GROUNDWORK

Furthering the Influence of Earth Science

Rapid Sediment Re-Deposition May Limit Carbon Release during Catastrophic Thermokarst Lake Drainage

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A CARBON SOURCE

Arctic soil organic carbon (SOC), the largest terrestrial organic carbon reservoir (Tarnocai et al., 2009; Schuur et al., 2015), is typically locked up in permafrost (Tarnocai et al., 2009; Olefeldt et al., 2016; Turetsky et al., 2020), but is under threat. The mean annual air temperature in the Arctic is rising twice as fast as the global average (Schuur et al., 2015). Permafrost will further degrade, exposing significant quantities of SOC to decomposition and respiration, releasing greenhouse gases (GHG), like CO_2 and CH_4, into the atmosphere (Walter et al., 2006; Mackelprang et al., 2011; Cory et al., 2014; Turetsky et al., 2020), driving a feedback loop of increasing air temperatures and degrading permafrost (Schuur et al., 2015).

A complex relationship of interlinked processes (e.g., climate, precipitation, erosion) drives permafrost degradation and differential land subsidence that generates thermokarst lakes (van Huissteden et al., 2011) (Fig. 1), which expand slowly through heat conduction, enhancing permafrost thaw and mass wasting at lake margins. Thermokarst lake expansion is projected to continue under future climate warming (Smith et al., 2005; Walter, et al., 2006; van Huissteden et al., 2011). Thermokarst lakes may also drain catastrophically (Mackay, 1988), creating thermo-erosion gullies (Figs. 1B and 1C) that result in substantial (discharge rates up to 25 m^3s^{-1}; Jones and Arp, 2015) sediment and SOC erosion from lake margins and along drainage channels. This is assumed to decrease the permafrost carbon store because the liberated SOC is vulnerable to degradation and GHG release (Vonk and Gustafsson, 2013), resulting in a net flux (positive) to the atmospheric carbon pool.

Catastrophic drainage events may increase in frequency (Jones et al., 2020), but the fate of released carbon is poorly constrained. A first-order approximation of carbon released by erosion during catastrophic thermokarst lake drainage events suggests that a significant volume of the eroded material, and potentially SOC, is rapidly re-deposited (hours to days) (Jones and Arp, 2015) in proximal downstream deltas/subaerial fans (Fig. 1B), limiting the net carbon release. Data on SOC volumes partitioned into particulate organic carbon (POC) available for re-deposition, or dissolved organic carbon

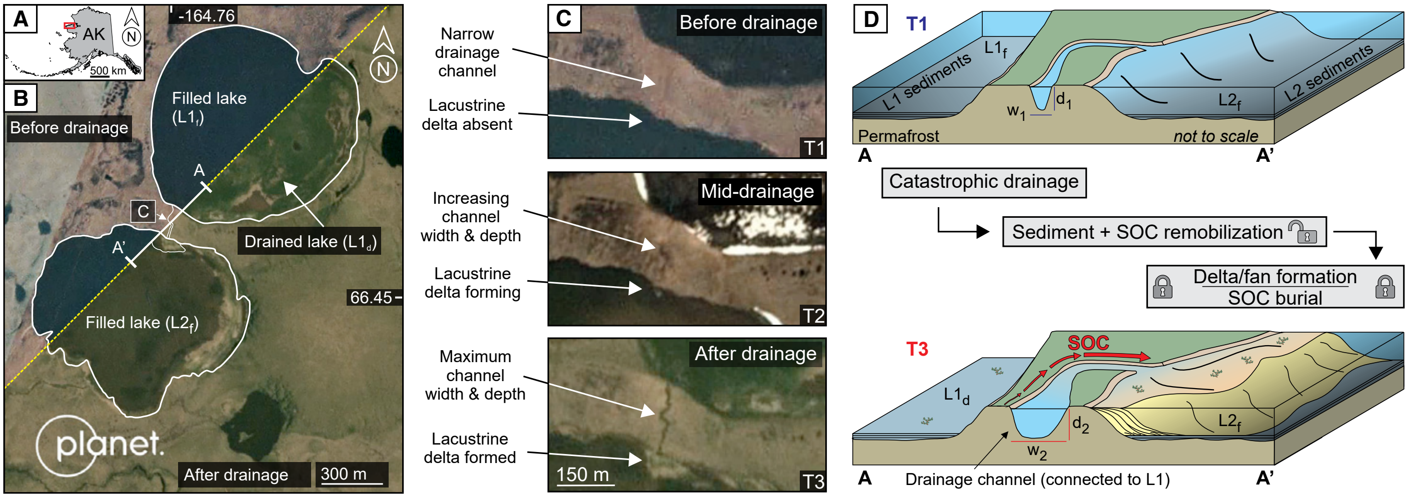

Figure 1. Catastrophic lake drainage and lacustrine delta formation. (A) Approximate location of the five thermokarst lakes analyzed herein. (B) Planet CubeSat imagery of two thermokarst lakes (Lake ID 99492) showing images before ($L1_f$) and after ($L1_d$) drainage, where lake L1 rapidly drained into lake L2 ($L2_f$). (C) Satellite imagery showing L1 drainage through a preexisting channel (T1: 27 Sept. 2017) that evolved into a thermo-erosion gulley (T2: 7 June 2018). This event eroded, transported, and deposited large volumes of sediment and remobilized soil organic carbon (SOC) into the delta in L2 (T3: 11 July 2020). (D) Schematic model of L1 drainage, creation of a thermo-erosion gulley, and deposition of a delta in L2. AK—Alaska.

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(DOC) available for degradation, are limited. If a significant volume of POC is buried in delta deposits, however, the potential for GHG release is minimized. Counterintuitively, catastrophic drainage of thermokarst lakes, and gully and lake margin erosion, may provide limited carbon release to the atmosphere.

METHODS AND RESULTS

We analyzed satellite imagery (Planet Team, 2017) for five thermokarst lakes (98.5–1,403 km^2) in NW Alaska that drained between 2017 and 2018 (Fig. 1A) (Nitze et al., 2020). Following catastrophic drainage, all channels widened by >1.7 m (Fig. 1C), and lengths remained constant (supplemental Table S1[1]). Channel depths could not be measured from available imagery. A delta or fan always formed in the receiving lake. SOC in the top two meters average 8843.31 g/m^2 (Zhu and McGuire, 2016), suggesting, conservatively, that >3.22 Gg of carbon may be remobilized during a single drainage event, or >42.2 Gg from the five events combined (supplemental Table S2 [see footnote 1]). Carbon eroded from lake margins proximal to channels could not be quantified, so the remobilized carbon calculations are conservative minima.

A CARBON SINK

Material eroded during catastrophic lake drainage is commonly rapidly re-deposited, burying remobilized organic carbon into proximal lacustrine deltas/fans (Fig. 1C). Organic carbon in superficial deltaic sediments may undergo further degradation (Blair and Aller, 2012), but most carbon in the delta may no longer represent a source of GHG. Our conceptual model (Fig. 1D) suggests that thermokarst lake deltas/fans produced by catastrophic drainage may serve as proximal sinks of organic carbon.

Long-term organic carbon fate in these deposits remains uncertain. An increased magnitude and frequency of drainage and re-deposition events will increase their impact on the local and regional carbon stores. Further work is required to identify the precise role of catastrophic thermokarst lake drainage in Arctic carbon fluxes.

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[1] Supplemental Material. Table S1: Geometric measurements obtained from satellite imagery of rapidly drained thermokarst lakes and associated deltas and thermo-erosion gullies. Lake ID relates to drained lakes identified in Nitze et al. (2020). Table S2: Estimated soil organic carbon content measured in gigagram (Gg) in top 2 m removed from thermo-erosion gullies. Estimates and approximate spatial resolution are derived from spatial statistical models presented in Zhu and McGuire (2016). Go to https://doi.org/10.1130/GSAT.S.19083299 to access the supplemental material; contact editing@geosociety.org with any questions.