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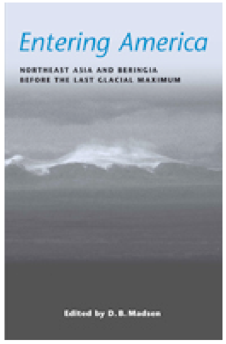

Entering America

Northeast Asia and the Beringia Before the Last Glacial Maximum

$50.00

Edited by D. B. Madsen
400 pp., 6 x 9
104 illustrations
Cloth $50.00
ISBN 0-87480-786-7
Archaeology / Anthropology

Where did the first Americans come from and when did they get here? That basic question of American archaeology, long thought to have been solved, is re-emerging as a critical issue as the number of well-excavated sites dating to pre-Clovis times increases. It now seems possible that small populations of human foragers entered the Americas prior to the creation of the continental glacial barrier. While the archaeological and paleoecological aspects of a post-glacial entry have been well studied, there is little work available on the possibility of a pre-glacial entry.

Entering America seeks to fill that void by providing the most up-to-date information on the nature of environmental and cultural conditions in northeast Asia and Beringia (the Bering land bridge) immediately prior to the Last Glacial Maximum. Because the peopling of the New World is a question of international archaeological interest, this volume will be important to specialists and nonspecialists alike.

"Provides the most up-to-date information on a topic of lasting interest."
—C. Melvin Aikens, University of Oregon

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Paleoenvironmental Conditions in Western Beringia before and during the Last Glacial Maximum

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Introduction

The landscapes of Alaska, the Yukon, and Northeastern Russia are unique to the Arctic, given the proximity of these regions to the shallow seas that divide them. Early scientific expeditions to the North Pacific and the Bering Strait never could have imagined that beneath the treacherous waters of the shallow Bering and Chukchi Seas lay a vast, unexplored former land bridge. This entire region, from roughly the Lena River of northeastern Siberia to the Mackenzie River in the Yukon, is known as Beringia (Figure 2.1), and both the land and the sea in this region are critically important to Earth's climate system. Only 20,000 years ago, during the last glaciation, the land bridge separated the deeper Bering Sea and North Pacific Ocean from the Arctic Ocean by more than 10a thousand kilometers of herb-dominated tundra. This barren landscape was the proverbial bridge across which early people and many other types of mammals presumably entered the New World. The Bering and Chukchi Seas are floored by some of the most extensive continental shelves on Earth, and their low bathymetric gradient makes them sensitive to relative sea level changes. Acting at times as a continent and at other times as an ocean gateway, due to late Cenozoic fluctuations in glacioeustatic sea level, the region has been a bottleneck to the migration of terrestrial and marine biota. Inspired by the writings of Hultén (1937), the concept of a vast emergent land bridge during the last glaciation was conceived and nurtured by David Hopkins (1959, 1967, 1973, 1982; Hopkins et al. 1965), who provided the impetus for interdisciplinary science on Beringian paleogeography and paleoenvironmental history in North America as well as in Russia.

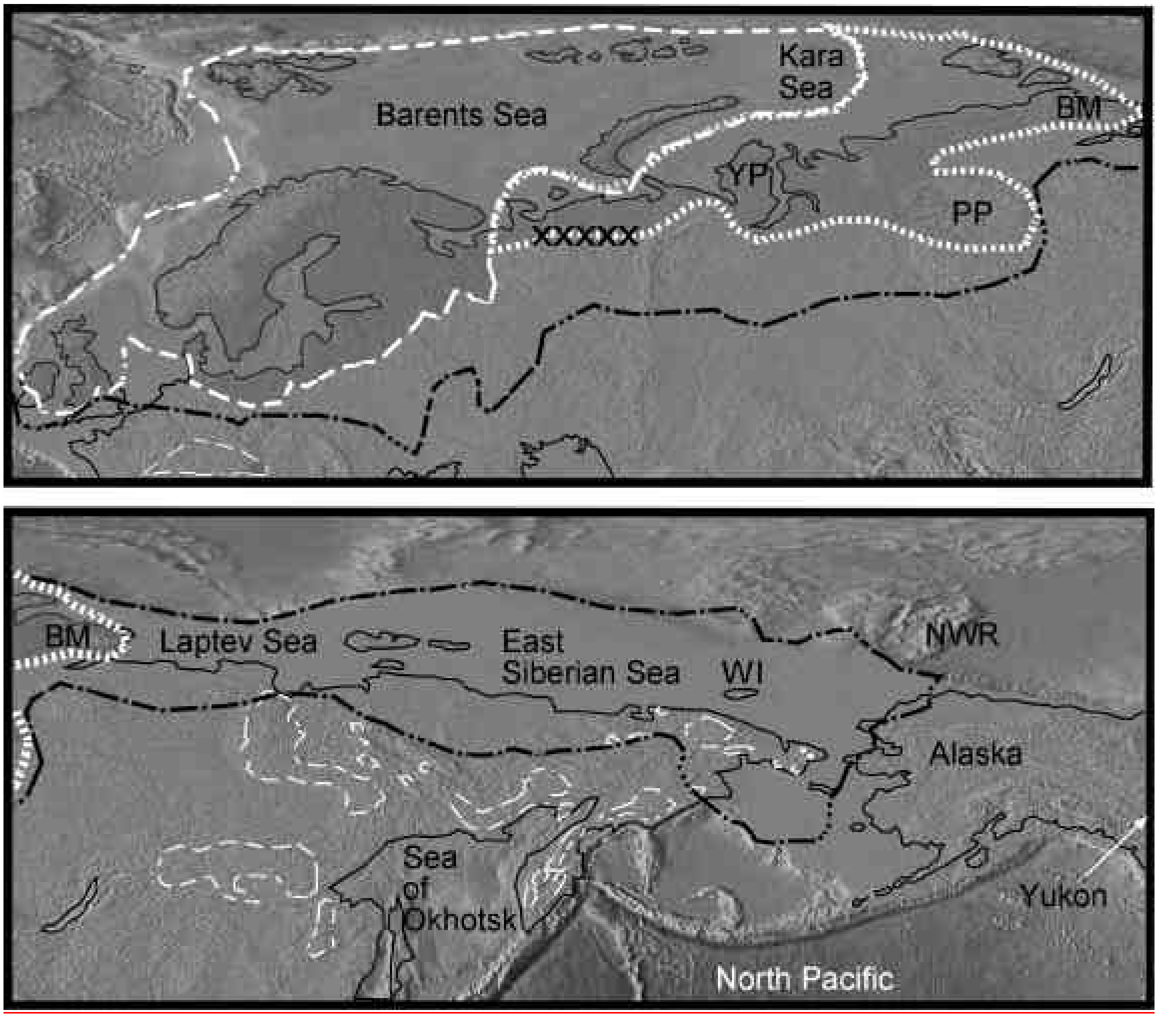

Figure 2.1: Western Arctic geography showing (top panel) the extent of late Pleistocene ice sheets including the coalesced Scandinavian Ice Sheet, the Barents Sea Ice Sheet and Kara Sea Ice Sheets (Svendsen et al. 1999). The white lines show the Zyryan (early Weichselian) ice extent with ice over the Byrranga Mountains (BM) and Putorana Plateau (PP). Ice retreated to the Markhida moraine (black Xs) by 60 ka BP (Mangerud et al. 2001). The LGM (MIS 2) ice limit was in the Kara Sea leaving the Yamal Penisula (YP) ice-free since 45 ka BP. The black dot and dashed line represents Grosswald's LGM ice limit. Over panel shows eastern Siberia and Beringia. Small white dashed lines show limited ice over the local mountains during the LGM vs. Grosswald's limits. WI= Wrangel Island; NWR=North Wind Ridge in Arctic Ocean. Detailed ice limits for western Beringia are shown in Figure 2.6).

Glacial-interglacial cycles imposed on the Bering Strait region are some of the most radical changes in paleogeography documented in the Northern Hemisphere, which in turn helped drive equally radical changes in Arctic climate. Today Beringia is dominated by weather patterns driven largely by the Siberian High and Aleutian Low, with complex interactions of the upper-level east Asian trough and western North American ridge and the surface Aleutian low- and Pacific subtropical high pressure systems (Bartlein et al. 1998; Mock et al. 1998). During most winters, sea ice generally extends across the northern half of the Bering Sea for a few months before retreating northward to the edge of the Chukchi shelf in summer. Unlike the warm Gulf Stream that enters the Barents Sea from the North Atlantic Ocean, the Pacific Kurosiwa western boundary current is deflected eastward from its northward path by the Aleutian Islands. preventing the penetration of warmer waters. Only the Alaskan Current flows through the deep channels between the Aleutians to warm the eastern side of the Bering Strait while delivering nutrient-rich waters to the Chukchi Sea (Weaver et al. 1999).

The modern vegetation of western Beringia (i.e., northeastern Siberia; eastern Beringia includes Alaska and part of the Yukon) is a mix of larch (*Larix dahurica*) forest and shrub tundra (Anderson and Lozhkin 2002). Valleys and mid-elevations in the mountainous interior support larch forests with understory shrubs of dwarf stone pine (*Pinus pumila*), shrub birch (*Betula middendorffii, B. exilis*), willow (*Salix*) species, heaths (Ericales), and a ground cover dominated by fruticose lichens. Coastal forests also include tree birch (*Betula platphylla, B. lanata*). Riparian communities in the mountains and southern coastal areas consist of *Chosenia macrolepis*, *Populus suaveolens,* and alder shrubs (*Duschekia fruticosa*), the latter also occurring with *Pinus pumila* to form dense shrub tundra immediately above altitudinal tree limit. Tundra dominates northernmost and westernmost regions. Vegetation of the northern coasts is dominated by graminoids (Poaceae-Cyperaceae, grasses-sedges) with prostrate shrubs of birch and willow. In neighboring uplands and eastern lowlands (e.g., Anadyr-Penzhina lowland), the vegetation is an erect shrub tundra with birch, willow, alder, and/or heaths being locally abundant. Dwarf stone pine is present but not common. Southernmost Chukotka supports a high shrub tundra of stone pine and alder.

The nature of Beringian landscapes during the last glacial maximum (LGM, marine isotope stage 2, MIS 2) and, to a lesser extent, the preceding interstadial (marine isotope stage 3, MIS3) has been the source of controversy in recent decades. The *productivity paradox* propelled much research on both sides of Bering Strait in the 1970s and early 1980s by paleoecologists and paleontologists attempting to understand a vegetation that was inferred by many to be tundra, yet was capable of supporting the foraging needs of the late Pleistocene megafauna across Beringia (see papers in Hopkins et al. 1982). Although no longer a main thrust of Beringian research, the issue remains open for debate. This grazing megafauna included mammoth, steppe bison, saiga, woolly rhinoceros, and horses, which could have been supported by arid, grass- and forb-dominated ecosystems (Guthrie 1989). Yurtsev (2001) argued for a greater diversity of herbaceous vegetation than found on the modern landscape. Continued research suggested that at the finest spatial scales, Beringia during the LGM likely existed as a "habitat mosaic" controlled by local factors such as topography and drainage (Anderson and Brubaker, 1994; Elias, Short, and Hirks 1997; Schweger, 1982, 1997).

The extent of glacial ice across Arctic Russia during the LGM has also been the source of much controversy over the last decade. The controversy comes largely from the hypothesis of a Beringian or East Siberian Sea ice sheet (Grosswald 1988, 1998; Grosswald and Hughes 1995, 2002). This theoretical ice sheet (see Figure 2.1) was thought to have emanated southward from the East Siberian Sea shelf, covering all of Chukotka Peninsula and, in some versions, terminating at the edge of the Bering shelf as a Ross Sea like ice shelf that calved into the North Pacific through the Aleutians (Grosswald and Hughes 1995). Futhermore, Hughes and Hughes (1994) used the notion to suggest that a Beringian ice sheet was *required* to explain why early foragers are not found in North America until after 12ka. In contrast to these hypothetical ideas, much earlier Russian literature (see Arkhipov et al. 1986a, 1986b) and a growing body of new field evidence from Chukotka and Wrangel Island contradicts this hypothesis. Rather, geomorphic and stratigraphic evidence demonstrates that regional glaciation was, in fact, limited and characterized by valley and cirque glaciation in local mountain ranges. Human foragers likely had a variety of migration routes along interior valleys or broad lowlands in the north and in central Beringia, unencumbered by large ice sheets. They may have also followed the latitudinally vacillating southern shore of the land bridge.

This paper provides an overview of what is known of the paleoenvironmental conditions of western Beringia (Figure 2.2, i.e., northeast Siberia) during MIS 3 and MIS

2. This region is exceptional in that it contains some of the largest contiguous land areas in the Arctic to have escaped continental-style glaciation (see fig 2.1). Consequently, continuous lake records, peats, loess, and alluvium spanning MIS 3 and MIS 2 from this region provide the best framework for comparing regional climate change with influences including changes in insolation, sea level, and the size and height of distant ice sheets. This background sets the stage for considering the habitats and conditions human foragers would have encountered while migrating into Alaska before the LGM. Admittedly, there is much we still do not know. However, the most influential factor affecting western and central Beringia was probably the position of large ice sheets in the circumarctic combined with regional changes in sea level and its maritime influence. This was especially true given that this vast landscape was positioned "downwind" of large ice sheets in Scandinavia and the Eurasian north, themselves creating widespread aridity during full glacial conditions (Siegert et al. 2001; see Figure 2. 1). Moisture stripped from the westerlies by these ice sheets left little but strong dry winds to sweep the landscapes of northeastern Russia, though this view may be oversimplified. Today the modern westerlies interact with mountains in Mongolia, the Urals, and the East Siberian Sea to provide precipitation to areas north of 60 degrees (Mock 2002). Moreover, there are issues related to circulation features shifting seasonally today and likely in the past that influence seasonal temperature, which also interacts with effective moisture.

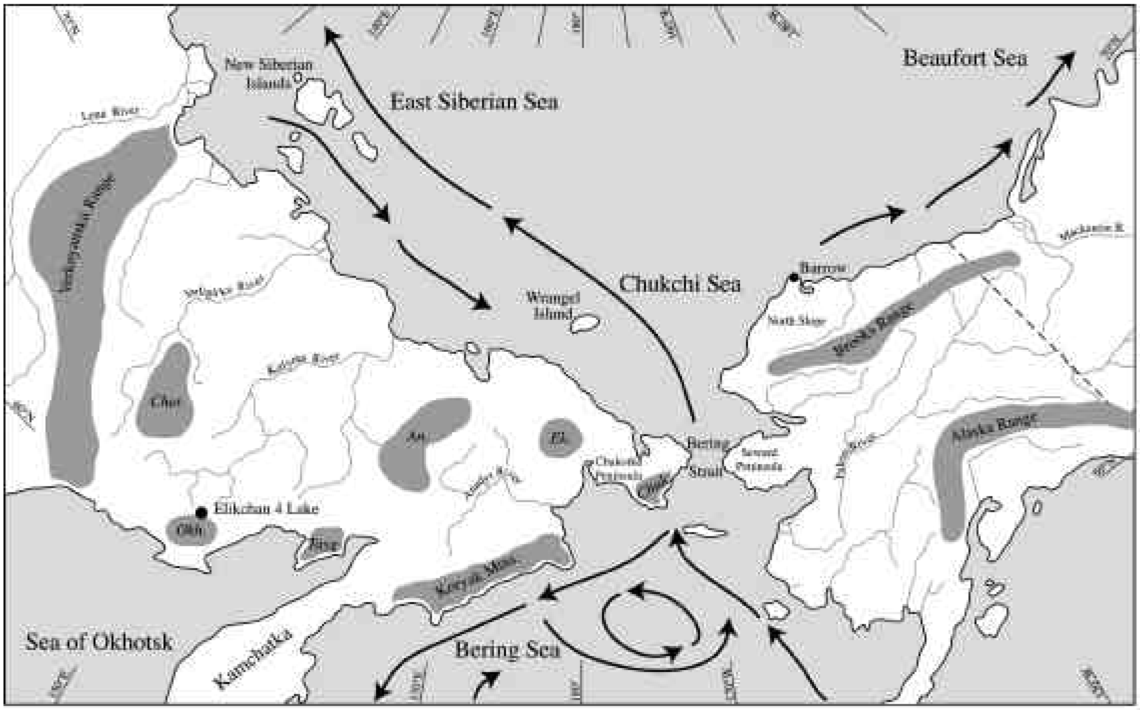

Figure 2.2: Regional map of Beringia with local mountain systems identified; Chersky (Cher); Okhotsk (Okh),Taygonoss (Tayg), Anyui (An), Ekityki (Ek), Chukotsk (Chuk) and placenames. Major ocean surface currents are shown schematically.

Sea-Level History and Millennial Scale Change in a Global Context

The climate and sea-level history of the Bering Strait are fundamentally linked to the global climate system. This ocean-atmosphere-terrestrial system can be influenced by external forcings in ways that create both linear and non-linear responses that propagate through the system on different temporal and spatial scales. While systemic changes in the North Atlantic region might be recorded globally, one is not always sure what the response time might be in any particular depositional system (lake cores, marine cores, ice cores, etc.) from a far field location. If the response time is rapid, one might infer a teleconnection due to rapid mixing in the atmosphere. If the response is lagged by a few thousands years, one might, for example, infer a teleconnection due to oceanic mixing or transient ice sheet growth or decay. Moreover, not all paleoclimate proxies (e.g., the migration of treeline, as recorded by the deposition of arboreal pollen) are as sensitive as others (e.g., ice core $\delta^{18}O$) to rapid climate change. Hence, if an event is not recorded at all, it implies either that a particular site was not sensitive, that it was not impacted, or that the proxy measured is insensitive. Part of the point here depends on temporal and spatial scales, both of which are completely intertwined with sedimentation rates and limitations in the geochronology.

The δ^{18}O record of temperature change over the Greenland ice sheet suggests that the North Atlantic experienced repeated episodes of rapid climate change in MIS 3 (60-28 ka cal yrs BP or 57-25 ka 14C yrs BP) and MIS 2 (28-12 ka cal yrs BP or 25-11 ka 14C yrs BP) (Figure 2.3). Shifts in δ^{18}O on the order of 4 to5 percent suggest rapid increases in temperature of nearly 6 ^{o}C, with each warm period lasting about 750 years. These events recorded in the ice cores, termed Dansgaard/Oeschger events, are found not only in the Greenland ice sheet but also in high-resolution marine records in the Santa Barbara Basin off California (Behl and Kennett et al. 1996), the Caribbean Sea's Cariaco Basin (Hughen et al. 1996.), the Arabian Sea (Schultz, von Rad, and Erlenkeuser 1998), and most recently in the Sea of Okhotsk (Nurenberger et al. 2003). The recognition of these events as nearly synchronous in a number of widepread locations implies that these were global in nature and a so-called fingerprint of large-scale ocean-atmosphere coupling (Bard 2002). The real cause of these events is still debated. However, Broecker and Hemming (2001) and Bard (2002) among others suggested they were likely the result of major and abrupt reorganizations of the ocean's thermohaline circulation.

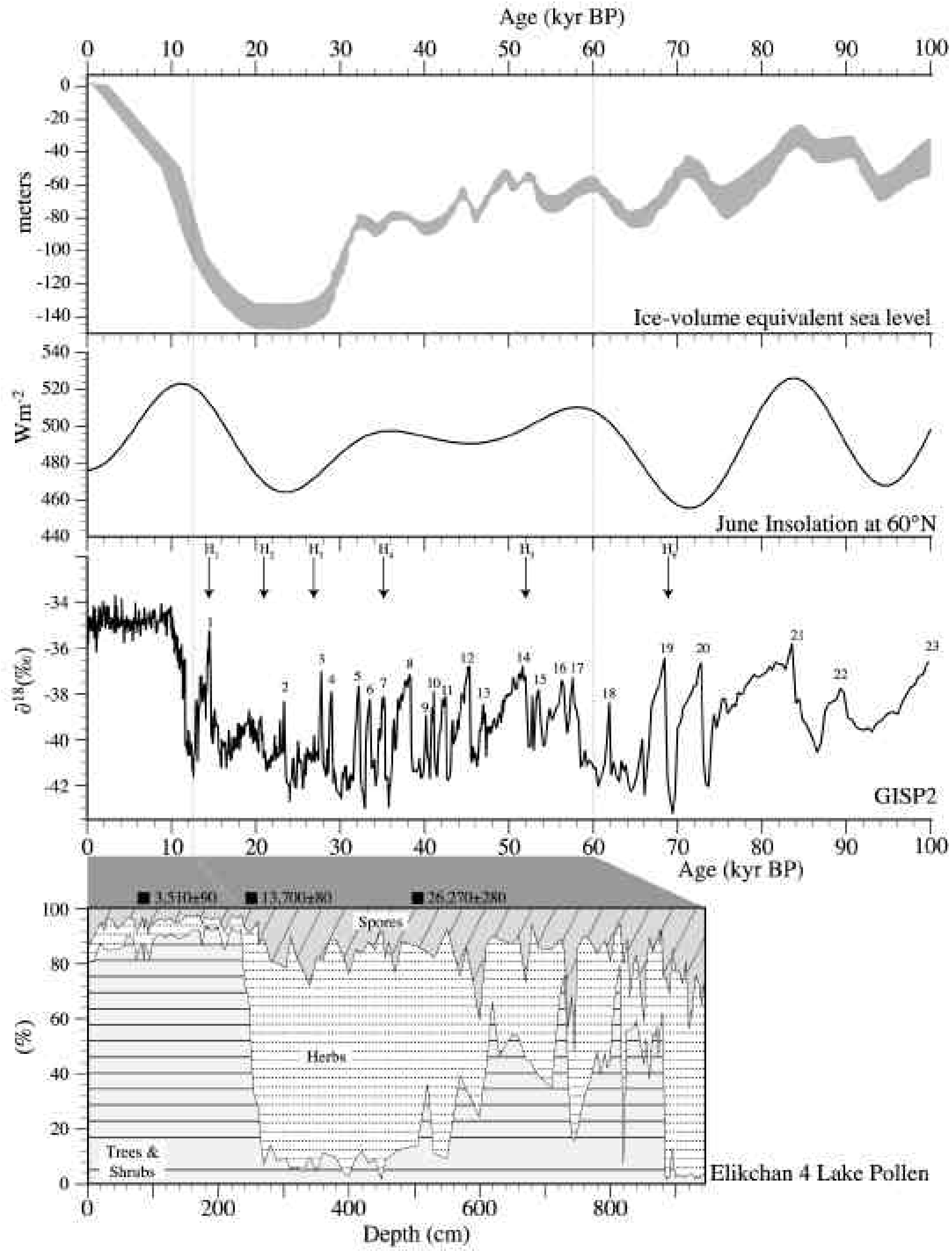

Figure 2.3. Correlation of global sea level curve (Lambeck et al. 2002), northern hemisphere summer insolation (Berger and Loutre, 1991,) and the Greenland Ice Sheet d^{18}O record (Grootes et al. 1993), ages all given in calendar years. The GISP2 record also shows the timing of Heinrich events (H1, H2 etc.) and numbered Dansgaard/Oscheger events. The bottom panel shows temporal changes in the percentages of the main taxa at Elikchan 4 Lake (located Figure 2.2). The base of this core is roughly 60 ka BP (Lozhkin and Anderson, 1996), acknowledging that beyond about 15ka, 14C ages are about 3ka younger than calendar years. Note that lake core axis is depth, and not time.

Superimposed on these North Atlantic Dansgaard/Oeschger events are so-called Heinrich events, representing the periodic collapse of the Laurentide ice sheet over Hudson's Bay and Baffin Island, when armadas of ice bergs and meltwater entered the North Atlantic (Heinrich 1988). In the last 65,000 years, this happened six times, at ca. 65ka, 45 ka, 38 ka, 30 ka, 22 ka, and 16 ka (calendar years), causing extreme cooling, at least in the Atlantic sector of the Northern Hemisphere (see Figure 2.3). Cold Heinrich events appear to correspond in time with cold episodes in Florida (seen as alternating episodes of pine and oak pollen in Tulane Lake [Grimm et al. 1993]), with periods of marine and terrestrial cooling in the western Mediterranean (Bard 2002), and in the Atlantic near Portugal and Spain (as seen in alkenone records [Sicre et al. 2002]) and in marine sediments offshore of Brazil, on the Amazon Fan (as recorded by Fe/Ca ratios [Arz, Patzold, and Wefer 1998]). There is still considerable debate about whether the Scandinavian and Barents Sea ice sheets also partially collapsed at the same time. Based on asynchronous ice-rafted debris (IRD) events, Dowdeswell et al. (1999) argue that ice sheets in the Nordic seas did not exhibit unstable behavior. But Volker (1999) and Van Kreveld et al. (2000) have demonstrated with high-resolution AMS dating that IRD events from the Irminger, Iceland, and Norwegian Seas were coeval with North Atlantic Heinrich events. Knies et al. (2001) show similar IRD events from the northern Barents and Kara Seas, suggesting that frequent iceberg discharges from the Barents ice sheet were coincident with Heinrich layers H2, H3, and H4 (22 ka, 30 ka, and 38 ka, cal yrs BP, respectively). This correspondence is critical because it implies similar cooling over a large region and/or linkage with ice sheet fluctuations through small sea-level events during MIS stages 3 and 2 (Bond and Lotti 1995; Elliot et al. 1998, Knies et al. 2001).

The implications for Beringia, lying downwind of thermohaline convection and the Scandinavian and Eurasian ice sheets, are that fluctuations of the Northern Hemisphere ice sheet in area and elevation, probably had an impact on regional vegetation and aridity. Moreover, these fluctuations likely caused the rapid migration of shorelines and encroachment of the sea across the flat Bering and Chukchi shelves during periodic ice sheet collapse. The encroachment of the sea would have locally cooled near-shore sites by changing summertime gradients in temperature and moisture.

Despite decades of paleoenvironment study across Beringia, the region still lacks an accurate relative sea level (RSL) curve for the past full glacial/interglacial cycle; this scientific plum is the focus of ongoing research (Brigham-Grette, Keigwin, and Driscoll 2003; Dalton 2003). Nevertheless, estimates of global sea level for the past 135,000 years come from the oxygen isotope records in marine cores as well as uplifted coral terraces from far field tropical sites unaffected by glacioisotatic influences (Figure 2.4). Terraces on the Huon Peninsula in Papua New Guinea (Chappell et al. 1996) and on Barbados (Fairbanks 1989; Bard et al. 1990, 1993) provide some of the most widely used indices of eustatic change. Lambeck,Yokoyama, and Purcell (2001) have recently combined coral terrace sea level data from seven well-known sites (including Huon Peninsula and Barbados) to develop various composite eustatic sea levels curve for different time intervals (see Figure 2.4). Their data suggest rapid oscillations of sea level between –80 and –55 m from 60-30 ka cal years. BP (~57-27 ka 14C yrs BP), with the largest drop of an additional 50 m in less than a 1000 yrs occurring ca. 30 ka cal yrs. BP (27 ka 14C yrs BP), near the beginning of MIS 2. Given the flat, broad nature of the Bering and Chukchi shelves, such fluctuations in sea level during MIS 3 would mean that vast portions of the Bering Strait would have been repeatedly submerged, resulting in rapid changes in the position of shorelines (Figure 2.5). Changes of this order would have bifurcated parts of central Beringia while producing dramatic local shifts in continentality and associated maritime moisture convergence (cf. Manley 2002; Beringian Atlas movie of the last 20 ka at www.ngdc.noaa.gov/paleo/pale/atlas/beringia/ lbridge.html).

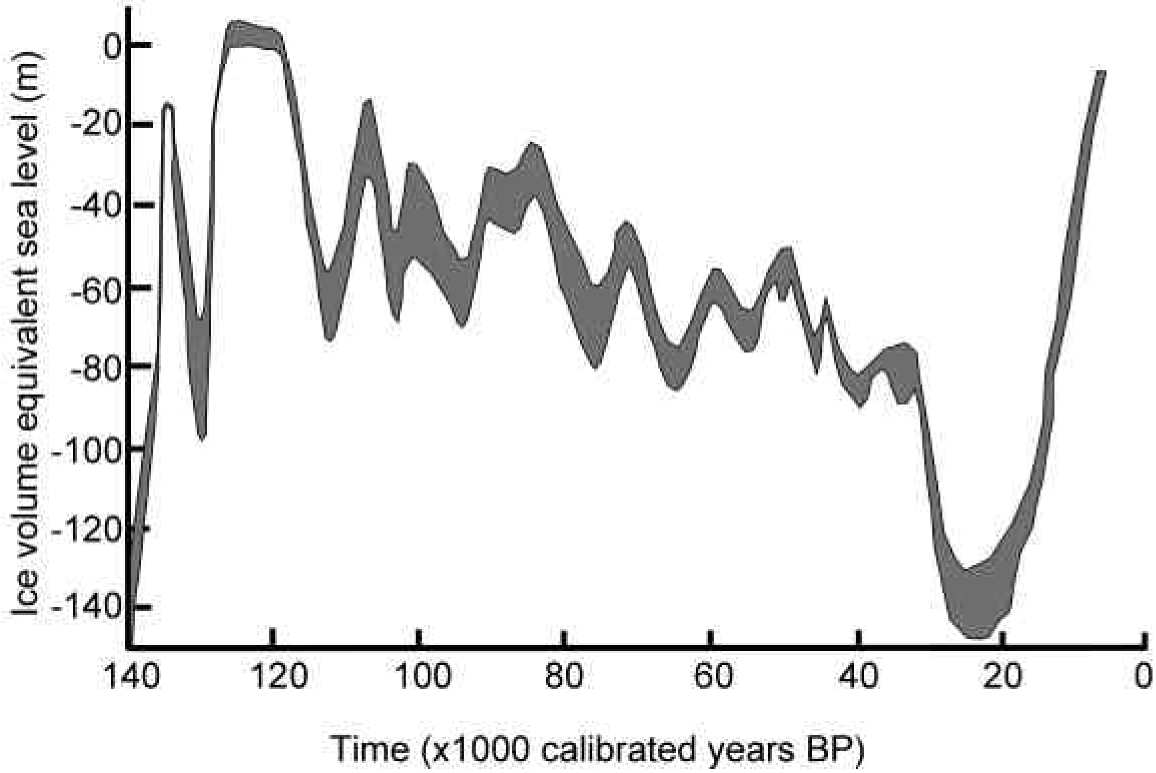

Figure 2.4. Composite ice-volume equivalent sea-level curve of Lambeck et al.(2002) based on well-documented sea-level data from six sites: Papau New Guinea, northwest Australia, Barbados, Tahiti, New Zealand, and Sunda Shelf off Vietnam. Relative sea level data for Beringia discussed in text.

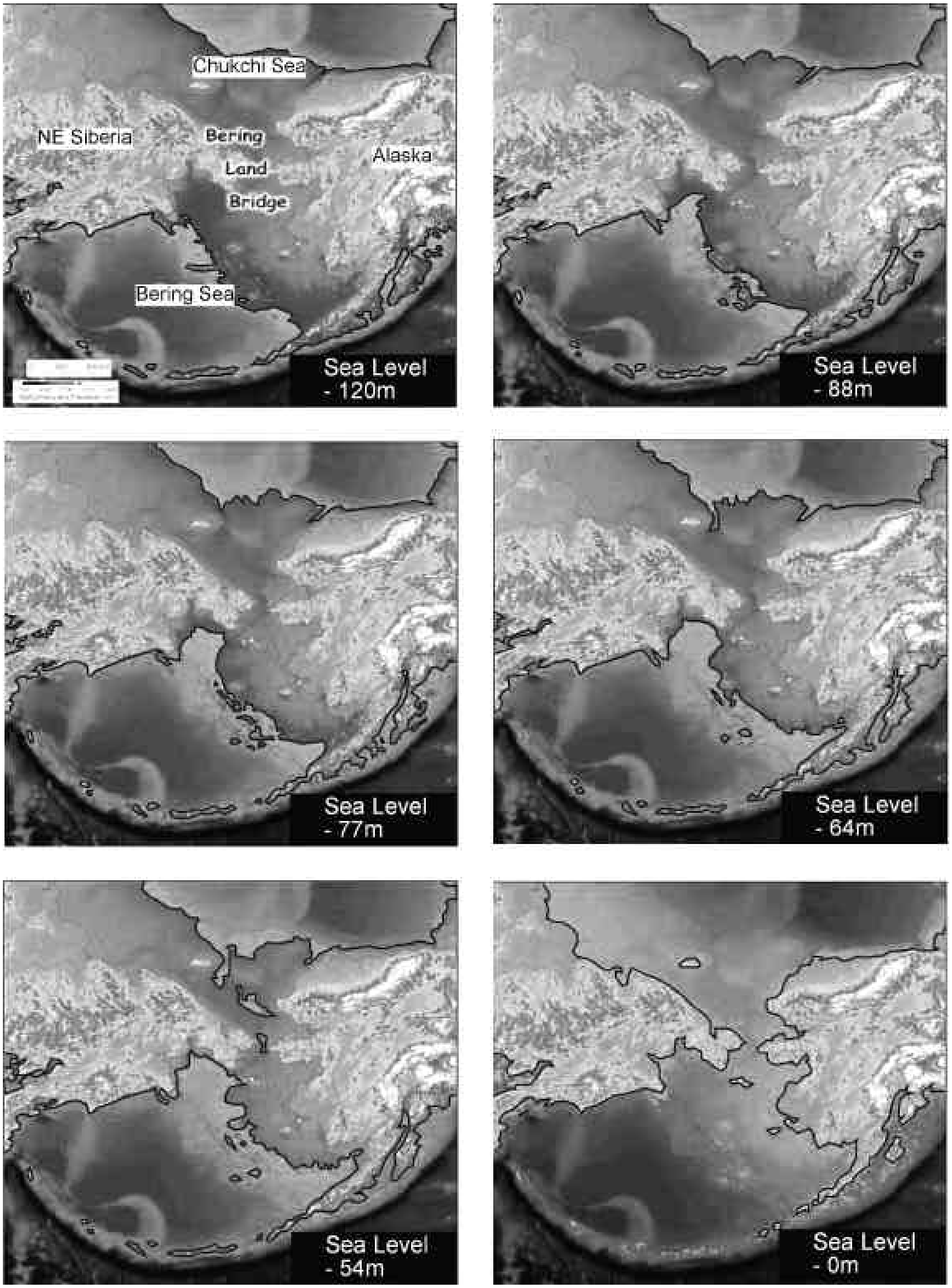

Figure 2.5. Schematic sea level reconstructions at modern, –54m, -64m, -77m and –88m, and -120m based on Manley (2002) without compensation for post-glacial sedimentation or tectonic influences.

The sea level history of Beringia probably differs somewhat from these tropical estimates (Lozhkin 2002) because eustatic sea level change varies spatially due to glacio- and hydrostatic adjustments as well as tectonic effects (Mackey et al. 1997). For example, global eustatic sea level during the LGM dropped to somewhere in the range of –125 to –135 m (Fairbanks 1989; Milne, Mitrovica, and Schrag, 2002), but locally sea level fell to about -90m on the eastern Bering Shelf (Knebel, Creager, and Echols 1975) and to about –100 to –90m in the western Bering Sea offshore of Chukotka (Ivanov 1986; Lozhkin 2002). In the Beaufort Sea, glacial shorelines are interpreted at a depth of –99 m, based on seismic data off Barrow, but deepen to -116m near the Canadian/Alaskan border (Dinter, Carter, and Brigham-Grette 1990). In the Canadian Beaufort Sea, RSL during the LGM was at least –140m (Blasco et al. 1990; Hill et al. 1985). Just how long sea level remained at its maximum low during the LGM is not clear. However, Lambeck, Yokoyama, and Purcell (2002) suggested that maximum ice volumes were approached by 30 ka cal years BP and increased only slightly over the next 10,000 years. If that is true, the Bering land bridge was at its widest configuration of nearly 1000 km for almost 10 millennia.

Yokoyama et al. (2000) suggest that sea level started to rise due to glacial melting as early as 19,000 cal years BP ago with only a slow rise of as little as 3.3 mm/year between 19 and 16 ka cal years. BP (Lambeck, Yokoyama, and Purcell 2002). Global sea level rose more quickly after 16 ka cal years BP, but an accurate post-glacial sea level history for Beringia awaits the results of hundreds of promising marine cores obtained from the Bering Strait in 2002. Hopkins' (1979) early summary called for flooding of the Bering Strait (-50m) by 15.5 ka 14C years BP (~ 18 ka cal yrs BP), with gradual submergence to -30m by 12 ka 14C years BP (~14 ka cal yrs BP) and -12m by 10ka 14C years BP (~ 11 ka cal yrs BP) based on bulk radiocarbon ages from a variety of sites. Elias, Short, and Phillips (1992), Elias et al. (1996) and Elias, Short, and Birks (1997) updated estimates of post-glacial sea level rise by Creager and McManus (1965) with new maximum age estimates of 11,000 14C years BP (~12.5 -13 ka cal yrs BP) for inundation of the Chukchi shelf at about -50 m, slightly earlier in time than indicated by the Lambeck et al. (2002) composite curve. These new age estimates are significant because they suggest that the shrinking land bridge was partially emergent 3,800 years longer than previously thought. However this conclusion is based on only two dates of terrestrial material from the Chukchi Sea. Submergence of the land bridge shortly after 11ka 14C years BP (12.5-13 ka cal yrs BP) is indirectly supported by evidence for the migration of endemic Pacific mollusks and the onset of seasonal whale migration to the Arctic between ~10 and 10.5ka 14C years BP (or ~11-11.5 ka cal yrs. BP; Dyke, Dale, and McNeeley 1996; Dyke, Hooper, and Savelle 1996).

While rates of post-glacial sea level rise are poorly known, even less is known about changes in sea ice during MIS 3 and 2. Knowing the history and extent of sea ice is important because permanent sea ice prevents latent heat exchange between the sea and atmosphere (and hence the surrounding land), perhaps affecting seasonal ocean salinity and stratification, and because it changes albedo. Sea-ice characteristics also may have influenced the way human foragers would have made use of marine resources. Most of what we know about the Bering Sea in the latest Pleistocene is from studies of siliceous microfossils. These investigations indicate that during the LGM, the sea was colder and sea ice persisted for as much as nine months per year (Morley and Robinson, 1986; Sancetta 1992; Sancetta et al. 1985; Sancetta and Robinson 1983). At the same time, the Arctic Ocean was locked with persistent perennial ice (Phillips and Grantz, 1997; Poore, Phillips, and Riech 1993; Speilhagen et al. 1997). Submergence of a large part of the land bridge, perhaps shortly after 11ka ^{14}C years. BP (12.8 ka cal yrs BP), coincided with the well-known rise in Northern Hemisphere insolation (7% >present by 9 ka ^{14}C yrs BP, or ~11 ka cal yrs BP; Kutzbach et al. 1998)), a factor that numerical climate models suggest may have significantly delayed the formation of sea ice in autumn (Kutzbach and Gallimore 1988; Mitchell, Grahame, and Needham 1988). This early Holocene warming lasted until ca. 9- 8.5 ka ^{14}C years BP (~10 ka cal yrs, Birch Period in Hopkins 1982; Lozhkin 1993) and is reflected in a reduction of sea ice at least throughout parts of the Canadian Arctic (Dyke, Dale, and McNeeley 1996; Dyke, Hooper, and Savelle 1996).

Physical Geography and Stratigraphy of Western Beringia

The large physiographic differences that exist between eastern and western Beringia clearly modify the response of these regions to climate variations on different scales (see Figure 2.2). The most important physical difference is that western Beringia is topographically much more complex and rugged. Eastward of the Taymyr Peninsula, the traditional reaches of central Arctic Siberia represent broad tectonic lowlands dissected by the large, northward-flowing rivers of the Lena, Indigirka, and Kolyma and punctuated by steep linear mountain ranges reaching maximum elevations of 2,000-3,000 meters and broad mountainous uplands to 1,000-2,000 meters. Broad tectonic depressions also characterize the northern coast of the Sea of Okhotsk and regions of the Anadyr River.

Broad, flat-to-undulating coastal plains of fluvial and eolian sediment and ice-rich permafrost stretch northward from the mountains to the Laptev and East Siberian Sea. Pervasive periglacial processes overprint the regional geomorphology with thermokarst and thick complexes of syngenetic ice wedges (Sher et al. 1979). The surficial deposits of this landscape are known to many Russian researchers as *yedoma*, consisting of organic-rich and inorganic silt and sand, thought to be of either eolian or fluvial origin, commonly interbedded with thick frozen peats (Sher 1997; Tomirdiaro 1982). Regional mountain climate systems with localized rainshadow effects give the appearance in some areas of basin and range topography. The complex topography of western Beringia restricts the penetration of maritime influences and enhances the continentality of inland basins (Mock, Bartlein, and Anderson 1998).

The regional late Pleistocene stratigraphic framework used to describe and characterize paleoclimatic events of the last 65 to 20 ka cal years BP across eastern Siberia and northeastern Russia is shown in Table 2.1. The terms Zyryan stade, Kargin interstade, and Sartan stade are widely used and updated across the Russian north with the best intentions of regional stratigraphic codes. Hopkins (1982) suggested adopting the terms *Boutellier Interval* for the Kargin interstade and *Duvanyar Interval* for the Sartan stade/late Wisconsinan, but the terms have never been widely applied by later workers. Anderson and Lozhkin (2001) and Astakov (2001) recommend using more reliable chronostratigraphic terms of simply Early, Middle, and Late Weichselian or Wisconsinan when referring to the timing of depositional sequences in northern Russia and Beringia. In this chapter, we have chosen this convention and further the notion that early, middle and late, Wisconsinan (Weichselian) terms are also <u>*approximately*</u> equivalent to MIS 4 (65-75 ka cal BP), MIS 3 (65-27 ka cal BP) and MIS 2 (27-11ka cal BP); for example, from the Russian perspective, the Sartan ends ca. 12.5 ka ^{14}C BP (see Table 2.1). This assumption acknowledges the caveat that accurate dating of events in MIS 3 is notoriously difficult due to the large error inherent in materials reaching the maximum useful range of radiocarbon techniques. For nearly all of the dates in this paper, we have assumed that calendar ages > 15 ka are uniformly older than ^{14}C ages by about 3,000 years, following the suggestion of Bard et al. (1993).

Table 1. Late Pleistocene Stratigraphic and Climatic Nomenclature for Western Beringia

Stratigraphic name*	***Marine isotopic stage approximate age equivalent***	***North America***	***Europe and Eurasia***
Zyryan (Zyryanskii)	4	Early Wisconsinan	Early Weichselian
Kargin (Karginskii)	3	Middle Wisconsinan	Middle Weichselian
Sartan (Sartanskii)	2	Late Wisconsinan	Late Weichselian

* "skii" is the adjective ending in Russian; both terms appear in the literature.

Paleoenvironments during MIS 3 / Middle Wisconsinan (Karginskii Interstade)

Glacial conditions

The paleogeography of MIS 3 is probably one of the most difficult time periods to characterize despite its nearly 40,000 year duration. Throughout much of Alaska and northern Eurasia the middle Wisconsinan followed the most extensive glaciation of the entire late Pleistocene. Recent revisions in the position of the ice sheet margin during this time period are significant because they set the stage for understanding just how early humans could have occupied parts of the Eurasian Arctic. The confirmation of human occupations at Mammontovaya Kurya just west of the Polar Urals as early as 40ka (Pavlov, Svendsen, and Indrelid 2001) speaks to both the resilience of these populations and the habitability of the periglacial landscape.

Compilations of work over the last decade by the EU-QUEEN Program (Quaternary Environments of the Eurasian North) have shown that during the early and middle Weichselian (Wisconsinan), the Kara ce sheet reached its maximum southern position along a well-developed system of moraine ridges that can be traced along the Taymyr Peninsula south of the Byrranga Mountains (Svendsen et al. 1999; see Figure 2.1). This ice limit is thought to have coalesced with a local ice mass over the Putorana Plateau during the early part of the glacial cycle, when the Scandinavian ice sheet to the west was still moderate in size (Moller, Bolshiyanov, and Bergsten 1999). Reconstructions of the Barents and Kara ice sheets at this time suggest that the glaciers came onto shore and dammed large proglacial lakes in the Ural Mountains as early as 85-90 ka cal years BP (Mangerud et al. 1999, 2001). Ice sheets then retreated northward and readvanced in MIS 4 to the Markhida Moraine by about 60 ka cal years BP. A similar stratigraphy occurs on the Taymyr Peninsula, with glacial ice encroaching from the Kara Sea damming large lakes over the peninsula ca. 78-81 ka cal years BP (Alexanderson et al. 2001). The Kara ice sheet then retreated to a well-mapped position on the northern edge of the Taymyr Peninsula, damming lower elevation lakes dated by optical luminescence to about 65 ka cal years BP (Alexanderson et al, 2001). Moller, Bolshiyanov, and Bergsten (1999) describe a marine transgression onto parts of the upper Taymyr River, probably the result of the isostatic depression of the region caused by this larger ice advance. Continuous sedimentation in Lake Taymyr between 37 ka and 17ka implies that the ice sheets retreated to the northern coast of the peninsula for most of the Middle Wisconsinan; Moller, Bolshiyanov, and Bergsten (1999) suggest, on the basis of highly weathered geomorphology, that this region has been free of glaciation since that time. Marine cores taken just north of the Taymyr Penisula support the notion of a reduction in the size of the Kara and Barents sea ice sheet during MIS 3 (Knies et al. 2001). Moreover alternating sequences of lacustrine sandy silt and peat were deposited from 45-35 ka 14C years BP (~48-38 ka cal yrs BP) on the Yamal Peninsula and overlain by cover sands dated 35-30 ka 14C years BP (~38-33 ka cal yrs BP; Forman et al. 1999a). Widespread eolian sand and fluvial deposits overlying these beds and dated from 30 to 11 ka indicate that the Kara ice sheet did not reoccupy any of the western Yamal Peninsula during the middle and late Wisconsinan.

Farther to the east in the New Siberian Islands, East Siberian Sea, Andreev et al. (2001) report evidence for continuously ice-free conditions since at least 43 ka 14C years BP. Connected to the mainland throughout MIS 3 and the LGM due to lowered sea level, populations of mammoth, horse, and bison survived, especially from 18-43 ka ^{14}C years BP (~21-45 ka cal yrs BP), on graminoid-rich tundra that apparently covered wide areas of the emergent shelf in this region. During MIS 3 in particular, summer temperatures are thought to have been as much as 2^{o}C warmer than today across the New Siberian Islands, in part due to increased continentality.

Changes in the height and extent of the Scandinavian and Barents/Kara Sea ice sheets likely had a significant influence on the temporal and spatial response of the eastern Siberia and western Beringia (northeastern Siberia) to hemispheric scale climate change. Ice sheet and GCM modeling of the Scandinavian and Eurasian ice sheets by Siegert and Marsiat (2000) clearly demonstrates the extent to which changes in the size of these ice sheets diminished the temperature and precipitation influence of the North Atlantic eastward across the Russian Arctic. Fine-tuned models of ice sheet size for parts of the Weichselian (Siegert et al. 2001) allow a more realistic assessments of how the physical stratigraphy of western Beringia may have been influenced by "downwind" effects while being upwind of the maritime influences of the Bering Strait and the conditions in the Bering Sea.

The best reconstructions of the larger northern hemisphere ice sheets for MIS 3 suggest that the Scandinavian ice sheet was reduced in size but still responded to North Atlantic influences. Along the Norwegian coast, ice advanced from the fjords out beyond the modern shore at about 41 ka cal years BP and again at 34 ka cal years BP (38 ka and 31 ka 14 C yrs BP, respectively) bracketing the warmer Alesund interstadial 35 to 39 ka cal yrs BP (~32-36 ka ^{14}C yrs BP) when ice retreated inland (Mangerud et al. in press; 2002). The Laurentide ice sheet was also much reduced in size occupying an area nearly the size of the Canadian Shield but still blocking the St. Lawrence sea-way (Dyke et al. 2002). Fluctuations in ice sheet volume for this time period can only be inferred from marine records in the Labrador Sea and the North Atlantic (Andrews et al. 1998) and from fluctuations along the Great Lakes (Dreimanis, 1992; Eyles and Williams, 1992).

In contrast to these larger ice sheet systems, even less is known of the distribution and size of valley glaciers across Siberia and western Beringia in MIS 3. The late Pleistocene stratigraphic framework for this region shows strong evidence for two separate episodes of glaciation which coincide with the widely used Zyryan and Sartan stages of Siberia (Arkhipov et al. 1986a; 1986b; Glushkova, 1992; Figure 2.6). From the Taymyr Peninsula to western Alaska, the early Wisconsinan (Zyryan, MIS 4) ice was regionally the most extensive of the late Pleistocene, producing valley glaciers and small mountain ice caps some 2 to 3 times larger than the LGM (Sartan; Glushkova 1992, 2001; Kaufman et al. 1986; Brigham-Grette et al. 2003). Though the numerical dating of the early Wisconsinan ice advances is imprecise, all of these events are known to have occurred beyond the range of radiocarbon dating. Where possible, these events are constrained using cosmogenic isotope dating, pollen analysis, and amino acid geochronology on coastal glaciomarine sequences linked to ice buildup during the later stages of MIS 5 or during MIS 4 (Heiser and Roush, 2001; Gualtieri, Glushkova, and Brigham-Grette 2000; Gualtieri et al. 2003; Brigham-Grette et al. 2001; 2003). Rates of retreat from these early Wisconsinan ice limits are unknown but are generally considered to be a consequence of ameliorating conditions in MIS 3 sometime after approximately 60 ka. If any minor glacial advances occurred in these mountain complexes during MIS 3, they had to have been less extensive then advances in MIS 2 and subsequently were obliterated in the morphostratigraphy by overlap.

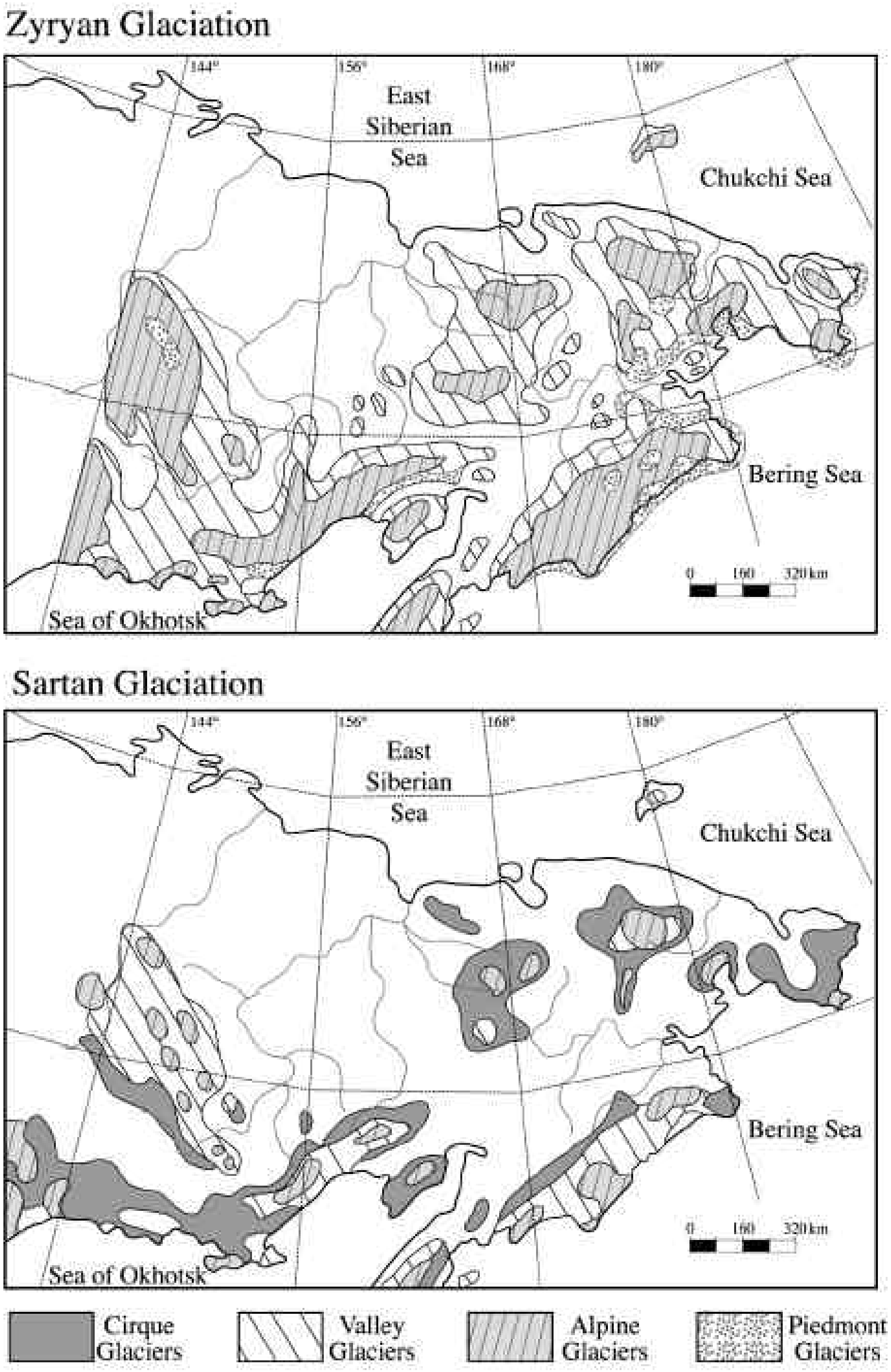

Figure 2.6. Glacial ice extent across western Beringia during the Early Wisconsinan (Zyryan Glaciation) and Late Wisconsinan (Sartan Glaciation) based on maps by Glushkova (1994; 2001) and field work discussed in the text. Note the significant difference in ice extent and dominance of cirque and small valley glaciers during the Late Wisconsinan.

Vegetation history

MIS 3 is a unique late Pleistocene interval, not only because of the number and extremes of vegetation and inferred climatic fluctuations in western Beringia but also because this period encompasses the most marked differences in paleoenvironmental changes between eastern and western Beringia (Anderson and Lozhkin 2001, and references therein). Major climate fluctuations recorded at Elikchan 4 Lake in the upper Kolyma drainage are inferred from the pollen record. For example, four distinct decreases in pollen percentages of dwarf stone pine to levels of only 20 percent (compared to less than 4 percent during MIS 2) suggest relatively cool conditions, whereas three intervals when pine pollen was much higher, including one interval with percentages close to those for the late Holocene (60 percent) indicate climates that were relatively warm, perhaps approaching modern summer temperatures (Figure 2.7). A recent investigation into insect fauna of the lower Kolyma region supports such conclusions, with Mutual Climatic Range (MCR) analyses suggesting summer temperatures that were 1.0-4.5° C warmer than present or a possible temperature range of 12.0-15.5° C (Alfimov, Berman, and Sher 2003). Palynological data from Chukotka and Priokhot'ye are too poor to be definitive, but existing evidence suggests that these areas probably did not experience large shifts in environmental conditions. However, at El'gygytgn Lake (see Figure 2.2), located 250 km inland from the Arctic Ocean, the pollen data lack any indication of a change from MIS 2-age herb-dominated tundra, although shifts in the magnetic susceptibility of lake sediments suggest changes in the duration of lake ice cover indicative of seasonal variations in temperature (Nowaczyk et al. 2002; Shilo et al. 2001).

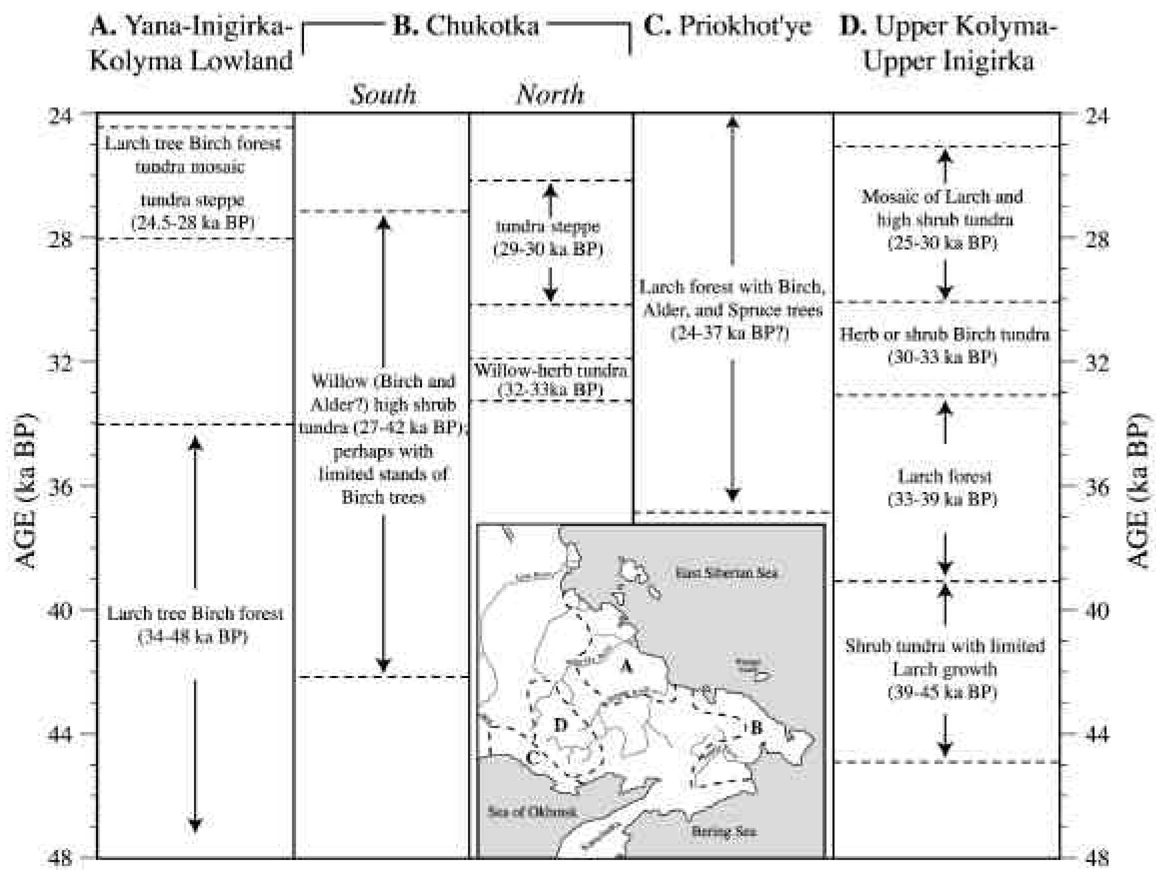

Figure 2.7. Summary of Middle Wisconsinan vegetation patterns, western Beringia. (after from Anderson and Lozhkin, 2001).

On the other hand, much of western Beringia bears strong evidence for one period of near-modern conditions, two periods when climate was much cooler than present but warmer than glacial conditions, a moderately warm period approaching modern conditions, and two intervals of moderate conditions, yet cooler and drier than modern (Anderson and Lozhkin 2001). This scheme describing variable paleoenvironments is consistent with earlier interpretations of the traditional Karginskii interstadial proposed for Siberia in general (Kind 1974) and for western Beringia in particular (Lozhkin, 1993).

The geochronology of these inferred climatic transitions remains problematic, especially for the early part of MIS 3. However, it is intriguing to speculate about the meaning of regional patterns, accepting the various problems with the physical stratigraphy as described by numerous workers. Radiocarbon dating combined with extrapolated sedimentation rates suggests that from about 45-39 ka 14C years BP (48-42 ka cal yrs BP) valleys in the upper Kolyma region contained larch forests in the lowlands and valley bottoms (Anderson and Lozhkin 2001). One of the best stratotypes for this interval is the Kirgirlakh Mammoth site associated with a frozen baby mammoth (known as Dima), documenting a significant cool interval from 39-45 ka 14C years BP (~42-48 ka cal yrs BP). Regional climate was cooler than present but mild compared to full glacial conditions. In contrast, the warmest period of MIS 3 across this region occurred for a brief period sometime between about 39 and 33 ka 14C years BP (42-36 ka cal yrs BP) when larch forests nearly reached their modern distributions (Anderson and Lozhkin 2001; Kind 1974). On Wrangel Island, an extraordinary woolly rhinoceros dated to 36 ka ^{14}C years BP (~ 40 ka cal yrs BP; Tikhonov, Vartanyan, and Joger 1999) was discovered in association with other Pleistocene megafauna (Sher 1997; Vartanyan, Garutt, and Sher 1993). Moreover, MacPhee et al. (2002) provide a synthesis of diverse megafauna inhabiting the Taymyr Peninsula and the northern Siberian lowlands back to just over 46 ka ^{14}C years BP (~49 ka Cal yrs BP). A cooler and dryer climate followed from 30-33 ka 14C years BP (~33-36 ka cal yrs BP), as indicated by the widespread appearance of herb and/or birch-shrub-tundra in areas once occupied by trees, accompanied by the development of ice wedges and active periglacial processes. The very end of MIS 3, from ca. 30-26 ka 14C yrs BP, is noteworthy because it is characterized by a brief interval of warmth, as indicated by the return of larch and birch forest-tundra in the Yana-Indigirka-Kolyma lowlands, mosaics of larch forest and shrub tundra in the upper Kolyma region, and the persistence of herb and shrub willow tundra on parts of Chukotka (see fig 2.7).

The vegetation history for MIS 3 in western Beringia contrasts sharply with that of eastern Beringia (Anderson and Lozhkin 2001). Although the latter region experienced shifts between warm and cool conditions, at no time did the vegetation or climate reflect anything similar to modern conditions. The warmest interval in the interior of Alaska was the Fox Thermal Event, dated ca. 30-35 ka 14C years BP, when fossil records indicate the establishment of spruce-forest tundra. Spruce forests were probably densest in areas of the Yukon Territory between 38-34 ka 14C years BP, but spruce distributions were far more restricted than in modern times. Climatic shifts inferred from the vegetation history are much more complex in eastern than in western Beringia (see Chapter 3, this volume), and problematic chronologies make conclusions about spatial and temporal variations between regions premature. However, Anderson and Lozhkin (2001) commented that the warmest interstadial interval for all of Beringia possibly occurred between 30-39 ka14C years BP, with strong signals from interior sites and little to no vegetation response in areas closest to Bering Strait. In general, climatic conditions in eastern Beringia appear to be harsher than modern for all of MIS 3. In contrast, MIS 3 climates of western Beringia achieved modern or near modern conditions during several intervals. Moreover, while the transition from MIS 3 to MIS 2 is clearly marked by a transition from warm/moist to cold/dry conditions across western Beringia, this transition is poorly detected in all but a few records from Alaska (Anderson and Lozhkin 2001).

Paleoenvironments during MIS 2 / Late Wisconsinan (Sartan Stade)

Glacial conditions

The extent of glaciation across the Eurasian A during MIS 2 has been the focus of much research over the past several decades. The International Quaternary Association's compilation of *Glaciations of the Northern Hemisphere* (Sibrava et al. 1986) is now somewhat outdated. However, this volume included maps and stratigraphic summaries of the glacial history of Russia, including some regions updated in English for the first time (Arkhipov et al. 1986a, 1986b; Velichko 1986; Velichko and Faustova 1986). The fall of the Soviet Union in 1990 opened the way for new international collaborations and opportunities for joint study of the Russian north. However, at the same time, Grosswald and Hughes began publishing a series of papers suggesting that the Eurasian north, including northeastern Russia, had once been covered by widespread Antarctic-style glaciation during the LGM (Grosswald 1988; 1998; Grosswald and Hughes 1995, 2002; Hughes and Hughes 1994). They hypothesized that this ice sheet complex formed one of several contiguous ice domes that rimmed the Eurasian Arctic from Scandinavia to Alaska (see Figure 2.1). Unfortunately, this theoretical ice sheet was not based on field evidence and ignored the published literature that demonstrated that such extensive ice cover did not exist (see summaries in Arkhipov et al 1986a, 1986b; Bespaly 1984; Biryukov et al. 1988; Hamilton, 1986; Isayeva, 1984). For a number of years, even the hypothesis of an east Siberian or Beringian ice sheet was erroneously perpetuated in the literature (cf. Kotilainen and Shackleton 1995) and incorporated, in a reduced form, in global geophysical models (e.g., Peltier 1994).

The *Grosswald ice sheet* hypothesis was provocative enough to generate over the last decade numerous field-based research programs to refine the glacial stratigraphy and geomorphology of the Russian Arctic, especially with an emphasis on geochronological methods. The EU-QUEEN program synthesis maps (Svendsen et al. 1999) redefined the relationship between the Scandinavian, Barents, and Kara ice sheet complex for the LGM (see Figure 2.1). Most important, they demonstrated that despite the large re-advances of the Scandinavian ice sheet, the Barents Sea ice sheets at maximum extent did not extend as far south into northern Russia and the Pechora Lowland as proposed by Grosswald (Astakhov et al. 1999; Larsen et al. 1999; Mangerud, Svendsen, and Astakhov 1999). Moreover, they demonstrated that the Kara Sea ice sheet was limited in extent and did not advance onto the mainland from Novaya Zemlya (Forman et al. 1999a, 1999b; Knies et al. 2001). Modeling by Siegert and Marsiat (2000; Siegert et al. 2001) suggested that the increased height and size of the LGM Scandinavian and Barents Sea ice sheets precluded the penetration of warm moist air into the Russian far north, creating cold, dry, polar desert conditions from the Kara Sea eastward to Beringia, though some insect data suggest warmer summers (Alfimov, Berman, and Sher 2003).

The lack of significant moisture across much of the Russian north during the LGM prevented the growth of large ice complexes across Siberia and eastern Beringia. Recent geomorphological studies are consistent with earlier Russian work suggesting that glaciation during the LGM was limited to valley and cirque glaciation in local mountainous regions. Maps produced by Glushkova (1984, 1992, 2001, Glushkova and Sedov 1984, unpublished; cf. Arkhipov et al. 1986a, 1986b; Brigham-Grette et al. 2003; Heiser and Roush 2001) show that valley glaciers were concentrated in a number of separate mountainous regions including Chersky, Anyui, Ekityki, Chukotka, Okhotsk, Taigonoss, and the Koryak mountians, as well as the highest portions of Kamchatka (Figure 2.6 bottom). In general, the intensity of glaciation decreased from west to east implying cold yet drier conditions toward the Bering Straits (Glushkova 1992), though some data suggest more mesic conditions in central Beringia (see below). In all of these mountain systems, moraines of LGM age are found up-valley from MIS 4 ice (Zyryan stade) and confined to mountain fronts covering only 14 percent of the region. The morphology of these moraine systems is fresh, with little modification by periglacial processes. Radiocarbon dating of wood and organic matter, along with cosmogenic isotope surface exposure ages, suggest that the LGM throughout eastern Siberia and western Beringia reached its maximum extent sometime between 24 ka and 17 ka 14C years BP (Brigham-Grette et al. 2003b; Glushkova 2001; Gualtieri et al. 2000; Lozhkin et al. 1993). Though more thorough investigations are now underway (Brigham-Grette, Keigwin, and Driscoll 2003), diatom floras from older Bering Sea sediment cores suggest nine months of nearly continuous sea-ice cover in the Bering Sea during the LGM. With sea level as low as -100 to -135 m for the duration of the LGM (inferred from Lambeck, Yokoyama, and Purcell 2002; see Figure 2.5), the ice-covered Bering Sea only added to the continentality of a Bering land bridge now some 1000 km wide from north to south. Sancetta et al. (1985) liken the LGM Bering Sea to the severe conditions in the Sea of Okhotsk today, given that the Alaska coastal current was prevented from entering the basin by glacial ice cover along the Aleutian chain.

Conditions along the Arctic Ocean coast of the Bering land bridge were likely more severe, as shown by the widespread occurrence of active dunes and exclusive development of sand wedges in the absence of thick snow cover across the Alaskan North Slope (Carter 1981). Sediment cores on the Northwind Ridge northeast of Wrangel Island (see Figure 2.1) are barren of all life, indicating pervasive perennial sea ice during full glacial conditions (Phillips and Grantz, 1997; Poore, Phillips, and Riech 1993; Speilhagen et al. 1997). Despite these severe circumstances, the vegetation still supported mammoth and other megafauna as far north as Wrangel Island throughout the duration of the LGM and into the Holocene with only a small gap in dates between 12-9 ka 14C years BP (Vartanyan, Garutt, and Sher 1993; Vartanyan, unpublished data).

<u>Vegetation History</u>

The most controversial of late Pleistocene vegetation reconstructions are those of MIS 2. A rather heated debate, best presented in Hopkins et al. (1982; see also Colinvaux and West 1984; Guthrie 1989), focused on a central paradox: Faunal remains of a variety of large, herbivorous mammals required a relatively productive landscape, whereas paleobotanical evidence suggested a depauperate environment. Paleoecologists, relying on the same faunal and floral data sets, offered such widely varying interpretations of the LGM vegetation as an expansive steppe or grassland (e.g., Matthews 1976), a barren tundra or polar desert (e.g., Ritchie and Cwynar 1982), or a mosaic of tundra types that reflected local influences, such as effective moisture and elevation (e.g., Schweger 1982). Such interpretive discrepancies, in large part, are the result of trans-Beringian palynological spectra that are dominated by grasses (Poaceae), sedges (Cyperaceae), and wormwood (*Artemisia*), taxa that have broad ecological tolerances, and an absence of analytical techniques providing unambiguous reconstructions (Anderson, Edwards, and Brubaker 2003).

In the decades since the mammoth-steppe paradox was the central focus of Beringian paleoecology, the addition of new fossil sites (e.g., Anderson and Brubaker 1993; Bigelow et al. 2003; Elias 2001), or in some cases the broader availability of data from sites analyzed long-ago in the Soviet Union (e.g., Velichko, 1984; see also Anderson and Lozhkin (eds.) 2002), permitted more insightful analyses on both regional and landscape scales. As to the latter, the discovery of a well-preserved LGM surface (the Kitluk surface), buried by a volcanic ash-fall on northern Seward Peninsula, revealed a full-glacial vegetation with an abundance of grasses and sedges, a rich diversity of forbs, and a ground cover dominated by acrocarpous mosses (Goetcheus and Birks 2001; Höfle et al. 2001). This paleo-landscape is not dissimilar to that seen in areas of modern Wrangel Island (Figure 2.8), with micro-relief in both past and present surfaces providing more suitable habitats for growth of woody species, such as willow. Comparisons of modern pollen spectra from Wrangel Island (Lozhkin et al. 2001) and LGM pollen assemblages from Beringia, using a squared chord-distance dissimilarity measurement (Anderson et al. 1989), indicate the presence of strong to good analogs for the fossil material (Anderson and Lozhkin, unpublished data). Pollen samples collected from the Kitluk surface have been categorized as grass-forb or prostrate shrub tundra (types found on Wrangel Island today), using a model of plant functional types (see below; Bigelow et al. 2003). Thus, earlier hypotheses of a fine-scale mosaic are supported by plant macrofossil and pollen analysis from the Kitluk surface. Similarity of LGM spectra between eastern and western Beringia (e.g., Anderson and Lozhkin 2002; Lozhkin et al. 1993) also suggests that local variation was an important characteristic of the vegetation of northeast Siberia. Such micro-to meso-scale spatial differences in environments clearly have implications for distribution of ancient peoples and subsistence resources.

For example, Yurtsev (2001) argued that some of the most floristically productive and diverse habitats were located in regions of contact between arid plains and mountain glaciers. Such localities would have experienced relatively warm summers with an ample water supply from the nearby glaciers, and possibly were centers for seasonal use by hunters and their prey.

Figure 2.8. Photograph taken on Wrangel Island in 2001 in an area reminiscent of herb- and forb-dominated tundra (photo of Pat Anderson).

Other researchers have focused on broader regional vegetation patterns that perhaps existed in Beringia (e.g., Alfimov and Berman 2001; Anderson and Brubaker 1994; Barnosky et al. 1987; Elias et al. 1996; Guthrie 2001; Hamilton et al. 1993). These patterns, in some cases based primarily on data from Alaska, suggest that more mesic, tundra-like environments occurred in central Beringia, with areas of far eastern and far western Beringia being more dry and/or steppic. These reconstructions are in general agreement with Yurtsev (1981), who postulated that central Beringia was dominated by hypoarctic tundra and that dry, calcareous habitats, although limited in extent, would provide pathways for xero- and cryoxerophytes to disseminate across the land bridge.

One of the most detailed arguments for regional variability is provided by Guthrie (2001), using faunal and floral data and variability in lengths of fossil records to propose that an “ecological interruption” in a vast, arid, steppe biome occurred in central Beringia. While an important aspect of the paleo-landscape, the presence of more mesic vegetation in central Beringia did not prevent the intercontinental dispersal of all steppe-adapted species, but it apparently was restrictive to some types, such as woolly rhinos, camels, and short-faced bears. Guthrie (2001) further proposed that this central region was not homogeneous but rather experienced a latitudinal gradient, with most mesic lands occurring, but not restricted, to the south. The crux of his arguments, regarding either regional patterning or the productivity paradox described above, depends on an increased frequency of clear skies giving rise to well-drained steppe (except in central Beringia, where nearness to maritime sources of moisture resulted in greater cloud formation) in contrast to shallow, water-logged, active layers associated with many types of modern tundra. A reduction in cloud cover would enhance conditions for growth of steppe plants by warming the soil, increasing summer thaw, and enhancing biotic activity in the soil, thereby reducing opportunities for paludification and permitting more extensive root systems. These characteristics, in combination with a relatively longer growing season, would ultimately result in: 1) higher plant productivity due to greater nutrient and carbon turn-over in the upper layer of the soil; and 2) a phytomass amenable to grazers from nutritional as well as foraging aspects. Additional evidence for the presence of steppic environments is that mammoth, bison, and horse, the most common of late Pleistocene megafauna, could not survive eating modern tundra plants (Guthrie 2001). Putschkov (1995) and Zimov et al. (1995) noted that grazing and trampling of the vegetation by the large Pleistocene herbivores may have caused the persistence of needed plant types (i.e., those found more commonly in steppe than in undisturbed tundra), regardless of larger-scale climatic controls.

Bigelow et al. (2003) used pollen data from across Beringia to assess possible variations at the biome level. (A biome is a physiognomically recognizable assemblage of plants that live within particular climatic parameters.) The Beringian LGM pollen taxa were assigned to one or more plant functional types (PFTs--defined by growth form, phenology, morphology, and bioclimatic traits), and the PFTs were then transformed into biomes using a rule-based algorithm (see Prentice et al. 1996). The LGM spectra in Beringia formed a mosaic of graminoid-forb tundra, prostrate dwarf-shrub tundra, and erect dwarf-shrub tundra. When applying a coupled vegetation-climate model dependent on the same approach to PFTs and biome definitions, similar biomes were simulated as those based on the pollen data alone (Kaplan 2001; Kaplan et al. in press). Farther to the west (e.g., Taymyr Peninsula), biomes were predominantly graminoid-forb and steppe (i.e., temperate grassland or xerophytic shrubland), lending further evidence for extreme aridity to areas downwind of the Scandinavian ice-sheet (Siegert and Marsiat 2001), although with results also suggesting greater effective moisture in the Beringian region. Biome results for central Siberia also indicate latitudinal changes, with areas to the north of 65° N being graminoid-forb tundra and to the south temperate steppe. No such regional patterns occurred in Beringia.

The LGM climates of Beringia have traditionally been described as cooler and drier than present, based on geomorphic and paleovegetational inferences (e.g., Ager and Brubaker 1985; Hopkins 1982). However, MCR analysis of insect remains, which often are steppe-associates (e.g., Berman, Alfimov, and Mazhitova 2001; Elias 2001), suggests that summer conditions may actually have been as warm or warmer than present. In the Kolyma lowlands, MCR reconstructions indicate that summer temperatures were 1.0-2.5° C higher than present or ca. 12.0-13.6° C (Alfimov, Berman, and Sher 2003). Although winter temperatures are more difficult to interpret, these data imply that January conditions were perhaps somewhat warmer than modern. Such summer results may not be too surprising, given the large reduction in sea level during the LGM, placing the modern Yana-Kolyma-Indigirka lowlands of western Beringia under continental conditions. Additionally, levels of summer insolation were near modern and, if regional climates were modified minimally by changes to LGM circulation patterns, would hint at comparatively mild conditions. If true, the presence of relatively warm summers argues that plant distribution is being limited more by effective moisture than by other factors, such as mean growing season temperature. Although quantitative estimates are absent for western Beringia, lake-level changes in interior Alaska suggest precipitation was 40 to 75 percent less than modern during the LGM (Barber and Finney 2000). Summers in the western Beringian lowlands perhaps were warmer than in the more mountainous interior regions and southern areas bordering the cool Sea of Okhotsk, thus yielding a climatic gradient different from present. Quite likely the larch forests or larch forest-tundra of the MIS 3 interstade survived as small populations both in the mountain valleys and at least in one southern coastal locality (Anderson et al. 1997; Lozhkin 2001). Yet it is an intriguing possibility that of the broad northern lowland, with its relatively warm climate, perhaps not only acted as a glacial refugium for the trees but was sufficiently populated by trees to act as a source for forest establishment to the south during the late glaciation and early Holocene (Anderson, Lozhkin, and Brubaker 2002).

Discussion

Over numerous glacial/interglacial cycles, the vast ice-free landscapes of Pleistocene Beringia have provided an essential link between the Eurasian and North American continents, and the extensive lowlands, rolling uplands, and river valleys have acted as an environmental backdrop for the adaptation and migration of plants and animals, including, at times, the human populations dependent on them. Hints that humans perhaps entered the New World long ago have existed for some time, as suggested by archaeological sites such as Bluefish Caves in Yukon Territory (Cinq-Mars 1979) and Meadowcroft Rock Shelter in Pennsylvania (Adovasio et al. 1977, 1978, 1980). However, it was the potential migration of early humans into South America, especially as far south as Monte Verde, Chile, by 12,500 14C years BP (Dillehay 1997) that caused most scientists to seriously reexamine the likelihood that early people successfully crossed the Bering land bridge prior to or even *during* the LGM or possibly sought alternate, maritime routes across Beringia's southern edge (e.g., Dixon 2001; Mandryk et al. 2001). What aspects of Beringian paleoenvironments, given our current state of knowledge, may have helped or hindered entrance into North America? The late Pleistocene landscapes often differed significantly from those of the late glaciation and early Holocene, the time when the first significant numbers of archeological sites appear in North America. Four interrelated elements, each of which had to be dealt with by people adapting to late Pleistocene Beringia, shaped the ice-age environment: (1) climatic variations, (2) glacial extent, (3) sea-level fluctuations, and (4) biota.

Although there is little evidence that human beings occupied areas of Beringia or North America during MIS 3, we include this interstadial period in our discussion. Perhaps no two periods are more unalike than MIS 2 and MIS 3, thus making an understanding of their contrast central to understanding the whys and wherefores of possible human presence or absence in Beringia during the late Pleistocene.

MIS 3 climates of western Beringia, particularly as indicated by the continuous pollen record from Elikchan 4 Lake, were variable and reminiscent of fluctuations described for the North Atlantic sector (see Figure 2.3). This characteristic of interstadial instability is relatively well documented in the latter region, with periodic collapses of the Laurentide ice sheet and dramatic changes both in air temperatures over the Greenland ice sheet and in surface temperatures of North Atlantic waters (Bard 2002 and references therein). That such distance linkages can occur has been shown in various studies; one of the more recent couples shifts in the Indian monsoon with temperature changes over the Greenland ice sheet, including MIS 3 (Fleitmann et al. in press; Schultz, von Rad, and Erlenkeuser 1998). Reasons for the specific Beringian climatic fluctuations remain uncertain. However, during MIS 3, peaks in northern hemisphere summer insolation (see Figure 2.3) coincide with the partial demise of large northern hemisphere ice sheets shortly after 60 ka years and changes in forest extent in Beringia, particularly a distinct maxima in tree cover ca. 33-39 ka. The insolation peaks at ca. 35 ka and 58 ka cal years BP are similar to one associated with post-glacial amelioration during the late glaciation and early Holocene. However, in the case of eastern Beringia, the timing of the post-glacial thermal maximum (PGTM) is offset from peak summer insolation, indicating that a combination of decreased Laurentide ice volume and higher-than-modern summer insolation likely resulted in maximum summer warmth (Bartlein et al. 1995).

Although perhaps not of direct importance to issues of human population of the New World, these patterns in the MIS 3 paleo-data suggest interesting teleconnections between the north Atlantic and at least portions of the north Pacific regions. The absence of an apparently similarly complex response in eastern Beringia (although this conclusion may be an artifact of poor chronology) or possibly a response of opposite sign (e.g., warming in eastern Beringia during the Fox thermal event at the same time of the Konotzel'skii cool interval in interior western Beringia; Anderson and Lozhkin, 2001) is difficult to explain, although modern climatology indicates that patterns often differ on each side of Bering Strait (Mock, Bartlein, and Anderson 1998). Such spatial climatic variability may have been characteristic of Beringia during warm times (i.e., interglaciations, warm interstades) but was likely absent during the LGM. Improvements in the paleo-data coupled with more sophisticated climate models may one day allow us to identify mechanisms responsible for the observed hemispheric to subcontinental climatic patterns, thereby permitting a fuller exploration of centennial-scale climatic instability and implications for large-scale movements of animals and people.

We are in a similar state regarding mechanistic explanations of apparently rapid changes in climate in western Beringia and the north Atlantic sector and implications for biota. Such centennial-scale or finer shifts in climate are thought to be non-Milankovitch related, although forcings have wide-ranging geographic influences (i.e., on the continental to hemispheric scale). Nonetheless, knowledge of causes of rapid climatic events and their propagation is incomplete, but given the rather broad similarity noted between such distant regions as Beringia and the north Atlantic, some causative link seems likely. Emerging evidence from new marine cores in the Sea of Okhotsk (Nurenberger et al. 2003) and cores from El'gygytgyn Crater in Chukotka (Nowaczyk et al. 2002) show strong atmospherically driven teleconnections to events documented best in the north Atlantic region. The extra-regional nature of this paleoclimatic signal suggests that the climatic fluctuations noted for Beringia are not simply the function of some regional-scale feedbacks, such as enhanced warming caused by albedo changes related to extensive boreal forest development, but rather are more likely a function of rapid reorganization in atmospheric circulation. Some of the proposed paleoenvironmental shifts for MIS 3 are of a scale that is more amenable to human behavior (i.e., centennial scale), but their very rapidity and relatively short duration make these events particularly difficult to document and model.

As clearly suggested by the example of the PGTM above, glacial extent is a key element to the paleoclimatic puzzle. These glaciers need not be nearby, with models describing possible influences of North American and Scandinavian ice sheets on Beringia climates (Bartlein et al. 1991, 1998; Siegert et al. 2001). Glacial extent obviously can play a direct role by blocking or "thinning" possible travel routes. For example, Hughes and Hughes (1994) suggested that a Beringian or East Siberian Sea ice sheet prevented the migration of early human populations into Alaska prior to 12 ka 14C years BP. As discussed previously, field evidence conclusively demonstrates that such a Grosswald-style ice sheet did not exist within northeastern Asia during the LGM or any recent glacial cycle. Rather, much of western Beringia and areas of Siberia bordering to the west were ice-free during MIS2, with only a small portion of the landscape occupied by valley and cirque-style glaciers (Glushkova, 1992).

Fluctuations in sea level, also related to glacial extent and paleoclimatic patterns, are of particular significance for Beringia, for without the dramatic lowering during glacial times, the land bridge and its geographic importance would be nonexistent. However, a detailed sea-level curve currently is absent for Beringia, although most investigations agree that minimum sea level, ranging from -125 to -135 m, occurred between ca. 25 and 21 ka cal year BP (~18-22 ka 14C years BP). Our current knowledge further suggests that sea-level lowering along the Bering and Chukchi coasts may have differed from other areas, perhaps being shallower by tens of meters. Global sea-level rise started as early as 19,000 cal years BP (~16,000 14C yrs BP), and our best estimates suggest that whales were able to migrate from the Pacific into the Chukchi and Beaufort seas by ~ 12 ka cal years BP (10.5 ka 14C years BP). As mentioned previously, new marine cores will clarify the timing of closure and opening of the Bering land bridge and its late Pleistocene extent.

The biota, with its exotic fauna of woolly mammoth, camel, and woolly rhinoceros and the presumably brave hunters who pursued them, has been as alluring a research theme as the physical aspects of the land bridge itself and its historical role as gateway to North America. Paleobotanical and insect data from MIS 3 deposits clearly show that vegetation and climates of western Beringia were at times not dissimilar to modern (Alfimov, Berman, and Sher 2003; Anderson and Lozhkin 2001). The interstadial larch forests or forest-tundras, which today support limited numbers of herbivores, were populated by mammoth and other members of the Paleolithic, late Pleistocene fauna. This immediately raises the question of why evidence is lacking for human occupation at the time. Is this a function of poor site preservation, or were people incapable of living in this environment? Instability of vegetation/climate is a characteristic of the MIS 3 in western Beringia. Although any single fluctuation would span several human generations, was there something peculiar to this region during the interstade that either prevented or discouraged settlement? Were Beringian populations coastal-adapted (and perhaps to a northern not a southern coast, the former to be washed away with rising sea levels) by this time, making little use of interior resources? We probably will never know for certain, but it is curious that archeological sites, which are few in western Beringia until modern conditions are in place, are also absent at times when environments were so similar to present.

The paleobotanical evidence points to a much more stable and uniform vegetation during the MIS 2 stade as compared to the MIS 3 interstade. Qualitative and quantitative interpretations of the pollen and plant macrofossil data strongly indicate the widespread occurrence of tundra and not steppe. This vegetation was dominated by graminoids, containing a diversity of forbs (some of them indicative of the Arctic and not cold interior steppes) and having locally abundant shrub willow. Other arguments, more focused on the faunal data and their implications, indicate that steppic environments are necessary to provide adequate food supplies to taxa that would not thrive or even survive on tundra plants alone. Thus, the exact nature of the LGM vegetation on the landscape scale, while no longer hotly contested, remains problematic (Zazula et al. 2003).

From a broader perspective, insect-based reconstructions coupled with paleovegetation interpretations suggest some regional variability across Beringia (e.g., Guthrie 2001; Yurtsev 1981). What role, if any, did a possibly more mesic central Beringia play in land use and possibly occupation by human populations? Additionally, fossil insect data imply that areas of the northeast Siberian lowlands experienced summer temperatures similar to present. In western Beringia, paleobotanical data suggest that larch trees and boreal shrubs survived the LGM in various localities in western Beringia, including Priokhot'ye, the upper Kolyma, and the northern lowlands (Anderson, Lozhkin, and Brubaker 2002; Lozhkin 2001). Were such areas extensive enough to act as glacial "oases," possibly attracting animals and people alike? As on the landscape scale, the exact nature of regional vegetational variation in Beringia and possible presence or numbers of glacial refugia are not definitively known. However, continued studies of the LGM indicate that conditions, particularly those in summer, probably were not as severe as thought previously and vegetation growth was most likely limited by effective moisture and not specifically seasonal temperatures. Thus, the picture of an extremely cold, arid environment may be true for portions of LGM Beringia, but it is insufficient to describe the whole of this vast subcontinent.

In more southerly areas, concern with human hunting strategies is limited to terrestrial mammals, but the far north provides a separate and important resource, sea mammals. Availability depends in large part on sea ice conditions, but the history of sea ice along southern shores of the Bering land bridge is not known in detail. However, nine months of sea ice cover, as inferred from marine records (cf., Sancetta et al. 1985), suggest several summer months of open water, much like what occurs along the north coast of Beringia today. Detailed examination of the schematic paleogeography maps (see Figure 2.5) implies that the southern shore of the Bering land bridge was geomorphically complex, with hundreds of islands located just off a coast riddled with bays and inlets. Such a coastline may have been a rich marine habitat for walrus and seals, both as haul-out spots and breeding localities. The possible abundance of such habitats has clear implications for the coastal migration theory, although detailed reconstructions of these paleo-shorelines will be a challenge due to the erosive nature of an open Bering Sea during the last transgression.

Sea ice cover does not only impacts human populations through influences on potential subsistence resources. The extent and seasonal distribution of marine ice also acts as a powerful climatic feedback. Sea ice and snow cover are key elements determining albedo at northern high latitudes. Because Arctic/subarctic climates are particularly sensitive to albedo-related changes (Kutzbach and Gallimore 1988; TEMPO 1996; Washington and Meehl 1996), information about snow and ice, both past and present, is necessary to more completely understand feedbacks and mechanisms of climate change in Beringia.

Sea ice and snow do not act alone. Vegetation, as previously mentioned, forms another vital factor in determining land-atmosphere-ocean interactions. The effects of bright ice and snow surfaces, when combined with distribution and composition of the arctoboreal vegetation (particularly the location of the forest tundra border, which separates relatively dark landscapes of the boreal forest from the more reflective tundra landscapes), act to enhance or dampen hemispheric-to-global scale climatic shifts (Foley et al. 1994; Texier et al. 1997). Of these three factors, we have the best, albeit not perfect, understanding of changes in composition and distribution of Beringian vegetation, and with new marine cores we are optimistic about improving our knowledge of sea ice behavior. Snow cover remains an elusive aspect of the paleolandscapes. Certain inferences can be drawn from the presence or absence of dwarf stone pine. This shrub pine has similar temperature requirements as western Beringian larch (Andreev, 1980; Kozhevnikov, 1981). However, unlike the deciduous larch, stone pine requires a deep snow cover to insulate its leaves from the harsh winter conditions. Thus, paleoecologists have inferred shifts in fall or winter precipitation based on differences in arrival times of the two taxa documented in the paleobotanical records (e.g., Lozhkin et al. 1993). Geomorphologists look for other clues concerning snow cover, especially in dunes and ice wedge formation. For example, the lack of snow across parts of Beringia during MIS 2 is indicated by the development of extensive dune complexes active in both summer and winter (Hopkins 1982). Across parts of northern Beringia, so little snow fell during the LGM that only sand wedges (and not ice wedges) formed when blowing sand filled thermokarst cracks (Carter 1981). Clues such as this, integrated with knowledge of vegetation, sea ice, and glacier extent, provide the best means of reconstructing Beringian paleoenvironments.

Summary

A number of primary parameters, including changes in insolation, the extent and height of ice sheets, sea-level fluctuations, and vegetation had direct and indirect impacts on the climate and environmental change of western Beringia during the past 60 kyrs. Warmer-than-present conditions at the end of the last interglaciation (stage 5) preconditioned the region to rapid glacierization (i.e., buildup of valley glaciers in later parts of stage 5 and into stage 4). Valley glaciers across the mountainous regions of northeastern Russia were 2 to 3 times more extensive in the early Wisconsinan than the late Wisconsinan. The middle Wisconsinan was a time of rapid and unstable environmental change, with large changes in sea level across the Bering/Chukchi shelves of between about -80 and -60 meters, by extrapolation from far field sea-level data. At the same time, western Beringia experienced large changes in environmental conditions marked by the repeated return of forests and shrub tundra to near modern configurations. Ice sheets in Scandinavia and Barents/Kara seas gradually became barriers to moisture by the westerlies, especially in MIS 2 (LGM), creating colder and drier conditions with some caveats. While the paleobotanical evidence points to a much more stable and uniform vegetation during the MIS 2 stade as compared to the MIS 3 interstade, pollen and plant macrofossil data strongly indicate the widespread occurrence of tundra and not steppe dominated by graminoids. This landscape contained a diversity of forbs (some indicative of the Arctic and not cold interior steppes), with locally abundant shrub willow. At the same time, data on the distribution of grazing megafauna indicate that steppic environments must have been part of the habitat mosaic necessary to provide adequate food supplies to taxa that could not survive on tundra plants alone. Global sea level was near its lowest levels for nearly 10 ka years between about 20 and 30 ka cal years BP (17-27 ka 14C yrs BP) leaving most of the land bridge exposed. Glaciation was limited to only local mountain ranges ,leaving large valleys and lowlands ice-free for the occupation of human foragers. Sea ice in the Bering Sea may have persisted for nearly nine months a year, increasing aridity during winter. However, this coast may have been rich with habitat for seals and walrus like the modern Arctic today. Emerging data from continuous archives of paleoenvironmental change and focused modeling efforts in the future will allow for scenarios of circumarctic impacts and forcings to be tested, e.g., the influence on western Beringia of large ice sheets and changes in thermohaline circulation. Equally important to appreciate are the challenges we still face in the accurate dating of materials over 25 ka years of age.

Notes: The authors wish to acknowledge the research support of the U.S. National Science Foundation, through Atmospheric Sciences/Earth System History initiative grant #0117406 to Patricia Anderson and Anatoly Lozhkin and Office of Polar Programs grants #94-23730 and #00-02643 to Julie Brigham-Grette. We also wish to acknowledge the support of the Russian Foundation for Fundamental Research. University of Massachusetts graduate students Mike Apfelbaum and Zach Lundeen created all of the figures.

References:

Adovasio, J.M., Gunn, D., Donahue, J., and Stuckenrath, R., 1977. Meadowcroft Rockshelter: retrospective 1976. *Pennsylvania Archaeolo*gist 47, 1-93.

Adovasio J.M., Gunn, D., Donahue, J., and Stuckenrath, R., 1978. Meadowcroft Rockshelter, 1977; an overview. *American Antiquity* 43, 632-651.

Adovasio J.M., Gunn, D., Donahue, J., and Stuckenrath, R., Guilday, E. and Volman, K., 1980. Yes Virgina, it really is that old: a reply to Haynes and Mead. *American Antiquity* 45, 588-595.

Ager, T.A. and Brubaker, L.B., 1985. Quaternary palynology and vegetational history of Alaska. In: *Pollen Records of Late Quaternary North American Sediments*, (V.M. Bryant, V.M. and Holloway, R.G., eds.), p. 353-384. American Association of Stratigraphic Palynologists, Dallas.

Alexanderson, H., Hjort, C., Moller, P, Antonov, O., and Pavlov, M., 2001. The North Taymyr ice marginal zone, Arctic Siberia--a preliminary overview and dating, *Global and Planetary Change* 31, 427-445.

Alfimov, A.V. and Berman, D.I. (2001). Beringian climate during the late Pleistocene and Holocene. *Quaternary Science Reviews* 20, 127-134.

Alfimov, A.V., Berman, D.I., and Sher, A.V. (2003). Tundra-steppe insect assemblages and reconstructions of late Pleistocene climate in the lower reaches of the Kolyma River. *Zoologicheskiy Zhurnal* 82. In press. In Russian.

Anderson, P.M., and Brubaker, L.B., 1994. Vegetation history of Northcentral Alaska: a mapped summary of late Quaternary Pollen data, *Quaternary Science Reviews*, v 13, n.1, 71-92.

Anderson, P.M. and A.V. Lozhkin, 2001. Late Pleistocene Interstade (Karginskii/Boutellier interval) of Beringia: variations in paleoenvironments and implications for paleoclimatic interpretations. *Quaternary Science Reviews* 20, 93-125.

Anderson, P.M. and A.V. Lozhkin (Eds.), 2002. *Late Quaternary Vegetation and Climate of Siberia and the Russian Far East: A Palynological and Radiocarbon Database.* NOAA Paleoclimatology and North East *Science* Center, Magadan. 369 pages.

Anderson, P.M. and A.V. Lozhkin, 2002. Palynological and radiocarbon data from late Quaternary deposits of northeast Siberia. In: *Late Quaternary Vegetation and Climate of Siberia and the Russian Far East: A Palynological and Radiocarbon Database,* (P.M. Anderson and A.V. Lozhkin, eds), pp. 27-34. NOAA Paleoclimatology and North East *Science* Center, Magadan.

Anderson, P.M. and Brubaker, L.B., 1993. Holocene vegetation and climate histories of Alaska. In: *Global climates since the last glacial maximum* (H.E. Wright, H.E., Jr., Kutzbach, J.E., Webb, T. III, Ruddiman, W.F., Street-Perrott, F.A., and Bartlein, P.J., eds.), p. 386-400, University of Minnesota Press, Minneapolis.

Anderson, P.M. and L.B. Brubaker, 1994. Vegetation history of northcentral Alaska: a mapped summary of late Quaternary pollen data. *Quaternary Science Reviews* 13, 71-92.

Anderson, P.M., A.V. Lozhkin, and L.B. Brubaker**,** 2002. Implications of a 24,000-yr palynological record for a Younger Dryas cooling and for boreal forest development in Northeastern Siberia. *Quaternary Research* 57, 325-333.

Anderson, P.M., B.V. Belaya, O. Yu. Glushkova, and A.V. Lozhkin, 1997. New data about the vegetation history of northern Priokhot'ye during the late Pleistocene and Holocene. In: *Beringia During the Late Pleistocene and Holocene*, (V.E. Glotov, ed.), pp. 33-54. North East Interdisciplinary Research Institute, Far East Branch Russian Academy of *Science*s, Magadan.

Anderson, P.M., Bartlein, P.J., Brubaker, L.B., Gajewski, K., and Ritchie, J.C., 1989. Modern analogues of late-Quaternary pollen spectra from the western interior of North America. *Journal of Biogeography* 16, 573-596.

Anderson, P.M., Edwards, M.E., and Brubaker, L.B., 2003. Results and paleoclimate implications of 35 years of paleoecological research in Alaska. In: *The Quaternary Period in the United States* (A.R. Gillespie, S.P. Porter, and B.F. Atwater, eds.). Elsevier, New York. In press.

Andreev, A.A., Peteet, D.M., Tarasov, P.E., Romanenko, F.A., Filimonova, L.V., and Sulerzhitsky, L.D., 2001. Late Pleistocene interstadial environment on Faddeyevskiy Island, East-Siberian Sea, Russia. *Arctic, Antarctic, and Alpine Research* 33 (1), 28-35.

Andreev, V.N. (Ed.) ,1980. *Vegetation and Soils of Subarctic Tundra*. Siberian Branch, Yakutia Subdivision, Biological Institute, USSR Academy of *Science*s, Novosibirsk. In Russian.

Andrews, J.T., 1998. Abrupt changes (Heinrich events) in late Quaternary North Atlantic marine environments: a history and review of data and concepts. *Journal of Quaternary Sciences* 13, 3-16.

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

Arkhipov, S.A., Bespaly, V.G , Faustova, M.A., Glushkova, O.Y. Isaeva, L.L., and Velichco, A.A., 1986b. Ice Sheet Reconstructions. Quaternary *Science* Reviews 5, 475-484.

Arz, H.W., Patzold, J., Wefer, G., 1998. Correlated Millennial-Scale changes in surface hydrography and terrigenous sediment yield inferred from Last-Glacial Marine deposits off northeastern Brazil. *Quaternary Research* 50, 157-166.

Astakhov, V., 2001. The stratigraphic framework of the upper Pleistocene of the glaciated Russian Arctic: changing paradigms. *Global and Planetary Change* 31, 283-295.

Astakov, V. I., Svendsen, J.I., Matiouchkov, A., Mangerud, J., Maslenikova, O. and Tveranger, J., 1999. Marginal formations of the last kara and Barents ice sheets in northern European Russia, *Boreas* 28 (1), 23-45.

Barber, V.A. and Finney, B.P., 2000. Late Quaternary paleoclimatic reconstructions for interior Alaska based on paleolake-level data and hydrologic models. *Journal of Paleolimnology* 24, 29-41.

Bard, E. 2002. Climate Shock: Abrupt Changes over Millennial Time Scales. *Physics Today* 55(12), 32-38.

Bard, E., B. Hamelin, R. Fairbanks, And A. Zindler, 1990. Calibration of 14C timescales over the past 30,000 years using the mass spectrometric U-Th ages from Barbados corals. *Nature*, 345, 405-410.

Bard E, Arnold M, Fairbanks RG, Hamelin B., 1993. 230Th/234U and 14C ages obtained by mass spectrometry on corals. *Radiocarbon* 35, 191-199.

Barnosky, C.W., P.M. Anderson, and P.J. Bartlein, 1987. Vegetational changes during the last deglaciation in the Pacific Northwest, Rocky Mountains, and Alaska. In: *North America and Adjacent Oceans During the Last Deglaciation*, (W. F. Ruddiman and H.E. Wright Jr., eds.). Boulder, CO, Geological Society of America, The Geology of North America, v. K-3, pp. 289-321.

Bartlein, P.J., Anderson, K.M., Anderson, P.M., Edwards, M.E., Mock, C.J., Thompson, R.S., Webb, R.S., Webb, T., III, amd Whitlock, C.W., 1998. Paleoclimate Simulations for North America over the Past 21,000 years: Features of the Simulated Climate and Comparisons with Paleoenvironmental Data. *Quaternary Science Reviews*, 17(6-7), 549-586.

Bartlein, P.J., Edwards, M.E., Shafer, S.L., and Barker, Jr., E.D., 1995). Calibration of radiocarbon ages and the interpretation of paleoenvironmental records. *Quaternary Research* 44, 417-424.

Bartlein, P.J., P.M. Anderson, M.E. Edwards, and P.F. McDowell, 1991. A framework for interpreting paleoclimatic variations in eastern Beringia. *Quaternary International* 10-12, 73-83.

Behl, R.L. and Kennett, J.P., 1996. Brief interstadial events in the Santa Barbara basin, NE Pacific, during the past 60 kyr. *Nature* 379, 243-246.

Berman, D.I., Alfimov, A.V., and Mazhitova, G.G., 2001. *Cold Steppe in North-eastern Asia.* Dal'nauka, Vladivostok. 183 pp. In Russian.

Berger, A. and Loutre, M., 1991, Insolation values for the climate of the last 10 million years. *Quaternary Science Reviews* 10, 297-318.

Bespaly,V.G., 1984. Late Pleistocene mountain glaciations 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, 31-33.

Bigelow, N.H., Brubaker, L.B., Edwards, M.E., Harrison, S.P., Prentice, I.C., Anderson, P.M., Andreev, A.A., Bartlein, P.J., Christiansen, T.R., Cramer, W., Kaplan, J.O., Lozhkin, A.V., Matveyeva, N.V., Murray, D.F., McGuire, A.D., Razzhivin, V.Y., Ritchie, J.C., Smith, B., Walker, D.A., Clayden, S.L., Ebel, T., Gajewski, K., Hahne, J., Holmqvist, B.H., Igarashi, Y., Jordan, J.W., Kremenetski, K.V., Melles, M., Oswald, W.W., Paus, A., Pisaric, M.F.J., Shilova, G.N., Siegert , C., Volkova, V.S., and Wolf, V.G., 2003. Climate change and arctic ecosystems I: Biome reconstructions of tundra vegetation types at 0, 6, and 18 radiocarbon kyr in the Arctic. *Journal of Geophysical Research*, in press

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

Blasco, S.M., Fortin, G., Hill, P.R., O'Connor, M.J., and Brigham-Grette, J., 1990. The late Neogene and Quaternary Stratigraphy of the Canadian Beaufort Shelf. In: A. Grantz, L. Johnson, and J.F. Sweeney, eds., The Arctic Ocean Region, v.L, Boulder, Colorado: *Geological Society of America, The Geology of North America*, p.459-490.

Bond, G. and Lotti, R., 1995. Iceberg discharges into the North Atlantic on Millennial time scales during the last glaciation. *Science* 267, 1005-1010.

Brigham-Grette, J., Hopkins, D.M., Ivanov, V.F.,Basilyan, A.,Benson, S.L.,Heiser, P.A., Puskar, 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* v. 20 (1-3), 419-436.

Brigham-Grette, J., Keigwin, L. and Driscoll, N., 2003. Investigating the Paleoclimate of an Arctic Gateway. *Geotimes,* American Geological Institute, 48(1), 20-23.

Brigham-Grette, J., Gualtieri, L. M., Glushkova, O. Yu., Hamilton, T.D., Mostoller, D., and Kotov, A., 2003. Chlorine-36 and ^{14}C chronology support a limited last glacial maximum across central Chukotka, northeastern Siberia, and no Beringian ice sheet. *Quaternary Research* 59, 386-398.

Broecker, W.S., and Hemming, S., 2001. Climate Swings come into Focus. *Science*, v. 294, 2308-2309.

Carter, L.D., 1981. A Pleistocene sand sea on the Alaskan Arctic Coastal Plain. *Science*, v. 211, n.4480, 381-383.

Chappell, J. Omura, A., Esat, T., McCulloch, M., Pandolfi, J., Ota, Y., and Pillans, B., 1996. Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep-sea meltwater discharge. Earth and Planetary *Science* Letters, 141, 227-236.

Cinq-Mars J., 1979. Bluefish Cave 1: A Late Pleistocene Eastern Beringian Cave Deposit in the Northern Yukon. *Canadian Journal of Archaeology* No. 3, pp. 1-32

Colinvaux, P.A. and West, F.H., 1984. The Beringian ecosystem. *The Quaterly Review of Archaeology* 5, 10-16.

Creager, J.S., and D. A. McManus, 1965. Pleistocene drainage patterns on the floor of the Chukchi Sea. *Marine Geology*, 3, 279-290.

Dalton, R., 2003. The Coast Road. *Nature* 422, 10-12.

Dillehay, T.D., 1997. *Monte Verde: a late Pleistocene settlement in Chile, vol.2 The Archaeological Content and interpretation*. Smithsonian Institution Press, Washington, D.C.

Dinter, D., Carter, L.D., and Brigham-Grette, J., 1990. Late Cenozoic Geologic Evolution of the Alaskan North Slope and adjacent continental shelves. In: A. Grantz, L. Johnson, and J.F. Sweeney, eds., The Arctic Ocean Region, v.L, Boulder, Colorado: *Geological Society of America*, *The Geology of North America*, p.459-490.

Dixon, E.J., 2001. Human colonization of the America: Timing, technology and process. *Quaternary Science Reviews* 20, 277-299.

Dowdeswell, J.A., Elverhoi, A., Andrews, J.T., Hebbeln, D., 1999. Asynchronous deposition of ice-rafted layers in the Nordic Seas and North Atlantic Ocean. *Nature* 400, 348-352.

Dreimanis, A., 1992. Early Wisconsinan in the NorthCentral part of the Lake Erie Basin: a new interpretation, In: P.U. Clark and P.D Lea (ed.s), The Last Interglacial-Glacial Transition in North America, Boulder Colorado, *Geological Society of America Special Paper 270*, 109-118.

Dyke, A.S., Hooper, J., and Savelle, J.M., 1996a. A history of sea ice in the Canadian Arctic Archipelago based on postglacial remains of the Bowhead Whale (*Balaena mysticetus*). Arctic 49 (3), 235-255.

Dyke, A.S., Dale, J.E., and McNeeley, R.N.,1996b. Marine molluscs as indicators of environmental change in glaciated North America and Greenland during the last 18,000. *Geographie physique et Quaternaire*, v. 50(2), 125-184.

Dyke, A.S., Andrews, J..T., Clark, P.U., England, J.H., Miller, G.H., Shaw, J., Veillette, J.J., 2002. Laurentide and Innuitian Ice sheets during the Last Glacial Maximum. Quaternary *Science* Reviews 21, 9-32.

Elias, S.A., S.K. Short and R.L. Phillips, 1992. Paleoecology of late-glacial peats from the Bering land bridge, Chukchi Sea shelf region, Northwestern Alaska. *Quaternary Research*, 38, 371-378.

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

Elias, S. A., Short, S. K., and Hirks, H. H., 1997. Late Wisconsin environments of the Bering Land Bridge. Palaeo[3]136,293-308.

Elias, S.A., 2001. Mutual climatic range reconstructions of seasonal temperatures based on late Pleistocene fossil beetle assemblages in Eastern Beringia. *Quaternary Science Reviews* 20, 77-92.

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

Elliot, M., Labeyrie, L., Bond, G., Cortijo, E., Turon, J.-L., Tisnerat, N., Duplessy, J.C., 1998. Millennial-scale iceberg discharges in the Irminger Basin during the last glacial period: relationship with the Heinrich events and environmental settings. *Paleoceanography* 13(5) 433-446.

Eyles N., and Williams, N.M., 1992. The sedimentary and biological record of the last interglacial-glacial transition at Toronto, Canada. In: P.U. Clark and P.D Lea (eds), The Last Interglacial-Glacial Transition in North America, Boulder Colorado, *Geological Society of America Special Paper 270*, 119-137.

Fairbanks, R. G., 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 342, 637-642.

Fleitmann, D., Burns, S.J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A., and Matter, A., in press. Holocene forcing of the Indian monsoon recorded in a stalagmite from Southern Oman. *Science*.

Foley, J.A., Kutzbach, J.E., Coe, M.T., and Levis, S., 1994. Climate and vegetation feedbacks during the mid-Holocene. *Nature* 371, 52-54.

Forman, S.L., Ingolfsson, O., Gataullin, V., Manley, W.F., and Lokrantz, H., 1999a. Late Quaternary stratigraphy of western Yamal Peninsula, Russia: New constraints on the configuration of the Eurasian ice sheet. *Geology* 27, 807-810.

Forman, S.L., Lubinsky, D.J., Zeeberg, J.J., Polyak, L., Miller, G.H.,Matishov, G., and Tarasov, G., 1999b. Postglacial emergence and late Quaternary glaciation on northern Novaya Zemlya, Arctic Russia. *Boreas* 28, 133-145.

Glushkova, O.Y., 1984. Morphology and paleogeography of Late Pleistocene glaciation in the northeastern USSR. In: *Pleistocene Glaciation of Eastern Asia* (Bespaly, V.G., Ed.), pp. 28-42. NEISRI FESC AS of the USSR, Magadan, [in Russian].

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. 339-344.

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

Glushkova, O. Yu. and Sedov, P.V., 1984. Late Quaternary and modern glaciations of the Pekulnei Range. In: Pleistocene Glaciation of Eastern Asia (Bespaly, V.G., and Akhlamova, A.A. *et al.* Eds.), pp. 131-140. NEISRI FESC AS of the USSR, Magadan, [in Russian].

Goetcheus, V.G. and Birks, H.H., 2001. Full-glacial upland tundra vegetation preserved under tephra in the Beringia National Park, Seward Peninsula, Alaska. *Quaternary Science Reviews*, 20, 135-147.

Grimm, E.C., Jacobson, Jr, G.L., Watts, W.A., Hansen, B.C.S., and Maasch K.A., 1993. A 50,000-year record of climate oscillations from Florida and its temporal correlation with Heinrich events. *Science* 261, 198-200.

Grootes, P.M., Stuiver, M., White, J.W.C., Johnsen, S., and Jouzel, J., 1993. Comparison of oxygen isotope records from the GISP2 and GRIP Greenland Ice cores. *Nature* 366, 522-555.

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., 1998, Late Weichselian Ice Sheets in Arctic and Pacific Siberia: Quaternary International, v.45/46, p. 3-18.

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

Grosswald, M., and Hughes, T., 2002. The Russian component of an Arctic Ice Sheet during the Last Glacial Maximum. *Quaternary Science Reviews* 21, 121-146.

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

Gualtieri, L., Vartanyan, S., Brigham-Grette, J., and Anderson, P.M., 2003. Pleistocene raised marine deposits on Wrangel Island, northeast Siberia and implications for the presence of an East Siberian ice sheet. *Quaternary Research* 59, 399-410.

Guthrie, R.D., 1989. Woolly arguments against the mammoth steppe — A new look at the palynological data. *The Review of Archeology* 10, 16-34.

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., and Thorson, R.M., (eds.), *Glaciations of Alaska: the Geologic Record*. Alaska Geologic Society, Anchorage, 9-50.

Hamilton, T.D., Ashley, G.M., Reed, K.M., Schweger, C.E., 1993. Late Pleistocene vertebrates and other fossils from Epiguruk, northwestern Alaska. *Quaternary Research* 39, 381-389.

Heinrich, H., 1988. Discovery and description of six layers rich in ice-rafted debris in the sediment cores from the Dreizack seamount in the Northeast Atlantic. *Quaternary Research* 29, 142-152.

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

Hill, P.R., Mudie, J.P., Moran, K., and Blasco, S.M., 1985. A sea level curve for the Canadian Beaufort shelf. *Canadian Journal of Earth Sciences*, v. 22, 1383-93.

Höfle, C., Edwards, M.E., Hopkins, D.M., Mann, D.M., and Ping, C.-L., 2001. The full-glacial environment of the northern Seward Peninsula, Alaska, reconstructed from the 21,500-year-old Kitluk paleosol. *Quaternary Research* 53, 143-153.

Hopkins, D.M., 1959. Cenozoic History of the Bering Land Bridge. *Science* 129, 1519-1528.

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

Hopkins, D.M., (Ed.) 1967, *The Bering Land Bridge*. Stanford University Press, Stanford, 495 pg.

Hopkins, D.M., Matthews, J.V., Jr., Schweger, C.E., and Young, S.B., eds., 1982. *Paleoecology of Beringia*. Academic Press, New York. 489 pg.

Hopkins, D.M., 1982. Aspects of paleogeography of Beringia during the late Pleistocene, In: *Paleoecology of Beringia,* Hopkins, D.M., Matthews, J.V., Jr., Schweger, C.E., and Young, S.B., (eds.). Academic Press, New York. 3-28

Hopkins, D.M. 1967. Quaternary marine transgressions in Alaska. In: *The Bering Land Bridge,* Hopkins, D.M., (Ed.), Stanford, California, Stanford University Press, 47-90

Hopkins, D.M. 1973. Sea level history in Beringia during the past 250,000 years. *Quaternary Research* 3, 520-540.

Hopkins, D.M., 1979. Landscape And climate of Beringia during Late Pleistocene and Holocene time, In: *The First Americans: origins, affinities, and adaptions,* Edited by W.S. Laughlin and A.B. Harper, New York, Gustav Fischer. 15-41

Hughen, K.A., Overpeck, J.T., Peterson, L.C., anderson, R.F., 1996. The *Nature* of varved sedimentation in the Cariaco Basin, Venezuela, and its paleoclimatic significance. In: Kemp, A.E.S. (ed) *Palaeoclimatology and Palaeoceanography from Laminated Sediments Special Publication 116*, 171-183.

Hughes, B.A., and Hughes, T.J., 1994. Transgressions: Rethinking Beringian Glaciation. *Palaeogeography, Palaeclimatology, Palaeoecology,* v. 110, p. 275-294.

Hulten, E., 1937. *Outline of the history of arctic and boreal biota during the Quaternary period*. Bokforlags Aktiebolaget Thule, Stockholm, 168 pg.

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

Ivanov, V.F., 1986. *Quaternary Deposits of Coastal Eastern Chukotka,* Vladivostok, Far East Science Center, Academy of Sciences of USSR, 137 pg. [*in Russian*]

Kaplan, J. O. ,2001. Geophysical Applications of Vegetation Modeling. Ph.D. thesis, Lund University, Lund, Sweden.

Kaplan, J.O., Bigelow, N.H., Bartlein, P.J., Christiansen, T.R., Cramer, W., Harrison, S. P., Matveyeva, N.V., McGuire, A.D., Murray, D.F., Prentice, I.C., Razzhivin, V.Y., Smith, B., Walker, D.A., Anderson, P.M., Andreev, A.A., Brubaker, L.B., Edwards, M.E., Lozhkin, A.V., and Ritchie, J.C., 2003. Climate change and arctic ecosystems II: Modeling paleodata-model comparisons, and future projections. *Journal of Geophysical Research*. In press.

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. 1986

Kind, N.V., 1974. Late Quaternary Geochronology according to Isotope Data, Transactions. Vol 257. Nauka, Moscow (in Russian).

Knebel, H. J., Creager, J. S., and Echols, R. J., 1975. Holocene sedimentary framework, east-central Bering Sea continental shelf. In: Herman, Y., ed., *Marine Geology and Oceanography of the Arctic Seas* New York, Springer-Verlag, p. 157-172.

Knies, J., Kleiber, H.-P., Mattiessen, J., Muller, C., Nowaczyk, N., 2001. Marine ice-rafted debris records constrain maximum extend of Saalian and Weichselian ice sheets along the northern Eurasian margin. *Global and Planetary Change* 31, 45-64.

Kotilainen, A. T., and Shackleton, N. J., 1995. Rapid climate variability in the North Pacific Ocean during the past 95,000 years. *Nature* 377, 323-326.

Kozhernikov, Yu.P., 1981. Ecology-floristic changes in the middle part of the Anadyr River basin. In: *Biology of Plants and Flora of North of the Far East* (M.T. Mazurenko, ed.), Institute of Biological Problems of the North, Far East Branch, USSR Academy of *Science*s, Vladivostok. In Russian. 65-78

Kutzbach, J., Gallimore, R., Harrison, S., Behling, P., Selin, R., and Laarif, F., 1998. Climate and biome simulations for the past 21,000 years. Quaternary *Science* Reviews 17, 473-506.

Kutzbach, J.E., and Gallimore, R.G., 1988. Sensitivity experiments on the effects of orbitally-caused insolationn changes in the interglacial climate of high northern latitudes. Quaternary International 10-12. 223-229.

Lambeck, K., Yokoyama, Y., and Purcell, T., 2002. Into and out of the Last Glacial Maximum: sea-level change during oxygen isotope stages 3 and 2. *Quaternary Science Reviews*, 21, 343-360.

Larsen, E., Lysa, A., Demidov, I., Funder, S., Houmark-Nielsen, M., Kjaer, K.H., and Murray, A.S., 1999. Age and extent of the Scandinavian ice sheet in northwest Russia. *Boreas* 28(1), 115-132.

Lozhkin, A.V., 1993. Geochronology of late Quaternary events in northeastern Russia. *Radiocarbon* 35, 429-433.

Lozhkin, A.V., 2001, Modern pollen spectra of arctic regions ofnortheast Siberia, In: *Paleogeography of Beringia* (K.V. Simakov, ed.) p. 20-41, North East Interdisciplinary Research Institute, Far East Branch, Russian Academy of Sciences, Magadan. In Russian.

Lozhkin, A.V., 2002. Boundaries of Beringia during the late Pleistocene and Holocene. In: *Quaternary Paleogeography of Beringia* (K.V. Simakov, ed.), North East Interdisciplinary Research Institute, Far East Branch Russian Academy of *Science*s, Magadan. 4-12

Lozhkin, A.V., P.M. Anderson, Eisner, W.R., Ravako, L.G., Hopkins, D.M., Brubaker, L.B., Colinvaux, P.A.,And Miller, M.C., 1993. Late Quaternary lacustrine pollen records from southwestern Beringia. *Quaternary Research* 39, 314-324.

Lozhkin, A.V. and Anderson, P.M., 1996. A late Quaternary pollen record from Elikchan 4 Lake. northeast Siberia. *Geology of the Pacific Ocean* 12, 6-9-616.

Lozhkin, A.V., P.M. Anderson, Vartanyan, S.L., Brown, T.A., Belaya, B.V., and Kotov, A.N., 2001. Reconstructions of late Quaternary paleo-environments and modern pollen data from Wrangel Island (northern Chukotka). *Quaternary Science Reviews* 20, 217-233.

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

MacPhee, R.D.E., Tikhonov, A.N., Mol, D., de Marliave, C., van der Plicht, H., Greenwood, A.D., Flemming, C., Agenbroad, L., 2002. Radiocarbon chronologies and Extinction Dynamics of the Late Quaternary Mammalian megafauna of the Taymyr Peninsula, Russian Federation, *Journal of Archaeological Science* 29, 1017-1042.

Mandryk, C.A.S., Josenhans, H., Fedje, D.W., and Mathewes, R.W., 2001. Late Quaternary paleoenvironments of northwestern North America: Implications for inland versus coastal migration routes. *Quaternary Science Reviews* 20, 301-314.

Mangerud, J. in press. Ice sheet limits on Norway and the Norwegian continental shelf. In: Ehlers, J. & Gibbard, P. (eds.), *Quaternary Glaciations - Extent and Chronology*. Vol. 1 Europe, Elsevier, Amsterdam.

Mangerud, J., Svendsen, J.I., and Astakhov, V.I., 1999. Age and extent of the Barents and Kara Sea ice sheets in Northern Russia. *Boreas* 28(1), 46-80.

Mangerud, J., Astakhov, V.I., Murray, A., Svendson, J.I., 2001. The chronology of a large ice-dammed lake and the Barents-Kara Ice Sheet advances, Northern Russia. *Global and Planetary Change* 31, 321-336.

Mangerud, J., Løvlie, R., Gulliksen, S., Hufthammer, A-K., Larsen, E., and Valen, V. 2002: Paleomagnetic correlations between Scandinavian Ice sheet fluctuations and Greenland Dansgaard-Oeschger Events, 45,000-25,000 yrs B.P. *Quaternary Research* 59, 211-220.

Manley, W.F., 2002. *Post-glacial Flooding of the Bering Land Bridge: A Geospatial Animation*. INSTAAR, University of Colorado, v.1, http://instaar.colorado.edu/QGISL/bering_land_bridge.

Matthews, J.V., Jr.,1976.. Arctic-steppe — An extinct biome. *Abstracts of the Fourth Biennial Meetings of the American Quaternary Association*, 73-77.

McManus, D.A., and Creager, J.S., 1984. Sea-level data for parts of the Bering-Chukchi shelves of Beringia from 19,000 to 10,000 14C yr. B.P. *Quaternary Research*, 21, 317-325.

Milne, G.A., Mitrovica, J.X., Schrag, D.P., 2002. Estimating past continental ice volume from sea-level data. *Quaternary Science Reviews* 21, 361-376.

Mitchell, J.F.B., Grahame, N.S., and Needham, K.J., 1988. Climate simulations for 9000 years before present: Seasonal variations and effect of the Laurentide ice sheet. *Journal of Geophysical Research*, 93, 8283-8303.

Mock, C.J., P.J. Bartlein, and P.M. Anderson, 1998. Atmospheric circulation patterns and spatial climatic variations in Beringia. *International Journal of Climatology*, 18, 1085-1104.

Mock, C.J., 2002. Regional Climates of Russia. In*: Late Quaternary Vegetation and Climate of Siberia and the Russian Far East (Palynological and Radiocarbon Database)*. (P.M. Anderson and A.V. Lozhkin, ed.), North East *Science* Center Far East Branch, Russian Academy of Science, Magadan. 17-226

Moller, P., Bolshiyanov, D. Yu. And Bergsten, H., 1999. Weichselian geology and palaeoenvironmental history of the central Taymyr Peninsula, Siberia, indicating no glaciation during the last global glacial maximum. *Boreas* 28(1), 92-114.

Morley, J. J., and Robinson, S. W., 1986. Improved method for correlating late Pleistocene/Holocene records from the Bering Sea: application of a biosiliceous/geochemical stratigraphy. Deep-Sea Research 33, p. 1203-1211.

Nowaczyk, N.R., Minyuk, P., Melles, M., Brigham-Grette, J., Glushkova, O., Nolan, M., Lozhkin, A.V., Stetsenko, T.V., Andersen, P., Forman, S.L., 2002. Magnetostratigraphic results from impact crater Lake El‘gygytgyn, north-eastern Siberia: a possibly 300 kyr long terrestrial paleoclimatic record from the Arctic. *Geophysical Journal International* 150, 109-126.

Nurenberger, D. Tiedemann, R., Kaiser, A. and Biebow, N, 2003. Paleoceanographic studies in the sea of Okhotsk--Implications for the glaciation history of NE Siberia. European Geophysical Society, *Geophysical Research Abstracts* 5, 11171.

Pavlov, P. Svendsen, J.I., and Indrelid, S., 2001. Human presence in the European Arctic nearly 40,000 years ago. *Nature* 413, 64-67.

Peltier, W.R., 1994. Ice Age Paleotopography. *Science* **265,** 195-201.

Phillips, R.L., and Grantz, A., 1997. Quaternary history of sea ice and paleoclimate in the Amerasia basin, Arctic Ocean, as recorded in the cyclical strata of Northwind Ridge. *Geological Society of America Bulletin* 109 (9), 1101-1115.

Poore, R.Z., Phillips, R.L., and Riech, H.J., 1993. Paleoclimate record for Northwind ridge, western Arctic Ocean. *Paleoceanography* 8, 149-159.

Prentice, I,C., Guiot, J., Huntley, B., Jolly, D., and Cheddadi, R., 1996. Reconstructing biomes from paleoecological data: a general method and its application to European pollen data at 0 and 6 ka. *Climate Dynamics* 12, 185-194.

Putschkov, P.V., 1995. *Were the Mammoths Killed by the Warming? Testing the Climatic Versions of Wurm Extinctions*. Vestnik Zoologii, Journal of the Schmalhausen Institute of Zoology, National Academy of *Science*s, Kiev.

Ritchie, J.C. and Cwynar, L.C., 1982. The late Quaternary vegetation of the north Yukon. In: *Paleoecology of Beriniga* , D.M. Hopkins, J.V. Matthews, Jr., C.E. Schweger, and S.B. Young, (eds.), Academic Press, New York. 113-126

Sibrava, V., Bowen, D.Q., and Richmond, G.M. (Eds.) 1986. Quaternary Glaciations of the Northern Hemisphere. Quaternary *Science* Reviews 5, 511pg.

Sancetta, C., 1992. Primary production in the glacial North Atlantic and North Pacific Oceans. *Nature* 360:249-251.

Sancetta, C., Heusser, L., Labeyrie, L., Sathy-Naidu, A., and Robinson, S. W., 1985. Wisconsin-Holocene paleoenvironment of the Bering Sea: evidence from diatoms, pollen, oxygen isotopes, and clay minerals. *Marine Geology* 62, 55-68.

Sancetta, C and S. W. Robinson, 1983. Diatom evidence on Wisconsin and Holocene events in the Bering Sea. *Quaternary Research* 20:232-245.

Schultz, H., von Rad, U., Erlenkeuser, H., 1998. Correlation between Arabian Sea and Greenland climate oscillations of the past 110,000 years. *Nature* 393, 54-57.

Schweger, C.E., 1982. Late Pleistocene vegetation of eastern Beringia: Pollen analysis of dated alluvium. In: *Paleoecology of Beriniga* , D.M. Hopkins, J.V. Matthews, Jr., C.E. Schweger, and S.B. Young, (eds.), Academic Press, New York. 95-112.

Schweger, C.E., 1997. Late Quaternary Palaeoecology of the Yukon: A review. In: H.V. Danks and J.A.Downes (eds) *Insects of the Yukon*, Biological Survey of Canada (Terrestrial Arthropods), Ottawa,p. 59-72

Siegert , M.J. and Marsiat, I., 2000, Numerical reconstructions of LGM climate across the Eurasian Arctic, *Quaternary Science Reviews* 20, 1595-1606.

Siegert, M.J., Dowdeswell, J.A., Hald, M. and Svendsen, J., 2001. Modelling the Eurasian Ice Sheet through a full (Weichselian) glacial cycle. *Global and Planetary Change* **31,** 367-385.

Sher, A.V., Kaplina, T.N., Giterman, R.E., Lozhkin, A.V., Arhangelov, A.A., Vyryna E.I., Zazhigin, V.S., Kiselev, S.V., Kuznetsov, U.V., 1979. Guide for scientific excursion devoted to the theme "The Late Cenozoic Deposits of the Calumba Lowland", XIV Pacific *Science* Congress (USSR, Khabarovsk, August, 1979)VINITI Press, 117pg. (in Russian)

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

Shilo, N.A., Lozhkin, A.V., Anderson, P.M., Belaya, B.V., Stetsenko, T.V., Glushkova, O. Yu., Brigham-Grette, J., Mellis, M., Minyuk, P.S., Novacek, N., and Forman, S., 2001. First continuous pollen record of vegetation and climate change in

Beringia during the last 300 thousand years. *Doklady Academii Nauk* 376 (2), 231-234.

Sicre M.-A., Bard E., Ezat U., Rostek F., 2002. Alkenones distributions in the North Atlantic and Nordic sea surface waters. *Geochemistry, Geophysics, Geosystems* (G-cubed) 3 (2), 2001GC000159, 1-13.

Speilhagen, R.F., and 14 others, 1997. Arctic Ocean evidence for late Quaternary initiation of northern Eurasian ice sheets. *Geology* 25, 783-786

Svendsen, J., Astakhov, V., Bolshiyanov, D., Demidov, I., Dowdeswell, J., Gataullin. V., Hjort, C., Hubberton, H., Larsen, E., Mangerud, J., Melles, M., Moeller, P., Saarnisto, M. and Siegert, M., 1999. Maximum extent of the Eurasian ice sheets in the Barents and Kara Sea region during the Weichselian. *Boreas* **28,** 234-242.

TEMPO , 1996. Potential role of vegetation feedback in the climate sensitivity of high-latitude regions, a case study at 6000 years B.C. *Global Biogeochemical Cycles* 10, 727-736.

Texier, D., de Noblet, N., Harrison, S.P., Haxeltine, A., Joussaume, S., Jolly, D., Laarif, F., Prentice, I.C., and Tarasov, P.E., 1997. Quantifying the role of biosphere-atmosphere feedbacks in climate change: a coupled model simulation for 6000 yr BP and comparison with palaeodata for northern Eurasia and northern Africa. *Climate Dynamics* 13, 865-881.

Tikhonov, A., Vartanyan, S., Joger, U., 1999. Woolly Rhinoceros (*Coelodonta antiquitatis*) from Wrangel Island. *Darmstadter Beitrage zur Naturgeschichte* 9, 187-192.

Tomirdiaro, S.V., 1982. Evolution of Lowland Landscapes in Northeastern Asia during Late Quaternary Time. In: Hopkins, D.M., Matthews, J.V., Jr., Schweger, C.E., and Young, S.B., (eds.), 1982, *Paleoecology of Beringia*, Academic Press, New York, 29-42.

Van Kreveld, S., Sarnthein, M., Erlenkeuser, H., Grootes, P., Jung, S, Nadeau, M., Pflaumann, U., Voelker, A., 2000. Potential links between surging ice sheets, circulation changes, and the Dansgaard-Oeschger cycles in the Irminger Sea, 60-18 kyr., *Paleoceanography* 15(4), 425-442.

Vartanyan, S.L., Garutt, V.E., and Sher, A.V., 1993. Holocene dwarf mammoths from Wrangel Island in the Siberian Arctic. *Nature* **362,** 337-340.

Velichko, A.A. (Ed.),1984. *Late Quaternary Environments of the Soviet Union.* University of Minnesota Press, Minneapolis. 327 pp.

Velichko, A.A., 1986. Methological approaches in the investigations of the development of glaciation in Northern Eurasia. *Quaternary Science Reviews* 5, 443-446.

Velichko, A.A., and Faustova, M.A., 1986. Glaciations in East European region of the USSR. *Quaternary Science Reviews* 5, 447-465.

Volker, A.H.L., 1999. Dansgaard-Oeschger events in ultra-high resolution sediment records from the Nordic Seas. [Dissertation], Institute of Geology, University of Kiel, Germany, 278pp.

Washington, W.M. and Meehl, G.A., 1996. High latitude climate change in a global coupled ocean-atmosphere-sea ice model with increased atmospheric CO_2. *Journal of Geophysical Research* 89, 9475-9503.

Weaver, A.J., Bitz, C.M., Fanning, A.F., and Holland, M.M., 1999. Thermohaline circulation: high latitude phenomena and the difference between the Pacific and Atlantic. Annual Reviews of Earth and Planetary *Science*s 27, 231-285.

Yokoyama, Y., Lanbeck, K., De Deckker, P., Johnson, P., Fifield, L.K., 2000. Timing of the Last Glacial maximum from observed sea level minima. *Nature* 406, 713-716.

Yurtsev, B.A., 1981. *Relic Steppe Biotopes of the Northeastern Asia.* Nauka, Moscow. In Russian.

Yurtsev, B.A., 2001. The Pleistocene “tundra-steppe” and the productivity paradox: the landscape approach. *Quaternary Science Reviews* 20, 165-174.

Zazula, G.D., Froese, D.G., Schweger, C.E., Mathewes, R.W., Beaudoin, A.B., Telka, A. M., Hartington, C.R., and Westgate, J.A., 2003. Ice-age steppe vegetation in east Beringia. *Nature* 423, 603.

Zimov, S.A., Chuprynin, V.I., Oreshko, A.P., Chapin III, F.S., Reynolds,J.F., and Chapin, M.C. (1995). Steppe-tundra transition: A herbivore-driven biome shift at the end of the Pleistocene. *American Naturalist* 146, 765-794.

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Australia, Barbados, Tahiti, New Zealand, and Sunda Shelf off Vietnam. Relative sea level data for Beringia discussed in text.

Figure 2.5. Schematic sea level reconstructions at modern, –54m, -64m, -77m and –88m, and -120m based on Manley (2002) without compensation for post-glacial sedimentation or tectonic influences.

Figure 2.6. Glacial ice extent across western Beringia during the Early Wisconsinan (Zyryan Glaciation) and Late Wisconsinan (Sartan Glaciation) based on maps by Glushkova (1994; 2001) and field work discussed in the text. Note the significant difference in ice extent and dominance of cirque and small valley glaciers during the Late Wisconsinan.

Figure 2.7. Summary of Middle Wisconsinan vegetation patterns, western Beringia. (after from Anderson and Lozhkin, 2001).

Figure 2.8. Photograph taken on Wrangel Island in 2001 in an area reminiscent of herb- and forb-dominated tundra (photo of Pat Anderson).