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A 40,000-yr record of environmental change from Burial Lake in Northwest Alaska

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ABSTRACT

Burial Lake in northwest Alaska records changes in water level and regional vegetation since ~39,000 cal yr BP based on terrestrial macrofossil AMS radiocarbon dates. A sedimentary unconformity is dated between 34,800 and 23,200 cal yr BP. During all or some of this period there was a hiatus in deposition indicating a major drop in lake level and deflation of lacustrine sediments. MIS 3 vegetation was herb-shrub tundra; more xeric graminoid-herb tundra developed after 23,200 cal yr BP. The tundra gradually became more mesic after 17,000 cal yr BP. Expansions of *Salix* then *Betula*, at 15,000 and 14,000 cal yr BP, respectively, are coincident with a major rise in lake level marked by increasing fine-grained sediment and higher organic matter content. Several sites in the region display disrupted sedimentation and probable hiatuses during the last glacial maximum (LGM); together regional data indicate an arid interval prior to and during the LGM and continued low moisture levels until ~15,000 cal yr BP. AMS ^{14}C dates from Burial Lake are approximately synchronous with AMS ^{14}C dates reported for the *Betula* expansion at nearby sites and sites across northern Alaska, but 1000–2000 yr younger than bulk-sediment dates.

Introduction

Moisture is increasingly recognized as an important control of long-term aquatic and terrestrial ecosystem dynamics at high northern latitudes. In Alaska, research shows moisture has been near or exceeded critical thresholds that control the composition and abundance of vegetation during the late Pleistocene and Holocene (Abbott et al., 2000; Barber and Finney, 2000; Barber et al., 2000; Mann et al., 2002). During the LGM (MIS 2), unglaciated northern regions were characterized by conditions that were both colder and drier than present (Hopkins, 1982); the change in moisture levels between the LGM and the Holocene interglacial is likely as significant to ecosystem development as the change in temperature. For example, at Birch Lake in interior Alaska, Abbott et al. (2000) used core-transect data to quantify the magnitude of lake-level changes during the late glacial (15,000–11,400 cal yr BP) and Holocene. Barber and Finney (2000) used those data to estimate precipitation change; they report a ~50% increase between the late glacial and present.

With few exceptions, records from unglaciated interior Alaska indicate that many small (<1 km^2), shallow (<15 m) lake basins were dry during the LGM (Ager, 1985; Bigelow, 1997; Abbott et al., 2000). Some records from lakes of similar size in northwest Alaska extend back through the LGM, suggesting less aridity in areas adjacent to the Bering land bridge (Anderson, 1985, 1988; Anderson and Brubaker, 1994; Berger and Anderson, 2000; Ager, 2003). Thus, it is now generally considered that the land-bridge region was moister than adjacent continental regions to the east and west (e.g., Elias et al., 1997; Guthrie, 2001). To date, however, no paleohydrologic studies have been done in western Alaska to assess the magnitude and duration of changes in the moisture regime.

The late glacial to Holocene transition in Alaska and adjacent regions is marked by a major increase in shrub cover. Anderson (1985, 1988) showed this increase to be earlier in the west than farther east in central Alaska (~14,000 rather than ~12,000 ^{14}C yr BP) and advanced the explanation of progressive flooding of the land bridge, which might have ameliorated the cold, dry climate sooner in the west. Bartlein et al. (1991) suggested that a switch from a dominant southeasterly flow to a westerly flow, related to the waning of the Laurentide ice sheet, caused a major increase in moisture advection to Alaska—a shift that should have generated a synchronous change across Alaska and NW Canada. Therefore, the pattern of dates is critical, and it is now known that, in the Arctic, AMS ^{14}C dates on terrestrial macrofossils sampled from the same sections tend to be younger than bulk-sediment counterparts because of contamination from ancient soil carbon (Abbott and Stafford, 1996).

New studies based on AMS ^{14}C chronologies should help resolve questions as to the synchronicity of a prominent late glacial shrub

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tundra increase and the magnitude of any full-glacial E–W moisture gradient. Here we present the record of lake-level and vegetation changes at Burial Lake, located in the Brooks Range of northwest Alaska, which extends back to ~39,000 cal yr BP, and we reassess other regional records in the light of these findings.

Study site and regional setting

Burial Lake (68.43°N, 159.17°W) lies at 460 m a.s.l. in the northwest Brooks Range to the north of the Noatak River (Fig. 1). Currently, the lake has a maximum depth of ~20 m and is roughly circular with an area of ~80 ha. The catchment is small; steep slopes rise from the lake to a gently rolling plateau, and there is a small outlet stream with limited flow. The lake is located near the northern edge of the Noatak Basin, a lowland that held large proglacial lakes in middle and late Pleistocene (Hamilton, 2001). The mountain glaciers that dammed the lake did not extend across the terrain on which Burial Lake lies (Hamilton, 2001), and the underlying moraine is thus likely to be middle Pleistocene or older in age, suggesting the lake basin may contain a long sedimentary record.

The region experiences long, cold winters and short, cool summers. Permafrost is widespread in the area. Vegetation is low-arctic tundra, dominated by sedges, *Salix*, shrub-*Betula*, and *Alnus* with occasional stands of *Populus balsamifera* in river valleys. The nearest riverine *Picea* forest lies ~100 km distant, farther west down the Noatak River.

Burial Lake is oligotrophic and a hydrologically open system. On August 20, 1997 it had a Secchi depth of 7.5 m and was well mixed with no evidence for thermal or chemical stratification. The surface waters had a pH of 6.5, a conductivity of 0.27 mS/cm, a temperature of 10.4°C, and dissolved oxygen of 7.7 mg/L. Stable isotope values of lake water $\delta^{18}O$ (−16.8‰ SMOW) and $\delta^{2}H$ (−135.6‰ SMOW) sampled during August of 1997 plot along the global meteoric water line, indicating minimal evaporative effects.

Other lakes in the region have been studied allowing the assessment of the Burial Lake record in light of other data, particularly

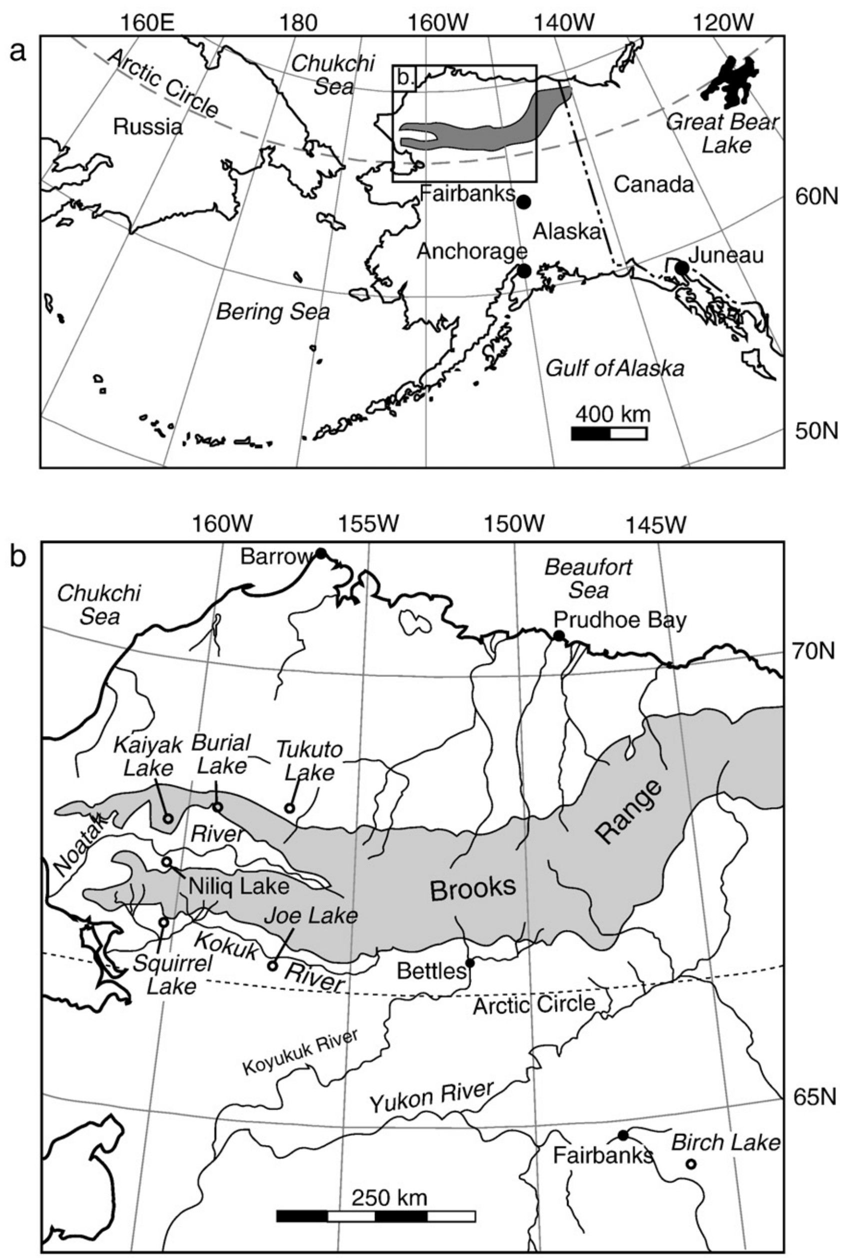

Figure 1. Location map of Burial Lake and other sites discussed in the text.

in relation to sediment hiatuses and radiocarbon chronologies. Anderson (1985, 1988) studied four lakes in the region: Kaiyak and Niliq lakes, farther west in the Noatak drainage, and Squirrel and Joe lakes in the Kobuk drainage to the south (Fig. 1). Oswald et al. (1999) studied Tukuto Lake (Fig. 1), to the east. Kaiyak, Squirrel, Tukuto and Joe lakes have sediment records extending to the LGM or beyond. Mann et al. (2001, 2002) investigated Lake of the Pleistocene in the Arctic Foothills, where water-level fluctuations occurred during the late glacial.

Methods

Sediment coring

Three cores were recovered though the lake ice from 5.0 m (Core A-98), 7.9 m (Core C-98), and 13.2 m (Core B-98) water depth using a square-rod piston corer (Wright et al., 1984). Cores were double wrapped in plastic, packed in PVC tubing, and secured with duct tape for transport. The upper two drives of Core B-98 were damaged during shipping, so our work focused on the other two cores. A surface core was also recovered from 17.75 m water depth using a K–B corer designed to take undisturbed sediment–water interface profiles. The 44-cm-long surface sediment core was sampled in the field at a 0.5-cm intervals down to 10 cm and at a 1-cm intervals to the base.

Geochronology

Samples were wet-sieved to isolate terrestrial macrofossils for AMS radiocarbon measurements. Fourteen radiocarbon ages obtained by AMS (accelerator mass spectrometry) on terrestrial macrofossils and wood are the basis for the core chronology (Table 1). A humic acid extraction was used for the lowermost sample because of a lack of macrofossil material; however, the age was considered anomalously old and not used in the age model (see below). This humic acid date highlights the problem of ancient carbon contamination of bulk sediment and isolated fractions of the organic matter: older soil carbon is well preserved in the cold conditions and continuously reworked in Arctic systems. All samples were processed using standard acid-base-acid pretreatment methods (Abbott and Stafford, 1996). Four dates were not used in the age model shown in Figure 2. Samples AA-35195 and AA-35198 were eliminated because they were small and likely contaminated with modern carbon during the combustion and graphitization process (Oswald et al., 2005), yielding ages that we interpret as being younger than the age of deposition. Although sample AA-35199, taken from 357.5 cm, was not used in the age model because it is 17.5 cm below a clear erosional unconformity at 340 cm in unconsolidated sand- to gravel-sized sediment, it does provide some limit on the age of the end of the LGM dry phase. We extrapolated the linear trend below the sample dated at 19,880 cal yr BP at 289-cm depth down to the 340-cm level to estimate the upper age of the unconformity. Finally, the basal sample OS-18369, the humic acid extraction, was not used because it was considerably older than the samples immediately above it that were measured on wood. It is possible that there are one or more unconformities between this sample and the overlying ones, but this is not supported by the core lithology.

The radiocarbon ages were calibrated using Calib 5.0.2 for measured radiocarbon ages <22,000 ^{14}C yr BP (Reimer et al., 2004) and the Fairbanks0107 calibration curve for ages >22,000 ^{14}C yr BP (Fairbanks et al., 2005). The age model was constructed by linear interpolation between radiocarbon ages above the unconformity (estimated to end after 23,200 cal yr BP; see below) and by fitting a line through the four dates used in the age model prior to this time (Fig. 2).

Lithostratigraphy

The sediment cores were split, photographed, described, measured for magnetic susceptibility, and sampled for bulk density, organic matter content by loss on ignition (Bengtsson and Enell, 1986), and pollen using standard laboratory procedures (Figs. 2 and 3). Magnetic susceptibility measurements were made on the whole core at 1-cm increments. Core lithology was determined from smear-slide mineralogy and detailed core logging including descriptions of Munsell color, sedimentary structures, and biogenic features. The laboratory measurements and detailed core descriptions were used to characterize the sediment units and transitions. The cores were archived in ODP D-Tubes and stored in a dark cold room at 1–3°C.

Pollen

The goals of the pollen study were correlation with other regional records and the definition of key transitions for AMS ^{14}C dating, as the main features of regional vegetation history are known from Anderson's (1985, 1988) work. Pollen analysis was therefore carried out at 10-cm intervals throughout most of Core C-98, and at 5-cm intervals across the *Betula* and *Alnus* increases. We used conventional methodologies for preparation, identification, and counting (Faegri et al., 1989), plus heavy-liquid separation (sodium polytungstate; Elias et al., 1999) for silt- and sand-rich samples. The pollen sum was ≥ 300 terrestrial pollen grains, excluding spores and aquatic taxa. Pollen reference material held at UAF was consulted when necessary. The pollen diagram was plotted using TILIA software, written by E.C. Grimm.

Table 1
Radiocarbon dates calibrated with 2 sigma ranges.

Sample ID	Core	Drive	Depth (cm)	Material	Raw age (^{14}C yr BP)	Error (yr)	Calib. age (5.0.2)	Calib. age (Fairbanks0107)	δ^{13}C
OS-18365	GL-1	1	20	Macrofossil >125 μm	1850	55	1785		−27
AA-35197	C	2	128.5	Macrofossil >125 μm	8390	140	9150–9530		−28
CAMS-73172	C	3	219	Macrofossil >125 μm	12,020	190	13,670–14,110		−25
AA-35195	C	3	220	Macrofossil >125 μm	640	85	550–670		−31.4
OS-17700	C	3	236	Wood	13,150	65	15,370–15,730		−27
OS-18367	C	3	272.5	Wood	15,300	180	18,510–18,870		−28.5
CAMS-73173	C	3	289	Macrofossil >125 μm	16,740	260	19,560–20,100		−25
AA-35198	C	4	306.5	Macrofossil >125 μm	14,660	250	17,180–18,420		−26
AA-35199	C	4	357.5	Macrofossil >125 μm	20,330	280	23,960–24,740		−28
OS-18368	C	4	375.5	Wood	30,300	300		35,690	−22.5
CAMS-73174	C	5	407.5	Macrofossil >125 μm	31,680	360		37,060	−25 (est.)
CAMS-73175	C	5	407.5	Wood	32,770	470		38,170	−25 (est.)
OS-27279	C	5	440	Macrofossil >125 μm	32,780	280		38,180	−25 (est.)
OS-18369	C	5	447.5	Humic acid extraction from bulk sediment	42,600	2800		Beyond cal	−27.2
AA-35196	A	1	92	Macrofossil >125 μm	16,900	270	19,620–20,340		−35.3

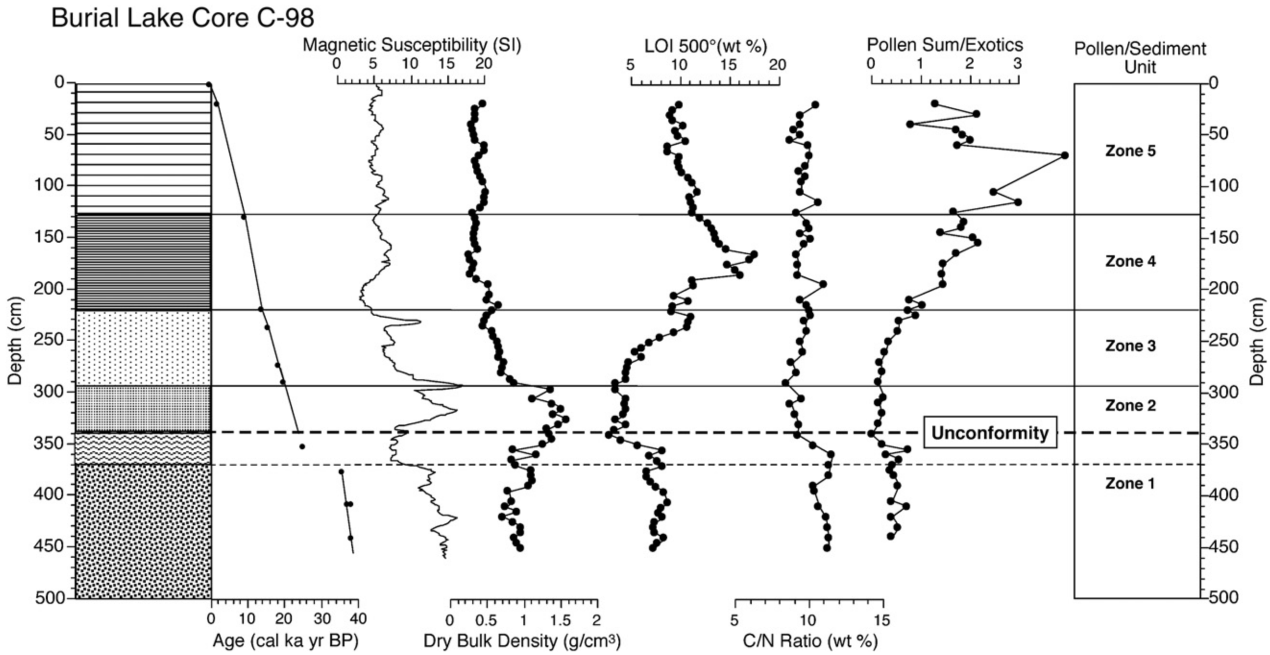

Figure 2. Lithostratigraphy and pollen/sediment units plotted against depth with magnetic susceptibility, dry bulk density, loss on ignition (LOI) at 500°C (organic matter content), C/N atomic ratio, and pollen sum/exotics ratio.

Results and discussion

Sediment description and interpretation

Our work focused on Core C-98, recovered from 7.9 m water depth; we used the two other cores for correlation and to help identify major water-level changes. Results of our sediment geochemical and pollen analyses (Figs. 2–5), combined with the age model described above, indicate five lithologic units and five pollen zones (Figs. 2, 4 and 5; Table 2). Notably, the lithologic and pollen boundaries fall at the same points.

~39.0 to 34.8 ka: lithologic unit #1 and pollen zone BL-1

The sediments deposited between ~39,000 and 34,800 cal yr BP are characterized by relatively coarse grain size (silt to fine sand with numerous gravel-sized clasts), high magnetic susceptibility (10 to 15 × 10^{-7} SI), and moderate organic matter content (6–8 wt %). Notably, the sediment dry bulk density generally increases throughout this unit (Fig. 4). The pollen record is dominated by Cyperaceae, Poaceae, and *Artemisia* in decreasing order of importance (Fig. 5). The characteristic tundra families Saxifragaceae, Brassicaceae, and Caryophyllaceae are well represented, and *Thalictrum* is also abundant. The shrubs *Salix* (~10%) and *Betula* (~5%) are a minor component of the pollen. The vegetation is interpreted as a tundra growing under relatively cool and dry conditions compared with the present, but more mesic than that which followed (see below). Similar vegetation is reported in other pollen records from the surrounding region.

The upper ~30 cm of this unit represent sediments with physical properties altered by processes related to subaerial exposure and shallow water environments during the lowstand(s) that created the unconformity between 34,800 and 23,200 cal yr BP. They contain high concentrations of sand and gravel with low, decreasing organic matter content (4 to <2%), higher C/N atomic ratios reflecting terrestrial carbon input, and very low pollen concentrations. The pollen sample at 340-cm depth contained no detectable pollen and <2% organic matter, consistent with a subaerially exposed surface. We interpret this sand–gravel layer to be a lag deposit formed by deflation and winnowing of the fine grain sizes during a period of prolonged aridity beginning sometime after 34,600 cal yr BP and ending around 23,200 cal yr BP. During this period, water level dropped below the unconformable surface in Core C-98, then at ~11.30 m BOL (i.e., below the overflow level). The duration of this particularly dry period remains unknown as the sediment record, if deposited at all, has been removed by wind erosion and lost; however, it is clear that lacustrine sedimentation resumed in areas of the basin deeper than ~11.30 m BOL shortly after 23,200 cal yr BP.

For this period, the pollen records from Kaiyak and Tukuto lakes show graminoid/herb tundra with *Salix*; the reported sediment properties for Tukuto suggest intermittently subaerial deposits, and this record is likely also affected by hiatuses.

23.2 to 19.8 ka: lithologic unit #2 and pollen zone BL-2

Lacustrine sedimentation resumed above the unconformable surface in Core C-98 at 11.3 m BOL at 23,200 cal yr BP (Table 1); at this stage the lake remained a closed-basin system. There is no evidence that lake level dropped below this point after this time. However, it appears water levels did not consistently rise above 5.8 m BOL until 19,800 cal yr BP, because there is evidence for soil formation overlying a gravel lag deposit in Core A-98 between 23,200 and 19,800 cal yr BP. The sediments in Core A-98 are characterized by coarse grain size (silt to fine sand), high magnetic susceptibility (10–15 × 10^{-7} SI), and moderate organic matter content (5–10 wt %) with blocky structure. Notably, there is no gravel in this upper unit that contains the blocky structure. The sediments in Core C-98 have high magnetic susceptibility (10–15 × 10^{-7} SI), and low organic matter content (<5 wt %). These sediments are typical of an environment of fluctuating water levels in a shallow setting where shorelines are reworked leaving behind the coarser grained particles. Although slightly moister than before, the period coinciding with the LGM at Burial Lake was dry, with unstable lake levels that likely fluctuated greatly.

The lowest pollen/exotic ratios in the record suggest low pollen productivity (Fig. 2). The pollen is characterized by virtually no *Salix*, low *Thalictrum*, the highest numbers of indeterminate grains in the record, and higher values of Asteraceae subf. Cichoridae, Brassicaceae, and Poaceae than in BL-3. The pollen assemblage may reflect locally

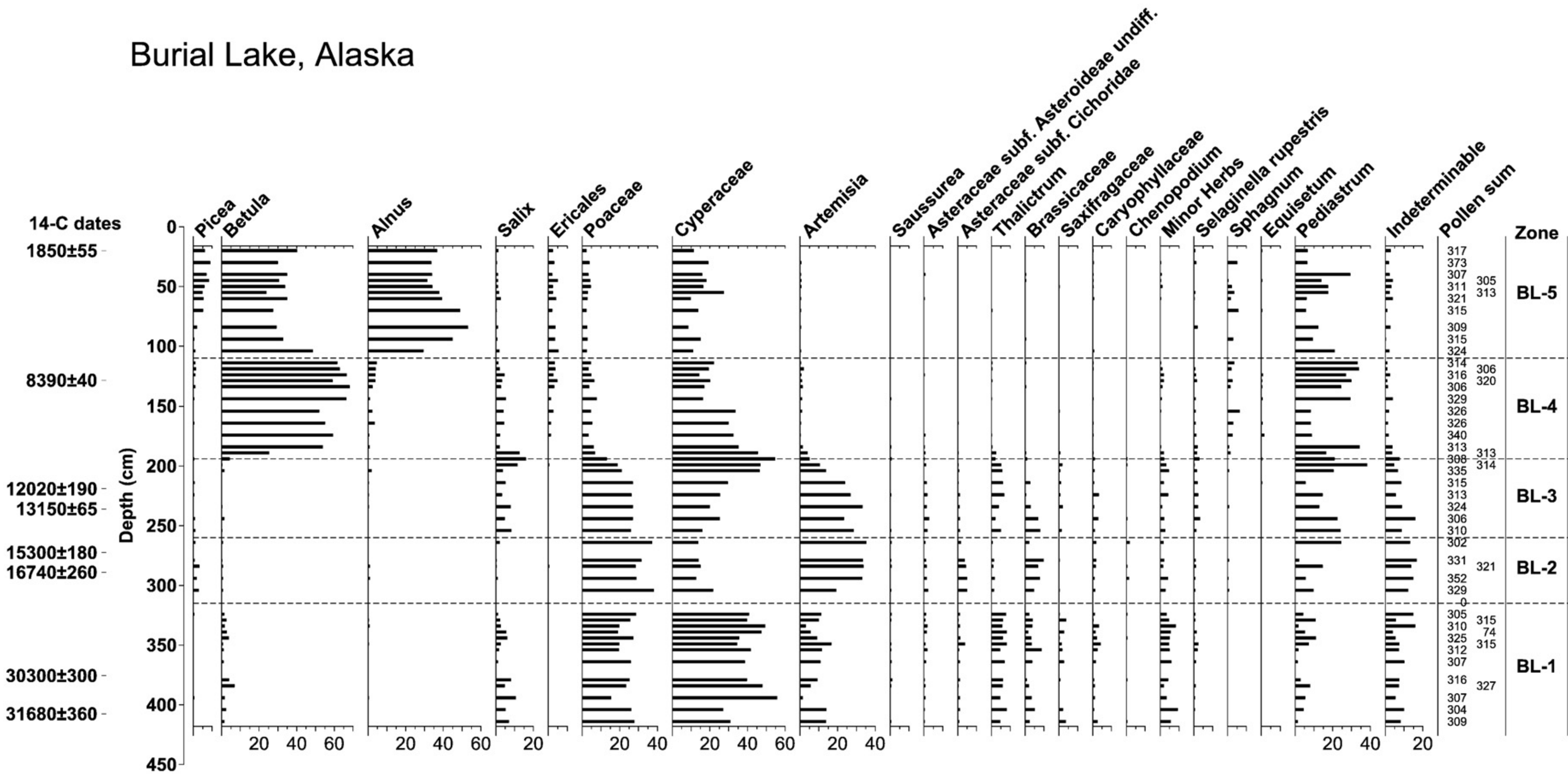

Figure 3. Frequencies (percentages) of major pollen and spore taxa at Burial Lake plotted against sediment depth from modern interface. The uncalibrated radiocarbon dates used in the age model are shown to the far left.

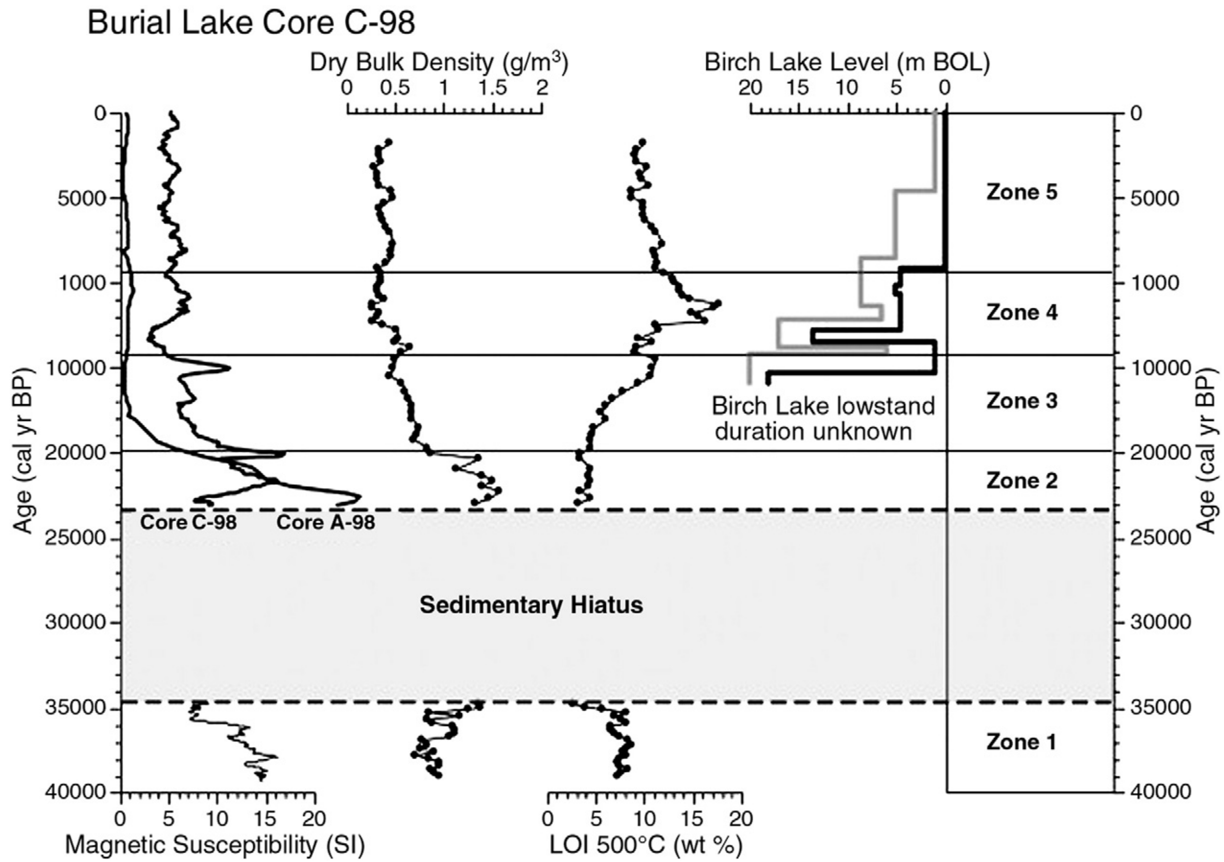

Figure 4. The large unconformity is highlighted by the plots of magnetic susceptibility, dry bulk density and LOI at 500°C against time. Comparison of the Burial and Birch Lake water-level reconstructions heights the onset of wetter conditions across eastern Beringia after 15,000 cal yr BP. The gray and black lines for the Birch Lake lake-level reconstruction estimate the range of the low and high water levels, respectively.

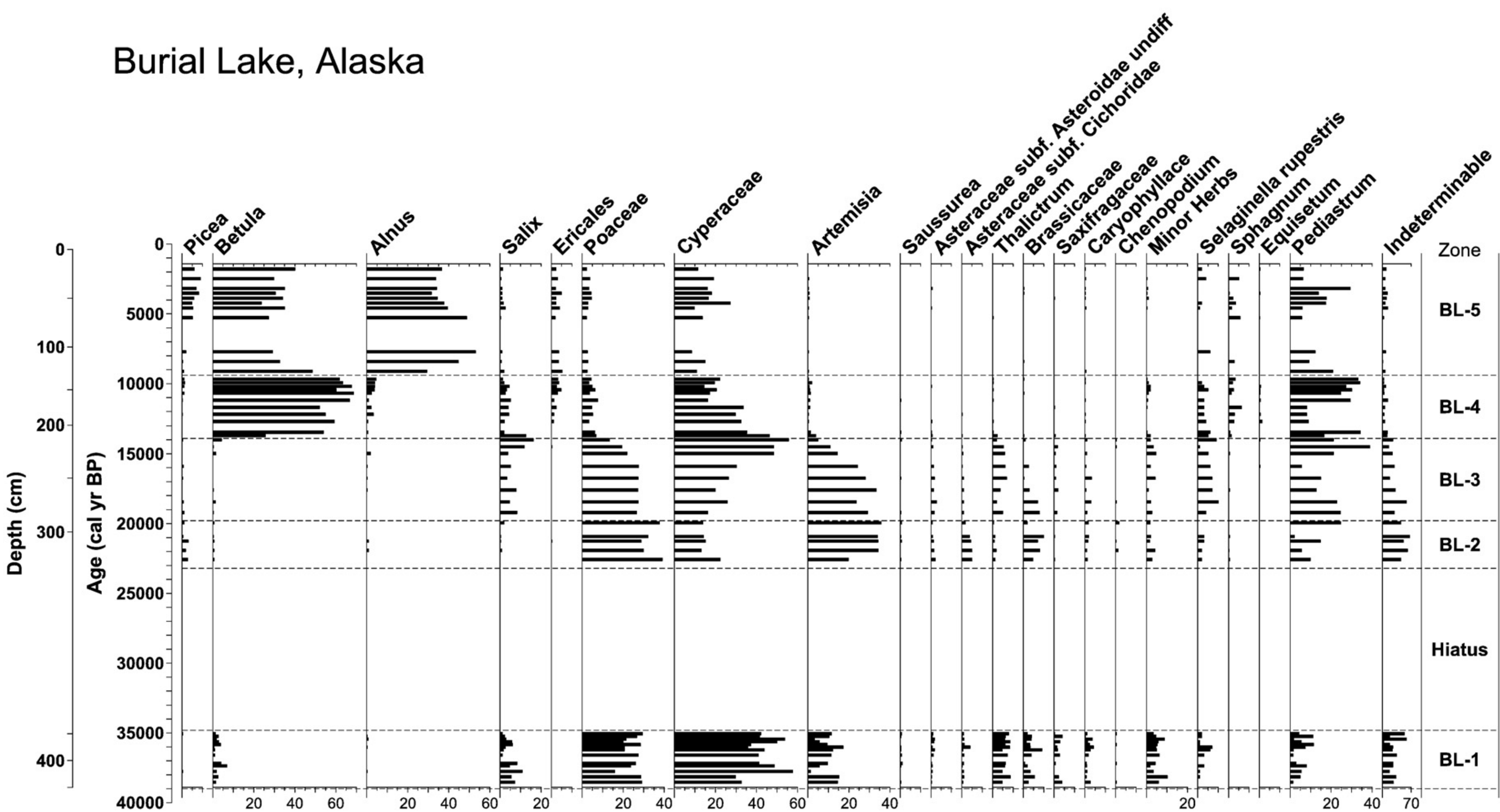

Figure 5. Burial Lake pollen frequencies plotted on an age axis. The pollen zones discussed in the text are shown on the right.

Table 2
Burial Lake stratigraphic units.

Sediment unit	Pollen zone	Depth below sediment interface (cm)	Age range (cal yr BP)
5	BL-5	128-0	9,400—present
4	BL-4	220-128	13,900–9,400
3	BL-3	290-220	19,800–13,900
2	BL-2	340-290	~23,200 to 19,800
(hiatus)	(hiatus)	(340: no pollen)	(~34,800 to ~23,200)
1	BL-1	460-340	~39,000 to ~34,800

unstable local terrestrial environments, such as the steep slopes surrounding the lake and fluctuating shorelines.

19.8 to 13.9 ka: lithologic unit #3 and pollen zone BL-3

After 19,800 cal yr BP, lake level rose above the 5.8 m BOL at the location of Core A-98 (Fig. 4) and there is no evidence that it dropped below this level again. The sediment record is characterized by decreasing grain size (from silt to fine silt and clay), decreasing magnetic susceptibility (from 10 to 5×10^{-7} SI), lower and stable C/N atomic ratios, and increasing organic matter content (from <5 to >10 wt %). The pollen of Poaceae, *Artemisia*, and Cyperaceae dominates (in decreasing order of importance), and other prominent taxa are *Thalictrum* and *Selaginella rupestris*. Pollen/exotic ratios increase through the zone (Fig. 2). A trend to more mesic conditions with time is evident: Cyperaceae and *Salix* increase over the zone at the expense of *Artemisia* and Poaceae. The other regional sites show similar vegetation patterns. Between 15,000 and 14,000 cal yr BP *Salix* pollen peaks briefly, reflecting shrub-willow expansion at the end of this pollen zone.

13.9 to 9.4 ka: lithologic unit #4 and lower lithologic unit #5, and pollen zone BL-4

A clear change after 13,900 cal yr BP appears to reflect increasing moisture, which likely raised lake level closer to its current overflowing position and stabilized the vegetation in the catchment. The sediment record is characterized by fine grain size (silt to clay), low magnetic susceptibility ($<8\times10^{-7}$ SI), decreasing bulk density (0.6 to 0.4 g/cm^3), and increasing organic matter content (from 10 to >15 wt %). Pollen/exotic ratios are at their highest, suggesting increased terrestrial productivity. At 13,900 cal yr BP there is a major rise in *Betula* pollen, reflecting a regional shrub-birch expansion dated similarly at Tukuto by AMS ^{14}C measurements on macrofossils (Oswald et al., 2005); this age is 1000–1500 yr younger than at Niliq, Kaiyak, Squirrel, and Joe lakes, which were all dated using bulk sediments for radiocarbon ages. The region-wide expansion of woody vegetation likely reflects both warmer and moister conditions. Both *Betula* and *Salix* are likely to have survived the LGM within the region, and thus this expansion can be assumed to have occurred as an immediate response to climate change (see Brubaker et al., 2005). Unlike many sites in northern Alaska, no *Populus* subzone is recorded at Burial Lake. This may reflect the relatively high and exposed location of the site; *Populus* pollen is not effectively dispersed (Birks, 1980; Edwards and Dunwiddie, 1985).

9400 cal yr BP to present: upper lithologic unit #5 and pollen zone BL-5

After 9400 cal yr BP water levels appear to stabilize and remain above the overflowing level with no evidence of lowering throughout the Holocene. The sediment record is characterized by fine grain size (fine silt to clay), low magnetic susceptibility ($<8\times10^{-7}$ SI), stable dry bulk density, and decreasing organic matter content (from >15 to 10 wt %). At ~9000 cal yr BP *Alnus* expands. This date for the *Alnus* rise obtained using terrestrial macrofossils is similar to that at Tukuto, but considerably younger than bulk-sediment dates from Squirrel, Joe, and Kayak lakes. The period is characterized at all sites by heaths and *Sphagnum*, which indicate development of moist shrub tundra, the dominant Holocene vegetation of the region. At Burial Lake, the increase of *Picea* pollen values to ~10% marks the regional expansion of spruce into nearby river valleys (also seen at Squirrel and Niliq lakes).

The full-glacial moisture record of northwest Alaska

To date, six lakes in northwest Alaska have been reported with sediments that are LGM or older: Burial, Tukuto (Oswald et al., 1999), Joe (Anderson, 1988; Anderson et al., 1994), Kaiyak (Anderson, 1985), Lake of the Pleistocene (Mann et al., 2002) and Squirrel (Anderson, 1985; Berger and Anderson, 2000). Of these, Burial, Tukuto, and Joe show clear evidence of hiatuses based on age–depth relationships, Tukuto during a period prior to ~25 cal ka BP, and Joe between ~20 and 30 ka. Zagoskin Lake in far western Alaska (Ager, 2003) provides a continuous record from >25,000 cal yr BP to present based on conventional bulk-sediment radiocarbon dates. Based on these dates sedimentation occurred in the deeper areas of all of these lake basins by about 23,000 cal yr BP, supporting our suggestion that the most arid conditions occurred prior to 23,000 cal yr BP. Nevertheless, continued lowstands at Burial until ~19,800 cal yr BP are supported by an *in situ* soil formed at 5.8 m BOL preserved in Core A-98 and results from pollen analysis of Core C-98 that indicate the area was virtually devoid of shrubs. As Core C-98 was not taken from the deepest part of Burial Lake, we are limited to identifying a drop in water level to more than 11.3 m (allowing for subsequent sedimentation) below current datum. The vegetation record indicates that conditions gradually became moister after ~17 cal ka BP, prior to a major increase in moisture at ~15,000 cal yr BP. Thus, the latter part of MIS 2 (~21,000 cal yr BP and later) in northwest Alaska may have seen an early, but subtle, moisture increase; perhaps too subtle to be sensed in more continental regions further to the east.

Overall, the evidence suggests significantly lower moisture availability in MIS 2 compared with the present; conditions may have been slightly, but not greatly, moister in northwest Alaska than further east, where many small lake basins were completely dry. Eolian activity was greater than present in glacial periods (Hopkins, 1982; Péwé, 1975; Muhs et al., 2001). This has several implications for lacustrine records, because it is possible during this time that lake basins accumulated thick packages of eolian sediments (Muhs et al., 2003). More commonly, sediments in dry basins were intermittently deflated, as at Burial Lake, leading to hiatuses that can also be difficult to identify, but which can make the retrieval of older (e.g. MIS 3) sediments more feasible with conventional coring techniques. This apparently happened at several lakes in the western Brooks Range (see above). These features suggest that detailed, continuous records of MIS 2, and even of late MIS 3, may be rare, even in NW Alaska, and the temporal resolution required to examine the terrestrial record for rapid events, such as those associated with the Dansgaard-Oeschger cycles of the North Atlantic (Johnsen et al., 1992), may be difficult to achieve from many lacustrine records.

Proximity to marine moisture sources has been invoked to explain the implied west-to-east LGM moisture gradient (e.g., Guthrie, 2001). GCM simulations for 21,000 cal yr BP carried out under the PMIP project (Braconnot et al., 2007) support this: all sets of simulations in the LGM experiment show moister conditions in northwest Alaska compared with more continental regions to the east. While some sites in western Alaska and the Brooks Range show apparently continuous lacustrine sedimentation through the LGM (e.g., Kaiyak and Squirrel [Anderson, 1985], Rebel and Redstone [Edwards et al., 1985], Zagoskin [Muhs et al., 2003]), most lake basins in eastern and interior Alaska began lacustrine sedimentation in the late glacial (see, for example, Ager, 1975; Abbott et al., 2000; Bigelow and Edwards, 2001). Other evidence for the moisture gradient includes the characteristics of a buried 21,000-yr-old soil on Seward Peninsula that indicate seasonally moist conditions (Höfle et al., 2000), and plant-macrofossil and beetle data from the Bering and Chukchi shelves indicating mesic tundra environments (Elias et al., 1996, 1997). However, the latter tend to reflect local, rather than regional, conditions and lack AMS ^{14}C dates from the LGM. Ager (2003) reports xeric vegetation from western Alaska for this time. Overall, the data suggest slightly moister (but still arid) conditions at 21,000 cal yr BP in northwest Alaska than further east, in line with general trends (but not absolute values of departures from present) in model simulations. However, very dry conditions are indicated earlier, in late MIS 3 and early MIS 2.

Late glacial and Holocene moisture increases

Burial Lake sediments indicate that the marked moisture increase after 15,000 cal yr BP stabilized substrates in the catchment, as indicated by lower magnetic susceptibility and the onset of fine-grained organic-rich sedimentation. Aquatic pollen abundance is greatest between ~15,000 and 10,000 cal yr BP at sites such as Kaiyak, Niliq, and Joe (Anderson, 1985,1988), and this was interpreted by Edwards et al. (2000) to reflect warmer and/or shallower conditions than present. Water levels fell at Lake of the Pleistocene and streams around it incised their floodplains from ~12,900 to 11,900 cal yr BP (10,900 to 10,200 ^{14}C yr BP) during a period coinciding with the Younger Dryas in the North Atlantic, after which lake levels increased and streams aggraded (Mann et al., 2002). In Birch Lake a similar lowstand occurred between about 13,500 and 12,000 cal yr BP. Both the Lake of the Pleistocene and Birch Lake records are dated with AMS ^{14}C methods so it is not clear if there is a dating problem with one or both sites, or if the two regions are responding differently to a common climate forcing. It is also possible that the two sites record different ages for increased moisture because the forcing acted on eastern sites earlier than lakes to the west, suggesting a mechanism related to ice sheet/atmosphere interactions. There is clearly room for improvement in radiocarbon dating methods for Arctic lakes as well as the methods used to reconstruct moisture balance.

Terrestrial pollen evidence indicates increasingly moist conditions and the expansion of shrubs. The AMS ^{14}C ages for the *Salix* and *Betula* increases are similar to dates reported from Tukuto Lake (Oswald et al., 1999) and for *Betula* at Lake of the Pleistocene (Mann et al., 2002). Given the tendency for AMS ^{14}C dates to be younger than bulk-sediment dates in paired comparisons (Abbott and Stafford, 1996; Oswald et al., 2005), the AMS ^{14}C chronologies bring the regional *Betula* rise in line with AMS ^{14}C ages across unglaciated Alaska. In this regard, a large-scale control, such as the circulation readjustment proposed by Bartlein et al. (1991) appears a more likely cause of the widespread moisture change than the gradual flooding of the land bridge. Environmental changes such as deeper snow cover and/or an increase in growing degree-days, for example, would promote a shift from prostrate *Salix* to cover of somewhat larger *Salix* and *Betula* shrubs. A continuing increase in moisture is reflected in the establishment of stable/overflowing conditions—reflecting the wettest part of the period of record—after ~9.4 cal ka BP, at which time *Alnus* became established in the region.

Conclusions

A close examination of past sediment deposition at Burial Lake indicates one or more unconformities related to greatly lowered lake levels, and we suggest that such features are apparent in other records from the region. During the late Pleistocene, the driest period in the region evidently preceded the LGM, and conditions became slightly moister subsequently, allowing a slight moisture gradient to develop from west to east across Alaska. While there is evidence to support a west–east gradient in moisture at the LGM, there is limited evidence for a strong gradient developing time-transgressively in the late glacial or early Holocene. Rather, AMS ^{14}C dates on key vegetation changes suggest that bulk-sediment dates may be too old and that late glacial vegetation changes were synchronous across Alaska. Lake basins that have large lake-level fluctuations or that dry out intermittently represent a challenge for dating and interpretation, but their sediments archive unprecedented information regarding the magnitude of past changes in regional water balance.

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