The Vuotso granite tors in the cold temperate Arctic Finland – cosmogenic isotope evidence for slow erosion and multiple episodes of glacial modification

Pyhä-Nattanen, northern Finland (68˚N)

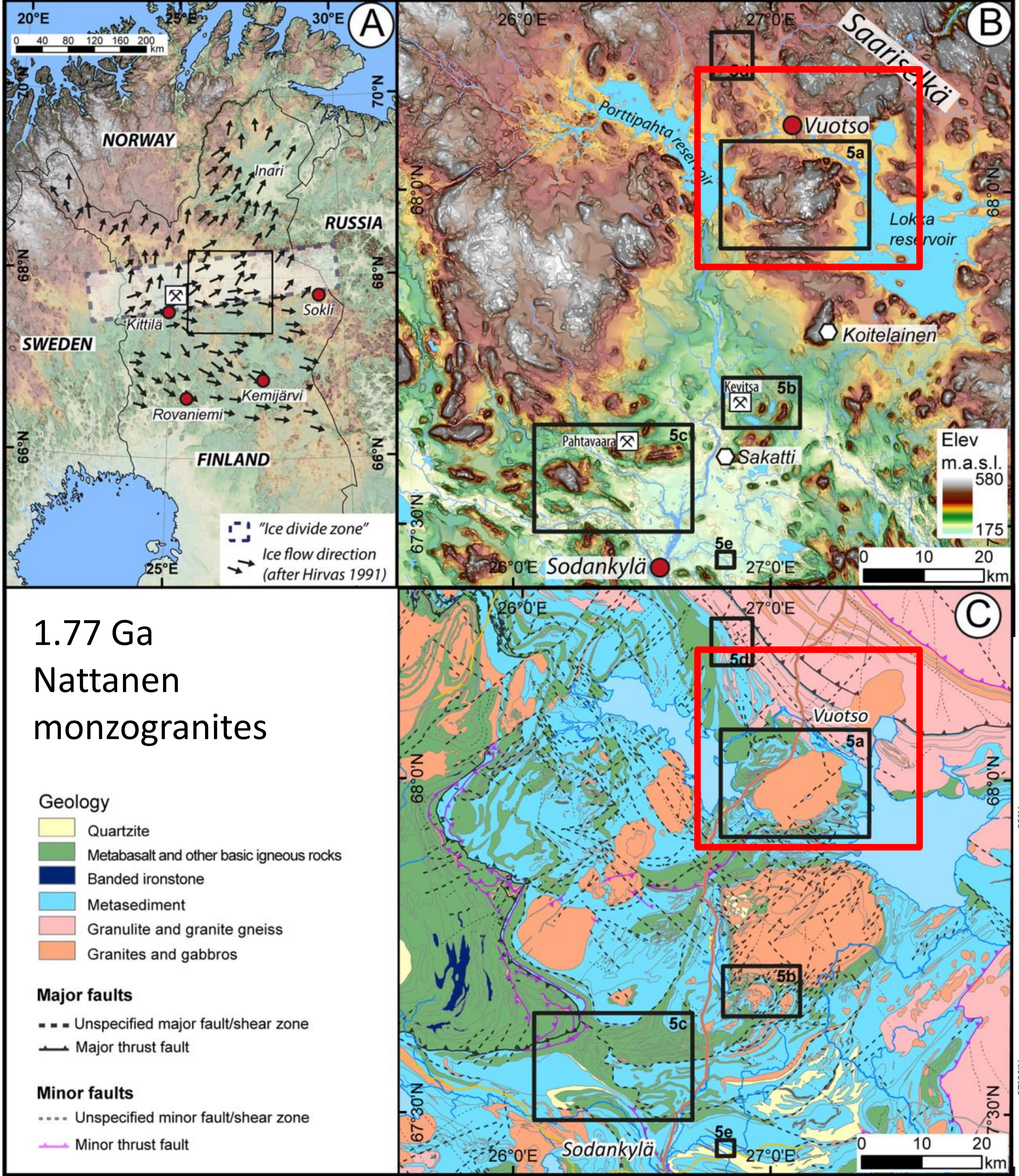
Adrian Hall (SU), Marc Caffee (Purdue), Karin Ebert (SU), Jakob Heyman (GU), Johan Kleman (SU).

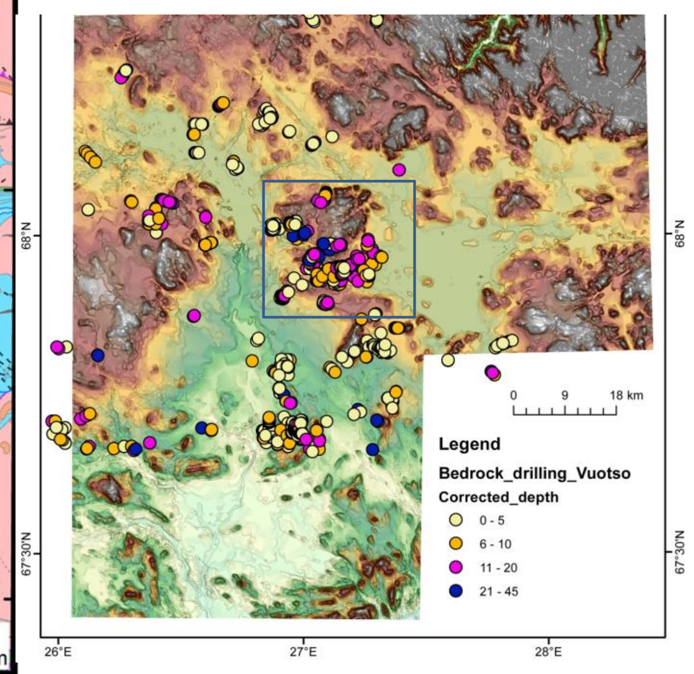
Nordic Winter Meeting 2018 Copenhagen

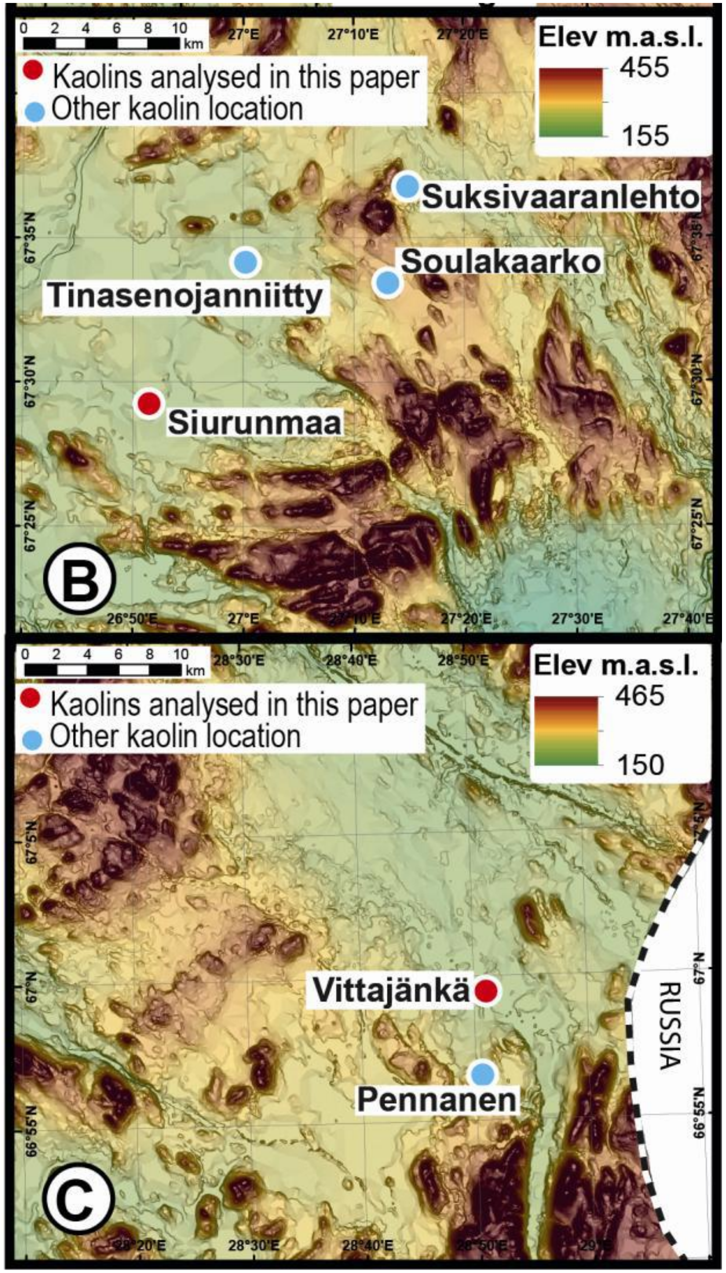
Vuotso Area

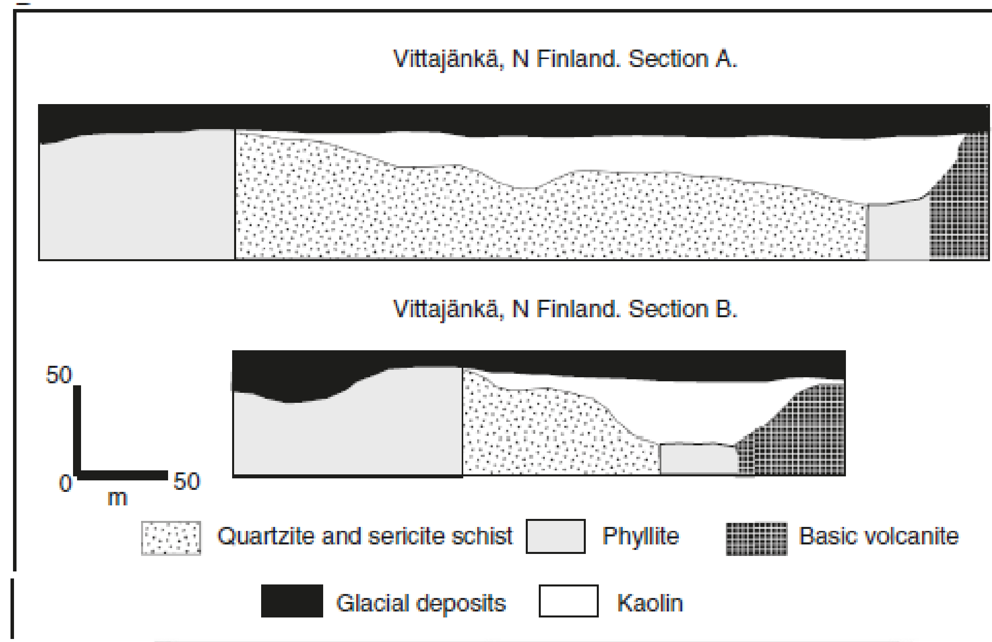
A. Ice divide
B. Topography
C. Granite domes
D. Deep weathering
- Miocene kaolins
- Plio-Pleistocene thick grusses

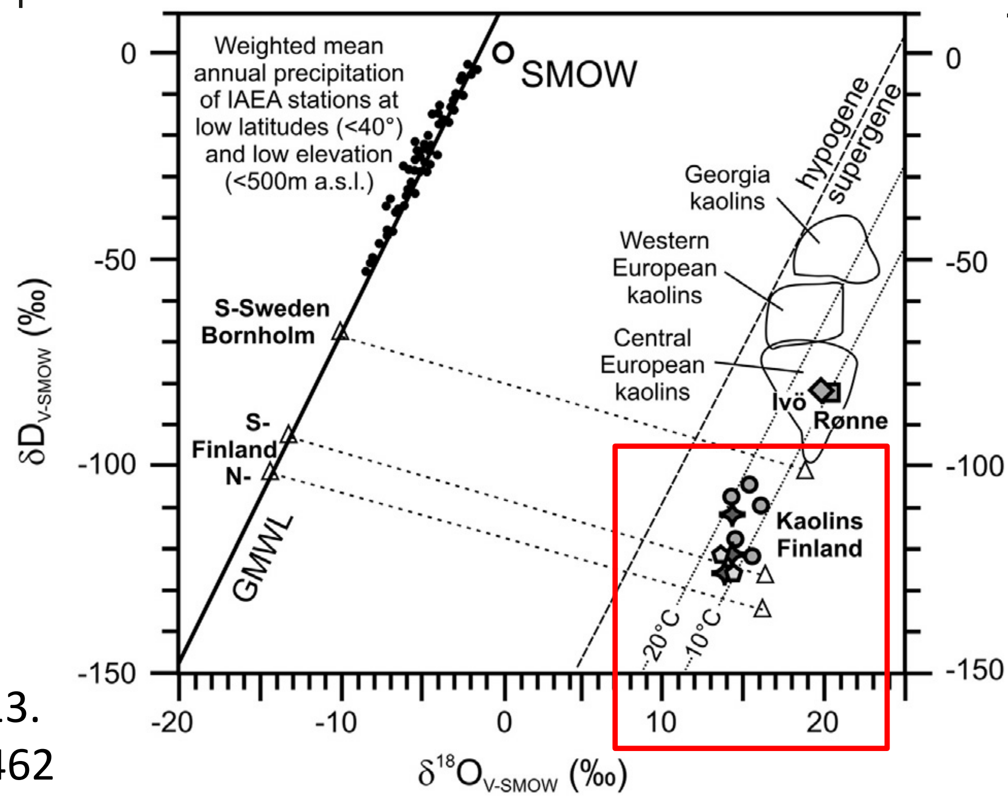
1.77 Ga Nattanen monzogranites



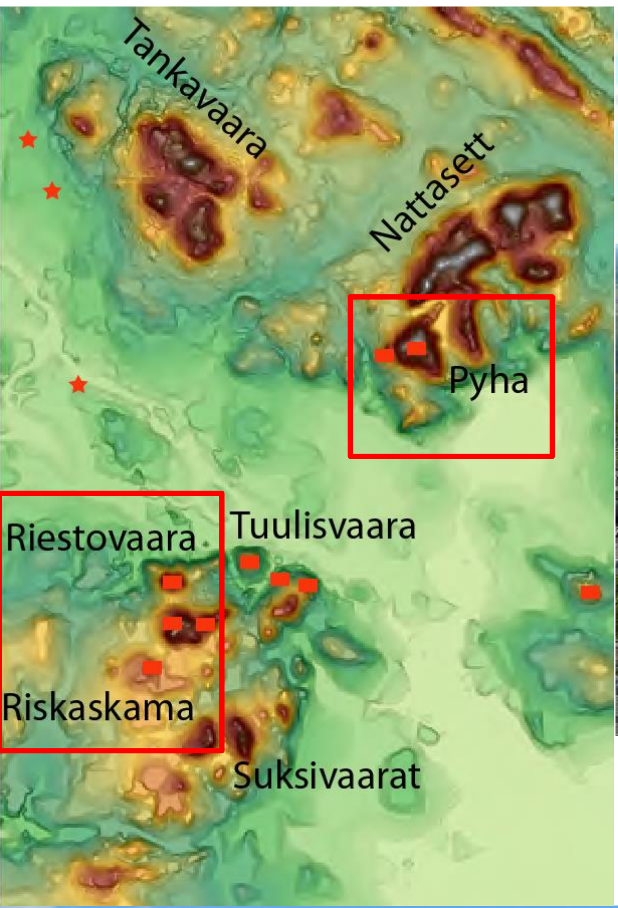




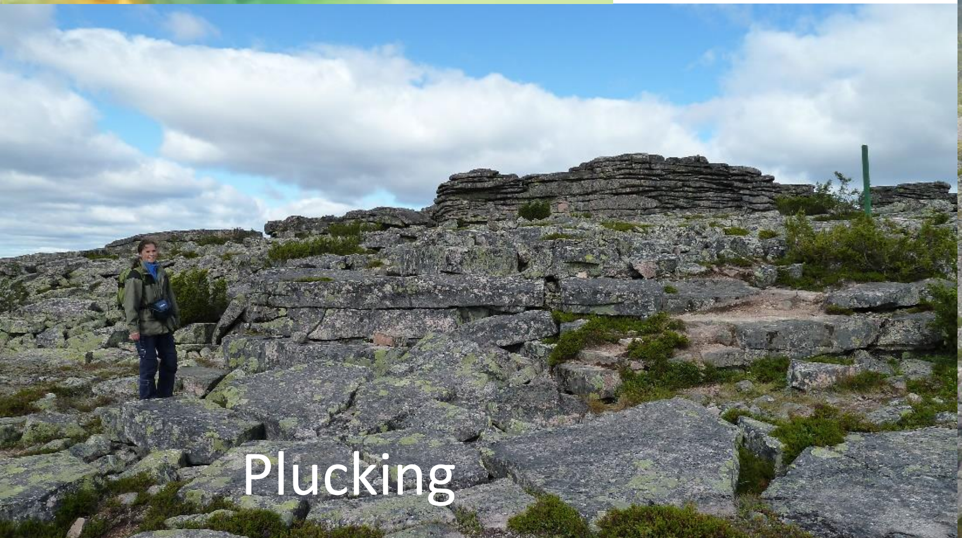




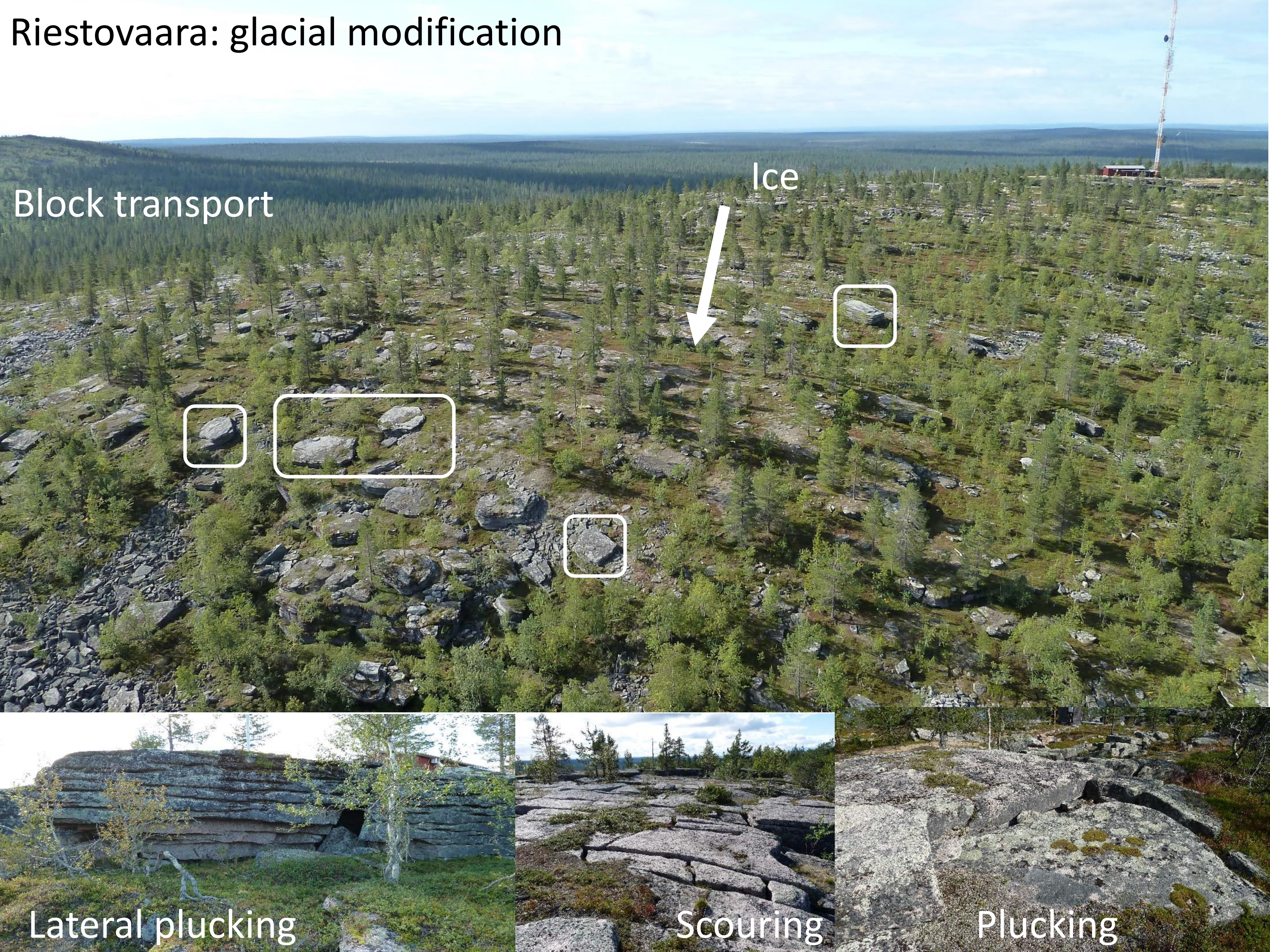
Gilg H A, Hall A M, Ebert K, Fallick A E, 2013. Cool kaolins in Finland. Pal³. 392, p. 454–462

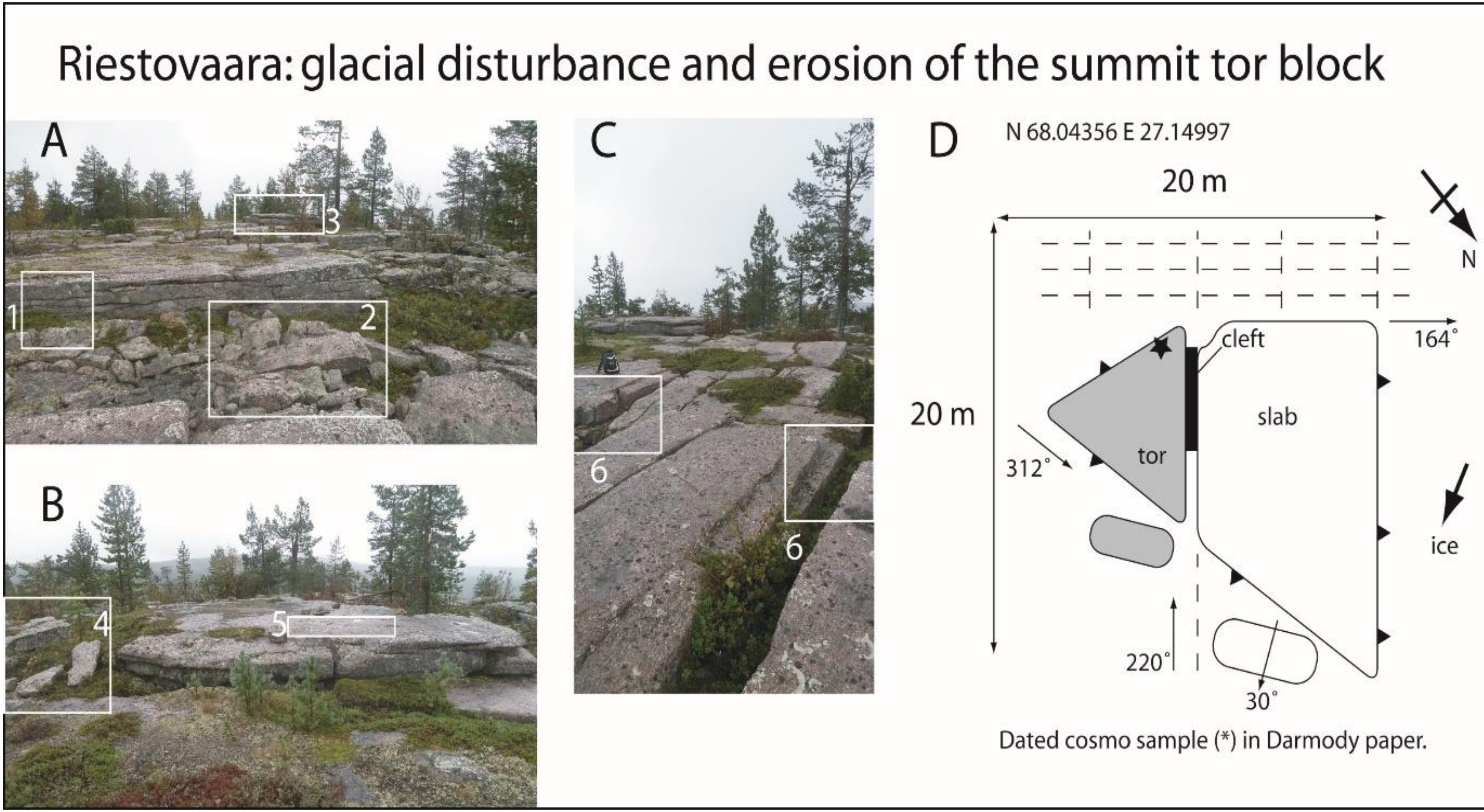


Tor weathering and erosion

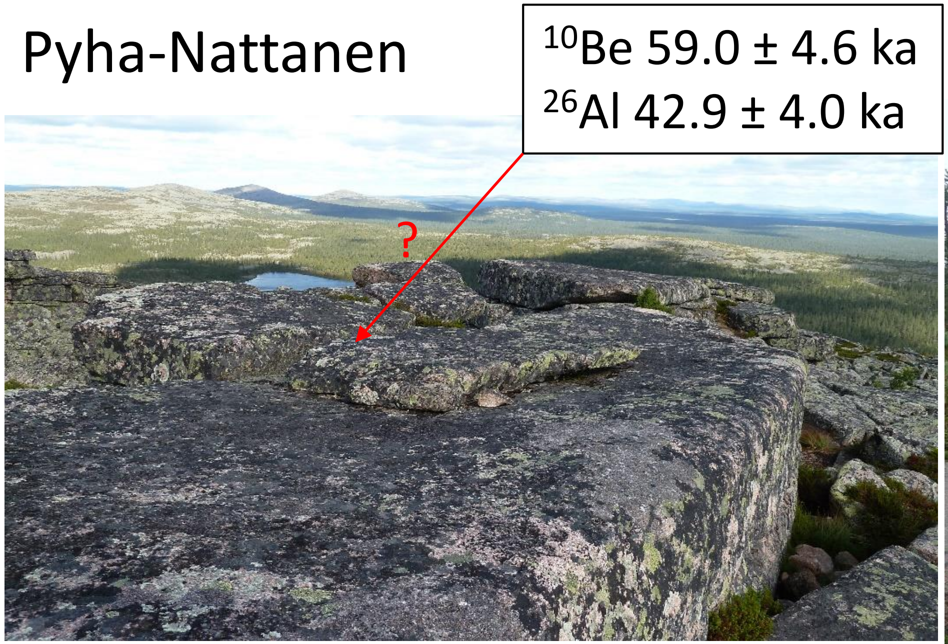


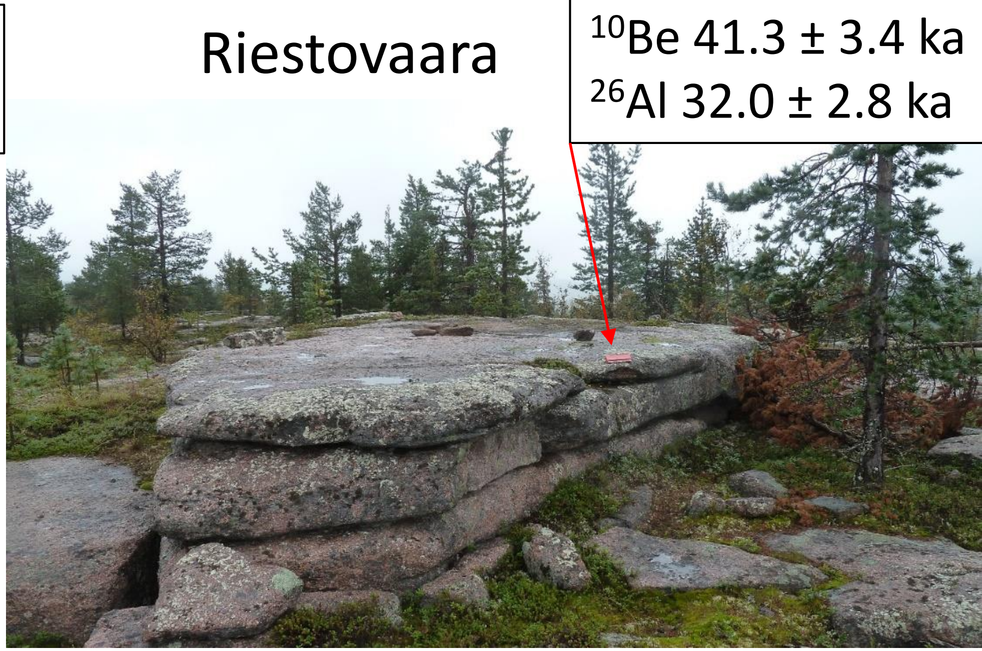
Riestovaara: glacial modification





A. View from the N. 1. Closely-spaced sub-horizontal sheet joints. Limited edge rounding, due to glacial quarrying. 2. Boulder deposition in depression at tor edge. On the S side of the hill, boulder trains are oriented W-E. 3. Summit tor block. B. View from the W. 4. Blocks moved away from edges on lee side of tor. 5. Little weathered top surface of summit block. C. Closer view from the N. 6. Pull-apart clefts where joints have been opened up by sub-glacial drag. D. Sketch of summit block, showing Darmody et al. sample location and orientation of main joint sets.

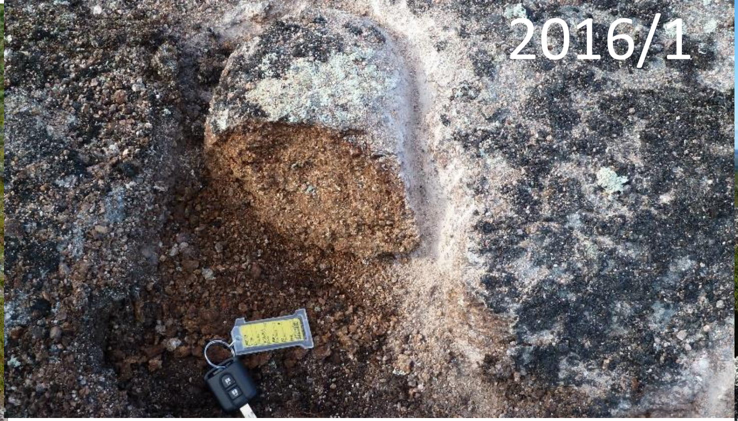




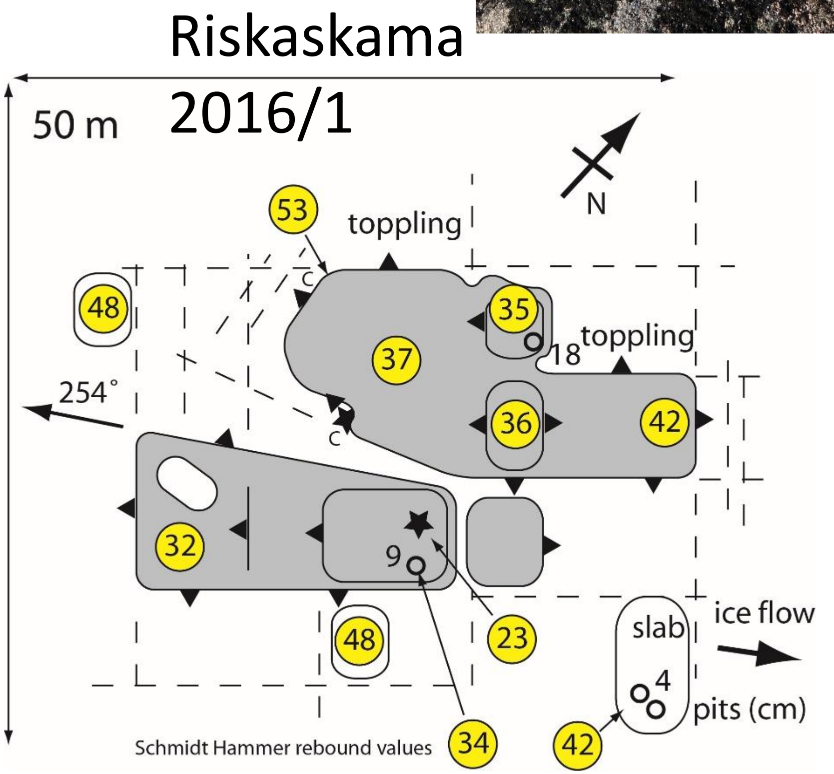
(Darmody et al., 2008) Geom. 96, 10-23 reported cosmogenic nuclides from two tor summits.

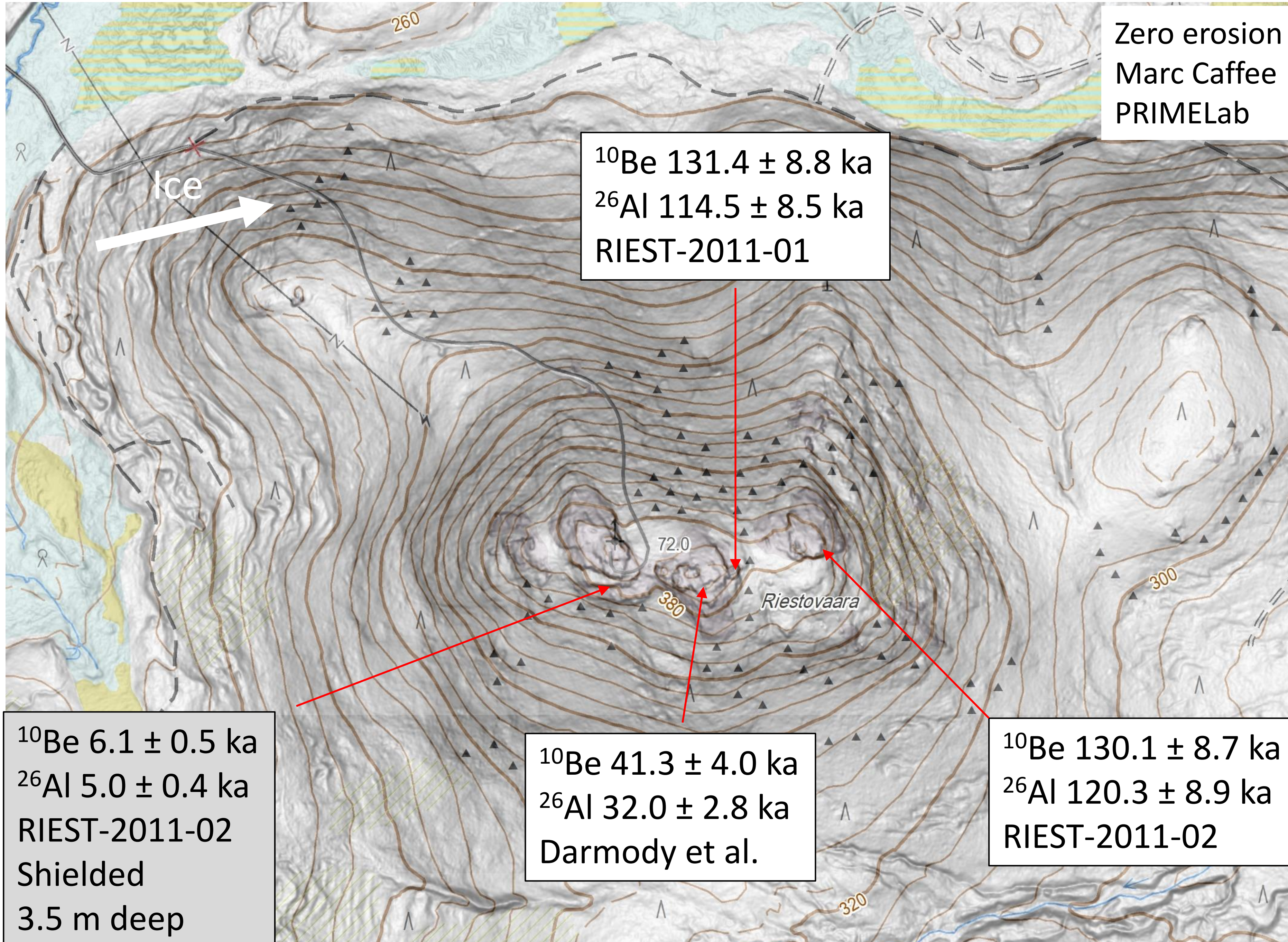
^{26}Al/^{10}Be ratios indicate minimum burial time of 502 kyr at Pyhä-Nattanen and 371 kyr for Riestovaara. Ice cover histories inferred from marine oxygen isotope records (DSDP 607) indicate that the tors have minimum estimated total exposure-burial durations of 997 kyr (Pyhä-Nattanen) and 858 kyr (Riestovaara) and survived at least 14-16 episodes of glaciation. **But** these ages had to be recalibrated and recent findings at Sokli indicate that ice cover was more restricted in time and space in Finnish Lapland during at least the last glacial cycle (Helmens, 2014).

Are these hard, likely glacially-modified tor summits the longest exposed rock surfaces in this area? Can we better constrain burial and exposure histories?

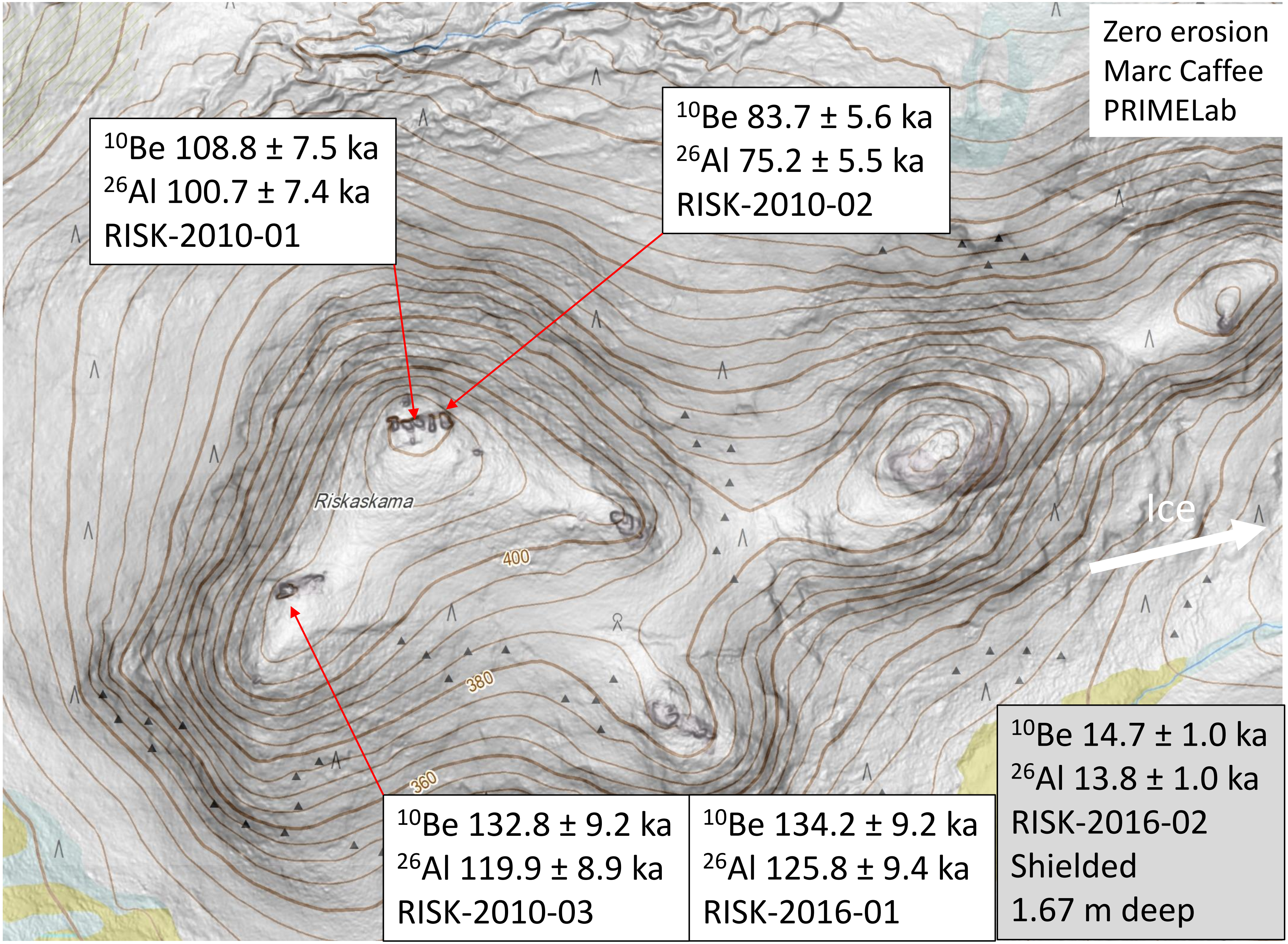


Weathered tor summits-
No signs of glacial modification





Zero erosion
Marc Caffee
PRIMELab
Ice
^{10}Be 131.4 ± 8.8 ka
^{26}Al 114.5 ± 8.5 ka
RIEST-2011-01
260
300
320
380
72.0
Riestovaara
^{10}Be 6.1 ± 0.5 ka
^{26}Al 5.0 ± 0.4 ka
RIEST-2011-02
Shielded
3.5 m deep
^{10}Be 41.3 ± 4.0 ka
^{26}Al 32.0 ± 2.8 ka
Darmody et al.
^{10}Be 130.1 ± 8.7 ka
^{26}Al 120.3 ± 8.9 ka
RIEST-2011-02



Zero erosion
Marc Caffee
PRIMELab
^{10}Be 108.8 ± 7.5 ka
^{26}Al 100.7 ± 7.4 ka
RISK-2010-01
^{10}Be 83.7 ± 5.6 ka
^{26}Al 75.2 ± 5.5 ka
RISK-2010-02
Riskaskama
400
380
360
Ice
^{10}Be 132.8 ± 9.2 ka
^{26}Al 119.9 ± 8.9 ka
RISK-2010-03
^{10}Be 134.2 ± 9.2 ka
^{26}Al 125.8 ± 9.4 ka
RISK-2016-01
^{10}Be 14.7 ± 1.0 ka
^{26}Al 13.8 ± 1.0 ka
RISK-2016-02
Shielded
1.67 m deep

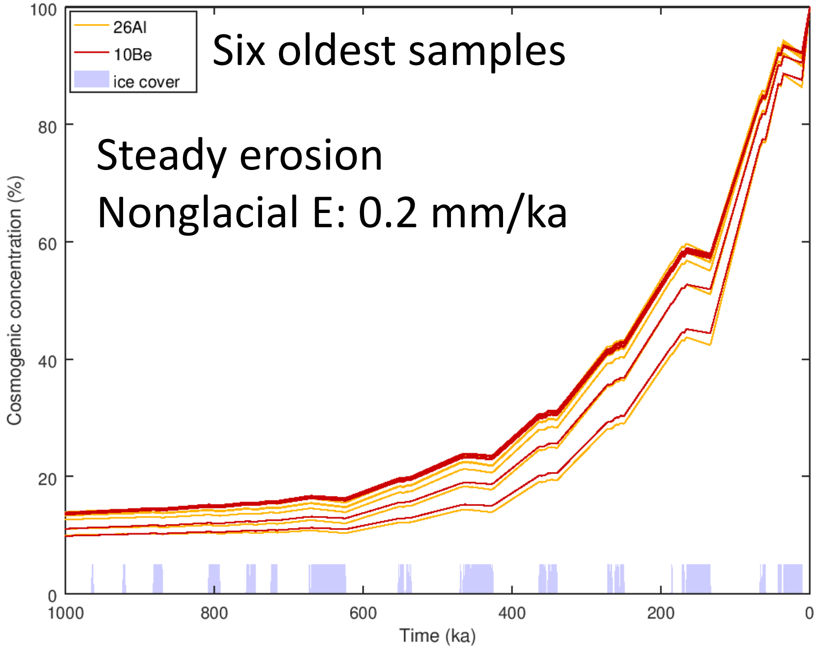
Jakob Heyman's exposure age calculator is at http://expage.github.io/calculator

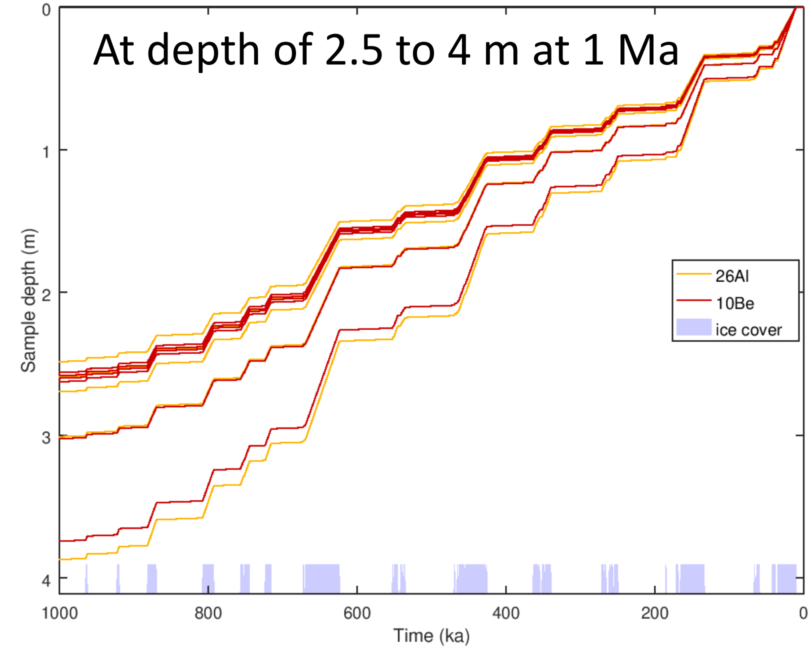
The calculator is based on the Balco et al. (2008) CRONUS calculator but differs:

- spallation production is the Lifton et al. (2014) nuclide-specific (and time-dependent) LSD scaling with reference production based on a global average (calibrated for this calculator).
- muon production is based on the LSD method as implemented in the Marrero et al. (2016) CRONUScalc calculator but changed to correct for a near-surface error and calibrated using the Beacon Heights Antarctica data for the expage calculator.

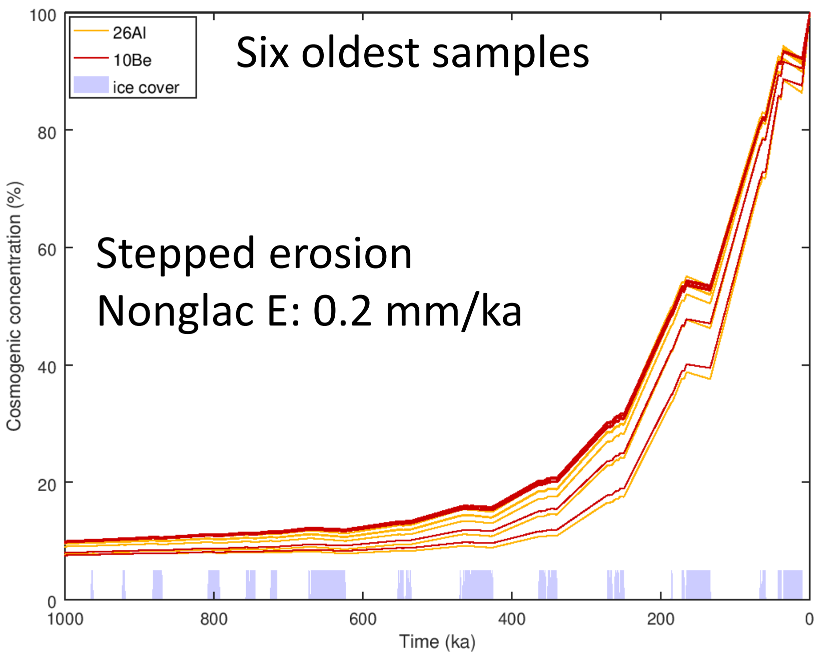
The glacial erosion calculator interpolates the measured ^{10}Be and/or ^{26}Al concentrations against expected concentrations for a range of glacial erosion rates/steps based on the input scenario. Potentially important points in the input are the non-glacial erosion rate, the ice cover scenario (defined by a per mil value in the LR04 stack data http://lorraine-lisiecki.com/LR04stack.txt , the last deglaciation age (overrules the ice cover scenario defined by LR04), and the choice of glacial erosion rate vs glacial erosion steps.

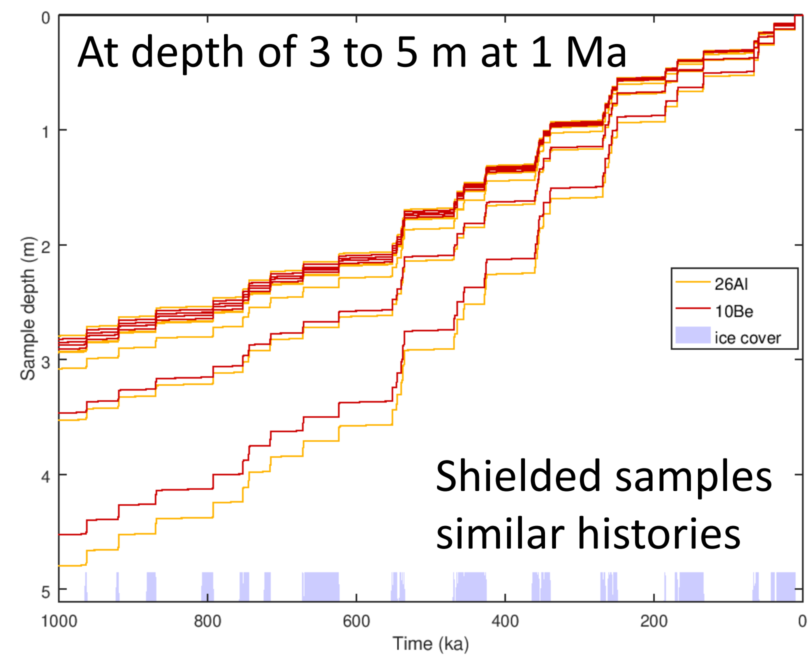
The model assumes the same glacial erosion (rate or step) for each ice cover period and this is most likely far too simple and unrealistic. All simulations start from 2.7 Ma.

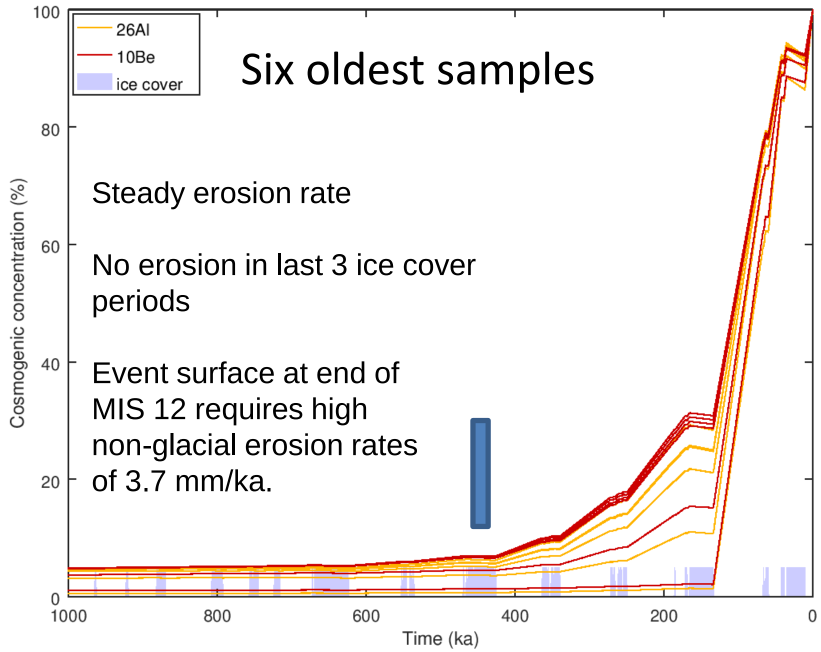


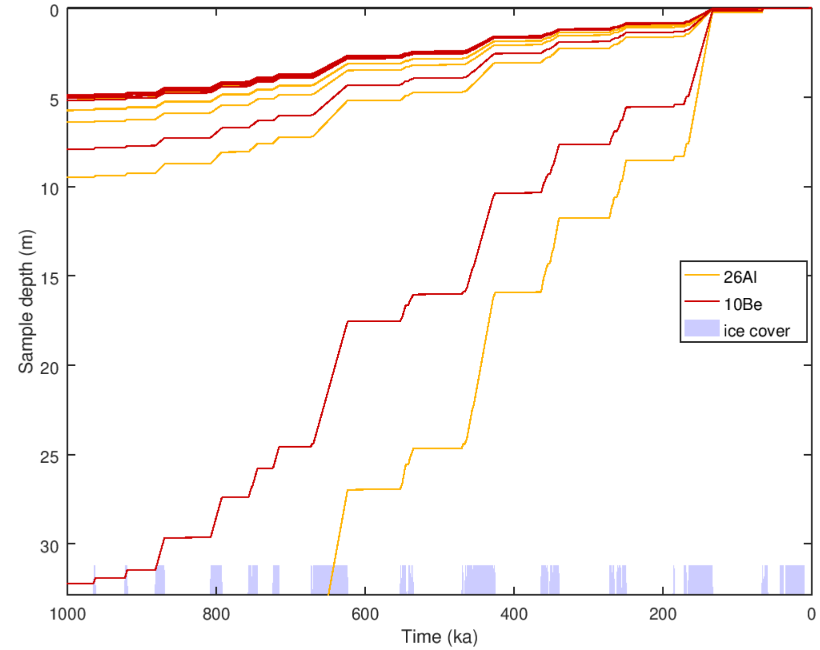


Cosmogenic isotope build-up and sample depth history starting at 2.7 Ma









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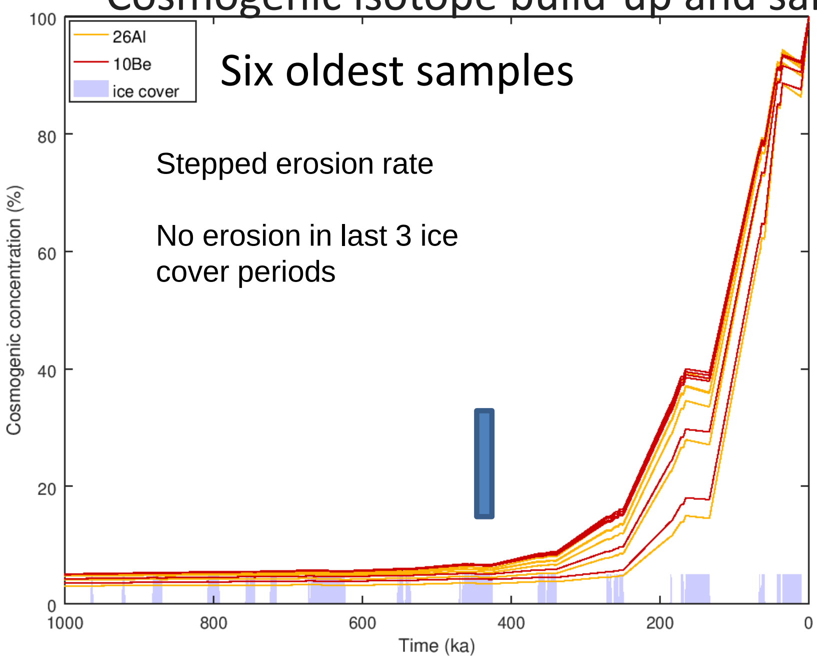
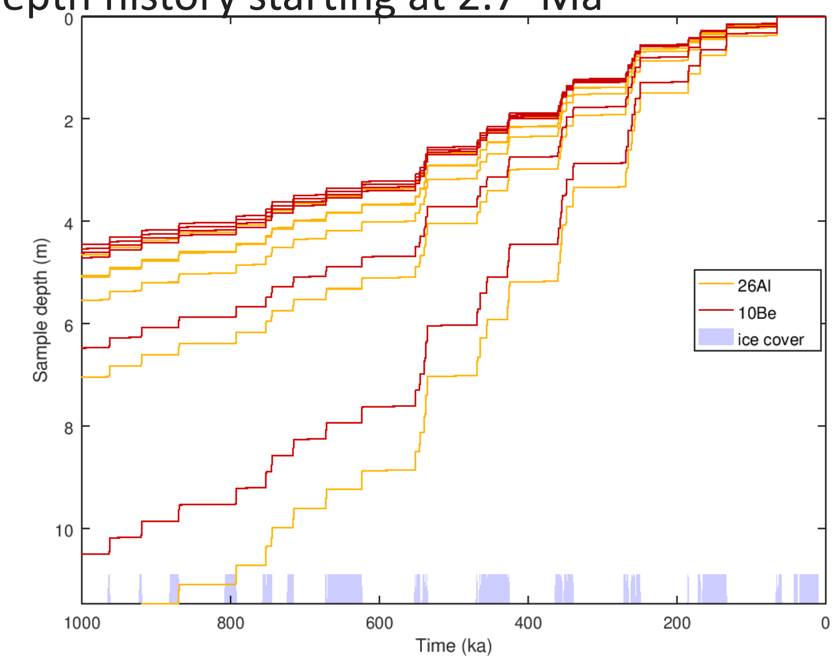
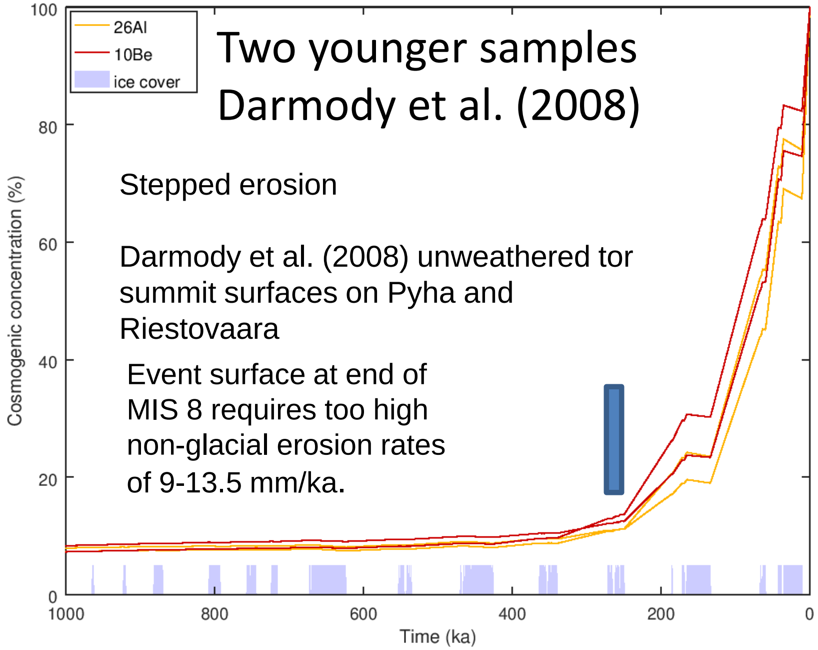
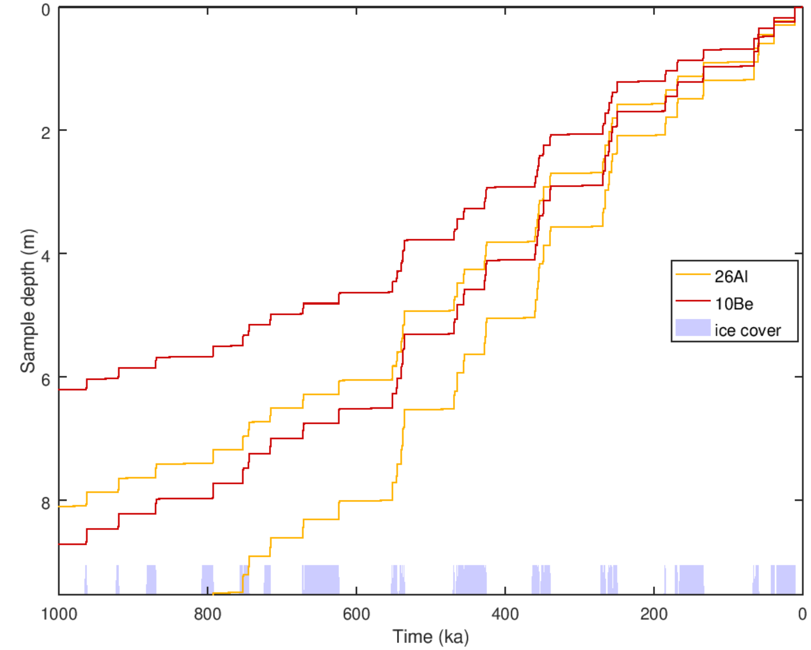
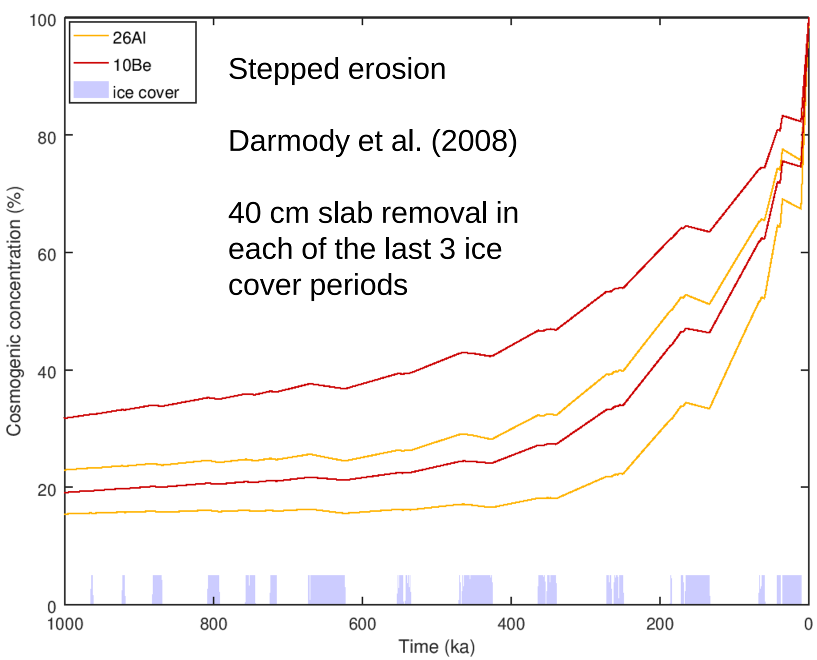


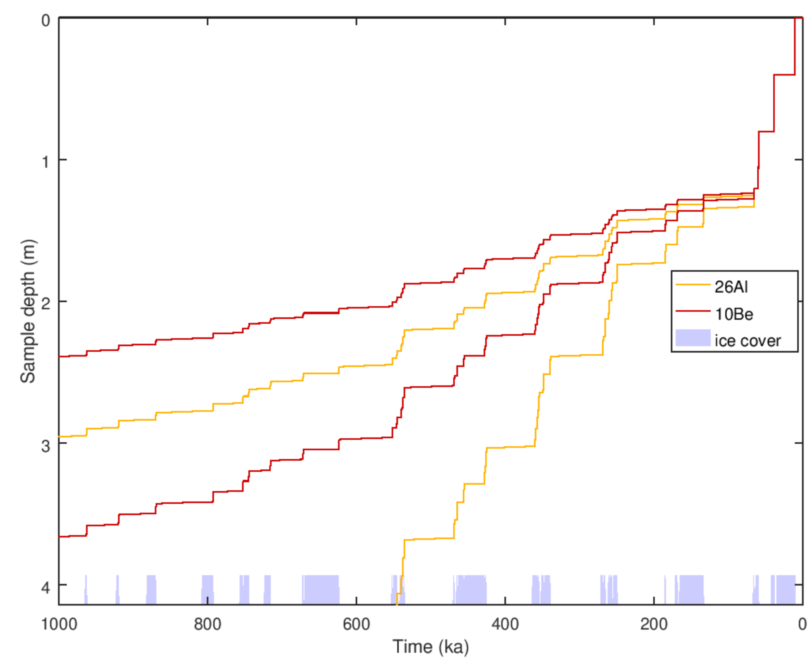






Cosmogenic isotope build-up and sample depth history starting at 2.7 Ma





1. Understanding the geomorphic context of samples is critical.
2. The Vuotso tor summit surfaces are amongst the highest exposure ages in N Europe (Cairngorms tor RF1 ^{10}Be 199 ka ^{26}Al 165 ka). Erosion rates on tor summits are low (2.5-5 m/Myr).
3. The three ^{10}Be apparent ages of 130-132 ka on different summits - any phase of glacial erosion on these tor summits is pre MIS 12.
4. The two unweathered tor summits sampled by Darmody et al. (2008) lost slabs but before MIS 8. Several other scenarios possible.
5. The tors have been modified through multiple phases of glacial and periglacial erosion through the Middle and Late Pleistocene. The tors are slowly-changing landforms of Pleistocene origin.

Our thanks to Matti Seppälä for introducing some of us to this fascinating study area.
Adrian Hall (SU), Marc Caffee (Purdue), Karin Ebert (SU), Jakob Heyman (GU), Johan Kleman (SU).
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adrian.hall@natgeo.su.se