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Last glacial–interglacial environments in the southern Rocky Mountains, USA and implications for Younger Dryas-age human occupation

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ABSTRACT

The last glacial-interglacial transition (LGIT; 19–9 ka) was characterized by rapid climate changes and significant ecosystem reorganizations worldwide. In western Colorado, one of the coldest locations in the continental US today, mountain environments during the late-glacial period are poorly known. Yet, archaeological evidence from the Mountaineer site (2625 m elev.) indicates that Folsom-age Paleoindians were over-wintering in the Gunnison Basin during the Younger Dryas Chronozone (YDC; 12.9–11.7 ka). To determine the vegetation and fire history during the LGIT, and possible explanations for occupation during a period thought to be harsher than today, a 17-ka-old sediment core from Lily Pond (3208 m elev.) was analyzed for pollen and charcoal and compared with other high-resolution records from the southern Rocky Mountains. Widespread tundra and *Picea* parkland and low fire activity in the cold wet late-glacial period transitioned to open subalpine forest and increased fire activity in the Bølling–Allerød period as conditions became warmer and drier. During the YDC, greater winter snowpack than today and prolonged wet springs likely expanded subalpine forest to lower elevations than today, providing construction material and fuel for the early inhabitants. In the early to middle Holocene, arid conditions resulted in xerophytic vegetation and frequent fire.

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Introduction

The transition between glacial and Holocene conditions (the last glacial–interglacial transition [LGIT]; 19–9 ka) has received much attention in investigations of environmental and human responses in the face of rapid climate change (Alley, 2000; Shuman et al., 2002; Meltzer and Holliday, 2010). The Gunnison Basin of Colorado is a closed, high-elevation basin that experiences today some of the coldest temperatures in the continental US. During the Younger Dryas Chronozone (YDC; 12.9–11.7 ka), Folsom Paleoindian groups occupied several sites in the Basin, most prominently the Mountaineer site (Fig. 1a). Located atop Tenderfoot Mesa (~2625 m elev.) and radiocarbon dated to 12.3 ka, excavations at the site have yielded remnants of several substantial house structures (Stiger, 2006). In an effort to understand the climatic and environmental context of the Paleoindian occupation of the Gunnison Basin, a sediment core was extracted from Lily Pond (38°56′06′′N, 106°38′37′′W, 3208 m elev.; Fig. 1b; Table 1), located in Taylor Park ~50 km northeast of the Mountaineer site. Results of the pollen, charcoal and lithological analyses help reconstruct the environmental conditions in the Gunnison Basin, and, compared with other datasets from the region, provide a broader paleoenvironmental understanding of the LGIT in the southern Rocky Mountains (Fig. 1). The Lily Pond data also allow us to make inferences regarding the environmental conditions that Paleoindians would have faced during the YDC.

Existing pollen and charcoal records in the Gunnison Basin provide a general picture of environmental change during the LGIT (Figs. 1b, 4h; Table 1). The high-elevation records (2700–3700 m elev.) indicate a change from *Picea* parkland (at middle elevations) or tundra (at high elevations) in the late-glacial period to an open forest of *Picea* and *Abies*. Most records show increasing *Pinus* species in the Holocene. A few records at upper elevations (>3300 m) in Colorado document abrupt fluctuations in alpine timberline during the LGIT (Reasoner and Jodry, 2000), and sites in northwestern Colorado, at the present-day transition between forest and steppe, exhibit slower changes in vegetation and fire activity during the LGIT (Jimenez-Moreno et al., 2011). Most records, however, lack the sampling resolution and chronologic control to discern fine-scale fluctuations in vegetation and climate during the LGIT. Lily Pond provides a high-resolution record of vegetation and fire that allows comparison with existing records from the Gunnsion region and elsewhere in Colorado and New Mexico, providing a glimpse of how ecosystems responded to abrupt climate change at different elevations in the southern Rocky Mountains.

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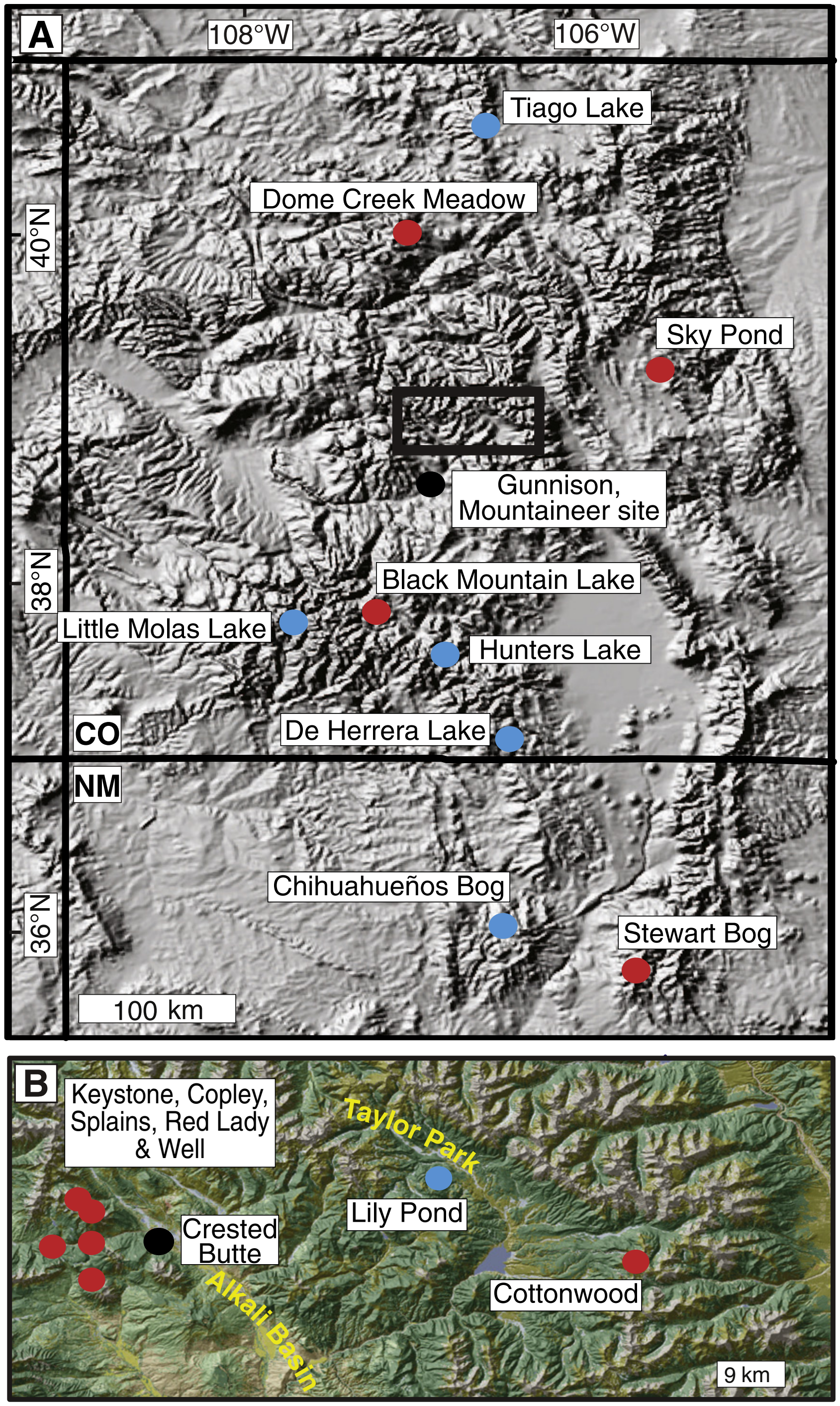

Figure 1. Location of study region and other sites discussed in the text (A), with insert of Taylor Basin and Crested Butte sites (B). Red dot = site with vegetation history; blue dot = site with vegetation and fire history; black dot = city or archaeology site. USGS present-day land cover on inset B shows subalpine forest/montane forest (dark to light green), herbs and grasses (olive), *Artemisia* steppe (beige), and tundra (gray).

Today, Lily Pond lies at the transition between montane and subalpine forest and is surrounded by *Pinus contorta* with *Pseudotsuga menziesii*, *Picea engelmannii* and *Abies lasiocarpa*. Subalpine forest of *Picea*, *Abies*, and *Pinus flexilis* lies above 3300 m elevation, gives way to parkland at 3400 m elevation, and then to alpine tundra above 3600 m elevation. At lower elevations (2700–3200 m), montane forest consists of *Pseudotsuga*, *P. contorta*, and minor amounts of *Populus,* and xeric sites support steppe communities of *Artemisia* and a variety of grasses and herbs (Fig. 1b; Fall, 1997a). Winter temperatures in Taylor Park average −12°C (average minimum of −22°C and maximum of −2°C) and summer temperatures average 12°C (average minimum of 3°C and maximum of 21°C). Mean annual precipitation is 426 mm, and falls mostly as snow from November through April, but summer precipitation is also significant (120 mm yr^{-1}) (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?cotayl).

Methods

A 4.25-m-long sediment core was obtained with a modified Livingstone piston sampler (Wright et al., 1984) from a sedge mat along the

Table 1
Site Descriptions.

Site name	Lat.	Long.	Elev (m)	Forest type	Reference
Sky Pond	40°16′ 42″	105°40′ 09″	3338	Tundra	Reasoner and Jodry, 2000
Tiago	40°34′ 49″	106°36′ 46″	2700	Montane-Steppe	Jimenez-Moreno, et al., 2011
Dome Creek	40°01′ 40″	107°03′ 16″	3165	Subalpine	Feiler et al., 1997
Lily Pond	38°56′ 06″	106°38′ 37″	3208	Subalpine-Montane	This Study
Cottonwood	38°49′ 50″	106°24′ 45″	3670	Tundra	Fall, 1997b
Red Lady	38°52′ 50″	107°2′ 30″	3350	Tundra-Subalpine	Fall, 1997b
Red Well	38°53′ 40″	107°3′ 15″	3290	Tundra-Subalpine	Fall, 1997b
Copley	38°52′ 28″	107°05′ 0″	3250	Subalpine	Fall, 1997b
Splains	38°50′ 0″	107°4′ 30″	3160	Subalpine	Fall, 1997b
Splains Gulch	38°50′ 0″	107°4′ 30″	3150	Subalpine	Fall, 1997b
Keystone	38°52′ 0″	107°2′ 30″	2920	Subalpine-Montane	Fall, 1997a,b
Alkali Basin	38°45′ 0	106°50′ 0″	2750	Steppe	Markgraf and Scott, 1981, Fall, 1997b
Black Mountain	37°50′ 41″	107°14′ 22″	3408	Tundra-Subalpine	Reasoner and Jodry, 2000
Little Molas	37°44′ 30″	107°42′ 30″	3360	Tundra-Subalpine	Toney and Anderson, 2006
Hunters	37°36′ 30″	106°50′ 40″	3516	Tundra-Subalpine	Anderson et al., 2008a
De Herrera	37°04′ 44″	106°25′ 36″	3343	Subalpine	Anderson et al., 2008a
Chihuahueños	36°02′ 50″	106°30′ 30″	2925	Montane	Anderson et al., 2008a,b
Stewart	35°40′ 0″	105°45′ 0″	3100	Subalpine-Montane	Jimenez-Moreno, et al., 2008

northern margin of Lily Pond. In the lab, magnetic susceptibility was measured at 0.5-cm intervals in the core to assess changes in inorganic allochthonous sediment (Gedye et al., 2000), using a Bartington magnetic susceptibility meter. One-cm^3 samples were taken at 2-cm intervals to measure weight-loss on ignition at 550°C for 2 hours, a basic indicator of organic production (Dean, 1974).

Pollen samples of 0.5-cm^3 volume were taken at intervals of 1–16 cm, prepared with standard methods, and a modified Schulze procedure to oxidize organics (Smol et al., 2001; Doher, 1980). Pollen was identified microscopically to the lowest taxonomic level possible with reference collections and atlases (Moore and Webb, 1978; Kapp et al., 2000). *Pinus* grains were separated into Haploxylon-type, Diploxylon-types, and "*Pinus* undifferentiated". Haploxylon-type was attributed to *Pinus flexilis* or *P. edulis* (not locally present). Diploxylon-type *Pinus* pollen likely came from *P. contorta* and/or possibly *P. ponderosa* (also not local). *Populus* is thinned-walled and degraded during oxidation of organics, and was not present in the processed samples. Alternatively, *Populus* today occurs in small abundances at the transition between *Artemisia* steppe and montane forest, and may have never been present in the Lily Pond watershed.

Past vegetation was reconstructed based on pollen percentages (with a denominator of total terrestrial pollen grains), comparison with modern pollen data (Fall, 1992a,b, 1994; Minckley and Whitlock, 2000; Minckley et al., 2008), and changes in the AP/NAP ratio, an indicator of forest cover (modern ratio is 0.75). The magnitude of vegetation change was determined from the SCD (values > ~0.10 considered significant) of pollen percentages at intervals of 100, 200 and 500 yr, based on a linear model to interpolate pollen percentages between radiocarbon-dated points (Overpeck et al., 1985; Shuman et al., 2002, 2005; Meltzer and Holliday, 2010).

Macroscopic charcoal particles were extracted from 2-cm^3 samples at contiguous 0.5-cm intervals and prepared following methods described in Whitlock and Larsen (2001). An abundance of large charcoal particles (> 125 microns in diameter) is associated with the occurrence of crown fires (Whitlock et al., 2004; Higuera et al., 2010). Charcoal concentrations and deposition times were binned into 15-yr intervals, the median sampling resolution. CHAR (particles cm^{-2} yr^{-1}) were calculated by multiplying the concentration data by the sample sedimentation rate, and the long-term trends in CHAR (i.e., background CHAR or BCHAR) were determined using a locally-weighted 1000-yr mean, robust to outliers. Positive deviations in the CHAR, above a 95% locally weighted threshold were identified as fire episodes, and fire frequency (number of fire episodes per 1000 yr) was determined by smoothing the charcoal peaks with a tri-cubic locally weighted regression to summarize long-term trends in fire activity.

Chronological control was based on calibrated radiocarbon ages ($n = 23$; Table 2) obtained from *in situ* terrestrial plant macrofossils, organic gyttja and bulk sediment, using CALIB 5.0.2 (Reimer et al., 2004; CALIB 6 calibrations yielded similar ages). Age–depth models were constructed with MCAgeDepth software, using linear interpolation and a

Table 2
Uncalibrated and calibrated ^{14}C ages for Lily Pond.

^{14}C Date Reference	Material Dated	Depth (cm)	^{14}C Date (yr BP)	^{14}C Error	Cal yr BP (median)	Cal yr BP (lower)	Cal yr BP (upper)
Model 1[a,b]							
Top depth[c]		0	−57				
244885[d]	peat	185.0	1620	40	1562	1417	1695
244886	seed	212	2560	40	2648	2448	2758
242757	wood	236	5080	40	5815	5675	5921
244888	gyttja	255	6440	40	7362	7268	7434
242758	gyttja	280	7870	40	8665	8553	8967
244887	gyttja	292	8790	50	9814	9569	10147
244889	gyttja	302	9400	40	10629	10504	10751
259112	gyttja	309	9860	50	11258	11187	11576
244890	gyttja	318	10450	60	12395	12080	12692
259113	gyttja	323	10580	50	12637	12389	12794
262534	gyttja	325	11140	70	13041	12895	13217
262535	gyttja	328	11240	70	13137	12945	13285
244891	gyttja	329	11240	60	13139	12957	13270
248105	gyttja	332	11780	40	13650	13453	13775
Model 2[e]							
From Model 1		332			13573		
244892	gyttja	340	11810	40	13667	13471	13796
262536	gyttja	345	12760	80		not used in age model	
244893	gyttja	352	11830	60	13681	13466	13827
242759	charcoal	357	11790	70	13637	13438	13804
248106	gyttja	385	12620	50		not used in age model	
244894	gyttja	391	11730	40	13575	13425	13733
Model 3[e]							
From Model 2		391			13631		
242760	organic clay	430	13310	70	15792	15409	16201
242761	organic clay	470	13870	70	16526	16140	16918
242762	organic clay	495	13700	70	16835	16646	17026

[a] ^{14}C calibrated ages derived using a Monte Carlo approach based on the probability distribution function of all ^{14}C ages (2 sigma error) in the age-depth Model 1 (see Methods).
[b] 99% confidence interval based on 2000 runs.
[c] Top depth from surface of sedge-peat mat. Coring started at 165 cm.
[d] ^{14}C age determinations from Beta Analytic.
[e] Model 2 and 3 constructed using linear interpolation of the median calibrated radiocarbon age (see Methods).

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cubic smoothing spline and Monte Carlo approach (Briles et al., 2008; Higuera et al., 2008). Three age–depth models were developed for Lily Pond to describe the cumulative array of radiometric-age determinations (Fig. 2 and Table 2). The first model, using a linear approach, was based on 14 ^{14}C AMS dates (between 165 and 332 cm core depth; 1.0 to 13.6 cal ka BP). The second linear interpolation model, representing a rapid sedimentation event, was based on the median calibrated age of four ^{14}C AMS dates (between 332 and 391 cm core depth; ~13.6 cal ka BP). The third linear interpolation model was based on the median calibrated age for three ^{14}C AMS dates (between 391 and 495 cm depth; 13.6 to 16.8 cal ka BP).

Results and discussion

Environmental conditions during the last glacial–interglacial transition

The Lily Pond results (Fig. 3) were compared with other pollen and charcoal records from the southern Rocky Mountains (see Table 1 for site information) (Fig. 4h). The North Greenland Icecore Project (NGRIP) record (Fig. 4b) and an understanding of regional climate history was used to define the LGIT chronology as follows: full-glacial period (26.5–19 cal ka BP), early late-glacial period (19–14.7 cal ka BP), Bølling–Allerød period (B/A; 14.7–12.9 cal ka BP), YDC (12.9–11.7 cal ka BP), early Holocene (11.7–9 cal ka BP), and middle Holocene (9–5.5 cal ka BP). An alkenone-derived sea-surface temperature record (Ocean Drilling Project [ODP] site 1019) off the coast of northern California (Fig. 4c) (Barron et al., 2003) and δ^{18}O speleothem records from Oregon Caves in southwestern Oregon and Fort Stanton Cave in southeastern New Mexico provide continuous information on LGIT air temperatures and precipitation from the western US during the LGIT (Fig. 4d) (Vacco et al., 2005; Asmerom et al., 2010).

Paleoclimate model simulations (Bartlein et al., 1998; Clark et al., 1999) suggest that a southward displacement of the jet stream to ca. lat. 35°N occurred during the last glacial maximum (LGM; ~21 cal ka BP) and resulted in greater precipitation in the southwestern US than today. Late-glacial increases in spring and summer insolation (Fig. 4a) led to warmer springs and summers, and the northward shift of the jet stream reduced precipitation. The summer insolation maximum in the early to middle Holocene (12–6 ka) increased summer temperatures, decreased effective moisture, and enhanced the onshore flow of moisture, thereby strengthening summer monsoonal circulation in the southwestern US (Mann and Meltzer, 2007); lower-than-present winter insolation led to colder winters. Decreasing summer insolation in the late Holocene led to cooler wetter summers than before (Bartlein et al., 1998).

Full-glacial and early late-glacial period (>14.7 cal ka BP)

During the LGM, Taylor Park was extensively glaciated, and Lily Pond, a kettle lake, is located near the terminal moraine of alpine glaciers coming from mountains surrounding the northwest of the lake (Brugger, 2006, 2007, 2010). The basal radiocarbon date at Lily Pond of ~16.8 cal ka BP (Table 2) falls within the age range of local glacier retreat based on cosmogenic ^{10}Be and ^{36}Cl dating (16.1–20.8 ka) (Brugger, 2007), as well as the timing of regional deglaciation in Colorado (Benson et al., 2005, 2007) and the western US (Licciardi et al., 2004). The Lily Pond cores registered rapid rates of sedimentation (~14 yr cm^{-1}), high magnetic susceptibility (>10×10^{-6} cgs), and low organic carbon content (<5%) prior to 13.6 cal ka BP that indicate significant in-washing of glacial sediments, colluvial debris from unstable slopes, and possibly eolian input (Fig. 3). This reconstruction is consistent with an unvegetated basin and an unproductive lake.

The earliest vegetation (Zone LP-1; Figs. 3 and 4h,f) >16.8 cal ka BP at Lily Pond was a mixture of tundra and subalpine parkland, based on high pollen percentages of *Artemisia* (up to 70%), lesser amounts of Poaceae (~3%), *Picea* (~5%), *Juniperus*-type (~2%), and *Pinus* (~20%), and a low arboreal/non-arboreal pollen ratio (AP/NAP; ~0.3). The low values of *Pinus* (<30%), a prolific pollen producer, imply its local absence, but likely not around Lily Pond. Low charcoal accumulation rates (CHAR: ~0.1 particles cm^{-2} yr^{-1}) indicate little

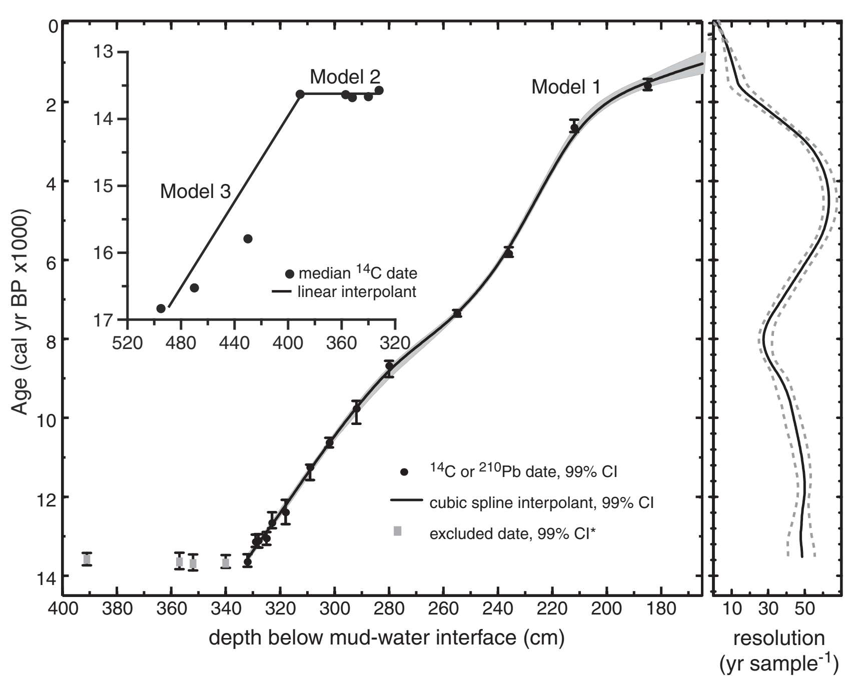

Figure 2. Age–depth curves and deposition time for Lily Pond based on calibrated ^{14}C dates (using Calib 5.0.1). Age–depth model 1 (between 165 and 332 cm core depth; 1.0 to 13.6 cal ka BP) was developed using a cubic smoothing spline and a Monte Carlo approach on the probability distribution function of all ^{14}C ages. The gray band reflects the modeled range of dates and deposition times and the black line the 50th (i.e., median age) percentile of all runs. Circles and bars reflect the 50th, 2.5th (i.e., lower age) and 97.5th (i.e., upper age) percentiles of the probability distribution function of the calibrated dates. Age–depth model 2 (between 332 and 391 cm core depth; ~13.6 cal ka BP), which describes a rapid sedimentation event, and age–depth model 3 (between 391 and 495 cm depth; 13.6 to 16.6 cal ka BP) were developed using linear interpolation of the median calibrated age. See Table 2 for age information and Methods.

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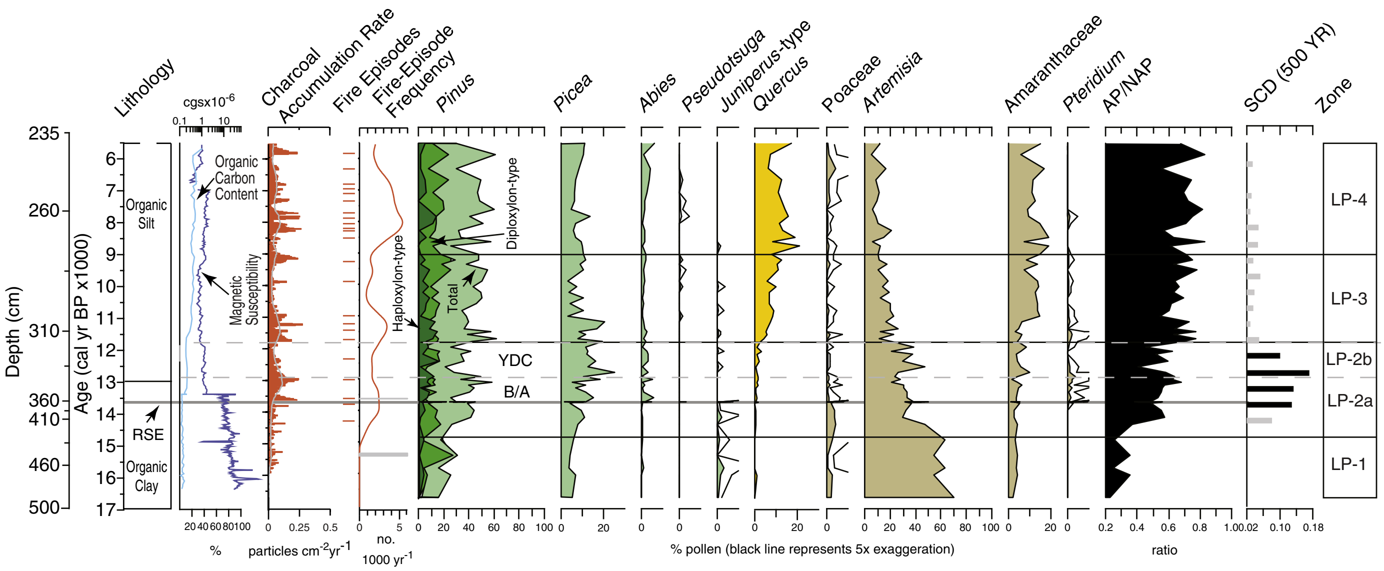

Figure 3. Lithologic (blue), charcoal (red) and pollen data for selected taxa (green = conifers, orange = shrubs, brown = herbs and ferns), AP/NAP ratios, and SCDs from Lily Pond (see Methods for details; RSE = rapid sedimentation event at 13.6 cal ka BP).

or no fire occurrence. Other pollen records near Crested Butte and on the Colorado Plateau indicate that between ~23 and 14.7 cal ka BP subalpine parkland was present below 3200 m elevation and tundra grew above that elevation (Fig. 4h). Upper treeline was at least 300–700 m in elevation lower than today (Fall, 1997b), and low temperatures and high snowpack resulted in discontinuous wet fuels that limited ignition and fire spread.

Estimates of LGM temperature depressions are ~7°C lower than present, based on paleoglacier equilibrium-line altitudes in Taylor Park (Brugger, 2010), and regionally 5–10°C lower than present based on model simulations and pollen inferences (Fall, 1997b; Bartlein et al., 1998; Anderson et al., 2000). The Fort Stanton speleothem data indicate high winter precipitation, a finding that supports paleoclimate simulations of a southward-displaced jet stream (Fig. 4e) (Bartlein et al., 1998; Asmerom et al., 2010).

Bølling–Allerød Period (14.7 to 12.9 cal ka BP)

Subalpine forest developed at Lily Pond between 14.7 and 12.9 cal ka BP, based on decreased *Artemisia* pollen (to 30%) and increased *Picea* (to 10%), *Abies* (to 1–2%), and *Pinus* (to 45%) pollen in Zone LP-2a (Figs. 3 and 4h, f). The ratio of AP/NAP increased dramatically (to 0.6), suggesting more forest cover than today. Decreased magnetic susceptibility ($>1\times10^{-6}$ cgs) and increased organic carbon content (to 11%) suggest stabilized slopes and a more productive lake than before. A rapid sedimentation event at 13.6 cal ka BP was followed by a rise in *Pteridium* spores (to ~2%; bracken is a disturbance-adapted and heliophytic fern), declines in *Picea* and *Pinus* percentages (to ~5% and ~30%, respectively), and increased CHAR. A dramatic change in plant communities is implied by square-cord distance (SCD) values as high as 0.13 at the 500-yr time scale. A striking aspect of the Lily Pond record was the increased fire activity (CHAR: 0.25 particles $cm^{-2}\,yr^{-1}$; ~2.5 fire episodes per 1000 yr) between 13.6 and 12.9 cal ka BP (Figs. 3 and 4f). The pollen and charcoal data are consistent with more forest cover, severe crown fires, and warmer drier summers than before.

A similar shift from tundra and parkland to subalpine forest occurred above 3400 m elevation in the southern Rocky Mountains (Sky Pond and Black Mountain Lake) (Fig. 4h) (Reasoner and Jodry, 2000). Near Crested Butte, *Picea* parkland transitioned into subalpine forest above 3200 m elevation (Fall, 1997b). At 2700 m elevation in northern Colorado (Tiago Lake), increasing *Picea* and fires (Fig. 4g) suggest gradual warming through the B/A (Jimenez-Moreno et al., 2011). In northern New Mexico, tundra persisted at 3100 m elevation in the southern Sangre de Cristo Mountains (Stewart Bog), but to the west in the Jemez Mountains, *Picea* parkland was present at 2900 m elevation and fire activity increased (Chihuahueños Bog) (Anderson et al., 2008a,b; Jimenez-Moreno et al., 2008).

The Fort Stanton $\delta^{18}O$ data suggest greater summer precipitation during the B/A period (Fig. 3e) (Asmerom et al., 2010), and sea-surface and land temperatures were only ~1°C lower than those at present (Fig. 3c and d) (Barron et al., 2003; Vacco et al., 2005). For the first time since the LGM, fire was an important disturbance agent in the southern Rocky Mountains, probably as a result of more continuous woody fuels, warmer growing seasons (from rising spring and summer insolation) and greater ignitions from summer monsoonal storms. Variations in the level of fire activity among sites likely reflect regional differences in fuel and ignition.

Younger Dryas Chronozone (12.9 to 11.7 cal ka BP)

Expanded subalpine forest cover is inferred at Lily Pond from Zone LP-2b (Figs. 3 and 4h, f), which shows abundant *Picea* (up to 20%), increased *Abies* (to 2–3%), moderate *Artemisia* (to 35%), and reduced *Pinus* (to 30%) percentages. The AP/NAP ratio declined (to 0.5) and low fire activity is inferred (CHAR: ~0.1 particles $cm^{-2}\,yr^{-1}$; ~1.5 fires per 1000 yr). High SCD values (>0.17 on a 500-yr time scale; 0.11 on a 100-yr time scale) point to rapid vegetation change leading into this zone. YDC glacial advances have been documented throughout the western US (Davis et al., 2009), but not yet in Taylor Park. The pollen and charcoal data imply cooling, but not as extreme as the early late-glacial period, and warm and effectively wetter springs and summers that limited fire activity.

Elsewhere, high-resolution pollen records above 3400 m elevation in Colorado (Sky Pond and Black Mountain Lake) show a return to tundra during the YDC, suggesting that upper treeline moved downslope by 60–120 m elevation (Reasoner and Jodry, 2000) (Fig. 4h). Sites near Crested Butte show no change in forest cover from before (Fall, 1997a,b), but subalpine forest was as low as 2700 m elevation in the Gunnison Basin from the B/A period through the YDC (Markgraf and Scott, 1981). At elevations between 3300 and 3500 m in southern Colorado, subalpine parkland shifted to a *Picea* and *Pinus*-dominated forest (De Herrera Lake) and tundra

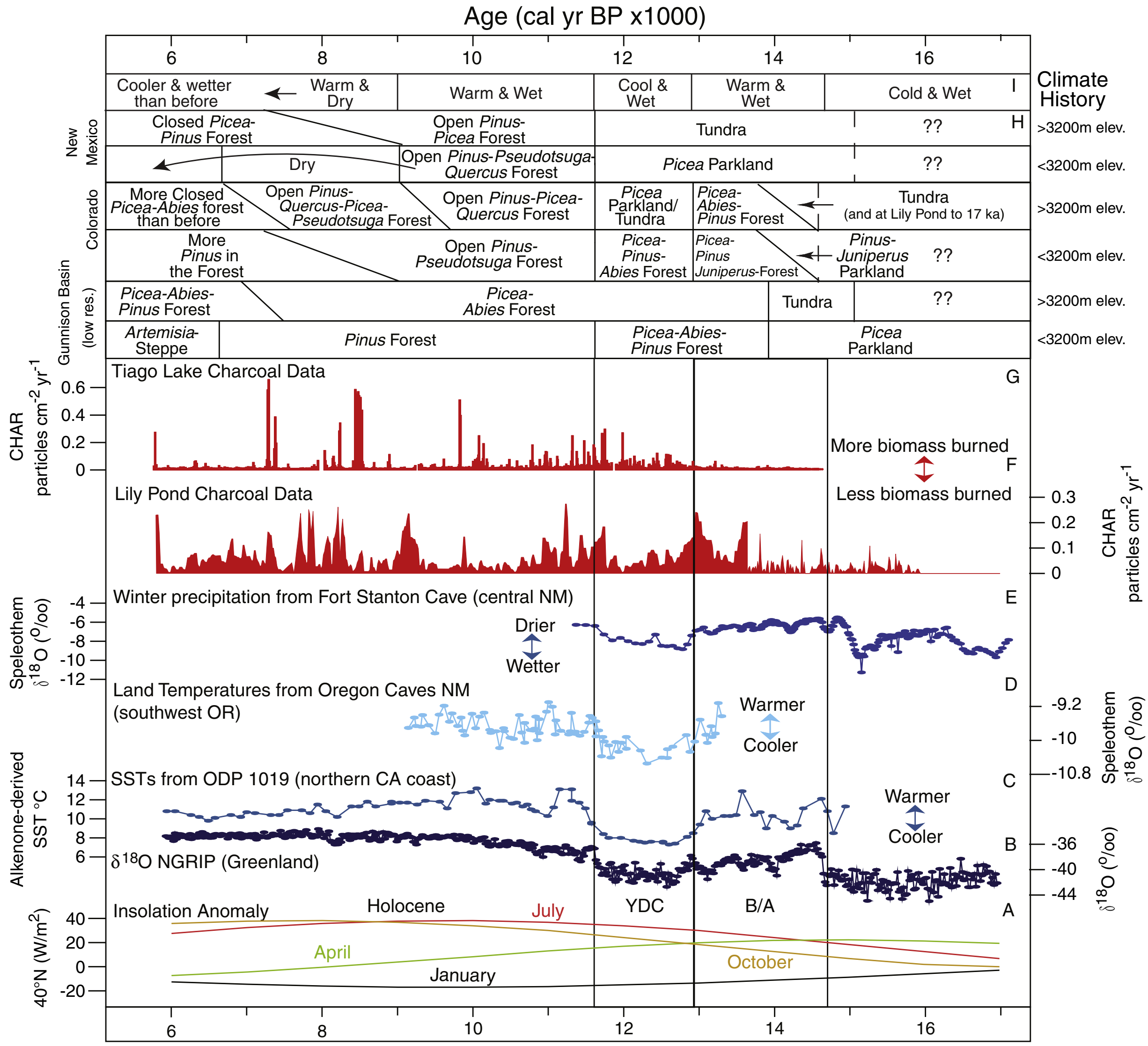

Figure 4. Regional vegetation, fire, and climate history from the southern Rocky Mountains (Colorado and northern New Mexico). Data displayed includes Jan., Apr., July and Oct. insolation anomalies (A), NGRIP $\delta^{18}O$ data (B), sea-surface temperatures from ODP1019 (C), speleothem temperature (Oregon Caves NM; D) and winter precipitation $\delta^{18}O$ data (Fort Stanton, NM; E), charcoal data from Lily Pond and Tioga Lake (F&G), regional vegetation (H), and regional climate history (I).

to subalpine forest (Hunters Lake) at ~12 cal ka BP (Anderson et al., 2008a), and both changes suggest warming. Likewise, in northern Colorado (Tiago Lake), high percentages of *Picea* in the early YDC were replaced by high values of *Pinus* in the late YDC (Jimenez-Moreno et al., 2011). Sites in northern New Mexico show persistent *Picea* parkland and tundra with no change during the YDC (Anderson et al., 2008a, b; Jimenez-Moreno et al., 2008), and initially low fire activity at Tioga Lake (Fig. 4g), Hunters Lake, De Herrera Lake, and Chihuahueños Bog increased through the YDC (Anderson et al., 2008a,b; Jimenez-Moreno et al., 2011). Thus, few sites show evidence of a climate change during the YDC to dramatically cooler conditions and, in fact, some suggest progressive warming.

The Fort Stanton speleothem data indicate increased winter precipitation during the YDC (Fig. 4e) (Asmerom et al., 2010). Cool wet winters, prolonged springs, and warm wet summers (caused by increasing spring and summer insolation) explain the expansion of *Picea* and dampened fire activity at Lily Pond, as well as the vegetation shifts at other locations. Pacific sea-surface and air temperatures were ~5°C lower than today and ~2°C lower than during the B/A period (Fig. 4c and d) (Barron et al., 2003; Vacco et al., 2005). An annual temperature estimate of 0.4–0.9°C lower than present in the southern Rocky Mountains seems reasonable based on modern pollen comparisons (Reasoner and Jodry, 2000).

Early Holocene (11.7–9 cal ka BP)

A transition from *Picea*- to *Pinus*-dominated forest occurred at the beginning of Zone LP-3 (Figs. 3 and 4h, f), between 11.7 and 10.8 cal ka BP, as inferred from the rise in *Pinus* (to 55%) and decline in *Picea* (to 20%) percentages and increased AP/NAP ratios (0.7). Fire activity also increased (CHAR: 0.25 particles $cm^{-2}yr^{-1}$; ~3 fire episodes per 1000 yr) along with *Pteridium* percentages (to ~1%). Effectively drier summer conditions than before (resulting from high summer insolation) and abundant fuels were likely responsible for the change. After 10.8 cal ka BP, *Quercus* and Amaranthaceae expanded upslope based on their increased percentages (to 8% and 15%, respectively). AP/NAP ratios declined slightly (0.6), and fire decreased. Low magnetic susceptibility implies stabilized slopes, and high organic content (to ~20%) indicates high lake productivity. The pollen, charcoal, and lithologic data are consistent with increasing summer warmth, open xerophytic vegetation, and few or low-severity fires, especially after 10.8 cal ka BP.

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All high-elevation sites in Colorado and northern New Mexico (>3200 m) indicate an upslope shift of upper treeline between 80 and 300 m elevation above their present limit (Markgraf and Scott, 1981; Carrara et al., 1984, 1991; Fall, 1997a,b; Feiler et al., 1997; Reasoner and Jodry, 2000; Toney and Anderson, 2006; Anderson et al., 2008a,b; Jimenez-Moreno et al., 2008; Jimenez-Moreno et al., 2011) (Fig. 4h). At lower elevations (<3200 m elev.), an expansion of xerophytic species, primarily *Pinus*, suggest the montane forest border lay 200 m below its present limit (Markgraf and Scott, 1981). Most charcoal records in Colorado and northern New Mexico show high fire activity at the onset of the Holocene, followed by a decline after ~10 cal ka BP (e.g., Fig. 4g). Annual (primarily summer) precipitation was 8–11 cm higher than today near Crested Butte, based on pollen data (Fall, 1997b). The Fort Stanton speleothem δ^{18}O data also indicate a shift from winter to summer precipitation (Fig. 4e) (Asmerom et al., 2010), and sea-surface temperatures rose (~4–5°C) 1–2°C above present after 11.7 ka (Fig. 4c) (Barron et al., 2003). Delta-deuterium measurements on wood fragments in a high-elevation lake in southwestern Colorado and on authigenic carbonates in a high-elevation lake in northwestern Colorado indicate a summer-dominated moisture regime in the early Holocene shifting to greater winter precipitation in the middle Holocene (Friedman et al., 1988; Anderson, 2011). Speleothem δ^{18}O values from Oregon Caves indicate a rise in air temperatures in the early Holocene (Fig. 4d) (Vacco et al., 2005). The paleoecological data in the southern Rocky Mountains are consistent with increased summer temperatures and precipitation. These conditions resulted in an expansion of forest at upper and lower treeline. The development of open xerophytic forest likely led to fewer crown fires and a shift to a surface fire regime at several locations.

Middle Holocene (9–5.5 cal ka BP)

Montane forest developed at Lily Pond in the middle Holocene, based on increased percentages of *Pinus* (primarily Diploxylon-type), *Quercus,* Amaranthaceae (to 50, 15 and 15%, respectively), and the presence of *Pseudotsuga* (~1%) in Zone LP-4 (Figs. 3 and 4h, f). Fire frequency peaked at 8 cal ka BP (CHAR: 0.2–0.25 particles $cm^{-2}\,yr^{-1}$; ~5 episodes per 1000 yr), corresponding with an increase in fire-adapted *Quercus* and *Pinus. Picea* and *Abies* values increased (to 10 and 5%, respectively) after 7 cal ka BP, suggesting a return to subalpine forests, and increased AP/NAP ratios (to ~0.7) indicate forest closure. Increased magnetic susceptibility and sedimentation (from ~50 to 30 yr cm^{-1}) may be related to the more-severe crown fires between 9 and 7 cal ka BP than before. The Lily Pond data imply that the middle Holocene featured greatest summer warmth and effectively dry conditions than previous or today, with somewhat cooler and wetter conditions after 7 cal ka BP.

The upslope expansion of xerophytic species occurred at all Colorado and New Mexico sites and is consistent with high summer temperatures and increased aridity, a likely consequence of weakening monsoons in the middle Holocene (Fig. 4h) (Markgraf and Scott, 1981; Carrara et al., 1984, 1991; Fall, 1997a,b; Feiler et al., 1997; Reasoner and Jodry, 2000; Toney and Anderson, 2006; Anderson et al., 2008a,b; Jimenez-Moreno et al., 2008, 2011). In addition, lake levels in the Rocky Mountains were at their lowest (Shuman et al., 2009). Fire activity was spatially variable during the middle Holocene, suggesting that fuels strongly influenced fire occurrence (e.g., Fig. 4f vs. g). As conditions became more mesic in the later part of the middle Holocene, subalpine forest moved downslope to elevations >3200 m and montane forest to ~2700 m, with *Artemisia* steppe persisting below that elevation.

Summary and conclusions

Paleoenvironmental data from Taylor Park and the southern Rocky Mountains suggest widespread tundra at elevations >3200 m and subalpine parkland below that elevation during the LGM and early late-glacial period. As summers warmed and became effectively drier during the B/A period, subalpine forests in Colorado expanded above 2700 m elevation and fire activity increased. Vegetation in northern New Mexico showed little change during the B/A period. The YDC was characterized by cool wet winters followed by mild springs and summers, primarily as a result of the amplification of the seasonal cycle of insolation. These climate conditions led to renewed glacial activity in some, but not all, mountain ranges. The regional data suggest that the environmental response to the Younger Dryas-aged cool event was spatially variable, with some locations experiencing little change. A downslope shift of subalpine forest occurred between ~3400 and 2700 m elevation (at least 500–600 m below its present lower limit), as did a downslope shift of upper and lower treeline. Effectively wet summers suppressed fire activity, compared with the high levels in the B/A period. In the early Holocene, the summer insolation maximum led to warm summers and stronger monsoonal flow and montane forests expanded above and below current limits. Crown fires were initially high in the early Holocene and declined with the increase in summer moisture between 11 and 9 cal ka BP. Montane forests of more xerophytic species continued to expand above their present elevation in the middle Holocene, and fires reached maximum frequency at 8 cal ka BP. After 7 cal ka BP, cooler conditions resulted in the downslope shift in plant communities and fires were either less frequent or were low severity surface burns.

Although the Lily Pond data do not bear on the immediate climatic and environmental setting of the Mountaineer site, these data do provide a context for understanding Folsom-age occupation of the Gunnison Basin. It appears, from circumstantial evidence, that the Mountaineer site was occupied during a YDC winter: notably, the substantial labor investment in building stone-lined, mud and aspen-walled structures atop a waterless mesa. These structures would have been unnecessary and logistically challenging were the site occupied only in summer. Although the YDC is marked by extreme cold and led to adaptive shifts, and in a few places regional abandonment of some parts of North America and Europe (Straus and Goebel, 2011), the Lily Pond record and regional reconstruction suggest that YDC conditions were not exceptionally cold in the Gunnison Basin. Moreover, the vegetation reconstructions from the Alkali Basin ~40 km to the north of the Mountaineer site (Markgraf and Scott, 1981; Fall, 1997a,b) suggest that *Populus tremuloides* was possibly more widespread during the YDC. This tree was apparently an important construction and fuel source for the Mountaineer site, but today it occurs only in a small isolated stand on the edge of the mesa. The Lily Pond record sheds little light on the food resources utilized by occupants of the Mountaineer site or other Folsom-age sites in the Gunnison Basin, but it, along with the other records from the region, provide insights as to why a high-elevation locality would have been occupied by human hunter-gatherer groups, even in the midst of a "cold event" during the Younger Dryas Chronozone.

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