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A latest Pliocene age for the earliest and most extensive Cordilleran Ice Sheet in northwestern Canada

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ABSTRACT

The Klondike gravel is a widespread glaciofluvial gravel marking the earliest and most extensive Cordilleran Ice Sheet (CIS) in NW North America. New terrestrial cosmogenic nuclide (TCN) burial ages indicate this gravel was emplaced $2.64^{+0.20}/_{-0.18}$ Ma (1σ). Coupled with previously interpreted paleomagnetic stratigraphy, this numerical age constrains the timing of the earliest CIS to the late Gauss Chron and provides a minimum age for the Upper White Channel gravel, a significant placer gold source in the Yukon. This implies the first CIS glacial maximum pre-dates the maximum extent of the Laurentide Ice Sheet, indicating that during the initial stages of northern hemisphere glaciation, the most extensive glaciers were present in the relatively cold and high elevation northern Cordillera. Our results verify the CIS as a likely source of persistent coeval ice-rafted debris in the northern Pacific, and suggest that the first CIS formed as a response to the establishment of the northern Pacific halocline and emergence of the 41 ka obliquity cycle during the Plio-Pliocene transition.

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1. Introduction

The onset of extensive northern hemisphere glaciation interrupted a gradual lowering of global atmospheric CO_2 and a slow cooling trend through the Pliocene (e.g. Pagani et al., 2009). The widespread occurrence of ice-rafted debris in late Pliocene and early Pleistocene marine sediments provides an indirect record of the growth of northern hemisphere glaciers with implications for the potential mechanisms that led to extensive continental glaciation (e.g. Maslin et al., 1998; Haug et al., 2005). Differences in the timing and magnitude of ice-rafted sediments in these records suggest regional differences in the distribution of glaciers that contributed to the marine record, but provide little indication of their former extent or distribution. Unfortunately, dating the sparse terrestrial record of early glaciation is difficult since subsequent glaciations tend to obscure the depositional record of earlier advances, and few numerical dating methods are applicable.

Beyond the limit of the last Cordilleran Ice Sheet (CIS) in northwestern Canada are multiple drift deposits that record the earliest glaciations in North America (Froese et al., 2000; Barendregt et al., 2010; Duk-Rodkin et al., 2010). The oldest CIS advance, which is associated with the most extensive glaciation to affect the northern Cordillera, is recorded in extensive drift—including the normally-magnetized Klondike glaciofluvial gravel—that marks the first presence of extrabasinal clasts in the region (Hughes et al., 1972; Froese et al., 2000). The advance was proposed to be of Pliocene age (late Gauss Chron) on the basis of normal magnetic polarity of basal tills in sedimentary sequences and associated outwash (Froese et al., 2000; Barendregt et al., 2010; Duk-Rodkin et al., 2010; Barendregt and Duk-Rodkin, 2011). Independent constraints on the late Gauss age interpretation are that this normally-magnetized outwash gravel (Klondike gravel) is inset by a terrace with a loess mantle having multiple polarities that record the Brunhes, Jaramillo and late Matuyama chrons (Froese et al., 2000). A Gauss interpretation is further supported by glass fission-track ages on tephra of 1.37 ± 0.13 Ma from loess cover below the Jaramillo-aged sediments, 1.03 ± 0.17 Ma within the Jaramillo-aged material, and 2.82 ± 0.24 Ma within gravel stratigraphically below the Klondike gravel (Westgate et al., 2003; Preece et al., 2011). However, because no close limiting ages from tephra beds overlying the outwash are known, it is possible that the normal magnetozone is either a subchron of the early Matuyama

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(i.e. Olduvai or Reunion) or late Gauss (Froese et al., 2000). The late Gauss interpretation is preferred because previous studies propose that pre-Olduvai periglacial and glacial conditions existed elsewhere in the northern Cordillera (Westgate et al., 1990; Barendregt et al., 1996; Duk-Rodkin et al., 1996; Froese et al., 2000), and since North Pacific marine cores indicate significant ice rafting in the late Pliocene (Krissek, 1995; Rea et al., 1995; Mudelsee and Raymo, 2005; Polyak et al., 2010). An Olduvai interpretation, however, is also possible as Olduvai deposition correlates to the onset of significant glacial events that define the former Pleistocene boundary. Here, we report new terrestrial cosmogenic nuclide (TCN) burial ages for the Klondike gravel that support the late Gauss interpretation for the earliest CIS.

1.1. Klondike area

The lower Klondike valley is located southeast of Dawson City, Yukon, near the confluence of the Yukon and Klondike rivers. The region is at the all-time limit of glaciation, marking the boundary of former Cordilleran ice and the non-glaciated portion of the Klondike Plateau (Fig. 1). Here, strata of gravel from small, non-glaciated catchments draining King Solomon Dome (White Channel gravel) and from glaciofluvial outwash (Klondike gravel) interbed where their drainages meet in the Klondike valley—indicating contemporaneous deposition of uppermost White Channel and basal Klondike gravel (Hughes et al., 1972; Froese et al., 2000).

The Klondike gravel forms the highest terrace in the lower Klondike valley, and can be traced westward into central Alaska (Duk-Rodkin et al., 2004) and eastward to the Flat Creek beds where a till is sandwiched between outwash gravel. The terrace surface descends from the Flat Creek beds toward the Klondike valley with paleoflow directions to the west (Froese et al., 2000). Outwash from this early Cordilleran glaciation also breached the divide from the Stewart River and spilled into the Indian River (Jackson et al., 2009). Paleoflow measurements and deposition of equivalent normally-magnetized outwash in the Indian River valley preclude a local montane ice source from the Ogilvie Mountains to the north; collectively this evidence indicates a CIS source for the Klondike and equivalent gravel, marking the most extensive CIS glaciation of the northern Cordillera (Froese et al., 2000; Duk-Rodkin et al., 2010). Pollen from overbank deposits within the Klondike gravel indicates shrub-tundra vegetation, marking the first appearance of vegetation typical of Pleistocene cold stages and the last occurrence of taxonomically-richer boreal forest associated with the Miocene and early Pliocene pre-glacial boreal forest (Schweger et al., 2011).

1.2. Sample site: Australia Hill

Recent mining in the Klondike Goldfields has exposed multiple 60–80 m thick sequences of Klondike and White Channel gravel. The exposure near the mouth of Hunker Creek (Australia Hill) was

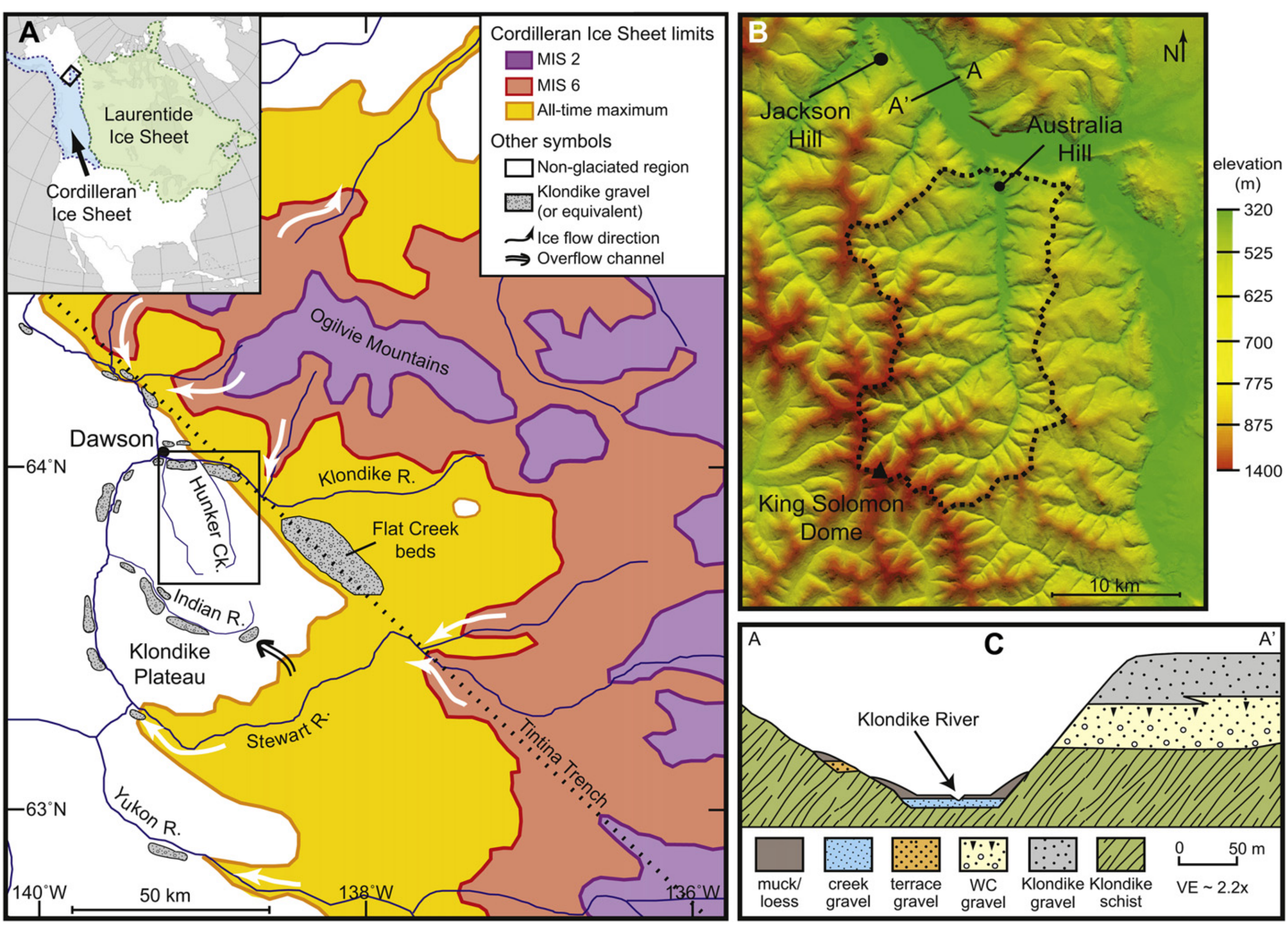

Fig. 1. Map of Yukon showing extent of major CIS advancements after Duk-Rodkin et al. (2004) (A) with inset DEM of Hunker Creek (B), and cross section of the Klondike River valley through the high terrace gravels (C).

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