PERGAMON

Quaternary Science Reviews 20 (2001) 15–24

QSR

New perspectives on Beringian Quaternary paleogeography, stratigraphy, and glacial history

Julie Brigham-Grette*

Department of Geosciences, University of Massachusetts, Amherst, MA 01003 USA

Abstract

Aspects of the paleogeography, stratigraphy, and glacial history of Beringia have been greatly revised over the past 15–20 yr. Access to North East Russia, in particular, has provided the opportunity to evaluate the Beringia landscape as a contiguous subcontinent during the Quaternary. For the first time, new research has made clearer the connection between tectonic forces and the submergence of the Bering Strait during the middle Pliocene. Revisions in the regional stratigraphy of glacial and interglacial deposits in northwest Alaska and northeast Russia provide a new foundation for assessing the causes for differences in glacial ice extent through time. The consensus of all field workers verifies that glacial ice throughout most of Beringia was of very limited extent during the last glacial maximum. The onset of regional glaciation during the waning stages of the last interglaciation is clearly out of phase with glaciation at lower latitudes. Despite the lack of much glacial activity during the early Holocene, Alaska contains a rich record of late Holocene glacial response to Neoglacial cooling. Changes in the Holocene environment of Beringia likely had a profound affect on early inhabitants. The curiosity-driven vision and spirit of both David Hopkins and the late Troy Pewe have had a profound influence on Arctic paleoenvironmental research. © 2000 Elsevier Science Ltd. All rights reserved.

Quaternary science has always progressed incrementally as new research, techniques, and proxies emerge as standard tools for understanding environmental change. Such incremental progress also requires periodic review and synthesis in order to redirect new questions being asked in Earth system science. Throughout his career David Hopkins has provided the impetus for creative thought on the Quaternary history of Beringia and has actively participated in continually questioning our collective knowledge of marine and terrestrial archives of climate change. As a subcontinent the geography of Beringia has been repeatedly bifurcated by periodic flooding of the broad Chukchi/Bering continental shelf. The notion that both Alaska and northeast Russia possessed comparable Quaternary histories propelled Hopkins' (cf. Hopkins et al., 1965) research efforts as he sought opportunities for collaboration with Russian scientists through the 1960s, 1970s and 1980s. The Beringian workshop held in September of 1997 provided the most recent forum for scientists from many countries to share their knowledge of the Great Land Bridge. As a complement to the paleoecological research summary of Elias (2001), here is summarized a perspective on the remaining collection of 15 papers (Fig. 1) along the themes of paleogeography, stratigraphy, and glacial/interglacial climate change. In detail these papers address several broad research issues including:

1. the biogeography and timing of the first submergence of Bering Strait;
2. long-term glacial/interglacial paleoclimate, especially the chronology and glacial ice extent of the Last Glacial Maximum (LGM);
3. the nature and stratigraphy of the Last Interglacial;
4. growing evidence for the so-called out-of-phase glaciations in Beringia;
5. the significance and extent of loess and "yedoma" sediment archives; and
6. Lateglacial/Holocene paleogeography and climate.

The purpose of this paper is to summarize the new findings presented at the 1997 workshop in view of both past research and new paradigms in our global understanding of the ocean, atmosphere, geosphere system.

1. First submergence of Bering Strait

The submergence of the Bering Strait has for many years been placed in the context of oceanic gateways

---

* Corresponding author. Tel.: 1-413-545-4840; fax: 1-413-545-1200.
E-mail address: brigham-grette@geo.umass.edu (J. Brigham-Grette).

PII: S0277-3791(00)00134-7

Fig. 1. Approximate location across Beringia of stratigraphic and paleogeographic studies documented in this volume. (A) Marincovich, Jr., L., and Gladenkov, A.Y., 2001; (B) Kaufman, D.S., Manley, W.F., Forman, S.L., and Layer, P.W., 2001; (C) Manley, W.F., Kaufman D.S., and Briner: J.P., 2001; (D) Hamilton, T.D., 2001; (E) Heiser, P.A., and Roush, J.J., 2001; (F) Glushkova, O.Y., 2001; (G) Brigham-Grette, J., Hopkins, D.M., Benson, S.L., Heiser, P.A., Ivanov, V.F., Basilyan, A., and Pushkar, V., 2001; (H) Felzer, B., 2001; (I) Calkin, P.E., Wiles, G.C., Gregory, C., and Barclay, D.J., 2001; (J) Khim, B.K., Krantz, D.E., and Brigham-Grette, J., 2001; (K) Berger, G.W., and Péwé, T.L., 2001; (L) Begét, J.E., 2001; (M) Jordan, J.W., 2001; (N) Mason, O.K., Bowers, P.M., Hopkins, D.M., 2001; Guthrie, R.D., 2001, not listed as it pertains to all of Beringia.

leading to full communication between the North Pacific and North Atlantic via the Arctic Ocean (Durham and MacNeil, 1967; Einarsson et al., 1967; Vermeij, 1991). The first strong temporal evidence for submergence came not from Beringia, but rather from Iceland with the post-strait arrival of boreal Pacific mollusks in the basal *Serripes* Zone of the Tjornes sequence (Einarsson et al., 1967). Dated by newly emerging paleomagnetic techniques and K/Ar dating of interbedded basalt flows, submergence of the Bering Strait was placed at slightly more than ca. 3.3 My and supported by the arrival of Atlantic endemic mollusks, especially *Astarte* in deposits of the Beringian transgression as first defined by Hopkins, 1959, 1967b; Hopkins et al., 1965. Kennett (1982) went so far as to implicate the nearly simultaneous emergence of the Isthmus of Panama and submergence of the Bering Strait as critical elements in Pliocene cooling of the Northern Hemisphere. This view persisted for more than a decade until Gladenkov et al. (1991) presented new evidence from Karaginsky Island off the Kamchatka Peninsula for the arrival of Atlantic mollusk endemics as early as 4.0–4.2 My, based on diatom biostratigraphy and fission-track ages. The discovery of a similar fauna in a bore hole offshore of Nome (Kaufman, 1992) concurred with placing the initial submergence earlier in time than the Beringian I transgression at Nome and earlier than the correlative Colvillian transgression on the Alaskan north slope (Brigham-Grette and Carter, 1992). New work by Marincovich and Gladenkov (1999, 2001), however, outlines new evidence for initial submergence as early as 4.8–5.5 My based on the occurrence of Arctic–Atlantic *Astarte* in the Bear Mountain Formation on the Alaskan Peninsula. The age of these deposits is founded on diatom biostratigraphic zones and is the focus on ongoing work. Moreover, new geochronologic evidence from the Karaginsky Island sequences suggests submergence possibly as early as 5.0–7.0 My (Marincovich and Gladenkov, 2001).

Significantly, this new research places the initial submergence of the Bering Strait in the context of its presumed tectonic origin. Mackey et al. (1997) have recently defined the Bering Sea, Chukotka Peninsula, Seward Peninsula and part of western Alaska as an independent tectonic block that has been rotated clockwise in tandem with the northwest subduction of the Pacific plate. Rotation of the Bering Block is thought to have been initiated 5.5 My ago providing a realistic mechanism for the initial extension, faulting and submergence of the Bering Strait region. For the first time, there is now converging geologic evidence for both the timing and origin of submergence more than 2.5–4.5 million years before the first major glaciation of the Northern Hemisphere. This new work will more accurately portray the role of the Bering Strait in oceanographic models aimed at exploring the global climatic significance of Pacific–Atlantic teleconnections (Reason and Power, 1994; Shaffer and Bendtsen, 1994).

2. Long-term glacial/interglacial paleoclimate and ice extent during the LGM

The Beringian region has long been recognized as an archive of late Cenozoic glacial and interglacial deposits. Compilations of the surficial geology of Alaska (Coulter et al., 1965) provided the impetus in the 1960s for mapping and stratigraphic study of moraine and glaciofluvial sequences with relative-age estimates supported by available radiocarbon ages. Hamilton's statewide compilation (Hamilton, 1986) and his more recent review paper of the glaciations of Alaska (Hamilton, 1994) set the framework for the evaluation of new work documenting at least four major ice advances out of the DeLong Mountains into the Noatak Basin in northwestern Alaska. These advances terminated into a complex series of superposed proglacial lake sequences representing repeated damming of the Noatak drainage during periodic glaciations dating back to the early Pleistocene. The rich record of glaciolacustrine sediments found here interbedded with interglacial fluvial sequences is the best studied in the state of Alaska (Hamilton and Ashley, 1993; Elias et al., 1999).

Correlations between land and sea are most firmly linked when glacial deposits are found interbedded with marine and coastal sediments. Ongoing research in the vicinity of the Ahklun Mountains of southwestern Alaska provides an emerging "rosetta stone" for evaluating the phasing and timing of glacial/interglacial climate change. Kaufman et al. (2001) and Manley et al. (2001) provide evidence for a long record of six or more glacial advances out of the Ahklun Mountains. Exposures of marine and glacial–marine sediments on Hagemeister Island in Bristol Bay may represent as many as four pre-Wisconsin glacier advances that occurred while eustatic sea level was relatively high sometime between ca. 500 and 280 ka based upon amino acid data and supporting geochronology used to subdivide the sequence (Kaufman et al., 2001). This is matched by the mapping and geochronology of Manley et al. (2001) who provide relative ages for at least one to three pre-Wisconsin moraine sequences recorded in the major drainages of the Ahklun Mountains. Both papers provide clear physical evidence for an extensive glacial advance reaching out to sea during the early Wisconsin followed by very limited ice extent during the LGM.

3. Out-of-phase glaciations in Beringia

Documentation for major glacial advances while eustatic sea level is still high through the Bering Strait, or the so-called out-of-phase glaciations, is a compelling new theme to emerge from Beringian research in the last 10 yr. Huston et al. (1990) followed by the work of Roof (1995) and Pushkar et al., (1999) demonstrated that the mountains to the north and west of Kotzebue Sound had to have been rapidly glaciated near the end of marine oxygen isotope stage 11 (possibly stage 9) in order to explain the continuous deposition of extensive pro-deltaic interglacial marine sediments overlain by glacially deformed glaciomarine muds. Because these deposits lie some 400 km from the edge of the shallow continental shelf, eustatic sea level had to have remained high as a consequence of widespread glaciomarine sedimentation in front of thin but extensive valley glaciers emanating from western Brooks Range. This set the stage for a re-evaluation of the glacial/interglacial sequence in northwestern Alaska, especially the need to determine the age of this last, most extensive mountain glaciation in this part of Beringia (Kaufman et al., 1991).

Revisions in the glacial/interglacial sequence in Alaska propelled bilateral research on the Russian side of the Bering Strait. Brigham-Grette et al. (2001) revise the Quaternary stratigraphy of Chukotka, most importantly by reassigning the famous Pinakul Formation, once thought to be of early Pleistocene age (Ivanov, 1986), to the last interglacial sensu lato (*marine isotope stage 5a-e*). Moreover, reinterpretation of the Pinakul sequence and correlative deposits near Enmelen on southwestern Chukotka argues for rapid glacierization of regional coastal mountains during or at the end of the last interglacial. While the dating is not completely clear, stratigraphic relationships argue for widespread glaciomarine sedimentation at either the marine isotope stage 5e/5d transition or the stage 5a/4 transition; however, the authors prefer the former. Glaciomarine sedimentation in the Pinakul Formation at the very center of the shallow Bering Strait requires that coastal mountains were glacierized while eustatic sea level remained high. A drop of only 40 m would otherwise cause the shoreline to regress hundreds of kilometers without the compensating effect of thick ice cover. However, tidewater glaciers in this area are known to have been thin based upon glacial trim lines in the Waring Mountains and the position of extensive kame terraces found up valleys of the Kobuk River.

Consistent with this framework for out-of-phase glaciation at the end of the Last Interglacial is the work presented by Kaufman et al. (1996, 2001) from the Bristol Bay region of southwestern Alaska. Their work clearly demonstrates that mountain glaciers extended as much 100 km from cirques and intersected the sea before eustatic sea level had dropped. Like the Pinakul sequence, the age of this advance is broadly considered to be "early Wisconsinan", but likely occurred either at the Stage 5e/5d transition or the Stage 5a/4 transition based on stratigraphic relationships with the underlying Old Crow Tephra (ca. 140 ka) and a TL age estimate of 70 ka ± 10 on basalt overrun by advancing glacier ice. However, calibrated amino acid age estimates and infrared-luminescence ages offer the best geochronological control.

Rapid glacierization of mountainous regions across southwestern Alaska and Chukotka is consistent with widespread evidence for the advance of glaciers across mountain regions of Siberia (Karabanov et al., 1998). I maintain, however, that this does not necessarily imply the presence of an ice sheet across the Russian arctic shelf as large as that suggested by Karabanov et al. (1998). Rather, the stratigraphy inland from the Laptev Sea and Kara Sea show that glacial ice limits at some time prior to 50 ka were more extensive than during the LGM but much less extensive than during the middle Quaternary (Svendsen et al., 1999). Combined with earlier work summarized by Miller and deVernal (1992), we now have nearly circumarctic evidence for rapid glacierization at the end of the Last Interglacial, presumably driven by a precipitous drop in insolation while oceanic temperatures remained warm and eustatic sea level remained relatively high.

But this model neglects other feedbacks at play in amplifying the Arctic climate system. Marine evidence suggests that major climate shifts, like the stage 5e/5d transition, also correspond to changes in deep water flux (e.g., Adkins et al., 1997). Since the ocean conveyor system clearly has a dramatic effect on heat transport to the high latitudes (cf. the Younger Dryas event), it seems likely that rapid reorganization of deepwater production at the 5e/5d transition over a period of less than 400 yr (Adkins et al., 1997) also contributed to the onset of widespread Arctic glaciation in sensitive regions.

4. Ice extent during the LGM

The extent of glaciers across Beringia during the last glacial maximum (LGM) has been the focus of much research over the past 30 yr with controversial issues arising only over the past decade. Ignoring years of field research Grosswald and Hughes have published a series of papers suggesting that an East Siberian Sea ice sheet covered most of central and western Beringia during the LGM (Grosswald, 1984, 1988; Hughes and Hughes, 1994; Grosswald and Hughes, 1995; Grosswald, 1997, 1999). They hypothesize that this ice complex formed one of several contiguous ice domes that rimmed the Eurasian Arctic from Scandinavia to Alaska. Unfortunately, this theoretical ice sheet is not based on physical field evidence despite long-standing published data demonstrating that such an ice sheet did not exist (see summaries in Bespaly, 1984; Isayeva, 1984; Arkhipov et al., 1986a, b; Hamilton, 1986; Biryukov et al., 1988). The hypothesis of an East Siberian Sea ice sheet has been erroneously perpetuated in the literature (cf. Kotilainen and Shackelton, 1995; Clark et al., 1999) and incorporated, even if in some reduced form, in global geophysical models (Peltier, 1993, 1994) used by climate modelers.

The overriding consensus view on this issue is that neither a Beringian Ice Sheet (ala Grosswald, 1998) or an East Siberian Ice sheet (Peltier, 1994; ala Grosswald and Hughes, 1995) existed over western and Central Beringia during the Late Pleistocene. Several papers in this volume directly support this consensus. Heiser and Roush (2001) used synthetic aperture radar images to map the distribution of glacial moraines across Chukotka, an effort that demonstrates the reproducibility of regional mapping by Glushkova (1992). This work demonstrates the value of remotely sensed image analyses; however, they carry the work an important step farther. By estimating surface roughness and distal slope angles on remote moraines, they use these data to subdivide the landforms into groups of middle and Late Pleistocene age based on comparisons with dated moraine sequences in northern and northwestern Alaska. The LGM moraines clearly define widespread valley glaciation in mountainous regions fronted by well-developed glaciofluvial sequences as described by Glushkova (2001). Cosmogenic isotope dating of moraines in the Pekulney Mountains northwest of Anadyr and the northern Koryak Mountains south of Anadyr (Gualtieri, 1998; Gualtieri et al., 2000) also supports research throughout much of Alaska for extensive middle Pleistocene mountain glaciation followed by more restricted glaciation during the late Pleistocene. In nearly all studies across Beringia, late Stage 5 to Stage 4 (early Wisconsinan or Zyrian age) glaciers were more extensive than during the LGM (Kaufman and Hopkins, 1986; Kaufman and Calkin, 1988; Kaufman et al., 1988, 1989, 2001; Peck et al., 1990; Hamilton, 1994; Mostoller, 1997; Briner and Kaufman, 2000; Brigham-Grette et al., 2001; Glushkova, 2001; Heiser and Roush, 2001; Manley et al., 2001).

Without doubt, at no time during the middle or late Pleistocene did an East Siberian Sea ice sheet flow south across Chukotka to calve into the deeper regions of the Bering Sea as suggested by Grosswald (1998). In fact the lack of any isostatically uplifted shorelines or marine terraces anywhere on Chukotka or the shores of Alaska definitively shows that it could not have existed (Heiser, 1998). Abundant mammoth remains dating back to over 20 ka (Vartanyan et al., 1993; Sher, 1995) under the supposed dome of the ice sheet also argues against its existence. Moreover, Russian colleagues cite evidence for continuous deposition since long before the middle Sartan (Wisconsinan) in areas of the Kolyma and Indirka rivers indicating that even a small East Siberian ice sheet northwest of Wrangel Island (cf. Peltier, 1993, 1994) could not have existed during the LGM (Sher, 1995; Anderson and Lozhkin, 2001). Felzer (2001) demonstrates using Genesis 2.0 and EVE (a global climate model coupled with vegetation ecology) that such an ice sheet, had it existed, would have actually *warmed* areas of Beringia south of the ice sheet during the LGM to an extent that is incompatible with available paleoecological evidence (cf. Lozhkin et al., 1993; Elias, 2001). Removal of the ice sheet from the model allows for the persistence of cold arid conditions across much of Beringia with snowline elevations much higher than expected based on snowlines from other parts of the world (Broecker and Denton, 1989; Heiser, 1998). The discovery of the so-called ice berg scours on the sea floor of the Chukchi Cap at 400–1000 m water depth in the Arctic Ocean north of Wrangel Island (Edwards et al., 1999; Polyak et al., 1999) is not substantial evidence of an East Siberian Sea ice sheet during the late Pleistocene.

5. Climatic extremes in the Last Interglacial

Marine and terrestrial deposits of the last interglacial across Beringia (marine isotope stage 5e) provide an important framework for understanding the full dynamic range of climate variability across the Arctic during warmer intervals of the past. By most proxies, the last interglacial was everywhere slightly warmer than modern conditions (Hamilton and Brigham-Grette, 1991; Brigham-Grette and Hopkins, 1995; Lozhkin and Anderson, 1995a; Berger and Péwé, 2001; McDowell and Edwards, 2001; Muhs et al., 2001). Previous work demonstrated that during 5e the winter sea-ice limit in the Bering Strait was at least 800 km farther north than it is now and the Arctic Ocean may have been ice-free some summers (Brigham-Grette and Hopkins, 1995). At the same time, treeline was more than 600 km farther north displacing tundra across all of Chukotka (Lozhkin and Anderson, 1995a). The recent thinning of the Arctic pack ice coincident with the warmest decade of the latest Holocene (McPhee et al., 1998; Mann et al., 1999; Parkinson et al., 1999; Vinnikov et al., 1999) could certainly mean we are now witnessing a shift to these more extreme conditions.

The Last Interglacial is the focus of several papers in this volume and they add a fresh dimension to widespread evidence for conditions warmer than present in different parts of Beringia (Berger and Péwé, 2001; Khim et al., 2001; McDowell and Edwards, 2001; Muhs et al., 2001). Elias (2001) summarized the ecological context of studies by McDowell and Edwards (2001) and Muhs et al. (2001) and we can add to these two additional papers with a focus on analytical techniques. Berger and the late Troy Péwé (2001) discuss refinements in the stratigraphy and numerical age of the Eva Forest Beds in the Fairbanks region of central Alaska. As a complement to a recent monograph on the stratigraphy and paleoecology of these beds (Péwé et al., 1997), this paper summarizes details of the geochronology of the Eva Forest Bed and bracketing Gold Hill Loess and Goldstream deposits based upon new thermoluminescence numerical ages on loess. While past work has suggested that the Eva Forest beds could be as young as 70 ka, the ages presented here demonstrate the deposits record the warmest portion of the last interglacial and are likely ~125 ka BP, deposited closely after the 140 ka Old Crow tephra but before 107 ka. Additional terrestrial sites in parts of Alaska have been ascribed to the last interglacial but few have been as firmly dated.

Evidence for warmer-than-present marine conditions offshore of Alaska during the last interglacial (Brigham-Grette and Hopkins, 1995) is further supported by the geochemistry of Khim et al. (2001). These authors have taken a novel approach and attempted to use stable oxygen and carbon isotope systematics in the annual growth bands of fossil mollusks to produce the first annually resolved record of watermass temperature and seasonality across parts of the Bering and Chukchi shelves. By comparing the $\delta^{18}O$ and $\delta^{13}C$ geochemistry of fossil shells with that in modern specimens, they determined that seasonality was similar to modern but water temperatures were slightly warmer than modern during the last interglacial. The success of this work should provide the impetus for future work to be carried out on suites of older fossils from the Pliocene sequences of western and northern Alaska. Such work would test hypotheses for much warmer conditions in the past when sea level may have been much higher than present (Brigham-Grette and Carter, 1992; Kaufman and Brigham-Grette, 1993).

6. Loess and "yedoma" sediment archives

Wind blown silts derived from the distal flood plains of glacial rivers and deposited across the periglacial landscape have long been an archive of paleoclimate information. Because much of Beringia was not glaciated, vast areas remained open to active eolian deposition through periods of glacial/interglacial climate change. Péwé (1955, 1975) was among the first to recognize the wealth of information contained in the loess deposits of central Alaska and it is his pioneering work that provided the impetus for modern investigations in the loess and dune record of Alaska. Begét (2001) offers a historical review of loess studies in Beringia and the rich archive they contain of Quaternary terrestrial environments on timescales that surpass most lacustrine records. The fortuitous interbedding of loess with abundant distal tephras across eastern Beringia offers outstanding opportunity for numerical dating of the sequences (Westgate et al., 1990; Preece et al., 1992). Combined with paleomagnetic studies, these loess deposits can be directly compared with critical marine chronologies for assessing differences between terrestrial and marine evidence of climate change.

In contrast to the loess and dunes found across eastern Beringia, deposits known as yedoma blanket large portions of the Russian arctic landscape. Yedoma is typically defined as fine grained, organic and ice-rich silt, but the origin of yedoma is widely debated. Many Russian scientists maintain that yedoma is eolian silt accumulating simultaneously with organic matter and syngenetic ground ice. Others have suggested that it is fluvial or even lacustrine in origin (cf. Grosswald, 1988). Sher (1997) argues that yedoma probably has several origins but typically blankets nearly all of western Beringia, across all elevations and is in all cases associated with continental conditions much colder than now. Long continuous records of yedoma rich in pollen and other organic material suggests that much of what is called yedoma is clearly eolian. However, future multi-disciplinary research is still needed to fully assess the depositional context of this widespread material.

7. Lateglacial/Holocene paleogeography and climate

The climate of the late glacial and Holocene is better understood than earlier intervals due to the larger number of archives from which we can tap paleoclimate information at millennial and finer timescales. In particular, the rapid growth of studies of lacustrine archives over the last decade has dramatically influenced our knowledge of regional climate change in the context of changing global boundary conditions from Lateglacial through Holocene time (Bartlein et al., 1998). As a complement to paleoecological studies in this volume, four additional papers discuss diverse aspects of changes in the paleogeography in the context of paleoclimate. Guthrie (2001) presents the most provocative hypothesis in this part of the volume. He suggests that changes in cloud cover over the whole of Beringia during glacial versus Holocene times may explain contrasts in time and space between records of wide spread aridity and more mesic conditions through the lowlands of the Bering Straits (Elias et al., 1996). The vast areas of the mammoth steppe and pervasive evidence for cold, arid conditions across the north was, no doubt, the result of a number of factors promoting clear skies. In contrast, he suggests that the narrow Bering Strait region formed a complex mesic refugium or "Beringian buckle" with variable biotic conditions creating in part, a sort of biogeographic filter. This paper complements the notion of a "mosaic alternative" (Schweger, 1982) as Guthrie puts it, to the mammoth steppe using distinct geographic differences as a paradigm between arid and mesic environments (the latter cf. Elias et al., 1996).

Broad scientific scrutiny of climate variability during the present interglacial is discretely focused on millennial and higher frequency climate change. Holocene climate systematics is viewed as a bellweather for discerning anthropogenic induced climate change from natural variability. Along with the isotopic and ice marginal records of low- to mid-latitude glaciers around the world, surviving glaciers in mountainous regions of Alaska also provide insight into changes in the ocean/atmosphere system. Skilled with the precision of tree-ring cross dating and radiocarbon dating, Calkin et al. (2001) review what is known of patterns in Holocene glaciation across southern and western Alaska. The lack of glacial activity in the early to mid-Holocene is contrasted with repeated episodes of advance and retreat during the later Holocene. Widespread cooling starting in the mid-Holocene lead to widespread advances in southern Alaska by about 3500 BP followed by distinct idiosyncrasies in the subsequent marginal response of land-based versus tidewater glacial systems. The so-called Little Ice Age is recorded as three distinct periods of glacial advance consistent with complex records for this asynchronous series of events from other parts of the world (Grove, 1988; Thompson, 1992; Bradley, 1999).

Although there was little glacial activity during the early Holocene, the coastal environment of Alaska underwent dramatic change long after eustatic sea level flooded the Bering Strait and glaciated coastal regions rebounded from glacial isostatic loading. In general the post-glacial sea level history for Beringia is poorly constrained despite new dates on sediment cores from the Chukchi Sea which place submergence at about 10.5 ka ^{14}C yr BP (Elias et al., 1996, 1997). Due to the difficulty of sorting out true post-glacial rebound from tectonic influences, we know even less about the magnitude of full isostatic depression along the heavily glaciated south coast of Alaska. Jordan (2001) has unsnarled issues of eustatic, isostatic, and tectonic influences on relative sea level at the tip of the Alaskan Peninsula with stratigraphic studies of terrace sequences placed in the context of the coastal geomorphology. Moreover, he is able to demonstrate how changes in relative sea level influenced human occupation of coastal sites.

Without a doubt the climate and paleogeography of Beringia during the Holocene influenced the early occupants of this vast landscape. However, it is ordinarily difficult to prove and always controversial. Mason et al. (2001) add a finishing touch to our updated knowledge of Beringian paleogeography by suggesting that the late glacial/early Holocene Denali technocomplex (13,000–7,000 BP) surprisingly flourished under cooler conditions. Rather than being more successful during the Early Holocene insolation maximum (our "urban-intuitive" assumption, as they call it), they suggest that populations (i.e., numbers of occupation sites) peaked during world-wide cooling associated with the so-called "8200 yr event" (Alley et al., 1997), referred to by Mason et al. (2001) as the "younger Younger Dryas". The hypothesis may bear further testing, but the notion that "warmer is not better" represents a paradigm shift for many as new data emerge.

8. End Note

Over the last 10 yr Quaternary science has entered a new era of research, expanding beyond the earlier North Atlantic science focus of the 1970 and 1980s. Since the last World War, research across eastern Beringia was dominated by federal agencies like the US Geological Survey and driven by agendas of military and strategic importance as well as mineral wealth. Nevertheless, two men led the direction of Alaskan Quaternary research both on and offshore. The recent retirement of David Hopkins and passing of Troy Péwé comes at a time when research agendas are largely driven by coordinated national and international programs. These programs assert a stronger circum-arctic perspective and a renewed focus on the Bering Land Bridge and the role of the Arctic Ocean in the global climate system. Oceanographic modeling (cf. Reason and Power, 1994; Shaffer and Bendtsen, 1994) and paleoceanographic work from ODP Leg 145 in the North Pacific and other projects (e.g., Keigwin and Gorbarenko, 1992; Keigwin et al., 1992; Rea et al., 1995) provided the science community with increasing recognition of the role of the North Pacific/Bering Strait region in the global ocean/atmosphere system. The rich contributions of the National Science Foundation's PALE Program (Paleoclimate of Arctic Lakes and Estuaries), in concert with the development of the Beringian Atlas (PALE Beringian Working Group, 1999), demonstrates the important insights to be gained from intense study of a region where the controls on regional climate, and effects on global climate are so much different than in the North Atlantic region. The work in this volume sets a new benchmark in Beringian research built on the curiosity-driven vision and spirit of two pioneers in Arctic paleoenvironmental research.

References

Adkins, J.F., Boyle, E.A., Keigwin, L., Cortijo, E., 1997. Variability of the North Atlantic thermohaline circulation during the last interglacial period. Nature 390, 154–156.

Alley, R.B., Mayewski, P.A., Sowers, T., Stuiver, M., Taylor, K.C., Clark, P.U., 1997. Holocene climate instability: a prominent, widespread event 8200 yr ago. Geology 25, 483–486.

Anderson, P.M., Lozhkin, A.V., 2001. The Stage 3 interstadial complex (Karginskii/Middle Wisconsinan Interval) of Beringia: variations in paleoenvironments and implications for interpretations. Quaternary Science Reviews 20, 93–125.

Arkhipov, S.A., Bespaly, V.G., Faustova, M.A., Glushkova, O.Y., Isaeva, L.L., Velichko, A.A., 1986a. Ice sheet reconstructions. Quaternary Science Reviews 5, 475–483.

Arkhipov, S.A., Isaeva, L.L., Bespaly, V.G., Glushkova, O.Y., 1986b. Glaciation of Siberia and North-East USSR. Quaternary Science Reviews 5, 463–474.

Bartlein, P.J., Anderson, K.H., Anderson, P.M., Edwards, M.E., Mock, C.J., Thompson, R.S., Webb, R.S., Webb III, T., Whitlock, C., 1998. Paleoclimate simulations for North America over the past 21,000 yr: features of the simulated climate and comparisons with paleoenvironmental data. Quaternary Science Reviews 17, 549–585.

Begét, J.E., 2001. Continuous Late Quaternary proxy climate records from loess in Beringia. Quaternary Science Reviews 20, 499–507.

Berger, G.W., Péwé, T.L., 2001. Last Interglacial age of the Eva Forest Bed, Central Alaska, from thermoluminescence dating of bracketing loess. Quaternary Science Reviews 20, 485–498.

Bespaly, V.G., 1984. Late Pleistocene mountain glaciation in Northeastern USSR. In: Velichko, A.A., Wright, H.E., Barnosky, C.W. (Eds.), Late Quaternary Environments of the Soviet Union. University of Minnesota Press, Minneapolis, pp. 31–33.

Biryukov, V.Y., Faustova, M.A., Kaplin, P.A., Pavlidis, Y.A., Romanova, E.A., Velichko, A.A., 1988. The paleogeography of Arctic shelf and Coastal Zone of Eurasia at the time of the Last Glaciation (18,000 yr B.P.). Palaeogeography, Palaeoclimatology, Palaeoecology 68, 117–125.

Bradley, R.S., 1999. Paleoclimatology: Reconstructing Climates of the Quaternary, 2nd Edition. Academic Press, San Diego, 613 pp.

Brigham-Grette, J., Carter, L.D., 1992. Pliocene marine transgressions of northern Alaska: circumarctic correlations and Paleoclimate. Arctic 43 (4), 74–89.

Brigham-Grette, J., Hopkins, D., 1995. Emergent marine record and paleoclimate of the last interglaciation along the Northwest Alaskan Coast. Quaternary Research 43, 159–173.

Brigham-Grette, J., Hopkins, D.M., Benson, S.L., Heiser, P., Ivanov, V.F., Basilyan, A., Pushkar, V., 2001. Last Interglacial (isotope stage 5) glacial and sea-level history of coastal Chukotka Peninsula and St. Lawrence Island, Western Beringia. Quaternary Science Reviews 20, 419–436.

Briner, J.P., Kaufman, D.S., 2000. Late Pleistocene glaciation of the Southwest Ahklun Mountains, Alaska. Quaternary Research 53 (1), 13–22.

Broecker, W.S., Denton, G.H., 1989. The role of ocean-atmosphere reorganizations in glacial cycles. Geochimica et Cosmochimica Acta 53, 2465–2501.

Calkin, P.E., Wiles, G.C., Gregory, C., Barclay, D.J., 2001. Holocene coastal glaciation of Alaska. Quaternary Science Reviews 20, 449–461.

Clark, P.U., Alley, R.B., Pollard, D., 1999. Northern Hemisphere ice-sheet influences on global climate change. Science 286, 1104–1111.

Coulter, H.W., others, 1965. Map showing the extent of Glaciations in Alaska: US Geological Survey Miscellaneous Geological Investigations Series Map I-415; Scale 1:2,500,000.

Durham, J.W., MacNeil, F.S., 1967. Cenozoic migrations of marine invertebrates thruough the Bering Strait region. In: Hopkins, D.M. (Ed.), The Bering Land Bridge. Stanford University Press, Stanford, CA, pp. 326–349.

Edwards, M.H., Polyak, L., Coakley, B.J., 1999. New perspectives on the Chukchi Cap and Northwind Rise from SCICEX-99 SCAMP data. EOS Transactions, American Geophysical Union 80 (46), 1001.

Einarsson, T., Hopkins, D.M., Doell, R.D., 1967. The stratigraphy of the Tjornes, northern Iceland, and the history of the Bering Land Bridge. In: Hopkins, D.M. (Ed.), The Bering Land Bridge. Stanford University Press, Stanford CA, pp. 312–325.

Elias, S., 2001. Beringian Paleoecology: results from the 1997 workshop. Quaternary Science Reviews workshop 20, 7–13.

Elias, S.A., Hamilton, T.D., Edwards, M.E., Beget, J.E., Krumhardt, A.P., Lavoie, C., 1999. Late Pleistocene environments of the western Noatak basin, northwestern Alaska. Geological Society of America Bulletin 111 (5), 769–789.

Elias, S., Short, S., Birks, H., 1997. Late Wisconsin environments of the Bering Land Bridge. Palaeogeography, Palaeoclimatology, Palaeoecology 136, 293–308.

Elias, S., Short, S., Nelson, C., Birks, H., 1996. Life and times of the Bering land bridge. Nature 382, 60–63.

Felzer, B., 2001. Climate impacts of an ice sheet in East Siberia during the Last Glacial Maximum. Quaternary Science Reviews 20, 437–448.

Gladenkov, Y.B., Barinov, K.B., Basilian, A.E., Cronin, T.M., 1991. Stratigraphy and paleoceanography of Miocene deposits of Karaginsky Island, eastern Kamchatka, USSR. Quaternary Science Reviews 10, 239–245.

Glushkova, O.Y., 2001. Geomorphological correlation of the Late Pleistocene glacial complexes of Western and Eastern Beringia. Quaternary Science Reviews 20, 405–417.

Glushkova, O.Y., 1992. Paleogeography of Late Pleistocene Glaciation of North-Eastern Asia. In: Proceedings of the International Conference of Arctic Margins. Russian Academy of Sciences, Far East Branch. Northeast Science Center, Magadan, pp. 339–344.

Grosswald, M.G., 1998. Late-Weichselian ice sheets in Arctic and Pacific Siberia. Quaternary International 45/46, 3–18.

Grosswald, M.G., 1988. An Antarctic-style ice sheet in the Northern Hemisphere: towards new global glacial theory. Polar Geography and Geology 12, 239–267.

Grosswald, M.G., Hughes, T.J., 1995. Paleoglaciology's grand unsolved problem. Journal of Glaciology 41, 313–332.

Grove, J.M., 1988. The Little Ice Age. Methuen Press, London.

Gualtieri, L., Glushkova, O., Brigham-Grette, J., 2000. Field Evidence for restricted ice extent during the last glacial maximum in the Koryak Mountains of Chukotkta, Far Eastern Russia. Geological Society of America Bulletin, v. 112, n. 7, 1106-1118.

Guthrie, R.D., 2001. Origin and causes of the Mammoth Steppe: a story of cloud cover, woolly mammal tooth pits, buckles, and inside-out Beringia. Quaternary Science Reviews 20, 549–574.

Hamilton, T.D., 1986. Late cenozoic glaciation of the central brooks range. In: Hamilton, T.D., Reed, K.M., Thorson, R.M. (Eds.), Glaciation of Alaska: The Geologic Record. Alaska Geological Society, Anchorage, pp. 9–50.

Hamilton, T.D., 1994. Late Cenozoic glaciation of Alaska. In: Plafker, G., Berg, H.C. (Eds.), The Geology of Alaska: Boulder Colorado, Geological Society of America, Geology of North America, Vol. G-1, pp. 813–844.

Hamilton, T.D., 2001. Quaternary glacial, lacustrine, and fluvial interactions in the western Noatak basin, Northwest Alska. Quaternary Science Reviews 20, 371–391.

Hamilton, T.D., Ashley, G.M., 1993. Epiguruk; a late Quaternary environmental record from northwestern Alaska; with Suppl. Data 9314. Geological Society of America Bulletin 105 (5), 583–602.

Hamilton, T.D., Brigham-Grette, J., 1991. The last interglaciation in Alaska: stratigraphy and paleoecology of potential sites. Quaternary International 10–12, 49–71.

Heiser, P.A, 1998. Extent, timing, and paleogeographic significance of multiple Pleistocene glaciations in the Bering Strait region. Ph.D. Dissertation, University of Alaska, Fairbanks Alaska 132 p.

Heiser, P.A., Roush, J.J., 2001. Pleistocene glaciations in Chukotka, Russia: moraine mapping using satellite synthetic aperture radar (SAR) imagery. Quaternary Science Reviews 20, 393–404.

Hopkins, D.M., 1959. Cenozoic history of the Bering Land Bridge. Science 129, 1519–1528.

Hopkins, D.M., MacNeil, F.S., Merklin, R.L., Petrov, O.M., 1965. Quaternary correlations across Bering Strait. Science 147, 1107–1114.

Hopkins, D.M., 1976b. Quaternary marine transgressions in Alaska. In: Hopkins, D.M. (Ed.), The Bering Land Bridge. Stanford University Press, Stanford, pp. 47–90.

Hughes, B.A., Hughes, T.J., 1994. Transgressions: rethinking Beringian glaciation. Palaeogeography, Palaeoclimatology, Palaeoecology 110, 275–294.

Huston, M.M., Brigham-Grette, J., Hopkins, D.M., 1990. Paleogeographic significance of middle Pleistocene glaciomarine deposits on Baldwin Peninsula, Northwest Alaska. Annals of Glaciology 1, 111–114.

Isayeva, L.L., 1984. Late Pleistocene glaciation of North-Central Siberia. In: Velichko, A.A., Wright Jr., H.E., Barnosky, C.W. (Eds.), Late Quaternary Environments of the Soviet Union. University of Minnesota Press, Minneapolis, pp. 21–30.

Ivanov, V.F., 1986. Quaternary deposits of coastal eastern Chukotka. Far Eastern Science Center, Academy of Sciences of the USSR, Vladivostok, 138 p. (in Russian).

Jordan, J.W., 2001. Late Quaternary sea level change in southern Beringia: post-glacial emergence of the western Alaska Peninsula. Quaternary Science Reviews 20, 509–523.

Karabanov, E.B., Prokopenko, A.A., Williams, D.F., Colman, S.M., 1998. Evidence from Lake Baikal for Siberian Glaciation during oxygen isotope substage 5d. Quaternary Research 50 (1), 46–55.

Kaufman, D.S., 1992. Aminostratigraphy of Pliocene–Pleistocene high sea level deposits, Nome coastal plain and adjacent nearshore area, Alaska. Geological Society of America Bulletin 104, 40–52.

Kaufman, D.S., Brigham-Grette, J., 1993. Aminostratigraphic correlations and paleotemperature implications, pliocene–pleistocene high sea level deposits, northwestern Alaska. Quaternary Science Reviews 12, 21–33.

Kaufman, D.S., Calkin, P.E., 1988. Morphometric moraine analysis of Pleistocene glacial deposits in the Kigluaik Mountains, Northwestern Alaska. Arctic and Alpine Research 20, 273–284.

Kaufman, D.S., Hopkins, D.M., 1986. Glacial history of the Seward Peninsula. In: Hamilton, T.D., Reed, K.M., Thorson, R.M. (Eds.), Glaciation of Alaska: The Geologic Record. Alaska Geological Society, Anchorage, pp. 51–78.

Kaufman, D.S., Calkin, P.E., Whitford, W.B., Przyble, B.J., Hopkins, D.M., Peck, B.J., Nelson, R.E., 1989. Surficial geologic map of the Kigluaik Mountains area, Seward Peninsula, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map 2074.

Kaufman, D.S., Forman, S.L., Lea, P.D., Wobus, C.W., 1996. Age of pre-late Wisconsin Glacial-Estuarine sedimentation, Bristol Bay, Alaska. Quaternary Research 45 (1), 59–72.

Kaufman, D.S., Hopkins, D.M., Calkin, P.E., 1988. Glacial geologic history of the Salmon Lake area, Seward Peninsula. United States Geological Survey Circular 1016, 91–94.

Kaufman, D.S., Walter, R.C., Brigham-Grette, J., Hopkins, D.M., 1991. Age of the Nome River (middle Pleistocene) glaciation, northwestern Alaska. Quaternary Research 36, 277–293.

Kaufman, D.S., Manley, W.F., Forman, S.L., Layer, P.W., 2001. Pre-Late-Wisconsin glacial history, coastal Ahklun Mountains, southwestern Alaska — new amino acid, thermoluminescence and ^{40}Ar/^{39}Ar results. Quaternary Science Reviews 20, 337–352.

Keigwin, L., Gorbarenko, S., 1992. Sea Level, Surface salinity of the Japan Sea, and the Younger Dryas Event in the Northwestern Pacific Ocean. Quaternary Research 37, 346–360.

Keigwin, L., Jones, G.A., Froelich, P.N., 1992. A 15,000 paleoenvironmental record from the Meiji Seamount, far northwestern Pacific. Earth and Planetary Science Letters 111, 425–440.

Kennett, J.P., 1982. Marine Geology, Prentice Hall-Publishers, Englewood, NJ, 813 pp.

Khim, B.K., Krantz, D.E., Brigham-Grette, J., 2001. Stable isotope profiles of Last Interglacial (Pelukian Transgression) mollusks and paleoclimate implications in the Bering Strait Region. Quaternary Science Reviews 20, 463–483.

Kotilainen, A.T., Shackelton, N.J., 1995. Rapid climate variability in the North Pacific Ocean during the past 95,000 yr. Nature 377, 323–326.

Lozhkin, A.V., Anderson, P.M., 1995a. The last interglaciation in Northeast Siberia. Quaternary Research 43, 47–158.

Lozhkin, A.V., Anderson, P.M., Eisner, W.R., Ravako, L.G., Hopkins, D.M., Brubaker, L.B., Colinaux, P.A., Miller, M., 1993. Late Quaternary lacustrine pollen records from Southwestern Beringia. Quaternary Research 39, 314–324.

Mackey, K.G., Fujita, K., Gunbina, L.V., Kovalev, V.N., Imaev, V.S., Koz'min, B.M., Imaeva, L.P., 1997. Seismicity of the Bering Strait region: evidence for a Bering block. Geology 25, 979–982.

Manley, W.F., Kaufman, D.S., Briner, J.P., 2001. Pleistocene glacial history of the southern Ahklun Mountains, southwestern Alaska: soil development, morphometric and radiocarbon constraints. Quaternary Science Reviews 20, 353–370.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1999. Northern hemisphere temperatures during the past millennium: inferences, uncertainties, and limitations American Geophysical Union. Geophysical Research Letters 26 (6), 759–762.

Marincovich Jr., L., Gladenkov, A.Yu., 1999. Evidence for an early opening of the Bering Strait. Science 397, 149–151.

Marincovich Jr., L., Gladenkov, A.Yu., 2001. New Evidence for the age of Bering Strait. Quaternary Science Reviews 20, 329–335.

Mason, O.K., Bowers, P.M., Hopkins, D.M., 2001. The early Holocene Milankovitch thermal maximum and humans: adverse conditions for the Denali complex of eastern Beringia. Quaternary Science Reviews 20, 525–548.

McDowell, P.F., Edwards, M.E., 2001. Evidence of Quaternary climatic variations in a sequence of loess and related deposits at Birch Creek, Alaska. implications for the Stage 5 climatic chronology. Quaternary Science Reviews 20, 63–76.

McPhee, M.G., Stanton, T.P., Morison, J.H., Martinson, D.G., 1998. Freshening of the upper ocean in the Arctic: Is perennial sea ice disappearing? Geophysical Research Letters 25(10), 1729–1732.

Miller, G.H., de Vernal, A., 1992. Will greenhouse warming lead to Northern Hemisphere ice-sheet growth? Nature (London) 355(6357), 244–246.

Mostoller, D., 1997. Relative-age geochronology of Pleistocene glaciations, Tanyurer River Valley, Northeastern Russia. Master's Thesis. University of Massachusetts, Amherst, 56 pp.

Muhs, D.R., Ager, T.A., Begét, J.E., 2001. Vegetation and paleoclimate of the Last Interglacial period. Central Alaska. Quaternary Science Reviews 20, 41–61.

PALE Beringian Working Group, 1999. Paleoenvironmental Atlas of Beringia presented in Electronic Form. Quaternary Research 52, 270–271. (http://www.ngdc.noaa.gov/paleo/pale/atlas/beringia/index.html).

Parkinson, C.L., Cavalieri, D.L., Gloersen, P., Zwally, H.J., Comison, J.C., 1999. Arctic sea ice extent, areas, and trends, 1978–1996. Journal of Geophysical Research (Oceans) 104 (C9), 20837–20856.

Peck, B.J., Kaufman, D.S., Calkin, P.E., 1990. Relative dating of moraines using moraine morphometric and boulder weathering criteria, Kigluaik Mountains. Boreas 19, 227–239.

Peltier, W.R., 1993. Time-dependent topography through a glacial cycle. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series #93-015, NOAA/NGDC Paleoclimatology Program, Boulder, CO, USA. (http://www.ngdc.noaa.gov/cgi-bin/paleo/pelttopo.pl).

Peltier, W.R., 1994. Ice age paleotopography. Science 265, 195–201.

Péwé, T.L., 1955. Origin of the upland silt near Fairbanks, Alaska. Geological Society of America Bulletin 66, 699–724.

Péwé, T.L., 1975. Quaternary geology of Alaska: U.S. Geological Survey Professional Paper 835, 145 pp.

Péwé, T.L., Berger, G.W., Westgate, J.A., Brown, P.M., Leavitt, S.W., 1997. Eva Interglaciation Forest Bed, unglaciated East-Central Alaska: global warming 125,000 yr ago. Geological Society of America Special Paper 319, 54 pp.

Polyak, L., Edwards, M.H., Jacobsson, M., Coakley, B.J., 1999. Glacial scouring in the Deep Arctic Ocean: Evidence from the Chukchi Plateau and the Lomonosov Ridge. EOS Transactions, American Geophysical Union 80 (46), 1000–1001.

Preece, S.J., Westgate, J.A., Gorton, M.P., 1992. Compositional variation and provenance of late Cenozoic distal tephra beds, Fairbanks area, Alaska. Quaternary International 13/14, 97–102.

Pushkar, V.S., Roof, S.R., Cherepanova, M.V., Hopkins, D.M., Ivanov, V.F., Brigham-Grette, J., 1999. Paleogeographic and paleoclimatic significance of diatoms from middle Pleistocene marine and glaciomarine deposits on Baldwin Peninsula, Northwestern Alaska. Paleogeography, Paleoclimatology, Paleoecology 152, 67–85.

Rea, D.K., Basov, I.A., Scholl, D.W., Allan, J.F. (Eds.), 1995. Proceedings of the Ocean Drilling Program: Scientific Results. Leg 145, College Station, Texas, 711 pp.

Reason, C.J.C., Power, S.B., 1994. The influence of the Bering Strait on the circulation in a coarse resolution global ocean model. Climate Dynamics 9, 363–369.

Roof, S.R., 1995. Sedimentology, stratigraphy, and paleoclimatic significance of middle Pleistocene marine, glaciomarine, and glacial deposits in Kotzebue Sound Region, Northwestern Alaska, Ph.D. dissertation, Department of Geology and Geography, University of Massachusetts, Amherst, 169 pp.

Schweger, C.E., 1982. Late Pleistocene vegetation of eastern Beringia — pollen analysis of dated alluvium. In: Hopkins, D.M., Matthews Jr., J.V., Schweger, C.E., Young, S.B. (Eds.), Paleoecology of Beringia. Academic Press, New York, pp. 95–112.

Shaffer, G., Bendtsen, J., 1994. Role of the Bering Strait in controlling North Atlantic Ocean circulation and climate. Nature 367, 354–357.

Sher, A., 1995. Is there any real evidence for a huge shelf ice sheet in East Siberia? Quaternary International 28, 39–40.

Sher, A., 1997. Yedoma as a store of paleoenvironmental records in Beringia. Beringian Paleoenvironments Workshop, Program and Abstracts, Florissant, Colorado, September 20–23, pp. 140–144.

Svendsen, J.I., Astakhov, V.I., Bolshiyanov, D.Yu., Demifov, I., Dowdeswell, J.A., Gataullin, V., Hjort, Ch., Hubberten, H.W., Larsen, E., Mangerud, J., Melles, M., Moller, P., Saarnisto, M., Siegert, M.J., 1999. Maximum extent of the Eurasian ice sheets in the Barents and Kara Sea region during the Weichselian. Boreas 28 (1), 234–242.

Thompson, L.G., 1992. Ice core evidence from Peru and China. In: Bradley, R.S., Jones, P.D. (Eds.), Climate Since A.D. 1500. Routledge, London, pp. 517–548.

Vermeij, G.J., 1991. Anatomy of an invasion: the Trans-Arctic interchange. Paleobiology 17 (3), 281–307.

Vinnikov, K.Y., Robock, A., Stouffer, R.J., Walsh, J.E., Parkinson, C.l., Cavalieri, D.J., Mitchell, J.F.B., Garrett, D., Zakharov, V.F., 1999. Global Warming and Northern Hemisphere Sea Ice Extent. Science 286, 1934–1939.

Westgate, J., Stemper, B., Pewe, T., 1990. A 3 m.y. record of Pliocene–Pleistocene loess in interior Alaska. Geology 18, 858–861.