Evidence of synchronous climate change across the Northern Hemisphere between the North Atlantic and the northwestern Great Basin, United States

Mladen Zic
Robert M. Negrini
Peter E. Wigand
Department of Physics and Geology, California State University, Bakersfield, California 93311, USA

ABSTRACT

From ca. 50 to 20 ka, Summer Lake, Oregon, rose and fell in tune with North Atlantic interstadial and stadial climatic oscillations, respectively. This record exhibits the complete morphology of the North Atlantic millennial-scale climate-change signal including Dansgaard-Oeschger oscillations, Heinrich events, and Bond cycles. The phase relationship of these climate change records (high Summer Lake during warm North Atlantic; low during cold) is demonstrated at millennial-scale resolution by the relative positions of the Mono Lake and Laschamp paleomagnetic excursions in these records. These results, in conjunction with comparisons of historical climate records, also presented here, imply a direct temporal connection at the subcentury scale between the North Atlantic and the northwestern Great Basin via an atmospheric teleconnection.

Keywords: Great Basin, lake level, excursions, paleoclimate.

INTRODUCTION

The communication of late Quaternary millennial-scale climate change throughout the Northern Hemisphere has been recognized in previous studies (Phillips et al., 1994; Clark and Bartlein, 1995; Mikolajewicz et al., 1997; Oviatt, 1997; Benson, 1999; Hendy and Kennett, 1999; Kienast and McKay, 2001). Of the studies focusing on lake records of North America, none has established a clear correspondence with the full spectrum of variations observed in the archetypal millennial-scale climate record from the North Atlantic for time intervals prior to the last glacial maximum (ca. 20 ka) (e.g., Benson, 1999, and references therein).

Here we present a new record of lake-level change from the Summer Lake basin, a subbasin of pluvial Lake Chewaucan located in the northwesternmost portion of the Great Basin (Fig. 1). As we demonstrate in the following, this record is strikingly similar to the millennial-scale climate record from Greenland ice cores and is dated well enough to establish an unambiguous phase relationship between wet and dry climate in the northwest Great Basin and warm and cool temperatures in the North Atlantic region. Furthermore, we show that this relationship may be active today.

MILLENNIAL-SCALE LAKE-LEVEL HISTORY FOR THE SUMMER LAKE BASIN FROM ca. 50 TO 20 ka

Previous low-resolution paleoclimate studies from Summer Lake, Oregon, have shown that relative lake level can be approximated using rapidly measured parameters that determine the relative concentration of (titano)magnetite (Roberts et al., 1994; Cohen et al., 2000; Negrini et al., 2000). These earlier works demonstrated that magnetite was the dominant magnetic mineral and that its concentration varied sympathetically with independent indicators of lake level based on lithology, sedimentary structures, palynology, ostracode paleontology, and geochemistry. For example, Negrini et al. (2000) found strong correspondence between high concentrations of total organic carbon (TOC) and low magnetite concentrations, which are concurrent with high silt/clay ratios indicating low lake level. Furthermore, low concentration of magnetite can be largely attributed to magnetite dissolution due to oxidative decomposition of organic matter during periods of high productivity (e.g., Snowball, 1993; Negrini et al., 2000; Lanci et al., 2001).

In this study we apply the same technique on a high-resolution record obtained from the ''Bed and Breakfast'' (B&B) core taken from the Summer Lake depocenter (42°48′27.0″N; 120°46′56.4″W). The B&B core contains 12 m of clay-rich silts deposited between ca. 50 and 20 ka (Negrini et al., 2000). The more recent sediments are missing due to deflation initiated ca. 20 ka by the diversion of the Chewaucan River into a neighboring subbasin (Davis, 1985). Each of the 344 samples taken from this core spanned ~1.9 cm of depth and was separated from adjacent samples by an interval of ~3.4 cm. Thus, the magnetite concentration of each sample represents a 40–50 yr average and is separated from the adjacent sample by an interval of 80–90 yr.

The three most commonly used estimates of magnetite concentration (isothermal remanent magnetization [IRM], magnetic susceptibility [κ], and anhysteretic remanent magnetization [ARM]) (Thompson and Oldfield, 1986; Peck et al., 1994) are plotted versus depth for the B&B core in Figure 2. These results exhibit three repetitions of a distinct, sawtooth-shaped cycle with a wavelength of ~4 m. Several shorter (~0.5–1.0 m) wavelength features are also evident. The shapes of each repetition of the sawtooth-shaped waveform resemble the repetitions of the Bond cycle found between Heinrich events H5 and H2, both in ice core (e.g., the GISP2 $\delta^{18}O$ temperature proxy; GISP2—Greenland Ice Sheet Project 2) and marine climate records from the North Atlantic region (Bond et al., 1993; Grootes et al., 1993; Broecker, 1994). Assuming a correspondence between these low-frequency features, we assigned GISP2 ages to their boundaries (Fig. 3). In this procedure we also tuned the record so that the shorter wavelength oscillations in IRM correlated to each Dansgaard-Oeschger (D-O) oscillation according to each of the latter's respective position in each repetition of the Bond cycle (e.g., IS 8 appears immediately after H4). This

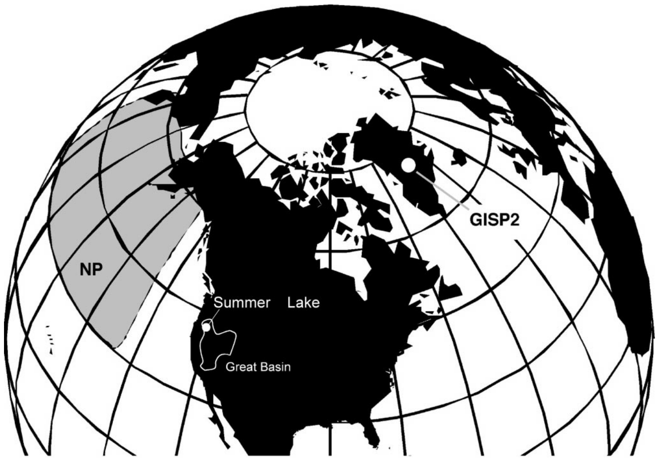

Figure 1. Location of Summer Lake relative to Greenland Ice Sheet Project 2 (GISP2) ice core site. Also shown is region of North Pacific (NP) used in calculation of NP Index of atmospheric pressure (Trenberth and Hurrell, 1994).

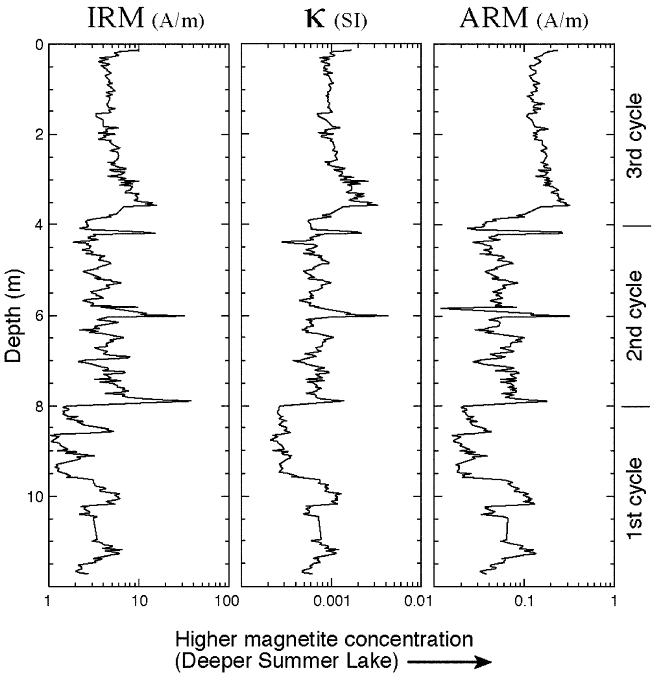

Figure 2. Magnetic concentration parameters for Summer Lake B&B core. Boundaries of repetitions of long-wavelength cycle discussed in text are shown at right. Magnetite concentration for all parameters and, hence, lake level increase to the right. IRM, isothermal remanent magnetization; κ, magnetic susceptibility; ARM, anhysteretic remanent magnetization.

exercise predicts a high-resolution chronology for the B&B record shown by the solid line in Figure 4.

TESTING THE CORRELATION MODEL WITH INDEPENDENT AGE CONTROL

A chronology for the B&B core, ostensibly precise at the century scale, is predicted by the correlation model shown in Figure 3. This model is supported by the following independent evidence, discussed in order of increasing resolution.

In support of multimillennial-scale chronology, ^{14}C dates on ostracodes from the B&B sediments and ^{14}C and thermoluminescence (TL) dates associated with the Wono and Mount St. Helens Cy tephra layers are plotted along with the predicted chronology in Figure 4. Five of the radiocarbon dates shown in Figure 4 are new and all are on ostracodes from the B&B core. The laboratory numbers, and ages before calibration, are as follows: Beta-66318/CAMS-9253 (33 350 $\pm$ 400 B.P.), Beta-74796/CAMS-15022 (38 440 $\pm$ 1060 B.P.), Beta-74797/CAMS-15023 (40 250 $\pm$ 1290 B.P.), Beta-74798/CAMS-15024 (41 030 $\pm$ 1430 B.P.), and Beta-66319/CAMS-9254 (37 610 $\pm$ 690 B.P.). These dates clearly support our assignment of each sawtooth-shaped variation in the level of Summer Lake to particular repetitions of the Bond cycle.

With regards to the millennial-scale precision of the chronology, first we note that the ^{14}C and TL dates are not precise enough to support the hypothesis of low lake levels in phase with D-O stadials. We can, however, support this hypothesis at least during the Mono Lake and Laschamp excursions by temporally correlating the B&B core record of these events with their expression in the Greenland ice cores (Fig. 3). Intervals of anomalously low inclination during both of these excursions fall within intervals of low paleomagnetic intensity (e.g., Coe and Liddicoat, 1994; Benson et al., 1998), which correspond to peaks in ^{36}Cl concentration observed in Greenland ice cores (Wagner

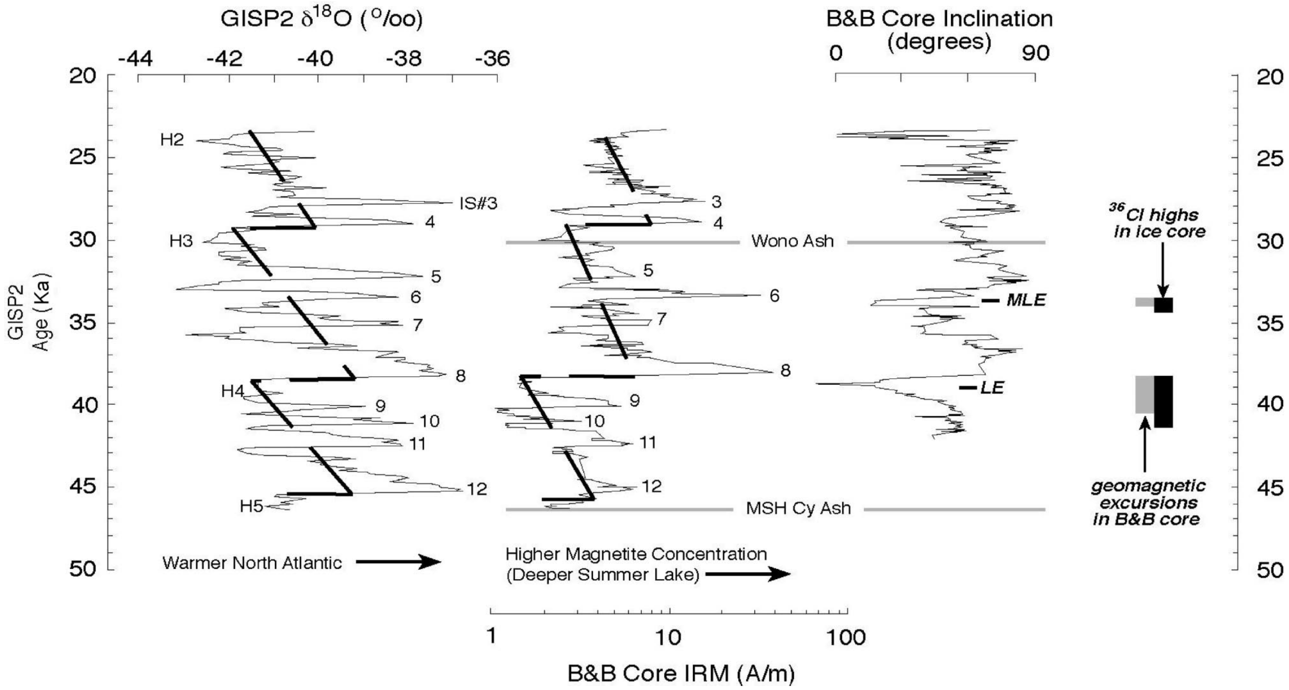

Figure 3. Correlation model of isothermal remanent magnetization (IRM)–based lake-level proxy from Summer Lake B&B core with North Atlantic region temperature proxy from Greenland Ice Sheet Project 2 (GISP2) ice core. Paleomagnetic inclination record from B&B core is also shown. Ages are in calendar years and are based on GISP2 chronology (Meese et al., 1994). Locations of interstadial halves of Dansgaard-Oeschger oscillations (IS) and Heinrich events (H) are indicated. Bond cycle is outlined in both paleoclimate records with bold dashed lines. Inclination lows associated with Laschamp (LE) and Mono Lake (MLE) excursions are shown, as are locations of Wono ash and Mount St. Helens (MSH) Cy tephra. Time spans containing inclination lows are indicated by gray boxes near right time scale. Black boxes show time spans containing ^{36}Cl peaks found in Greenland Ice Core Project (GRIP) ice core that have been attributed to intensity lows associated with two excursions (Wagner et al., 2000a, 2000b). Tephra correlations were discussed in Negrini et al. (2000).

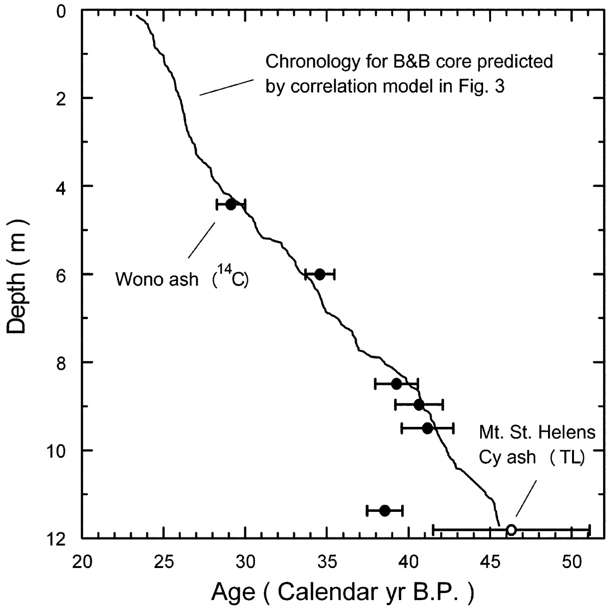

Figure 4. Independent age control for Summer Lake B&B core. Chronology for B&B core is based on correlation model of Figure 3 and is depicted by solid line. Solid circles denote ^{14}C-based ages, all of which are on ostracodes from B&B core, except for that associated with Wono ash (Benson et al., 1997). Open circle is thermoluminescence (TL) data point on Mount St. Helens Cy ash layer (Berger and Busacca, 1995). ^{14}C-based ages were corrected for variable production rates according to method of Laj et al. (1996). Correction of 1613 ± 508 yr was subtracted from ^{14}C ages for reservoir effects. This correction value corresponds to average age of modern carbonates measured in Mono Lake (Benson et al., 1990). We assumed that this reservoir correction was also applicable at Summer Lake because Wono tephra layer in B&B core projects onto Mono Lake paleomagnetic inclination record at same age as that measured for ash (Benson et al., 1997, 1998).

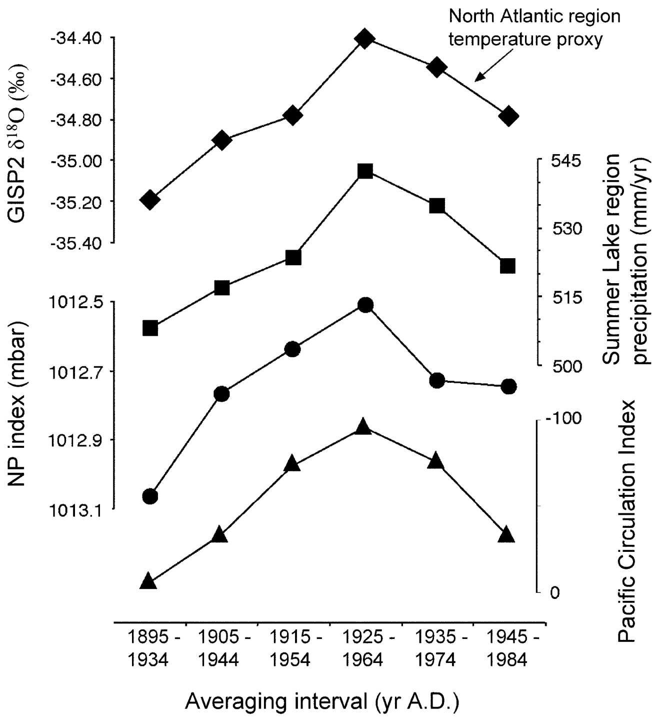

Figure 5. Comparison of North Atlantic region temperatures (diamonds) with precipitation in Summer Lake region (squares) and two indices of North Pacific (NP) storm intensity: NP Index of atmospheric pressure (solid circles) and Pacific Circulation Index (triangles). See text for description of data points.

et al., 2000a, 2000b). In particular, the inclination low for the Mono Lake excursion and the corresponding zone of high ^{36}Cl concentration in the ice-core record are both contained completely within the low-lake (stadial) event between interstadials (IS) 6 and 7. This strongly suggests that the Summer Lake and Greenland ice-core records are temporally phase locked (Fig. 3); more specifically, Summer Lake rises during North Atlantic interstades and vice versa. We also note that our findings are consistent with the occurrence of a highstand event during the Bølling interstadial in the nearby ZX basin, a subbasin of pluvial Lake Chewaucan (Licciardi, 2001).

We note that other studies that have correlated high-resolution records to the ice-core records based on strikingly similar morphology (e.g., Hendy and Kennett, 1999) have argued that their correlations are precise to the multidecadal scale represented by the typical sample, particularly in the vicinity of rapid transitions. We support a similar presumption of multidecadal precision for the B&B correlation model with independent evidence (Fig. 5) showing that climates in the Summer Lake and North Atlantic regions have been in phase during historic times at a multidecadal time scale. Figure 5 presents a comparison of historic data sets that include analogs for the paleoclimate data of Figure 3. The top set of data consists of the same δ^{18}O temperature proxy from the GISP2 ice core (Stuiver and Grootes, 2000). The second set consists of precipitation data spatially averaged over Oregon climate zones 5 and 7 by the National Climatic Data Center (Oregon Climate Service, 2001). Summer Lake is located at the boundary of these climate zones. This figure also includes the North Pacific (NP) Index and the Pacific Circulation Index (PCI). The NP Index is the atmospheric pressure (Trenberth and Hurrell, 1994) spatially averaged over the North Pacific Ocean (Fig. 1) in the region associated with the Aleutian low, an important atmospheric phenomenon associated with storm activity in the northern Great Basin (Houghton, 1969). The PCI, also related to the Aleutian Low, reflects the strengths of westerly and southwesterly winds from the Pacific (King et al., 1998); when strong, these winds appear to increase the likelihood that moisture-bearing storms will move into eastern Oregon, generally from the southwest, from October to June (Sneva and Calvin, 1978). The ordinate axes of these indices are inverted so that upward trends reflect greater storm activity. All data sets are averaged over 40 yr intervals, which is about the same interval over which the paleoclimate data from Summer Lake are averaged (Figs. 2 and 3). The time interval starts at the earliest year for which precipitation data are available and ends at the latest 40 yr interval for which ice-core data are available. Assuming that local precipitation is closely related to the level of Summer Lake, we conclude that the close correspondence of the top two data sets is strong evidence for the multidecadal synchronicity of North Atlantic region temperatures and moisture levels in the Summer Lake area during the historical period. Because the NP Index and the PCI correlate with the upper two data sets, it appears that variations in storm activity in the North Pacific play a strong role in the aforementioned synchronous relationship, thereby supporting the results of earlier studies calling for hemisphere-scale atmospheric teleconnections.

CONCLUSIONS

Our analyses demonstrate that Summer Lake rose and fell in phase with the full array of millennial-scale oscillations between interstadial and stadial conditions in the Northern Atlantic region between Heinrich events 5 and 2 (Fig. 3). Furthermore, this relationship appears to exist today, although at a much more subdued level than during the late Pleistocene, perhaps reflecting the correspondingly lower amplitude of change in historic climates (Fig. 5).

Previous works have proposed that a migrating polar jet stream induced by changes in the size of the Laurentide ice sheet is one possible mechanism for a connection between North Atlantic millennial-scale climate change and lake level in the Great Basin (Oviatt, 1997; Benson, 1999). Our results demonstrate that teleconnected ocean and atmosphere conditions between the North Atlantic and the North Pacific may be sufficient for climate change in the Great Basin at millennial-scale and higher frequencies. Thus, dramatic changes in the size of the Laurentide ice sheet may not be necessary for high-frequency climate changes like D-O oscillations. In particular, the historic data shown in Figure 5, which are not influenced by Laurentide ice sheet dynamics, imply a teleconnection where an increase in Summer Lake precipitation of ~30 mm/yr corresponds to a change in GISP2 $\delta^{18}O$ of ~0.70‰. Assuming that this relationship is scaled linearly, the millennial-scale, high-amplitude $\delta^{18}O$ changes that characterized late Pleistocene millennial-scale climate change would correspond to northwestern Great Basin precipitation changes on the order of 250–300 mm/yr. This value is consistent with precipitation estimates for this region during this time implied by the appearance of Whitebark Pine at low elevations during pluvial maxima (Wigand and Nowak, 1992; Thompson et al., 1999, p. 82, 205).

ACKNOWLEDGMENTS

We are grateful for helpful reviews by L.V. Benson, C.G. Oviatt, and two anonymous readers. Martha Hemphill, Pat Mungary, Vic Mungary, Dan Erbes, and Peter van de Water provided help during coring. Early phases of this research were supported by National Science Foundation grant EAR-9117778.

REFERENCES CITED

Benson, L., 1999, Records of millennial-scale climate change from the Great Basin of the western United States, *in* Clark, P.U., et al., eds., Mechanisms of global climate change at millennial time scales: American Geophysical Union Geophysical Monograph 112, p. 203–225.

Benson, L.V., Currey, D.R., Dorn, R.I., Lajoie, K.R., Oviatt, C.G., Robinson, S.W., Smith, G.I., and Stine, S., 1990, Chronology of expansion and contraction of four Great Basin lake systems during the past 35 000 years: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 78, p. 241–286.

Benson, L., Smoot, J.P., Kashgarian, M., Sarna-Wojcicki, A.M., and Burdett, J., 1997, Radiocarbon ages and environments of deposition of the Wono and Trego Hot Spring tephra layers in the Pyramid Lake sub-basin, Nevada: Quaternary Research, v. 47, p. 251–260.

Benson, L.V., Lund, S.P., Burdett, J.W., Kashgarian, M., Rose, T.P., Smoot, J.P., and Schwartz, M., 1998, Correlation of late Pleistocene lake-level oscillations in Mono Lake, California, with North Atlantic climate events: Quaternary Research, v. 49, p. 1–10.

Berger, G.W., and Busacca, A.J., 1995, Thermoluminescence dating of late Pleistocene loess and tephra from eastern Washington and southern Oregon and implications for the eruptive history of Mt. St. Helens: Journal of Geophysical Research, v. 100, p. 22 361–22 374.

Bond, G.C., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., and Bonani, G., 1993, Correlations between climate records from North Atlantic sediments and Greenland ice: Nature, v. 365, p. 143–147.

Broecker, W.S., 1994, Massive iceberg discharges as triggers for global climate change: Science, v. 372, p. 421–424.

Clark, P.U., and Bartlein, P.J., 1995, Correlation of late Pleistocene glaciation in the western United States with North Atlantic Heinrich events: Geology, v. 23, p. 483–486.

Cohen, A.S., Palacios-Fest, M.R., Negrini, R.M., Wigand, P.E., and Erbes, D.B., 2000, A paleoclimate record for the past 250 000 years from Summer Lake, Oregon, USA: II. Sedimentology, paleontology and geochemistry: Journal of Paleolimnology, v. 24, p. 151–182.

Coe, R.S., and Liddicoat, J.C., 1994, Overprinting of natural magnetic remanence in lake sediments by a subsequent high-intensity field: Nature, v. 367, p. 57–59.

Davis, J.O., 1985, Correlation of late Quaternary tephra layers in the long pluvial sequence near Summer Lake, Oregon: Quaternary Research, v. 23, p. 38–53.

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, v. 366, p. 552–554.

Hendy, I.L., and Kennett, J.P., 1999, Latest Quaternary North Pacific surface-water responses imply atmosphere-driven climate instability: Geology, v. 27, p. 291–294.

Houghton, J.G., 1969, Characteristics of rainfall in the Great Basin: Reno, Nevada, Desert Research Institute, 205 p.

Kienast, S.S., and McKay, J.L., 2001, Sea surface temperatures in the subarctic Northeast Pacific reflect millennial scale climate oscillations during the last 16 kyrs: Geophysical Research Letters, v. 28, p. 1563–1566.

King, J.R., Ivanov, V.V., Kurashov, V., Beamish, R.J., and McFarlane, G.A., 1998, General circulation of the atmosphere over the North Pacific and its relationship to the Aleutian Low: North Pacific Anadromous Fish Commission, Document 318, 18 p.

Laj, C., Mazaud, A., and Duplessy, J.-C., 1996, Geomagnetic intensity and ^{14}C abundance in the atmosphere and ocean during the past 50 kyr: Geophysical Research Letters, v. 23, p. 2045–2048.

Lanci, L., Hirt, A.M., Lotter, A.F., and Sturm, M., 2001, A record of Holocene climate in the mineral magnetic record of Alpine lakes: Sägistalsee and Hinterburgsee: Earth and Planetary Science Letters, v. 188, p. 29–44.

Licciardi, J.M., 2001, Chronology of latest Pleistocene lake-level fluctuations in the pluvial Lake Chewaucan basin, Oregon, USA: Journal of Quaternary Science, v. 16, p. 545–553.

Meese, D.A., Alley, R.B., Gow, A.J., Grootes, P., Mayewski, P.A., Ram, M., Taylor, K.C., Waddington, E.D., and Zielinsky, G., 1994, Preliminary depth-age scale of the GISP2 ice core: Hanover, New Hampshire, U.S. Army Corps of Engineers CRREL Special Report 94-1, 66 p.

Mikolajewicz, U., Crowley, T.J., Schiller, A., and Voss, R., 1997, Modelling teleconnections between the North Atlantic and North Pacific during the Younger Dryas: Nature, v. 387, p. 384–387.

Negrini, R.M., Erbes, D.B., Faber, K., Herrera, A.M., Roberts, A.P., Cohen, A.S., Wigand, P.E., and Foit, F.F., Jr., 2000, A paleoclimate record for the past 250 000 years from Summer Lake, Oregon, USA: I. Chronology and magnetic proxies for lake level: Journal of Paleolimnology, v. 24, p. 125–149.

Oregon Climate Service, 2001, Oregon climate divisions precipitation data, available at http://www.ocs.orst.edu/pub_ftp/climate_data/divisions/orprcp.html (accessed January 2001).

Oviatt, C.G., 1997, Lake Bonneville fluctuations and global climate change: Geology, v. 25, p. 155–158.

Peck, J.A., King, J.W., Colman, S.M., and Kravchinsky, V.A., 1994, A rock-magnetic record from Lake Baikal, Siberia: Evidence for late Quaternary climate change: Earth and Planetary Science Letters, v. 122, p. 221–238.

Phillips, F.M., Campbell, A.R., Smith, G.I., and Bischoff, J.L., 1994, Interstadial climatic cycles: A link between western North America and Greenland?: Geology, v. 22, p. 1115–1118.

Roberts, A.P., Verosub, K.L., and Negrini, R.M., 1994, Middle/Late Pleistocene relative paleointensity of the geomagnetic field from lacustrine sediments, Lake Chewaucan, western United States: Geophysical Journal International, v. 118, p. 101–110.

Sneva, F.A., and Calvin, L.D., 1978, An improved thiessen grid for eastern Oregon: An interstation correlation study determining the effect of distance, bearing, and elevation between stations upon the precipitation correlation coefficient: Agricultural Meteorology, v. 19, p. 471–483.

Snowball, I.F., 1993, Geochemical control of magnetite dissolution in subarctic lake sediments and the implications for environmental magnetism: Journal of Quaternary Science, v. 8, p. 339–346.

Stuiver, M., and Grootes, P.M., 2000, GISP2 oxygen isotope ratios: Quaternary Research, v. 53, p. 277–284.

Thompson, R., and Oldfield, F., 1986, Environmental magnetism: Winchester, Massachusetts, Allen and Unwin, 227 p.

Thompson, R.S., Anderson, K.H., and Bartlein, P.J., 1999, Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America: Introduction and conifers: U.S. Geological Survey Professional Paper 1650A, 269 p.

Trenberth, K.E., and Hurrell, J.W., 1994, Decadal atmosphere-ocean variations in the Pacific: Climate Dynamics, v. 9, p. 303–319.

Wagner, G., Beer, J., Laj, C., Kissel, C., Masarik, J., Muscheler, R., and Synal, H.-A., 2000a, Chlorine-36 evidence for the Mono Lake event in the Summit GRIP ice core: Earth and Planetary Science Letters, v. 181, p. 1–6.

Wagner, G., Masarik, J., Beer, J., Baumgartner, S., Imboden, D., Kubik, P.W., Synal, H.-A., and Suter, M., 2000b, Reconstruction of the geomagnetic field between 20 and 60 kr BP from cosmogenic radionuclides in the GRIP ice core: Nuclear Instruments and Methods in Physics Research, v. B181, p. 597–604.

Wigand, P., and Nowak, C., 1992, Dynamics of northwest Nevada plant communities during the last 30 000 years, *in* Doyle-Jones, V., et al., eds., The history of water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains, Volume IV, White Mountain Research Station Symposia: Berkeley, University of California Press, p. 40–62.

Manuscript received February 5, 2002
Revised manuscript received March 21, 2002
Manuscript accepted April 9, 2002

Printed in USA