Vegetation at the northern pole of cold during the climate extremes of the late Pleistocene

Fossil records from the Batagay mega thaw slump, Yakutia

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The Arctic during the last glacial period

Beringia - key region for northern ecosystem evolution

- the only northern region unaffected by ice sheet formation
- uniquely stable cold-continental climate
- continuous habitat for northern ecosystems
- center of origin, refugium and center of dispersal of many arctic biota
- corridor (during sea level lows) or barrier (during sea level highs) for intercontinental migration

Eurasia

North America

Beringia

cold-continental climate

cold enough for ice complex formation
Instead of ice sheets, there formed the Yedoma Ice Complex.

- Extremely ice-rich permafrost
- Syngenetically frozen sediments
- Organic matter is preserved frozen
- Perfect palaeontological archive
- Susceptible to warming
Verkhoyansk – the Pole of Cold of the Northern Hemisphere:

- t° mean January: -44.9 °C
- t° mean July: +13.2 °C
- t° mean annual: -15.2 °C
- Precipitation: 181 mm

Cold-continental climate?
The Batagay mega thaw slump

formed within 40 years triggered by changes of the radiation budget as result of timber cutting and other anthropogenic disturbances of the isolating vegetation cover.
Journey to the past

Late Pleistocene
Middle Pleistocene
not accessible at the time of sampling

Science on camera

Announcing the winners of the inaugural Scientist at Work photo competition.

BY JACK LEWNING

Photobotanist Ksenia Ashastina took this picture of her supervisor Frank Koenig, collecting samples of ancient plants from a permafrost exposure in northeastern Siberia, in June 2014. Ashastina, who is a PhD student at the Senckenberg Research Station of Quaternary Palaeontology in Würzburg, Germany, says it was a welcome 20°C. At that time, the region of the world endures temperatures below freezing for 7 months a year. Over hundreds of thousands of years, the water in the soil has frozen and thawed over and over, carving deep cuts into the ground and creating steep, icy formations like the one pictured above.

It’s a remote area. Ashastina and Koenig were the only people there, and there was no phone signal. It doesn’t look it, but it’s windy, says Ashastina. “There are tons of mosquitoes there trying to bite you. There is cracking ice and cracking trees. It’s dangerous. You need to be crazy to enjoy it, but in a good way.”

The permafrost under the exposed surface makes this area perfect for Ashastina’s research, because it’s too cold for her samples to be digested by bacteria. The same goes for the bones of the mammals that once roamed this area, around 20,000 years ago, when a green, energy-rich land bridge joined Asia and North America. Femurs, skulls, tibias, and tibias are churned up every summer as the ice melts along the formation, and the cats work further into the forest.

GUNS AND IVORY

Shortly after this photo was taken, Ashastina and Koenig camped near the formation, two locals—drunk and carrying guns—emerged from the forest and demanded to know what the scientists were doing. Every summer, the pair had made money by pulling the tusks.
Batagay is known for spectacular finds of **Megafauna**

- Complete carcass of a Pleistocene wild horse foal
- Mammoth tusk 30m above the cirque bottom
- Diverse megafauna remains incl. steppe bison, horse, mammoth and wooly rhino

Permafrost as palaeontological archive

Photo: Northeast Federal University, Yakutsk
Aim:

to reconstruct the vegetation in the refugial area of arctic megafauna during key intervals of the Late Pleistocene:

• The last cold stage
• The last warm stage (in comparison to the current warm stage)

• to understand: the impact of Quaternary climate changes
• causes and consequences of megafauna demise
• herbivore vegetation interaction
Yedoma ice complex of the last cold stage

Organic accumulation of the last interglacial (LIG)

Two representative fossil assemblages

Fossil ground squirrel nest dated to the LGM

LGM plant remains (and ground squirrel droppings)

LIG plant remains
Last glacial assemblage
from the onset of the Last Glacial Maximum

winter storage of an Arctic ground squirrel (Urocitellus parryii)

AMS $^{14}$C-dating of herb remains (Plantago sp., Artemisia sp.) and ground squirrel droppings

26.180 ± 0.22 ka BP calibrated 30.915 - 29.828 cal ka BP
25.620 ± 0.22 ka BP calibrated 30.483 - 29.217 cal ka BP

The nest was built during a time of massive global ice sheet formation equivalent to 40m sea level drop within less than 2000 years – the coldest period of the late Pleistocene

Lambeck et al., 2014 PNAS
Last glacial assemblage

Plant remains in the ground squirrel nest indicate steppe grassland vegetation.
• In small well-drained, dry habitats, steppe vegetation still occurs in Central Yakutia, the Yana Highlands around Batagay and at other places in Northeast Siberia outside of the steppe zone (extrazonal).

• The LGM assemblage from Batagay is almost exclusively composed of plants diagnostic for steppe vegetation suggesting that steppe was the zonal vegetation at this time, i.e. there was a continuous steppe belt extending from Central Asia to Yakutia.
Last interglacial assemblage

bottom of a woody organic fill of a former depression

plant remains after sieving

directly below the (last cold stage) Yedoma Ice Complex

indefinite AMS $^{14}$C age of >44 ka BP

OSL date of $142.8 \pm 25.3$ ka from sediments underlying the sampled deposits
Last interglacial assemblage

Plant remains in the organic accumulation indicate open woodland vegetation.
Modern vegetation at the site
open woodland vegetation as well but with crucial differences

Pinus pumila as indicator of thick snow cover is widespread today but was absent during the LIG

Larches are the only tree species today. Birches are absent but were present during the LIG

there is no herb layer but, instead, a thick cover of mosses and lichens, which are sensitive in terms of mechanical disturbances

shrub birch and shrub alder are present today and during the LIG but wild roses and raspberries are absent today
### Last interglacial assemblage: the herb layer

<table>
<thead>
<tr>
<th>Steppe plants suggest persistence of grasslands as potential food basis for megafauna during the LIG</th>
<th>Typical constituent of the herb layer in boreal forests</th>
<th>Ruderal plants indicate disturbances and nutrient nitrogen input by megafauna</th>
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</thead>
<tbody>
<tr>
<td><em>Potentilla tollii</em></td>
<td><em>Silene repens</em></td>
<td><em>Moehringia laterifolia</em></td>
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<tr>
<td><em>Urtica dioica</em></td>
<td><em>Chenopodium album</em></td>
<td><em>Corispermum crassifolium</em></td>
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</tbody>
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Living plant photos: plantarium.ru
Conclusions

the study area was covered with grasslands during cold stages and with woodlands during warm stages

grasslands occurred in the Yana Highlands during the entire investigated timespan of the Quaternary, as zonal steppes during cold stages or as small extrazonal patches in during warm stages

nitrophytic ruderal plants, especially the abundant *Urtica dioica*, suggest that the area was a refugium for large herbivores during the last interglacial

the absence of stone pine suggests thin snow cover; the presence of raspberry and wild rose suggests well drained ground during the LIG, thus, conditions drier than today at the site

modern steppe occurrences in the Yana Highlands are relicts of a formerly continuous steppe belt extending from Central Asia to Northeast Yakutia during Pleistocene cold stages