History of Late Pleistocene Permafrost in Southern Ural revealed by studies of speleothems and cave sediments

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In the area of the European-Asian border, in the Ural Mountains, the southern boundary of permafrost has moved in meridional direction by more than 1000 km in response to Quaternary climate variations. During cold climate states, permafrost extended as far south as the Southern Ural (53°N). We studied three independent archives in three caves in the Southern Ural (Shulgan-Tash, Victoria and Grandioznaya) in order to gain insights into the long-term dynamics of permafrost in the region.

Common speleothems (e.g., stalagmites and flowstone) require liquid water to form, and are therefore restricted to permafrost-free periods. Cryogenic cave carbonates (CCC) form when the temperature in the cave is close to or slightly below 0°C (permafrost conditions). These two types of speleothems were dated using the ²³⁰Th-U method in order to determine the timing of permafrost and permafrost-free conditions. As a novel indicator of freezing conditions in caves we identified frost wedges in silty cave sediments filled by sand. These sands were dated using OSL to constrain the timing of sub-zero rock temperatures (required to form frost wedges) in caves.

Stalagmites, abundant in in South Uralian caves, exhibit two prominent growth phases, associated with interglacials – MIS 5e and Holocene. In addition, mm-thin layers of flowstone formed in one chamber of Shulgan-Tash cave in association with smaller-scale warming episodes during MIS 3 (Greenland interstadials GI-9 and GI-8) and MIS 2 (GI-1; Bølling-Allerød). All CCC in Shulgan-Tash and Victora caves yielded MIS 3 ages, typically lagging cooling events (Greenland stadials) GS-16.1, GS-15.1, GS-13, GS-12, GS-10, and GS-7 by several hundred years up to one 1 ka. CCC from Grandioznaya cave formed during a single episode following GS-1 (Younger Dryas). Sand filling frost wedges in Victoria cave was washed into the cave during MIS 2, ca. 24-25 ka BP. Apparently, during this time the karst massif hosting the cave was engulfed by permafrost (to a depth of at least 90 m) and flow of water through the cave was severely restricted, which led to back-flooding of the cave passage and the accumulation of several m-thick silt deposits, interspersed with thin sand layers.