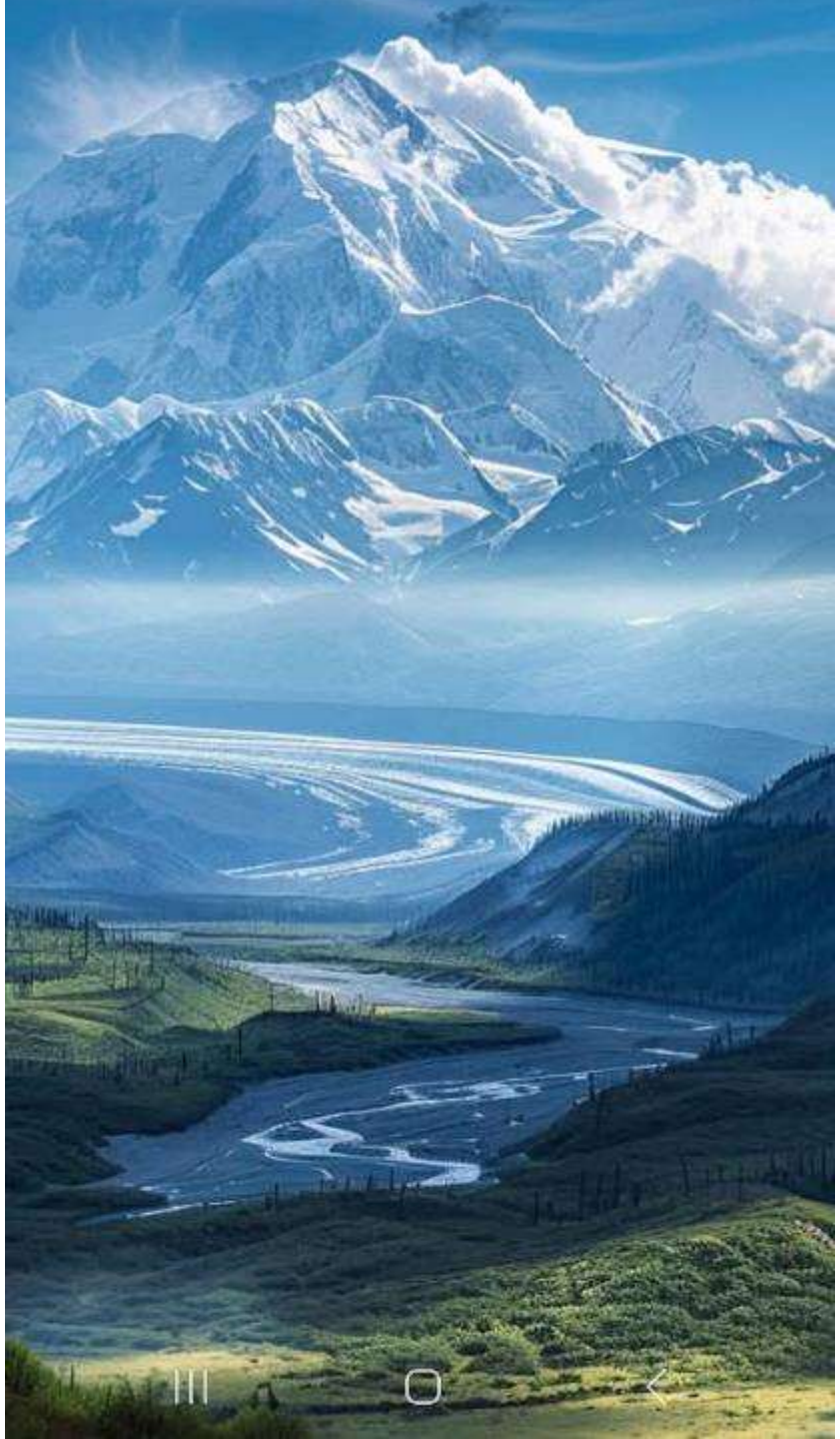
Depositional Glacial Features on Land

Lecture 7

Skaftafelljokull (glacier)

Part 0

Glacial Feature in Pics from Social Media



Part 1

10Be Exposure Dating

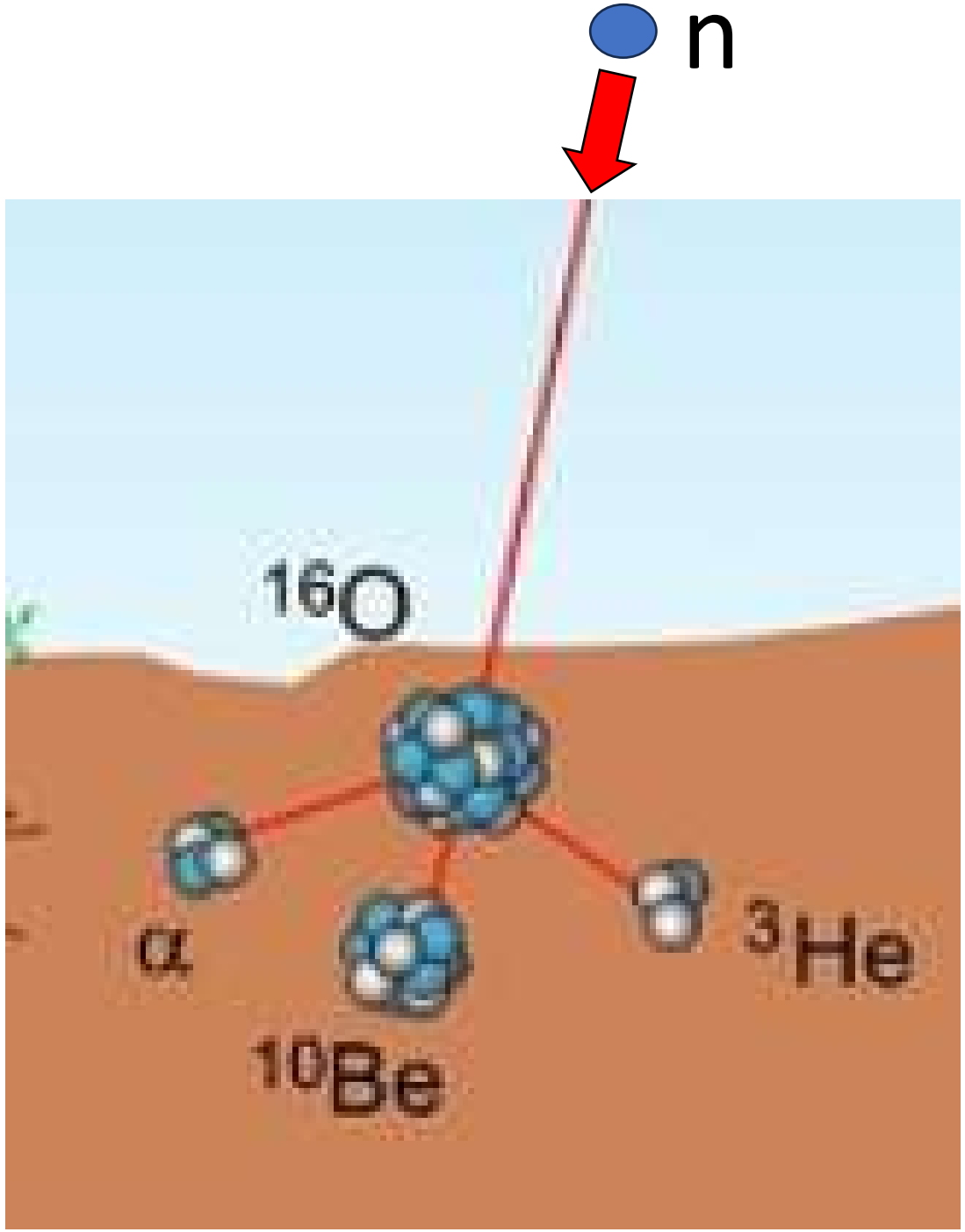
Beryllium-10, ^{10}Be

General	
Symbol	^{10}Be
Names	beryllium-10, 10Be, Be-10
Protons (*Z*)	4
Neutrons (*N*)	6
Nuclide data	
Natural abundance	trace
Half-life ($t_{1/2}$)	1.39×10^6 years

Long compared to end of Ice Age

Short compared to age of typical rocks

Produced by neutrons from cosmic rays interacting with oxygen in rocks



production rate is

3.6 atoms per year per gram

in quartz

production rate

thought to be fairly constant

when averaged over
hundreds of years

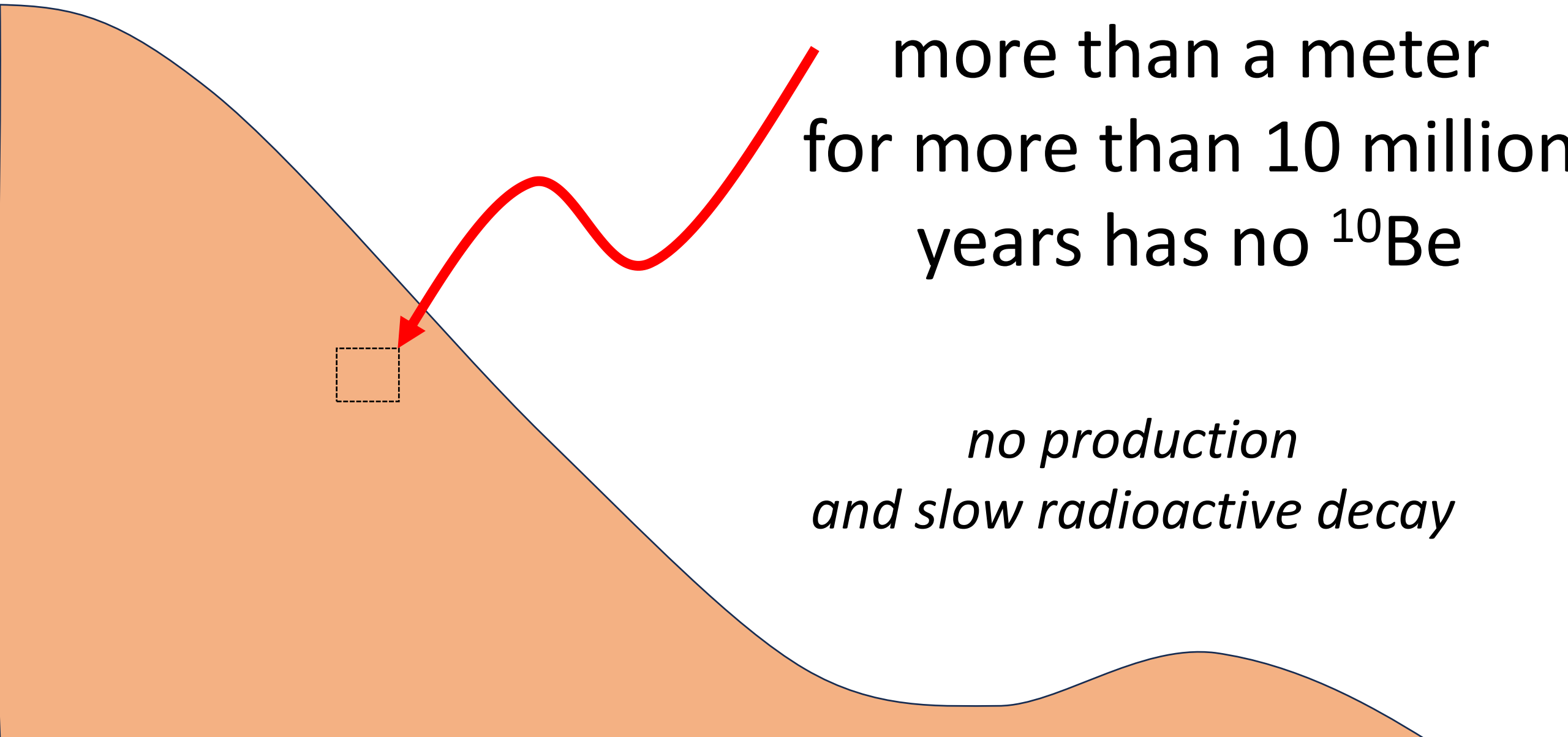
10 grams

432,000 atoms of ^{10}Be
since end of Ice Age

mixed with

$4x10^{23}$ atoms of oxygen

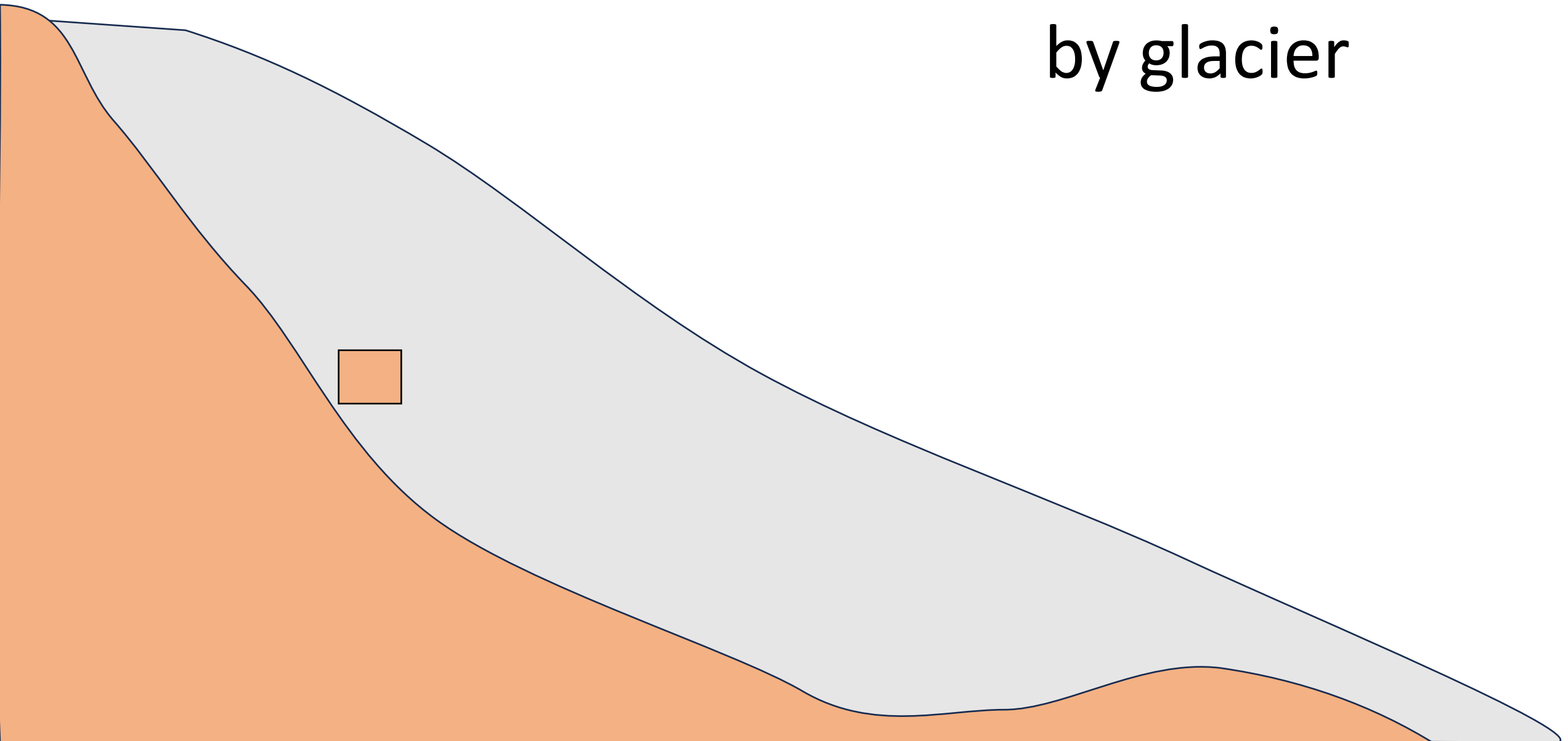
penetration depth of neutrons into rock is a few centimeters



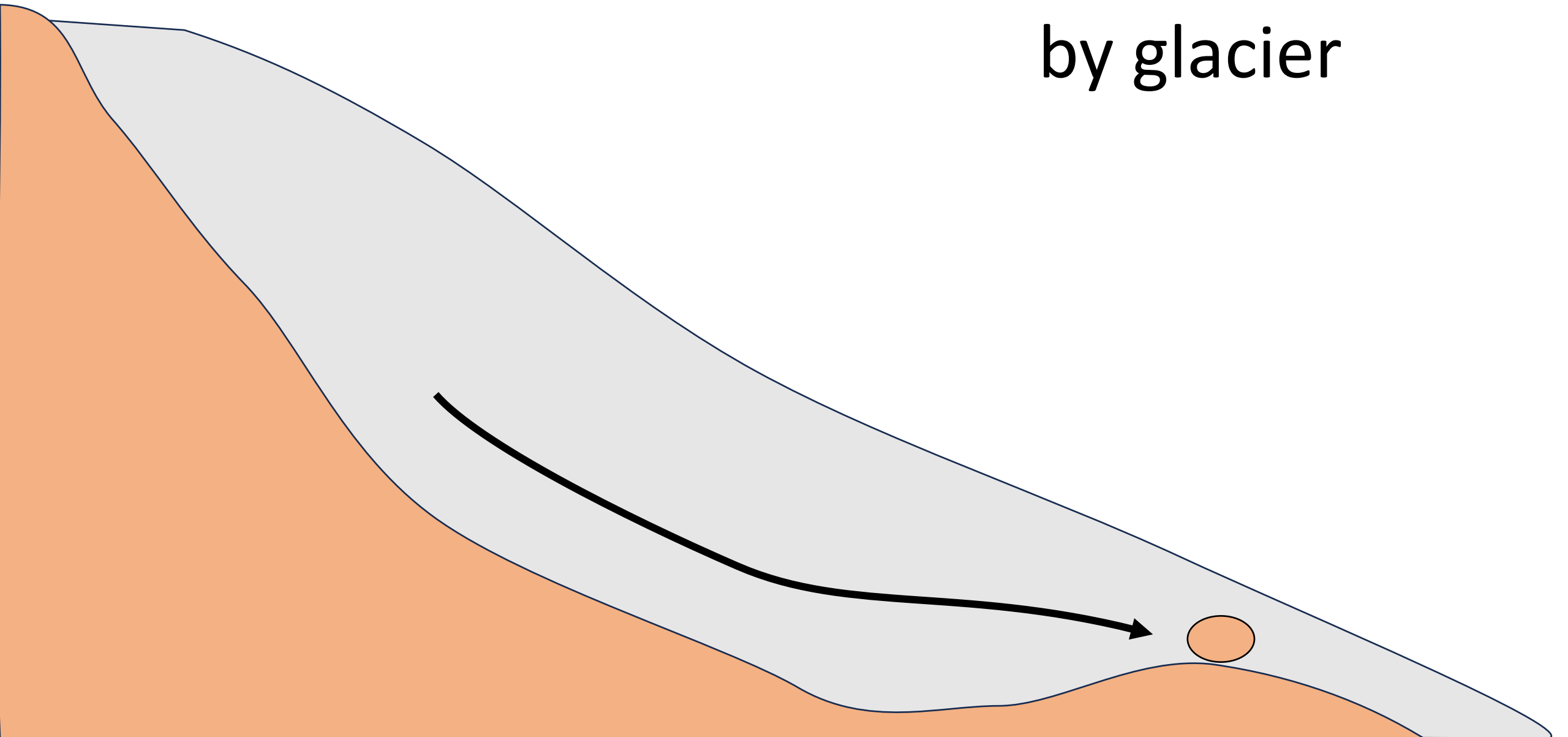
rock buried
more than a meter
for more than 10 million
years has no ^{10}Be

no production
and slow radioactive decay

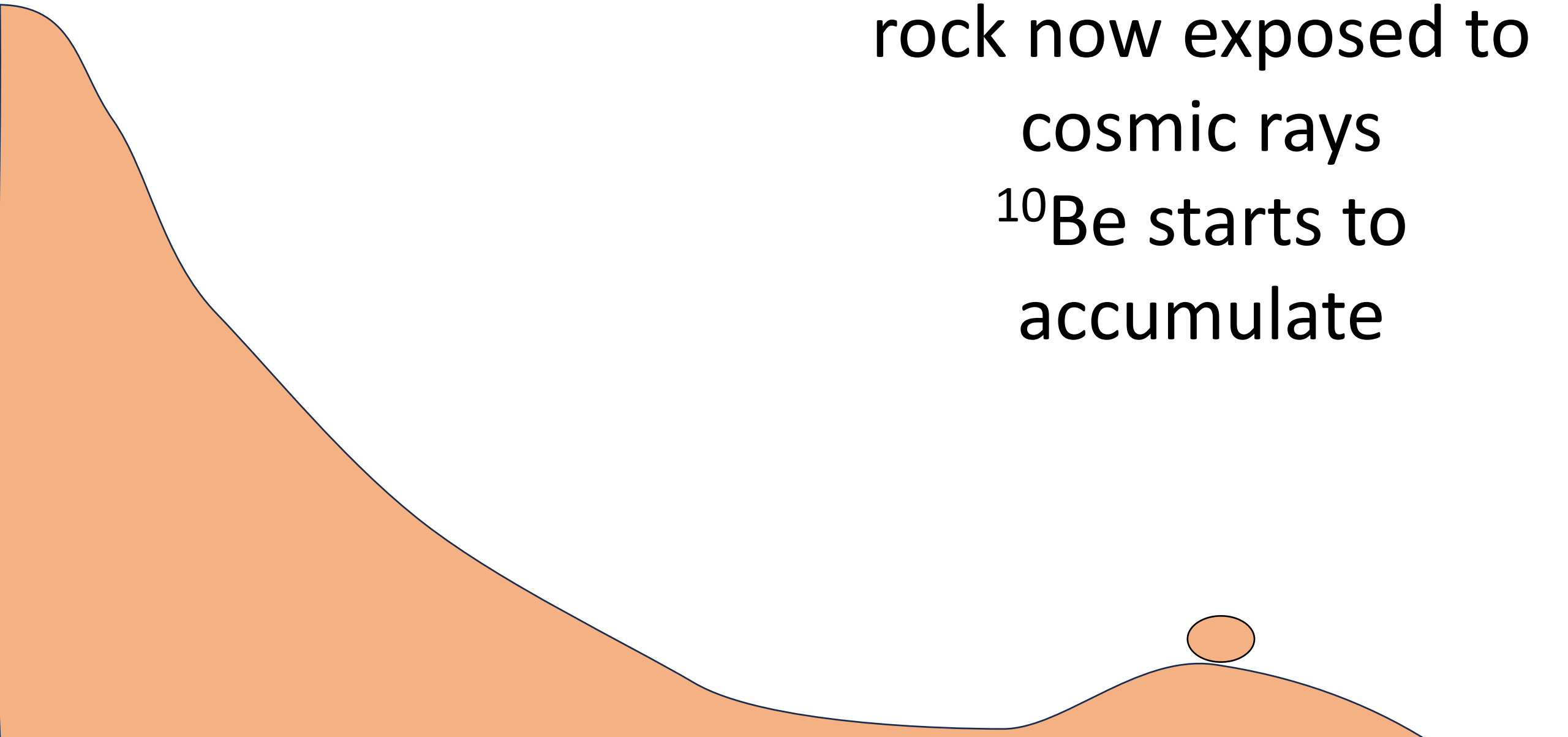
rock quarried by glacier



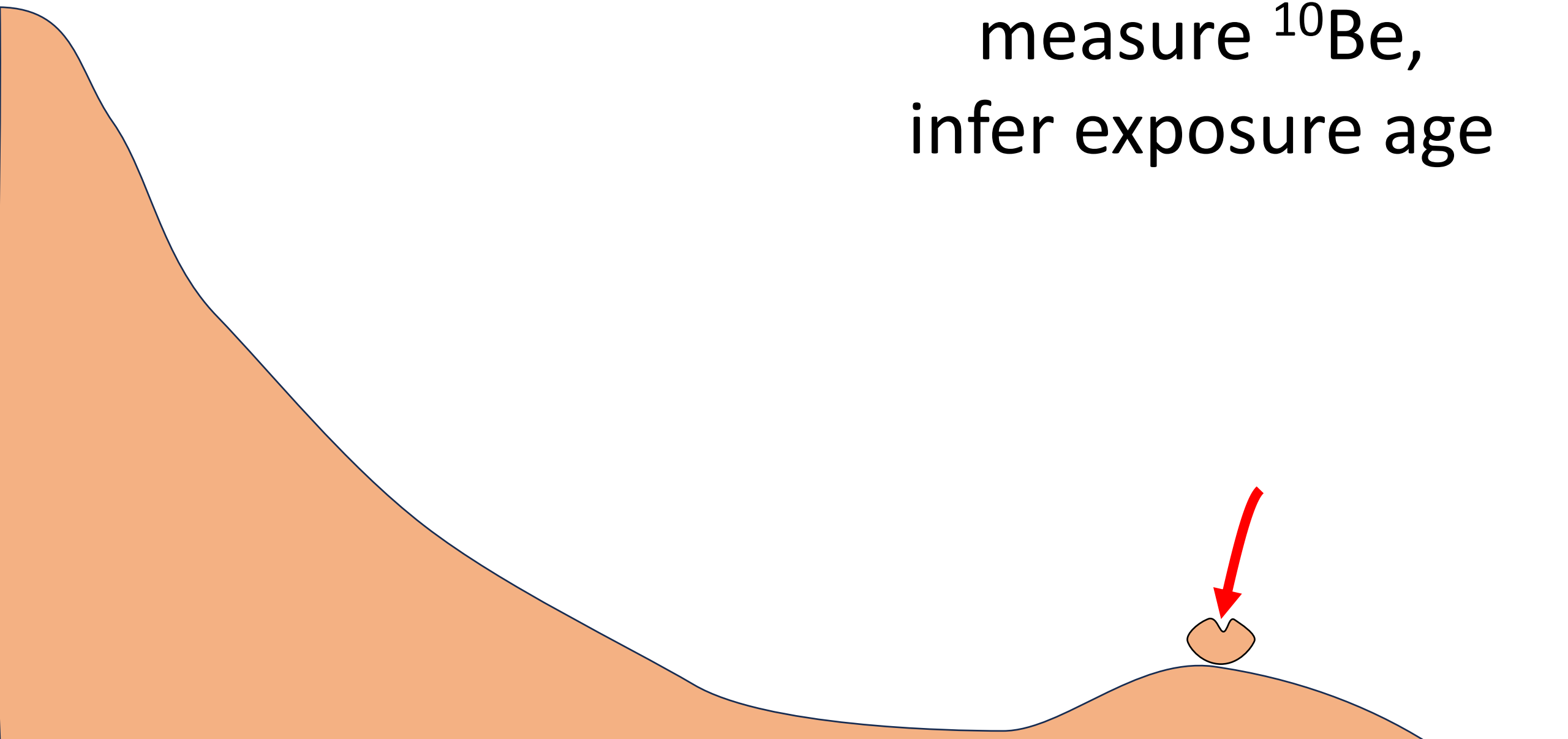
rock transported
by glacier



glacier melts
rock now exposed to cosmic rays
^{10}Be starts to accumulate



sample rock,
measure ^{10}Be,
infer exposure age

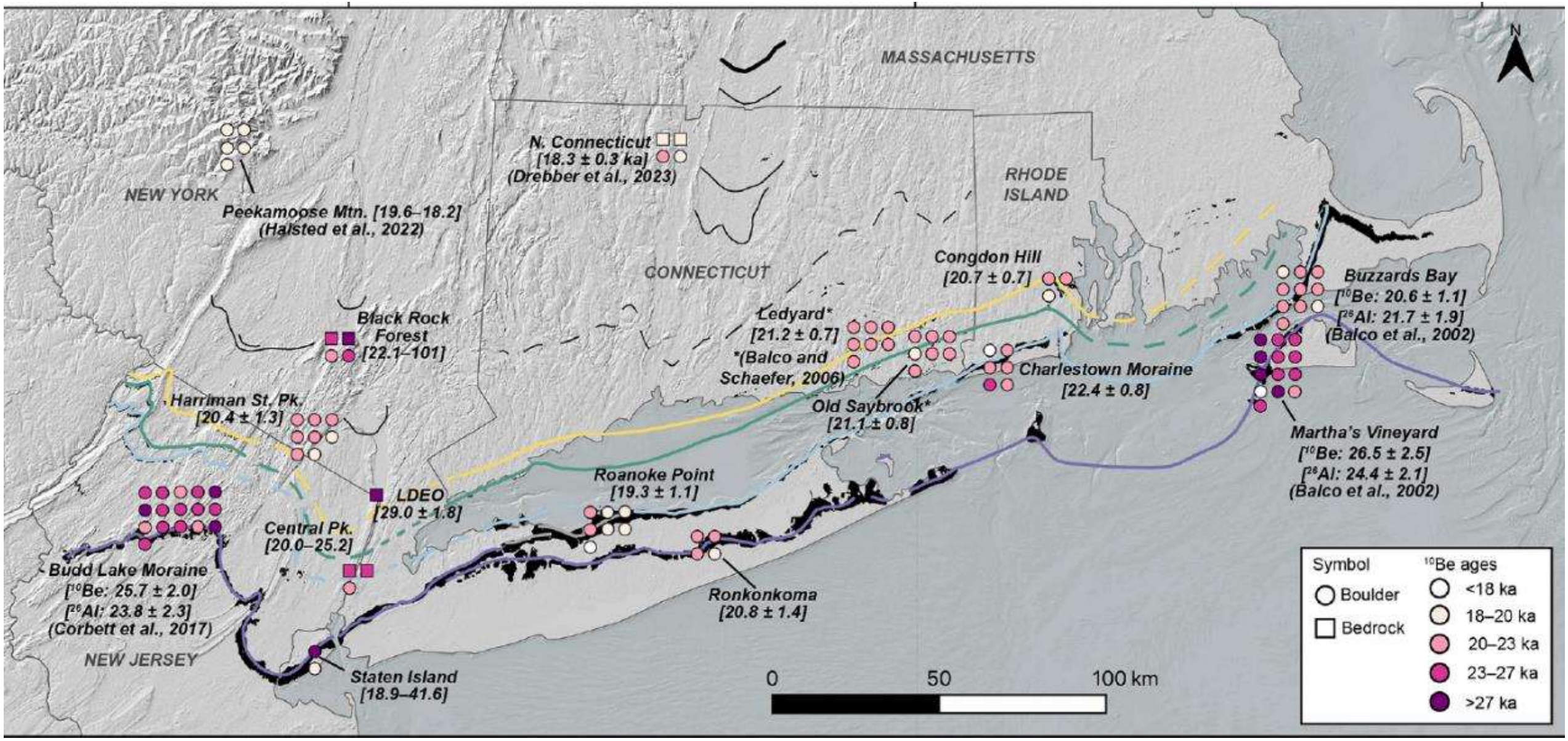


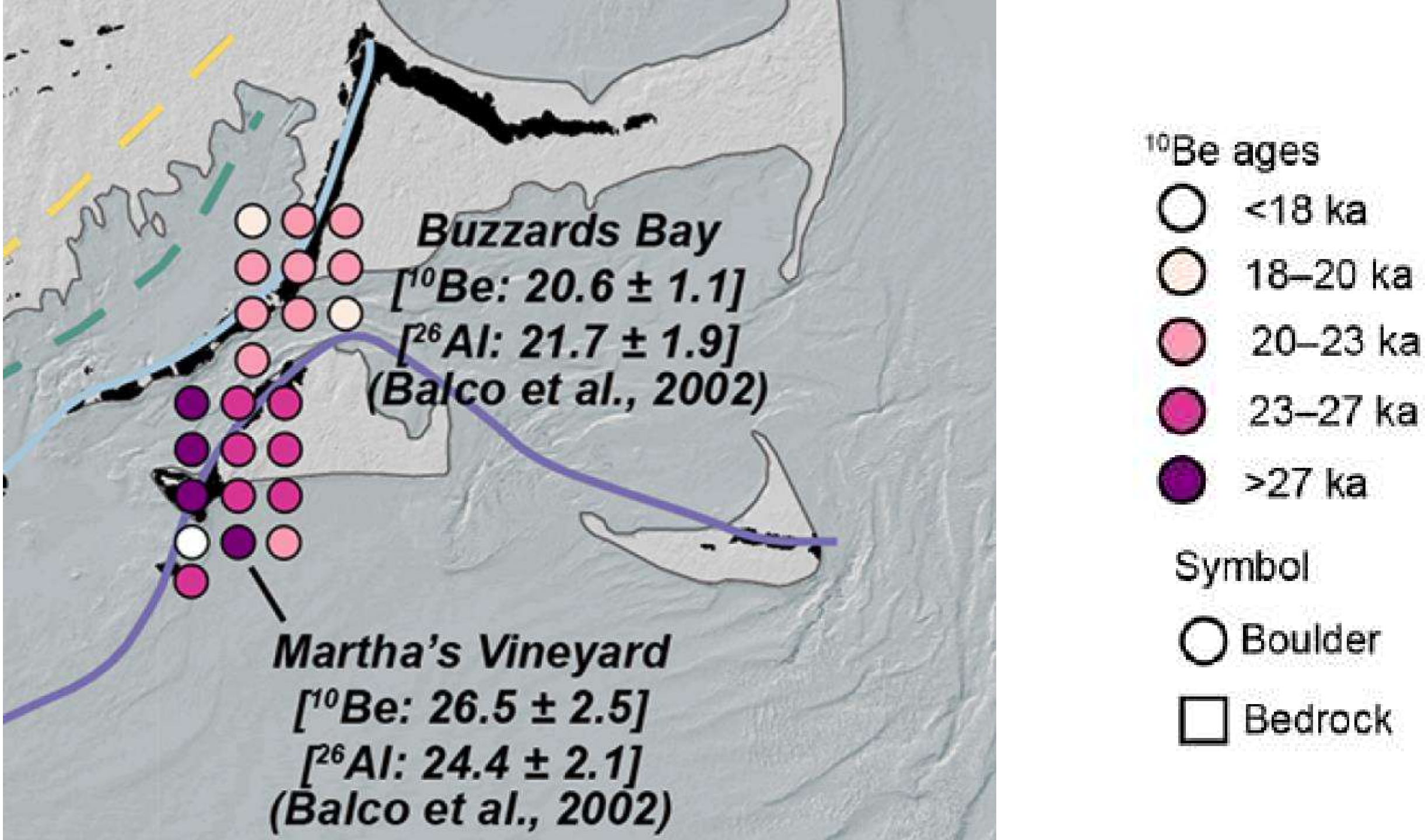
Part 2A

Using Erratic Boulders to date the end of the Ice Age

Part 2A

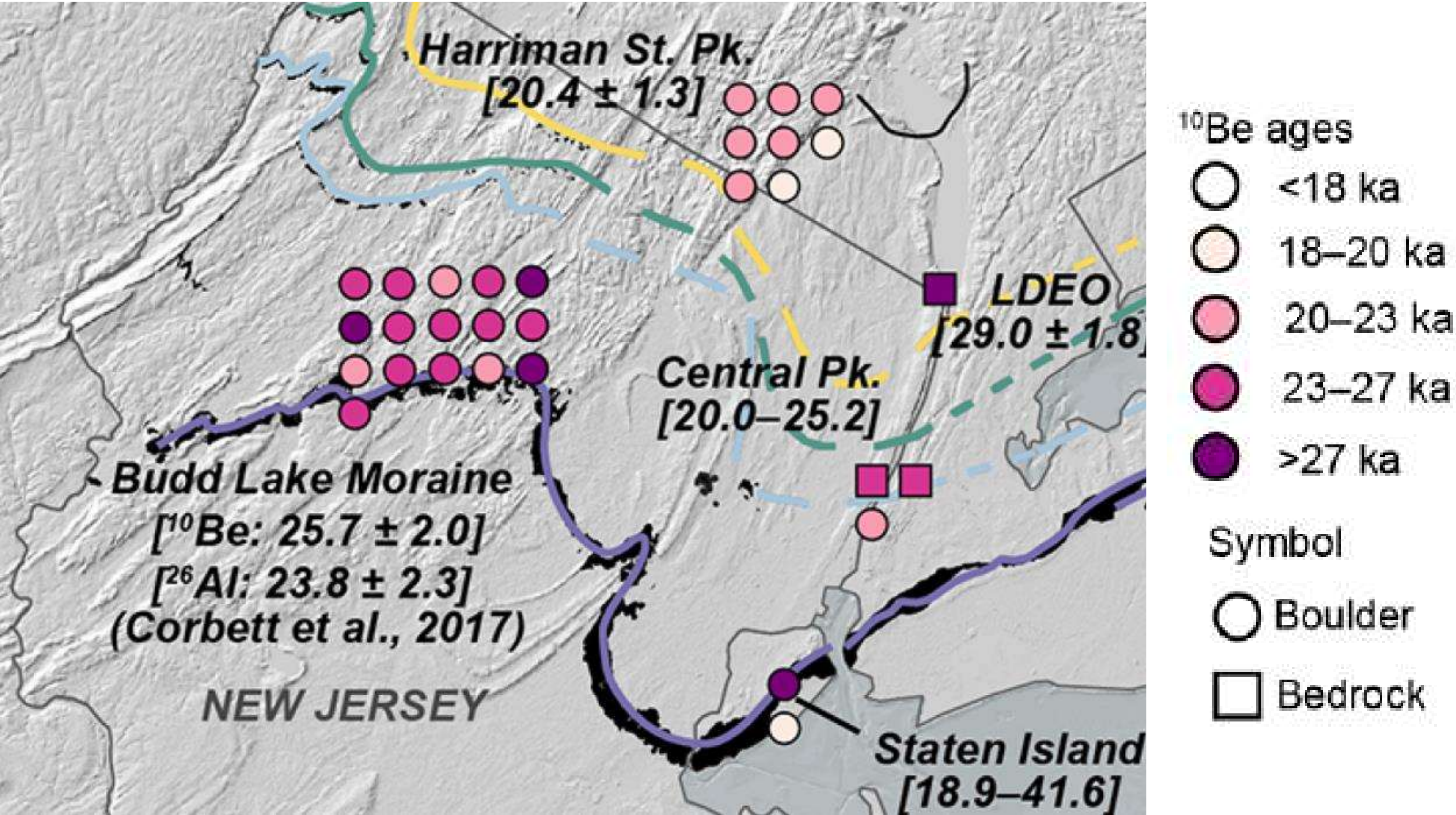
Erratic Boulders


MASSACHUSETTS
N
NEW YORK
Peekamoose Mtn. [19.6–18.2]
(Halsted et al., 2022)
N. Connecticut
[18.3 ± 0.3 ka]
(Drebber et al., 2023)
RHODE
ISLAND
CONNECTICUT
Congdon Hill
[20.7 ± 0.7]
Buzzards Bay
[10Be: 20.6 ± 1.1]
[26Al: 21.7 ± 1.9]
(Balco et al., 2002)
Black Rock
Forest
[22.1–101]
Ledyard*
[21.2 ± 0.7]
*(Balco and
Schaefer, 2006)
Charlestown Moraine
[22.4 ± 0.8]
Harriman St. Pk.
[20.4 ± 1.3]
Old Saybrook*
[21.1 ± 0.8]
Martha's Vineyard
[10Be: 26.5 ± 2.5]
[26Al: 24.4 ± 2.1]
(Balco et al., 2002)
Roanoke Point
[19.3 ± 1.1]
LDEO
[29.0 ± 1.8]
Central Pk.
[20.0–25.2]
Budd Lake Moraine
[10Be: 25.7 ± 2.0]
[26Al: 23.8 ± 2.3]
(Corbett et al., 2017)
Ronkonkoma
[20.8 ± 1.4]
NEW JERSEY
Staten Island
[18.9–41.6]
0
50
100 km
Symbol
Boulder
Bedrock
10Be ages
<18 ka
18–20 ka
20–23 ka
23–27 ka
>27 ka


Buzzards Bay
[10Be: 20.6 ± 1.1]
[26Al: 21.7 ± 1.9]
(Balco et al., 2002)
Martha's Vineyard
[10Be: 26.5 ± 2.5]
[26Al: 24.4 ± 2.1]
(Balco et al., 2002)
10Be ages
<18 ka
18–20 ka
20–23 ka
23–27 ka
>27 ka
Symbol
Boulder
Bedrock

about

5,000 year age difference
between the two moraines


Harriman St. Pk.
[20.4 ± 1.3]
LDEO
[29.0 ± 1.8]
Central Pk.
[20.0–25.2]
Budd Lake Moraine
[10Be: 25.7 ± 2.0]
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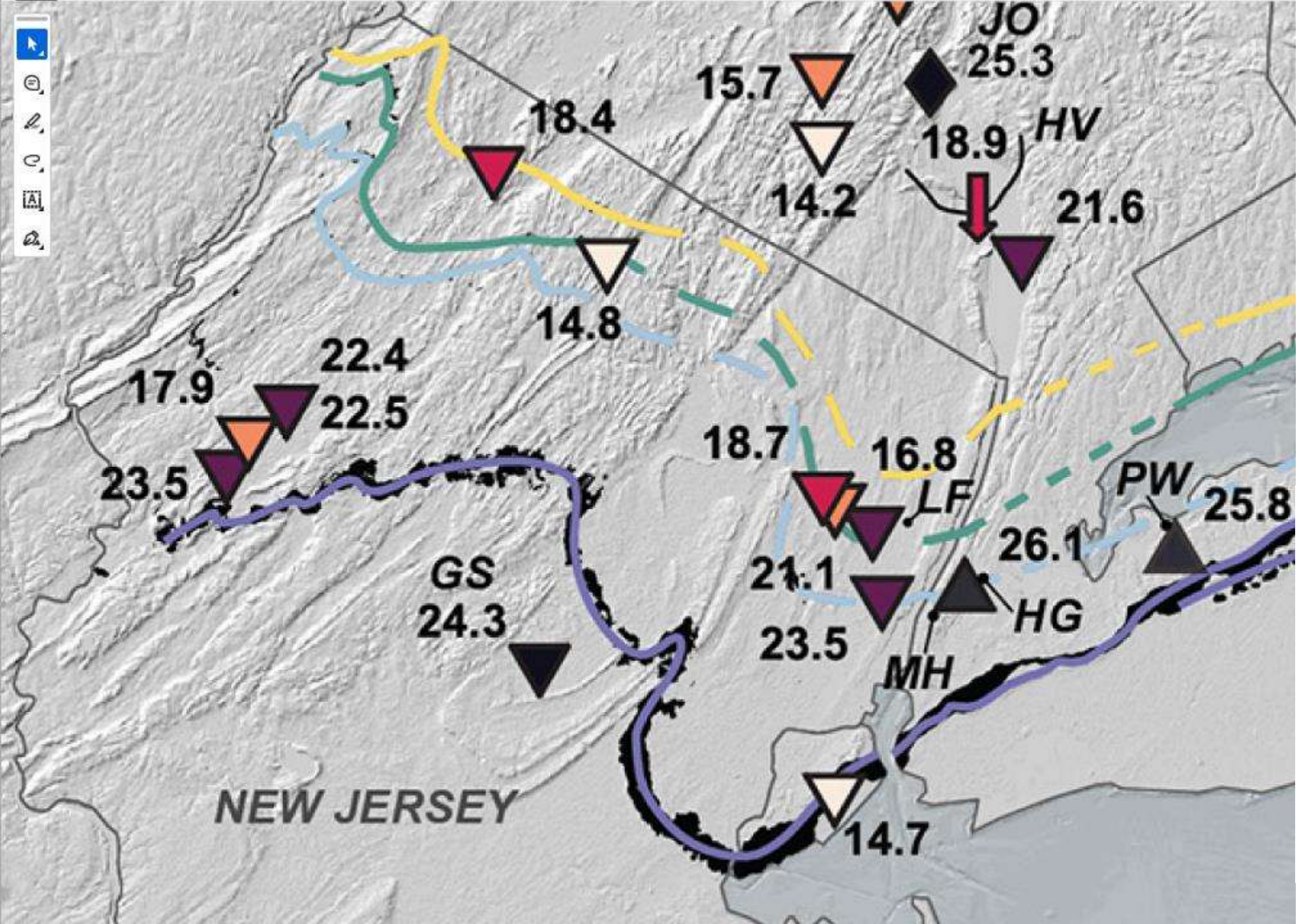
(Corbett et al., 2017)
NEW JERSEY
Staten Island
[18.9–41.6]
10Be ages
<18 ka
18–20 ka
20–23 ka
23–27 ka
>27 ka
Symbol
Boulder
Bedrock

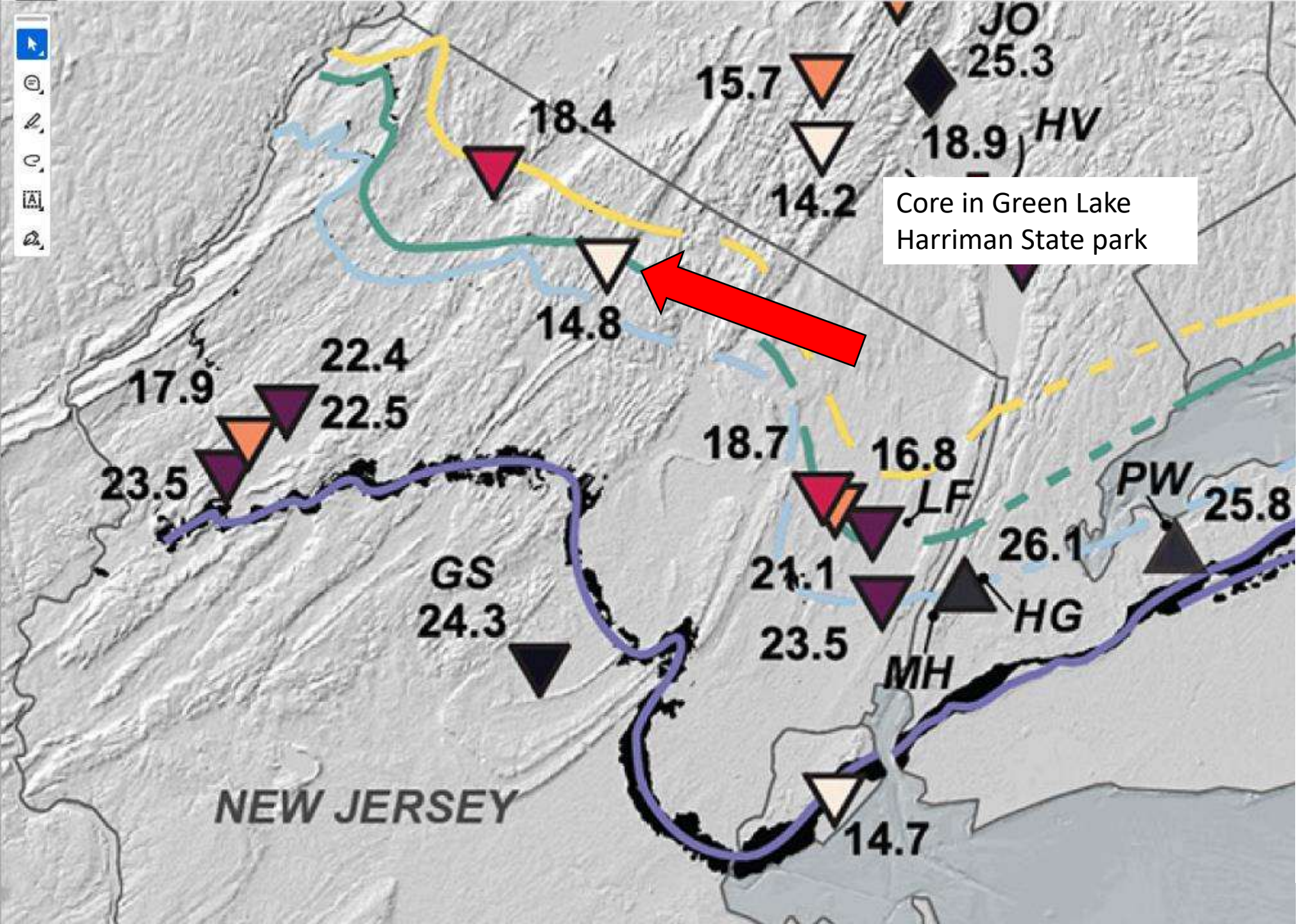


Age (ka)

- <15
- 15–18
- 18–20.5
- 20.5–24
- >24

Symbol

- Min. ^{14}C age
- Max ^{14}C age
- Ice proximal varv
- OSL age
- Basal varve age
- Min. varve limit



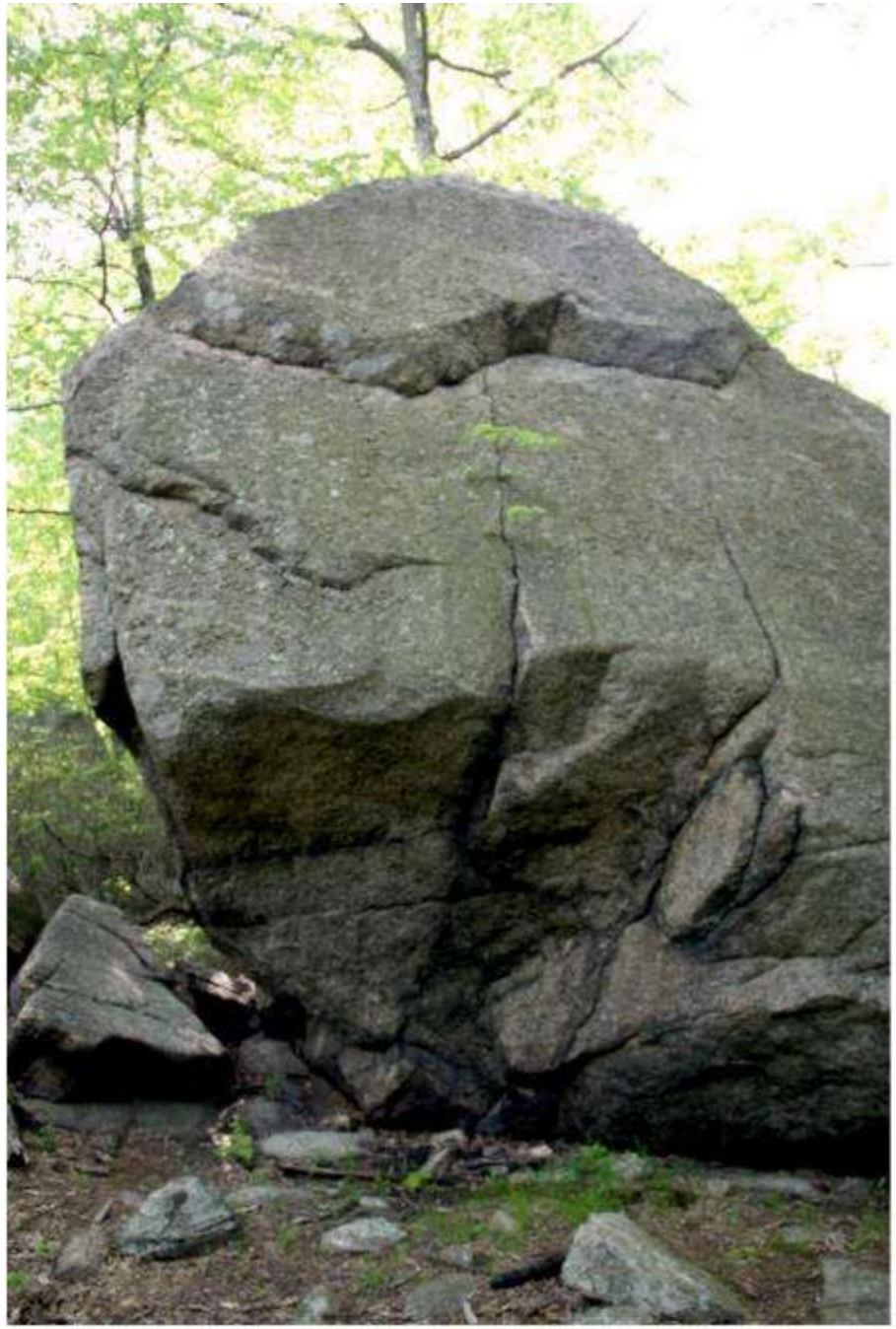
Age (ka)

- <15
- 15–18
- 18–20.5
- 20.5–24
- >24

Symbol

- Min. ^{14}C age
- Max ^{14}C age
- Ice proximal varv
- OSL age
- Basal varve age
- Min. varve limit

Green Pond

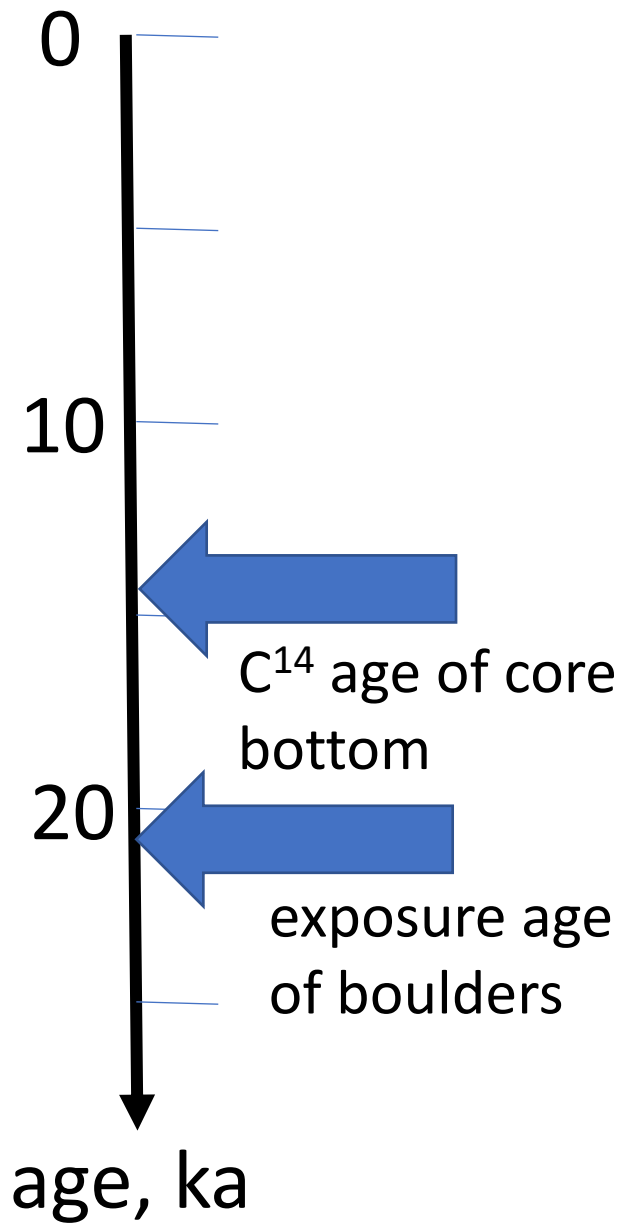


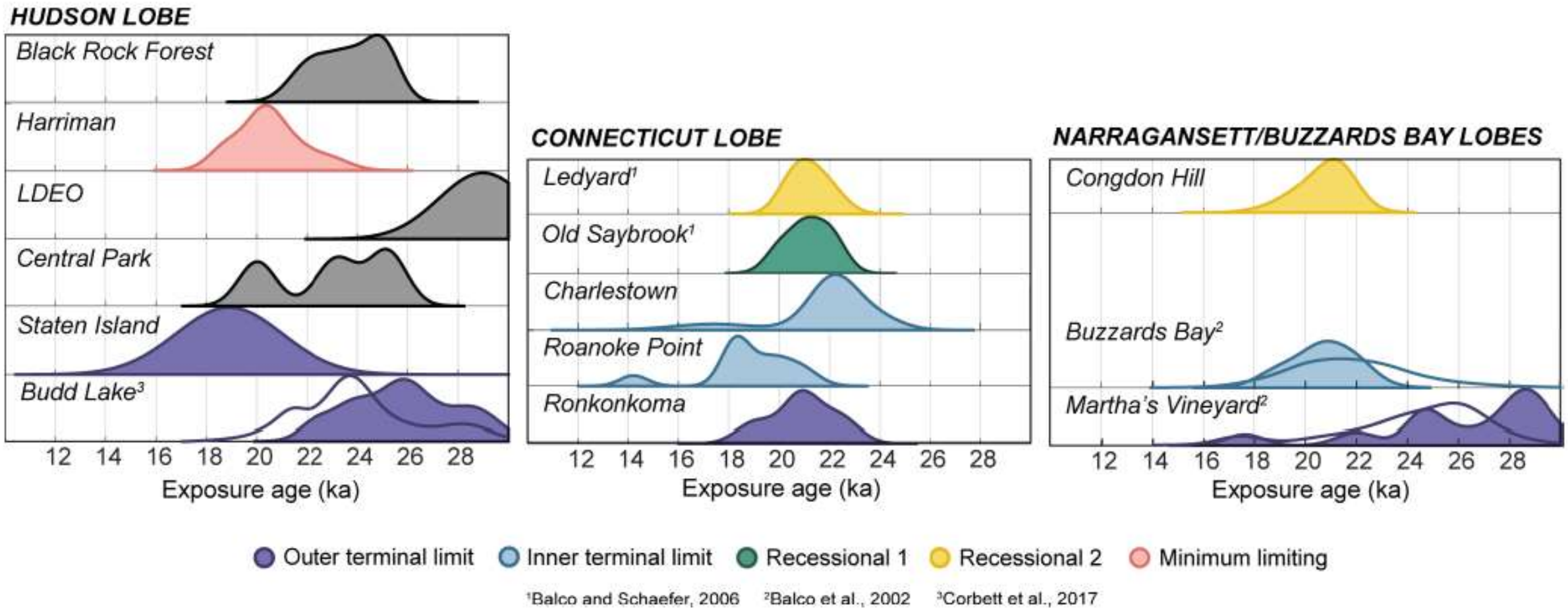
Grandpa Rock, along Suffern - Bear Mt Trail

Unsolved mystery: why the big age difference?

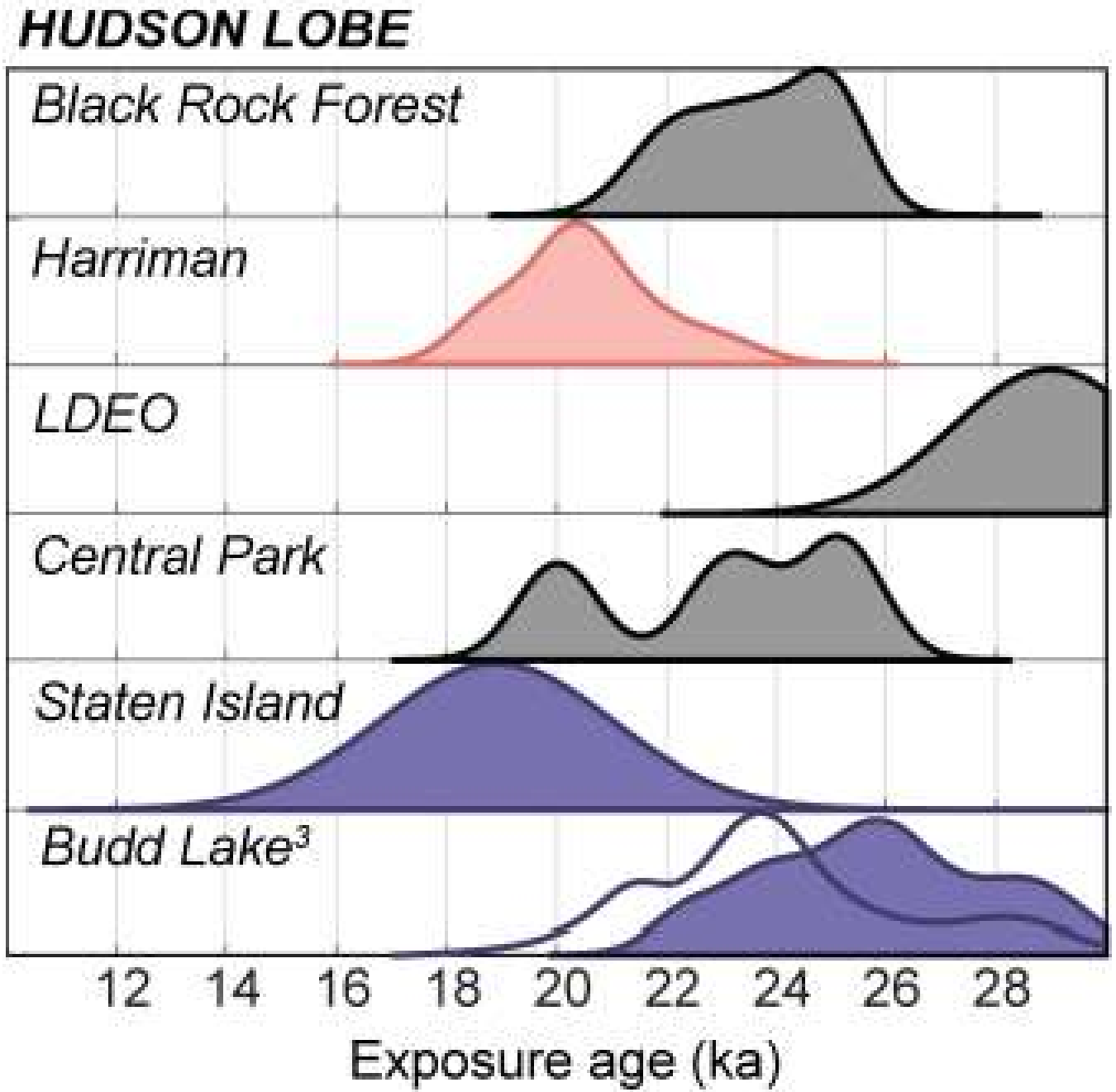
Green Pond

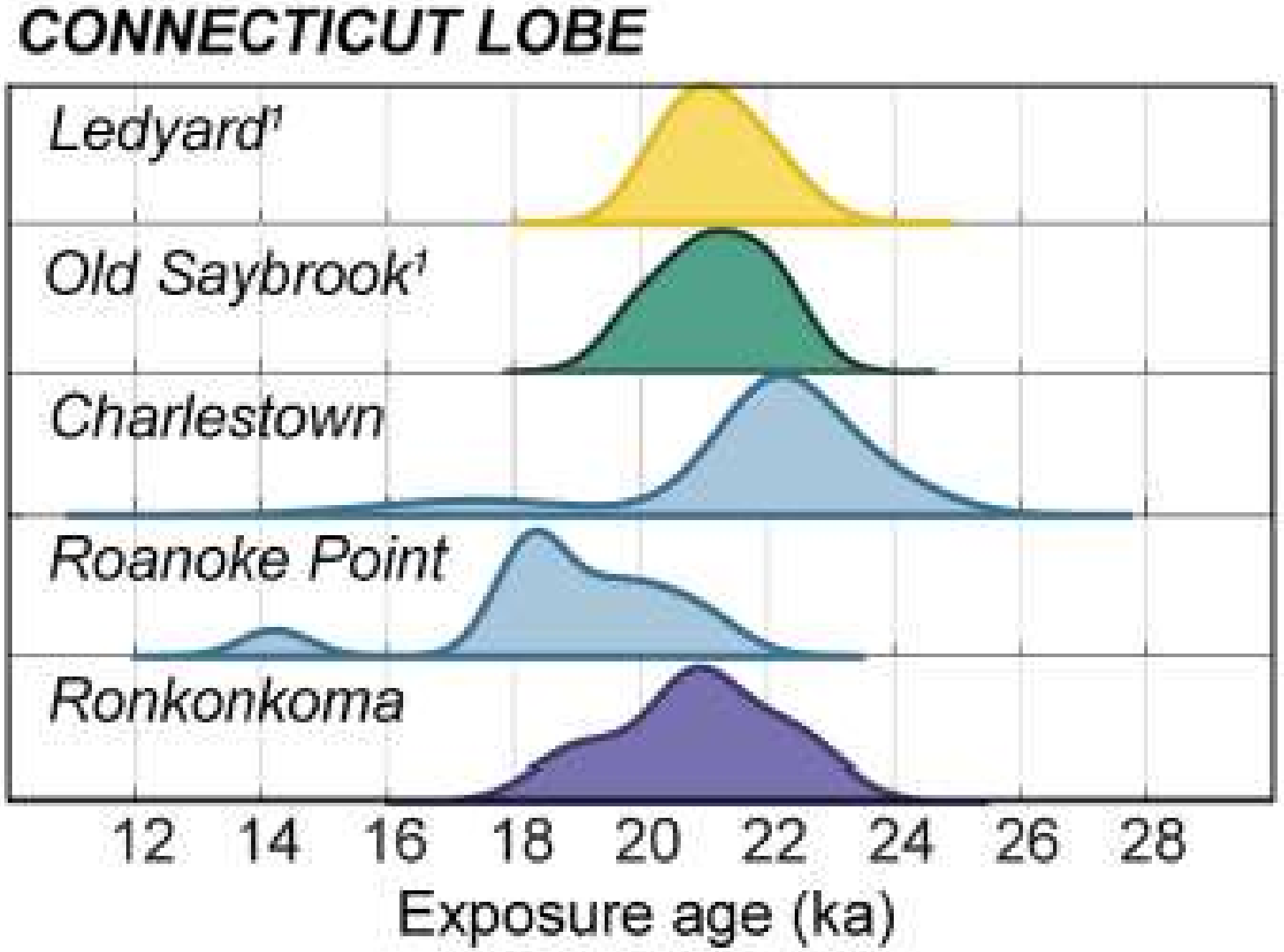
Grandpa Rock, along Suffern - Bear Mt Trail



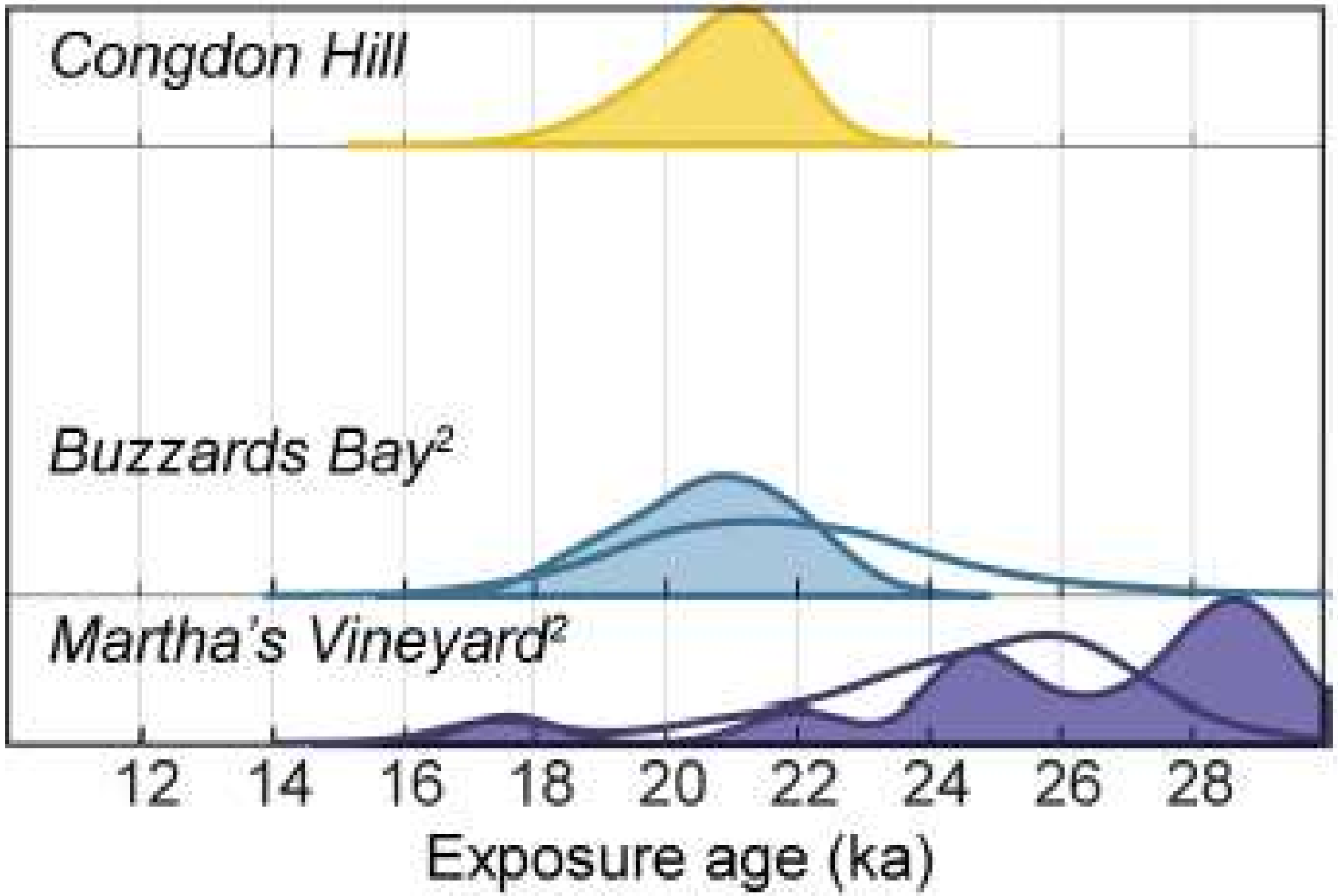


[1]Balco and Schaefer, 2006 [2]Balco et al., 2002 [3]Corbett et al., 2017


HUDSON LOBE
Black Rock Forest
Harriman
LDEO
Central Park
Staten Island
Budd Lake[3]
12
14
16
18
20
22
24
26
28
Exposure age (ka)

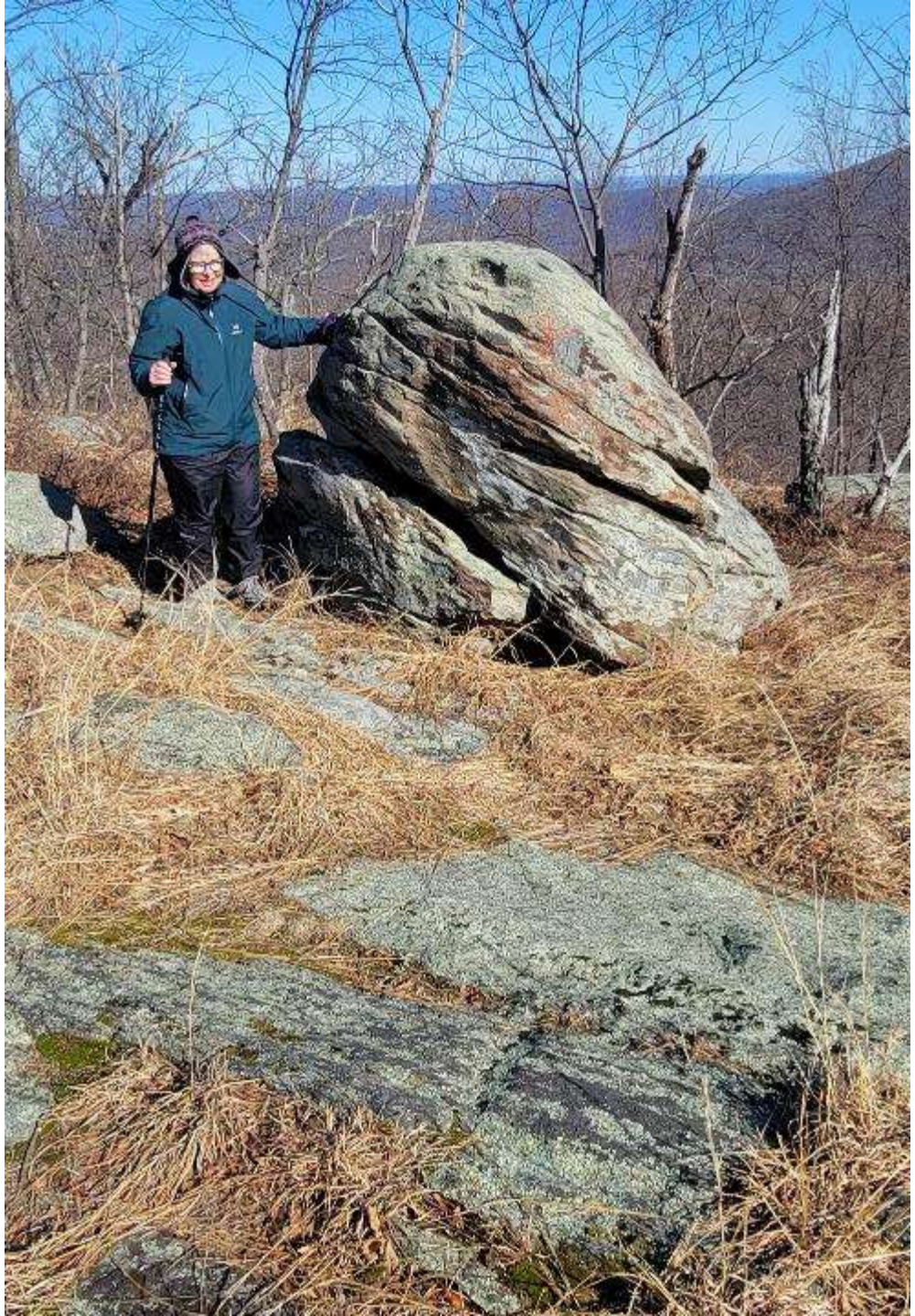

CONNECTICUT LOBE
Ledyard[1]
Old Saybrook[1]
Charlestown
Roanoke Point
Ronkonkoma
12
14
16
18
20
22
24
26
28
Exposure age (ka)

NARRAGANSETT/BUZZARDS BAY LOBES



Part 2**B**

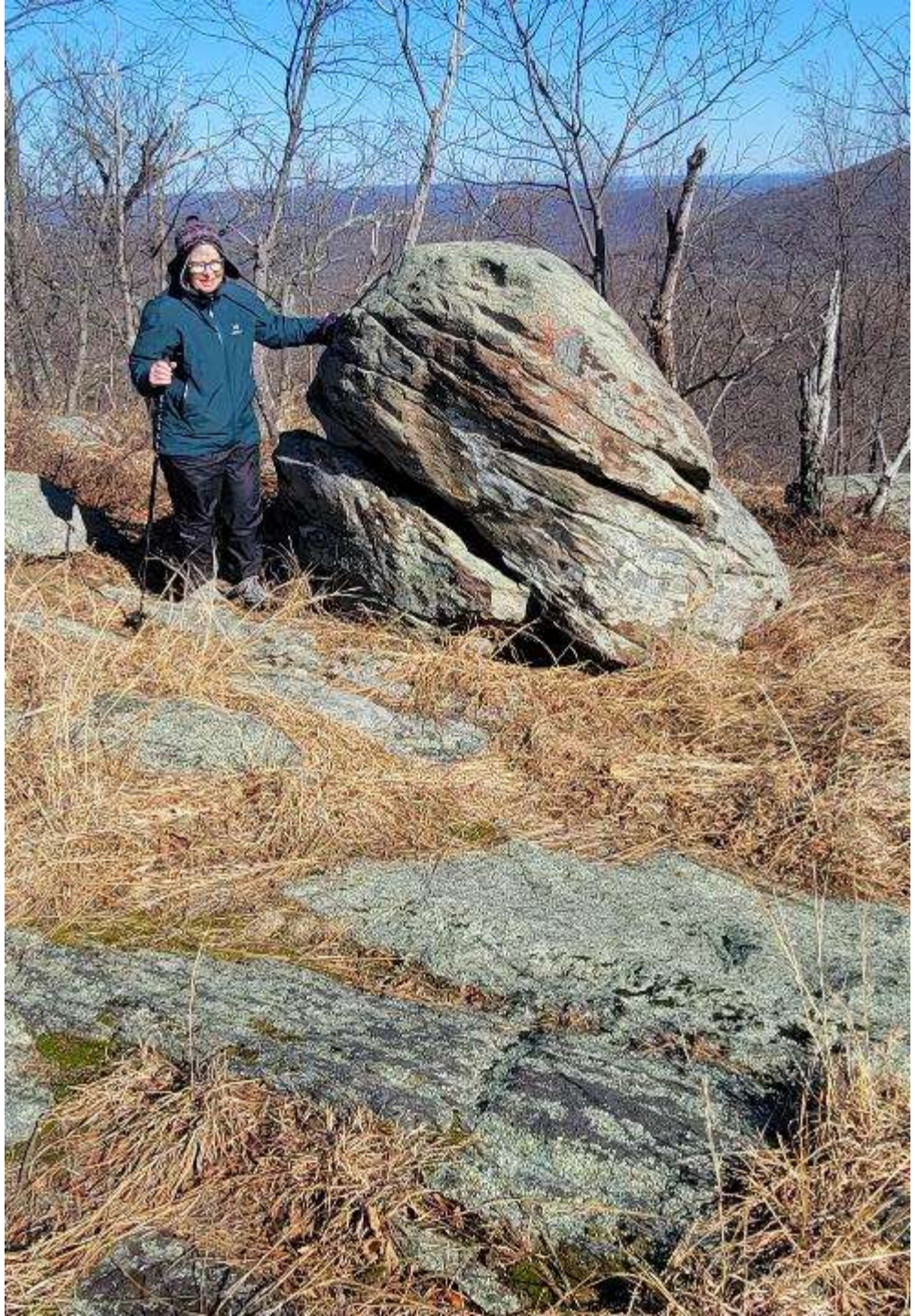
Using Erratic Boulders to Determine Ice Flow Directions



Erratic Boulder

Sandstone Boulder

Gneiss Ledge



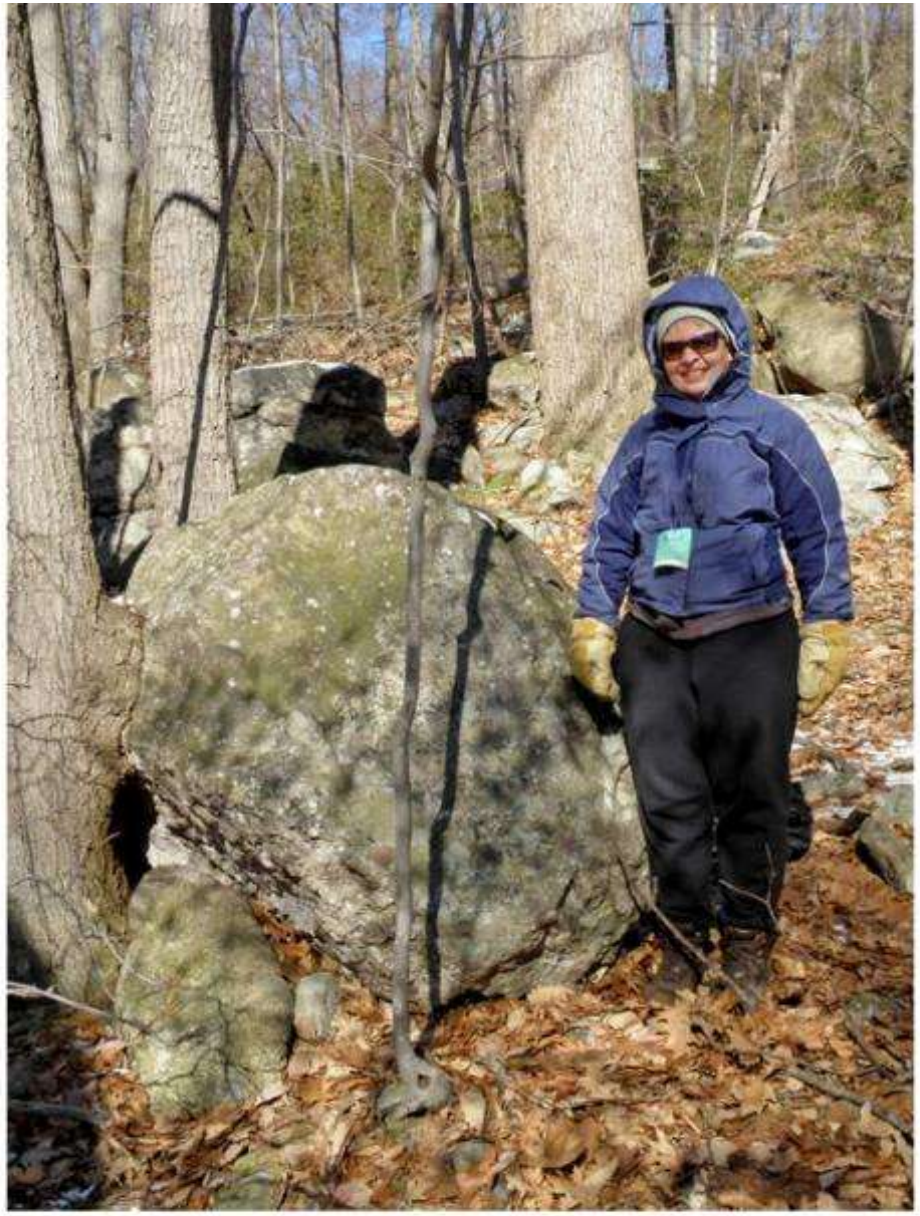
Sandstone is a very common sedimentary rock so lots of places sandstone could have come from

Fossil imprints of Brachiopod shells

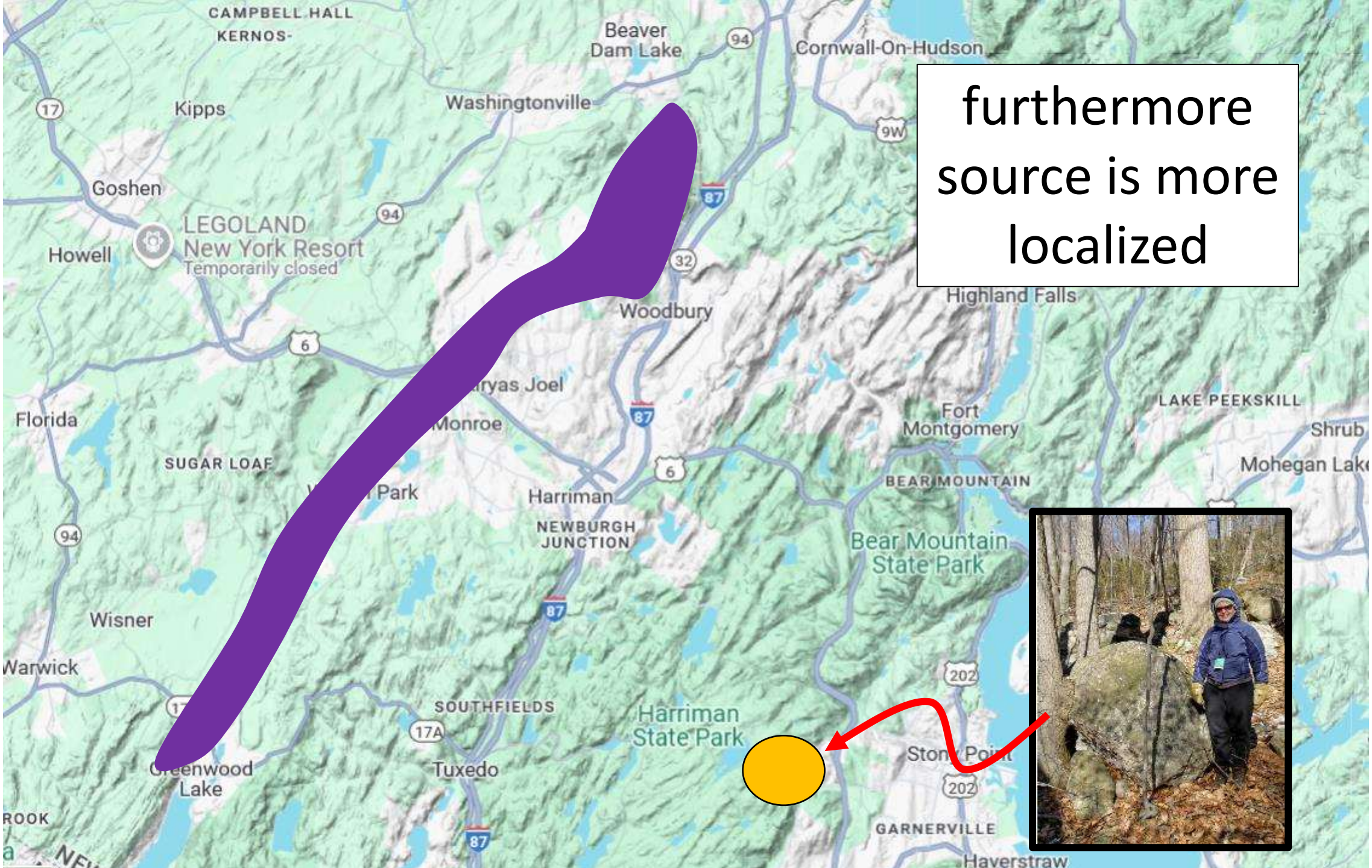
might help to reduce source possibilities

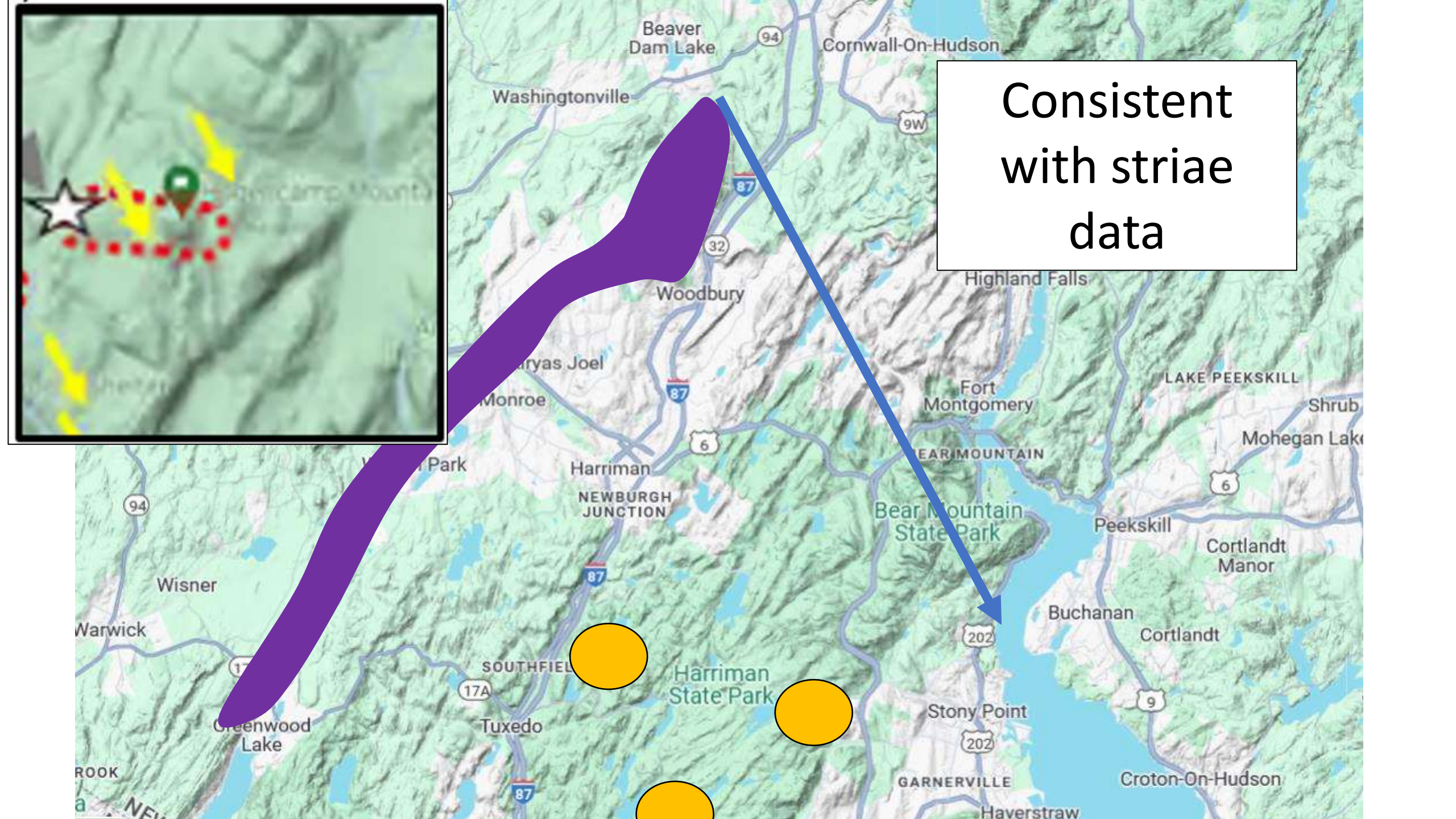
Puddingstone on Schunemunk Mountain

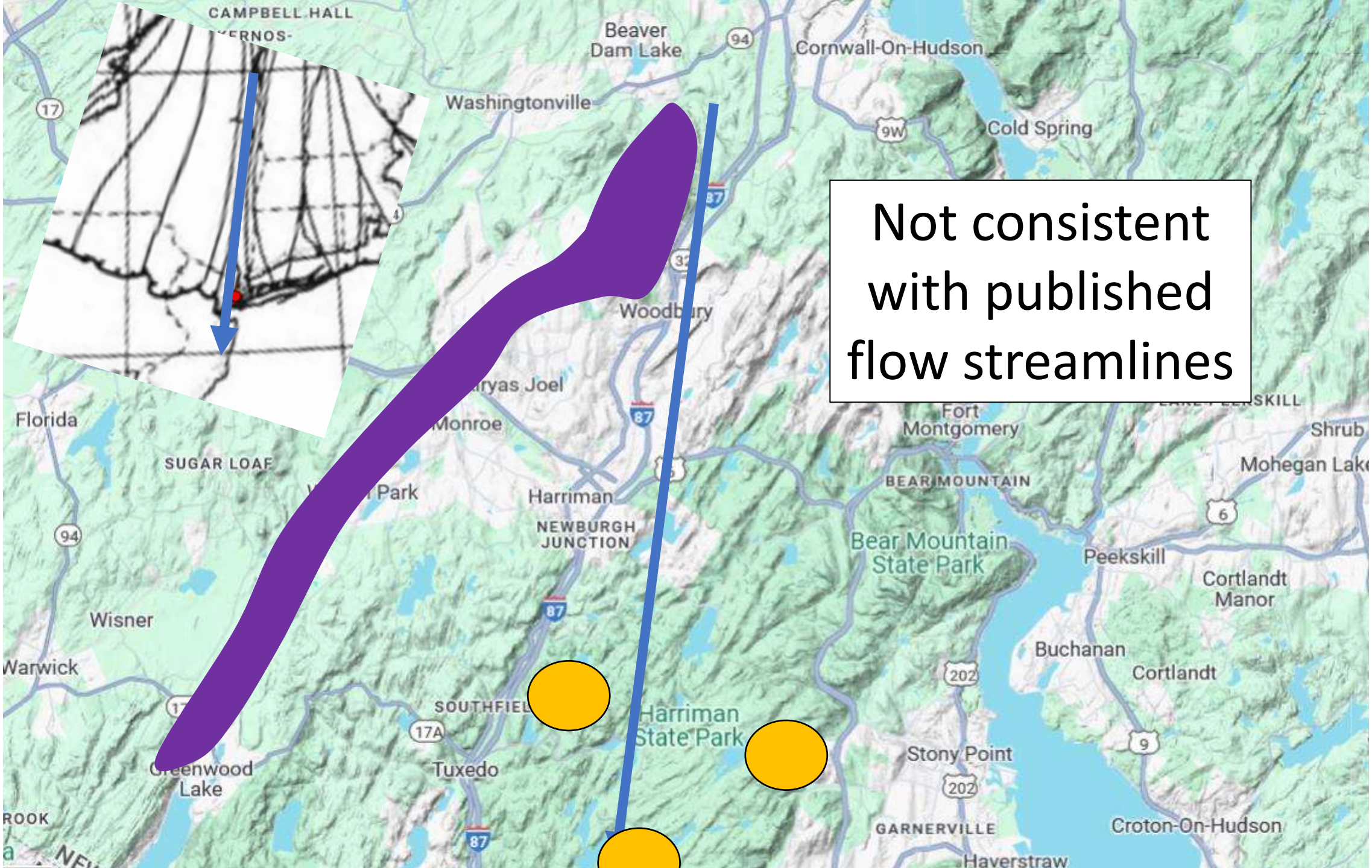
very recognizable

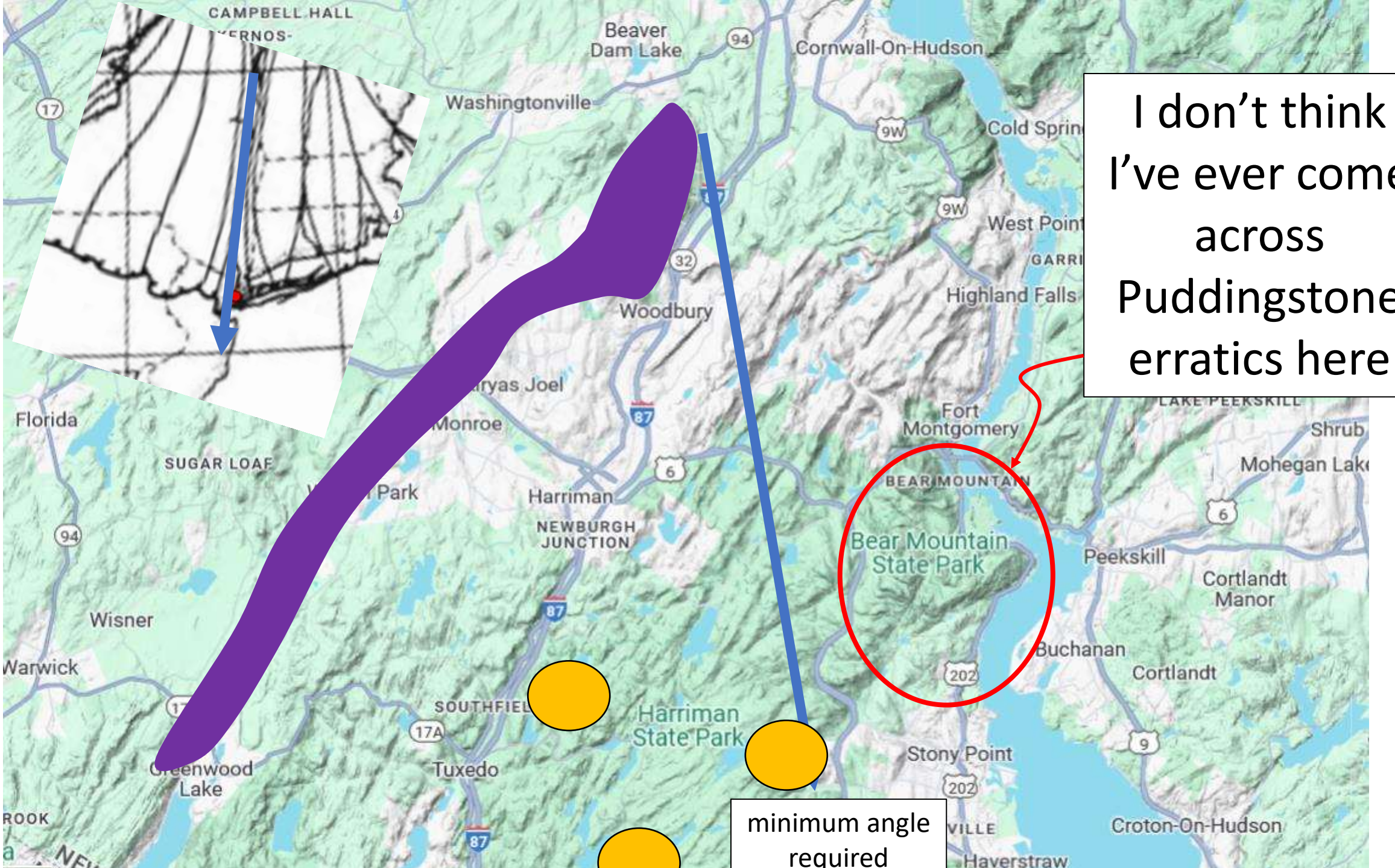


Dallas Abbott, by glacial eratic boulder composed of Skunnemunk Conglomerate


CAMPBELL HALL
KERNOS-
Beaver Dam Lake
Cornwall-On-Hudson
Washingtonville
Kipps
Goshen
LEGOLAND New York Resort
Temporarily closed
Howell
Woodbury
Highland Falls
Florida
SUGAR LOAF
Monroe
Harriman
NEWBURGH JUNCTION
Fort Montgomery
LAKE PEEKSKILL
Shrub
Mohegan Lak
BEAR MOUNTAIN
Bear Mountain State Park
Wisner
Warwick
SOUTHFIELDS
Harriman State Park
Tuxedo
Greenwood Lake
Stony Point
GARNERVILLE
Haverstraw
furthermore source is more localized

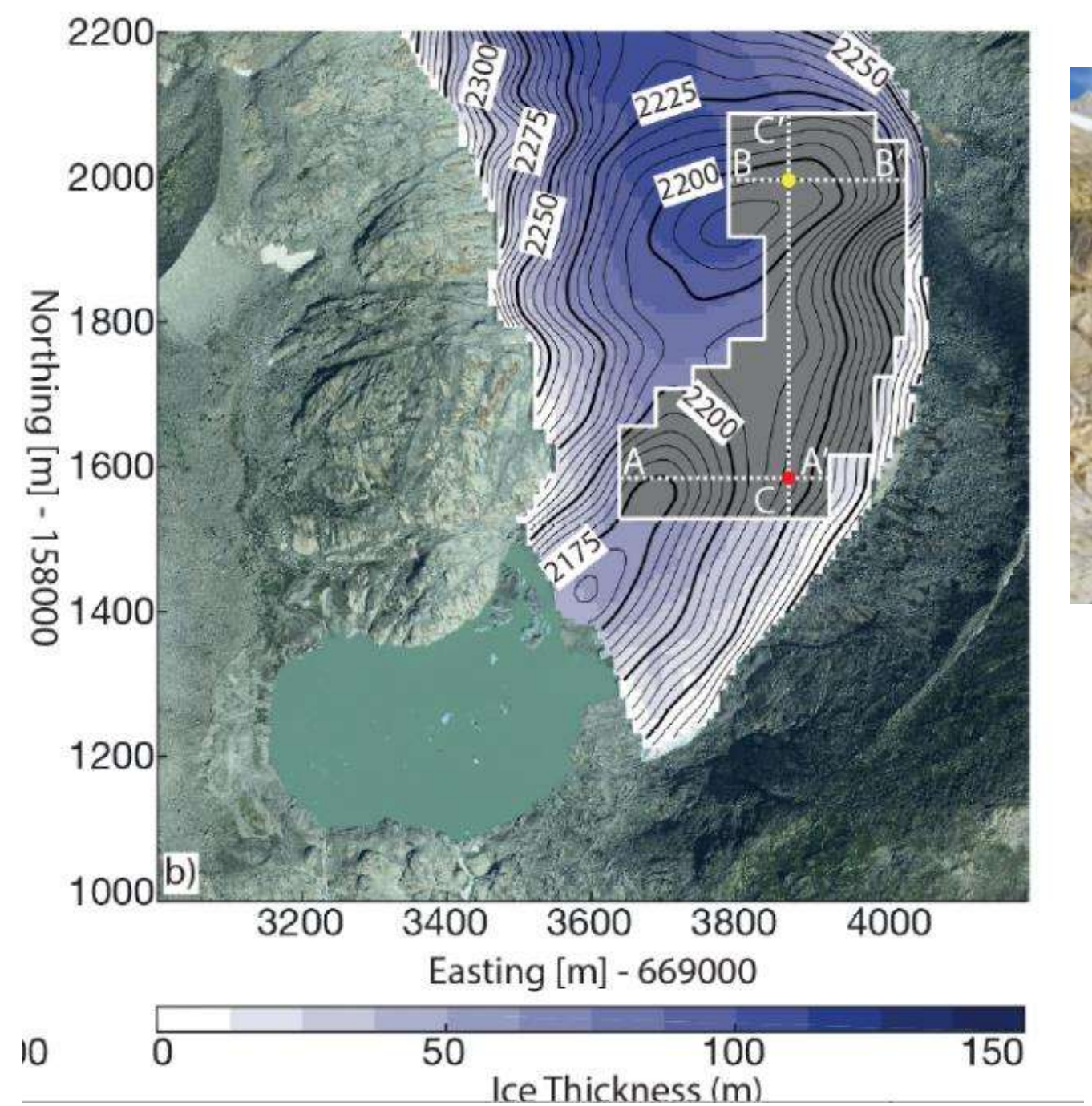

Consistent with striae data
Beaver Dam Lake
Washingtonville
Cornwall-On-Hudson
Woodbury
Highland Falls
Monroe
Harriman
NEWBURGH JUNCTION
Fort Montgomery
LAKE PEEKSKILL
Shrub
Mohegan Lak
BEAR MOUNTAIN
Bear Mountain State Park
Peekskill
Cortlandt Manor
Buchanan
Cortlandt
Wisner
Warwick
SOUTHFIELD
Harriman State Park
Tuxedo
Greenwood Lake
Stony Point
GARNERVILLE
Croton-On-Hudson
Haverstraw
Park
94
87
32
9W
6
17A
202
9


Not consistent with published flow streamlines
CAMPBELL HALL
Beaver Dam Lake
Cornwall-On-Hudson
Washingtonville
Cold Spring
Woodbury
Florida
SUGAR LOAF
Monroe
Harriman
NEWBURGH JUNCTION
Fort Montgomery
BEAR MOUNTAIN
Bear Mountain State Park
Peekskill
Cortlandt Manor
Shrub
Mohegan Lake
Wisner
Warwick
Buchanan
Cortlandt
Harriman State Park
Stony Point
Tuxedo
Greenwood Lake
GARNERVILLE
Croton-On-Hudson
Haverstraw

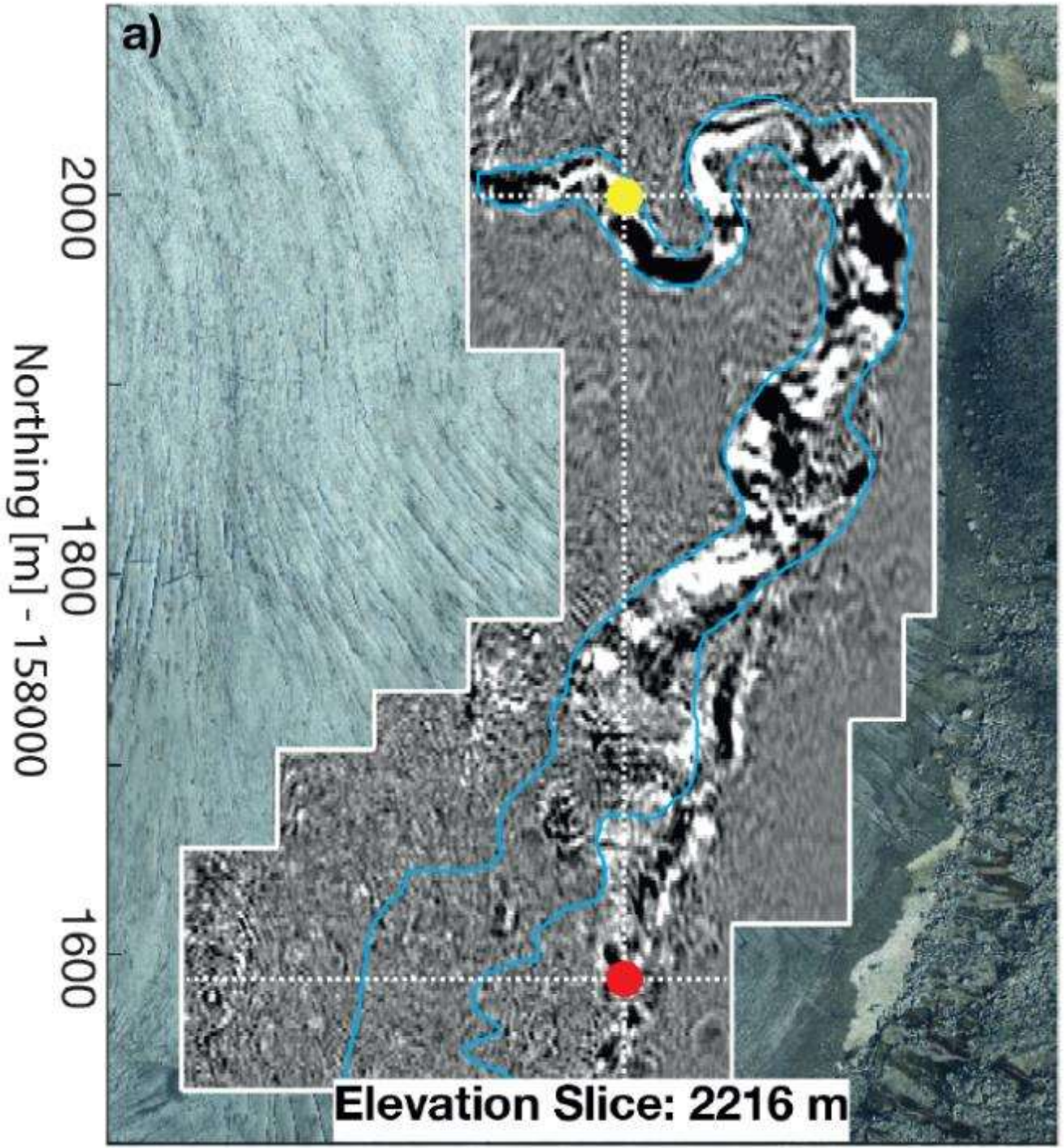

I don't think I've ever come across Puddingstone erratics here
minimum angle required
CAMPBELL HALL
Beaver Dam Lake
Cornwall-On-Hudson
Washingtonville
Cold Spring
West Point
Highland Falls
Woodbury
Florida
SUGAR LOAF
Monroe
Harriman
NEWBURGH JUNCTION
Fort Montgomery
BEAR MOUNTAIN
Bear Mountain State Park
Peekskill
Cortlandt Manor
Shrub
Mohegan Lake
Wisner
Warwick
Buchanan
Cortlandt
Harriman State Park
Stony Point
Tuxedo
Greenwood Lake
Croton-On-Hudson
Haverstraw

Part 3

Eskers
(subglacial stream beds)



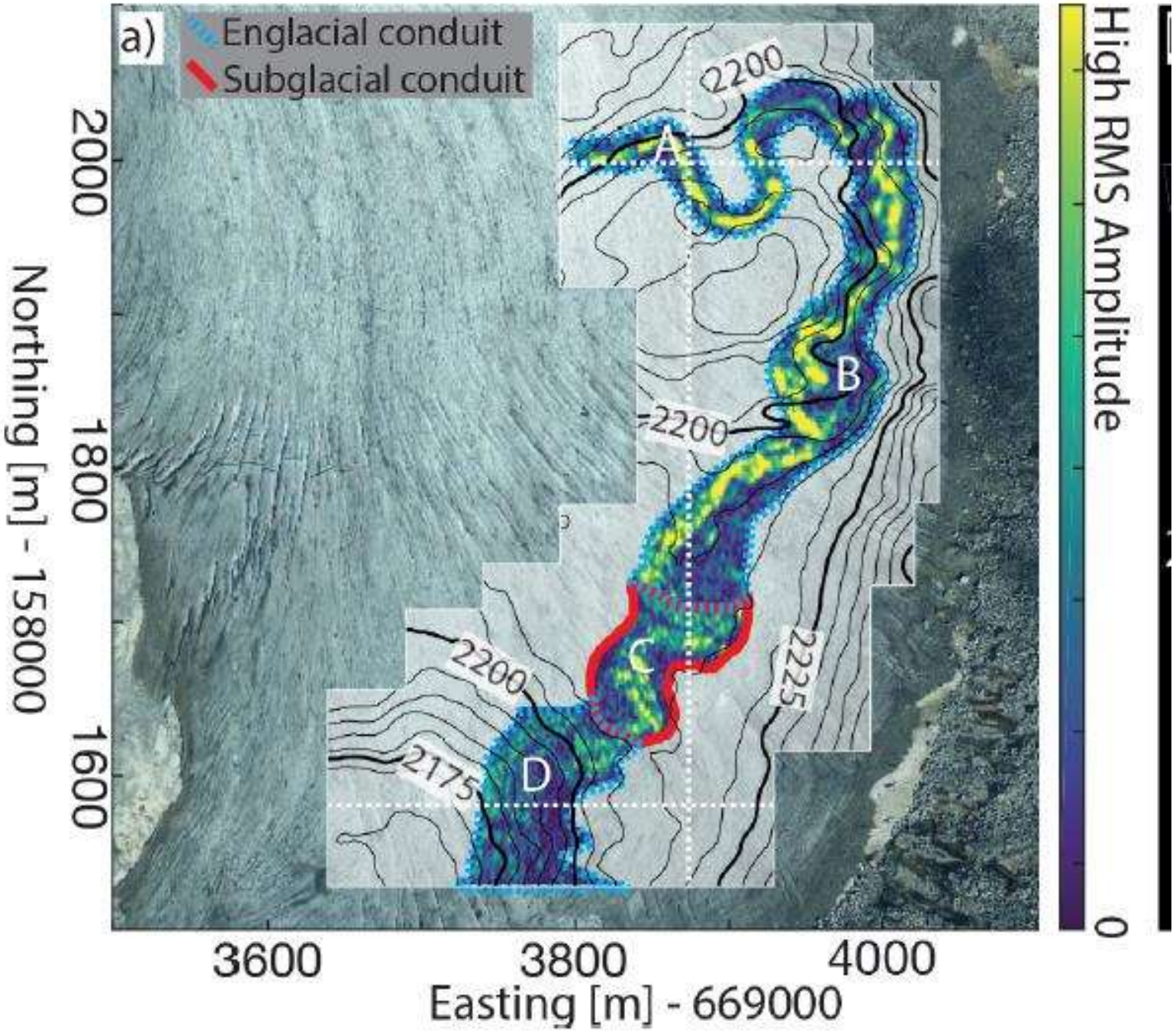
what do subglacial streams look like?



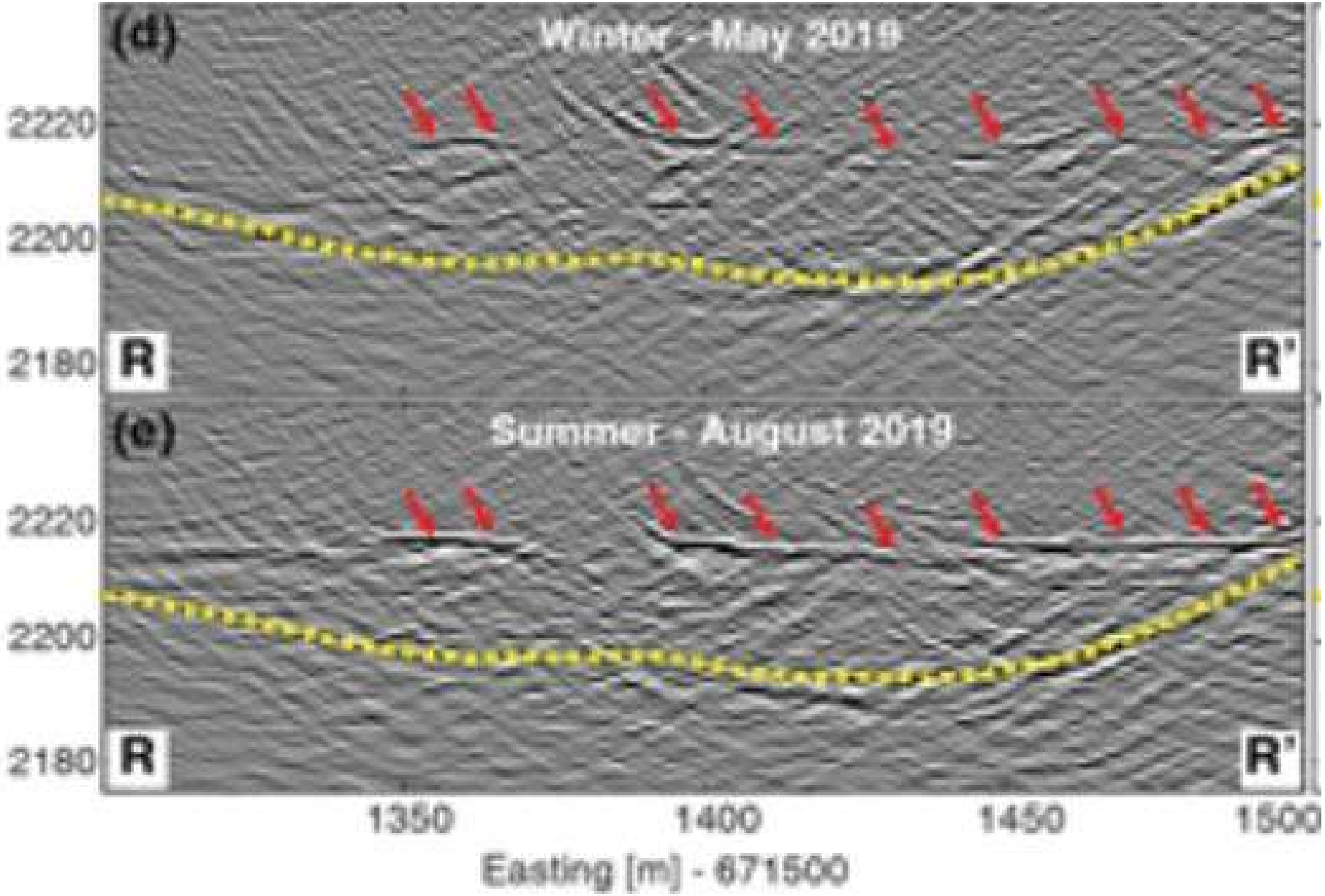
radar image of englacial / subglacial stream

englacial
=
within glacier

subglacial
=
beneath glacier



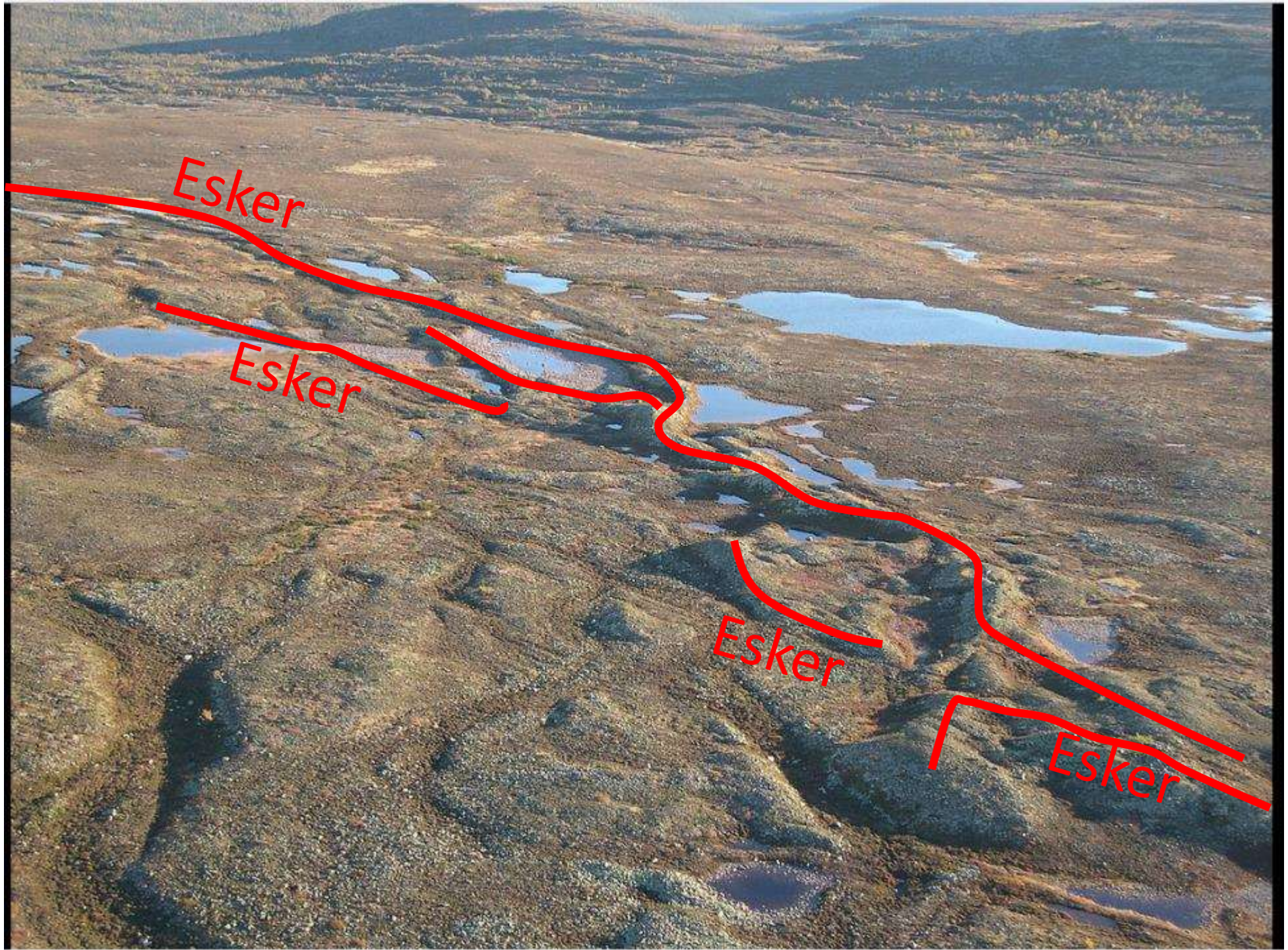
has meandering character



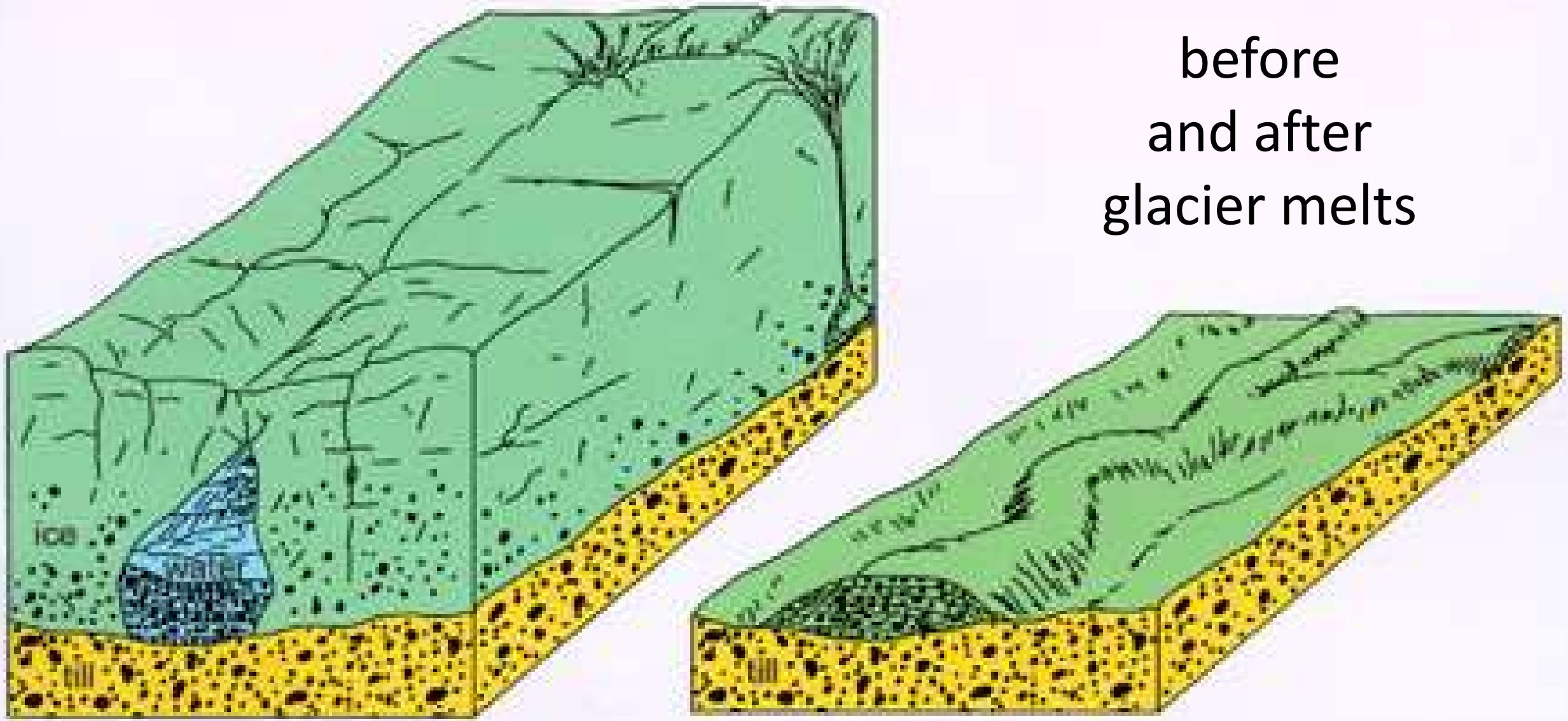
radar can image seasonal changes

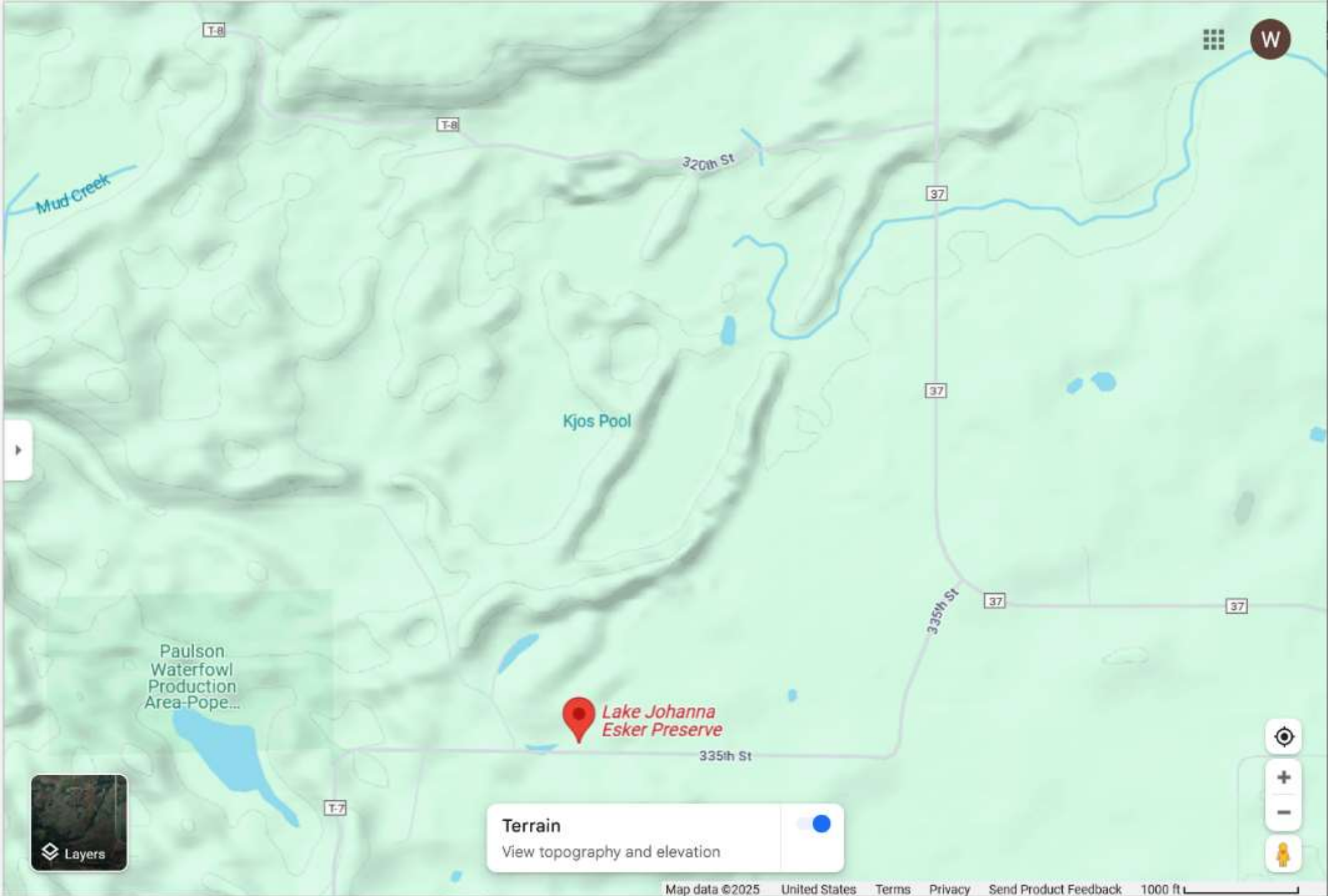
water conduit in glacier (red arrows)

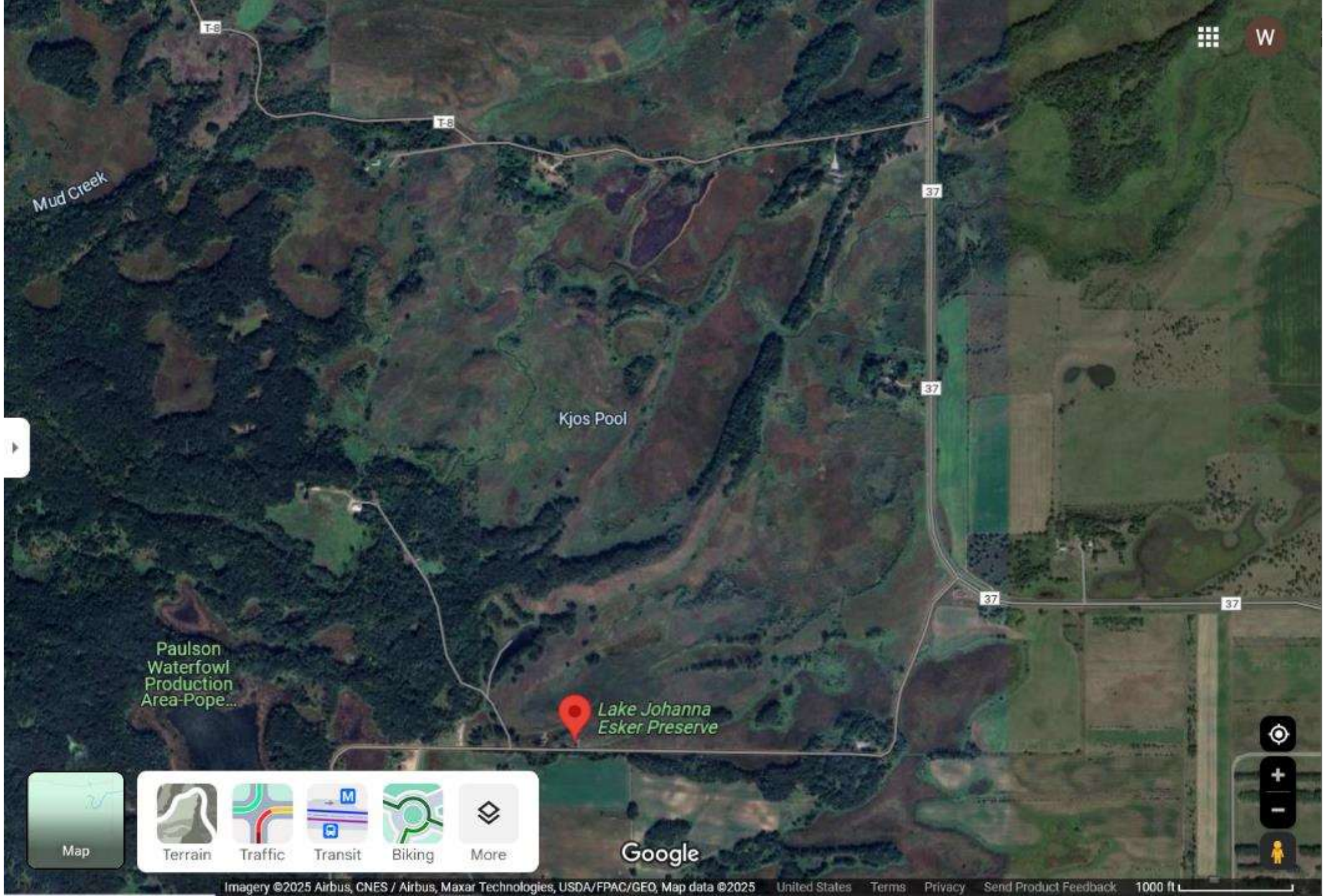
glacial bed yellow


Esker
Esker
Esker
Esker

before
and after
glacier melts




T-8
T-8
320th St
Mud Creek
37
Kjos Pool
37
335th St
37
37
Paulson
Waterfowl
Production
Area-Pope...
Lake Johanna
Esker Preserve
335th St
T-7
Layers
Terrain
View topography and elevation
Map data ©2025
United States
Terms
Privacy
Send Product Feedback
1000 ft


T-8
T-8
Mud Creek
37
Kjos Pool
37
37
37
Paulson
Waterfowl
Production
Area-Pope...
Lake Johanna
Esker Preserve
Map
Terrain
Traffic
Transit
Biking
More
Google
Imagery ©2025 Airbus, CNES / Airbus, Maxar Technologies, USDA/FPAC/GEO, Map data ©2025
United States
Terms
Privacy
Send Product Feedback
1000 ft

Dallas Abbott, on an esker, Whitten Woods, Ashland, New Hampshire

Rocks and sand exposed in an esker, Whitten Woods, Ashland, New Hampshire

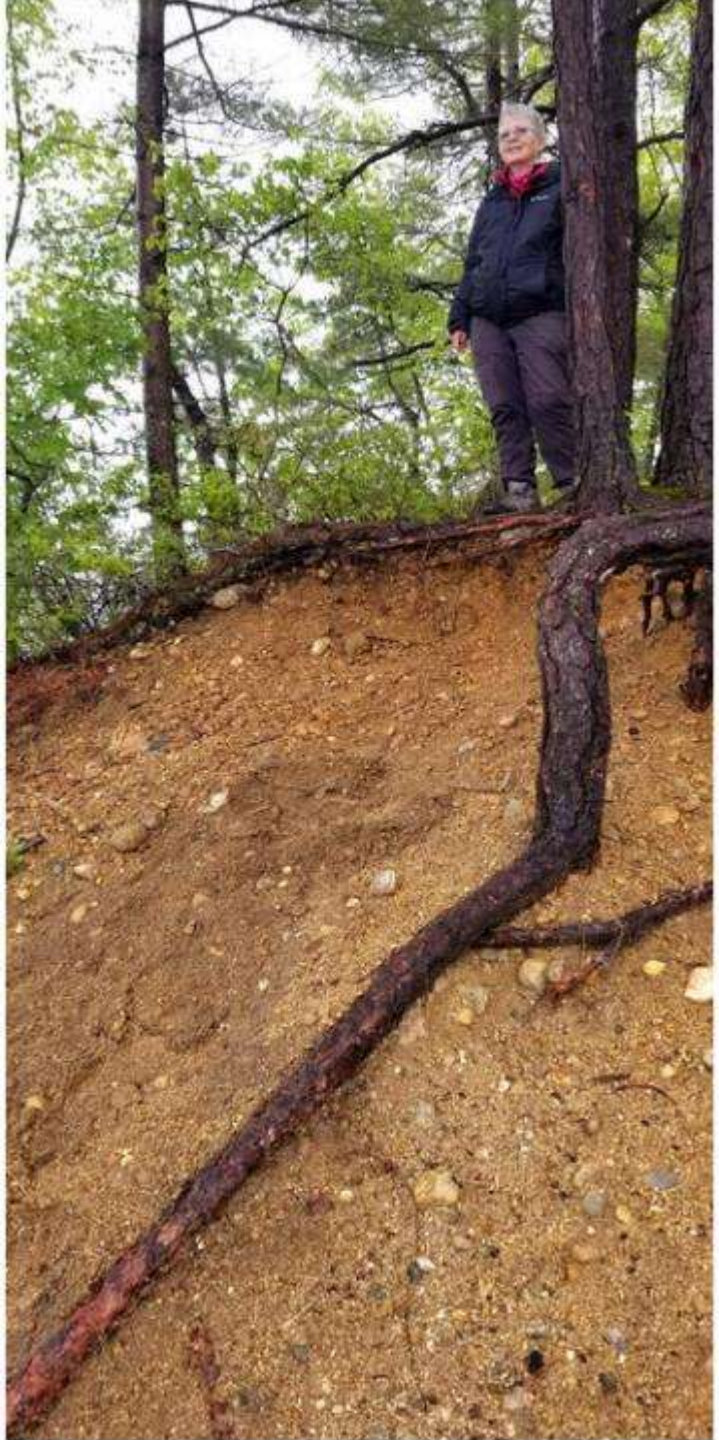
Esker composed of sand and gravel with occasional glacial boulders

Boulder with glacial straie, in an esker, Whitten Woods, Ashland, New Hampshire

Esker, with a younger lake surrounding it

Blueberry brambles on northern section of esker

Esker, Lower Range Pond, Poland, Maine



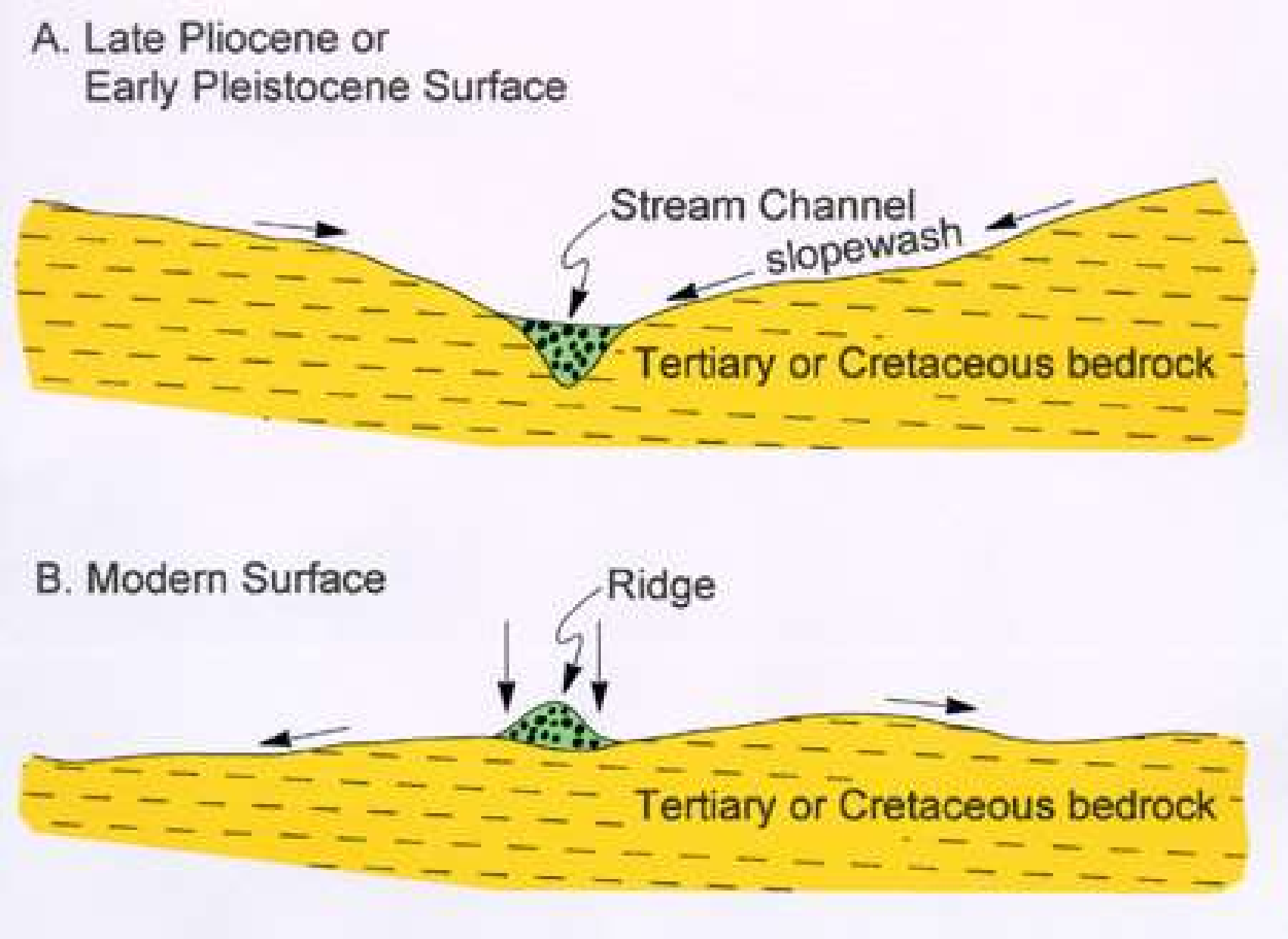
Poorly sorted sediment exposed where Esker has been eroded

Eskers

confirmation an area was subglacial

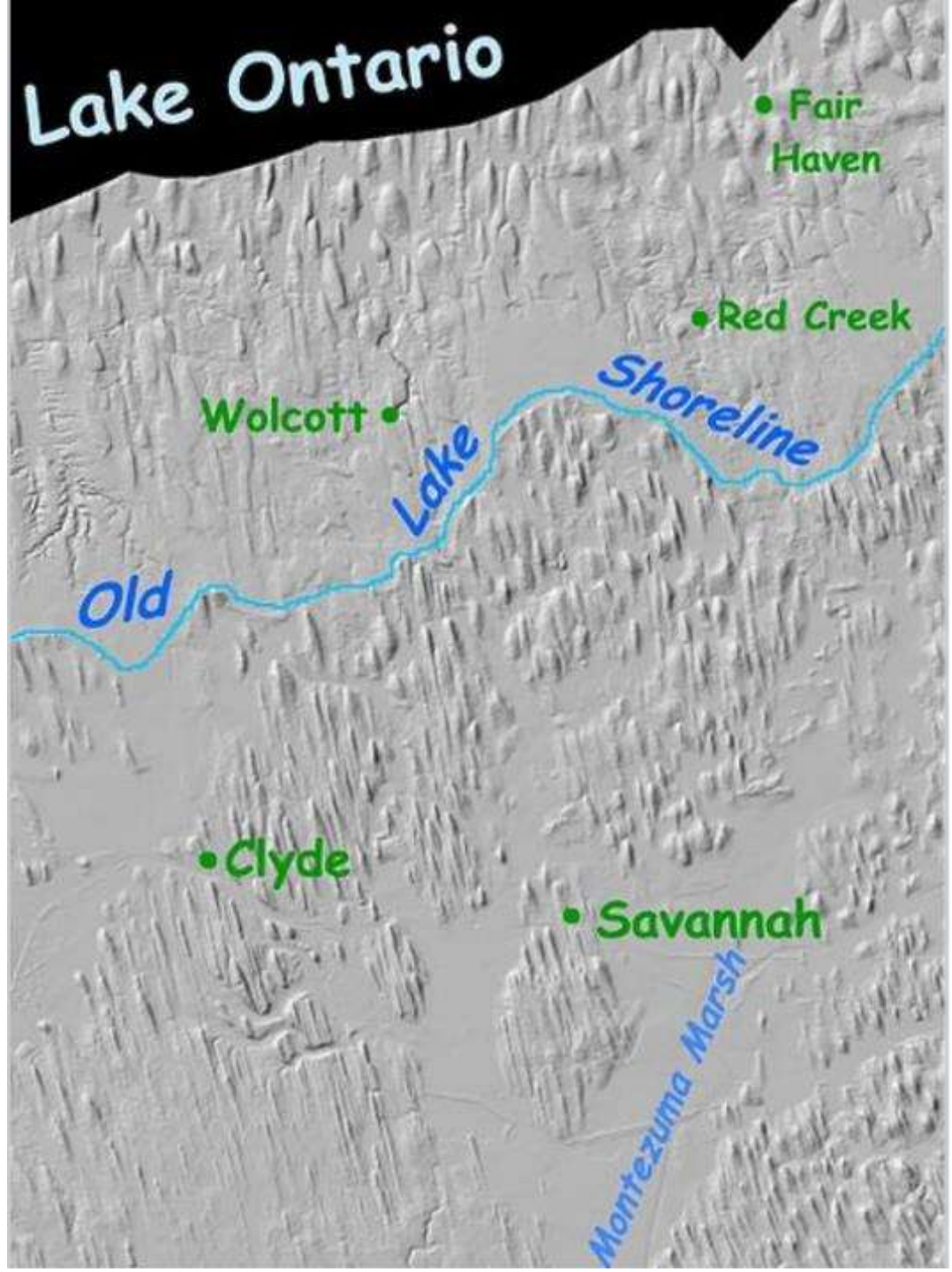
indicator of direction of subglacial water flow

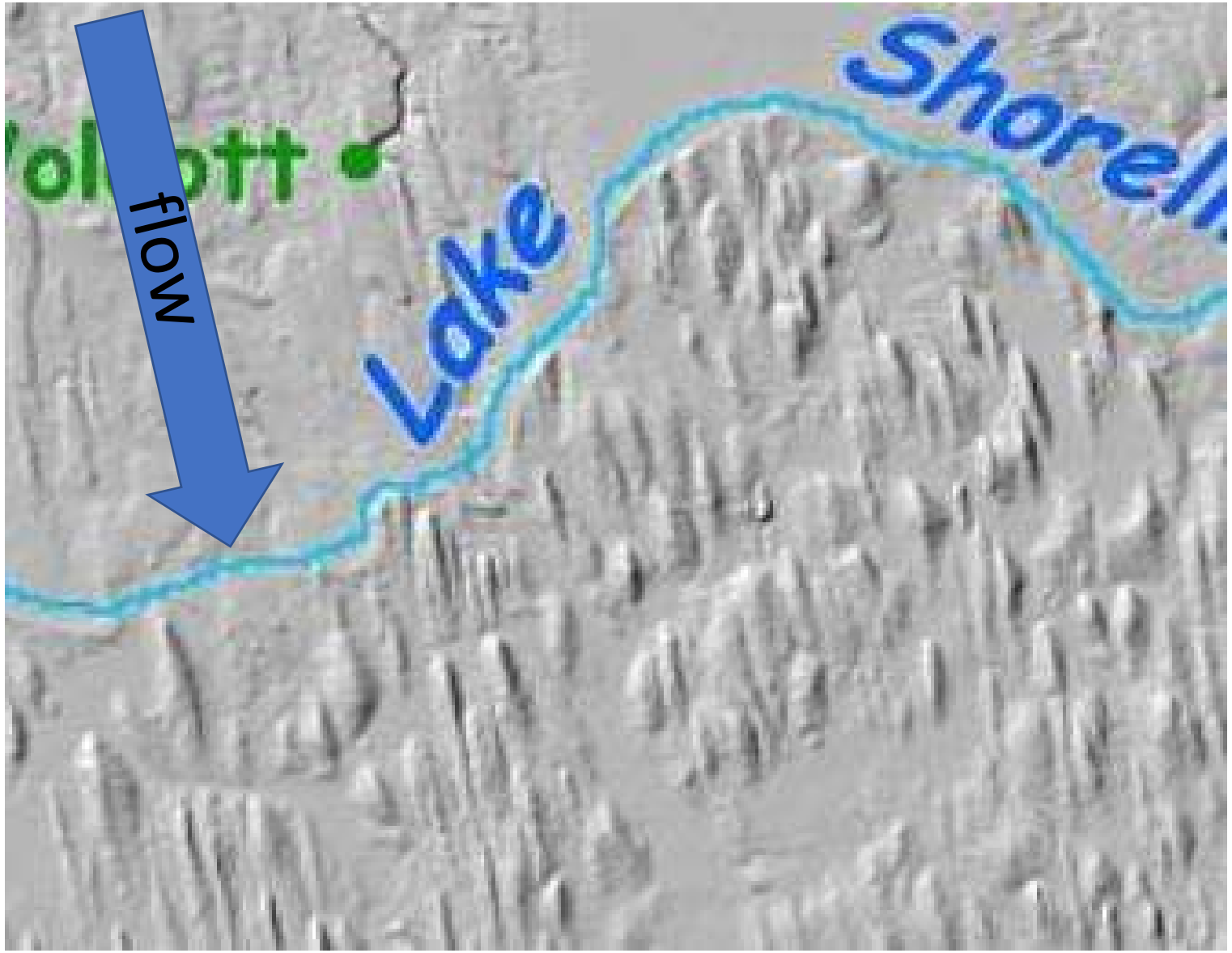
But beware: differential erosion can create features that mimic eskers



Part 3

Drumlins
(subglacial sediment hills)


Lake Ontario
Fair Haven
Red Creek
Wolcott
Lake Shoreline
Old
Clyde
Savannah
Montezuma Marsh

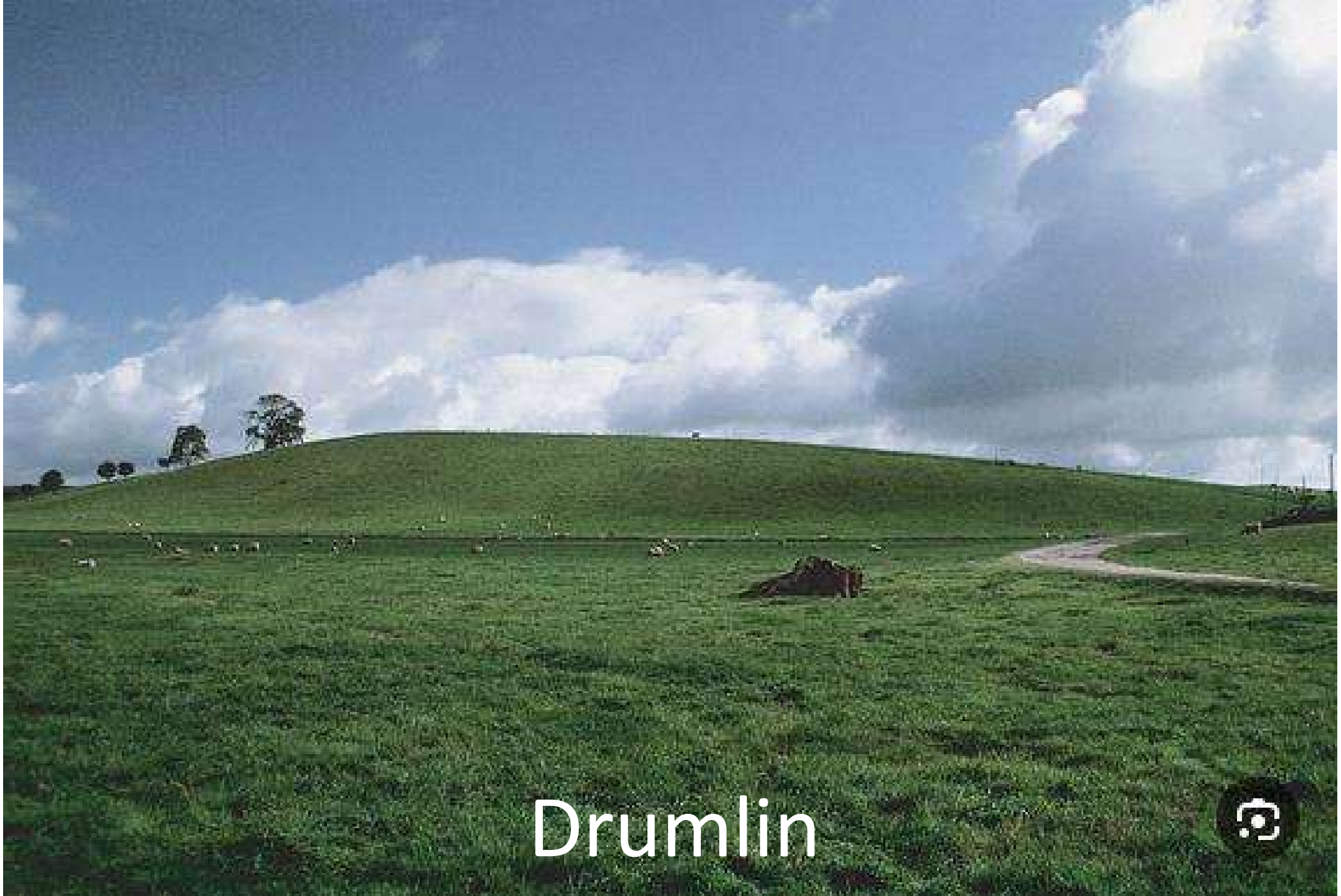


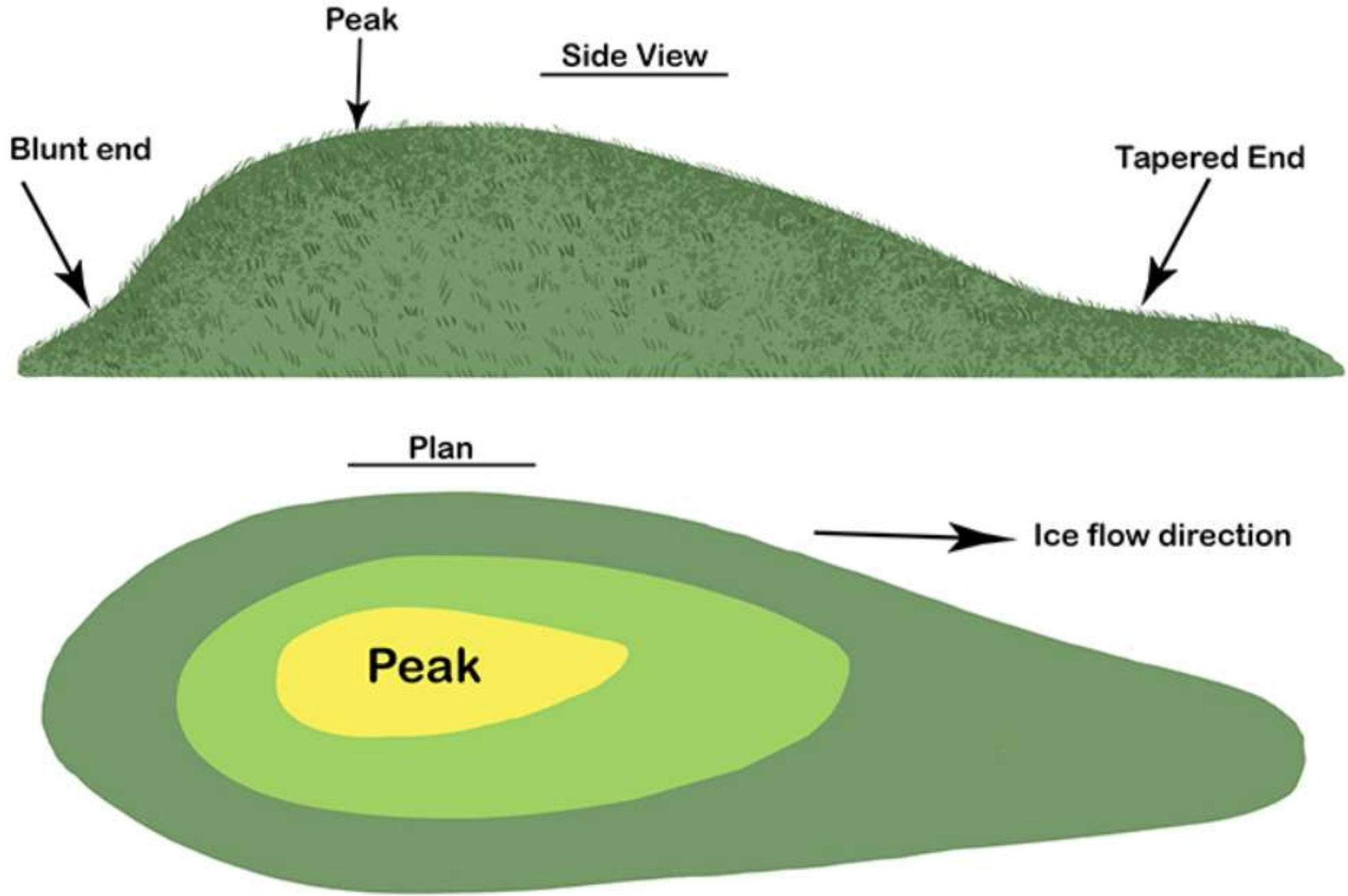
Drumlins

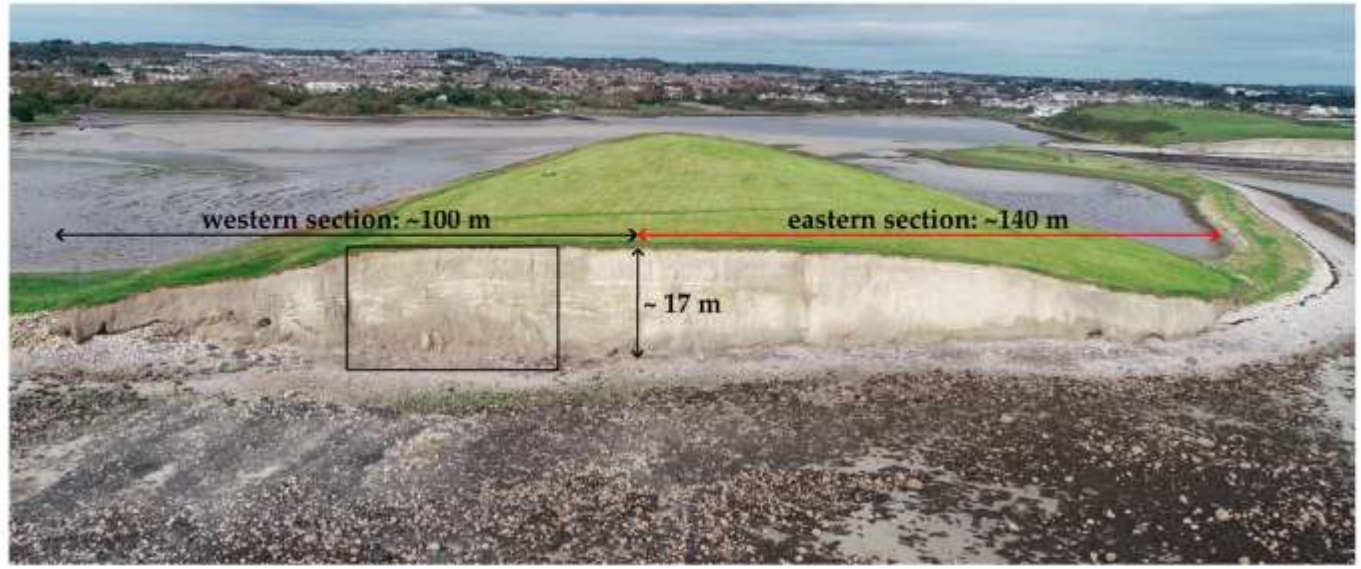
shaped like
a roche moutonnette

BUT direction reversed!

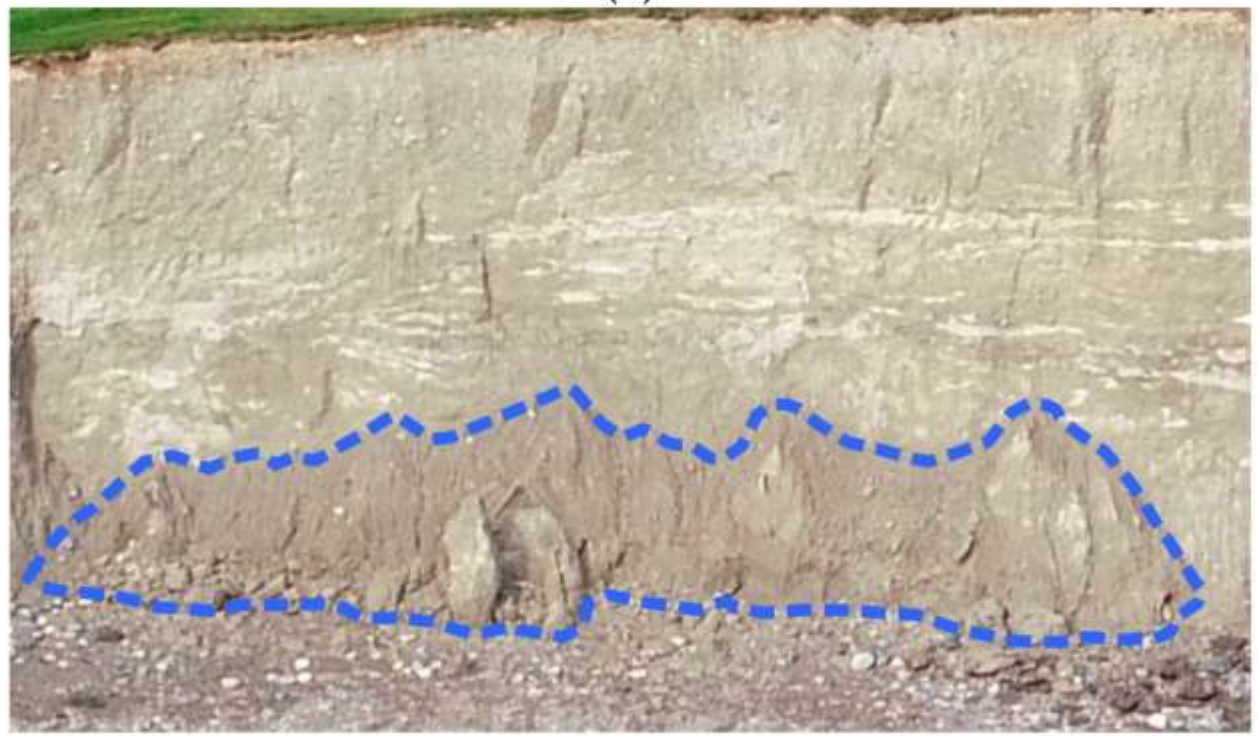

Drumlin


Drumlin

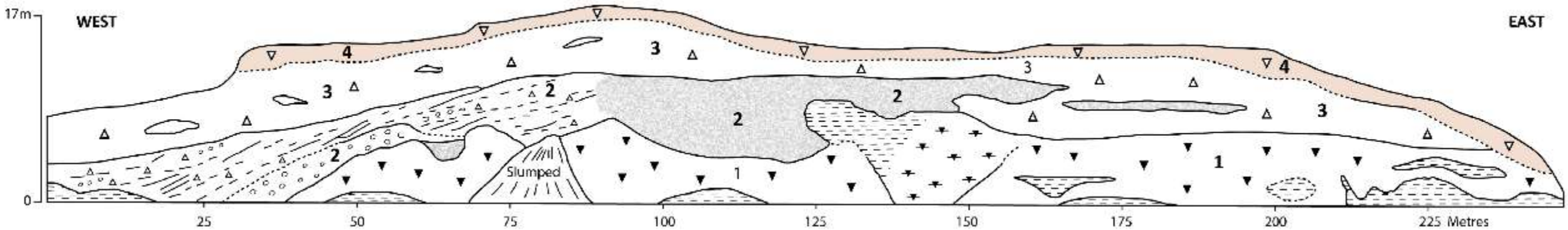

Peak
Side View
Blunt end
Tapered End
Plan
Ice flow direction
Peak



(**a**)



(**b**)



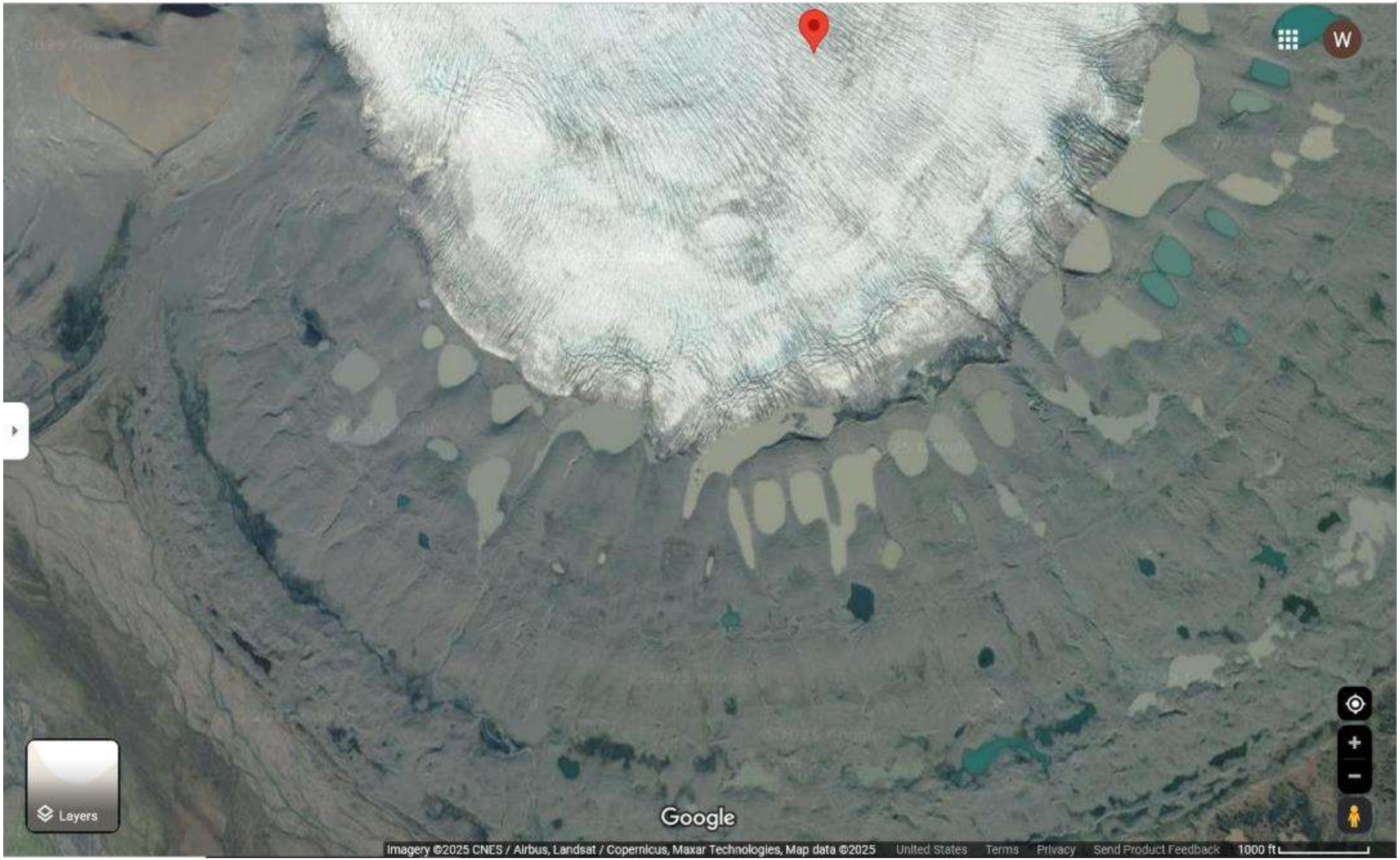
1 Stratified diamict
Muddy diamict
Mud

2 Diamict
Gravel
Sand

3 Massive diamict

4 Upper diamict

Diamict = poorly sorted sediment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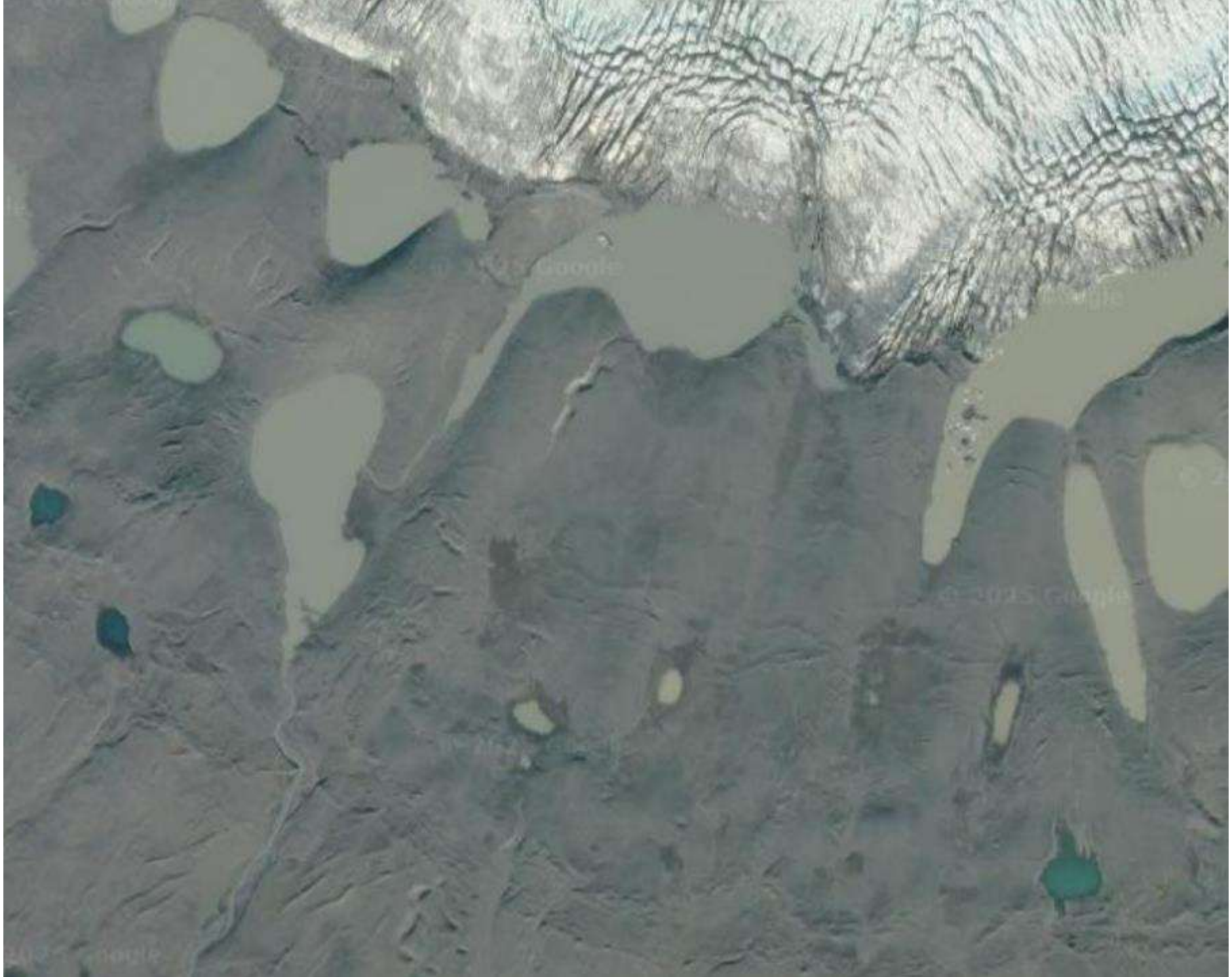


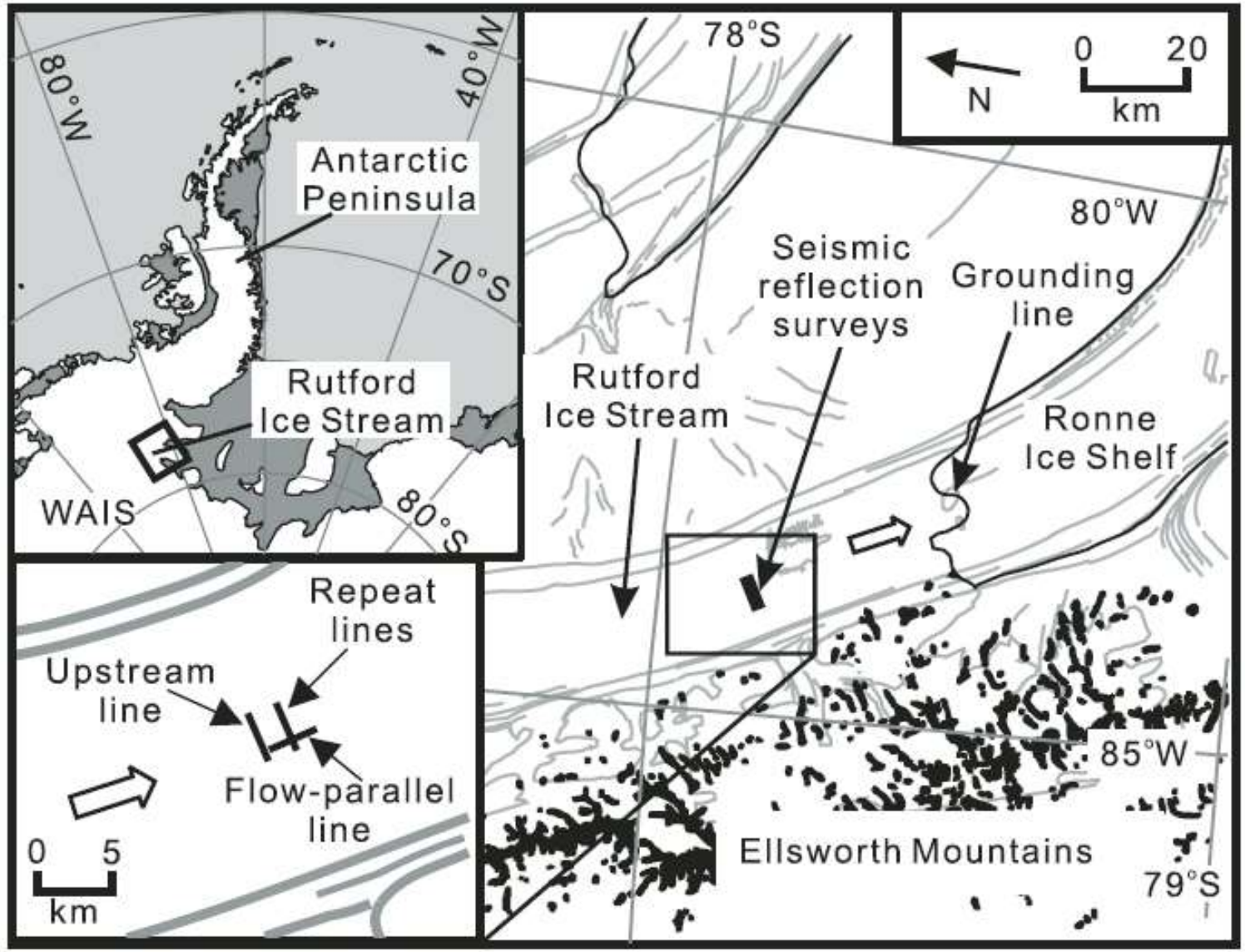


Figure 1. Location map for Rutford Ice Stream. White arrows show ice flow direction. Lower inset box shows layout of seismic lines (solid black lines). WAIS—West Antarctic Ice Sheet.

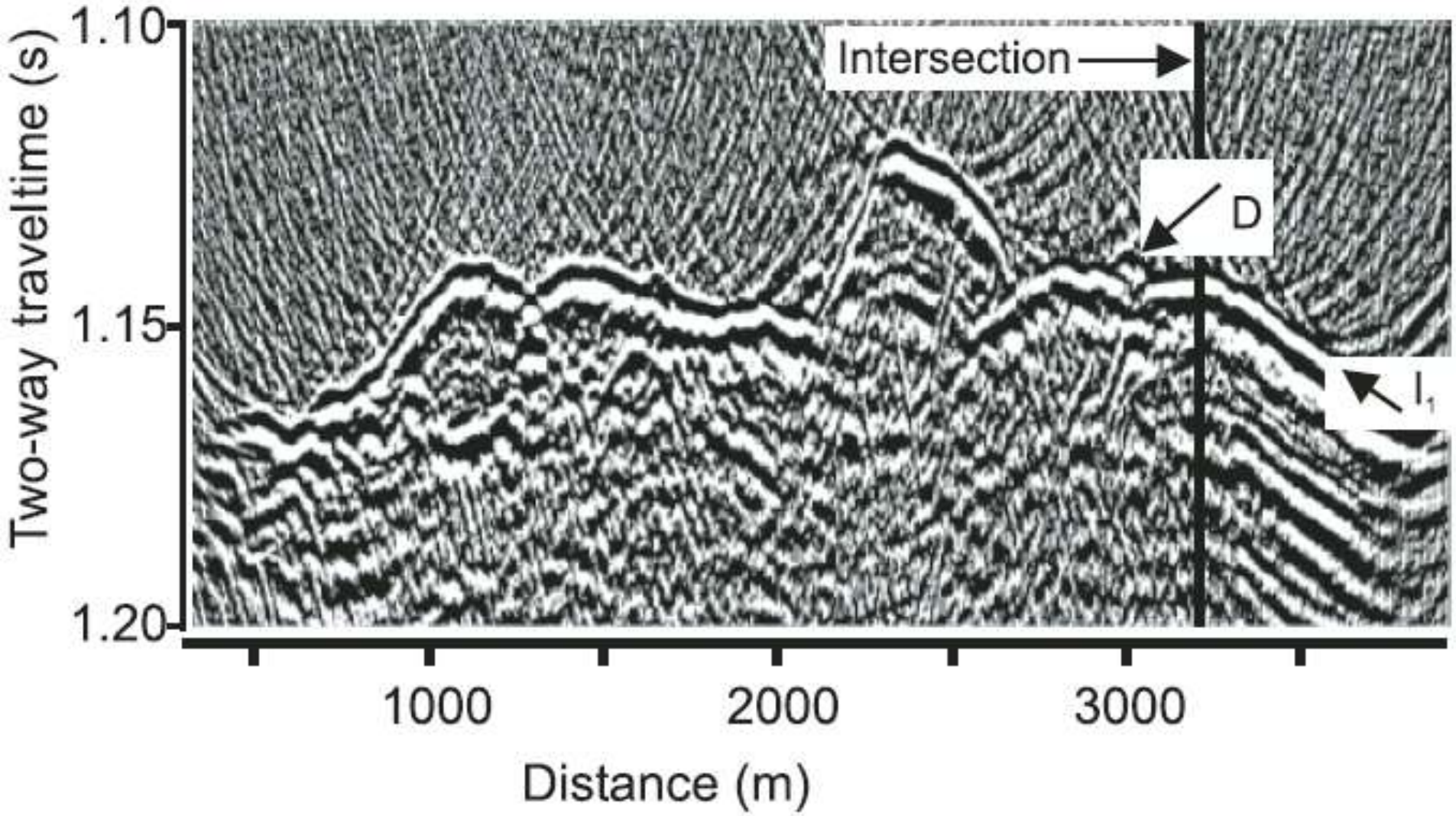
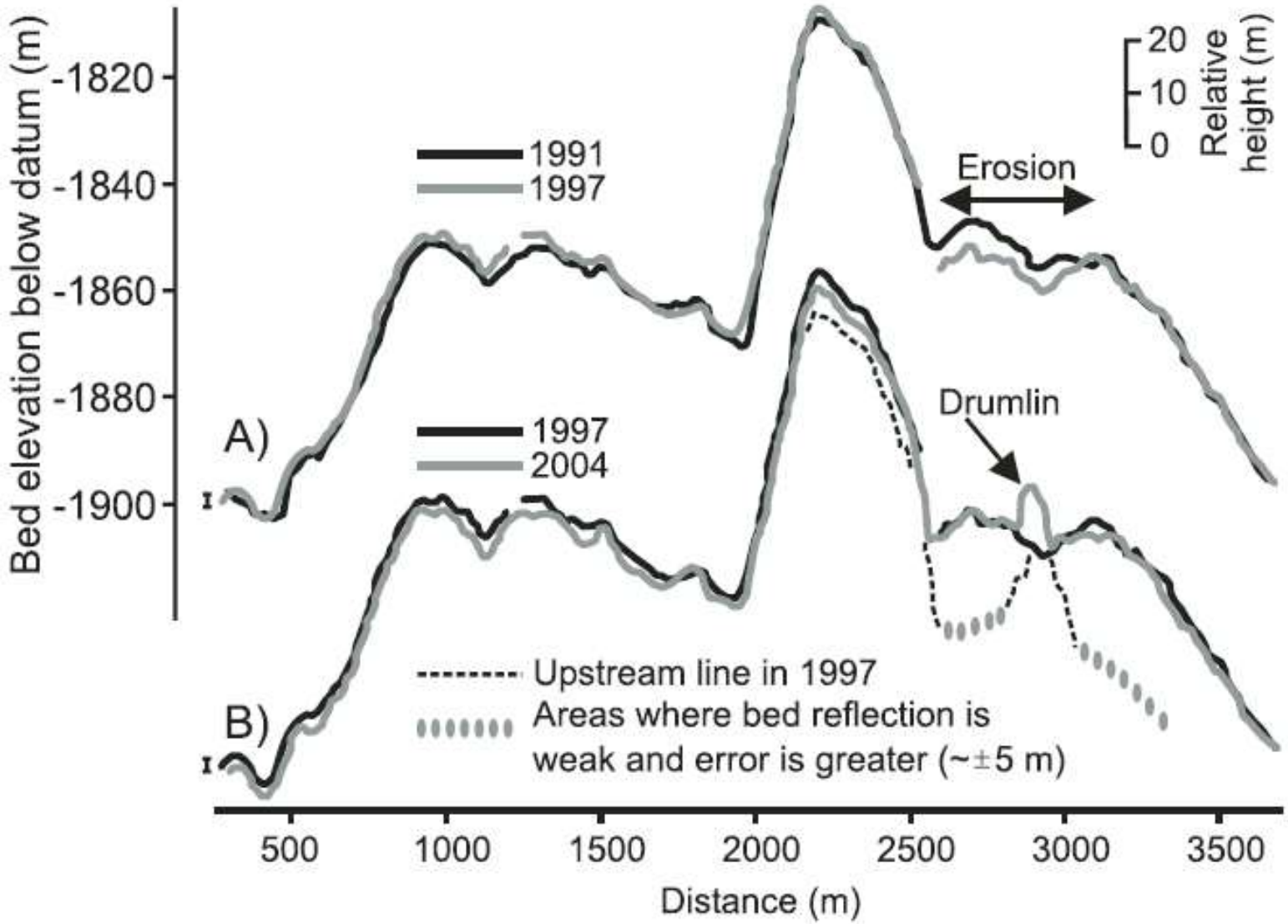


Figure 2. Seismic section from the 2004 survey. Ice flow is into the page. I_1 is reflection from the ice-bed interface; D is reflection from the drumlin; intersection with flow-parallel line is indicated.


Bed elevation below datum (m)
-1820
-1840
-1860
-1880
-1900
1991
1997
Erosion
20
10
0
Relative height (m)
A)
1997
2004
Drumlin
B)
Upstream line in 1997
Areas where bed reflection is weak and error is greater (~±5 m)
500
1000
1500
2000
2500
3000
3500
Distance (m)

Origin hypothesis 1:
Some sort of flow instability in a wet, viscous layer of till at the bottom of the glacier

Origin hypothesis 2:
Accumulation of sediment in originally air- or water-filled cavities in the bottom of the glacier

Hypothesis 1:

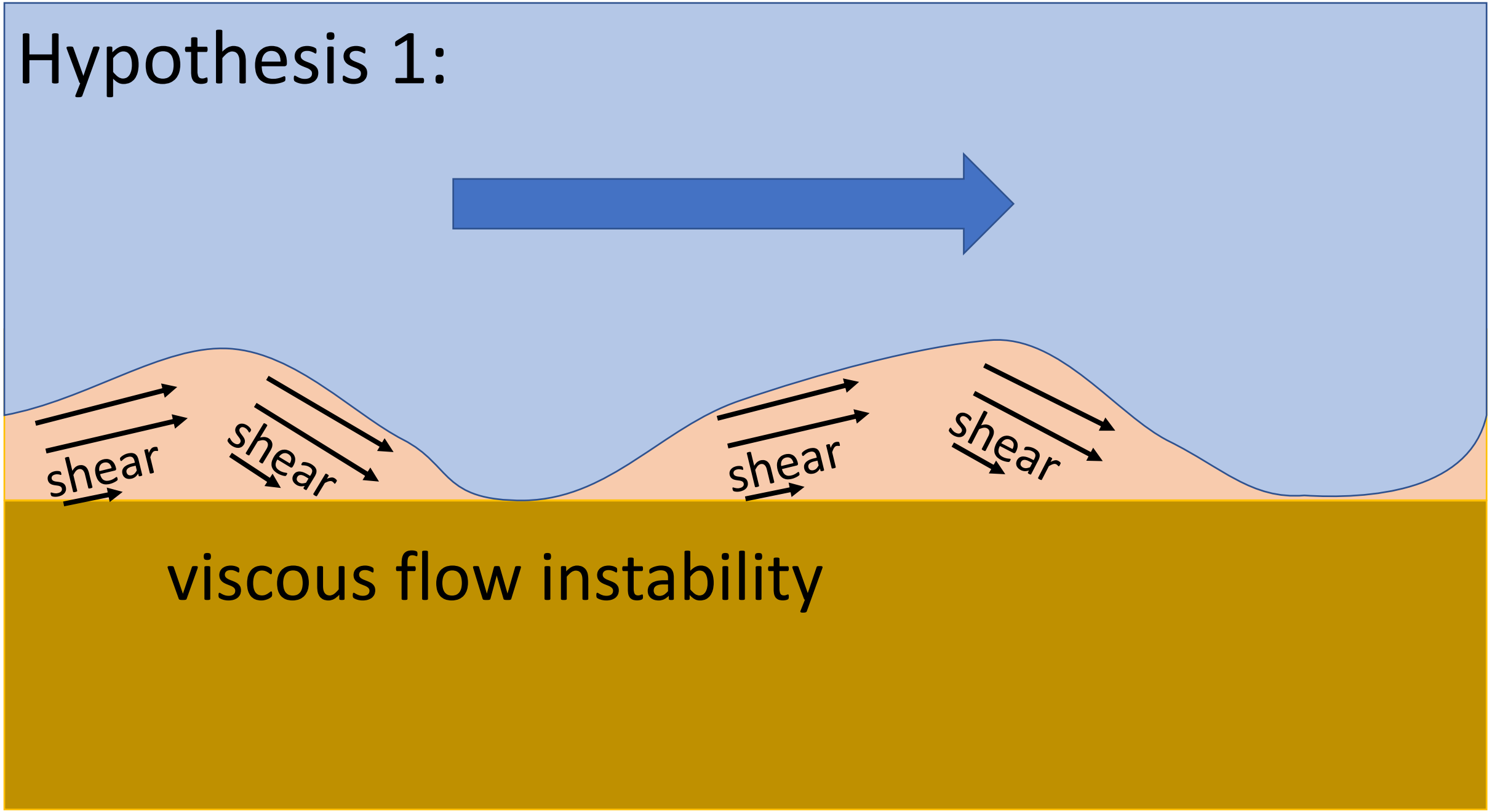
glacier

wet, soft sediment

shear shear shear shear

Bedrock or stiff sediment

Hypothesis 1:



Hypothesis 2:

glacier

wet, soft sediment

Bedrock or stiff sediment

Hypothesis 2:

glacier

wet, soft sediment

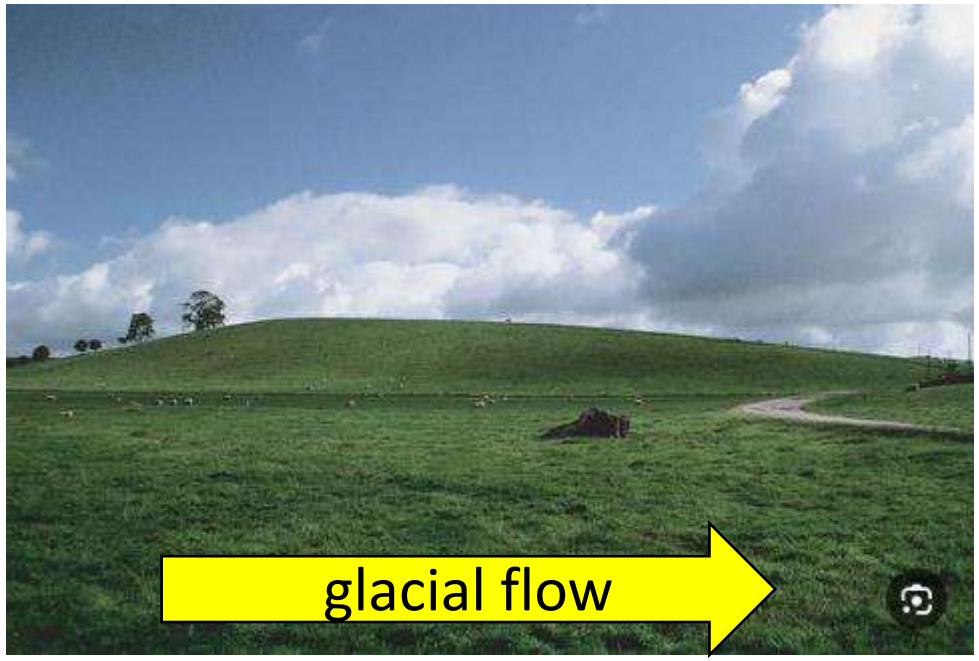
Bedrock or stiff sediment

Drumlins

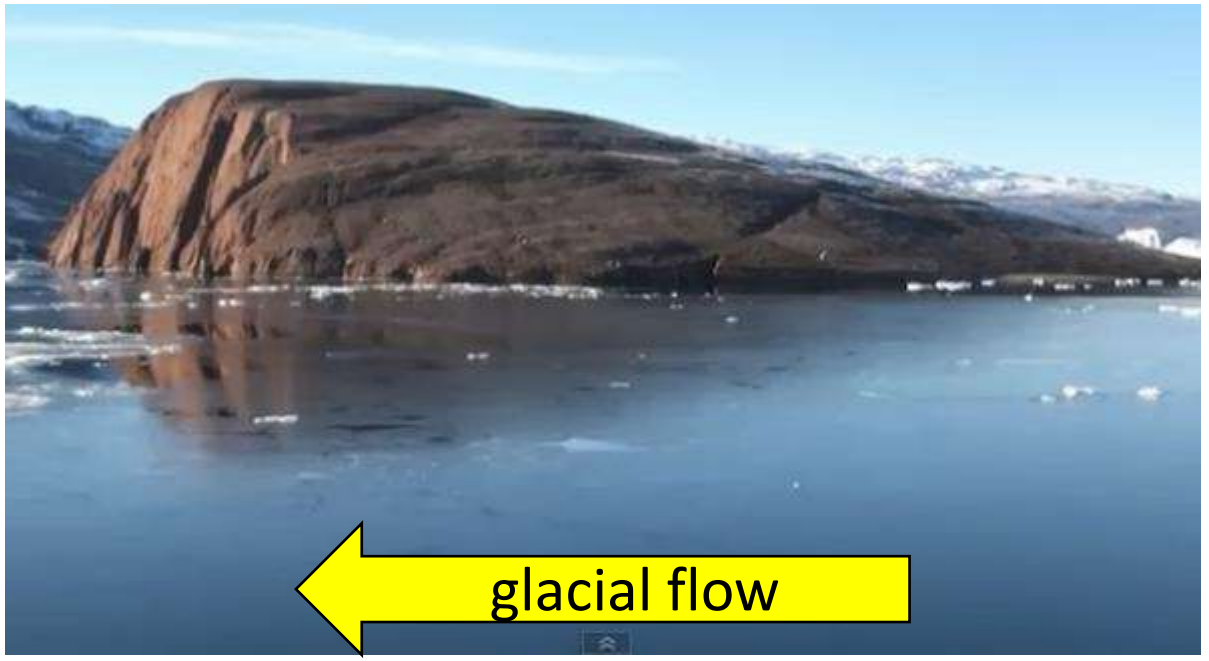
confirmation an area was subglacial

indicator of direction of glacial flow

But beware: if you mistake them for a roche moutinnee you'll reverse the glacial flow direction!



drumlin



roche moutinnee