Across the Great Divide: The Flow-to-Fracture Transition and the Future of the West Antarctic Ice Sheet

Richard B. Alley[1], Byron R. Parizek[1,2], Knut Christianson[3], Robert M. DeConto[4], David Pollard[1] and Sridhar Anandakrishnan[1]

[1]*Department of Geosciences, and Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA, 16802*
[2]*Mathematics and Geoscience, Pennsylvania State University, Dubois, PA 15801*
[3]*Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195*
[4]*Department of Geosciences, University of Massachusetts, Amherst, MA 01003;*

Physical understanding, modeling, and available data indicate that sufficient warming and retreat of Thwaites Glacier, West Antarctica will remove its ice shelf and generate a calving cliff taller than any extant calving fronts, and that beyond some threshold this will generate faster retreat than any now observed. Persistent ice shelves are restricted to cold environments. Ice-shelf removal has been observed in response to atmospheric warming, with an important role for meltwater wedging open crevasses, and in response to oceanic warming, by mechanisms that are not fully characterized. Some marine-terminating glaciers lacking ice shelves "calve" from cliffs that are grounded at sea level or in relatively shallow water, but more-vigorous flows advance until the ice is close to flotation before calving. For these vigorous flows, a calving event shifts the ice front to a position that is slightly too thick to float, and generates a stress imbalance that causes the ice front to flow faster and thin to flotation, followed by another calving event; the rate of retreat thus is controlled by ice flow even though the retreat is achieved by fracture. Taller cliffs generate higher stresses, however, favoring fracture over flow. Deformational processes are often written as power-law functions of stress, with ice deformation increasing as approximately the third power of stress, but subcritical crack growth as roughly the thirtieth power, accelerating to elastic-wave speeds with full failure. Physical understanding, models based on this understanding, and the limited available data agree that, above some threshold height, brittle processes will become rate-limiting, generating faster calving at a rate that is not well known but could be very fast. Subaerial slumping followed by basal-crevasse growth of the unloaded ice is the most-likely path to this rapid calving. This threshold height is probably not too much greater than the tallest modern cliffs, which are roughly 100 m.