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Wisconsinan and early Holocene glacial dynamics of Cumberland Peninsula, Baffin Island, Arctic Canada

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A B S T R A C T

Three glacier systems—an ice sheet with a large marine-based ice stream, an ice cap, and an alpine glacier complex—coalesced on Cumberland Peninsula during the Late Wisconsinan. We combine high-resolution mapping of glacial deposits with new cosmogenic nuclide and radiocarbon age determinations to constrain the history and dynamics of each system. During the Middle Wisconsinan (Oxygen Isotope Stage 3, OIS-3) the Cumberland Sound Ice Stream of the Laurentide Ice Sheet retreated well back into Cumberland Sound and the alpine ice retreated at least to fiord-head positions, a more significant recession than previously documented. The advance to maximal OIS-2 ice positions beyond the mouth of Cumberland Sound and beyond most stretches of coastline remains undated. Partial preservation of an over-ridden OIS-3 glaciomarine delta in a fiord-side position suggests that even fiord ice was weakly erosive in places. Moraines formed during deglaciation represent stillstands and re-advances during three major cold events: H-1 (14.6 ka), Younger Dryas (12.9–11.7 ka), and Cockburn (9.5 ka). Distinctly different responses of the three glacial systems are evident, with the alpine system responding most sensitively to Bølling-Allerød warming whereas the larger systems retreated mainly during Pre-Boreal warming. While the larger ice masses were mainly influenced by internal dynamics, the smaller alpine glacier system responded sensitively to local climate effects. Asymmetrical recession of the alpine glacier complex indicates topoclimatic control on deglaciation and perhaps migration of the accumulation area toward moisture source.

1. Introduction

Cumberland Peninsula on Baffin Island has one of the most studied Pleistocene glacier systems in Canada. Part of the fascination with the peninsula, which is intermediate in size between Switzerland and Ireland, resides in the interaction of three independent glacier systems during the last glaciation: The northeastern fringe of the Laurentide Ice Sheet (LIS), the expanded Penny Ice Cap (PIC, still one of the largest extant ice caps in Arctic Canada, >6000 km^2, Fig. 1), and an expanded alpine glacier complex, the remnants of which still cover about a third of the eastern part of the peninsula with valley and cirque glaciers (some tidewater) and isolated summit ice caps (collectively larger than PIC). Cumberland Sound, a 60 km wide trough that defines the southwest coast of the peninsula, was occupied by LIS ice, which for much of its history produced a prominent ice stream (Cumberland Sound Ice Stream, CSIS, Kaplan et al., 1999). The CSIS extended across the continental shelf during the Last Glacial Maximum (LGM, Jennings, 1993; Jennings et al., 1996).

Despite the significant amount of geomorphic and glacial geologic work on Cumberland Peninsula during the last five decades (Fig. 1a, e.g., Miller, 1973; Andrews et al., 1976; Sugden and Watts, 1977; Dyke, 1979; Dyke et al., 1982; Locke, 1987; Wolfe, 1994; Steig et al., 1998; Bierman et al., 1999; Marsella et al., 2000; Miller et al., 2002), most previous field work was restricted to segments of the coast. In 2009 and 2010, the Geological Survey of Canada *Geomapping for Energy and Minerals* project for Cumberland Peninsula established a camp in the interior of the peninsula and provided helicopter support to map both bedrock and surficial geology of most of the peninsula at a scale of 1:100,000.

The objectives of the surficial component included i) analysis of the glacial chronology among the different ice systems on the

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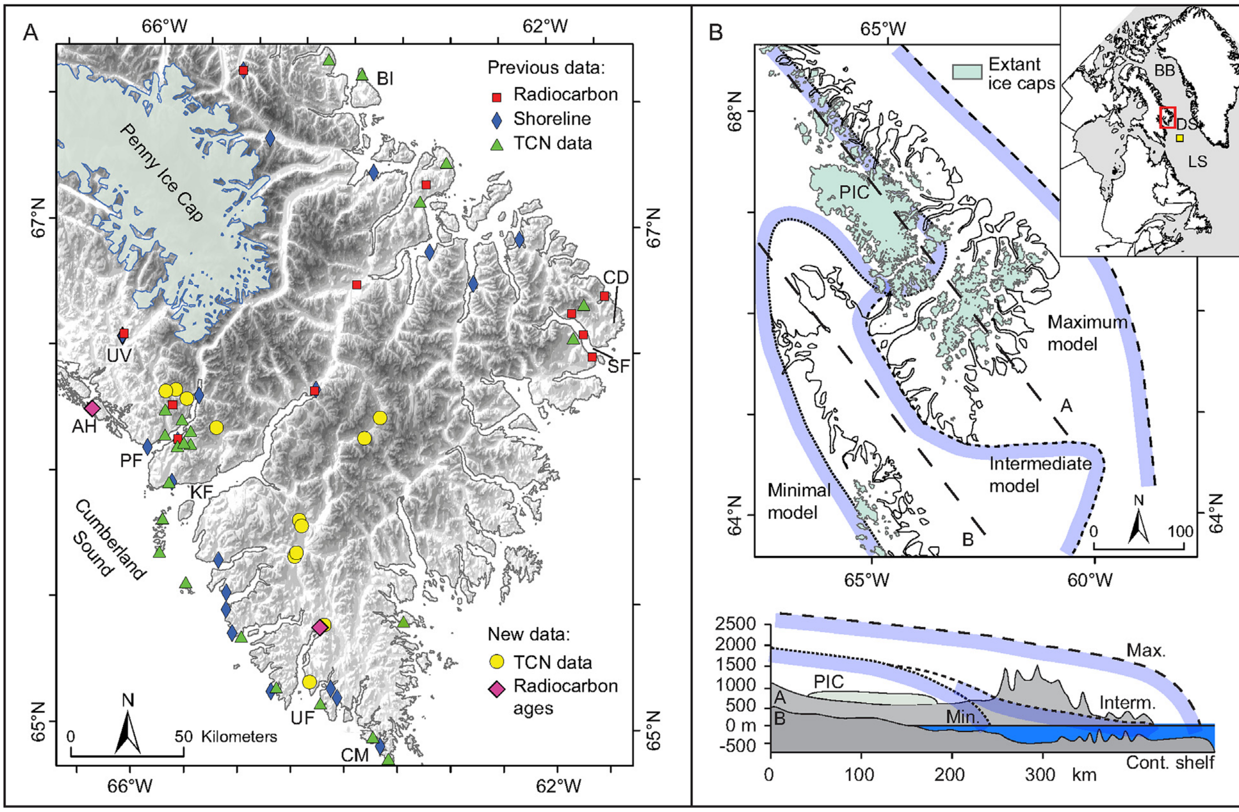

Fig. 1. A. Digital elevation map of Cumberland Peninsula with previous sample locations referred to in this study (squares: radiocarbon dating, diamonds: shoreline measurements, triangles: TCN data), new TCN sample locations (circles), and new radiocarbon ages (rotated squares). BI: Broughton Island, CD: Cape Dyer, SF: Sunneshine Fiord, CM: Cape Mercy, UF: Ujuktuk Fiord, KF: Kingnait Fiord, PF: Pangnirtung Fiord, AH: American Harbour, UV: Usualuk Valley. **B.** Schematic illustration of the three major conceptual ice-sheet models: Maximum model (Flint, 1943), Intermediate model (Miller et al., 2002), and Minimal model (Ives, 1978). Approximate locations of elevation-profiles A and B for the vertical section are indicated with dashed lines. Vertical cross-section showing two elevation-profiles is adapted from Miller et al. (2002). Location of Cumberland Peninsula in the Eastern Canadian Arctic is marked by the red box in inset map and location of sediment core discussed in the text is shown by the yellow square. BB: Baffin Bay, DS: Davis Strait, LS: Labrador Sea. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

peninsula during the late Quaternary, and ii) linkage of the differences and trends in the ice systems dynamics to paleoclimate and glaciological controls. To achieve these objectives, we obtained the first chronology for glacial deposits throughout the interior of the peninsula. Here we combine that with published ages and the new maps of glacial deposits and landforms (Dyke, 2011a,b,c,d,e,f; 2013a,b,c) to locate and interpolate ice marginal positions for three major late-glacial cooling events that affected the North Atlantic region: (i) the end of Heinrich Event 1 (H-1, ~20–14.6 ka, Stanford et al., 2011), (ii) the end of the Younger Dryas chron (YD, 12.9–11.7 ka, Rasmussen et al., 2006), and (iii) an early Holocene LIS advance that formed the outer Cockburn moraines (9.5–8.5 ka, Ives and Andrews, 1963; Falconer et al., 1965a,b; Miller and Dyke, 1974; Andrews and Ives, 1978; Briner et al., 2009b). From these time-slice maps, we extract time-distance diagrams of ice recession for the three different glacier systems and discuss their sensitivities to climate change.

2. Background

Conceptual ice cover models for the Eastern Canadian Arctic have changed considerably over the last half century (Fig. 1b) and Cumberland Peninsula was one of the main stages where the debates about models occurred. The idea of a single-dome ice sheet for North America (Flint, 1943) that completely covered northeastern Canada was eventually dismissed on the basis of observations that highly weathered upland plateaus lacked evidence of glacial erosion or deposition (Ives, 1966), the occurrence of disjunct plant species in coastal highlands of Baffin Island and Labrador (Fernald, 1925), and the inference of multiple dispersion centres for the LIS (e.g., Dyke and Prest, 1987). A minimum ice sheet model was proposed for Cumberland Peninsula and elsewhere in eastern Canada to accommodate putative ice-free conditions on upland plateaus that served as refugia for bryophytes and arthropods (Nunatak Hypothesis, Ives, 1974, 1978). However, the occasional occurrence of erratic blocks and subtle glacial modification of tors on upland plateaus of Cumberland Peninsula indicated extensive coverage at higher elevations by cold-based ice (Sugden and Watts, 1977). Building on the concept of selective linear erosion and cold-based ice (Sugden, 1977, 1978), a new conceptual model of ice extent in the eastern Canadian Arctic seemingly reconciled much of the conflicting field evidence for Cumberland Peninsula ("Goldilocks model", Miller et al., 2002). This "intermediate ice cover" model (Fig. 1b) proposed that fast-moving, low-gradient outlet glaciers occupied marine embayments and fiords, while slow-moving ice that was frozen to its bed covered the intervening upland plateaus.

The lack of paleo-ice margin chronology for large areas has been the greatest obstacle in evaluating various models. For instance, the increase of rock weathering with altitude was interpreted to signify progressively thinner and therefore less extensive ice cover throughout the last few glacial cycles (Boyer and Pheasant, 1974; Dyke, 1979; Watts, 1979). The fact that lateral moraines paralleled and coincided with trimlines, and that