Pleistocene Maximum and Late Wisconsinan glacier extents across Alaska, U.S.A.

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Introduction

This report summarises the results of a collaborative effort among glacial geologists working in Alaska to produce an updated compilation of statewide glacier extents. It summarises evidence used to draw glacial limits in 15 regions across the state and highlights the most significant changes from previous mapping. This report also provides an overview of the glacial-geological record in Alaska, identifies prior efforts to synthesise data on Alaskan glacial geology and briefly discusses the broader implications of the newly mapped glacial extents.

In addition to the digital maps provided with this report, the authors have created a website devoted to the palaeoglaciation of Alaska (http://instaar.colorado.edu /QGISL/ak_paleoglacier_atlas). The website serves sev-eral purposes: (1) it presents a single, coherent geospatial database that encompasses all of Alaska and exclusively Alaska (whereas the base maps used for this digital map segment the state and adjacent territories into several tiles); (2) the *Alaska PaleoGlacier Atlas* will be periodically updated to incorporate the results of new mapping and geochronology; and (3) the website provides the spatial database in several GIS formats and includes related digital products and images. The digital maps in this report are from version 1 of the *Alaska PaleoGlacier Atlas*.

The map draws extensively from the last statewide compilation. The map by Coulter *et al.* (1965) was completed forty years ago and published three years later. It was based primarily on first-generation, unpublished, photo-interpretive, glacial-geological mapping by the six co-authors who formed the Alaska Glacial Map Committee of the United States Geological Survey and who were listed alphabetically in the authorship (H.W. Coulter, D.M. Hopkins, T.N.V. Karlstrom, T.L. Péwé, C. Wahrhaftig and J.R. Williams). Similarly, the contributors to this report and map are also listed alphabetically, except for DSK and WFM who lead the effort. Contributors to this report provided previously unpublished information and their specific input is recognised in the 'Regional Summaries' below.

The digital map and this report focus on the two glacial limits that can most confidently be determined across the state (Fig. 1): (1) the maximum extent of glaciers; and (2) the Late Wisconsinan. The maximum extent of glaciers largely 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 regional geographical patterns and general geomorphology. The extent of Late Wisconsinan (= late Weichselian) glaciers is delimited more accurately. The Late Wisconsinan limit on the digital map roughly coincides with Coulter et al.'s (1965) map unit Qg₄ (areas covered by ice during the glacial advances of Late Pleistocene age). In places, however, Coulter et al.'s (1965) Qg₄ unit included areas that are now assigned to pre-Late-Wisconsinan glaciations. The major differences between the current compilation and that of Coulter et al. (1965) are discussed in the 'Regional Summaries' below. Generally, Late Wisconsinan deposits are easily recognised by their sharply-defined moraines on which the details of glacial constructional relief are well preserved.

Spatial data compilation

Standard geographical information system (GIS) techniques were used to compile the glacial limits, incorporating information from a variety of sources (documented below). Processing was conducted with two statewide coverages, one for each age limit, using North American Datum 1927 and an Alaska Albers projection. A first draft of the digital atlas was created by scanning, georectifying and digitising Coulter *et al.*'s (1965) map. Additional maps from six publications and unpublished mapping by WFM and DSK were scanned and georectified. Polygons delineating former glaciers were then added and edited in *ArcMap* (v. 8.1 and 8.2, digitising onscreen at resolutions better than the



Fig. 1. Pleistocene maximum, Late Wisconsinan and modern glacier extents across Alaska.

source maps, commonly in streaming mode with vertex spacing of 1-5 km). This version was distributed for community review and subsequently updated to include limits from 19 additional publications as well as unpublished research by the authors and 17 contributors. In sum, the digital atlas integrates information from 42 source maps.

Finally, the glacier limits were classified according to 'certainty'; a measure of confidence relating to both age determination and geographical position. For example, well-dated moraines were ascribed a high level of certainty, comparable to a solid line on traditional glacial geological maps. 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' boundaries on traditional maps). A low level of certainty was attributed to arcs bounding polygons where ice limits are interpreted for offshore positions, or for areas lacking detailed air-photograph interpretation or significant, field-based glacial-geological study. The measures of certainty are based on available mapping and publications and are commensurate with the target scale of 1:1,000,000.

The digital maps contained in this report correspond with version 1 of the *Alaska PaleoGlacier Atlas*. Although version 1 is sufficiently well resolved for public release, some relatively small glacier systems that are known to have developed during the Pleistocene are not shown in this version, including St. Lawrence Island, Blackburn Hills, Horn Mountains, Shotgun Hills, Taylor Mountains, parts of the Yukon Tanana Upland, fringes of the Ahklun Mountains, central and eastern Brooks Range, and the Cordilleran Ice Sheet. Sufficient glacial-geologic mapping is lacking for many of the Aleutian Islands, and for the continental shelves of the Gulf of Alaska.

Previous reviews of Alaskan glacial geology

The first attempt at a statewide summary of Pleistocene glacier extents was compiled by Péwé (1953). This effort led to the only statewide superficial map yet produced (Karlstrom *et al.*, 1964) and its derivative map of glacier extents (Coulter *et al.*, 1965), which was published at a scale of 1:2,500,000. By the mid-1960's, the overall distribution of Quaternary glaciers in Alaska was generally recognised. Fifteen local Quaternary glacial sequences had been studied and the major advances in each sequence were tentatively correlated (Péwé et al., 1965). The drift was subdivided into three principal units: Wisconsinan, Illinoian and pre-Illinoian, based mainly on semi-quantitative relative-weathering criteria and comparison with the mid-continent. About half of the local sequences included a two-fold subdivision of the Wisconsinan glaciation (Early and Late) and many authors recognised multiple advances early during the Holocene. Drift interstratified with marine deposits around Nome, Kotzebue (Hopkins et al., 1965) and Cook Inlet (Karlstrom, 1964) provided additional age control based on the now-discredited Th/U dating of molluscs and a few radiocarbon ages had been determined. The dramatic difference between the limited extent of Late Wisconsinan glaciers and the vast extent of pre-Wisconsinan ice was identified in most areas and the exceptionally long record of glacio-marine sedimentation, dating back to the latest Miocene, had been recognised around the Gulf of Alaska (Miller, 1957).

Péwé (1975) reviewed the Quaternary geology of Alaska. His comprehensive synthesis included the first and, as yet, only statewide compilation of glaciation thresholds. By the 1980's, widespread application of radiocarbon dating had greatly refined the chronology of Late Wisconsinan glacier fluctuations; in Alaska, the technique was then and has been since, most extensively applied to deposits of the Cordilleran Ice Sheet (Hamilton & Thorson, 1983) and in the Brooks and northern Alaska ranges (Porter *et al.*, 1983). These studies demonstrated that the most recent major glaciation in Alaska took place between 24.0 and 11.5 ka and was therefore broadly synchronous with Marine Isotope Stage (MIS) 2.

Hamilton et al. (1986) edited the most complete collection of glacial geological studies in Alaska. That volume includes detailed reports on ten different glaciated regions of the state. Readers interested in the glacial geology of a particular region are referred to this volume. The regional studies employed a wide range of approaches, but nearly all included ¹⁴C ages or other geochronology, descriptive accounts of relative-weathering features and palaeoclimatological interpretations. The authors recognised new complexities in the glacial sequences resulting from their detailed stratigraphical and geochronological studies; these were commensurate with their emerging understanding of Quaternary global climate changes provided by marine oxygen isotopes. Around the same time, evidence for Holocene glaciation in Alaska was reviewed by Calkin (1988) and modern glaciation was discussed by Krimmel & Meier (1989).

Hamilton's (1994) review of Pleistocene glaciation of Alaska is the most up-to-date and complete synthesis. Based largely on the 1986 regional summaries and updated with information from 109 additional papers published after 1986, Hamilton (1994) integrated evidence for late Cenozoic glaciation in 15 regions of the state and correlated glacial deposits within six broad age categories.

Overview of Pleistocene glaciation in Alaska

In North America, Alaska is unique because the state encompasses the largest contiguous land area at high latitude that was never glaciated (Fig. 1). Even more land was exposed during intervals when eustatic sea level was lower. The regressed shoreline not only exposed a vast area of continental shelf, but it reduced the maritime influence that today penetrates the state. Continentality increased in some areas by as much as 800 km. Lower atmospheric temperature and increased sea-ice cover further reduced the availability of moisture during glacial intervals. Areas beyond the limit of erosion by Pleistocene glaciers preserve an unusually long depositional and geomorphological record of arctic palaeoenvironmental changes (e.g., Hopkins, 1982; Carter et al., 1989). Despite their relatively limited extent, glaciers nonetheless influenced these sequences across long distances from the ice margins via fluvial, aeolian, lacustrine and marine systems. Because the glacier fluctuations were driven by the same climatic changes that affected many other geomorphological and biological processes, and because the glaciers themselves influenced an array of interrelated geomorphological processes, the glacial record provides a fundamental stratigraphical framework for the Pleistocene history of much of the state (Hamilton, 1994).

Although most of Alaska and its adjacent continental shelves were never glaciated (contra Grosvald & Hughes, 1995; Grosvald, 1998), its vast mountainous terrain generated a mass of glacier ice comparable to that of all the rest of the Western United States combined. The largest expanse of glaciers comprised the coalescent ice caps and piedmont lobes that extended from the Alaska Range to the Gulf of Alaska and from the south-eastern 'panhandle' to the Aleutian Islands. This amalgamation formed the western extension of the North American Cordilleran Ice Sheet and contained most of the glacial ice in Alaska. The ice caps that grew in the Brooks Range, the northern extension of the Rocky Mountain system in northern Alaska, and the Ahklun Mountains in south-western Alaska were the only other major centres of ice accumulation in the state. Lower uplands across the state supported hundreds of smaller valley glaciers; most notable are the small ranges of Seward Peninsula and the Yukon Tanana Upland. In all, glaciers once covered about 1,200,000 km² of Alaska and its adjacent continental shelf; during the Late Wisconsinan, the area was 727,800 km². At present 74,700 km² of Alaska is covered by ice, or 4.9% of the state; most present-day glacier-ice volume is in the coastal ranges proximal to moisture sources around the Gulf of Alaska.

Because most of Alaska was unglaciated, glaciers were free to expand onto adjacent lowlands, where they left a rich record of moraines and morphostratigraphically related glacial-geological features. Evidence for the extent of glaciers around the Gulf of Alaska is now submerged and obscured, but elsewhere, a succession of moraines is preserved along most mountain fronts. Evidence for multiple glacier fluctuations is also preserved in successions of glacially influenced deposits of lacustrine (e.g., Lake Atna, Ferrians, 1963; and Lake Noatak, Hamilton, 2001), marine (e.g., Yakataga Formation, Plafker & Addicott, 1976; Hagemeister Island, Kaufman *et al.*, 2001a), fluvial (e.g., Epigurak Bluff, Hamilton *et al.*, 1993) and aeolian systems (loess and sandsheets, Lea & Waythomas, 1990; Begét, 2001; and dunes, Carter, 1981; Mann *et al.*, 2002). The glacial history is often better-dated in these depositional settings where volcanic products and organic materials are more commonly preserved.

The available age control shows that Alaska has experienced glaciations for as long as anywhere else in the Northern Hemisphere. The geochronology also shows that glaciers fluctuated on time scales ranging from tens of thousands of years to decades, consistent with other records of global climatic changes. The ages of Holocene (e.g., Calkin et al., 2001) and Late Wisconsinan (e.g., Porter et al., 1983) glacial fluctuations are best documented. The ages and correlations of glacial deposits of the next-older (penultimate) ice advance are beyond the range of radiocarbon dating and have remained controversial, as they are in other places in North America. Previous studies generally interpreted the penultimate advance to be younger than the Last Interglacial (Early Wisconsinan s.l.) and several new studies have amassed geochronological evidence for an Early Wisconsinan (s.l.) age. On the other hand, tephrostratigraphical, palaeoecological, pedogenic and luminescence evidence from the southern and central parts of Alaska suggest that the penultimate drift might predate the Last Interglacial. This discrepancy underlies the map unit classifications of Coulter et al. (1965), which included 'Late Pleistocene' (Qg₄) and 'Middle to Late Pleistocene' (Qg₃) units. The penultimate drift was placed into Qg4 by workers who favoured an Early Wisconsinan age and into Qg₃ for those who preferred a pre-Wisconsinan (e.g., Illinoian) age. The present authors agree with Hamilton (1994), who suggested that the penultimate drift might be different ages in different places.

Regional summaries

The following regional reviews briefly describe the geographical framework for each of the 15 ice accumulation centres in the state and summarise the evidence for the ages and extents of the most widespread glaciation and the Late Wisconsinan. The regions are arranged roughly from north to south.

Brooks Range (Fig. 2)

Central Brooks Range. Although the nomenclature and inferred ages of glacial-geological features have evolved since the early work of Fernald (1964) and Porter (1964), the currently accepted regional sequence for the central Brooks Range (Hamilton, 1986) includes four major glacial

episodes ranging in age from late Tertiary to Late Wisconsinan. Nowhere else in the western U.S.A. has the glacial geology of a contiguous area been mapped as systematically by one individual as the Brooks Range has by T.D. Hamilton. His 1:250,000-scale maps span the width of the range and extend >500 km west to east (Hamilton, 1978, 1979a, b, 1980, 1981, 1984a, b, 2002a, b). The Late Wisconsinan and maximum glacier limits on the digital map were digitised from a 1:1,000,000-scale, unpublished map compiled by TDH, based on his extensive mapping and the research of others over the past four decades.

The maximum limit of glaciation encompasses discontinuous patches of erratic-bearing drift and buried till that have collectively been assigned to Gunsight Mountain Drift (Hamilton, 1986). The drift has been mapped beyond both flanks for the Brooks Range. In the northern foothills, it is traceable for over 330 km and defines a series of large piedmont lobes that extend c. 60 km beyond the range front and stand c. 100 m above modern drainages. South of the Brooks Range, ice once extended as much as 90 km beyond the Late Wisconsinan limits. Glaciers expanded into the Koyukuk River lowlands where remnants of till buried by loess and lake deposits have been mapped collectively as Gunsight Mountain drift. In the Kobuk River valley, drift of the next younger glaciation (Anaktuvuk River) is reversely magnetised indicating that it and the Gunsight Mountain drift are Early Pleistocene or older (Hamilton, 1986).

The Late Wisconsinan limit shown in the digital map coincides with the extent of Itkillik II glaciers (Hamilton, 1986; also referred to in some publications as 'Walker Lake'). Glaciers of Itkillik II age were sourced in compound cirques that coalesced to form a nearly contiguous network of transectional valley glaciers. These glaciers were confined within deep troughs excavated during previous glaciations. Less commonly, short valley glaciers terminated in tributary valleys above the confluent ice. The limits of the former glacial system is demarked by sharp lateral moraines and bulky end moraines extending between 5 and 25 km beyond the northern flank of the range. In the Itkillik-Sagavanirktok River area, along the north flank of the Brooks Range, Hamilton (2003) identified two distinct moraine sets of Itkillik II age that probably formed between c. 24 and 13 ka. In southern valleys, drift of Itkillik II age largely comprises icestagnation deposits that dam large lakes in many of the major river valleys. In most valleys, one or more welldefined moraine sets mark a readvance of glaciers late during Itkillik II time, about 13.0 and 11.5 ka (Porter et al., 1983).

Eastern Brooks Range. East of about 147° longitude, the Pleistocene glacial-geological record of the Brooks Range has received less research attention. The maximum extent of ice shown in the digital map is taken from the 1:1,000,000 map compiled by TDH, based on Coulter *et al.* (1965) and modified according to recent field observations and interpretation of aerial photography and satellite imagery. Much of the limit is uncertain throughout this



Fig. 2. Pleistocene maximum, Late Wisconsinan and modern glacier extents, Brooks Range and Yukon-Koyukuk region.

region, reflecting limited evidence. Similarly, the extent of ice during the Late Wisconsinan is taken mostly from TDH's 1:1,000,000 unpublished map (comparable to Coulter *et al.*, 1965). Late Wisconsinan limits in the southern valleys appear to coincide with well-defined end moraines. In the northern valleys, however, the Late Wisconsinan limit is poorly constrained. Only a few possible Late Wisconsinan moraines have been identified on aerial photographs by DSK and NLB (unpublished), suggesting that only the highest north-facing valleys held ice during the Late Wisconsinan.

Western Brooks Range. West of 158° longitude, summit elevations lower and the range bifurcates into the DeLong Mountains in the north and the Baird Mountains in the south. Hamilton's (2001) recent study of the rich stratigraphical record exposed in the Noatak basin has revealed evidence for multiple glaciers that expanded from the DeLong Mountains and dammed a succession of proglacial lakes.

The maximum extent of ice shown in the digital map is based on TDH's 1:1,000,000-scale compilation and is similar to Coulter *et al.* (1965). The maximum limit is poorly defined and probably corresponds to glaciations of different ages in different places. In the Kotzebue Sound area, the mapped limit coincides with the composite ridge that forms the Baldwin Peninsula (McCulloch, 1967). This huge morainic complex consists of marine, glacio-marine and glacio-terrestrial deposits that delimit either an ice cap that occupied the Kobuk River and Selawik River lowlands (Hamilton & Hopkins, 1982), or coalescent piedmont lobes sourced in the western Brooks Range. Amino-acid geochronology indicates that the moraine formed during the Middle Pleistocene (Huston *et al.*, 1990; Roof, 1995). Whether ice of earlier glaciations extended further west in Kotzebue Sound is not known.

New photo-interpretative mapping (TDH and DSK, unpublished) and radiocarbon dating (TDH, unpublished) indicates that glaciers were considerably less extensive (by an order of magnitude) in the DeLong Mountains during the Late Wisconsinan than has been depicted in previous statewide compilations. Ice was confined within the highest mountain valleys. The pattern of restricted ice in the DeLong Mountains during the Late Wisconsinan is congruent with the near absence of glaciers in the Baird Mountains south of the Noatak River (DSK, unpublished).



Fig. 3. Pleistocene maximum and Late Wisconsinan glacier extents, Seward Peninsula. No modern glaciers in this region.

The digital map incorporates our new interpretations for the Late Wisconsinan for the western Brooks Range.

Seward Peninsula (Fig. 3)

The southern half of the Seward Peninsula encompasses four relatively small mountain ranges that were glaciated during the Pleistocene. From west to east these are the York, Kigluaik, Bendeleben and Darby mountains. The Kigluaik Mountains are the largest of the four ranges. They generated nearly as much glacier ice as the other three combined and they have been mapped in the most detail (Kaufman, 1986; Kaufman et al., 1988, 1989), with extensive relative-weathering studies of the glacial deposits (Kaufman & Calkin, 1988; Peck et al., 1990). The Kigluaik Mountains were the source of ice that advanced south across the present-day coast and deposited drift that is interstratified with auriferous and fossiliferous beach deposits on- and offshore of the coastal plain at Nome (Hopkins et al., 1960; Kaufman & Hopkins, 1989). Radiometric ages on lava (Kaufman et al., 1991), and amino-acid analyses on molluscs from interglacial marine deposits (Kaufman, 1992) provide some age control for the interstratified drift.

The glacial history of the Seward Peninsula includes at least eight glacial episodes ranging in age from Pliocene (?) to the late Holocene (Kaufman & Hopkins, 1986). The oldest drift forms a featureless surface buried by loess and

marked by erratics. The maximum extent of the drift is interpreted where it has been studied in rare natural exposures (e.g., Hopkins et al., 1974), recovered by dredges working on- and offshore (e.g., Kaufman & Hopkins, 1989) and where it has been recorded in marine seismic profiles (e.g., Nelson & Hopkins, 1972). The drift has been collectively ascribed to the Sinuk Glaciation, although it probably dates to different glacial episodes in different places and pre-Sinuk drift may be present in the York Mountains (Kaufman & Hopkins, 1986). The mapped limit shown in the digital map corresponds closely to that of Kaufman & Hopkins (1986), which was updated from Coulter et al. (1965) to include new evidence for more extensive drift in the York Mountains and the coastal plain east of Nome. Mapping in the field by Kaufman (1986) could not confirm that the uplands in north-eastern Seward Peninsula had previously been glaciated, as indicated by Coulter et al. (1965).

The amount of glacial ice that developed on the Seward Peninsula during the Late Wisconsinan (Mount Osborn Glaciation) was an order of magnitude less than when ice expanded to its outermost limit. Only the highest tributary valleys supported small glaciers that extended up to 3 km beyond their cirque headwalls. Glaciers did not reoccupy any of the major trunk valleys that were excavated during the multiple glaciations that preceded the Late Wisconsinan. The Late Wisconsinan limit is clearly marked by sharp-creased moraines enclosing freshly eroded, rocky upper valley segments that head in cirques



Fig. 4. Pleistocene maximum, Late Wisconsinan and modern glacier extents, north-eastern Alaska Range and Yukon Tanana Upland.

with cliff-like headwalls that rise high above a narrow talus. Late Wisconsinan limits on the digital map were taken from an ongoing GIS study of former equilibrium-line altitudes and mapping at a scale of 1:63,360 (Manley & Kaufman, 2001, founded on references cited above). The Mount Osborn Glaciation is evidently of Late Wisconsinan age, although the available radiocarbon age control is weak.

St Lawrence Island

Glacier ice, originating on the Chukotka Peninsula expanded eastward across the Bering/Chukchi shelf and encroached onto St Lawrence Island at least twice during the Pleistocene (Hopkins *et al.*, 1972; Brigham-Grette *et al.*, 2001). The limit of drift is delineated 45 km east of Gambell on the north-western tip of the island; ice also encroached onto the south-western part of the Island. In addition, cirque glaciers formed in local uplands in the south-west during the Late Wisconsinan (Heiser, 1997; not shown on the digital map).

Yukon-Kuskokwim delta

Two isolated massifs near Cape Romanzof were glaciated (Coulter *et al.*, 1965). Aerial photographic interpretation by WFM suggests that cirque moraines there date from the penultimate glaciation and that the area was ice-free during the Late Wisconsinan.

Yukon-Koyukuk region (Fig. 2)

This area spans from the southern margin of Brooks Range glaciers on the north to the Yukon River on the south. It encompasses six massifs, each cored by a plutonic body, including the compact ranges of (1) Purcell Mountains (2) Zane Hills in the north-east that rise high above the surrounding lowlands and (3) nearby Angutikada Peak; (4) the small Indian Mountain massif in the centre that was barely high enough to support glacier ice; and (5) the more diffuse uplands of the Kokrines Hills and (6) Ray Mountains, which border the Yukon River to the south. Little glacial-geological mapping has been completed in this region. Coulter *et al.* (1965) show the general extent of

older drift for the Purcell Mountain and Zane Hills area and Late Pleistocene drift is mapped in the Kokrines Hills and Ray Mountains. Relating the mapped extents in Coulter et al. (1965) to specific topographic features shown on 1:63,360 scale maps and aerial photographs is difficult, however. Instead, the glacier limits shown in the digital map are based on DSK's and NLB's unpublished analysis of aerial photographs with field checks in the Zane Hills (where Hamilton, 2002a, also mapped the easternmost part of the range) and Kokrines Hills. Yeend (1971) and Reger (1979) guided the mapping in the Ray Mountains and Indian Mountain areas, respectively. The maximum extent of glaciers is poorly constrained by the outer limit of morainal forms in some valleys. In contrast, the extent of ice during the Late Wisconsinan is more clear; glaciers were generally short (<2 km) and sourced only in the deepest cirques. Cosmogenic surface exposure ages are pending from the Zane Hills (DSK, JPB, NLB).

Blackburn Hills

Unpublished field mapping and aerial photo interpretation by TKB has identified the extent of glaciation in the Blackburn Hills (not shown on the digital map). The Blackburn Hills cover over 500 km² immediately west of the Yukon River and east of Norton Sound. Eight peaks above 1000 m generated ice during the Pleistocene; these were not recognised previously as having been glaciated. Evidence for the oldest glaciation consists of isolated patches of drift at the heads of the South Fork of Bear Creek, the North Fork of Blackburn Creek, and in Thompson Creek. The till is highly modified and dissected by streams. A few glacial erratics define the maximum extent of glaciation, which advanced about 4 km down the South Fork of Bear Creek. Deposits tentatively correlated with the late Wisconsinan are confined within 18 welldefined cirques in the Blackburn Hills.

Yukon Tanana Upland (Fig. 4)

This broad region encompasses rolling hills punctuated by several rugged peaks scattered between the Yukon and Tanana rivers in east-central Alaska. The glacial history of the Mount Prindle area was discussed by Weber & Hamilton (1984); Weber (1986) provided a summary of the entire region. During the maximum phase of glaciation, more than 20% of the area was glaciated. Ice caps probably developed on all massifs above 900 m altitude, with outlet glaciers radiating as much as 56 km down major troughs. The maximum limit of Pleistocene glaciers shown on the digital map corresponds closely with that of the Charley River Glaciation of Weber (1986; also see Hamilton, 1994, Fig. 7). Glaciers of the Late Wisconsinan were generally restricted to circues and tributary valleys above 1200 m altitude. Although the extent of Late Wisconsinan glaciers on Coulter et al.'s (1965) 1:250,000 scale map is generally

correct, the polygons are not well placed. Instead, the limits shown in the digital map correspond with the Convert Glaciation in the Mount Prindle area (Weber & Hamilton, 1984, Fig. 2) and with the Salcha Glaciation for the Ramshorn Creek area (Weber, 1986). These were then modified slightly and extrapolated to the entire upland region based on aerial photograph interpretation and field survey by WFM and DJL (unpublished). Recent cosmogenic exposure dating in the Ramshorn Creek valley confirms that moraines of the Salcha Glaciation were deposited during the Late Wisconsinan (Manley *et al.*, 2002).

Kuskokwim Mountains (Fig. 5)

The Kuskowim Mountains region includes at least 13 isolated highlands, all located within about 50 km of the Kuskokwim River, that generated alpine glaciers during the Pleistocene (Kline & Bundtzen, 1986). From north-east to south-west, they include the Von Frank, Mystery, Sunshine, Page, Twin-Cloudy, Beaver, Granite, Horn, Russian, Chuilnuk-Kiokluk, Taylor and Kilbuck mountains. Most of these massifs are not shown as having been glaciated on Coulter et al.'s (1965) statewide map. Subsequent work in the Beaver Mountains (Bundtzen, 1980), Horn Mountains (Bundtzen et al., 1999), Russian Mountains (Kline & Bundtzen, 1986; Bundtzen & Laird, 1991) and the Chuilnuk-Kiokluk-Buckstock Mountains (Waythomas, 1990; WFM and TKB, unpublished) has provided detailed maps of the most heavily glaciated massifs. The Beaver Mountains are the most extensively glaciated of all the massifs and are considered the type area of the glacial sequence of the region (Kline & Bundtzen, 1986).

In the Beaver Mountains, the maximum extent of glaciers shown in the digital map coincides with the Beaver Creek Glaciation (Kline & Bundtzen, 1986). The distribution of deeply-buried till and erratic boulders exposed in river channels indicates that glaciers radiated as much as 26 km from an ice cap centred over the central divide. A similar pattern of maximum glacier extent is shown for the Oskawalik Creek Glaciation in the Chuilnuk-Kiokluk-Buckstock Mountains (Waythomas, 1990). Elsewhere, the maximum extent of glaciers is based on interpretations of the geomorphology guided by the generalised map of Kline & Bundtzen (1986).

During the Late Wisconsinan, only the largest and highest massifs generated glaciers. Glaciers did not reform, or did not advance beyond the highest few cirques in many of the massifs during the Late Wisconsinan (Kline & Bundtzen, 1986). Valley glaciers did form in the Beaver, Horn, Russian, Taylor and Chuilnuk-Kiokluk-Buckstock mountains, however. During the Late Wisconsinan, 15 valley glaciers 3-6 km long formed in the Buckstock Mountains alone (TKB, unpublished). The Late Wisconsinan limit shown in the digital map coincides with the Tolstoi Lake Glaciation as mapped by Kline & Bundtzen (1986) for the Beaver and Russian Mountains. In



Fig. 5. Pleistocene maximum, Late Wisconsinan and modern glacier extents, north-western Alaska Range and Kuskokwim Mountains.

the Chuilnuk-Kiokluk-Buckstock Mountains, the limit coincides with the Buckstock Glaciation of Waythomas (1990, Fig. 5-5). The largest Late Wisconsinan glaciers occupied the Beaver and Chuilnuk-Kiokluk-Buckstock mountains where they expanded up to *c*. 7 km and formed well-preserved moraines. The lack of quartz-bearing, durable rocks in the Kuskokwim Mountains have discouraged attempts to obtain cosmogenic surface exposure ages from these massifs, except for the Chuilnuk-Kiokluk-Buckstock Mountains from which exposure ages are pending (WFM and JPB).

Ahklun Mountains (Fig. 6)

The Ahklun Mountains of south-western Alaska supported the largest centre of Pleistocene glaciers outside of the Cordilleran Ice Sheet and the Brooks Range. Research during the last decade has clarified the age and extent of multiple Quaternary glacial expansions throughout the region (Lea, 1990; Kaufman *et al.*, 1996, 2001a, 2001b, 2003; Briner & Kaufman, 2000; Briner *et al.*, 2001, 2002; Manley *et al.*, 2001; Axford, 2000; Levy *et al.*, 2003). Extensive coastal outcrops and glacial-geomor-phological features inland have been dated using an array of geochronological methods (amino-acid, luminescence, tephra, ${}^{40}\text{Ar}/{}^{\overline{3}9}\text{Ar}$, surface-exposure and radiocarbon). The results show that extensive piedmont glaciers advanced south across the present-day coast as many as five times during the Pleistocene, most recently during the Early Wisconsinan (s.l.). An ice cap repeatedly formed over the highest part of the Ahklun Mountains. Outlet glaciers radiated down all of the major troughs; on the east, where the range is highest and steepest, outlet glaciers carved a spectacular system of interconnected fjord-like lakes. In addition to the ice cap and its associated transectional and outlet glaciers, independent mountain glaciers formed in numerous satellite ranges and small massifs that punctuate the surrounding unglaciated hills. In places, including the Eek Mountains and Shotgun Hills, mountain glaciers never merged with glaciers from the Ahklun Mountain ice cap. During the Late Wisconsinan, when ice was relatively restricted, mountain glaciers terminated well above the ice cap glaciers in dozens of small massifs, including the Kisogle Mountain area (Briner & Kaufman, 2001).



Fig. 6. Pleistocene maximum, Late Wisconsinan and modern glacier extents, Ahklun Mountains.

The maximum extent of Pleistocene glaciers was much greater south and east of the Ahklun Mountains than it was to the north and west of the range. The oldest drift reported from the Ahklun Mountains is found: (1) in boreholes around Goodnews Bay (Kemuk Drift of Porter, 1967); (2) in coastal bluffs around Nushagak Bay (the Nichols Hill Drift of Lea *et al.*, 1991); and (3) in coastal exposures on the south coast of Hagemeister Island (Kaufman *et al.*, 2001a). Amino-acid geochronology on shells from glaciomarine deposits on Hagemeister Island suggest an age of about 500 ka, but whether this correlates with drift found elsewhere is not known. South of the Ahklun Mountains, Coulter *et al.* (1965) show that glaciers once covered the shelf area of Bristol Bay. Presumably, the limit mapped by

Coulter *et al.* (1965) was determined using unreferenced seismic surveys. The authors have no new information to evaluate the maximum extent of ice in the Bristol Bay region and Coulter *et al.*'s (1965) mapped limit is retained here. East of the Ahklun Mountains, glaciers apparently merged with ice flowing westwards from the Aleutian Range (FHW, unpublished). Drift, with lithologies exclusive to the Aleutian Range, is exposed along the coast and the Nushagak River and shows that piedmont lobes from the Aleutian Range extended westward to 158° longitude. The maximum extent of ice on the north side of the Ahklun Mountains has not been mapped in the field, but the northward expansion of ice appears to have been restricted by the unglaciated hills of the Kuskokwim Moun-



Fig. 7. Pleistocene maximum, Late Wisconsinan and modern glacier extents, Cordilleran Ice Sheet.

tains. The authors' mapping along the major rivers draining the western flank of the Ahklun Mountains largely agrees with Coulter *et al.*'s (1965), with a few modifications, especially in the north-eastern corner for the range front.

During the Late Wisconsinan, an ice cap reformed over the Ahklun Mountains, but glaciers were much smaller than during preceding glaciations. Along the southern Ahklun Mountains, our mapping of the Late Wisconsinan limit (Manley et al., 2001) broadly coincides with Coulter et al.'s (1965) Late Pleistocene drift. Subsequent statewide summary maps (e.g., Péwé, 1975; Hamilton, 1994) adopted a Late Wisconsinan configuration 60-80 km more extensive than originally depicted by Coulter et al. (1965), based on a Late Wisconsinan age assigned to the youngest drift in the Goodnews Bay area (the Unaluk Drift of Porter, 1967). However, recent geochronological data (Kaufman et al., 2001a; Manley et al., 2001) indicate that: (1) correlative drift in the region is pre-Late-Wisconsinan, (2) the c. 45 ka radiocarbon ages of Porter (1967) should be considered non-finite minimum ages; and (3) the dated Late Wisconsinan limits for southern outlet lobes of the Ahklun Mountains ice cap lie significantly up-valley, broadly coinciding with Coulter et al.'s (1965) Late Pleistocene drift. In addition to the mapping of Manley *et al.* (2001) for the area south of 60° latitude, the Late Wisconsinan limit, shown in the digital map, includes data from unpublished field and aerial photographic studies by DSK, WFM, JPB and YA. The timing of the Late Wisconsinan in the Ahklun Mountains has been determined from exposure ages on moraines (Briner *et al.*, 2001) and radiocarbon ages from lake sediment cores (Kaufman *et al.*, 2003). The outlet glacier draining the south-western sector of the Ahklun Mountains ice cap attained its Late Wisconsinan limit *c.* 24-20 ka. Glaciers then experienced a series of fluctuations, the most dramatic culminating at the end of the Younger Dryas Chronozone (Briner *et al.*, 2002).

Cordilleran Ice Sheet

The greatest concentration of glaciers currently in Alaska, as in the Pleistocene, is in the southern part of the state, closest to moisture source in the North Pacific. During the Pleistocene, two great mountain belts generated voluminous glacier ice that coalesced to form the western extension of the Cordilleran Ice Sheet (Hamilton & Thorson, 1983). The



Fig. 8. Pleistocene maximum, Late Wisconsinan and modern glacier extents, Alaska Peninsula.

northern rim of the ice sheet was fed from the prominent system of mountains extending from the Aleutian Range on the west, to the Alaska Range, where the highest peaks in North American form the apex of the arc, east to the Wrangell Mountains. 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 south-eastern 'panhandle'. The two mountain belts are separated by troughs that once contained large proglacial lakes and estuaries, and are now occupied by Cook Inlet and the Susitna and Copper river basins. On the western and eastern ends, the mountains merge and they supported a single ice divide during the Pleistocene. The Cordilleran Ice Sheet is unique in Alaska, not only for the vastness of the glaciated terrain - about half of all the glaciated area in state - but also for the relative extent of the glaciers during the Late Wisconsinan; in many places, glaciers expanded nearly to the limit of those of earlier glaciations.

Alaska Range (Fig. 7). During the Pleistocene, glaciers flowed north and south from an ice divide centred over the Alaska Range (Hamilton & Thorson, 1983). Southwardflowing ice coalesced with the Cordilleran Ice Sheet and, in places, ultimately extended to the Gulf of Alaska. Northward-flowing ice occupied separate troughs and terminated short distances beyond the tectonically active range front. Troughs that tapped the ice sheet through low passes to the south extended farther than those shielded to the south by the highest parts of the range.

The maximum limit of glaciers along the northern Alaska Range, shown in the digital map, broadly follows that of Coulter et al. (1965), supplemented by unpublished or recently updated contributions from RMT, AW and FRW. In the north-western Alaska Range, the oldest drift extends up to 25 km beyond the range front where it has been assigned to the Big Salmon Fork Glaciation (Kline & Bundtzen, 1986; Bundtzen et al., 1994). It contains faceted and striated boulders that form homoclinal ridges indicating post-depositional deformation. In the Nenana River valley, the oldest drift comprises the Nenana Gravel Formation, a late Miocene and early Pliocene clastic wedge that was deposited during the exhumation of the modern Alaska Range and which, at one time, blanketed the entire foothill belt in this area (Thorson, 1986). The Nenana Gravel coarsens upwards first into glacial outwash containing striated, faceted stones, then possibly into boulder-bearing

diamicton, depending on how the formation is defined. The isolated boulders mapped as Browne(?) erratics by Wahrhaftig (1958) may be derived from the Nenana Gravel. The outer limit of these ancient erratics is based on unpublished mapping by RMT; it defines the outer limit of glaciation regardless of whether they were derived from the Nenana Gravel or deposited directly from glacier ice. It should not be confused with the outer limit of Browne erratics, which form a well-defined limit first identified by Wahrhaftig (1958). In the north-eastern Alaska Range, the maximum limit shown in the digital map was modified from Coulter *et al.* (1965) to incorporate unpublished mapping by FRW from Delta Junction to the Canadian border.

The Late Wisconsinan limit along the north flank of the Alaska Range is broadly consistent with Coulter et al.'s (1965). In the westernmost Alaska Range (Lime Lakes area), however, new aerial photographic analysis and field surveys by DSK, JPB and AW indicate that the Late Wisconsinan limit is located 20-30 km inside Coulter et al.'s (1965) limit. The present limit coincides more closely with the major end-moraine complex mapped by Coulter et al. (1965) as the 'outer limit of significant glacial advance' and contained within their Qg₄ limit. Continuing from west to east, the Late Wisconsinan limit shown in the digital map coincides with the Farewell II Glaciation in the Farewell area (Kline & Bundtzen, 1986), the McKinley Park Glaciation in the McKinley Park area (Ten Brink & Waythomas, 1985; AW, unpublished), the Riley Creek Glaciation in the Nenana River valley (Wahrhaftig, 1958; Thorson, 1986), the Donnelly Glaciation in the Delta River area (Péwé, 1961; FRW, unpublished) and the Takomahto Lake Glaciation in the upper Tanana River valley (Fernald, 1965; FRW, unpublished). Porter et al. (1983) summarised the stratigraphical and geochronological data for the Late Wisconsinan glaciation of the northern Alaska Range. At least four distinct advances are recognised in most valleys, with the Late Wisconsinan limit reached by 25-20 ka and full-glacial conditions terminated by c. 14 ka.

Aleutian Range (Fig. 8). This vast region includes the active volcanic arc, concave to the north, extending from the Aleutian Islands on the south-west to the Alaska Range on the north-east. The Aleutian Island archipelago spans 1800 km from 172° E to 164° W longitude. From there, the Alaska Peninsula extends north-eastwards another 700 km where it merges with the Alaska Range in the mainland of Alaska.

Ice-rafted detritus in sediment cores from the North Pacific Ocean and Bering Sea provide strong evidence for widespread glaciation throughout the Pleistocene (Sancetta & Silvestri, 1984; de Vernal, 1997). During the Pleistocene, the entire arc was largely covered by an elongate glacial complex (Mann & Peteet, 1994; Mann & Hamilton, 1995). Ice was thicker and extended further southwards on the Gulf of Alaska side; it was steeper and less extensive on the Bristol Bay side. The ice divide of the asymmetric ice sheet was situated south of the topographic divide over the continental shelf. Ice flowed northwards, from offshore to onshore, along most of the Alaska Peninsula. No evidence has been found to support the model of Grosvald & Hughes (1995) who suggested that a marine-based ice sheet covered the southern Bering Sea Shelf and flowed southwards (Brigham-Grette, 2001).

The age and the maximum extent of glaciers across this region is not known, but grounded glacier ice extended onto the submerged continental shelf both north and south of the Aleutian Range. Coulter *et al.* (1965) do not map pre-Late-Wisconsinan drift on the submerged continental shelf of the Gulf of Alaska. To the north of the Aleutian Range, they depict the maximum limit as including all of Bristol Bay, but their map does not extend west of the Alaska Peninsula. The maximum glacier limit shown in the digital map is based on Coulter *et al.* (1965) and Hamilton (1994), both guided by shelf bathymetry. To the authors' knowledge, maximum limits for the middle and outer Aleutian Islands are not constrained by field-based evidence and are not shown on the digital map.

During the Late Wisconsinan, glacier ice probably capped all of the major islands in the Aleutians and extended onto the now-submerged Aleutian platform, forming the westernmost extension of the Cordilleran Ice Sheet (Hamilton & Thorson, 1983; Thorson & Hamiltion, 1986). Recent work by CFW (unpublished) has confirmed the former presence of Pleistocene glaciers on several of the islands, although some features interpreted as glacial might have formed by mass wasting. The western limit of coalesced ice is unknown and some islands may have supported independent ice caps. The limit of Late Wisconsinan ice north and south of the Aleutian Islands is also unknown. Northwards, glaciers may have extended into the Bering Sea and terminated in a floating ice shelf (Black, 1976); southwards they may have met the open Pacific Ocean as a calving margin (Thorson & Hamilton, 1986). Because of these uncertainties, Late Wisconsinan limits were not included for the Aleutian Islands, west of 169° W longitude.

The extent of Late Wisconsinan glaciers along the Alaska Peninsula is better-defined (Detterman & Reed, 1973, Detterman et al., 1981, 1987; Riehle & Detterman, 1993; Mann & Peteet, 1994; Stilwell & Kaufman, 1996; Wilson et al., 1997), although detailed correlations along the length of the peninsula are uncertain (e.g., Kaufman & Thompson, 1998; Wilson & Weber, 2001). The limit shown in the digital map is based on Mann & Peteet (1994, Fig. 9), comparable with the outermost extent of the area covered by ice during the four-fold Brooks Lake Glaciation of Detterman (1986). North of Iliamna Lake, Coulter et al.'s (1965) 'outer limit of significant glacial advance' was used, which is approximately equivalent to Detterman's (1986) Brooks Lake limit and is consistent with observations from field surveys along the Kvichak River (Stilwell & Kaufman, 1996) and further north in the Lime Lake area (DSK, JPB and AW, unpublished). The age of the oldest Brooks Lake advance is not well constrained, but in the type area is probably younger than c. 23 ka (Mann & Peteet, 1994; Stilwell & Kaufman, 1996).

Mountains Rimming the Gulf of Alaska (Kodiak Island, Kenai, Chugach, Wrangell and St Elias Mountains) (Fig. 7). The system of coastal mountains that rim the Gulf of Alaska is the most extensively glaciated region of the state. The oldest Cenozoic glacial deposits in North America are found in this sector of Alaska. The Yakataga Formation is exposed along the eastern Gulf of Alaska and records the uplift of the coastal ranges and the consequent onset of tidewater glaciation during the latest Miocene (Eyles et al., 1991). During repeated Pleistocene glaciations and as recently as the Late Wisconsinan, ice may have coalesced over the continental shelf, as is depicted by Coulter et al. (1965) for the west side of the Gulf of Alaska. Molnia (1986) summarised evidence for the former extent of ice in the northern and north-eastern Gulf of Alaska. He concluded that, because the Pleistocene deposits are largely undated, the extent of Late Wisconsinan ice is not known. In the digital map, the authors adopt Molnia's (1986, Fig. 3A) 'maximum limit of late Pleistocene glaciers' as the maximum ice limit. It coincides with an interpreted calving margin at about the 200 m isobath, at about the shelf break, 100 km beyond the modern shoreline. For the Late Wisconsinan limit, the authors adopt Molnia's (1986, Fig. 3B) 'minimum area of glacial ice cover'. This model depicts piedmont lobes occupying the major troughs carved into the shelf as the seaward extension of major fjord systems. In this model, glaciers were restricted to the trough systems of glacial origin and terminated in calving margins; about half of the continental shelf remained ice-free.

On the northern and western sides of the coastal ranges, glaciers merged with ice that flowed southwards from the Alaska Range and eastwards from the Aleutian Range, although the extent to which the coalescent ice filled the intermontane basins varied between glacial episodes (Péwé, 1975). During less-extensive ice advances, including the Late Wisconsinan, confluent ice from the two major mountain systems did not entirely fill the interior lowlands. A large area in the Copper River basin and surrounding upland surfaces remained ice-free during the Late Wisconsinan (Ferrians, 1963, as digitised from Coulter et al., 1965). Hamilton & Thorson (1983) reviewed the radiocarbon evidence and concluded that the most recent major advance into the basin occurred between about 25.0 and 13.5 ka. Other unglaciated uplands, some occupied by ice-marginal lakes, are reported from south-western Kodiak Island (Mann & Peteet, 1994; Fig. 2). Numerous small Late Wisconsinan nunataks were adopted from Coulter et al. (1965).

In the Cook Inlet and Kenai lowlands, the most recent studies (Reger & Pinney, 1996; Schmoll *et al.*, 1999) suggest that only a small area remained ice free during the Late Wisconsinan (the Moosehorn Stadial of the Naptown Glaciation). Whereas previous workers inferred a large icefree area centred over the Kenai lowlands and filled with lacustrine (Karlstrom, 1964) or marine water (Schmoll & Yehle, 1986), Reger & Pinney (1996) suggest that much more extensive ice flowed from the Aleutian Range, advanced east to cover most of the Cook Inlet and Kenai lowlands and merged with ice from the Kenai Mountains.

Hamilton & Thorson (1983) discussed the complications associated with the glacial history of the Cook Inlet region and recognised that, because of the uncertain age control for the Late Wisconsinan, ice might have been more extensive in the region than previously thought. Similarly, Schmoll & Yehle (1986) acknowledged that even their oldest and most extensive glaciomarine association (East Foreland) could be as young as the Late Wisconsinan, a view consistent with that of Reger & Pinney (1996). In the digital map, Reger & Pinney's (1996) reconstruction is used for the Late Wisconsinan limit and the large ice-free area shown in the Cook Inlet-Susitna lowland region by Coulter et al. (1965) is omitted. Further south, the offshore Late Wisconsinan limit near Kodiak Island from Mann & Peteet (1994, Fig. 9) grades into that shown by Molnia (1986) further east.

Southeast Alaska (Fig. 9). This region is dominated by glacially scoured island massifs separated by an intricate network of deep fjords within about 50 km from the shelf edge. The glacial history, as summarised by Mann (1986), is poorly understood. Hamilton (1994) suggested that the history of glacial advances in most parts of southeast Alaska is unknown. During the Pleistocene, glaciers of the Cordilleran Ice Sheet originating in the St Elias Mountains on the north and the coastal mountains of British Columbia to the east, expanded over the archipelago and, in places, coalesced with local glaciers. Like the broader shelf area in the northern Gulf of Alaska, the extent to which glaciers expanded over continental shelf in southeast Alaska during the Late Wisconsinan or earlier glaciations is not well constrained. Coulter et al. (1965) did not map glacier limits in southeast Alaska, although they interpolated ice-surface contours for the most recent major glaciation; they reconstructed a relatively uniformly sloping surface high enough to cover the highest summits of the region. Mann (1986) presented a contrasting view of Late Wisconsinan glaciers in which onshore highlands blocked ice flowing westwards from the interior and prevented major accumulation of ice in some places along the continental shelf. Glacier cover on the continental shelf may have been locally variable and ice-free areas may have existed near the present coastline. The Late Wisconsinan limit shown here is consistent with the more-limited ice model and is supported by recent work of TAA and PC (unpublished), who have mapped along the Alexander Archipelago and who used the most current and detailed bathymetric charts to align reconstructed glacier limits with major geomorphological features.

Implications

The digital map provides the most detailed, geospatial compilation of former glacial extents across Alaska. Generally, the outermost and Late Wisconsinan limits mapped are similar to Coulter *et al.*'s (1965). The most significant modifications involve the previous authors' identification of the Late Wisconsinan limit. The previous



Fig. 9. Pleistocene maximum, Late Wisconsinan and modern glacier extents, southeast Alaska.

map did not show the limit consistently because of controversy over the age of the penultimate drift and because of the authors' choice of map units. Their Late Pleistocene (Qg_4) unit encompassed drift of the penultimate glaciation where workers thought it was Early Wisconsinan in age, whereas more restricted Late Pleistocene limits (i.e., Late Wisconsinan) were drawn where the penultimate drift was thought to be pre-Wisconsinan. The Late Wisconsinan limit shown in this digital map is more restricted than Coulter *et al.*'s (1965) Late Pleistocene (Qg_4) unit in the western Brooks Range and along the western flank of the Aleutian and Alaska ranges. Elsewhere, this map depicts new glaciated massifs that where not previously recognised by Coulter et al. (1965), mainly in the Yukon-Koyokuk region and the Kuskokwim Mountains and it extends the interpreted Late Wisconsinan limit around the Aleutian Islands and southeast Alaska.

The digital map of glacier extents reflects an improved understanding of the glacial history of Alaska and the benefits of new digitally-based mapping technologies that have developed since the last compilation. Nonetheless, major uncertainties prevail. Mapping in most places is based on interpretations of aerial photographs; there are major gaps in on-the-ground mapping and geochronological control. The glacial history along the continental shelf of the Gulf of Alaska is largely unknown and major discrepancies persist in the Cook Inlet area. Indeed, across much of the state, the limits are uncertain or extrapolated, even at a scale of 1:1,000,000.

Despite these shortcomings, several interpretations can be drawn from the spatial distribution of the glacial limits. The distribution of Pleistocene glaciers largely follows that of present-day glaciers, with the most massive accumulations of ice proximal to the southern moisture sources. The maximum glacier extent was greater relative to the Late Wisconsinan for the western Brooks Range and for the Seward Peninsula than for other regions. In part, this reflects the effects of Quaternary tectonism, especially for the northern Alaska Range where active uplift benefits more recent glaciations. In part, it also reflects hypsometric effects where snowline lowers over expansive surfaces. Regional differences in the relative extents of Late Wisconsinan versus the maximum glacier limit also reflect differences in palaeoclimatology and palaeoceanography. The most extensive glaciers in the western part of the state probably grew when the adjacent continental shelves were

submerged and the glaciers were preferentially nourished by a proximal moisture source that was cut off during the Late Wisconsinan.

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