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Excavation of sediments by tidewater glacier advance and implications for the oceanic sediment record, Taku Glacier, Alaska, USA

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Taku Glacier, located in southeast Alaska, has advanced 7.5 km over the last 115 years, overriding its own glaciomarine and outwash sediments, and also deltaic sediments derived from nearby Taku and Norris Rivers. The advance is driven by long-term positive net mass balance and a high accumulation to total area ratio (0.85). The 60 km long, 700 km^{2}glacier mantles the Coast Mountains on the border with Canada. Taku Glacier calved icebergs into a 100 m deep fjord during the late 19^{th} century. Sediment that was excavated and remobilized by the advancing glacier filled this fjord and caused the terminus to become shoal by the mid 20^{th} century. We consider Taku Glacier to be in the advance phase of the so-called "Tidewater Glacier Cycle." We have documented significant excavation of the overridden sediments based on hydrographic surveys conducted in 1890, 1937, and 1952 AD, and our radio echo sounding (RES) in 1989 and 2003-04.

A cross-glacier RES transect in 2003, located 6.5 km upglacier from the current terminus, revealed an ice thickness of up to 610 m with the glacier bed at 260 m below sea level (bsl) near the centerline. Based on comparisons to 1989 RES measurements, the highest rates of sediment excavation occurred near the centerline and averaged 3.7 $\pm$ 0.8 m a^{-1} over this period. Excavation fell to below detection limits about 1 km to either side of the centerline as valley walls were approached. Comparing 1989 RES results to early hydrographs, we estimate that about 160 m of sediment were excavated along the glacier bed centerline between $\sim$1905 AD, when the terminus first advanced to this position, and 1989, when the glacier was 560 m thick. The equivalent excavation rate was roughly 1.9 m a^{-1}, about half of the current rate.

We also conducted detailed RES surveys of a 2 km^2 area of ice near the terminus to delineate subglacial geomorphology in a region where recent glacier advance has significantly disrupted proglacial sediments. The RES surveys revealed a 250 m wide subglacial canyon that has been eroded into sediments to depths of 140 m bsl since 1952, the date when the glacier first began overriding this region and proglacial sediments were then above sea level. The highest rates of sediment erosion documented here are 2.7 ($\pm$ 0.2) m a-1. The surrounding subglacial terrain is also being eroded but at much slower rates. The trough is in line with the mouth of a major subglacial stream, suggesting the trough is being eroded by glaciofluvial processes.

Our results have several implications. (1) Caution must be exercised when estimating glacier growth solely from surface elevation measurements for glaciers advancing over sediment. Entrenchment can play an important role in a glacier's dynamics and needs to be taken into account when measuring volume changes. (2) Excavation and redistribution of sediments have positive and negative feedbacks on the advance of a tidewater glacier. Shoal conditions reduce calving and enhances advance, while entrenchment into sediments may slow advance. (3) Down-fjord redistribution of subglacially excavated sediments has had a profound effect on the evolution of the local and regional landscape at Taku Glacier. Extrapolating to larger scales, we suggest that evidence of sediment fluxes from such rapid excavation and redistribution during periods of major tidewater glacier advance should be present in the oceanic sediment records on continental shelves. (4) Extreme caution should be exercised when inferring bedrock erosion rates from measurements of proglacial sediment fluxes at the termini of advancing glaciers. A significant fraction of the flux may be remobilized sediment rather than sediment derived from primary bedrock erosion. (5) Freeze-on layers and sediment deformation cannot account for excavation and transport of such large quantities of sediment. We propose that glaciofluvial processes must play the dominant role in subglacial erosion of soft sediment and its subsequent transport. (6) The deep troughs that tidewater glaciers excavate to well below sea level during their advance will eventually lead to the glacier's rapid demise once a retreat is initiated. Deep water accelerates retreat, which then becomes almost entirely independent of climate conditions.