Frozen ground deep beneath the Suwałki region

Permafrost in Poland?

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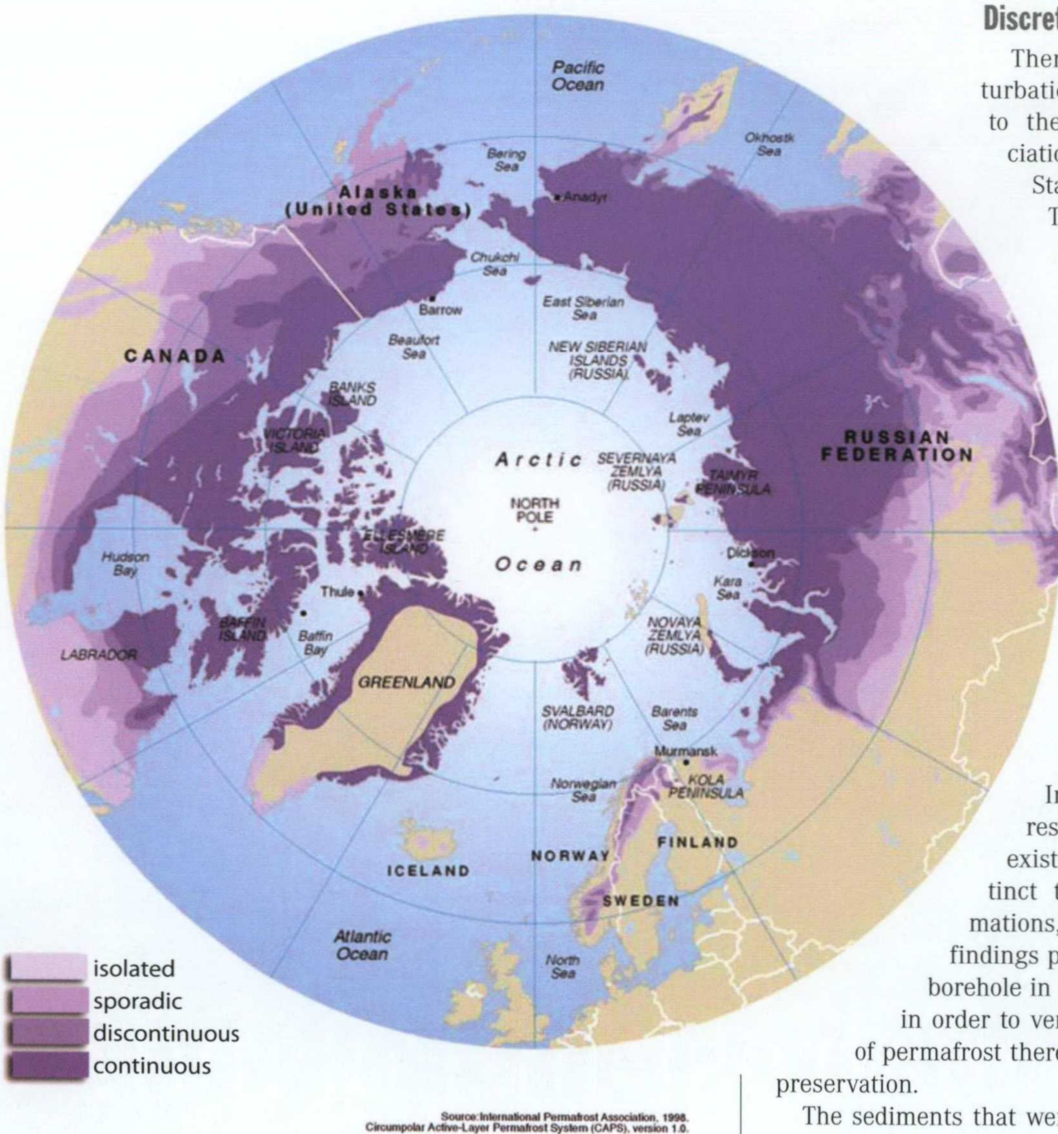
The permafrost that was discovered beneath the northeastern Polish village of Udryń in 2010 is a relict of the climatic conditions that prevailed across a sizeable share of the northern hemisphere back in the Pleistocene. The permafrost was then probably quite thick, which is why we can now detect remnants of it deep within the Earth (357 meters below ground). But how has it managed to survive to this very day?



The occurrence of permafrost in arctic regions around the Arctic Circle (from Rekacewicz, 2005; UNEP/GRID-Arendal Maps and Graphics Library)

Permafrost is a situation when sediments (and the water they contain) remain frozen for longer than two successive years, irrespective of the season. It is possible for the Earth's crust to freeze only when its temperature falls below 0°C. If such conditions are maintained, the freezing begins to extend further and further down. It is no surprise, therefore, that permafrost is today found in areas neighboring on the polar circle, such as in Alaska, Canada, eastern Siberia, northern Mongolia, the Scandinavian Mountains, and Greenland. But in Poland? The key to this riddle turns out to lie in a distinctive preservation mechanism.

Discrete observation

Thermal-hydrogeochemical perturbations that could be linked to the period of Pleistocene glaciation have been noted by the State Hydrogeological Service. Thermal profiles showed a drop in temperatures in part of the Suwałki region, where an anorthosite magma massif occurs in a deep substratum about 800 m below ground (a structure formed 1.55 billion years ago, when more malleable magma from deeper within the Earth intruded between hard, less malleable rock layers). Moreover, this drop was seen in every instance near the same sandy formations of the Lower Cretaceous, around 100 million years old. Independent hydrogeological research had also identified the existence of groundwater with distinct traces of cryogenic transformations, typical of permafrost. These findings prompted researchers to drill a borehole in the municipality of Szypliszki in order to verify the presumed occurrence of permafrost there, and to identify its degree of preservation.

The sediments that were found to contain relict permafrost (paleopermafrost) date back to the transition from the Lower to Upper Cretaceous. They take the form of medium-grained glauconitic sandstone, silts and siltstones (from the Albian - 112 million years ago), quartz sandstones with carbonate-glauconitic binders (from the Cenomanian - 99 million years ago), and flint-containing chalk (from the Turonian - 93 million years ago).

Evidence

To obtain clear-cut proof that the sediments for which a temperature below 0°C had been registered had actually undergone transformations caused by freezing, a scanning electronic microscope (SEM) was used to analyze the surface of quartz grains recovered from those strata. Quartz grains are less resistant to the effect of freezing than feldspars, for instance, partly because they contain fluid and gaseous inclusions. The greatest effects of frost weathering, which breaks rocks apart and causes them to crumble as a result of repeated freezing

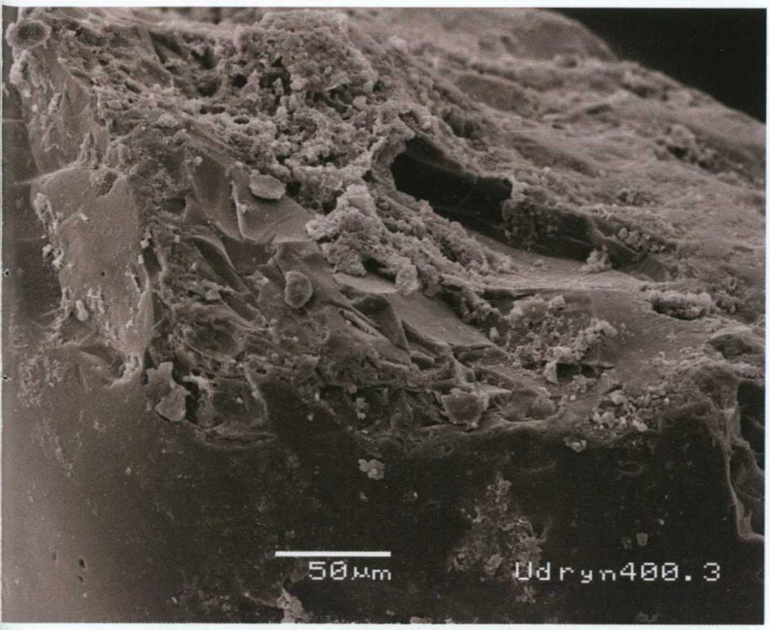
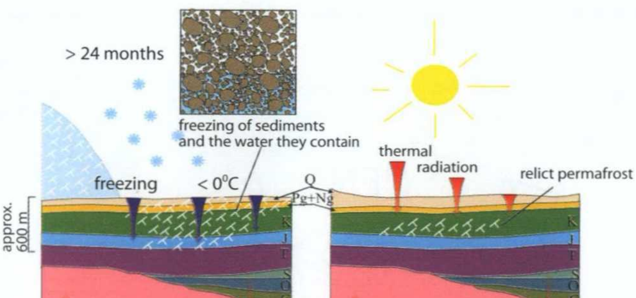


Diagram of how the relict permafrost (paleopermafrost) near Udryń in the Suwałki region of northeastern Poland (from Rychel, 2014)

and thawing of the water contained in their fissures, were observed in formations occurring within a depth interval of 396.75-401.75 m. The quartz grains studied had been damaged under periglacial conditions, as a consequence of two types of frost weathering: P and F. Type P weathering involves the presence of lenses of segregation ice in the soil, which arise through the migration of unfrozen water to the zone of freezing. Moreover, when freezing, water expands its volume by 9%, causing the ice lens to grow larger. This process results in grains being pressed together, causing them to subtly shift position with respect to one another and become damaged. Type F frost weathering is the result of the breakage of concave microstructures existing on the grain surface, due



Fragment of a quartz grain examined with a scanning electron microscope, with a microstructure revealing breakage blocks that indicate the sediment underwent freezing (from Woronko, 2011)

to water freezing in grooves or microcracks, for instance. The presence of microstructures related to frost weathering showed that the sediments studied had undergone repeated freeze-thaw cycles and that this had occurred most intensely in the more external layers of the current relict permafrost. That means that the paleopermafrost found today in the Suwałki region is a holdover from several successive Pleistocene glaciations, not just the most recent one (the Vistula glaciation).

Thermal inversion

Geothermal heat, coming from inside the Earth, generally makes it impossible for deep-seated rock strata to freeze. The preservation of the permafrost in the Udryń region is related to a reduced heat flow, limiting or even preventing geothermal heat from reaching higher layers of the Earth's crust. This is due to the anorthosite magma massif, which acts as a thermal insulator. That is why the borehole and the previous thermal profiling showed that the underground temperature here decreases with increasing depth – a phenomenon known as thermal inversion. The Udryń PIG-1 well, drilled in the center of the Suwałki massif down to a depth of about 357 m, revealed a record-low temperature (for that depth) of -0.395°C. The temperatures registered during the period of temperature stability (values from -0.34 to -0.39°C) correspond to the phase-change temperature of ice under the hydrostatic pressure conditions found here. The overall thickness of frozen rocks in the borehole studied is at least 93 meters.

Such deep permafrost could only have arisen and been preserved thanks to a low subsurface heat flow occurring above the anorthosite magma massif, related to its very low level of background radiation, in other words it generates little energy from ionization and the presence of radioactive elements. Another important reason may lie in the very high porosity of the overlying deposits.

Taking our lead from on these findings, we can surmise that preserved paleopermafrost may be waiting to be discovered also in other parts of Poland, where an intrusive magma massif acts as a similar thermal "insulator." ■

Further reading:

Pochocka-Szwarc K., Przasnyska J., Tekielska A., Rychel J. (2014). *Mapa geologiczno-turystyczna Suwalski Park Krajobrazowy, skala 1:35 000* [Geological-Tourist Map of the Suwałki National Park, 1:35000 Scale].

Szewczyk J., Nawrocki J. (2011). *Deep-seated relict permafrost in northeastern Poland.* Boreas, 10.1111/j.1502-3885.2011.00218.x.

Woronko B., Hoch M. (2011). The Development of Frost-weathering Microstructures on Sand-sized Quartz Grains: Examples from Poland and Mongolia. *Permafrost and Periglacial Processes 22*, 3: 214-227, DOI: 10.1002, 725.