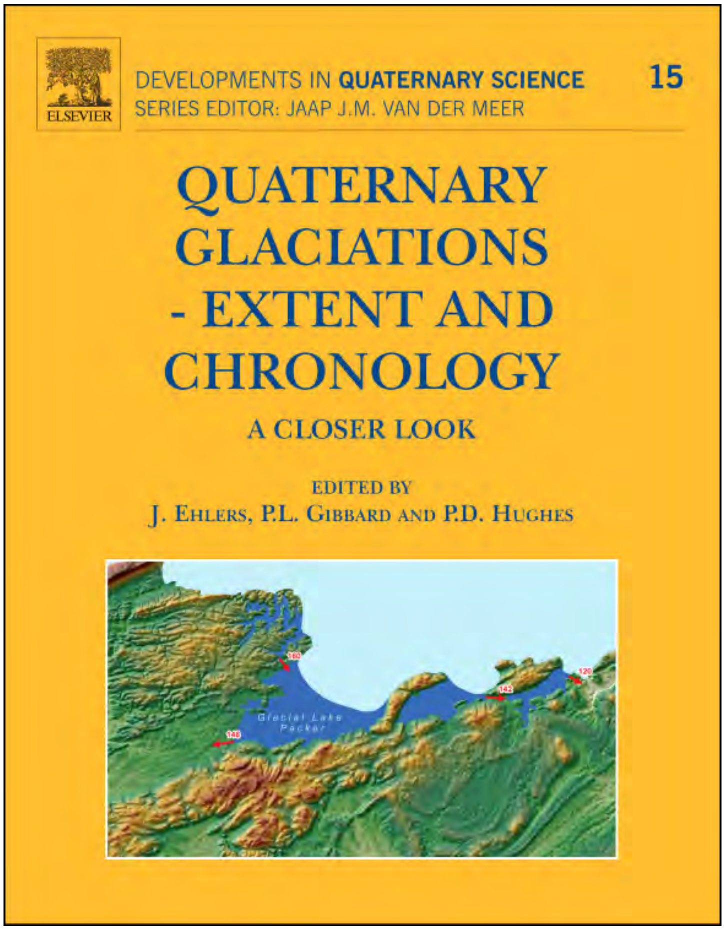

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Chapter 33

Alaska Palaeo-Glacier Atlas (Version 2)

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33.1. INTRODUCTION

This report is an update of the *Alaska Palaeo-Glacier Atlas* (APG Atlas), a collaborative effort among glacial geologists working in Alaska to compile a coherent map of former glacier limits from across the state. The previous version of the digital atlas (v1) was originally available online in 2002 (Manley and Kaufman, 2002). The evidence used to draw the glacial limits in 14 regions across Alaska was described in a subsequent report (Kaufman and Manley, 2004), which was part of a larger effort to create a global database of Pleistocene glacial extents with a target scale of 1:1,000,000. This update (APG Atlas v2) is based on a more detailed map scale and, therefore, provides more accurately resolved limits of former glacier extents. In addition, the previous version included the only two glacier limits that could be most confidently mapped and correlated around the state: (1) the all-time maximum extent of former glaciers; and (2) the late Wisconsinan extent (=late Weichselian=marine isotope stage (MIS) 2=spanning the period between about 24,000 and 12,000 years ago). In this update, we added a third mapped limit for areas where it has been sufficiently well studied, namely for the penultimate glaciation, which over most of Alaska occurred during the early Wisconsinan.

This version of the APG Atlas (v2) builds on the pervious version (v1), which synthesized information from 42 published and unpublished source maps (Kaufman and Manley, 2004). Version 2 includes revisions based on information from an additional 12 source maps that were published since v1 was completed in 2002, or that relate to the extent of early Wisconsinan drift, and on additions provided by the four contributing authors whose input is recognized below. This new version of the APG Atlas is available in GIS formats (including kmz for Google Earth at www.ncdc.noaa.gov/paleo/alaska-glacier/). Anyone who has new information on the extent of palaeo-glaciers in Alaska and would like to make that information available, please contact the authors to update the online version of the APG Atlas.

The update also includes a compilation of all cosmogenic exposure ages that have been published from Alaska ($n=249$), with each sample locality linked to the geospatial database. Each sample is identified by a placemark in Google Earth. The placemarks are colour coded according to glaciation; they are labelled according to the cosmogenic exposure age, and include the sample identification and the reference publication. This comprehensive, mapped compilation of ages is useful for visualizing the extent of coverage and the detailed location of cosmogenic exposure ages available from Alaska and in the context of former glacier extents. Combining glacier extents with the locations of cosmogenic exposure ages in GIS format enables easy reference to sample location relative to geomorphic features at a zoomable scale without relying solely on small or schematic figures provided in journal article format. Readers are referred to the original references for calculations used for each of the ages.

For more information about the glacial geology of Alaska and the history of previous investigations, readers are referred to the edited volume of Hamilton et al. (1986), which is the most complete collection of glacial geologic studies in the Alaska, and to more recent summaries by Hamilton (1994), Kaufman et al. (2004) and Kaufman and Manley (2004). A review of the most secure chronologies of Pleistocene mountain glacier advances in Alaska is provided by Briner and Kaufman (2008). Holocene glaciation in Alaska is summarized by Barclay et al. (2009), and historical glacier fluctuations are reviewed by Molnia (2007, 2008)

33.2. GIS PROCEDURES

Standard GIS techniques were used to compile the glacier limits, incorporating information from a variety of sources.

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The procedure used to create the digital shapefiles in the original version (v1) of the APG Atlas is briefly described by Kaufman and Manley (2004), with additional details in Manley and Kaufman (2002; overview page and metadata). We converted the v1 polygon shapefiles from datum NAD27 to NAD83 and continue to use the Alaska Albers projection. Working copies were edited in both ArcGIS Desktop with ArcOnline world imagery and Google Earth to overlay the polygons onto a zoomable digital base of orthorectified, high-resolution imagery. A benefit of this high-resolution imagery is that ice-marginal features (e.g. moraines and outwash fans) can often be identified and used to demarcate former ice extent in areas where field-based mapping is unavailable. Within ArcMap (v. 9.3), newly added polygons and refinement of v1 polygons were digitized onscreen at resolutions greater than 1:250,000, which in some cases were at resolutions better than the base map. Spacing between vertices was generally less than 1 km and often <500 m for regions with detailed mapping. Polygons for the late Wisconsinan reconstruction were converted to lines, and attributed by "certainty" level (see below). The spatial data were then compiled in one dataset, formatted with symbology and converted to a kmz file for distribution and presentation.

33.3. PALAEO-GLACIER LIMITS

Pleistocene glaciers in Alaska included a vast assortment of types and sizes (Fig. 33.1). Their former extents have been mapped at a wide range of scales by many glacial geologists

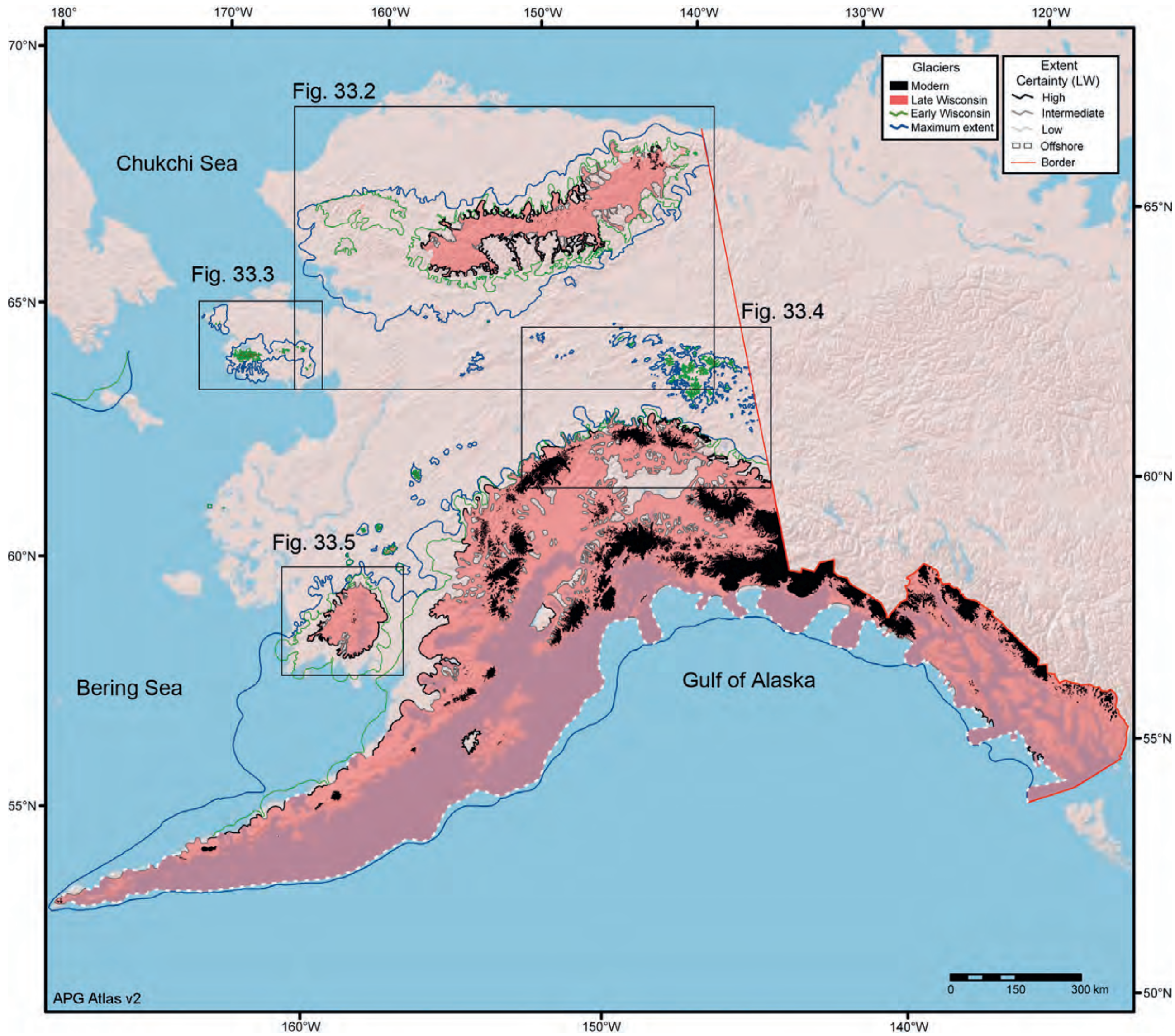

FIGURE 33.1 Alaska Palaeo-Glacier Atlas v2 showing the Pleistocene maximum, early Wisconsinan, late Wisconsinan and modern glacier extents across Alaska.

for different purposes. This results in contrasting styles of mapped limits among regions. For small valley glaciers, the former extent of ice has been delimited precisely at a scale of 1:63,360 or more detailed, and includes the elevational upper limit of the reconstructed glacier. In contrast, the former limits of ice caps and the Cordilleran Ice Sheet are more generalized. They cover large continuous areas with little attention to delimiting the innumerable unglaciated upland areas that extended above the ice sheets, especially around their margins. The largest and most generalized of all the ice limits is along the southern margin of the Cordilleran Ice Sheet where ice terminated on the continental shelf south of Alaska, and little information is available to constrain the former extent.

33.3.1. All-Time Maximum Extent of Glaciers

Pleistocene glaciers in Alaska once covered $>1.2\times10^6$ km^2. The reconstructed maximum extent of glaciers in this version (v2) of the APG Atlas is essentially the same as in the original version (v1). The limit is only loosely constrained relative to the high-resolution base. The drift is largely buried by eolian sediment or no longer exhibits diagnostic constructional relief features, and the high-resolution base maps do not afford additional geomorphological evidence for further refinement. The reconstructed maximum extent of glaciers generally coincides with the outer limit of drift mapped by Coulter et al. (1965). It does not represent a single ice advance, but ranges in age from late Tertiary (e.g. the Nenana River Valley) to middle Pleistocene (e.g. the Baldwin Peninsula). The placement of the maximum glacial limit in many places is essentially an educated guess, based on extrapolation of limited data and guided by large-scale geographical patterns and general geomorphology. The limit is depicted as a line rather than a polygon in v1 to emphasize the lack of detailed information about ice-free areas within the area of the maximum extent of glacier ice, and we have omitted certainty estimates (see below) because the limit is generally located only approximately.

33.3.2. The Penultimate Glaciation (Early Wisconsinan)

The first moraines located beyond the geomorphologically well-defined limits of the late Wisconsinan ice have been studied in several areas of Alaska. The glaciation represented by these moraines is known collectively as the “penultimate glaciation”, recognizing that, other than their morphostratigraphical position beyond the late Wisconsinan limit, there is often little basis for assigning an age or for correlating deposits regionally. Most previous studies (e.g. Hamilton, 1994) correlated the penultimate glaciation with a global glacial interval younger than the last interglaciation. Several more recent studies (reviewed by Briner and Kaufman, 2008) report geochronological evidence that generally agrees with this age assignment. A growing number of cosmogenic exposure ages (Table 33.1) combined with ^{14}C, luminescence, and tephra-based ages from the few well-dated deposits place the culmination of the penultimate glaciation into MIS 4 or early MIS 3, between around 60 and 50 ka. In the Kvichak Bay area, the penultimate glaciation appears to correlate with late MIS 5 or early MIS 4 (discussed below). In contrast, tephrostratigraphical and other evidence from a few sites suggest that the penultimate drift along the northeast Alaska Range might predate the last interglaciation (discussed below). For simplicity, we refer to the penultimate limit as early Wisconsinan, while recognizing that it probably includes drift older than MIS 4 in places, and might date to MIS 6 in a few places. Version 2 includes mapped limits for the penultimate glaciation where previous studies provide some basis for constraining the former ice extent. We do not attempt to represent the ice-free areas within the limits of early Wisconsinan ice nor to assign certainty levels to the mapped limits, as we do for the late Wisconsinan. The certainties are generally low, but are higher in those areas with geochronological control, which primarily constitutes cosmogenic exposure ages whose locations are viewable in GIS (including kmz format for Google Earth).

33.3.3. Late Wisconsinan Glaciation

Late Wisconsinan glaciers occupied 725,800 km^2 of Alaska. The extent of late Wisconsinan glaciers is delimited more accurately than it is for the other two glacier limits. Generally, late Wisconsinan deposits are easily recognized by their sharply defined moraines on which the details of glacial constructional relief are well preserved. The late Wisconsinan limit on our map roughly coincides with areas covered by ice during the glacial advances of late Pleistocene age, as shown originally on Coulter et al.’s (1965) 1:2,500,000-scale statewide map. In places, however, Coulter et al.’s (1965) late Pleistocene unit included areas that are now assigned to the penultimate glaciation. The APG Atlas v1 refined the limits of late Wisconsinan mountain glaciers based on a compilation of many published maps, and it added palaeo-glacier reconstructions from numerous small mountain ranges that were previously unmapped. Version 2 includes the limits for the small glaciers that emanated from the highest cirques in the Blackburn Hills, Sunshine Mountains, Horn Mountains, Taylor Mountains and Shotgun Hills.

The extent of ice during the late Wisconsinan glaciation in v2 was modified from v1. In areas where the v1 glacier limits were based on detailed (1:63,360) mapping (small mountain glaciers), no adjustments were made. For the Brooks Range, the mapped glacier limits in v1 were largely inferred from a 1:1,000,000 scale, unpublished map

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
Ages from late Wisconsinan (or younger) drift						
FL06-01	63.549	−144.357	22.4 ± 0.6	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-02	63.554	−144.369	9.3 ± 0.4	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-03	63.545	−144.416	16.5 ± 0.5	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-04	63.546	−144.427	16.3 ± 0.4	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-05	63.544	−144.455	16.5 ± 0.5	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-06	63.547	−144.469	16.6 ± 0.4	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL06-12	63.552	−144.391	9.5 ± 0.3	^{10}Be	Northeast Alaska Range	Young et al. (2009)
US07-09	63.505	−144.526	15.4 ± 0.6	^{10}Be	Northeast Alaska Range	Young et al. (2009)
US07-10	63.505	−144.526	13.9 ± 0.4	^{10}Be	Northeast Alaska Range	Young et al. (2009)
US07-11	63.504	−144.527	13.2 ± 0.3	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL07-01	63.510	−144.516	6.6 ± 0.2	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL07-02	63.510	−144.518	11.3 ± 0.3	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL07-06	63.511	−144.535	5.3 ± 0.2	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL07-07	63.511	−144.539	8.5 ± 0.4	^{10}Be	Northeast Alaska Range	Young et al. (2009)
FL07-08	63.510	−144.537	11.8 ± 0.7	^{10}Be	Northeast Alaska Range	Young et al. (2009)
US07-04	63.500	−144.523	11.6 ± 0.8	^{10}Be	Northeast Alaska Range	Young et al. (2009)
WM01-1D	61.277	−157.887	15.8 ± 1.8	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-1C	61.279	−157.889	14.6 ± 1.5	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-1A	61.296	−157.891	12.1 ± 2.0	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-1B	61.283	−157.891	9.3 ± 1.8	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-2E	61.293	−157.862	17.7 ± 1.5	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-2C	61.294	−157.861	16.4 ± 1.7	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-2D	61.293	−157.862	15.2 ± 1.5	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
WM01-2B	61.296	−157.859	14.3 ± 1.2	^{10}Be	Chuilnuk Mountains, Interior Alaska	Briner et al. (2005)
NLL-00-2	61.458	−155.359	38.1 ± 2.1	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
NLL-00-1	61.459	−155.360	25.6 ± 4.5	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR2-00-2	61.481	−154.535	21.3 ± 0.9	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR2-00-5	61.475	−154.504	19.3 ± 1.0	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR2-00-3	61.486	−154.568	19.2 ± 0.8	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR2-00-4	61.459	−154.466	18.2 ± 0.7	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
KH 2-1	65.142	−154.359	30.0 ± 1.4	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
KH 2-2	65.141	−154.356	23.7 ± 1.0	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
KH 2-3	65.141	−154.355	23.3 ± 1.7	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
KH 2-4	65.142	−154.357	21.1 ± 1.3	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
WM00-09A	64.673	−143.357	28.4 ± 1.1	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-09B	64.673	−143.355	25.4 ± 1.8	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-09D	64.673	−143.353	18.3 ± 1.2	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
WM00-09E	64.672	−143.354	∼15.7	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-08B	64.703	−143.367	28.2±1.2	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-08E	64.702	−143.377	20.9±1.2	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-08D	64.702	−143.377	17.1±0.9	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-08 C	64.703	−143.369	16.4±1.1	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
BR02-15	69.455	−144.082	76.0±1.9	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-16	69.458	−144.081	50.0±1.3	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-14	69.454	−144.082	27.3±0.9	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-8	69.460	−143.794	55.7±1.4	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-7	69.460	−143.800	26.3±0.7	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-6	69.458	−143.801	24.8±0.6	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-5	69.445	−143.787	21.6±0.6	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-9	69.461	−143.796	20.1±0.7	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-11	69.461	−143.713	42.3±1.1	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-10	69.460	−143.711	26.9±0.7	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-12	69.459	−143.715	12.8±0.5	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-13	69.449	−143.743	9.2±0.4	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-4	69.343	−143.561	21.6±0.4	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-1	69.339	−143.578	20.9±0.6	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-3	69.349	−143.576	18.1±0.7	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
BR02-2	69.337	−143.575	15.6±0.5	^{10}Be	Northeastern Brooks Range	Briner et al. (2005)
Denali-15	63.454	−150.741	146.4±10.4	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-16A	63.449	−150.676	7.4±2.2	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-16B	63.449	−150.676	5.7±2.5	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-17	63.444	−150.616	2.5±0.3	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-18A	63.445	−150.585	11.5±1.0	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-18B	63.445	−150.585	28.3±2.0	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-20A	63.454	−150.546	141.7±9.8	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-20B	63.454	−150.546	27.9±1.9	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
Denali-21	63.457	−150.552	4.3±0.5	^{10}Be	Denali NP, Central Alaska Range	Dortch et al. (2010a)
DFCR-1	63.212	−144.828	11.7±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-2	63.211	−144.828	10.5±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-3	63.211	−144.828	11.7±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-4	63.208	−144.833	10.3±1.0	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-5	63.208	−144.834	11.3±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-6	63.206	−144.835	11.0±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-7	63.209	−144.829	10.2±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
DFCR-8	63.209	−144.832	11.2±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCR-9	63.209	−144.832	11.2±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCRSD-1	63.212	−144.828	10.9±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFCRSD-2	63.209	−144.829	10.9±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMF-1	63.152	−144.591	13.2±1.4	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMF-2	63.152	−144.590	12.9±1.4	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMF-3	63.150	−144.597	12.4±1.3	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMF-4	63.150	−144.596	14.3±1.5	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMF-5	63.151	−144.594	11.6±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMFSD-1	63.152	−144.591	10.4±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFMFSD-2	63.151	−144.594	10.9±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFSC1	63.463	−148.644	14.9±1.6	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFSC2	63.463	−148.644	16.0±1.7	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFSC3	63.462	−148.644	15.1±1.6	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFSC7	63.461	−148.648	15.9±1.7	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFSC8	63.459	−148.652	14.9±1.6	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFWC-1	63.488	−148.084	2.1±0.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFWC-2	63.487	−148.085	2.4±0.4	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFNM-1	62.617	−143.032	10.1±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFNM-2	62.617	−143.032	11.5±1.3	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFNM-1R	62.617	−143.032	12.2±1.3	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFNM-RG	62.617	−143.032	9.3±1.0	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFDP-1	62.672	−143.156	10.2±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFDP-2	62.673	−143.155	8.0±0.8	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFDP-3	62.672	−143.153	14.1±1.5	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFDP-4	62.672	−143.156	12.3±1.3	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-6	62.674	−142.807	13.0±1.4	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-7	62.674	−142.807	14.3±1.5	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-8	62.669	−142.809	16.1±1.7	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-9	62.670	−142.814	9.2±1.0	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-10	62.670	−142.814	10.8±1.2	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-11	62.674	−142.812	13.2±1.4	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DFTR-12	62.674	−142.812	9.9±1.1	^{10}Be	Central Alaska Range	Matmon et al. (2006)
DDDN-1	63.784	−145.742	17.4±1.9	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DDDN-1-SD	63.784	−145.742	17.2±1.9	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DDDN-2	63.778	−145.763	23.6±2.6	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DDDN-2-SD	63.778	−145.763	16.8±1.9	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
DDDN-3	63.774	−145.774	18.1 ± 2.0	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DDDN-3-SD	63.774	−145.774	17.0 ± 1.9	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DR1-1	63.777	−145.756	13.2 ± 1.5	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DR1-2	63.777	−145.757	16.8 ± 1.9	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DR1-3	63.779	−145.753	11.9 ± 1.3	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DR1-4	63.780	−145.753	13.1 ± 1.5	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
DR1-5	63.779	−145.756	67.6 ± 7.4	^{10}Be	Delta River Valley, central Alaska Range	Matmon et al. (in press)
Ala-126A	63.610	−148.777	15.0 ± 2.3	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-126B	63.610	−148.777	14.4 ± 2.2	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-127	63.606	−148.799	20.4 ± 3.4	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-128	63.605	−148.799	14.9 ± 2.0	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-130	63.603	−148.800	12.5 ± 2.5	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-132	63.599	−148.799	15.9 ± 2.7	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-133	63.598	−148.799	12.9 ± 4.1	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-134	63.597	−148.799	15.6 ± 2.4	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-119	63.675	−148.842	10.9 ± 1.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-120	63.675	−148.842	57.3 ± 9.3	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-121	63.676	−148.841	19.1 ± 3.1	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-122	63.701	−148.872	11.3 ± 3.5	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-123	63.699	−148.886	8.4 ± 2.7	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-15	63.736	−148.893	0.8 ± 0.1	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-16	63.736	−148.893	9.3 ± 1.7	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-18	63.735	−148.894	6.9 ± 1.4	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-19	63.735	−148.895	8.1 ± 4.1	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-20	63.735	−148.894	1.0 ± 0.1	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-135	63.897	−149.117	12.7 ± 1.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-136	63.897	−149.124	15.2 ± 2.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-137A	63.865	−149.132	73.6 ± 7.2	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-137B	63.865	−149.132	97.3 ± 9.5	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-156	63.868	−149.130	43.7 ± 4.5	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-151	63.404	−148.843	12.0 ± 2.5	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-152	63.403	−148.843	12.5 ± 1.8	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-153	63.401	−148.847	14.1 ± 2.0	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-154	63.401	−148.840	12.9 ± 1.9	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-155	63.400	−148.847	13.4 ± 2.0	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-158	63.402	−148.858	11.2 ± 1.4	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-159	63.401	−148.858	15.6 ± 2.5	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
Ala-160	63.401	−148.858	16.7±4.1	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-161	63.899	−148.866	15.6±3.3	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-162	63.899	−148.866	12.5±2.4	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-164	63.893	−148.860	15.6±3.5	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-165	63.893	−148.860	13.2±2.1	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-166	63.893	−148.860	16.0±3.8	^{10}Be	Reindeer Hills, central Alaska Range	Dortch et al. (2010b)
Ala-41	63.303	−148.211	1.2±0.2	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-42	63.303	−148.210	1.6±0.2	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-43	63.302	−148.205	12.0±1.5	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-145	63.306	−148.212	21.3±2.8	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-147	63.305	−148.210	15.0±2.1	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-148	63.305	−148.210	31.0±3.5	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-140	63.238	−147.778	12.5±1.9	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-141	63.238	−147.777	12.2±1.8	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Ala-143	63.238	−147.774	11.8±1.9	^{10}Be	Monahan Flat, central Alaska Range	Dortch et al. (2010b)
Wattamuse T-1	59.349	−161.299	26.7±0.9	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse T-2	59.349	−161.298	20.4±0.9	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse T-3	59.350	−161.300	57.7±4.4	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse T-4	59.352	−161.303	30.3±2.5	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse T-5	59.352	−161.302	39.1±2.0	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse T-6	59.351	−161.301	30.3±2.3	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse R-1	59.346	−161.318	25.9±0.8	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse R-2	59.346	−161.318	26.4±1.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Wattamuse R-3	59.363	−161.317	47.0±1.3	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Kisogle-1	59.445	−161.226	17.9±1.4	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Kisogle-2	59.444	−161.225	17.1±1.5	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Kisogle-3	59.444	−161.232	3.1±0.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Kisogle-4	59.449	−161.236	18.6±1.8	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Kisogle-5	59.446	−161.241	16.6±1.3	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Cloud Lake-1	59.423	−161.198	17.2±1.1	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Cloud Lake-2	59.423	−161.198	24.0±1.3	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
Cloud Lake-3	59.423	−161.198	18.1±1.4	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Cloud Lake-4	59.421	−161.198	15.0±1.2	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Cloud Lake-5	59.419	−161.194	16.0±1.2	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Chilly Valley-1	59.606	−160.589	26.7±1.0	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Chilly Valley-2	59.606	−160.586	19.5±1.0	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Chilly Valley-3	59.608	−160.582	6.2±0.2	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Chilly Valley-4	59.608	−160.579	16.8±0.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Gusty Lakes-1	59.612	−160.599	19.3±0.4	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Gusty Lakes-2	59.612	−160.599	20.2±0.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Gusty Lakes-3	59.609	−160.598	17.6±0.5	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Gusty Lakes-4	59.606	−160.600	20.7±0.4	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Gusty Lakes-5	59.608	−160.605	9.4±0.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
MB1-99-1	59.870	−159.222	11.2±2.0	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB1-99-2	59.871	−159.224	15.6±1.6	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB1-99-3	59.873	−159.227	16.1±2.1	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB1-99-2	59.871	−159.224	14.1±2.2	^{26}Al	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB1-99-3	59.873	−159.227	16.2±2.2	^{26}Al	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB1-00-4	59.868	−159.220	11.0±0.6	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB4-00-1	59.869	−159.276	11.7±1.2	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB4-00-2	59.869	−159.276	9.4±1.5	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB4-00-3	59.870	−159.271	10.1±0.8	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB6-00-1	59.868	−159.217	9.8±0.7	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
MB6-00-2	59.868	−159.218	11.2±0.5	^{10}Be	Ahklun Mountains, southwestern Alaska	Briner et al. (2002)
Ages from early Wisconsinan drift						
WM00-06B	64.661	−143.528	61.4±3.9	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-06D	64.662	−143.536	46.4±2.7	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-06A	64.661	−143.528	39.2±1.4	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-06C	64.662	−143.532	25.3±1.0	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-07A	64.637	−143.541	66.9±2.2	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-07D	64.633	−143.548	115.9±3.7	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-07C	64.633	−143.548	91.4±2.5	^{10}Be	Yukon–Tanana Upland, Interior Alaska	Briner et al. (2005)
WM00-07B	64.634	−143.546	77.6±3.1	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR1-00-2	61.474	−154.540	55.4±1.4	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR1-00-4	61.470	−154.503	51.4±1.6	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR1-00-1	61.474	−154.544	47.9±1.7	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
SR1-00-3	61.468	−154.489	44.2±1.8	^{10}Be	Lime Hills, western Alaska Range	Briner et al. (2005)
KH 1-3	65.169	−154.422	51.6±1.7	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)

Continued

TABLE 33.1 Cosmogenic Exposure Ages from Late and Early Wisconsinan Drift in Alaska (Included as a kmz File for Google Earth)—cont'd

Sample ID	Latitude (°N)	Longitude (°W)	Age (ka)	Isotope	Region	Reference
KH 1-1	65.167	−154.419	23.9±1.1	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
KH 1-2	65.167	−154.419	18.8±1.2	^{10}Be	Kokrines Hills, Interior Alaska	Briner et al. (2005)
DFDD1	63.774	−145.715	43.5±4.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DFDD2	63.774	−145.715	34.8±3.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDOC-1	63.772	−145.715	32.5±3.6	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDOC-2	63.772	−145.715	34.1±3.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DFDD3	63.802	−145.777	39.7±4.4	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DFDD4	63.802	−145.777	28.6±3.2	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-1	63.797	−145.788	18.2±2.0	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-2	63.862	−145.627	57.2±6.3	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-3	63.844	−145.605	55.5±6.1	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-4Q	63.777	−145.778	16.0±1.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-4 G	63.777	−145.778	16.0±1.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-5	63.804	−145.781	12.4±1.4	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-6	63.763	−145.692	46.3±5.1	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DDDL-8	63.766	−145.681	28.2±3.1	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DR2-1	63.854	−145.733	51.2±5.6	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DR2-2	63.854	−145.726	70.8±7.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DR2-3	63.856	−145.741	43.8±4.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DR2-4	63.857	−145.734	57.0±6.3	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
DR2-5	63.854	−145.724	25.7±2.8	^{10}Be	Delta River Valley, central Alaska	Matmon et al. (in press)
Ala-11	63.845	−149.034	44.8±4.8	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-12	63.848	−149.025	51.8±6.2	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-13	63.848	−149.025	50.7±5.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-23	63.834	−149.000	55.5±6.0	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-24	63.833	−149.000	52.8±5.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-25	63.834	−149.001	55.8±5.6	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-107	63.837	−148.978	53.2±5.4	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-108	63.834	−148.975	49.6±4.9	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Ala-157	63.855	−149.043	26.6±3.6	^{10}Be	Nenana River Valley, central Alaska Range	Dortch et al. (2010b)
Olympic Creek-1	59.379	−161.202	57.9±1.8	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Olympic Creek-2	59.378	−161.202	62.3±1.7	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Olympic Creek-3	59.380	−161.197	57.5±1.6	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)
Olympic Creek-4	59.381	−161.202	63.9±2.3	^{36}Cl	Ahklun Mountains, southwestern Alaska	Briner et al. (2001)

Note: Ages are as reported in the original reference. Most 10Be and 26Al ages use the same or very similar production rate. All 36Cl ages use the same production rates. Refer to original reference for all details of age and scaling calculations, in addition to how authors handle erosion rate and snow shielding. The location of all samples can be obtained in the Google Eearth KML file. Latitude/longitude datum WGS84.

compiled by T.D. Hamilton. For APG Atlas v2, we overlaid all of Hamilton's 1:250,000 published surficial geologic maps from across the Brooks Range in Google Earth and used the mapped extent of drift to guide the location of the former ice limits. For the Cordilleran Ice Sheet, which contained the vast majority of Pleistocene glacier ice in Alaska, the original (v1) glacier limits were based mainly on 1:2,500,000-scale statewide map (Coulter et al., 1965), which resulted in significant inaccuracies when superposed onto the high-resolution imagery. The reconstructed glacier extents were adjusted to align with visually obvious geomorphic transitions, including the outer edge of prominent moraines and kettled drift, and they were drawn to fit major topographical constraints while adhering to basic principles of glacier flow. The original mapping was retained where the location of the former ice margin was ambiguous. Additional polygons were added, and some were modified according to the new information since v1, as described below.

Reconstructed margins of late Wisconsinan glaciers were classified according to their relative "certainty": a measure of confidence relating to *both* age determination and geographical position. Well-dated moraines were ascribed a high level of certainty, comparable to a solid line on traditional glacial geologic maps. Because they are based on detailed mapping, the certainty for small mountain glaciers is also generally high. Certainty classifications were omitted from all alpine glaciers, however, because the lines obscure the small polygons when zoomed out. Intermediate certainty was encoded for limits without well-resolved ice-marginal features, or those with little or no direct geochronological control (comparable to dashed lines for "uncertain" contacts on traditional maps). A low level of certainty was attributed to areas lacking detailed air-photo interpretation or substantial, field-based glacial geologic study. This includes the southern margin of the Cordilleran Ice Sheet where the reconstructed ice margin is based on little evidence where ice terminated on the presently submerged continental shelf. The location of the offshore margin is designated as the lowest certainty level.

The ages of the moraines used to delimit the late Wisconsinan glaciers vary by thousands of years across the state. Although still sparse, the chronologies do show some pattern in timing of the maximum extent of mountain glaciers during MIS 2 (Briner and Kaufman, 2008). Many of these chronologies are based on cosmogenic exposure ages of moraine boulders, which likely date the timing of moraine stabilization upon glacier retreat (Briner et al., 2005). In northern Alaska, glaciers retreated from their late Wisconsinan terminal moraines by 25 ka, compared with 22–20 ka in central and southern portions of the state. Following the maximum phase of the late Wisconsinan, glaciers across the state constructed end moraines during subsequent periods of stabilization or re-advance. Although most glaciated valleys across Alaska contain multiple moraines, few have been dated, hampering statewide comparisons; however, glaciers in many valleys built sizeable moraines near terminal moraines shortly following their initial retreat. In the Ahklun Mountains, for example, prominent end moraines were deposited about 20 ka, and in the Alaska Range, end moraines post-dating the terminal moraine formed around 19 ka. In both cases, glaciers stabilized near their former limits for one or two thousand years following the maximum phase.

33.4. REGIONAL UPDATES FOR APG ATLAS V2

The following describes only the specific revisions included in v2 of the APG Atlas. The reader is referred to Kaufman and Manley (2004) for references to source maps used to delimit former glacier extents in v1. The regions are arranged roughly from north to south.

33.4.1. Brooks Range

33.4.1.1. Early Wisconsinan

The extensive suite of moraines in the Itkillik River area, central Brooks Range (Fig. 33.2), serves as the reference locality for late Pleistocene glaciations of the Brooks Range (Hamilton and Porter, 1975; Hamilton, 1982, 1986). The late Pleistocene moraines were subdivided into the Itkillik I (=penultimate glaciation) and Itkillik II (=late Wisconsinan glaciation) advances. Glaciers expanded up to 40 km north of the northern range front during the Itkillik I glaciation, and up to 25 km north of the range front during the Itkillik II glaciation. Recent detailed mapping in the Itkillik River area resulted in further subdivision of the glacial deposits (Hamilton, 2003a). The Itkillik I glaciation was subdivided into two phases based on differences in postglacial modification of moraines; both are older than non-finite ^{14}C ages of 53 ka, and are believed to be younger than the last interglacial maximum (MIS 5e; Hamilton, 1994). In the Noatak River basin of the western Brooks Range, two separate advances are younger than the Old Crow tephra (131 ± 11 ka; Péwé et al., 2009) and older than 36–34 ka (Hamilton, 2001).

In the Brooks Range, the early Wisconsinan glacier limit in v2 of the APG Atlas coincides with the outer extent of drift of the Itkillik I glaciation as mapped by Hamilton (1978, 1979a,b, 1980, 1981, 1984a,b, 2002a,b, 2003b) in his series of 1:250,000-scale surficial geologic maps that extend across much of the Brooks Range, from 162°W longitude in the west to 147°W longitude in the east. In the area east of Hamilton's coverage, we know of only two other studies that have identified the extent of glaciers during the early Wisconsinan glaciation. Namely, moraines have

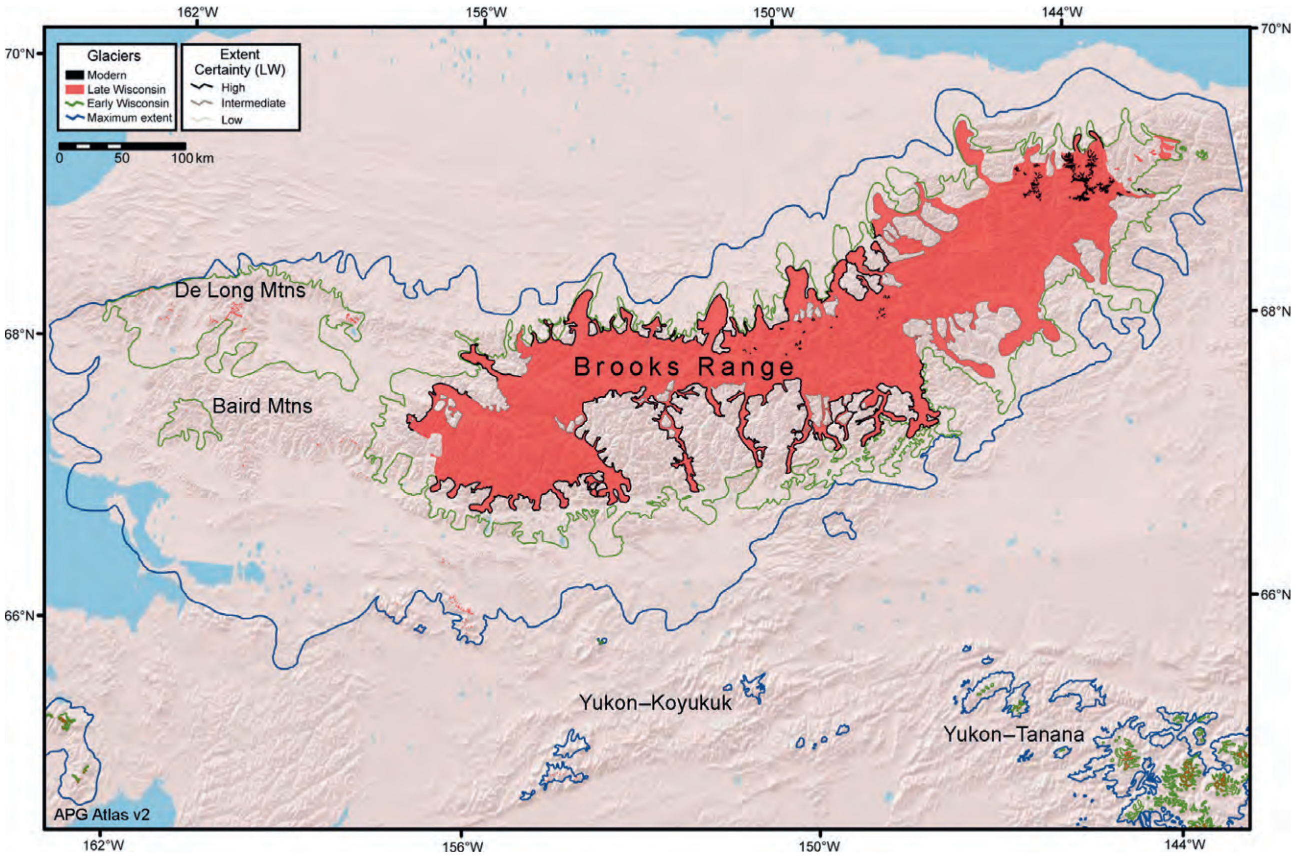

FIGURE 33.2 Pleistocene maximum, early Wisconsinan, late Wisconsinan and modern glacier extents, Brooks Range and Yukon–Koyukuk region.

been correlated with the Itkillik I glaciation both in the Jago River area (Balascio et al., 2005a) and in the Kavik River area (Carson, 2009). The glacier limit outside these areas largely follows the Qg_3 limit of Coulter et al. (1965).

33.4.1.2. Late Wisconsinan

The late Wisconsinan limit in v2 coincides with the outer extent of drift of the Itkillik II (or Walker Lake) glaciation as mapped by T.D. Hamilton in his series of 1:250,000-scale surficial geologic maps referenced above. Westward of the main body of coalescent Brooks Range ice (west of 157°W longitude), summit elevations are lower and late Wisconsinan glaciers were confined to the highest mountain valleys. We retain the reconstruction of late Wisconsinan glaciers in the western Brooks Range (DeLong and Baird Mountains) from the APG Atlas v1, which was based on photo-interpretive mapping at 1:63,360 scale by DSK (Darrell S. Kaufman), and which was used to reconstruct equilibrium-line elevations across the Brooks Range (Balascio et al., 2005b). Our late Wisconsinan limits in the western Brooks Range agree with more recent 1:250,000-scale mapping by Hamilton (2003b). The only significant difference is the moraines near the mouth of Avan River valley, which Hamilton (2003b) ascribed to "an unusually large valley glacier", but which we interpret as a moraine from an older, more extensive glacier advance. Like Hamilton (2003b), we find no evidence for extensive alpine glaciation in the DeLong Mountains during the late Wisconsinan, as was recently suggested by Hill et al. (2007) based on evidence for seismic stratigraphy and sediment coring of meltwater channels that extend offshore of northwest Alaska on the shelf of the Chukchi Sea. In the area east of Hamilton's coverage, we relied on mapping by Balascio et al. (2005a) and Carson (2009).

33.4.2. Seward Peninsula

Moraines of the Salmon Lake (=early Wisconsinan) glaciation have been mapped at 1:63,360 scale across the Kigluaik Mountains (Kaufman et al., 1989), the largest of the four glaciated ranges on Seward Peninsula (Fig. 33.3). In the three other ranges, the limit of Salmon Lake drift mapped by Kaufman (1986) was used to guide the reconstructed ice extent.

33.4.3. Yukon–Koyukuk Region

Little is known about the extent of ice during the early Wisconsinan in the several small mountain ranges located south of the Brooks Range and north of the Yukon River. Relating

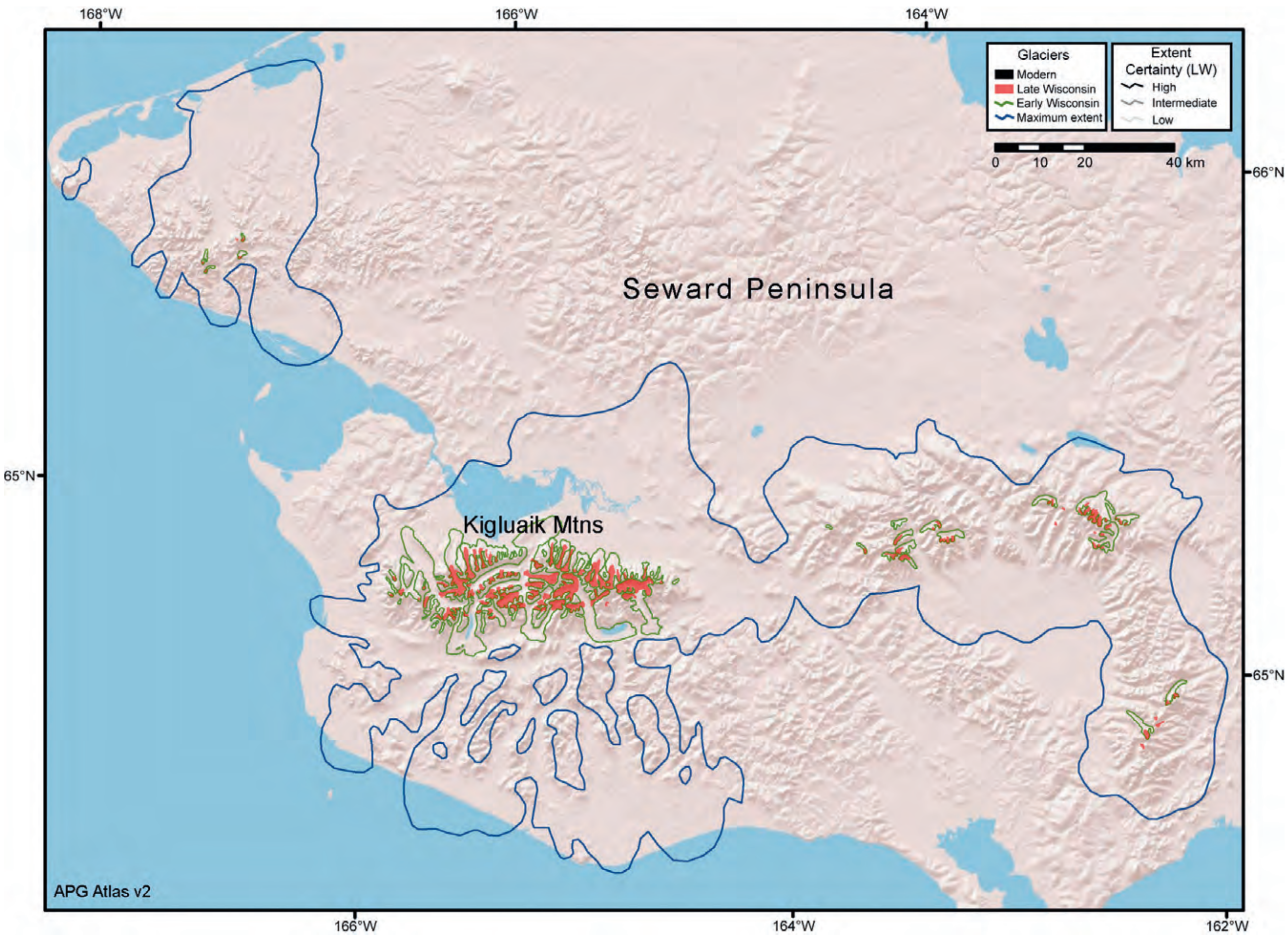

FIGURE 33.3 Pleistocene maximum and early Wisconsinan, late Wisconsinan glacier extents, Seward Peninsula. No modern glaciers in this region.

the mapped extents shown in Coulter et al. (1965) to specific topographical features in high-resolution imagery is difficult and is not included in APG Atlas v2. The early Wisconsinan extent for the Indian Mountain massif is based on Reger (1979). Cosmogenic surface exposure ages on moraines of the penultimate glaciation in the Kokrines Hills indicate an early Wisconsinan age (Briner et al., 2005; Table 33.1 and Fig. 33.2). Mapping of these moraines has not been completed and are not shown in the APG Atlas.

33.4.4. Yukon–Tanana Upland

This region encompasses rolling hills punctuated by several rugged peaks scattered between the Yukon and Tanana rivers in east-central Alaska. The limit of early Wisconsinan glaciers coincides with moraines of the Eagle glaciation as mapped around Mt. Prindle by Weber and Hamilton (1984), modified slightly based on aerial-photo interpretation and field survey by W. F. M. For most of the rest of the Yukon–Tanana upland (Fig. 33.4), the early Wisconsinan reconstruction was taken from Weber (1986) and Hamilton (1994). Cosmogenic surface exposure ages on moraines of the Eagle glaciation indicate an early Wisconsinan age (Briner et al., 2005; Table 33.1), consistent with earlier interpretations (Weber, 1986).

33.4.5. Kuskokwim Mountains

The Kuskowim Mountains region encompasses at least 13 isolated highlands, all located within about 50 km of the Kuskokwim River, that generated alpine glaciers during the Pleistocene. The early Wisconsinan reconstruction in v2 was taken from Waythomas (1990) for the Chuilnuk and Kiokluk Mountains, where it is represented by the Chuilnuk glaciation. We retain this designation despite cosmogenic isotope ages that indicate a younger age of the Chuilnuk glaciations (Briner et al., 2005). In the Russian and Beaver Mountains, it is represented by the Bifurcation Creek glaciation of Kline and Bundtzen (1986), and in the Taylor Mountains, we assumed it coincides with unit Qgu of Coulter et al. (1965).

Two of the small ranges, the Horn and Sunshine Mountains, contained small valley glaciers during the late Pleistocene that were not shown in the APG Atlas v1. For this version, we have added the glacier limits inferred from drift

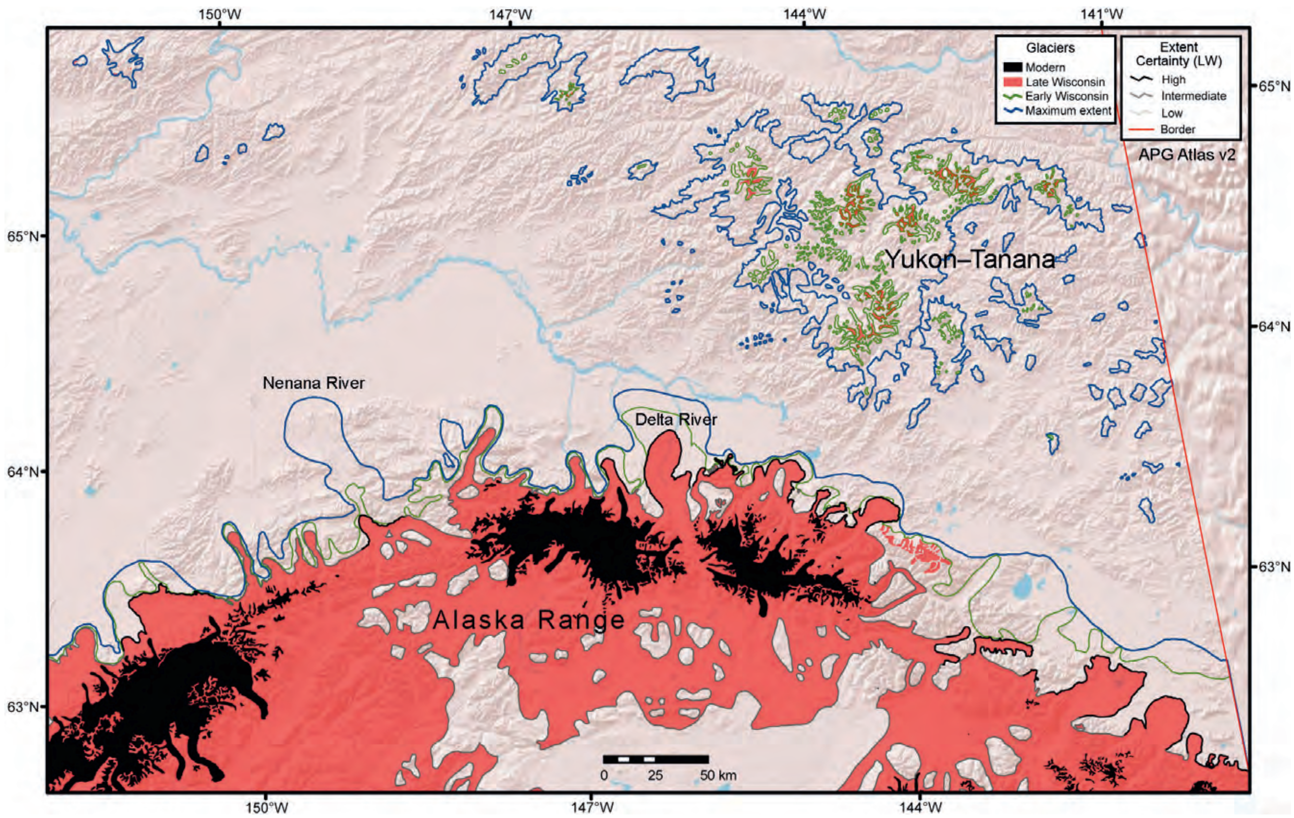

FIGURE 33.4 Pleistocene maximum, early Wisconsinan, late Wisconsinan and modern glacier extents, Cordilleran Ice Sheet.

mapped by Bundtzen et al. (1999) in the Horn Mountains, where till of the Bifurcation Creek glaciation marked the extent of early Wisconsinan ice, and till of the Tolstoi glaciation was used to delimit the extent of late Wisconsinan valley glaciers. Version 2 now includes the small valley glaciers that emanated from several of the highest cirques in the Sunshine Mountains during the late Wisconsinan (D. S. K. unpublished aerial-photo-interpretative mapping). Similarly, two small, isolated plutonic stocks, the Taylor Mountains and the Shotgun Hills, located northeast of the Ahklun Mountains, also supported late Wisconsinan glaciers (D. S. K. unpublished field and aerial-photo-interpretative mapping) and are now shown in v2. Finally, v2 includes new unpublished mapping of late Wisconsinan limits by TKB (T.K. Bundtzen) for the Blackburn Hills adjacent to the lower course of the Yukon River.

33.4.6. Ahklun Mountains

During the late Pleistocene, the Ahklun Mountains hosted an ice cap over its east-central spine that expanded radially, extending farther to the south and west than to the north and east; isolated alpine glaciers occupied the highest valleys beyond the ice cap margin (Fig. 33.5). In most valleys, late Pleistocene drift is composed of several moraine belts formed by outlet glaciers of the central ice cap (Manley et al., 2001). Moraines of the Arolik Lake (=early Wisconsinan) glaciation are dated in several locations across the range. In the southern Ahklun Mountains, Kaufman et al. (2001) reported a thermoluminescence (TL) age of 70 ± 10 ka on lava-baked sediment that underlies penultimate drift and provides a maximum-limiting age on the glaciation. Manley et al. (2001) report a minimum ^{14}C age of 39.9 ^{14}C ka BP on organic material that overlies Arolik Lake drift. In the western Ahklun Mountains, Briner et al. (2001) used four ^{36}Cl exposure ages on erratic boulders deposited in the Goodnews River valley to constrain the age of the Arolik Lake glaciation to between 56 and 53.8 ± 2.6 ka. Thus, the ^{36}Cl ages on boulders deposited during the Arolik Lake glaciation fit well between the TL maximum age of 70 ± 10 ka and the ^{14}C minimum age of 40 ka ^{14}C ka BP. These ages are, in general, agreement with amino acid and luminescence ages from glacial-estuarine sediments of the penultimate glaciation in the Bristol Bay lowland, which ranged between 90 and 55 ka (Kaufman et al., 1996). Collectively, these ages indicate a major glaciation in the Ahklun Mountains roughly coincident with MIS 4; around Nushagak and Kvichak bays, however, it appears that the advance culminated late during MIS 5 (Kaufman and Thompson, 1998).

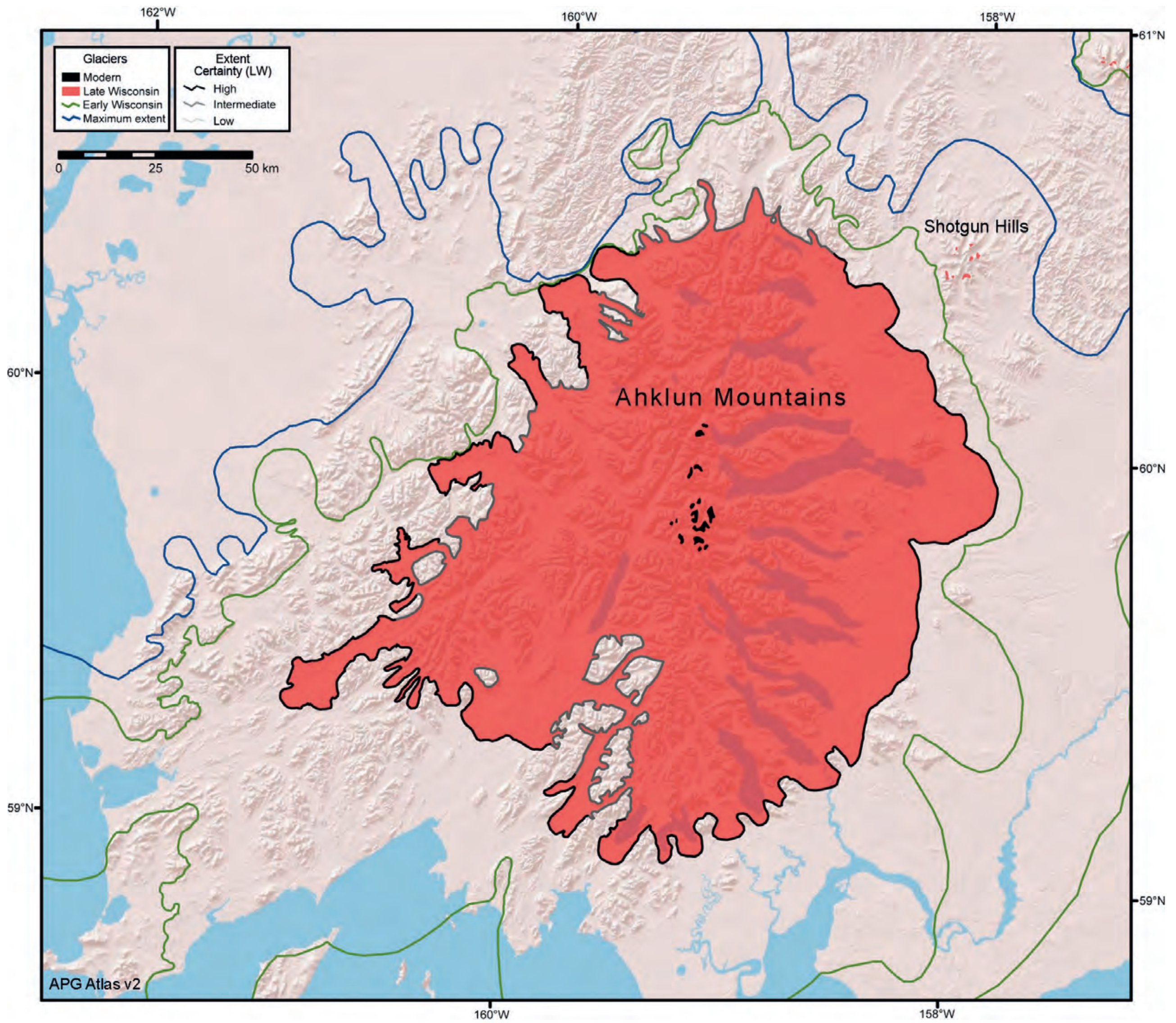

FIGURE 33.5 Pleistocene maximum, early Wisconsinan, late Wisconsinan and modern glacier extents, Ahklun Mountains.

33.4.7. Alaska Range (Fig. 33.4)

33.4.7.1. Early Wisconsinan

The APG Atlas v2 now includes the limits of glaciers during the penultimate glaciation along the north side of the Alaska Range where it largely follows the northern extent of Coulter et al.'s (1965) unit Qg_3. The ages of moraines have been determined in three places:

1. A moraine sequence deposited along the Delta River Valley beyond the northern Alaska Range front constitutes the reference locality of the Donnelly (=late Wisconsinan) and Delta (=early Wisconsinan) glaciations (Péwé, 1953). An outwash terrace that grades to the Delta moraine is overlain by the Old Crow tephra (Begét and Keskinen, 2003), suggesting that it is older than 131 ± 11 ka (Péwé et al., 2009). Matmon et al. (2010) analysed ^{10}Be ages of 15 boulders and sediment samples from the surface of the inner portion of the Delta moraine, near Donnelly Dome. The ^{10}Be ages range from ~70 to ~12 ka, with the majority between ~70 and ~40 ka. The new ^{10}Be ages suggest that this portion of the Delta moraine stabilized during MIS 4/3. Recent mapping indicates that the Delta moraine is a composite feature comprising drift of two ages, with drift just down-valley of the Donnelly terminal moraine significantly younger than the drift farther down valley near Delta Junction, which was probably deposited during MIS 6 (Reger et al., 2008).
2. A more detailed moraine sequence in the Nenana River Valley, north-central Alaska Range (Thorson, 1986), was the focus of a recent exposure-dating study. Dortch

et al. (2010b) obtained nine ^{10}Be ages on boulders from landforms created during the Healy glaciation, which is thought to be the equivalent to the moraine deposited in the Delta River Valley during the Delta glaciation (Hamilton, 1994). The landforms of the Healy glaciation, excluding one young outlier, range between 56 and 51.6 ± 3.8 ka (Dortch et al., 2010b).

3. In the Swift River valley of the western Alaska Range, Briner et al. (2005) mapped a sequence of moraines and correlated them with the Farewell I (= early Wisconsinan) and Farewell II (= late Wisconsinan) moraines in the nearby Farewell region (Kline and Bundtzen, 1986). The Farewell I equivalent moraine, dated by four ^{10}Be ages, stabilized between 58 and 52.5 ± 5.6 ka (Briner et al., 2005).

In sum, ^{10}Be ages from three sites along the northern Alaska Range indicate that moraines of the penultimate glaciation stabilized between 58 and 52 ka, and tephrostratigraphy constrains the outer part of the Delta moraine to > 140 ka. A pulse of loess deposition in the Tanana River valley (Begét, 2001) that appears to coincide with MIS 4 supports the notion of a regionally significant early Wisconsinan glacier advance in the north Alaska Range.

33.4.7.2. Late Wisconsinan

New surficial geologic studies associated with sighting the corridor for a gas pipeline has provided new information on the extent of late Wisconsinan glaciation along the northeastern Alaska Range (Reger et al., 2008). In addition, three studies add new chronologic control to late Wisconsinan drift from the north side of the Alaska Range. (1) Dortch et al. (2010b) provide dozens of ^{10}Be ages on moraines in the Nenana River Valley. The ^{10}Be ages are scattered, but indicate that the late Wisconsinan moraines stabilized between ~20 and 10 ka. (2) Matmon et al. (2010) provide 11 new ^{10}Be ages from the Donnelly moraine near Donnelly Dome, which they interpret to indicate that the maximum phase of the Donnelly glaciation culminated by ~17 ka. (3) Young et al. (2009) found a similar age for the culmination of the Donnelly glaciation in the Fish Creek valley, ~70 km east of the Delta River. The mapping of the late Wisconsinan limit in this area is updated according to Young et al. (2009). Finally, v2 of the APG Atlas includes minor modifications of the late Wisconsinan limit based on unpublished mapping by AW (A. Werner) in the Wonder Lake area.

33.4.8. Aleutian Range

During Pleistocene glaciations, the Cordilleran Ice Sheet extended westward from the Alaska Range to the Aleutian Range. The elongate arc of glacier ice encompassed the volcanic peaks of the Alaska Peninsula and the adjacent continental shelf, and extended west some distance along the Aleutian Island archipelago (Mann and Hamilton, 1995). Evidence for the age and extent of Pleistocene ice is sparse along the entire 3000-km-long arc that extends from the eastern Alaska Peninsula west to Kamchatka.

In the east, costal bluffs rimming Kvichak Bay expose superposed drift units of at least two glaciations (Kaufman et al., 1996; Kaufman and Thompson, 1998). The uppermost drift contains clast lithologies from the Alaska Peninsula, and amino acid and luminescence geochronology indicate that the drift is younger than the last interglaciation, possibly 75–90 ka, or perhaps early MIS 4. In this area, the extent of early Wisconsinan (*sensu lato*) shown in v2 follows the mapping of Kaufman et al. (1996); to the west, it merges with northern limit of unit Qg_3 shown by Coulter et al. (1965). The limit of early Wisconsinan ice is unknown westward of Coulter et al.'s mapping, which extends to 163.7°W longitude.

The extent of late Wisconsinan drift has been clarified in a few places along the Alaska Peninsula. In the Pavlof Bay area, Dawson tephra overlies what had previously been mapped as late Wisconsinan drift. The tephra has been dated to 27 ka (Mangan et al., 2003), providing a minimum age for the underlying drift. Therefore, the late Wisconsinan ice limit in v2 was relocated along the outer edge of the next younger moraine in this area, supplemented by mapping by Wilson and Weber (2001). Version 2 also includes minor modifications of the late Wisconsinan limit based on unpublished mapping by JH (J. Harvey) in the Lake Clark area.

33.4.9. Cook Inlet Area

Version 2 includes recent unpublished mapping by RDR (R.D. Reger) in the Cook Inlet area. A volcanic plateau between 600 and 900 m elevation and 22 km southeast of the summit of Mt. Spurr remained unglaciated through the late Pleistocene. The margins of this volcanic plateau are rimmed by the highest granitic erratics of the penultimate glaciation, perched well above the high-relief lateral moraines of the last major (Naptowne) glaciation. In the southeastern Cook Inlet, the southern Kenai lowlands remained unglaciated during the late Wisconsinan (Reger et al., 2007). Fluted features in this area west of the Caribou Hills indicate that ice flow was oriented parallel to the trough axis. High-level massive sand deposits overlain by 1-m-thick diamictons on the northern end of the Caribou Hills are interpreted as early Wisconsinan ice-marginal lake deposits (RDR, unpublished). Apparently, the Cook Inlet trough was filled with ice to the summit of the Caribou Hills during the penultimate glaciation.

33.4.10. Southern Margin of the Cordilleran Ice Sheet

The southern rim of the ice sheet was supplied with ice by the coastal mountains extending from Kodiak Island on the west, to the Kenai, Chugach and St. Elias Mountains, which border the northern Gulf of Alaska, and to the Alexander Archipelago of the southeastern panhandle. Nowhere else in Alaska is the extent of Pleistocene glacier ice more poorly constrained than along the southern margin of the Cordilleran Ice Sheet. We know of no evidence for the extent of ice during the early Wisconsinan anyplace along the southern margin of the Cordilleran Ice Sheet. Even during the late Wisconsinan, the position of the southern margin of the ice sheet is speculative, as discussed by Kaufman and Manley (2004). We retain the restricted-ice model shown by Molnia (1986) around the Gulf of Alaska. The only modification made in v2 was to extend the late Wisconsinan limit to beyond the present-day coast around the Copper River delta because we expect this major trough to have conveyed a major outlet of the Cordilleran Ice Sheet rather than remained free of glacier ice. Previously unpublished mapping in the southern Alexander Archipelago, which was included in v1, is now published by Carrara et al. (2007). Their work highlights evidence of unglaciated refugia along the west coast of several islands. A similar palaeogeography might extend northward along the panhandle, but we are unaware of other studies that map Pleistocene ice extents along the continental shelf in the Gulf of Alaska region.

33.5. DISCUSSION

The updated version of the APG Altas provides the first statewide look at the extent of ice during the penultimate glaciation. This version also includes the first statewide georeferenced compilation of all cosmogenic exposure ages published to date from late and early Wisconsinan drift. Further, several features in Google Earth improve visualization, such as viewing areas of interest obliquely in 3D, and panning around the compass from different vantage points. Version 2 is another step towards a more accurate geospatial database of glacier extents, including the addition of reconstructed mountain glaciers in five small ranges in southwestern Alaska, which are important because they barely intersected the snowline elevation during the late Wisconsinan, as well as some more major refinements of the larger ice mass, which have now been located more accurately because their moraines are visible on high-resolution satellite imagery. APG v2 provides a comprehensive, up-to-date compilation of limits and ages in a format that is publicly available and user-friendly.

The geospatial data in v2 contributes to both education and research. The website for v1 has received more than 20,000 visits to date, with more than 3500 dataset downloads. Beyond visualization, mapping and outreach, the new data will be valuable for modelling and quantitative analysis by glacial geologists, with application more broadly to geological sciences, geomorphology, palaeoclimatology, ecology and land resource management.

FULL CITATION

Kaufman, D.S., Young, N.E., Briner, J.P., Manley, W.F., 2011. Alaska Palaeo-Glacier Atlas (Version 2). In: Ehlers, J. & Gibbard, P.L. (eds), Quaternary Glaciations Extent and Chronology, Part IV: A Closer Look. *Developments in Quaternary Science 15*, Amsterdam, Elsevier, 427–445.

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