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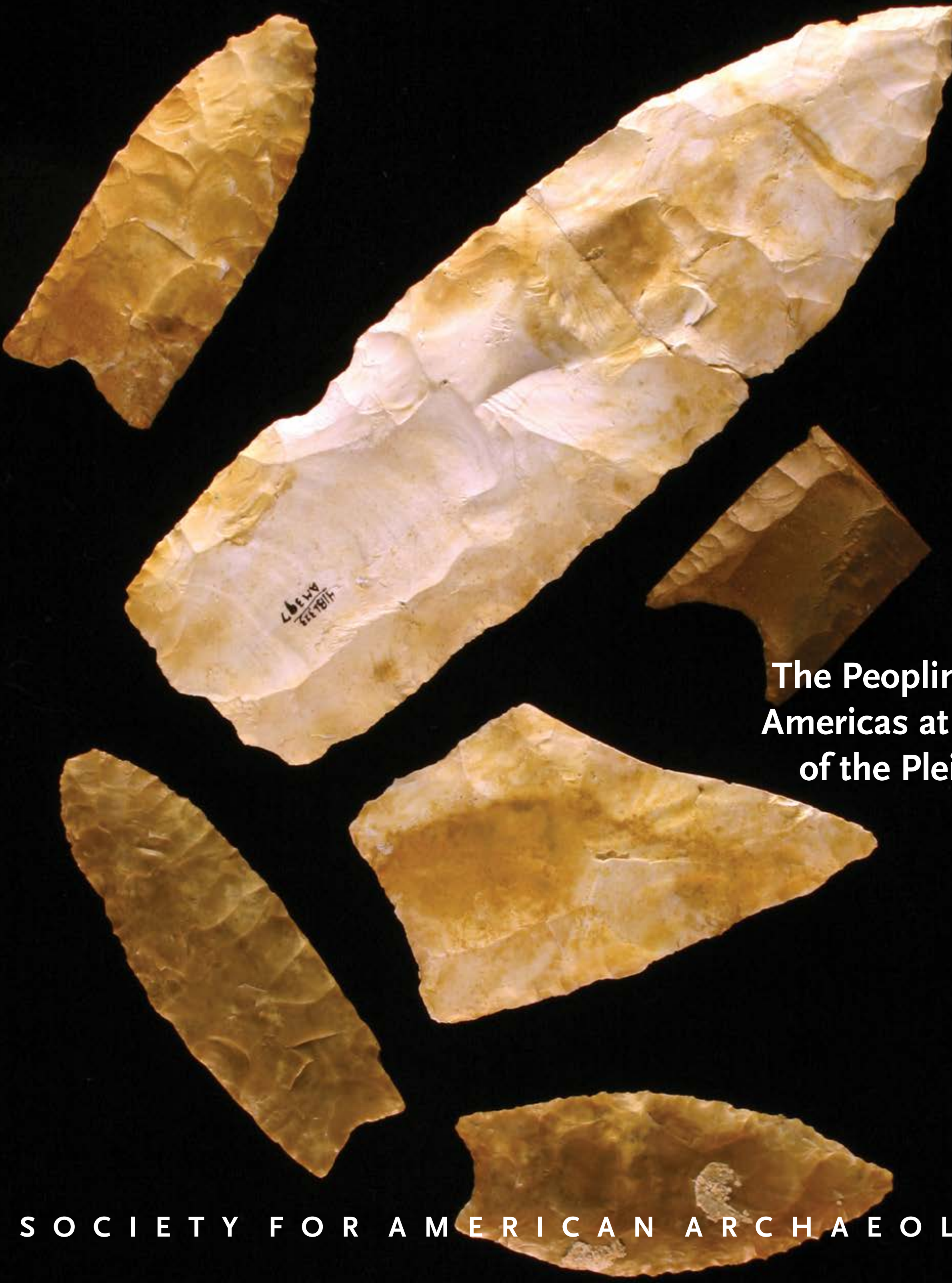

The Peopling of the Americas at the End of the Pleistocene

SOCIETY FOR AMERICAN ARCHAEOLOGY

AVAILABILITY AND VIABILITY OF THE ICE-FREE CORRIDOR AND PACIFIC COAST ROUTES FOR THE PEOPLING OF THE AMERICAS

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Potential routes between Beringia and continental North America have taken on special significance as a new generation of techniques have provided insight into the timing of human occupation of North America, including pre-Clovis sites (e.g., Waters et al. 2018), and the deep lineages preserved in modern and ancient genomes (e.g., Llamas et al. 2016). These approaches have pushed the limits of our understanding of potential routes, forced reassessment of the chronology of North American ice sheets, and, most recently, spurred new work to address these limitations (e.g., Darvill et al. 2018; Lesnek et al. 2018). Recently, several papers have provided assessments of the chronology, viability, and potential connectivity between Beringia and continental North America, as a means to understand peopling of the Americas (Braje et al. 2017; Darvill et al. 2018; Heintzman et al. 2016; Lesnek et al. 2018; Pedersen et al. 2016; Potter et al. 2018). These studies have largely highlighted a particular collection of dates or paleoecological data to make statements about the potential viability of either the Pacific Coastal Route (PCR) or the interior Ice-Free Corridor (IFC) during the critical interval from circa 16,000 to 13,000 cal yr BP. In this review, we assess these chronologies in terms of their constraints on ice sheet history, the reliability and internal consistency of these dates, and the viability of these environments as reflected in immediately post-glacial paleoenvironmental data.

Ice Sheet Chronologies: *Caveat emptor*

The most commonly cited reconstruction of the deglacial chronology for the Laurentide (LIS) and Cordilleran (CIS) ice sheets is that of Dyke and colleagues (2003). This chronology is based primarily on the large database of radiocarbon dates generated over the last ~50 years. In preparing the ice sheet summary, the authors place emphasis on the highest quality dates available, but given the history of investigations, they include many dates that were produced using methods that would not typically be used in modern studies. These include dates on materials such as mixed or bulk samples, including materials like aquatic macrofossils that may not have been in equilibrium with atmospheric CO_2 at the time the organism was living, resulting in an erroneous date. As well, early dates were typically dated via radiometric methods, the only radiocarbon option available prior to the late 1970s. Radiometric (or conventional) radiocarbon dating is not in itself problematic, but the technique requires much larger sample sizes than modern Accelerator Mass Spectrometry (AMS) dating, and so it can be difficult to select discrete materials of sufficient size for reliable dating. In contrast, AMS radiocarbon dating allows isolation of particular organic remains such as individual plant macrofossils, or the opportunity to isolate discrete organic fractions, including in the case of bone, ultrafiltration of collagen, or even single amino acids, that can be advantageous in producing accurate radiocarbon dates (e.g.,Waters et al. 2015). In the case of bone, ultrafiltration separates the high molecular weight proteins from shorter fragments that are the most common source of contaminants that may be incorporated in the bone following burial. These contaminants, which are most likely sourced from the environment and not the organism, are typically of younger age, and may preclude accurate dating (e.g., Froese 2014).

Radiocarbon-based chronologies can also have biases related to the relationship between the organic material and the dating of ice margin retreat. First, the period of ecesis, the time between the ice sheet leaving an area and colonization by a plant or animal, is generally unknown and may be significant. And secondly, the organic material is usually in a detrital context with some unknown period between the death of the organism and its inclusion in the sedimentary record. These biases and potential inaccuracies in the largely radiocarbon-based chronology for the LIS and CIS have led to alternative chronometers for dating ice sheet retreat, including luminescence (e.g., Munyikwa et al. 2017) and cosmogenic radionuclide dating (e.g., Menounos et al. 2017). There are, however, considerable differences between the uncertainties provided by radiocarbon dates (typically 1%–2% for modern calibrated dates at two standard deviations), and those from cosmogenic radionuclide and luminescence dates, where propagated uncertainties are typically ~8%–10% at one standard deviation. These uncertainties can be reduced through averaging of multiple ages associated with a particular landform or sedimentary unit. It should be noted that the multiple dating approaches used to constrain ice sheet chronology, including terrestrial cosmogenic radionuclide (e.g., ^{10}Be, ^{36}Cl), calibrated radiocarbon, and luminescence dates, are broadly comparable and presented here as cal yr BP.

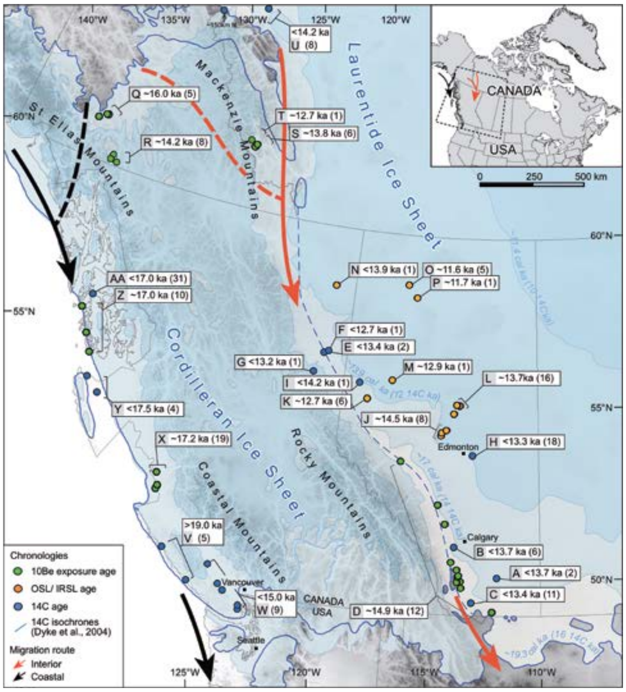

Figure 1. Cordilleran and western Laurentide Ice Sheet deglaciation from circa 19,000–11,400 cal yr BP (after Dyke et al. 2003). PCR and Interior IFC routes into continental North America from eastern Beringia (unglaciated Yukon and Alaska). The IFC includes the over-the-top route through the Mackenzie Valley and the alternative route through the Yukon Plateaus in northeastern British Columbia. Labels (A–Z, AA) show dates with groups (closely co-located sites) of dates with approximate age (OSL/IRSL, 10Be, 14C; Tables S1, S2, S3). Samples in close association have been grouped with outliers removed following original authors or as explained in text, and average ages indicated along with the number of samples (n) for each site. Individual dates, by indicated site, are plotted in Figures 2 and 4.

Routes into the Americas

Archaeological data indicate that early human populations were present in eastern Beringia by ~14,000–15,000 cal yr BP, with records potentially pre-dating that time (Potter et al. 2018). Sites south of the LIS and CIS indicate that people were present by at least 14,200 cal yr BP (Jenkins et al. 2012) and perhaps as early as ~15,000 cal yr BP (Waters et al. 2018). Two potential routes are generally considered either through the interior IFC route down the Mackenzie Valley or along the PCR (Figure 1). Typically the IFC route is shown as the over the top path into the northern Mackenzie Valley, available following the detachment of the LIS and CIS to the south along the mountain front (Figure 1). A variant of the IFC route is through the Yukon Plateaus of the northern Cordillera that may have been available with early deglaciation of the upland areas prior to the main valleys (e.g., Menounos et al. 2017; Figure 1).

Alternatively, if maritime adaptations were available, the PCR may have provided an abundance of natural resources (Braje et al. 2017; Fladmark et al. 1979). Understanding the PCR and the potential distribution of sites has been hampered by rapid sea level change, poorly constrained deglacial chronologies, and complex sea level histories along the coast, leading to the need to develop local sea level records repeatedly over short distances (e.g., Fedje et al. 2018; Josenhans et al. 1997; Shugar et al. 2014). The potential of these routes for the first people into the Americas is largely dependent on the geological constraints on the obstacle-forming ice sheets and sea level history, as well as on the extent to which these areas were biologically viable to early human populations.

Ice-Free Corridor Route

Three different scenarios have been proposed recently for the availability and viability of the IFC route. First, Pedersen and colleagues (2016), based on the analysis of two lake sediment cores, suggest that the LIS persisted much later than in other reconstructions, but also argue that sufficient biological resources were only available after ~12,600 cal yr BP. Alternatively, Potter and colleagues (2018) place emphasis on luminescence ages

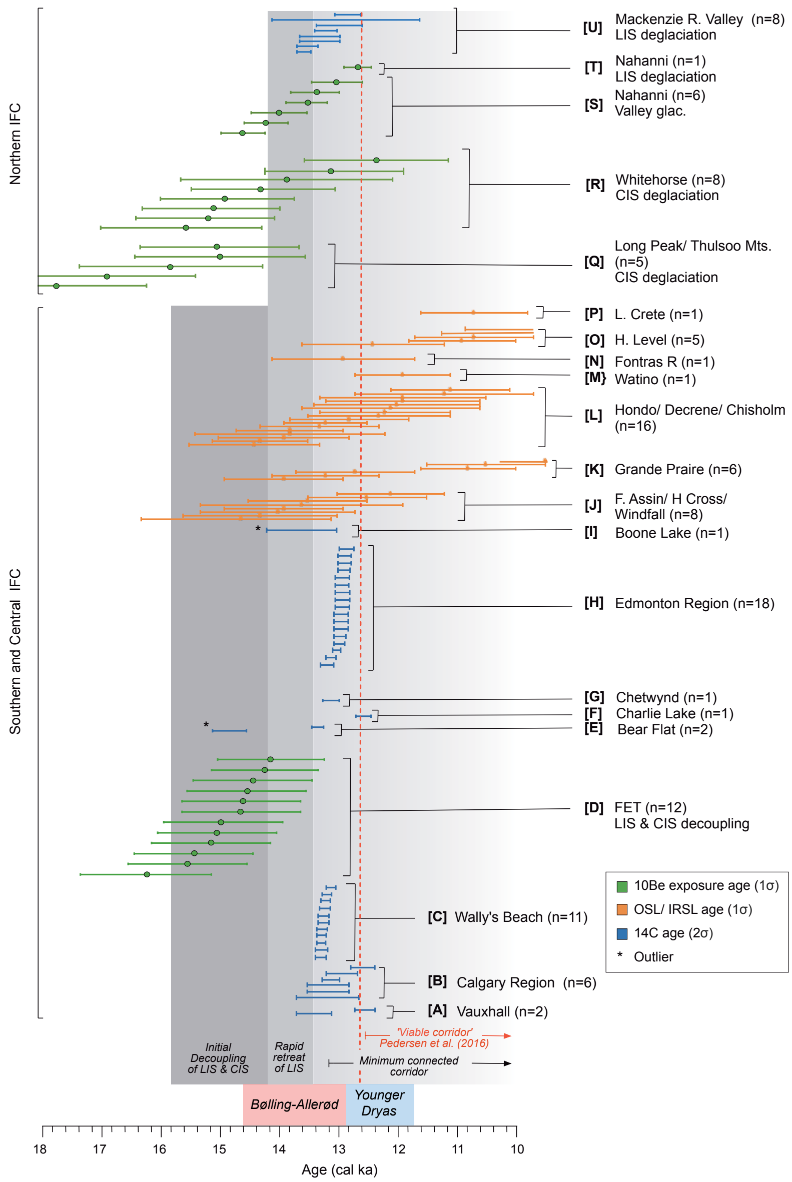

Figure 2. Synthesis of 10Be, OSL, and 14C dates (in cal yr BP) for Cordilleran and western Laurentide Ice Sheet deglaciation. Cosmogenic dates plotted at one standard deviation uncertainty with scaling, erosion rate, and production rate as indicated by authors. Luminescence dates plotted at one standard deviation uncertainty with propagation of error as indicated by authors. Radiocarbon dates calibrated and presented at two standard deviation uncertainty. Individual dates with references in Tables S1 and S3. [A] refers to locations on Figure 1.

from the region (Sites J–P, Figure 1), coupled with a date on a taiga vole (Site E, Figure 1), and to some extent regional cosmogenic dates, to argue that the IFC was potentially available as early as 15,000 cal yr BP. The third scenario, on the basis of bison phylogeography from ancient maternal lineages, indicates that the earliest dispersal of Beringia bison (most closely related to Yukon and Alaska populations) took place by ~13,200 cal yr BP with the appearance of northern bison in northeastern British Columbia (Site G, Figure 2) and Edmonton (Site H, Figure 2; Heintzman et al. 2016). In order to evaluate these hypotheses, we compiled the available chronologic information, not including dates on bulk sediments, terrestrial shells, or mixed assemblages known to be problematic in providing reliable chronologies, and present these graphically in Figure 2; individual 'higher quality' dates and their references are listed in Tables S1, S2, and S3 (please see https://www.saa.org/publications/the-saa-archaeological-record for supplementary materials).

The key means by which the coalescence and initial detachment of the LIS and CIS has been dated is the Foothills Erratics Train (Figure 3; Jackson et al. 1997; Margold et al. 2019). The Foothills Erratics Train is a linear concentration of large quartzite blocks derived from a rockfall onto the surface of a valley glacier, flowing from the Athabasca Valley, that carried the blocks to the eastern slopes of the Rocky Mountains where the glacier merged with the LIS (Figures 1, 3). These boulders, stretching over several hundred kilometres, were carried south along the Foothills, marking the zone of coalescence of the LIS and CIS. Jackson and colleagues (1997) used one of the early applications of cosmogenic dating (whole rock ^{36}Cl) to estimate the age of several erratics, with a central group of dates ranging between circa 19,900 and 10,800 cal yr BP. These dates were key to demonstrating the late Wisconsinan coalescence of the LIS and CIS and movement away from the primacy of the IFC for peopling of the New World (Ives et al. 2013). Recently, Margold and authors (2019) dated many of the same boulders using ^{10}Be concentrations from quartz to derive a more precise age (Table S3). Of the 16 boulders that were dated, 12 dates are tightly clustered between 16,300 and 14,200 cal yr BP, and provide a weighted mean age, including propagated uncertainty, of 14,900 ± 900 cal yr BP (Site D, Figures 1, 2). These dates indicate initial decoupling of the LIS and CIS took place at about 15,000 cal yr BP.

Munyikwa and authors (2017) place emphasis on luminescence ages from eolian sands to constrain deglaciation of the LIS in western Canada. The authors argue that, unlike radiocarbon-based approaches for ice sheet chronology, which require plants or animals to colonize the formerly glaciated terrain, luminescence dating of eolian deposits should more closely relate to the time of deglaciation. While this principle is strong, the large uncertainties associated with luminescence dating (typically 8%–10% at one standard deviation when uncertainty is propagated) make individual dates more difficult to interpret than radiocarbon dates. We plot the dates and their one standard deviation uncertainties, grouped by sites within 30 km, on Figure 2 (Sites I–P on Figure 1). We have removed outliers proposed by the original authors. By focusing on groups of dates, rather than individual dates, site means can be calculated where larger numbers of dates exist in close proximity. This approach gives mean site ages of circa 14,500 ± 1125 (Site J: n = 8, Figure 2) and 13,700 ± 1160 (Site L: n =16, Figure 2). Additional sites are consistent, though generally younger than these ages (Figure 2).

Figure 3. Quartzite block of the Foothills Erratics Train sampled for 10Be cosmogenic radionuclide dated to 15,500 ± 1000 cal yr BP. Photo by Martin Margold.

Potter and colleagues (2018) emphasize the date on a taiga vole from northeastern British Columbia (Site E, Figure 2) to demonstrate the viability of the IFC route by circa 15,000 cal yr BP. That site produced several dates, ranging from nearly ~20,000 cal yr BP to late Holocene, most on mixed aliquots of charcoal, presumably including non-finite material, leading to unrealistically old ages for this glaciated area. Two voles at the site yielded dates of 15,150–14,565 cal yr BP and 14,225–13,030 cal yr BP (Table S1), while bounding charcoal ages are mid-Holocene (Hebda et al. 2008). Potter and colleagues (2018) focus on the earlier vole date to demonstrate the viability of the IFC by ~15,000 cal yr BP, but when considered within the scope of other ages in western Canada, the age is outside their distribution and clearly anomalous (Figure 2). This date pre-dates other regional chronologies, including the coalescence dates indicated by the Foothills Erratics Train (Site C, Figure 2), the average age of the luminescence dates, and all other vertebrate records we are aware of in deglacial settings in western Canada. These bone dates are on standard collagen, and the lack of ultrafiltration leaves open the strong potential for contamination. Given these caveats and its lack of replication, we treat this date as an outlier and remove it from discussion of the IFC (Figure 2).

Coastal Route

The PCR has taken on special significance because of the potential late opening of the IFC, the possibility of abundant resources along the coast, and the rapid passage that may have been available for marine-adapted people (e.g., Braje et al. 2017; Fladmark et al. 1979;). Understanding of the geologic constraints on the PCR has been hindered by the complex record of sea level change along the coast, and the seeming differences in the history of advancing and retreating local and CIS glaciers through the late Pleistocene. Lesnek and colleagues (2018) used cosmogenic dating in the Alexander Archipelago along with earlier vertebrate dates to constrain deglaciation and the potential viability of the northern coast (Figure 1). They demonstrate that the CIS extended onto the continental shelf until ~17,000 cal yr BP when ice retreated. The cosmogenic dates indicate that islands and other low-lying areas along the coast were increasingly ice free by about 16,000 cal yr BP (Site Z, Figure 1, Figure 4). This chronology is consistent with vertebrate records on Prince of Wales Island that show a hiatus in bone dates between ~19,800 and 17,200 cal yr BP with an increase in the frequency of dates and diversity of taxa after 15,000 cal yr BP (Figure 4). Similarly,

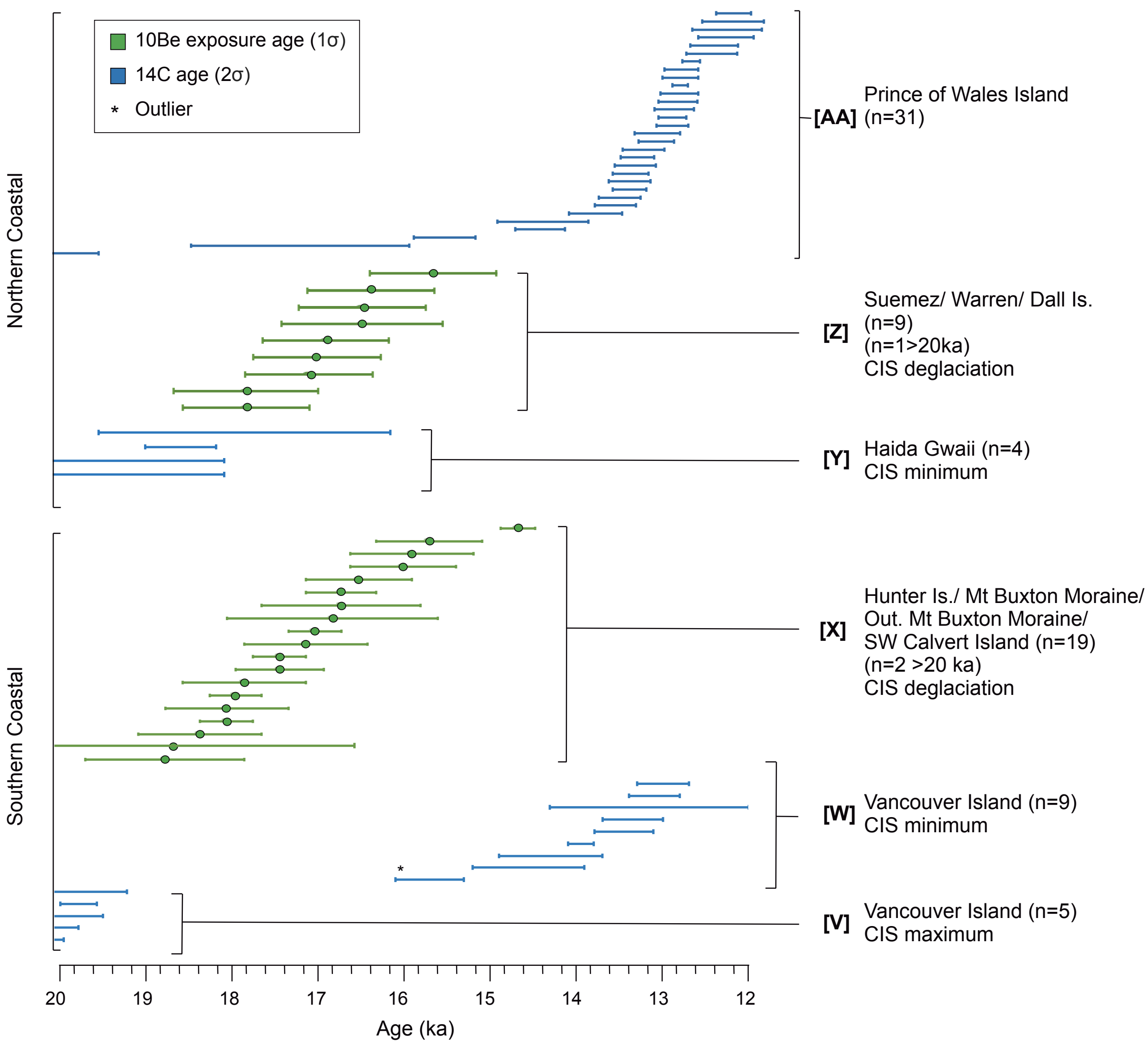

Figure 4. Synthesis of key late Pleistocene 10Be and 14C dates (in cal yr BP) on the Pacific Coast. Cosmogenic dates plotted at one standard deviation uncertainty with scaling, erosion rate, and production rate as indicated by authors. Radiocarbon dates calibrated and presented at two standard deviation uncertainty. Individual dates with references in Tables S2 and S3. [V] refers to locations on Figure 1.

sites on Haida Gwaii (Site Y, Figure 4) suggest the CIS reached the area after 22,000 cal yr BP and was retreating as early as 19,400 cal yr BP (Figure 4).

Along the central coast of British Columbia, cosmogenic dates on boulders indicate the CIS began retreating around 18,000 cal yr BP while still reaching its maximum in areas to the south at circa 17,000 cal yr BP (Darvill et al. 2018). Dates from sites further within the extent of the coastal CIS indicate ice was retreating and exposing lowland sites by ~16,000 cal yr BP (Site X, Figures 1, 4). This record is broadly similar to the radiocarbon-based chronology from Vancouver Island that indicates ice reached the area after ~19,000 cal yr BP and was retreating from the area after ~15,000 cal yr BP (Site W, Figures 1, 4).

Discussion and Conclusions

In terms of the interior IFC route, three hypotheses have been presented for its availability and viability. The first, the 'minimally-available and minimally-viable' IFC of Pedersen and colleagues (2016), argues that a significant bottleneck in the Peace River area maintained the LIS locally with a proglacial lake barrier extending to near Site F (Figure 1) until ~12,900 cal yr BP with the area only becoming biologically viable after 12,600 cal yr BP. LIS reconstructions and stratigraphic data place the LIS boundary in northeastern Alberta beyond sites O and P at that time in order to account for the northwest outlet of glacial Lake Agassiz and the Mackenzie Valley stratigraphy (e.g., Murton et al. 2010). This reconstruction of a lack of LIS barrier in central and northern Alberta at 12,900 cal yr BP is consistent with luminescence chronologies (sites J–L, Figure 2) and minimum radiocarbon dates from central Alberta (e.g., Site H). The argument with respect to the viability of the IFC prior to 12,600 cal yr BP is best addressed by the abundance of Quaternary vertebrate data and paleobotanical indicators that suggest a diverse grazing megafauna present in the central corridor region prior to 13,200 cal yr BP (sites G, H, I, Figure 2).

The second hypothesis, that of Potter and colleagues (2018) that the IFC was likely available by ~15,000 cal yr BP, places emphasis on questionable dates that have not been replicated , such as the taiga vole and the early ranges of date distributions of luminescence and cosmogenic dates (Figure 2). New dates on the Foothills Erratics Train, indicating coalescence until about 15,000 cal yr BP (Margold et al. 2019; Figure 2), provide further support to reject the early IFC availability, consistent with averaging closely spaced luminescence dates on sand dunes through central and northern Alberta (Figures 1, 2). Collectively the cosmogenic, luminescence, and minimum radiocarbon dates from the IFC present a consistent record of LIS-CIS detachment beginning at ~15,000 cal yr BP with substantial retreat of the LIS only after circa 14,000 cal yr BP (e.g., sites A–C, H–L, Figures 1 and 2).

The intermediate IFC hypothesis of Heintzman and colleagues (2016) argues for a viable corridor connected to eastern Beringia by 13,200 cal yr BP at Site G (Figure 1) with the appearance of a Beringian bison. This provides a minimum age for IFC connectivity between Beringia and areas south of the LIS. However, it should be noted that this is a minimum age estimate and it is unlikely that the earliest bison was indeed sampled, leaving open the possibility for earlier IFC connectivity, although the extent of this bias is unknown.

Since the late 1990s, with the recognition of the rapid sea level change and potential for extensive areas to be potentially available along the coast (Josenhans et al. 1997), coupled with recognition that the LIS and CIS coalesced during the last glacial maximum (Jackson et al. 1997), attention has been drawn to the PCR. In recent years, with increasing numbers of deglacial dates spanning the southern through central coast, an emerging picture indicates initial retreat of the CIS along the outer margin beginning after ~18,000 cal yr BP with extensive lowland areas available by ~15,000 cal yr BP. It is more difficult to estimate the continuity of these landscapes than in the areas of the IFC because of the complex and variable relative sea level and ice margin histories (e.g., Shugar et al. 2014) necessitating careful, local reconstructions in the search for archaeological sites (e.g., Fedje et al. 2018).

The archaeological data south of the LIS and CIS indicate the presence of early human populations by at least 14,200 cal yr BP (Jenkins et al. 2012) and perhaps as early as 15,000 cal yr BP (Waters et al. 2018). Existing data for the IFC provide no compelling evidence for the availability or viability of this route until well after 14,000 cal yr BP and likely until nearer 13,200 cal yr BP. In contrast, the PCR provides suggestions for extensive lowland landscapes after ~15,000 cal yr BP and increasingly diverse and abundant vertebrate records by ~14,500 cal yr BP. If the first peoples did indeed traverse from Beringia to continental North America by ~15,000–14,500 cal yr BP, the existing evidence strongly favours the PCR.

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