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Pliocene–Pleistocene megafloods as a mechanism for Greenlandic megacanyon formation

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Dam et al. (2020a) argue in their Comment that some of the vast canyon networks in Greenland predate the inception of the ice sheet and were carved by fluvial processes unrelated to glaciation. We appreciate that their Comment provides critical context for understanding Greenlandic landscape evolution and the delivery of sediments to basins in the North Atlantic over hundreds of millions of years (Ma; Dam et al., 2020b). In this Reply, we note that the mechanism we propose for canyon formation is not mutually exclusive with preexisting topography that predates the Pliocene–Pleistocene. At the same time, our mechanism is consistent with a number of lines of evidence that bedrock incision in Greenland and delivery of Greenland-derived sediments to the ocean increased as the ice sheet in north Greenland expanded during the Pliocene–Pleistocene.

The water routing we propose, informed by numerical ice-sheet and glacial isostatic adjustment (GIA) modeling, concentrates outburst floods along preexisting bedrock structures and would accentuate these features, contributing to the fluvially formed canyon networks observed beneath the ice sheet today (e.g., Bamber et al., 2013; Cooper et al., 2016). This does not preclude that canyons were present on the landscape as early as the Carboniferous, as Dam et al. (2020a) suggest, nor does it imply that every canyon network resulted from large outburst flood events. Indeed, as we show in our analysis, the erosive potential of outburst floods in north Greenland results from interactions between bedrock, GIA, and the retreating ice sheet which concentrate flow along discrete outlets in northeast Greenland (Keisling et al., 2020).

Though our hypothesis requires further testing, some offshore sediment records are consistent with the mechanism for landscape evolution we propose. In northern Baffin Bay, high-resolution seismic surveys reveal thick Pliocene and Pleistocene sediment deposits (Knutz et al., 2019). Additional seismic studies off northwest Greenland have mapped sediment packages ranging in age from Miocene to Pleistocene (Kristoffersen and Mikkelsen, 2006). One transect in the Lincoln Sea revealed seven depositional units, three of which are Pliocene or younger. The oldest of these, characterized by high sediment input, was attributed to enhanced terrestrial input during the intensification of Northern Hemisphere glaciation (Kristoffersen and Mikkelsen, 2006). Off northeast Greenland, changes in sedimentation rates through the Pliocene–Pleistocene are also consistent with glacial processes resulting in large changes in sediment delivery (Berger and Jokat, 2009).

In addition to offshore records, sediments beneath the ice sheet may reflect its history. Silty ice was recovered from the base of the Camp Century and Northern Eemian ice core sites (Willerslev et al., 2007; Goossens et al. 2016). Dahl-Jensen et al. (2003) used receiver function analysis to identify mantle structure beneath Greenland and found it necessary to assume ~100 m of sediment in north-central Greenland to fit the data there. Ground-based seismic survey mapped a ~8 km package of dilatant till beneath the main trunk of the northeast Greenland ice stream (Christianson et al., 2014). While none of these data prove the existence of repeated outburst flood events, they are all consistent with our proposed mechanism.

Greenland’s deep inland canyons and associated coastal fjords have undoubtedly been altered by the dynamics of glaciation in the Pliocene–Pleistocene. In northeast Greenland, most of the incision of Independence Fjord has occurred since 2.5 Ma (Pedersen et al., 2019). Similarly, apatite ages indicate that the deep glacial troughs in northwest Greenland had not been fully excavated by 1.9 Ma (Christ et al., 2020). Styles of glaciation have also been variable since that time, with deposition on the continental shelf shifting between focused and distributed (Knutz et al., 2019). These studies point to a close association between ice-sheet fluctuations and the establishment of modern-day bed topography, which the mechanism we proposed expands on (Keisling et al., 2020).

Many questions remain about how Greenland’s topography has influenced, and been influenced by, the growth and decay of ice sheets. Yet, none of the evidence outlined here precludes landscape evolution prior to the Pliocene–Pleistocene, as Dam et al. (2020a) show. Future work to test the hypothesis we propose, along with continued examination of the myriad processes that have shaped Greenland’s bedrock, will be critical for understanding the history of this remarkable landscape.

REFERENCES CITED


