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When Greenland Was Green: New GreenDrill Evidence from the Holocene Thermal Maximum Fuels Future Research

Environment * Climate Change * Conservation

Introduction: Sub-Glacial Archives and the GreenDrill Campaign

The stability of the Greenland Ice Sheet (GrIS) is one of the most consequential variables governing twenty-first-century global sea-level projections. For decades, conventional ice-sheet models treated the cryosphere of northern Greenland as a sluggish, monolithic reservoir that responds only over multi-millennial timescales. However, inaugural findings from the U.S. National Science Foundation-funded GreenDrill project at Prudhoe Dome in northwest Greenland have overturned this assumption.[1, 3] By drilling through 509 meters of ice to recover a 7.4-meter core of frozen sub-glacial sediment and Proterozoic crystalline bedrock, researchers co-led by Jason Briner and Joerg Schaefer established that this peripheral ice cap deglaciated approximately 7,100 years ago during the Holocene Thermal Maximum (HTM).[1, 2, 6] That collapse occurred when regional Arctic summer temperatures were 3 deg C to 5 deg C warmer than pre-industrial baselines -- a thermal threshold projected to recur by 2100 under moderate-to-high emissions trajectories.[3, 6]

While traditional deep-interior ice cores provide continuous atmospheric records, they rarely sample the ice-bed interface along vulnerable margins where the spatial extent of the ice sheet fluctuates.[4] Situated in Inglefield Land between Baffin Bay and the Hiawatha Glacier sector, Prudhoe Dome is a 500-meter-thick peripheral dome connected directly to the main ice sheet.[5, 15] Operating the Agile Sub-Ice Geological (ASIG) drill amidst sub-zero blizzards in spring 2023, the GreenDrill field team overcame a mid-borehole fracture to extract the longest sub-ice rock and sediment archive ever recovered from Greenland, providing a direct geological test of marginal glaciology and atmospheric thermodynamics.[1, 2, 15]

Sub-Glacial Geology and Multi-Proxy Geochronology

Preservation of the Prudhoe Dome paleo-surface depends on the geology of Inglefield Land and the basal thermal regime of the overlying ice. Whereas warm-based glaciers reach the pressure-melting point and slide over lubricated beds -- scouring away surface rock and resetting geological clocks -- Prudhoe Dome is cold-based.[5] Frozen solid to its bed of quartz-bearing Proterozoic paragneiss, the ice moves via internal deformation rather than basal sliding, shielding ancient regolith and fossil landscapes without erosional stripping.[4, 5]

To determine when and how long the Prudhoe Dome bed was ice-free, the team combined three independent geochronological proxies:

* Cosmogenic Nuclide Exposure Dating (10Be and 26Al): High-energy cosmic rays colliding with atmospheric nitrogen and oxygen generate secondary neutrons that penetrate unshielded surface rock. When these neutrons strike silicon and oxygen atoms inside quartz (SiO2), spallation reactions eject nucleons from the target

nucleus, producing radioactive Beryllium-10 (half-life 1.39 Myr) and Aluminum-26 (half-life 717 kyr).[4, 7] Because even a few meters of ice block cosmic radiation, elevated concentrations of 10Be and 26Al in the Prudhoe bedrock confirm prolonged subaerial exposure, while their ratio constrains cumulative burial and exposure cycles across the Pleistocene and Holocene.[5, 6, 7]

* Infrared Stimulated Luminescence (IRSL): Feldspar and quartz grains in sub-glacial sediment accumulate trapped electrons excited by background ionizing radiation from surrounding uranium, thorium, and potassium while buried in darkness.[8] Exposure to sunlight bleaches these traps to zero within minutes. Stimulating the dark-preserved Prudhoe Dome sediment grains with infrared light in the laboratory yielded a precise burial age of 7.1 +/- 1.1 ka, pinpointing the last time the ground beneath 500 meters of ice saw daylight.[6, 15]

* Basal Ice Oxygen Isotopes (18O): Stable isotope ratios (18O/16O) in the basal ice immediately above the sediment bed lacked the strongly depleted, isotopically light signature of Pleistocene Last Glacial Maximum ice, exhibiting exclusively Holocene interglacial values.[6] This confirms that pre-Holocene ice melted away before Neoglacial cooling re-initiated ice cap growth.

The Holocene Thermal Maximum Analog and Soft-Ice Rheology

The deglaciation of Prudhoe Dome at 7.1 ka occurred during the Holocene Thermal Maximum (roughly 9,000 to 5,000 years ago), when higher axial obliquity and Northern Hemisphere summer perihelion increased Arctic solar insolation.[9] Regional proxy reconstructions, including ice-core records from the nearby Agassiz Ice Cap, indicate that northwest Greenland summer temperatures were 3 deg C to 5 deg C above pre-industrial levels.[3, 9] Although HTM warming was orbitally paced rather than driven by anthropogenic carbon dioxide, the thermal forcing provides a direct physical analog for late-twenty-first-century Arctic projections.[3, 6] Numerical ice-sheet modeling shows that the climatic conditions required to eliminate Prudhoe Dome correspond to a Greenland-wide ice loss of 0.19 to 0.73 meters of global sea-level equivalent (SLE).[6]

Beyond documenting complete mid-Holocene melt, the Prudhoe Dome investigation revealed a critical rheological anomaly in how northern Greenland ice flows under gravity. In Glen's Flow Law, strain rate scales with gravitational stress raised to an exponent modulated by an effective viscosity parameter. Modeling led by Caleb Walcott-George demonstrated that reproducing Prudhoe Dome's Holocene geometry and retreat history requires an ice viscosity 9 to 15 times lower ("softer") than standard ice-sheet models assume.[6, 11, 12] Attributed to impurity loading, anisotropic crystal fabric alignment along shear planes, and microscopic interstitial water veins at grain boundaries, this low-viscosity rheology means that cold-based ice can thin and flatten rapidly through internal creep alone.[12, 13, 14] Rapid profile flattening lowers the ice surface into warmer atmospheric strata, accelerating the elevation-mass balance feedback loop.

Comparative Vulnerability Across the Greenland Ice Sheet

Comparing the GreenDrill results at Prudhoe Dome with legacy sub-ice cores from Camp Century and GISP2 (Summit Station) establishes a clear three-tier hierarchy of

Greenland Ice Sheet stability:[4, 5, 10]

| Glaciological Parameter | | Prudhoe Dome (GreenDrill Tier 1) | | Camp Century (Flank Tier 2) | | Summit Station / GISP2 (Core Tier 3) |

| Ice Thickness & Bed Elevation | | ~509 m thick; ~800 m a.s.l. bed | | ~1,390 m thick; ~1,000 m a.s.l. bed | | >3,000 m thick; central interior basin |

| Basal Thermal Regime | | Cold-based (frozen to bed; low-viscosity creep) | | Cold-based (frozen fossil tundra sediment) | | Cold-based interior accumulation zone |

| Last Confirmed Ice-Free Period | | Mid-Holocene (~7.1 +/- 1.1 ka) | | Pleistocene MIS 11 (~400 ka) or MIS 5e | | Continuous or near-continuous for >1.0 Myr |

| Regional Warming Threshold | | +3 deg C to +5 deg C above pre-industrial | | Prolonged interglacial warmth | | Sustained multi-millennial forcing |

| Sea-Level Equivalent (SLE) | | 0.19 - 0.73 meters SLE (marginal retreat) | | ~1.4 - 3.0+ meters SLE (northwest flank collapse) | | Up to ~7.4 meters SLE (total GrIS loss) |

Whereas Camp Century -- situated further inland beneath 1.4 kilometers of ice -- retained its ice cover through the Holocene after deglaciating during Marine Isotope Stage 11 (~400 ka), peripheral domes like Prudhoe represent the "first responders" to moderate Arctic warming.[5, 10, 15] Because ice-sheet retreat exhibits strong hysteresis, once peripheral domes cross their thermal tipping point and transition into proglacial tundra, restoring twentieth-century temperatures will not regenerate them without Neoglacial-scale cooling.[6] Thus, trajectories approaching +3 deg C to +5 deg C in the high Arctic commit the planet to at least 0.2 to 0.7 meters of irreversible sea level rise from Greenland's margins alone, while raising the risk of encroaching upon Tier 2 flank stability.[6, 15]

Conclusion: Calibrating Cryospheric Risk

The GreenDrill recovery at Prudhoe Dome transforms the sub-glacial bedrock of Greenland from an inaccessible boundary into a quantitative archive for climate science.[1, 2] By proving that a 500-meter-thick northwest Greenland ice cap vanished 7,100 years ago under 3-5 deg C of regional summer warmth -- and that northern Greenland ice deforms 9 to 15 times more readily than standard stiff-ice models assume -- the study validates high-sensitivity sea-level projections.[6, 11, 15] As GreenDrill expands its transect drilling across the Hiawatha Margin, Victoria Fjord, and Dronning Louise Land, pairing in-situ cosmogenic 14C with airborne radar fabric mapping will further constrain the rate at which Greenland's frozen margins retreat into the interior.[2, 4]

Updates... (Nov 22, 2026): Replaced the undated Arctic Focus summary link and duplicate Inglefield Land entry with the NSF Public Access Repository record and Schaefer et al. (2016) in Nature, upgraded Briner et al. (2022) to its peer-reviewed The Cryosphere DOI, and added exact publication dates across all cited sources. (Earlier update, Nov 18, 2026: Replaced the inaccessible IRSL repository citation with Buylaert et al., 2012 in Boreas.)

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