Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada

Edited by Kathleen M. Haller and Spencer H. Wood

Open-File Report 2004-1222

U.S. Department of the Interior
U.S. Geological Survey

Late Pleistocene Alpine Glaciation in the Southeastern Sawtooth Mountains, Idaho: Moraine Characteristics, Sediment Coring, and Paleoclimatic Inferences

By Glenn D. Thackray[1], Kari A. Lundeen[2], and Jennifer A. Borgert[3]

Introduction

Glaciers descended the eastern flanks of the Sawtooth Mountains repeatedly during late Pleistocene time, constructing an extensive moraine belt at the range front in the Sawtooth Valley. The glacial sequence and the numerous lakes it hosts preserve a detailed record of those fluctuations, themselves a reflection of complex climatic processes during the last glaciation. In particular, we infer that the chronology derived to date reflects strong influences of Pacific moisture delivery on the alpine glacial system.

The last glaciation involved dramatic reorganization of oceanic, atmospheric, and cryospheric systems. The complexity of glaciation is particularly stark in western North America, where the growth and subsequent shrinkage of the Laurentide/Cordilleran ice-sheet system strongly influenced atmospheric patterns and, thus, precipitation-delivery patterns. Coupled with the diverse orography of the cordillera, those precipitation patterns exerted complex influences on mountain glacier systems during middle Wisconsin time (ca. 50,000 to 25,000 yr), late Wisconsin full-glacial time (ca. 21,000 to 17,000 cal yr BP) and late-glacial time (ca. 17,000 to 11,000 cal yr BP). Consequently, the timing of maximum alpine glacier advances shows considerable variation across the region (*e.g.*, Chadwick and others, 1997; Thackray, 1999 and 2001; Licciardi and others, 2001) as does the more detailed timing of late-glacial advances, particularly pre-Younger Dryas (*e.g.*, Clark and Gillespie, 1997) versus syn-Younger Dryas advances (*e.g.*, Gosse and others, 1995).

Extensive mountain glacier fluctuations left an extensive moraine and lake system on the eastern flank of the Sawtooth Mountains constructed during late full-glacial time (ca. 16,00–17,000 cal yr BP) and early late-glacial time (ca. 13,000–14,000 cal yr BP). Herein, we describe these features and a sequence of older moraines, yet undated but inferred to have originated during early or middle Wisconsin time, and an apparent lack of moraines correlative with the ice-sheet maximum. We infer that the advances required reinvigoration of moisture transport into the northwestern interior of the United States.

Setting and Context

The Sawtooth Mountains comprise one of the highest ranges in central Idaho. The range trends roughly north-south and rises to about 3,300 m, exposing Cretaceous granitic rocks and Paleozoic metasedimentary wall rocks of the Idaho batholith as well as Eocene granites of the Sawtooth batholith. Most importantly, the Sawtooth Mountains represent the first high orographic barrier encountered by moist Pacific air masses east of the Cascade Range. Indeed, the Sawtooth Mountains today receive the bulk of their precipitation from winter and spring Pacific storms and mark the transition between the wetter forested ranges of western Idaho and drier, largely unforested ranges to the east. The latter are dominated by summer monsoonal precipitation (see fig. 4 of Whitlock and Bartlein, 1993). Inferred late-Pleistocene equilibrium line altitudes (ELAs) rise steeply across the range (Stanford, 1982; Borgert, 1999; Lundeen, 2001), indicating similar influence of prevailing, moist westerly winds.

Major valleys marking the eastern and western flanks of the Sawtooth Mountains hosted large valley glaciers (>10 km length) during late-Pleistocene glacial episodes. On the eastern flank, glaciers constructed a broad moraine belt in the adjoining extensional basin. Late Pleistocene moraines dominate the moraine belt in the southeastern portion of the range (Williams, 1961; Breckenridge and others, 1988; Borgert and others, 1999), the focus of this study.

Methods

We employed surficial geologic mapping, relative weathering assessment of glacial landforms, analysis of sediment cores, and radiocarbon dating. Surficial geologic mapping, utilizing air photo and topographic map interpretation, digital terrain analysis, and field observation, identified 7 to 9 equilibrium moraines in each of four valleys. In order to determine

[1]Department of Geosciences, Idaho State University, Pocatello, ID 83209, thacglen@isu.edu

[2]Connecticut Department of Environmental Protection, Hartford, CT 06106, kari.lundeen@po.state.ct.us

[3]Retec, Inc., St. Paul, MN, JBorgert@retec.com

Table 1. Radiocarbon ages for core samples described in this report. Additional radiocarbon dates are reported in Borgert (1999) and Lundeen (2001).

Location name	Sample name	CAMS	^{14}C age	± (1 σ)	Material submitted	Calibrated age*	± (1 σ)
McDonald Lake	Mac 2-126	60638	10,590	50	wood	12,780	60
McDonald Lake	Mac 3-132	60639	11,640	50	gyttja	13,570	100
McDonald Lake	Mac 3-140	60637	11,920	90	gyttja	13,960	140
Pettit Lake	P1-94	73098	10,010	50	conifer needle	11,390	60
Pettit Lake	P2-63	73099	11,930	40	charcoal	13,940	150
Lost Boots Marsh	LBM1	41458	9,960	40	plant fragments	11,300	40
Lost Boots Marsh	LBM2	41457	10,300	40	gyttja	12,010	60
Lost Boots Marsh	LBM3	41459	11,990	60	gyttja	13,980	120
Lost Boots Marsh	LBM4	41460	13,660	70	plant fragments	16,400	240
Lost Boots Marsh	LBM5b	51315	14,060	300	plant fragments	16,860	410
Lost Boots Marsh	LBM5a**	41461	11,030	120	plant fragments		

* Calibrated per Stuiver and others (1998). Age ranges with the highest probability are reported.

** Sample 5a produced the initial date on this horizon, derived from a very small amount of carbon; therefore, this date is disregarded. Two additional cores subsequently were obtained from the site and the horizon resampled to obtain sample LBM5b.

relative-age moraine groups, we collected soil and morphometric data from the moraine sequences and performed simple statistical analysis on those data. We then collected sediment cores from 10 sites, including lakes, marshes, and fens, in order to analyze glacial and post-glacial sediment patterns. We collected several types of data from the cores, including visual description, magnetic susceptibility, total organic carbon, and grain-size distribution. Our methods are described fully in Borgert (1999) and Lundeen (2001). Finally, we submitted 19 samples to the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory for radiocarbon dating (table 1). Where possible, macrofossils were submitted, but bulk gyttja samples were submitted in several cases, as noted in table 1.

Results

Relative Age Assessment

As noted, 7–9 end moraines were delineated in each of four valleys (fig. 1). All moraines we describe here are distinctly better defined, more steeply sloping, and more sharply crested than are middle Pleistocene moraines in drainages within 20 km to the north. Therefore, we consider all moraines in this study to be of late Pleistocene age. This broad age determination is consistent with that of Williams (1961) and Breckenridge and others (1988), who mapped the outermost moraines in these four valleys as late Pleistocene in age.

Our analysis of soil and moraine morphometry data from the late Pleistocene moraine sequence delineated two relative age groups (Lundeen, 2001; Borgert, 1999). Moraine crest angularity and depth to B horizon proved to be the most consistent relative age indices (fig. 2). The downvalley group of voluminous, broad-crested, multiple-ridged moraines (Busterback Ranch moraine group) is statistically distinct from the upvalley group of smaller, sharp-crested moraines (Perkins Lake moraine group; Lundeen, 2001). Because of the distinct differences between the moraine groups, we infer that the Busterback Ranch group is at least 10,000 yr older than the Perkins Lake group and that the age difference probably is considerably larger. The difference between inferred equilibrium-line elevations (ELAs) of the two moraine groups is small; while the moraines are widely separated spatially, their elevational separation is relatively small. Paleo-ELA estimates lie between 2,400 and 2,700 m, with an ELA difference of less than 200 m in each valley. The moraine groupings are shown in figures 1 and 2.

Sediment Cores and Radiocarbon-Age Constraints

Cores from 3 of 10 locations provide reliable constraints on the timing of glacier fluctuations. At Lost Boots Marsh, which lies within 0.5 km upvalley of the oldest moraine in the Perkins Lake moraine group in the Alturas valley (fig. 1), we collected three cores with similar stratigraphy (fig. 3A). The most notable feature of these cores is the radiocarbon date of 16,860±410 cal yr BP, which was obtained from an organic-bearing silt layer about 15 cm above ice-proximal sandy gravel. We consider this date a close minimum limiting date for the moraine lying 0.5 km downvalley. Overlying laminated

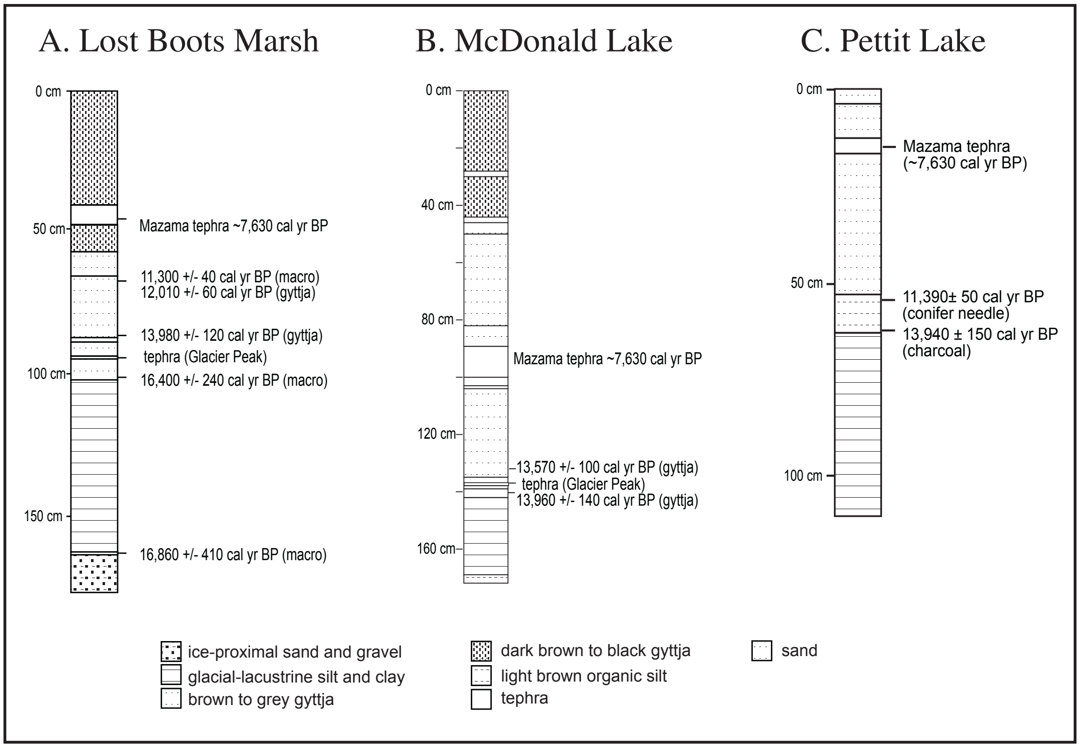

Figure 1. Map of moraines in the southeastern Sawtooth Mountains, showing moraine groups, core sites, and field-trip stops. Moraine groups are delineated by relative weathering criteria. We infer that the two moraine groups are separated in age by at least 10,000 yr.

silt and clay, with high magnetic susceptibility and low total organic carbon, represent glacial-lacustrine sedimentation, most likely a larger lake than those of today, dammed by the moraine downvalley of the core site. Glacial-lacustrine sedimentation terminated and organic-rich sedimentation began ca. 16,400 cal yr BP. The transition to organic-rich sedimentation at that time represents either the retreat of glaciers from the lake margin, coupled with the invigoration of organic production, or the partial drainage of the inferred, large lake and consequent isolation of the marsh from the adjacent, smaller lakes. Also of note is an anomalous, 3-cm-thick, light-brown layer within the organic-rich section. This layer did not produce distinct total organic carbon, magnetic susceptibility, or grain-size values; however, its anomalous color and minimum limiting date of 13,980±120 cal yr BP, which correlates with dates in the two cores described below, suggest that it pertains to a glacial readvance upvalley or to a distinct climatic episode that reduced organic production or increased inorganic sedimentation in the Alturas Lake drainage.

The McDonald Lake 3 core (fig. 3B), one of three taken from this small (9 ha) lake in the Yellowbelly drainage, constrains a later portion of the glacial record. McDonald Lake is dammed by the youngest moraine in the Busterback Ranch group, and three moraines of the Perkins Lake group lie within 2 km upvalley. Our core did not reach ice-proximal sediment.

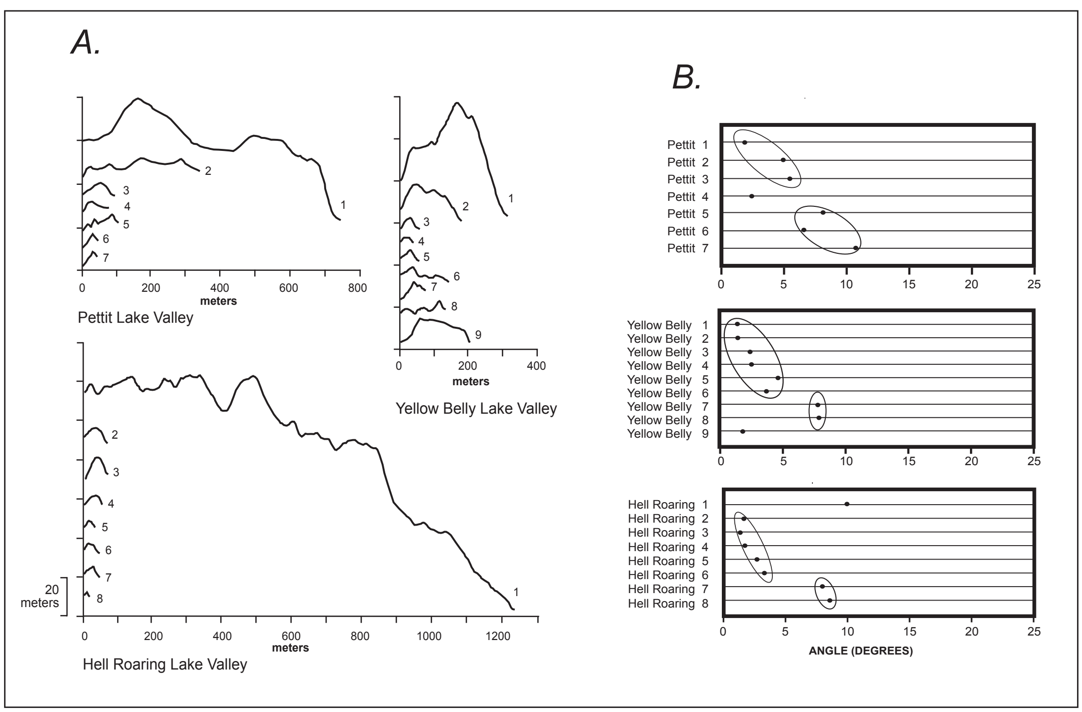

Figure 2. Moraine profiles (A) and morphometry data (B) for eastern Sawtooth valleys. Relative-age groupings, which consider the statistical variability of the moraine profiles, are circled.

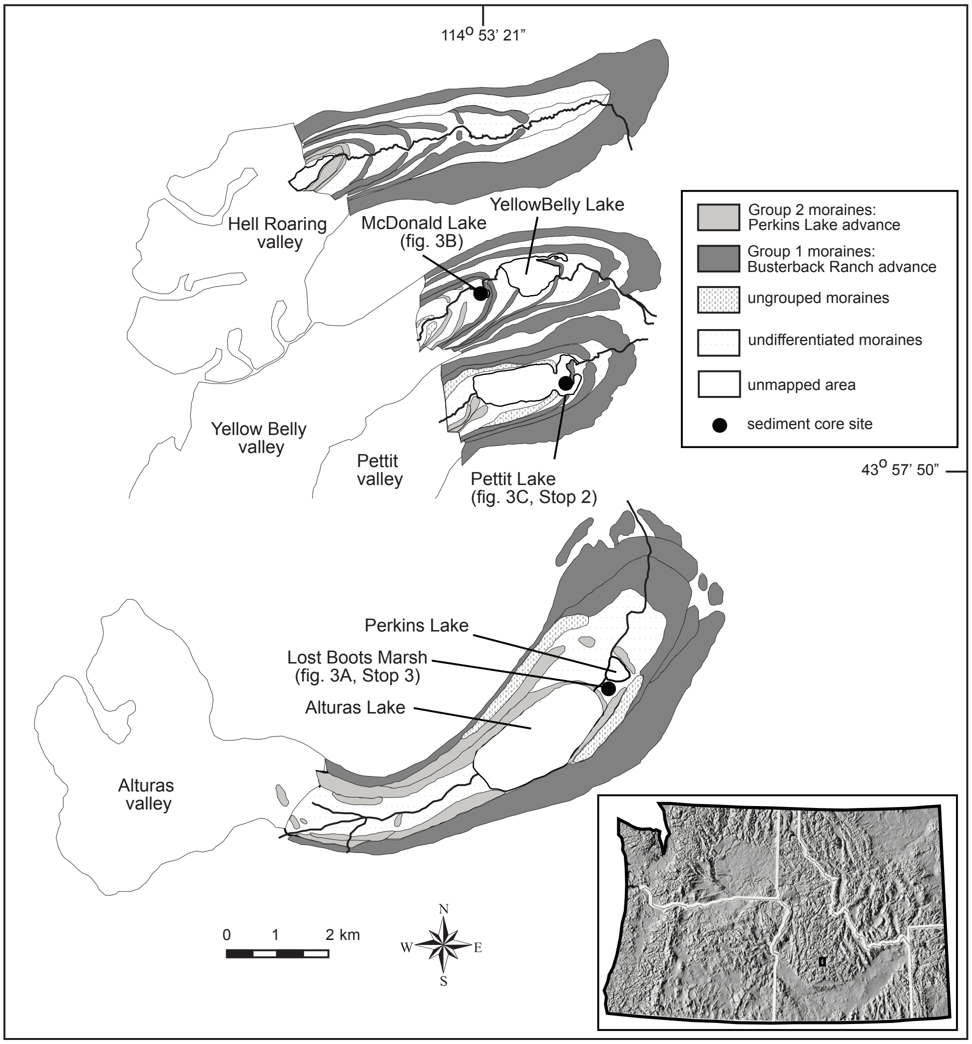

Figure 3. Data from three cores that provide reliable age constraint for the younger moraine group. (A) Lost Boots Marsh, Alturas valley. (B) McDonald Lake 3, Yellowbelly valley. (C) Pettit Lake (composite of two cores), Pettit valley.

However, the core does contain about 30 cm of glacial-lacustrine sediment at its base. The sediment has characteristics of a high glacier activity index (sensu Souch, 1994). Because two sediment-trapping lakes lie upvalley of the youngest Perkins Lake moraines, we infer that the glacial-lacustrine sediment in the core was deposited during the time the glacier constructed those moraines. Thus, the minimum-limiting date of 13,960±140 cal yr BP for the glacial-lacustrine sediment constrains, indirectly, the age of the moraines upvalley of the lake.

The Pettit Lake core (fig. 3C), one of three obtained from the downvalley end of the lake, contains a similar sedimentary sequence, and we make a similar inference regarding the relation of cored glacial-lacustrine sediment with upvalley moraines. A minimum limiting date of 13,940±150 cal yr BP was obtained from a horizon immediately above the glacial-lacustrine sediment.

In summary, these three cores provide close minimum limiting ages for two glacier advances and/or significant recessional stillstands, both associated with the Perkins Lake moraine group. The near-basal date of 16,860 cal yr BP from Lost Boots Marsh provides a minimum limiting age for the oldest moraine in the Perkins Lake group. Closely correlative dates from the McDonald Lake and Pettit Lake cores provide a minimum limiting date of ca. 13,950 cal yr BP for younger moraines of that group. A third date of 13,980 cal yr BP, at the top of the anomalous, light-colored horizon in the Lost Boots Marsh core, lends support to those dates.

The Busterback Ranch moraine group was likely constructed during marine oxygen isotope stage (OIS) 3 or 4. As discussed above, relative weathering data indicate that the Busterback Ranch moraine group is at least 10,000 yr older than the Perkins Lake group. With a minimum limiting age of 16,900 cal yr BP for the oldest moraine in the Perkins Lake group, we estimate that the Busterback Ranch group was constructed prior to around 27,000 yr BP.

Regional Correlations and Paleoclimatic Inferences

Two aspects of this glacial record are noteworthy. First, the close minimum limiting date of ca. 16,900 cal yr BP pertains to the maximum ice advance during marine oxygen isotope stage 2 (OIS 2) in these valleys; the maximum OIS 2 advance thus postdates the peak of the ice-sheet last glacial maximum (ca. 21,000 cal yr BP) by ca. 4,000 cal yr BP. Second, the dates of ca. 14,000 cal yr BP, pertaining to the youngest moraines in this sequence, imply that extensive ice volume—with paleo ELAs less than 200 m above those of the outermost moraines—was maintained into or reestablished in early late-glacial time.

We infer from the local chronology and from correlations with similar records in the Puget Lowland, Wallowa Mountains, and Yellowstone Plateau, that the Sawtooth glaciers responded strongly to fluctuations in precipitation. The glacier extent was apparently diminished by weakened westerly flow (and consequent diminished moisture transport). Westerly flow was apparently diminished by two factors: by the inferred Laurentide ice sheet anticyclone, and by a minimum in orbitally modulated seasonality (*e.g.*, Kutzbach and others, 1993). These inferences are more thoroughly discussed in Thackray and others (2004).

Finally, we suggest that other "moisture dependent" glacial systems—those typically exposed to moist westerly flow and with mass balance characteristics adjusted to abundant precipitation—likely responded similarly. Improved glacial chronologies across the Western United States should further constrain temporal and spatial patterns of Pacific moisture delivery.

Field Guide

The field guide that follows focuses on the moraine sequences and relevant sediment cores in five major valleys on the eastern flank of the Sawtooth Mountains. The guide is derived from information in Breckenridge and others (1988), Borgert and others (1999), Borgert (1999), Lundeen (2001), and Thackray and others (2004).

Acknowledgments

Radiocarbon dating was performed by John Southon of the Center for Mass Spectrometry at Lawrence Livermore National Laboratory. Doug Clark provided invaluable practical and scientific input at various stages of the project. We were assisted in the field by Will Glasgow, David Bates, Doug Whitmire, Zachary Lundeen, Emma Thackray, Diane Wheeler, and Butch Wheeler. Funding was provided by Idaho Board of Education Specific Research Grant S98-071 to GDT, by Geological Society of America student research grants and Idaho State University Graduate Student Research Committee grants to KAL and JAB, and by a Sigma Xi student research grant to KAL.

Mileage Cum.	Inc.	
0.0	0.0	At Stanley, turn right (south) on Idaho Highway 75. Reset odometer. Upper Stanley sits on high terraces described by Breckenridge and others (1988) as Bull Lake outwash terraces. South of Stanley, Highway 75 passes close to the risers of these terraces.
4.5	4.5	Turn right to enter Redfish Lake area. Road passes through moraines of Pinedale age (Williams, 1961; Breckenridge and others, 1988) within 0.5 mi of turnoff.
6.3	1.8	Turn left toward visitor center and North Beach picnic area (not toward lodge).
6.7	0.4	Turn right into North Shore picnic area.

Stop 1. Redfish Lake Area Glacial Geomorphology Overview and Lunch

Redfish Lake lies on a platform of Pleistocene glacial sediment, rimmed by Pinedale-age moraines and flanked to northwest and southeast by Bull Lake-age moraines and outwash terraces (Williams, 1961; Breckenridge and others, 1988). The prominent morainal ridges high above the lake to the northwest and southeast are similar to the large, outermost moraines marking major drainages farther south on the Sawtooth front, likely constructed during early or middle Wisconsin time (Borgert, 1999; Lundeen, 2001; Thackray and others, 2004). Due west of this location are similar moraines, merging with the large Redfish moraines but constructed by glaciers descending the Fishhook Creek drainage. Smaller, younger moraines mark the shores of Redfish Lake and areas upvalley, but, surprisingly, remain unstudied.

Mileage Cum.	Inc.	
		Return to Highway 75.
8.9	2.2	Turn right (south). The highway is cut through Pinedale moraines just south of the junction.
9.5	0.6	Breckenridge and others (1988) described a road cut section near the bridge, since reclaimed. The exposure revealed Bull Lake-age outwash, overlain by glacial-lacustrine sediments and till, interpreted as evidence for damming of the Salmon River during Bull Lake time by Redfish Lake moraines.
13.5	4.0	Bull Lake-age moraines are visible as low-relief hills to right (west) of the road. The long, wooded ridge ahead and to the right (2:00 to 12:00) is a lateral moraine on the north edge of Hell Roaring Creek constructed early in the last glaciation.
15.7	2.2	Sessions Lodge, store and gas station.
18.9	3.2	Landslides to left on Sawtooth Springs Ranch (formerly Thousand Springs Ranch). Breckenridge and others (1988) describe deltaic glacial-lacustrine sediments in the landslide head scarp and suggested that they represent a long-lived glacier-dammed lake. The sediments remain undated and their relation with similar sediments near Redfish Lake is unclear.

19.1	0.2	Cross 4th of July Creek. Williams (1961) and Breckenridge and others (1988) mapped glacial landforms and sediments in this drainage within several kilometers of the highway. They inferred Pinedale ages for two distinct drift units and a Bull Lake age for the third.
21.1	2.0	Moraines of the Yellow Belly drainage lie to right of highway. The visible moraines are the voluminous, outermost moraines that mark the major drainages on the eastern side of the Sawtooths. These moraines will be discussed at the Pettit Lake stop.
21.4	0.3	Cross Salmon River.
22.3	0.9	Moraines of the Pettit drainage lie to right.
22.6	0.3	Turn right (west) on marked gravel road, toward Pettit Lake. After crossing Alturas Lake Creek, the road passes through the two outermost moraines, of seven in the lower part of this drainage. Note the very steep distal edge of the outermost moraine.
24.2	1.6	Turn right (north) at road junction.
24.3	0.1	Just past Pettit Lake Creek, turn right (northeast) again. Road crosses second moraine in sequence.
24.5	0.2	Parking for the next stop can be found in pullouts on either side of the road, over the next 0.3 mi. We first will walk downvalley from here, then upvalley, so the specific parking location does not matter. After parking, continue downvalley (east) on foot until the road rises to cross the outermost moraine. Turn left (north) to climb to top of moraine.

Stop 2. Pettit Lake Moraines: Moraine Morphometry and Lake Coring

The Pettit Lake moraine sequence is an easily accessible example of the moraines marking the major drainages on the eastern flank of the Sawtooth Mountains. As noted in the text, we have used moraine morphometry data, derived from measured moraine profiles, to distinguish two moraine groups: the older Busterback Ranch Group and the younger Perkins Lake group. The start of this moraine walk is the crest of the outermost moraine in the Busterback Ranch group. The moraine crest is approximately 70 m above the Sawtooth Valley floor, reflecting the large volumes of sediment moved by glaciers in the initial late Pleistocene advance. The considerable height and volume of this moraine are typical of the outermost moraines in each drainage, and likely are a result of erosion of sediment accumulated in the valley during the last interglaciation. Note the rounded crest and slightly muted topography of this moraine. Walking upvalley toward Pettit Lake, one crosses the second moraine of the Busterback Ranch group, smaller than the first but also with a rounded crest. Pettit Lake is impounded, in part, by this moraine. The third moraine in the Busterback Ranch group forms a small peninsula that includes the day-use parking area. The younger Perkins Lake group includes three moraines, none of which are easily accessible. They are located in the wooded hills at the upvalley end of Pettit Lake. The Perkins Lake moraines are characterized by smaller volume, sharper crests, and steeper slopes in comparison to the Busterback Ranch moraines. An additional, intermediate-age moraine forms the paired, cabin-laden peninsulas and associated shoal (<2-m deep!) that separate the small, relatively shallow (6 m) lower lake basin from the large, deep (>100 m) upper basin. This moraine did not fall into either morphometric moraine group (fig. 2), probably because cabin construction has altered its form.

We collected sediment cores from the lower basin of Pettit Lake and from McDonald Lake in the adjacent Yellow Belly drainage. Both coring sites lie in the same position with respect to the moraine sequence (*i.e.*, between the youngest Busterback Ranch moraine and the oldest Perkins Lake moraine). None of the cores penetrated to coarse-grained, ice-proximal glacial sediment, so the age of the Busterback Ranch moraines cannot be constrained by the cores. However, the cores partially penetrate thick sequences of glacial-lacustrine sediment with a high glacier activity index (sensu Souch, 1994), indicating that the glacier terminus was located a short distance upvalley. We infer that those glacial-lacustrine sediments were deposited while the glacier terminus lay at or near the positions of the younger moraines in the Perkins Lake group. Radiocarbon dates at the top of the glacial-lacustrine sediments are very similar: 13,940±150 cal yr BP in the lower basin of Pettit Lake and 13,960±140 cal yr BP at McDonald Lake. Thus, we infer that the glacier termini in the two valleys remained at or near the positions of the upper Perkins Lake moraines until ca. 14,000 cal yr BP. Contrasts in equilibrium line altitudes for the entire moraine sequence are minimal (<150 m), so near full-glacial ELAs were maintained until that time.

Mileage Cum.	Inc.	
24.5	0.0	Return to cars and drive back to Highway 75.
26.4	1.9	At Highway 75, turn right (south) toward the Alturas drainage.
27.8	1.4	Turn right (west) onto gravel road. Road crosses outwash terrace for about 0.9 mi.
28.7	0.9	Bear left (southwest) at first road junction since the highway.

29.0	0.3	Fork in road. Follow the left (southern) fork and continue around the outermost Alturas valley moraine.
29.6	0.6	Crest of second moraine in the Busterback Ranch moraine group.
30.1	0.5	Crest of third moraine, also in the Busterback Ranch group. Note the character of the moraines in this area. While they have broad crests like the outermost Pettit moraines, these moraines are of lower relief and contain abundant dry kettle depressions. The low relief and hummocky topography indicate substantial burial of dead ice during construction. The stranding of this ice likely was caused by overextension of the Alturas valley glacier into its low-gradient lower valley, where a small rise in ELA would cause rapid retreat of the terminus.
31.6	1.5	Junction with paved road near northwestern shore of Alturas Lake. Turn left (east-southeast).
32.2	0.6	After crossing Alturas Lake Creek at the lower end of Alturas Lake, turn right into gravel road turnoff. Park and walk across road for Stop 3.

Stop 3. Lost Boots Marsh: Age Constraint on the Younger Moraine Group

Lost Boots Marsh lies between two moraines of the Perkins Lake group, and cores from this site provide further constraint for the moraine group. The moraine that retains Perkins Lake lies 500 m downvalley of this site, while the moraine that retains Alturas Lake lies approximately 300 m upvalley. The former is the oldest moraine in the Perkins Lake group in the Alturas valley.

Three sediment cores from this site reveal a succession of depositional environments and provide radiocarbon constraint on basinal changes (fig. 3A). The most notable feature of these cores is the radiocarbon date of 16,860±410 cal yr BP, which was obtained from an organic-bearing silt layer approximately 15 cm above ice-proximal sandy gravel. We consider this date to be a close minimum limiting date for the Perkins Lake moraine. Overlying laminated silt and clay, with high magnetic susceptibility and low total organic carbon, represent glacial-lacustrine sedimentation, most likely in a larger lake than those of today, dammed by the Perkins Lake moraine. Glacial-lacustrine sedimentation terminated and organic-rich sedimentation began ca. 16,400 cal yr BP. The transition to organic-rich sedimentation at that time represents either the retreat of glaciers from the lake margin, coupled with the invigoration of organic production, or the partial drainage of the inferred, large lake and consequent isolation of the marsh. Also of note is an anomalous, 3-cm-thick, light-brown layer within the organic-rich section. This layer did not produce distinct total organic carbon, magnetic susceptibility, or grain-size values; however, its anomalous color and minimum limiting date of 13,980±120 cal yr BP, which correlates with minimum dates on glacial lacustrine sediments in Pettit Lake and McDonald Lake cores (figs. 3B and 3C) , suggest that it pertains to a glacial readvance upvalley or to a distinct climatic episode that reduced organic production or increased inorganic sedimentation in the Alturas Lake drainage.

Mileage Cum.	Inc.	
32.8	0.6	Perkins Lake moraine is on left (northwest) side of road. Wooded hills to right (southeast) are lateral moraines of the Busterback Ranch group.
35.0	2.2	Road passes through moraines of the Busterback Ranch group.
35.2	0.2	Intersection with Highway 75. Turn right (south) toward Galena Summit and Sun Valley.
35.6	0.4	Distal edge of Busterback Ranch moraine (Alturas Valley) at right.
37.8	2.2	Enter Sawtooth City, home of Smiley Creek Lodge (good food and milkshakes, as well as gas and a small convenience store). Note moraines at right, constructed by glaciers descending the Smiley Creek drainage.
38.5	0.7	Terminal moraines at the mouth of Pole Creek, a major drainage in the Boulder-White Clouds Mountains to the east. These moraines and a sediment core obtained from a kettle pond within the moraine sequence are described by Breckenridge and others (1988).
40.9	2.4	Cross the mighty Salmon River. Formerly glaciated headwaters lie to the right (south).
41.6	0.7	Road cuts at left, extending the next 0.6 mi, expose till in lateral moraine of the Pole Creek drainage.
44.8	3.2	Turn right into viewpoint parking lot for Stop 4. Parking here will be tight, and the traffic sometimes is a bit hazardous, so please use caution.

Stop 4. Galena Summit Viewpoint

This viewpoint provides a final overview of the Sawtooth Mountains and Sawtooth Valley. The Sawtooth Mountains include abundant high elevation area that served as accumulation zones for the large Pleistocene glaciers. The wooded hills at the foot of the range are the moraines constructed by glaciers descending the major Sawtooth drainages, while the sagebrush-covered valley floor is largely outwash fill. To the right (east) are moraines of the Pole Creek drainage, while directly below the viewpoint are moraines of the Salmon River headwaters drainage.

Mileage		
Cum.	Inc.	
45.8	1.0	Continue south on Highway 75 to Galena Summit.
55.4	9.6	Prairie Creek area lies to the right (west). Glaciers descending this drainage from the crest of the Smoky Mountains constructed moraines that represent the type locality of the Bull Lake-age Prairie Creek advance (Pearce and others, 1988).
61.4	6.0	Boulder Creek area lies to the left (north). Moraines in this drainage, constructed by glaciers descending from the crest of the Boulder Mountains, represent the type locality of the Pinedale-age Boulder Creek advance of Pearce and others (1988).
75.2	13.8	Enter Ketchum.

References

Borgert, J.A., 1999, Extent and chronology of alpine glaciation in the Alturas Valley, Sawtooth Mountains, Idaho: Pocatello, Idaho State University, unpublished M.S. thesis, 100 p.

Borgert, J.A., Lundeen, K.A., and Thackray, G.D., 1999, Glaciation of the southeastern Sawtooth Mountains, central Idaho, *in* Hughes, S.S., and Thackray, G.D., eds., Guidebook to the geology of eastern Idaho: Special Publication of the Idaho Museum of Natural History, p. 205–217.

Breckenridge, R.M., Stanford, L.R., Cotter, J.F.P., Bloomfield, J.M., and Evenson, E.B., 1988. Glacial geology of the Stanley Basin, *in* Link, P.K., and Hackett, W.R., eds., Guidebook to the geology of central and southern Idaho: Idaho Geological Survey Bulletin 27, p. 209–221.

Chadwick, O.A., Hall, R.D., and Phillips, F.M., 1997, Chronology of Pleistocene glacial advances in the central Rocky Mountains: Geological Society of America Bulletin, v. 109, p. 1443–1452.

Clark, D.H., and Gillespie, A.R., 1997, Timing and significance of late-glacial and Holocene cirque glaciation in the Sierra Nevada, California: Quaternary International, v. 38/39, p. 21–38.

Gosse, J.C., Evenson, E.B., Klein, J., Lawn, B., and Middleton, R., 1995, Precise cosmogenic ^{10}Be measurements in western North America—Support for a global Younger Dryas cooling event: Geology, v. 23, p. 877–880.

Kutzbach, J.E., Guetter, P.J., Behling, P.J., and Selin, R., 1993, Simulated climatic changes—Results of the COHMAP climate-model experiments, *in* Wright, H.E., Kutzbach, J.E., Webb, T., III, Ruddiman, W.F., Street-Perrott, F.A., and Bartlein, P.J., eds., Global climates since the last glacial maximum: Minneapolis, University of Minnesota Press, p. 24–93.

Licciardi, J.M., Clark, P.U., Brook, E.J., Pierce, K.L., Kurz, M.D., Elmore, D., and Sharma, P., 2001, Cosmogenic ^{3}He and ^{10}Be chronologies of the late Pinedale northern Yellowstone ice cap, Montana, USA: Geology, v. 29, p. 1095–1098.

Lundeen, K.A., 2001, Refined late Pleistocene glacial chronology for the eastern Sawtooth Mountains, central Idaho: Pocatello, Idaho State University, unpublished M.S. thesis, 117 p.

Pearce, S., Schlieder, G., and Evenson, E.B., 1988, Glacial deposits of the Big Wood River valley, *in* Link, P.K., and Hackett, W.R., eds., Guidebook to the geology of central and southern Idaho: Idaho Geological Survey Bulletin 27, p. 203–207.

Souch, C., 1994, A methodology to interpret downvalley lake sediments as records of Neoglacial activity, Coast Mountains, British Colombia, Canada: Geografiska Annaler, v. 76A, p. 169–185.

Stanford, L.R., 1982, Glacial geology of the upper South Fork Payette River, south-central Idaho: Moscow, University of Idaho, unpublished M.S. thesis, 83 p.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24000-cal BP: Radiocarbon, v. 40, p. 1041–1084.

Thackray, G.D., 1999, Pacific moisture delivery and the variability of alpine glacier chronologies in western North America: Geological Society of America Abstracts with Programs, v. 31, no. 4, p. 58.

Thackray, G.D., 2001, Extensive early and middle Wisconsin glaciation on the western Olympic Peninsula, Washington, and the variability of Pacific moisture delivery to the Pacific Northwest: Quaternary Research, v. 55, p. 257–270.

Thackray, G.D., Lundeen, K.A., and Borgert, J.A., 2004, latest Pleistocene alpine glacier advances in the Sawtooth Mountains, Idaho, USA—Reflections of mid-latitude moisture transport at the close of the last glaciation: Geology, v. 32, p. 225–228.

Whitlock, C., and Bartlein, P.J., 1993, Spatial variations of Holocene climatic change in the Yellowstone region: Quaternary Research: v. 39, p. 231–238.

Williams, P.L., 1961, Glacial geology of the Stanley Basin: Moscow, Idaho Bureau of Mines and Geology Pamphlet 123, 29 p.