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High reactivity of ancient permafrost carbon upon hydrological release

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Half of the global stock of soil organic carbon (OC) is stored in Arctic permafrost. About one third of this pool consists of so-called yedoma, organic-rich deposits that were formed during the Pleistocene. Previous studies show rapid respiration of yedoma upon thawing, with the potential release of large quantities of relict OC into the contemporary C cycle. The fluvial and coastal reactivity and fate of this OC, however, remain unclear. Duvannyi Yar is a well-studied yedoma exposure on the banks of Kolyma River in Northeastern Siberia. It can serve as a model for the >7000 km long East Siberian Arctic coastline that is dominated by similarly exposed yedoma cliffs, and is increasingly vulnerable to erosion with climate warming-induced decreases in sea-ice, and increases in storms and wave-fetch.

Permafrost thaw on the Duvannyi Yar exposure produces thaw streams that are heavily loaded with freshly thawed yedoma sediments (suspended load ca. 650 g/L; particulate OC ca. 8-10 g/L; dissolved OC ca. 150-300 mg/L). We traced organic carbon loss and oxygen utilisation during incubations of Duvannyi Yar stream water, and a series of dilutions of Duvannyi Yar water and Kolyma River and East Siberian Sea water. Concurrent measurements of enzyme activities were taken to investigate the processes limitating degradation. The overall goal of the study was to investigate the relative bioavailability of contemporary versus ancient organic carbon pools over short time scales (days-weeks).

Radiocarbon ages of the dissolved OC in the thaw streams were 19-29 ky BP, and particulate OC 19-38 ky BP. These ages are far older than any previously published values and clearly illustrate the mobilization of ancient permafrost organic matter into the contemporary carbon cycle. Incubation experiments showed that the ancient dissolved OC was highly susceptible to degradation, losing 34% of its carbon in 14 days (and 41% in 28 days). River and ocean water samples spiked with ancient carbon (filtered Duvannyi Yar stream water) showed dissolved OC losses of 19-20%, 19-22%, and 34-37% for 0.5%, 1.0% and 10% old OC additions, respectively, for 28 days. Carbon degradation rates inferred from biological oxygen demand assays were in the same range as the incubations. Extracellular enzyme activity analyses showed increased activities (T=10d compared to T=0) of phosphatase and leucine aminopeptidase suggesting that the availability of phosphorus and nitrogen limited the continued degradation of old organic carbon.

These results suggest that thawing ancient OC is highly reactive upon fluvial release. The extremely high biolability suggests that a substantial proportion of it may degrade in just a few weeks, within the time it takes for water to transit from headwaters to the mouths of major Arctic rivers.