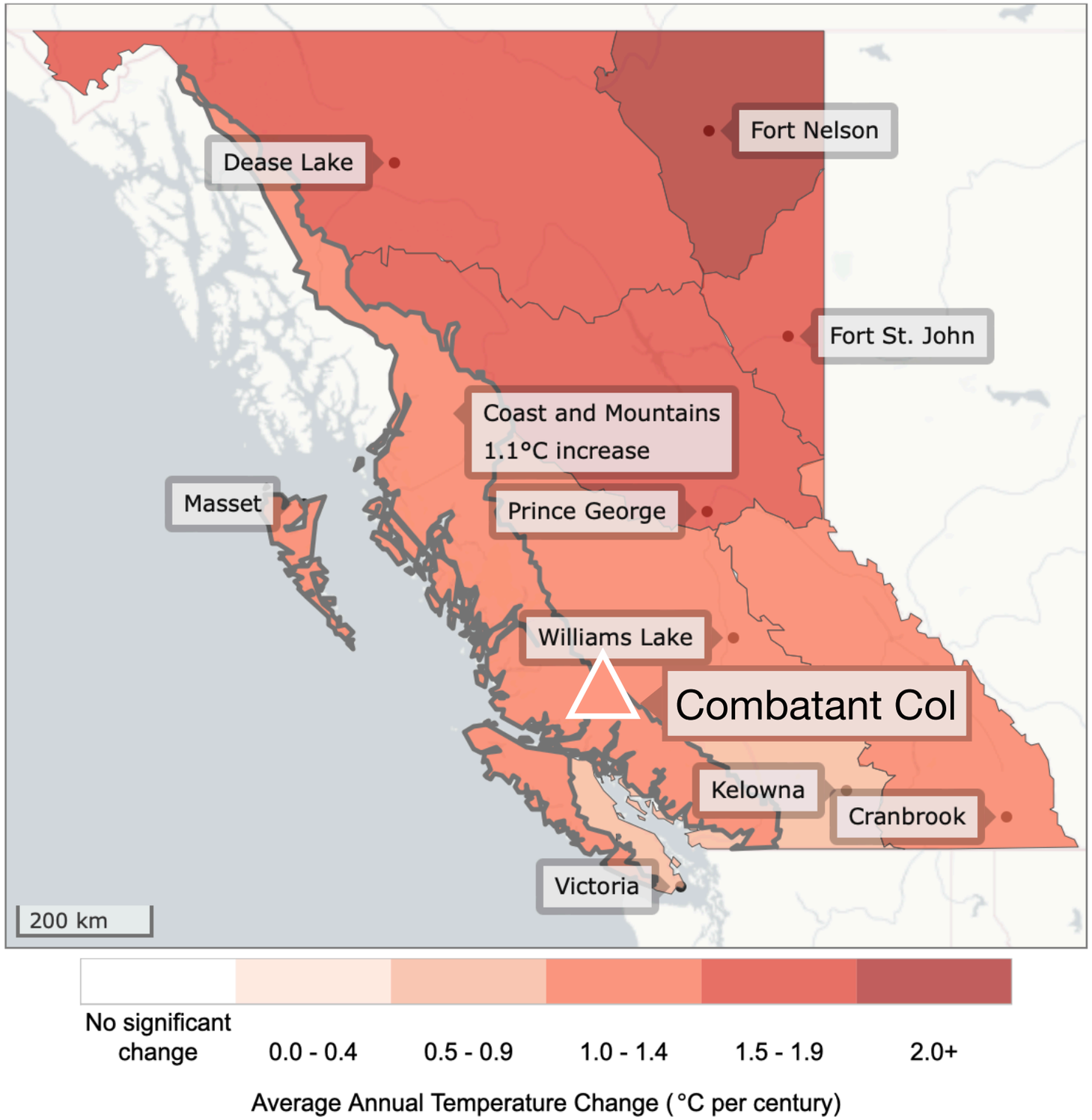
Water Stable Isotopes - Preliminary Timeseries

~18th - 20th Century cooling of **0.7°C**?

~1960s - 2020s warming of **1.3°C**?



Water Stable Isotopes - Preliminary Timeseries



Combatant Col

~1960s - 2020s warming of **1.3°C**?

Reasonable result given observed BC centennial warming trends

https://www.env.gov.bc.ca/soe/indicators/climate-change/temp.html

Combatant Col Ice Core

2002441, 2001961

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Frankie Carino

Combatant Col Ice Core

From a drilling perspective, a unique temperate water-filled setting from 50 - 219 m

US 3" Thermal Drill performed well after 2019 refurbishment

Ethanol to prevent freezing in 2023 borehole was not necessary

Piston down-hole sediment vacuum ineffective; thermal conical tool possible option for clearing sediment accum. at melt annulus

2002441, 2001961

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Combatant Col Ice Core

219 m long ice core from southern BC Coast Mountains after multiple attempts

Annual stratigraphy preserved despite summer melt & firn aquifer presence

Preliminary water stable isotopes show **clear annual layering**, thinning with depth confirmed by ECM

Annual dating in progress but ice-flow agescale suggests a **250 year-long time series**

2002441, 2001961

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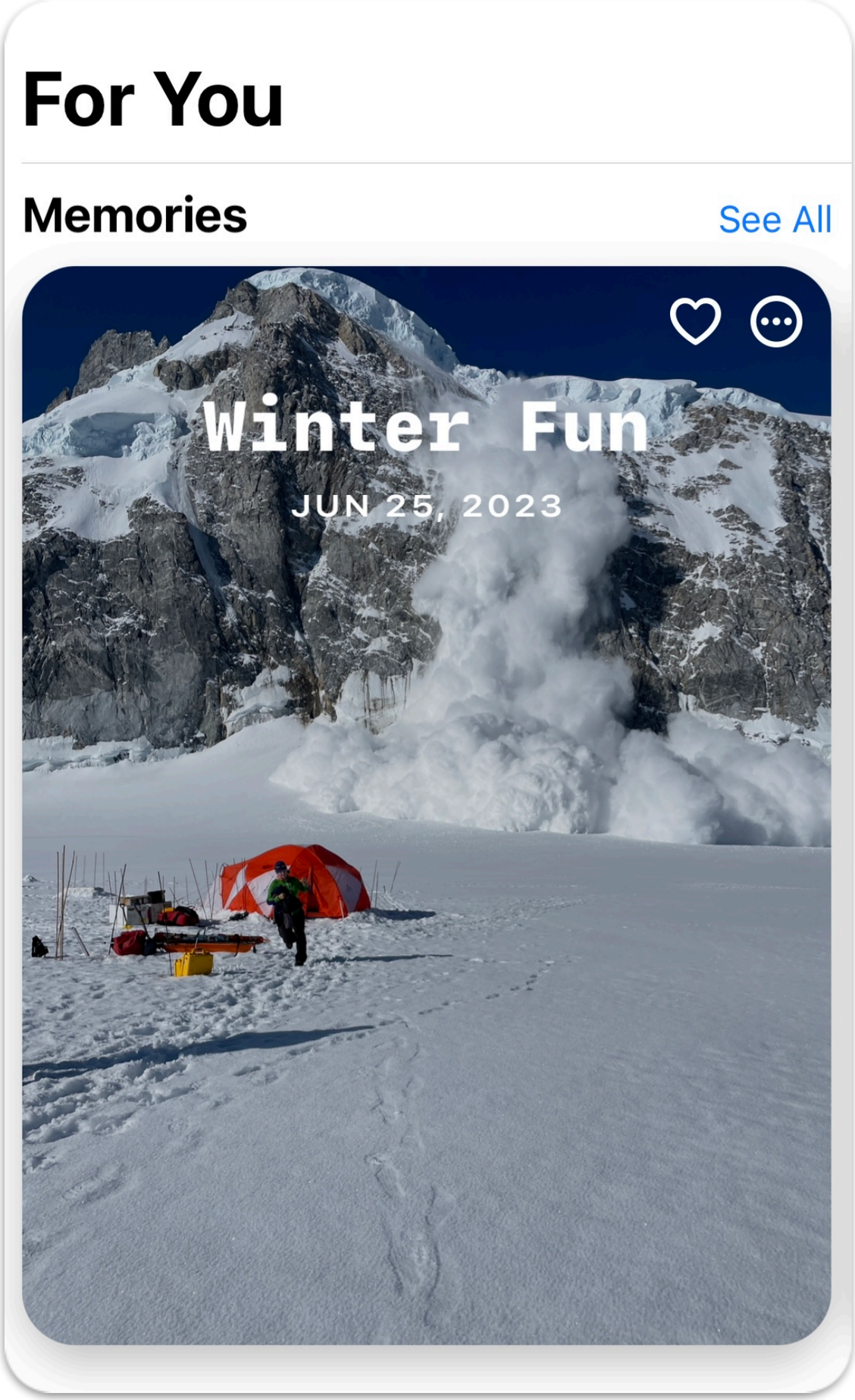


How my iPhone reminded me after drilling was done...

Unique alpine hazards:

Helicopter

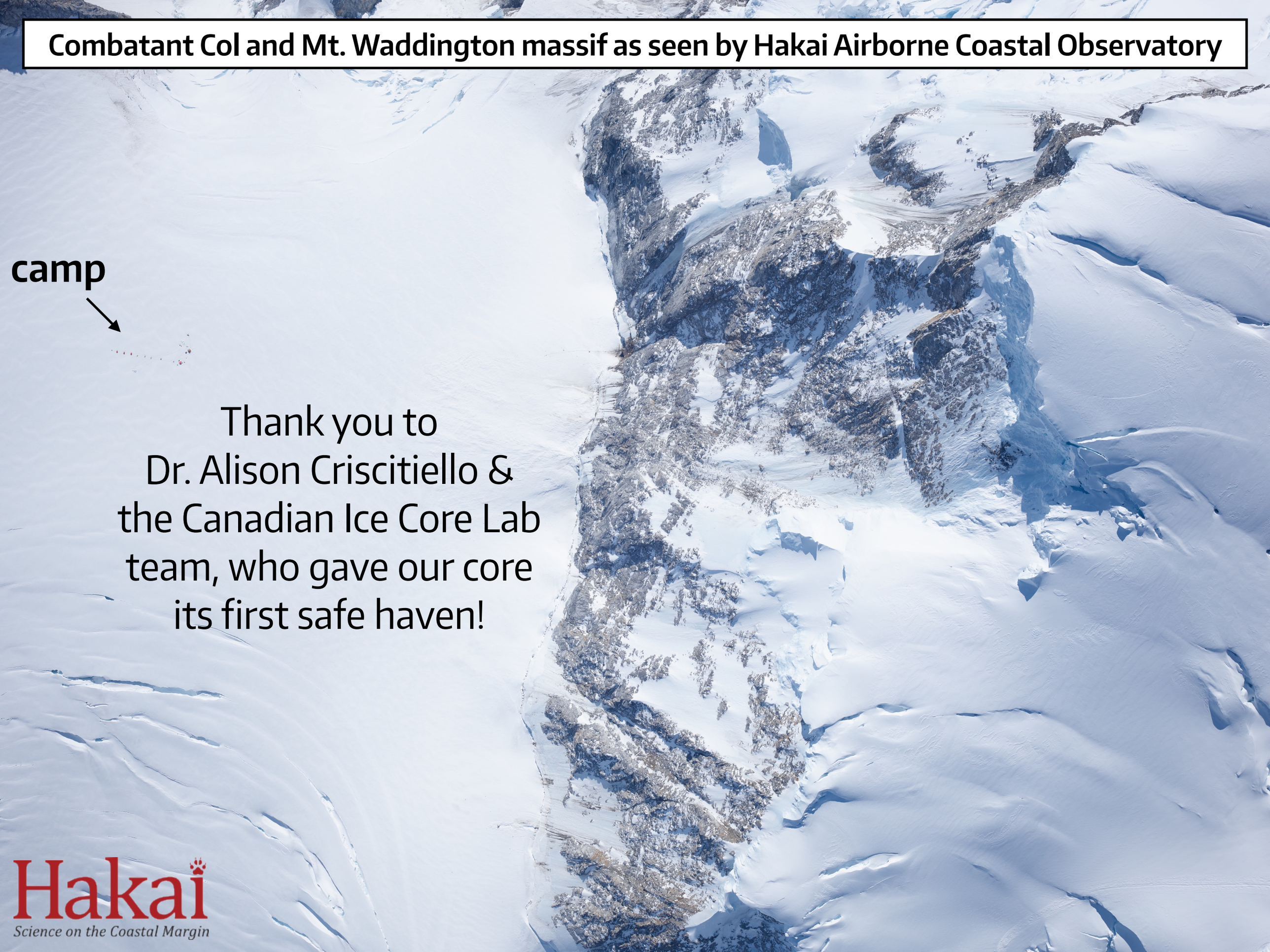
Crevasse

Avalanche

Thunderstorm

Windstorm

Snowstorm


Combatant Col and Mt. Waddington massif as seen by Hakai Airborne Coastal Observatory
camp
Thank you to
Dr. Alison Criscitiello &
the Canadian Ice Core Lab
team, who gave our core
its first safe haven!
Hakai
Science on the Coastal Margin