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FIELD GUIDE TO THE QUATERNARY GEOLOGY OF JACKSON HOLE, WYOMING

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Includes **"Holocene Vegetation and Climate of Grand Teton National Park and Vicinity"** by Cathy Whitlock[3],

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Cover drawing is *French Trapper* drawn by Frederic Remington in 1891 graciously supplied to us by the Buffalo Bill Historical Center of Cody, Wyoming. There it is a gift of the Vain and Harry Fish Foundation in memory of Vain and Henry Fish.

In our acknowledgements, we neglected to thank two scientists quite important to this study. Maynard Fosberg described the three soil profiles included in this guidebook, as well as many others not included but important to our study. Steve Schilling assisted in the field work, including digging many soil pits and taking cores from Jackson Lake.

Table 2 is reproduced here because it outlines in a simple way why the last glaciation had such a complex history.

Change in relative size of three glacial lobes through time in northern Jackson Hole during the last or Pinedale glaciation. Note trend from east to west through time.

	West		East
Pinedale Glacial Phase	**Snake River lobe**	**Pacific Creek lobe**	**Buffalo Fork lobe**
Burned Ridge (oldest)	0	X	XXX
Hedrick Pond	X	XXX	0
Jackson Lake (youngest)	XX	XX	0

Explanation of symbols:

0 = lobe not confluent with other lobes at terminus

X = lobe confluent but slightly smaller than other lobe.

XX = lobe confluent and very similar in size to the other lobe at terminus.

XXX = lobe confluent slightly larger than other lobe at terminus.

FIELD GUIDE TO THE QUATERNARY GEOLOGY OF JACKSON HOLE, WYOMING

KENNETH L. PIERCE AND JOHN D. GOOD

INTRODUCTION

This guide is prepared for the *Friends of the Pleistocene* (Rocky Mountain Cell) field trip to Jackson Hole, Wyoming, September 11-13, 1992. It is an expansion of an earlier, one-day field trip (Pierce and Good, 1990). The three-day field trip is subdivided into road segments for convenience and use at other times (Fig. 1). This guide is intended for use with the U.S.G.S. 1:62,500-scale topographic map of Grand Teton National Park. The following overview provides a general context in which the significance of the stops may be understood. Because topographic map altitudes and vehicular distances are in English units, we differ from current scientific practice and use English units (giving metric equivalents in parenthesis).

This guide to the "Quaternary geology" focuses on the last two Pleistocene glaciations (Table 1), which span only the last one-tenth of all of Quaternary time. Most of the prominent glacial features of Jackson Hole were described by Fryxell (1930); we differ from Fryxell in attributing a lesser role to glaciers from the Teton Range and a larger role to the southern part of the Yellowstone ice mass. Montagne (1956) and Love and Reed (1971) have summarized the glacial history. In the last 5 pages of this guide, Cathy Whitlock summarizes the post-glacial vegetation history of the Jackson Hole region.

Strong climatic gradients occur across Jackson Hole and are manifest in vegetation changes as well as soil development. For example, the mean annual precipitation (MAP) at Jackson is about 17 inches (430 mm), whereas at a slightly lower altitude at Wilson 6 miles (10 km) to the west, the MAP is about 40 inches (1,000 mm) (J. D. Love, oral commun., 1992).

ACKNOWLEDGMENTS

We wish to thank Dave Love for sharing with us his vast knowledge of the bedrock and surficial geology of Jackson Hole. Some of this information is summarized in Love and Reed (1971). Both the bedrock and surficial geology are shown at a scale of 1:62,500 on Love and others (1992). Dave does not agree with all the interpretations presented here. In particular, he thinks Munger ice extended much farther down the Snake River, that there is a tectonic depression in the Moran Junction area, and that many of the linear escarpments rising above the margins of some terraces are fault scarps.

Linda Pierce, my now grown children Jennifer and Daniel, and Matt Houston (Colorado College) have helped this study as volunteer field assistants, editors, and supporters in residence. Sharon Rosema helped with FOP mailings and preparation of this guidebook.

We also extend heartfelt thanks to archeologists Melissa Connor, Cal Calabrese, and Adrienne Anderson (National Park Service) for their collaborative studies and financial support of geologic studies in the Jackson Lake drawdown area; to Superintendents Jack Stark and Jack Neckels, and the staff of Grand Teton National Park for help, logistical support, and keen interest in our work; to Shar Milligan (Grand Teton National History Association) for helping our work reach the public; to Steve Colman (U.S.G.S) for marine geophysics studies on Jackson Lake; to Bob Smith, John Byrd, and Dave Susong (Univ. of Utah) for information on the Teton fault and Jackson Lake; to Dean Ostenaa, Karl Wirkus, Jerry Gilbert, and Allen Lockhart (U.S. Bureau of Reclamation) for geologic information on all of Jackson Hole and particularly the Jackson Lake Dam area, to the University of Wyoming-National Park Service Research Center (Ken Diem and others) for logistical support and financial support for subaqueous studies on Jackson Lake. Most especially, we thank Edna Good of GTNP for solving countless logistical problems, for great meals, and for being there.

OVERVIEW OF QUATERNARY GEOLOGY

The magnificent landscapes of Jackson Hole strongly reflect Quaternary geologic processes, particularly tectonics and glaciation. We think that the Yellowstone hotspot is fundamental to the dynamics of both tectonics and glaciation; it produced (1) late Cenozoic activity on the Teton

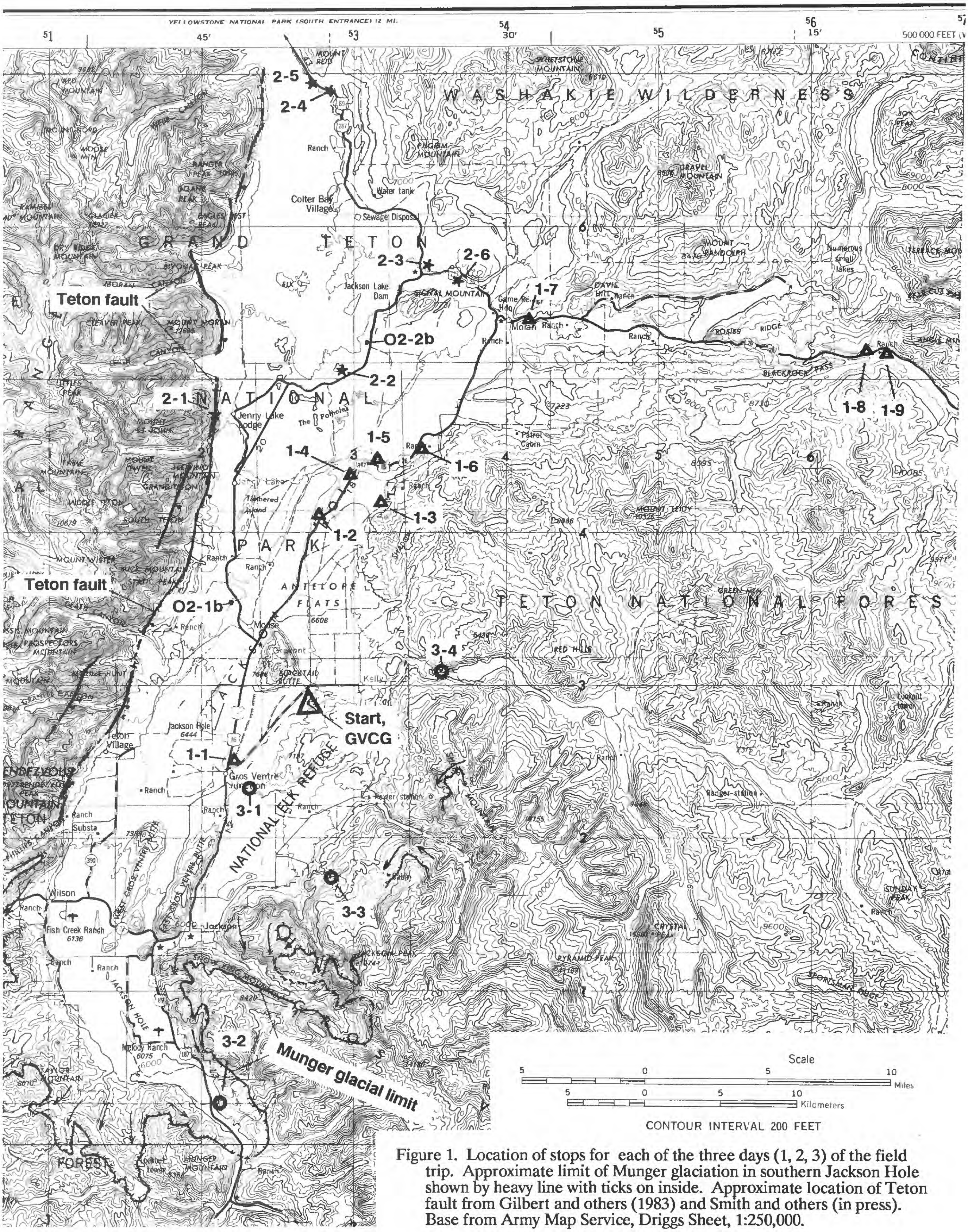


Figure 1. Location of stops for each of the three days (1, 2, 3) of the field trip. Approximate limit of Munger glaciation in southern Jackson Hole shown by heavy line with ticks on inside. Approximate location of Teton fault from Gilbert and others (1983) and Smith and others (in press). Base from Army Map Service, Driggs Sheet, 1:250,000.

Table 1, Quaternary stratigraphic terms and correlations, Jackson Hole, Wyoming

Beyond Jackson Hole			Jackson Hole Terms and Events			
Time divisions[1]	Marine isotope stages[2]	Regional terms[3]	Names for glacial deposits	Correlative outwash locations	Lakes	Loess or soil formation
-0 ka Holocene -10 ka	-0 ka **1**	Neoglaciation -4 ka Altithermal -9 ka	Cirque moraines		Present Jackson Lake	soil
late Pleistocene	-11 ka **2** -35 ka **3** -65 ka **4** -79 ka **5**	Pinedale glaciation ? ?	->11 ka Jackson Lake [4] **2** Hedrick Pond/Dogleg [4] **2**? or **3**? Burned Ridge {#3, #2, #1} [4] **2**? or **3**? or **4**?	4 Channelways Snake River & Dogleg moraine Antelope Flats Blacktail terrace	? Triangle X-2 Triangle X-1	loess soil loess loess soil loess
-132 ka middle Pleistocene	-132 ka **6**	-132 ka Bull Lake(?) glaciation	-132 ka Munger glacial deposits [4] **6**? {recessional, maximum}	Timbered Island Windy Point SE Jackson Hole		loess

1 From Richmond and Fullerton (1986)

2 After Shackleton and Opdyke (1973) as recalibrated by Richmond and Fullerton (1986)

3 Partly from Pierce (1979)

4 Underlined bold numbers indicate possible marine-isotope stage correlations.

fault, (2) uplift of the greater Yellowstone region, and (3) a hotspot track (eastern Snake River Plain) through which storms carry snows to the greater Yellowstone area (Pierce and Morgan, 1990, 1992).

TECTONICS

The spectacular front of the Teton Range is a product of one of the most active normal faults in the United States. Post-glacial fault scarps formed in the last 14,000 years at the center of the range (Stop 2-2) are up to 113 ft (34 m) high with surface offsets of up to 63 ft (19 m) indicating offset rates between 1 and 1.5 mm/yr (Gilbert and others, 1983; Smith and others, 1990, Smith and Byrd, in press). These rates have persisted throughout the Quaternary and are likely to continue for thousands of years into the future. Presently, the Teton fault is ominously quiet (Doser and Smith, 1983; Smith and Byrd, in press).

Tilting into the Teton fault of originally horizontal volcanic and sedimentary rocks at Signal Mountain can be used to define the fault's late Cenozoic history (Fig. 2; Stop 2-3). The 9-10 Ma Teewinot Formation has dips averaging 22° (27, 20 and 17° (Love and others, 1992) and the Ma tuff has a dip of (22°) into the fault (Fig. 2), suggesting the current activity on the fault post-dates 5 Ma (Pierce and Morgan, 1990, 1992). Since 2 Ma (about 1.25 mm/yr), activity has been very high and similar to post-glacial activity. Projection of the Huckleberry Ridge Tuff westward to the Teton fault suggests as much as 4,000 to 7,000 ft (1,300 to 2,000 m) (Gilbert and others, 1983, Fig. D-4) of fault-basin fill has accumulated in the last 2 Ma (essentially Quaternary time) in central-western Jackson Hole (See Love and Love 1983 and Love and others, 1992 for map relations).

Pleistocene Glaciations

The last (Pinedale) glaciation terminated in central Jackson Hole but the next older glaciation (Munger, Bull Lake?) filled all of Jackson Hole with ice (Fig. 1). Records of older glaciations are obscure, although the thick fill of Jackson Hole probably preserves a record of previous glaciations; 10 or so are known to have occurred in the last million years (Shackleton and Opdyke, 1973). These older glaciations would also have eroded the parts of glaciated valleys surrounding Jackson Hole.

Pleistocene glaciers flowing into Jackson Hole headed in the Yellowstone/Absaroka source area to the east and north. This source area was much more important than the Teton Range for two reasons: (1) the Teton Range occupies a much smaller area, and (2) the Yellowstone/Absaroka source area includes extensive uplands that were near Pleistocene equilibrium-line altitudes (ELA's). ELA's on these Pleistocene glaciers were probably about 9,000 feet (2,700 m). Pleistocene glaciers rose above this altitude either at the margins of Jackson Hole (Pinedale time) or in central Jackson Hole (Munger time). Thus the source area producing glacial ice was not restricted to cirque areas far away, but also included areas near the margins of Jackson Hole in Pinedale time and actually within Jackson Hole in Munger time.

Munger Glaciation

The Munger glaciation filled all Jackson Hole with ice (Fig. 1) and thus might be humorously called the Jackson "Whole" glaciation. The Munger glaciation is named for Munger Mountain at the south end of Jackson Hole, for here the glacier divided and flowed to termini along the Snake River 2 miles (3 km) north of Hoback Junction (near Stop 3-2) and along Fall Creek downstream from Coburn Creek. As shown on Figure 1, the Jackson Whole glacier of Munger age terminated at an altitude of about 6,300 ft (1,920 m) near Hoback Junction. From there, this glacier surface face rose to 7,430 ft (2,265 m) on the north end of Munger Mountain (near Stop 3-2), to 7,800 ft (2,380 m) on Snow King Mountain immediately south of Jackson, to 8,050 ft (2,450 m) on Phillips Ridge northwest of Wilson, to 8,840 ft (2,700 m) south of Flat Creeks (Stop 3-3), to between 9,600 and finally 10,000 ft (2,930-3,050 m) on Sheep Mountain for the Gros Ventre glacier flowing into Jackson Hole. The surface of Munger ice continued to rise north of the Kelly-Moose area, covering nearly all the topography on the east side of Jackson Hole.

This thick glacier scoured the valley walls of Jackson Hole (Stop 2-3), streamlined East and West Gros Ventre Buttes west of Jackson, and probably excavated deep scour basins in southern Jackson Hole. Most of the side valleys feeding into Jackson Hole were filled with ice; during the Munger advance and recession, much glacial debris was trapped in these side valleys (Stop 3-4). Glaciers from the Tetons formed the west side of the Jackson Whole glacier, depositing Precambrian crystalline rocks along the west side of Jackson Hole to the terminus on Fall Creek.

Munger glacial deposits are characterized by a well-developed soil which is commonly buried by Pinedale loess. This holds for both the terminal moraine area and the areas of recessional deposits that extend all the way north to the Pinedale limit. Near the Snake River, this loess is thicker than

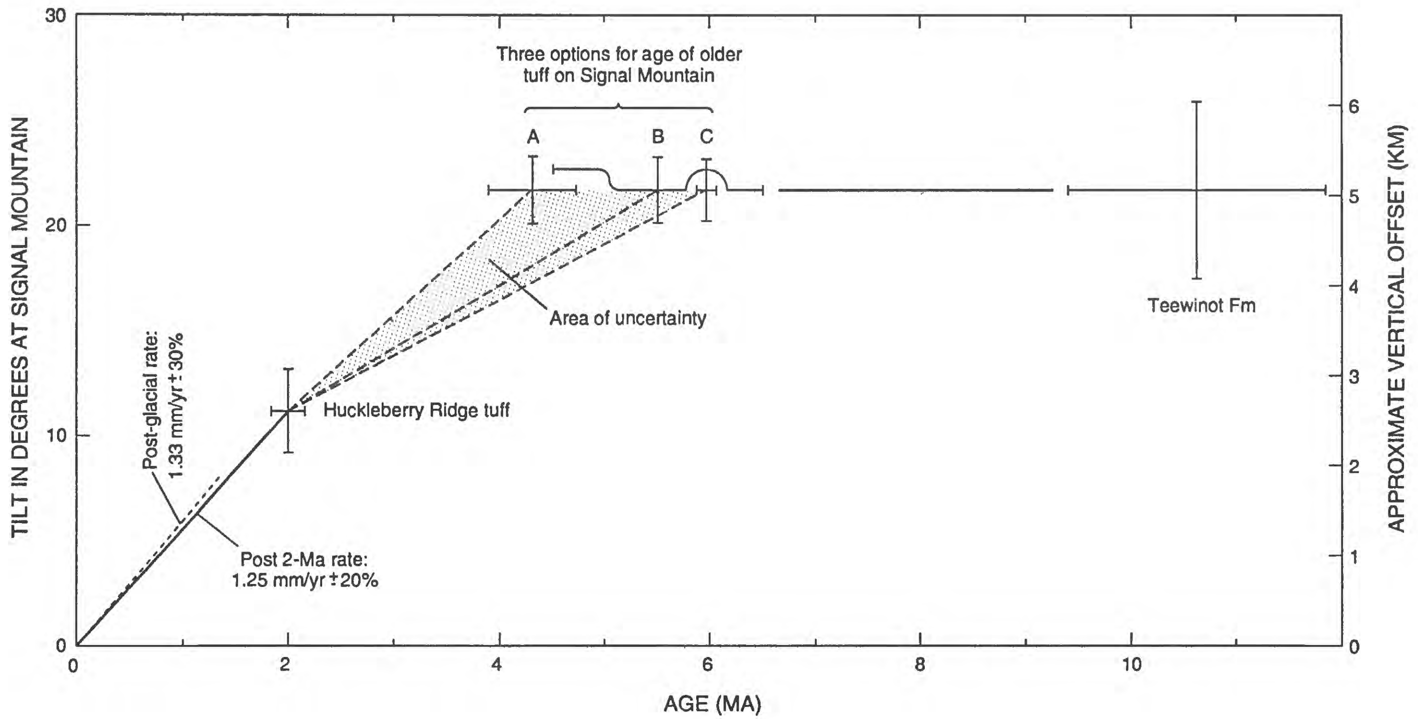


Figure 2. Inferred late Cenozoic history of the Teton fault based on tectonic rotation into the fault of beds in the Signal Mountain area. Signal Mountain is 13 km east of the central part of the Teton fault. See Pierce and Morgan (1992) for three options of age 4-6 Ma tuff. The present episode of tilting started after 6 Ma, and high tilt rates have persisted since at least 2 Ma. Offset since 2 Ma has been about 1.25 mm/yr (solid line). Since 15 ka near String Lake (Stop 2-1), 63 ft (19.2 m) of vertical offset (Gilbert and others, 1983) yields a rate of 1.3 mm/yr (dashed line).

10 ft (3 m) (Glenn and others, 1983). There, the buried soil is actually a soil complex with as many as three B horizons (Stop 3-2). For recessional deposits, such as those at Windy Point (Optional Stop 2-1b), Timbered Island, and the National Elk Refuge (Stop 3-1), no major standstill is recognized, and because these deposits have the same appearance and soil development as the full-glacial Munger deposits, they are assigned to the same glaciation. Munger moraines and erosional forms are relatively little modified, except for a loess mantle locally thicker than 10 ft (3 m). Except for this thick loess mantle, they are similar in stratigraphic sequence and preservation of morphology to typical Bull Lake deposits elsewhere in the Rocky Mountains. In addition, no glacial moraines of an age intermediate between those assigned to the Pinedale and Munger glaciations are known in Jackson Hole. Thus, based on soil development, the loess/soil stratigraphic sequence, and the mapped moraine sequence, we correlate the Munger glaciation with the Bull Lake glaciation.

We also correlate Munger deposits with those found well beyond Pinedale terminal moraines around the margin of the greater-Yellowstone glacial-source area. These are (clockwise around the greater Yellowstone ice mass from Jackson Hole), (1) Bull Lake moraines in the Ashton, Idaho, area (Richmond, 1976; as correlated by Colman and Pierce, 1981 and Scott, 1982), and (2) Bull Lake moraines of a Yellowstone glacier that filled the West Yellowstone, Montana, basin (Richmond, 1964; Pierce, 1979). Near West Yellowstone, the age of this glaciation is estimated to be about 140,000 years (Table 1) and to correlate with oxygen-isotope stage 6 (Table 1) based on obsidian hydration calibrated by K-Ar methods (Pierce and others, 1976; Pierce, 1979). Bull Lake glaciers with source areas in the southern and western part of Yellowstone were much larger than Pinedale glaciers; however those with source areas east and north of Yellowstone were smaller and thus Bull Lake terminal moraines were overrun by Pinedale glaciers. A northeast-moving wave of uplift followed by subsidence associated with the Yellowstone hotspot may be responsible for this Bull Lake/Pinedale spatial pattern (Pierce and Morgan, 1990, 1992).

Pinedale Glaciation

After years of struggling with the perplexing Pinedale record, we have come up with a history so complicated that it is a challenge to follow. One "hidden" dimension of the problem is that Pinedale outwash deposition, aided by downfaulting on the Teton fault, has built up deposits more than 200 ft (60 m) thick in the Pinedale end moraine/outwash areas and buried the landscapes that were encountered by the advancing Pinedale glaciers. To understand the Pinedale sequence, one needs to look beneath this outwash fill and *recognize the pre-Pinedale and intra-Burned Ridge-Hedrock Pond valleys of the Snake River, Pacific Creek, and Buffalo Fork.* This is a problem we have only partially resolved with our primitive "X-ray vision".

In Pinedale time, the Buffalo Fork lobe flowed into Jackson Hole from the east, the Pacific Creek lobe from the northeast, and the Snake River lobe from the north. The details of the Pinedale glacial history are complicated, because the size of these three glacial lobes changed through time, indicating the highest part of the glacial source area migrated to the west (Table 2). This probably reflects orographic buildup on the western side of the Yellowstone/Absaroka source area by storms moving eastward up the Snake River Plain. Glaciers from the Tetons were of lesser size, as illustrated by the end moraines of valley glaciers separate from the Yellowstone/Absaroka ice source that extended no more than 1.5 mi (2.5 km) beyond the Teton front. Some examples are the moraines encompassing Jenny, Bradley, Taggart, and Phelps Lake. North of Jenny Lake, glaciers from the Teton Range joined the south-flowing Snake River lobe.

<u>Burned Ridge phase</u>--.During this, the oldest phase of the Pinedale glaciation (Table 1) represented by end moraines of the Yellowstone/Absaroka source area, the Buffalo Fork and Pacific Creek lobes joined and flowed westward into Jackson Hole and deposited moraines flanked by outwash (Fig. 3). At their confluence, the Buffalo Fork lobe was probably slightly larger as shown by its southward extension into central Jackson Hole. Three major stands in Burned Ridge time (BR-1, BR-2, and BR-3), each with an outwash fan (Stop 1-3), are shown in the northern and eastern parts of Antelope Flats. The ice-marginal Spread Creek spilled into the eastern side of Jackson Hole and deposited outwash fans more than 200 ft (60 m) thick. These enormous quantities of quartzite-rich gravel were derived from both glacial and non-glacial sources feeding into the dissected area between the southern margin of the Buffalo Fork lobe and the Mt. Leidy highlands (from Stop 1-3 to Stop 1-9). This outwash-dominated glacial system resulted in partial or total burial of end moraines. For example, the BR-1 ice margin is only recognized by kettles 3.5 km (2.2 mi) beyond the BR-3 ice margin. The depositional slope of these Burned Ridge outwash fans arcs from west to

Table 2. Change in relative size of three glacial lobes through time in northern Jackson Hole during the last or Pinedale glaciation. Note trend from east to west through time.

	West		East
Pinedale Glacial Phase	**Snake River lobe**	**Pacific Creek lobe**	**Buffalo Fork lobe**
Burned Ridge (oldest)	0	X	XXX
Hedrick Pond/	X	XXX	0
Jackson Lake (youngest)	XX	XX	0

Explanation of symbols:

0 = lobe not confluent with other lobes at terminus

X = lobe confluent but slightly smaller than other lobe.

XX = lobe confluent and very similar in size to the other lobe at terminus.

XXX = lobe confluent slightly larger than other lobe at terminus.

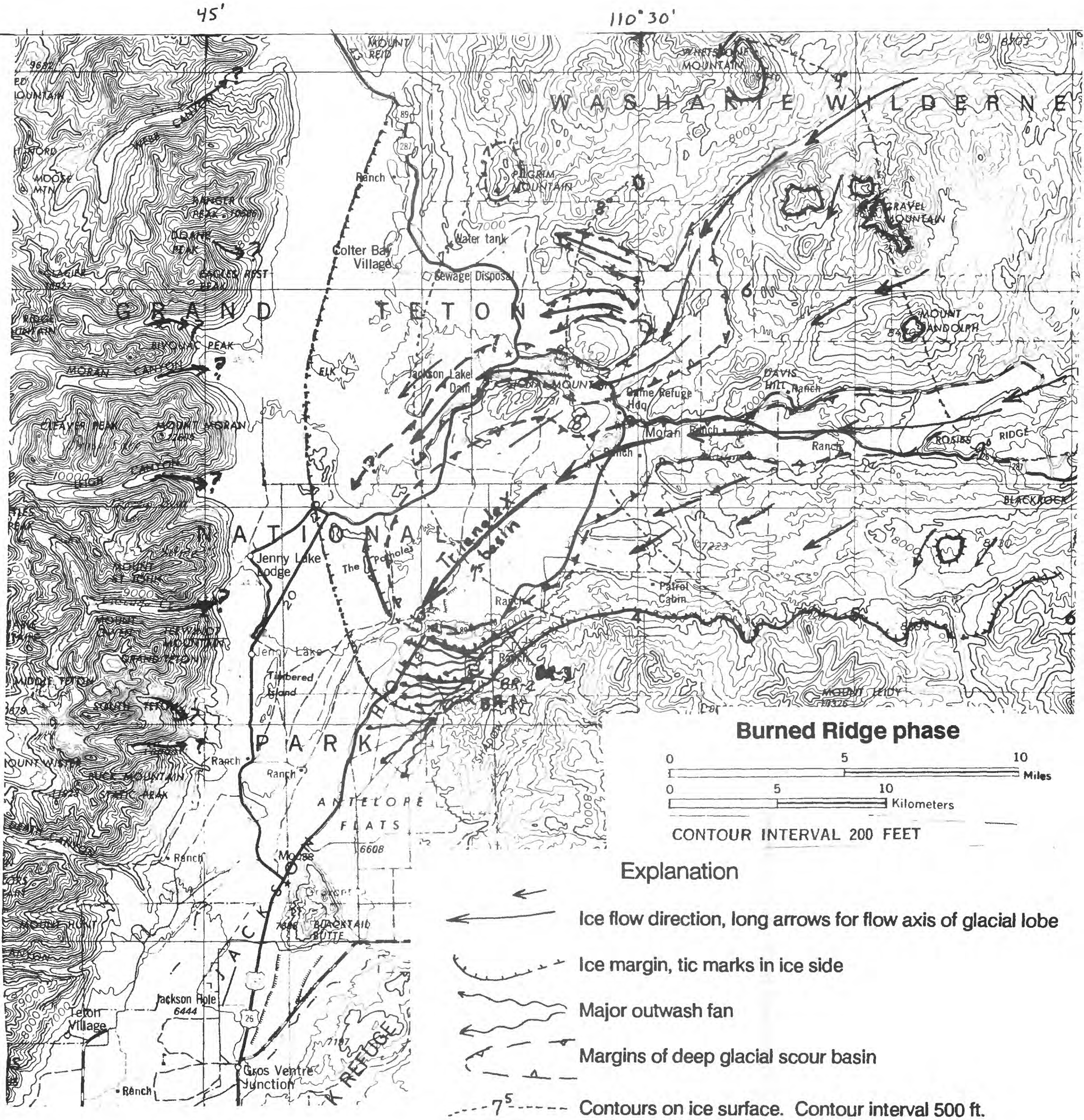


Figure 3. Approximate limit of Burned Ridge phase of the Pinedale glaciation along southern margin of the Yellowstone/Absaroka ice mass. The glacial limits in the upvalley areas of the Tetons, and Buffalo Fork, Pacific Creek, and the Snake River is not shown here or suceeding figures, although much of it has been located in the field.

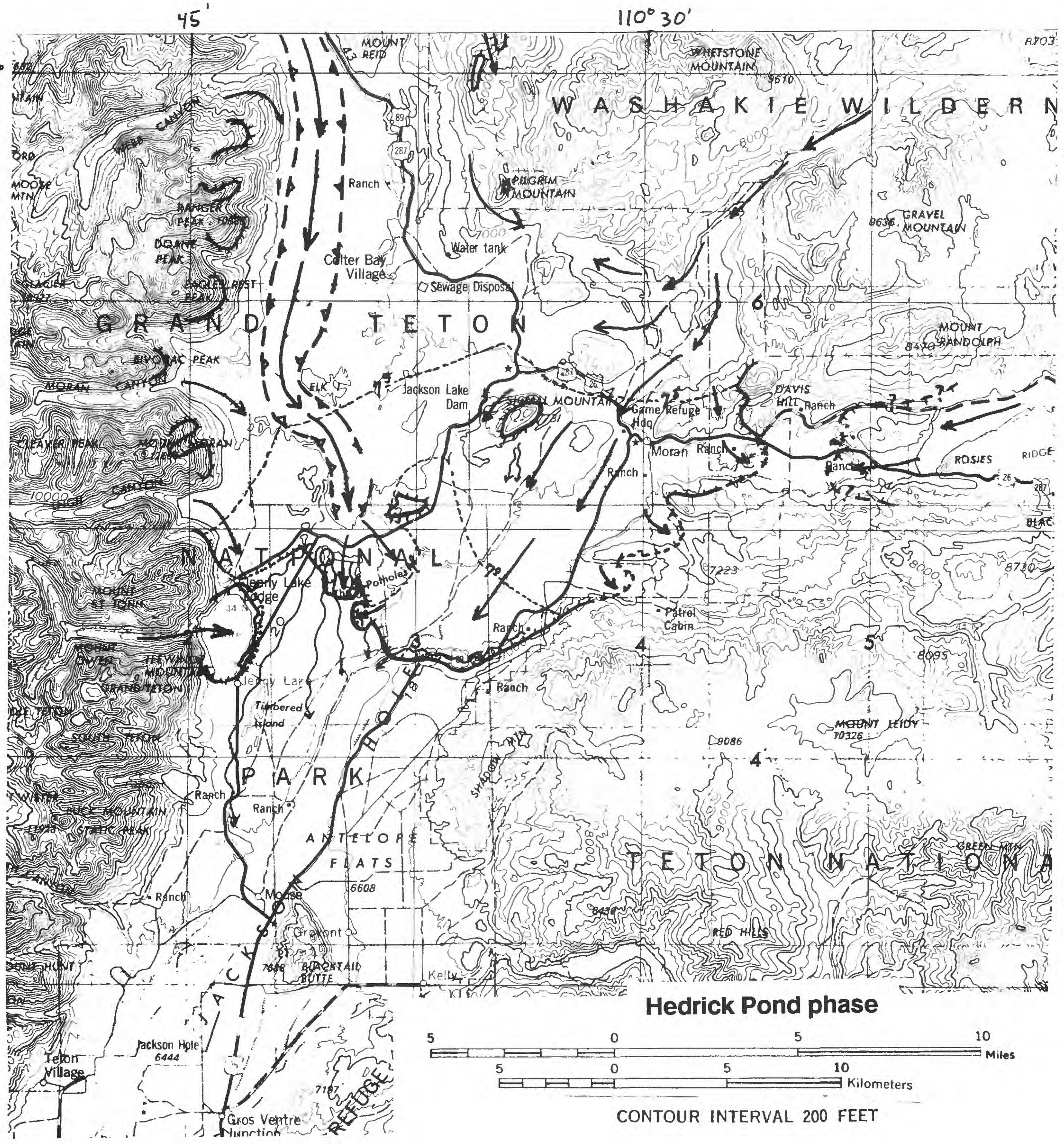


Figure 4. Approximate limit of Hedrick Pond phase of the Pinedale glaciation along southern margin of the Yellowstone/Absaroka ice mass. Symbols and comment concerning glacial limit the same as Figure 3.

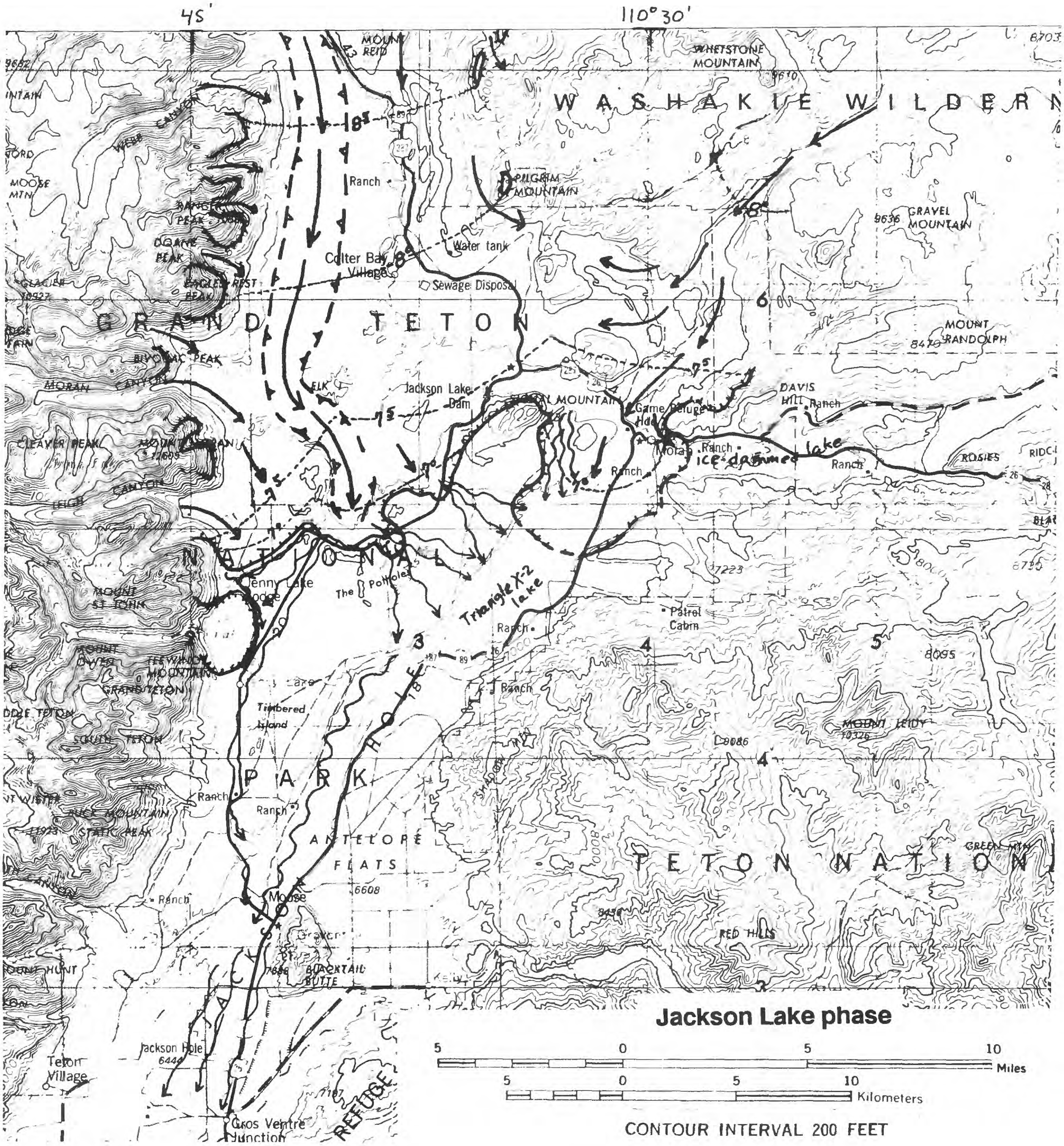


Figure 5. Approximate limit of Jackson Lake phase of the Pinedale glaciation along southern margin of the Yellowstone/Absaroka ice mass. Symbols and comment concerning glacial limit the same as Figure 2.

south. The west slope results primarily from deposition, and the expected tilting due to downdropping on the Teton fault is difficult to isolate. West of the present Snake River, Burned Ridge outwash is buried by Hedrick Pond and Jackson Lake outwash from the Spalding Bay source to the north.

The Buffalo Fork and Pacific Creek lobes excavated deep scour basins (Fig. 3). The Buffalo Fork lobe excavated a scour basin more than 15 miles long that extends from Deadmans Bar up the Snake River to the Moran Junction area and up the Buffalo Fork to at least Rosies Ridge. This basin was about 4 miles wide in the area extending from the Triangle X Ranch northeast to the "Inner road" of Grand Teton National Park (GTNP). After the Burned Ridge advance but prior to the Hedrick Pond advance, this scour basin was the site of the inferred Triangle X-1 lake. Another scour basin at least 10 miles (16 km) long extends down Pacific Creek, and westward on the north side of Signal Mountain to the Spalding Bay area. Beneath the northern dike of the Jackson Lake Dam, about 600 ft of unconsolidated sediments (Gilbert and others, 1983) fill this scour basin. These sediments created the foundation problems that required rebuilding the dam in the 1980's. Basins now holding Emma Matilda and Two Ocean Lakes were also excavated by the west-flowing Pacific Creek lobe in Burned Ridge time.

Moraines and outwash along the northern half of the Burned Ridge ice margin have been overridden by younger advances, but the abundance of Pinyon-type quartzite and paucity of Huckleberry Ridge Tuff clearly indicate their deposition by the Pacific Creek lobe rather than Snake River lobe (Optional Stop 2-3b). The Snake River lobe terminated somewhere north of Jackson Lake at this time. The numerical age of the Burned Ridge phase is not known, but is estimated to be sometime between 30 and 70 ka.

Hedrick Pond phase--.During the intermediate, or Hedrick Pond phase (Table 1), the Snake River lobe advanced to the south of Jackson Lake where it joined the slightly larger Pacific Creek lobe (Fig. 4; Table 2). The Buffalo Fork lobe had receded upvalley and was not confluent as shown by Hedrick Pond moraines that slope up valley of the Buffalo Fork (Stop 1-7).

Hedrick Pond glaciers advanced into the Triangle X-1 lake which filled the basin scoured by Buffalo Fork ice in Burned Ridge time (Stops 1-5, 2-2). The Pacific Creek lobe advanced to the escarpment left at the BR-3 ice margin, including the type area at Hedrick Pond as well as through a breach in Burned Ridge located between 0.9 and 1.4 mi (1.4 and 2.3 km) north of the Snake River (old outlet valley of Buffalo Fork?). The gradient on this ice surface in the Triangle X basin was less than that of the even thicker Burned Ridge glacier, probably because flow in Hedrick Pond time was across a readily deformable bed of lake sediments of the Triangle X-1 lake (Stop 1-5).

The Snake River lobe advanced southward through Spalding Bay, and (1) deposited small moraines of Hedrick Pond age on both sides of the northern end of the landform called "Burned Ridge", (2) also left ice blocks that forms kettles on the east and west side of "Burned Ridge", and (3) draped small moraines on a hill northeast of the Potholes channelway (Stop 2-2). This perplexed us for a long time, for the northern 2/3rds of "Burned Ridge" consists of buried moraines of Burned Ridge age *covered* by moraines of Hedrick Pond ice deposited by the Snake River lobe. The Snake River and Pacific Creek lobes were confluent in the northwestern part of the Triangle X-1 lake basin, and as the ice receded and space for deposition opened up, outwash from the Snake River lobe washed across ice blocks of the Pacific Creek lobe (Stop 2-2).

A large outwash fan of Hedrick Pond age was built from the head of the Spalding-Bay-west channelway. In a water well east of the Jenny Lake Lodge on the west side of this fan, obsidian-hydration rims in outwash gravels indicate Pinedale ages to depths of about 250 ft (75 m). The eastern side of the Spalding Bay fan crosses the present Snake River near the Teton Point Turnout (Stop 1-2) and overlaps and buries Burned Ridge outwash in the southern part of Antelope Flats.

The numerical age of the Hedrick Pond advance is not well known, but its close spatial relations to the Jackson Lake phase correlated with oxygen isotope stage 2 suggest Hedrick Pond may correlate with stage 2 or perhaps stage 3.

Hedrick Pond and Jackson Lake phases undifferentiated--.The south flowing Snake River lobe excavated the north-south Jackson lake basin in Hedrick Pond and Jackson Lake time. Much of this excavated material was carried to the ice margin and released at the Spalding-Bay-west channelway (Stop 2-1) and the Potholes channelway (Stop 2-2). The drumlinoid topography near the east side of Jackson Lake was molded by the overriding Snake River lobe (Optional Stop 2-3b and aerial photo). Glaciers from the Teton Range (Leigh, Moran, and Berry Canyons) joined the Snake River lobe and flowed along its west side to deposit the end moraines between String Lake and the Spalding Bay west channelway. The southeast deflection of the scour basin where the Moran glacier joined the Snake River lobe suggests both glaciers were of comparable size where they met.

Jackson Lake phase--.The Jackson Lake phase is named for moraines that flank the south side of Jackson Lake (Fig. 5). Its outer boundary is inside and generally within a mile (kilometer) of the Hedrick Pond phase (Figs. 4, 5), except for the Triangle X lake-basin where the Jackson Lake ice margin was as much as 5 miles (8 km) inside the Hedrick Pond ice margin (Figs. 4, 5). When this area was vacated by Hedrick Pond ice, it was mostly occupied by the Triangle X-2 lake.

Near the ice margin, outwash of Jackson Lake age forms terraces inset into the fill terrace of Hedrick Pond age. Such outwash forms the quartzite-rich gravel that fronts and buries the moraines of Jackson Lake age between String Lake and the Spalding-Bay-west channelway (Stop 2-1, Optional stop 2-1c). Jackson Lake outwash forms the Spalding-Bay-west channelway whose incised terrace sequence with terrace scarps of variable height and orientations was studied by Nash (1987). Just outside the surface moraines enclosing Jenny Lake, outwash of Jackson Lake age from the Spalding Bay west channelway buries an outer, older set of moraines that were graded to a lower, older outwash level of inferred Hedrick Pond age (Stop 2-1).

In the area of the Triangle X-2 lake, Jackson Lake outwash forms three large fans that head at, from west to east, the Potholes channelway (Stop 2-2), the South Landing channelway (Optional Stop 2-2b), and the channels near Cow Lake on the east side of Signal Mountain. At their lower ends this outwash prograded into the Triangle X-2 lake, resulting in a conspicuous sequence of lake sediment overlain by gravel exposed in the Snake River bluffs .

The outlet of the Triangle X-2 lake was near the Snake River Overlook (Stop 1-4). This lake decreased in altitude from an early level of 6,820 ft to a later level of 6,720 ft, as shown by a progression of delta fronts in the Triangle X area (Stop 1-6). From the Snake River Overlook area, a prominent inset terrace extends downstream and converges with the maximum Pinedale fill terrace of Hedrick Pond age to eventually overlap and bury it at about the position of Moose. Further down the Snake River near the Jackson Hole Airport (Stop 1-1), the maximum fill terrace is of Jackson Lake age. We call the inset terrace for about 6 mi (10 km) downstream from Deadmans Bar the "flood flume". Gravel flood bars occur at the edges of and below the brim of the fill terrace. The floor of the flood flume has large scale bars and swales. Such floods apparently eroded the flood flume and consequently the outlet of the Triangle X-2 lake from about 6,820 to 6,720 feet. These flood waters may have come from a lake dammed in the Buffalo Fork valley by the Pacific Creek lobe in later Hedrick Pond and Jackson Lake time (Stop 1-7). Repeated failure of this glacial dam would occur when the impounded lake reached 9/10ths the glacier thickness.

From its maximum extent near the southern margin of Jackson Lake (Stop 2-2, Optional Stop 2-2b), the Snake River lobe of Jackson Lake age retreated rapidly, leaving well preserved sub-glacial topography (aerial photograph for Optional Stop 2-3b) with few well defined recessional positions. It was fed by the Yellowstone icecap (Richmond, 1976) which stagnated rapidly after it experienced a negative mass balance (Pierce, 1979; Porter and others, 1983). Carbon-14 ages from inside the Jackson Lake moraine at the Jackson Lake dam, as well as from the Yellowstone source area, suggest ice had receded from the Jackson lake area by 15,000 yr B.P.

Other Aspects of Drainage Histories--.The fill terrace of Pinedale age that floors most of Jackson Hole decreases in both age and height above the Snake River with distance southward from the Burned Ridge-3 moraine as follows:
0 mi (km) -- 300 ft (91 m), Burned Ridge age (Stop 1-4, Snake River Overlook);
5 mi (8 km) -- 130 ft (40 m), Hedrick Pond age (Stop 1-1b, Glacier View Turnout);
11 mi (18 km) -- 60 ft (18 m), Jackson Lake age (Stop 1-1, near Jackson Hole Airport); and
22 mi (36 km) -- 10 ft (3 m), younger? Jackson Lake age (west of Jackson near Boyles Hill).

After Burned Ridge time and prior to Hedrick Pond time, the Snake River probably flowed near the Teton front. Buffalo Fork and Pacific Creek would have flowed southwesterly to join it, perhaps in the two areas of anomalous kettles on the west side of Burned Ridge. The present course of the Snake River follows topographic lows resulting from the complex history of the Pinedale glaciation. Outwash more than 200 ft (60 m) thick impounds the southern margin of Jackson Lake, blocking an outlet in that area. The Snake River outflow from Jackson Lake is eastward through the scour basin excavated by the west-flowing Pacific Creek lobe. Then, just below its junction with Pacific Creek, it crosses a bedrock threshold, eroded to a low, narrow divide by westward and then southward flow of glacial lobes in Burned Ridge, Hedrick Pond and Jackson Lake time. Upon crossing this low bedrock threshold, it flows through the Triangle X lake basin excavated by the Buffalo

Fork lobe in Burned Ridge time. Its outflow from this basin is at the seam between the two Pinedale outwash fans of Burned Ridge (east side) and Hedrick Pond (west side) age.

On the east side of Jackson Hole and south of the Yellowstone/Absaroka ice margin, Ditch Creek, the Gros Ventre River, and Flat Creek built large alluvial fans of Pinedale age. These fans fill low areas around Blacktail Butte, East Gros Ventre Butte, and West Gros Ventre Butte; this aggradation aided fluvial faceting of these bedrock buttes (log to Stop 3-4).

POST-GLACIAL ACTIVITY

The braided channel of the Snake River is constantly changing due to its plentiful load of quartzite cobbles. Pilgrim Creek and Spread Creek have built large fans from readily erodible, quartzite-cobble-bearing landscapes.

Earthquakes have tilted Jackson Hole towards the Teton fault, forming as many as 10 submerged shorelines in the southwest part of Jackson Lake (Pierce and Colman, unpublished records), and have apparently tilted the Snake River upstream from its bedrock threshold at Pacific Creek to form the deep water of the Oxbows area. Much nearer the Teton fault, part of the same tilting has backflooded a late-glacial stream channel to form the shallow basin holding String Lake (Stop 2-1).

At the Lawrence site just east of the Snake River delta, abundant archeological materials are found on sandy beach deposits of late glacial to late Holocene age, including hundreds of hearths with fire cracked rock (Connor and others, 1991). The Snake River has built a delta southward into Jackson Lake, an area with a rich late Holocene archeological record (Connor and others, 1991; Frison and others, 1989).

ROAD LOG

Day 1, Eastern Jackson Hole area

Today we will look at Pinedale deposits along the eastern side of Jackson Hole, and travel eastward nearly to Togowotee Pass.

Miles (double underline) from road junction or other starting point. Distance in opposite direction is given at end of description, also double underlined. (for example (4.5)

0.0 **Start at 8:00 AM, entrance road to Gros Ventre Campground**, Grand Teton National Park (GTNP). Please line up the carpool vehicles on the right side of the road leading out of the campground. Arrange to carpool using vehicles that can carry the most people, and please have no vehicles with less than 4 people. ***We will not start until all vehicles have at least 4 people.*** The lucky person that gets the front right seat, also gets the honor of being the official guidebook monitor and is responsible to see that someone informs the driver and others of what is in the guidebook. (4.5).

Head southwest on road traversing younger Pinedale terrace on the northwest side of the Gros Ventre River. The highest terrace north of the road is a loess-mantled terrace of inferred early Wisconsin age, with little or no buried soil .

2.2 Road converges with but does not climb loess-mantled terrace. The light-colored, ashy Teewinot Fm. (9-10 Ma) crops out in lower part of roadcuts, and, south across the Gros Ventre River, forms the hills of the Elk Refuge. (2.3)

2.6 Optional Stop 1-1b. At top of roadcuts is loess mantled terrace with little or no buried soil, which we will see at Stop 1-1. (1.9)

4.3 Descend to slightly lower terrace. (0.2)

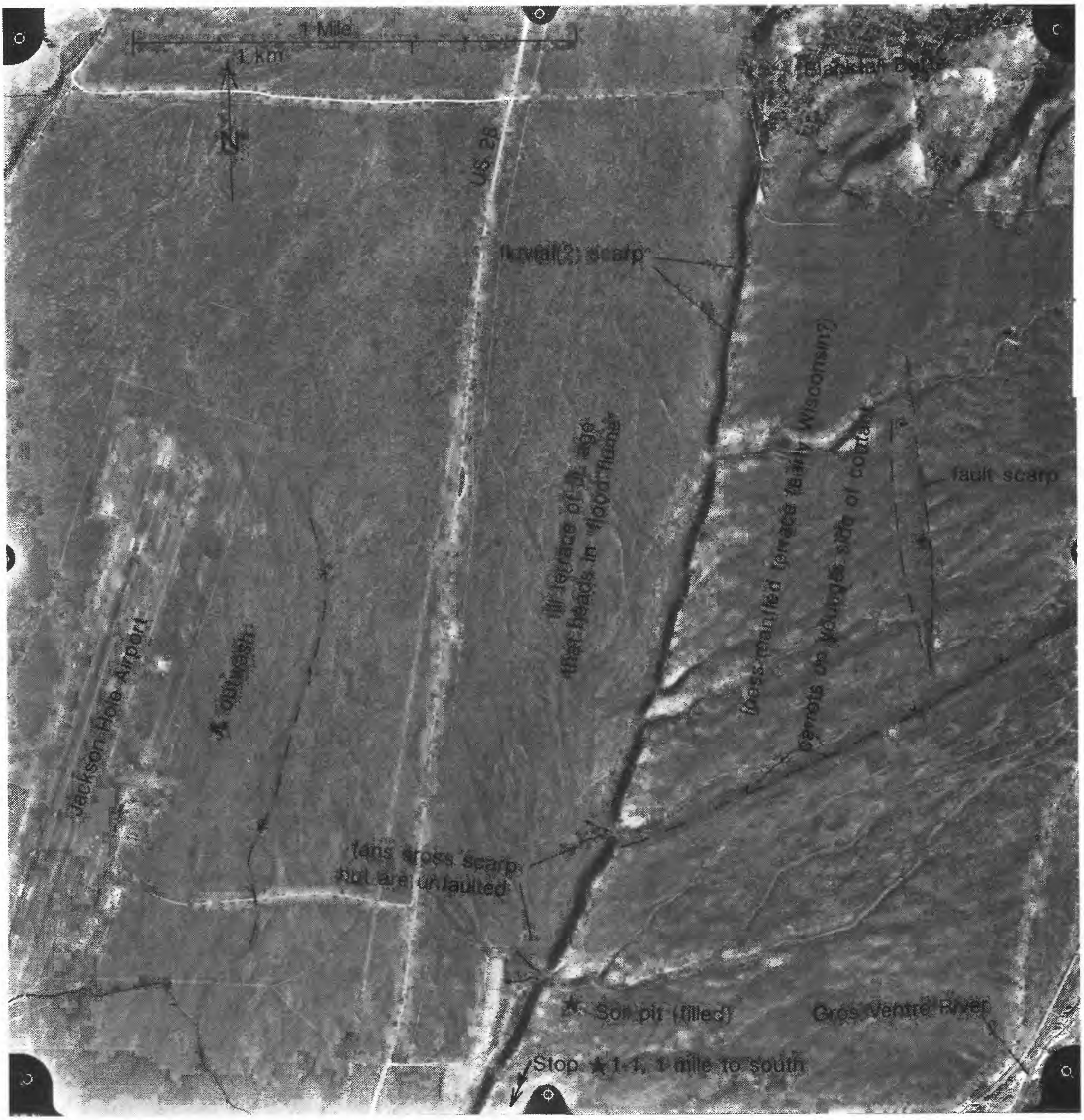
4.5 **Gros Ventre Junction.** (0.0)

Gros Ventre Junction to Moose Junction

0.0 Gros Ventre Junction. Turn north (right) on U.S. 26. Climb onto the younger Pinedale terrace from which you just descended. (5.5)

0.5 **Stop 1-1.** Park on east (right) side of highway with left tire near edge of pavement and walk east away from highway to where an irrigation ditch cuts into low, loess-mantled terrace. **About 3 m of Pinedale loess resting on early Wisconsin(?) gravel of Gros Ventre river outwash(?).** About 1 mile north of here, no buried soil was recognized in 11 ft-deep (3.3 m) soil pit (see annotated aerial photo) that went from loess into gravel. At this stop only a reddened zone and thin carbonate coats are present in the upper part of the gravel, suggesting at most only a weakly developed soil, or simply sub-surface processes occurring at the permeability boundary. Because of the thick loess mantle, this seems to be the oldest Pinedale deposit recognized in Jackson Hole, and is the best candidate for a surface deposit of "early Wisconsin" age. Between here and Blacktail Butte, a muted graben occurs in this loess-mantled terrace (see annotated aerial photo; Gilbert and others, 1983; Love and Love 1988).

The Gros Ventre terrace that we traveled on from the Gros Ventre Campground to the Gros Ventre Junction spreads out when it leaves the confined Gros Ventre valley to form a fan that here slopes northward against the generally southward slope of the terrace on which the airport is built. The airport is on the highest fill terrace of Snake



Annotated aerial photograph showing surficial geologic relations near **Stop 1-1**. Photograph is north of actual stop, but does show location of soil pit and relation of terrace escarpment to Blacktail Butte. Loess mantled terrace of early Wisconsin(?) age has linear escarpment where undercut by outwash of Jackson Lake (JL) age. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 11, 1979.

River, here of Jackson Lake age and traceable upvalley into the "flood flume" of the inset Snake River terrace. Across the Snake River valley, the post-glacial scarp of the Teton fault can be traced near the foot to the range northward from the Phillips Ridge area, through the lower part of the Jackson Hole Ski area, and through the lateral moraines at the mouths of Granite and Death Canyons.

After stop continue north still going down Gros Ventre alluvial fan built out onto airport terrace. (5.0)

0.9 Road crosses seam between the north-sloping Gros Ventre fan (grassy) and the south-sloping fill terrace (sagebrush) of the Snake River. The Snake River fill terrace is here of Jackson Lake age, and the Gros Ventre fan is younger, but also of late-glacial, Jackson Lake age. (4.6)

1.9 **Jackson Hole Airport road**, still on Snake River fill terrace of Jackson Lake age. Note the loess mantled "early Wisconsin?" terrace continues to the east of the road (see aerial photo). Here a soil pit 11 ft (3.3 m) deep extended through 8 ft (2.4 m) of loess but did not encounter a recognizable soil between the loess and gravel.

The fill-terrace on which the airport is built correlates roughly with the cutting of the inset "flood flume" below Deadmans Bar. The escarpment between the fill terrace we are driving on and the loess-mantled one to the east is remarkably linear, and intersects the bedrock of Blacktail Butte ahead of us at about 1:00. We think this is a fluvial escarpment whose linearity results from three factors: (1) the resistant bedrock buttress of Blacktail Butte, (2) the large discharges from the flood flume, and (3) aggradation which requires river waters to repeatedly impinge on materials at the margins of the fill terrace level. A fault scarp is present, however, east of the escarpment. (3.6)

3.7 At 2:00, note the horizontal contact near the southeast end of Blacktail Butte about 120 ft (35 m) above the road. This is a pre-Pinedale gravel mantled by loess and colluvium, a curious outcrop of a buried terrace. (1.8)

4.6 Road descends to a slightly younger Pinedale terrace, which is also probably related to flood-flume discharges of Jackson Lake age. (0.9)

5.5 Moose Junction (0.0)

Moose Junction to Snake River Overlook

0.0 Moose Junction. Continue north on U.S. 89. Old mine in Blacktail Butte due east of here produced dump rich in Mt. Owen quartz monzonite and Flathead quartzite which may indicate Blacktail Butte is connected to basement (J.D. Love, oral commun., 1991), but the occurrence at this end of Blacktail Butte of a Cenozoic boulder conglomerate containing Precambrian boulders but no Pinyon-type quartzite makes other interpretations possible. (8.3)

0.8 Parking area for practice rock climbing at north end of Blacktail Butte. Vertical Madison Limestone forms the climbing face. (7.5)

1.0 Cross Ditch Creek at the north end of Blacktail Butte. Ditch Creek has built large alluvial fans of Munger and Pinedale ages to the east of here. (7.3)

2.6 Climb across an intermediate terrace up onto fill terrace here called Antelope Flats. *Small well-drained gravelly flood bar occurs on edge of till terrace.* Antelope Flats is a composite, nearly concordant terrace surface ranging in age from Burned Ridge #1, #2, and #3 to Hedrick Pond. (5.7)

3.3 **Glacier view Turnout, Optional Stop 1-1c.** Similar to the Teton Point Turnout (stop 1-2), except there Hedrick Pond outwash overlaps Burned Ridge outwash. This viewpoint is 5 miles downstream from the Pinedale terminus in northern Jackson Hole. At 9:00 (west) across the valley at the base of the Teton Range are Pinedale moraines enclosing Bradley and Taggart Lakes. At 10:00 is Timbered Island, one of the farthest upvalley remnants of loess-mantled till and outwash of Munger age. At 3:00, aspen trees on the loess-covered, Munger age part of the Ditch Creek alluvial fan. At 4:00 is Sheep Mountain, glaciated near timberline (about 9,600 to 10,000 ft/2,930-3,050 m) by Munger ice. Near the mouth of the Gros Ventre valley is the Gros Ventre Slide that released along a dip slope in 1925. (5.0)

West from this viewpoint, the surface of the prominent inset terrace of the Snake River is marked by large-scale flood bars and channels. These flood features were formed by the last of probably many floods that rushed from the Deadmans Bar area down this flood flume. The highest and oldest of this flood sequence left longitudinal flood bars near the edge of the highest terrace.

5.3 **Stop 1-2, Teton Point turnout.** (The "clock" direction of 12:00 is the upvalley continuation of the Snake River bluff on which we are standing). As noted on the annotated aerial photo, to the northeast is an outwash fan of Burned Ridge age which heads at the ice-marginal Spread Creek (1:00). This fan was built the southwest to here and to the west towards the next stop (Stop 1-4). We are standing on Hedrick Pond outwash (see air photo) contiguous with the large fan that heads at 11:00 across the Snake River at the Spalding Bay west channelway. From its head, this fan was built

Annotated aerial photograph showing surficial geologic relations near **Stop 1-2**. Note the onlap relation between (1) an outwash fan that heads to the northeast at the head of the ice-marginal Spread Creek fan of Burned Ridge (BR) age and (2) an outwash fan that heads to the northwest at the Spalding Bay west channelway of Hedrick Pond (HP) age. The channel pattern on the older fan is more muted due to a thicker loess mantle. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 14, 1979.

southeast to here and southwest to String Lake; at 3:00, note the low scarp where this Hedrick Pond outwash trims the Burned Ridge (BR) outwash fan that heads at 1:00. At 9:00, the inset terrace along the Snake River is of Jackson Lake age. We call this inset terrace the flood flume, for it displays large-scale bedforms formed by flood waters 30 to 45 ft deep and 1 mile wide. Across the valley, flood bars occur along the valley wall and up to the margin of the fill terrace. The walls of the flood flume have an unusual deposit of pebble gravel that blankets the lower terrace scarp and extends up to a height of 30 ft (10 m). The last flood is estimated to have been 30 to 45 ft (10 to 15 m) deep and 1 mile (1.5 km) wide.

Looking along the length of the Snake River (from 12:00 to 6:00), this inset terrace of Jackson Lake age converges with the Hedrick Pond fill terrace we are standing on and rises above it near Moose. The Snake River floodplain occurs in the cottonwoods, and is characterized by branching and continuously changing channels.

Burned Ridge moraines occur at the head of outwash between 11:00 and 1:00, and represent the youngest of three sets of Burned Ridge moraines (BR-3) recognized. Looking up the Snake River past these moraines, you can see the cavity left by the ice that deposited the BR-3 moraines and is occupied by the Triangle X 1 and 2 lakes. The oldest Burned Ridge ice position, BR-1, is represented by several kettles where the grassy ridge at 2:00 comes down to outwash level. The intermediate set (BR-2) of moraines locally rise above the outwash level at about 1:30.

Thus the fill terrace becomes increasingly younger downvalley from the Pinedale end moraines; it is of Burned Ridge age on the east side of the river upvalley from here, is of Hedrick Pond age from here to near Moose, and of Jackson Lake age from Moose past the airport where we saw it at Stop 1-1.

The general directions for the three lobes (Table 2) feeding from the Yellowstone/Absaroka glacial source area into Jackson Hole are: 11:00 - Snake River lobe, 12:30 - Pacific Creek lobe, and 1-2:00 - Buffalo Fork lobe.

Along the Teton front at about 8:00, Pinedale moraines form large mounds which encompass Bradley and Taggart Lakes. The Teton fault runs along the front above these moraines and continues north to where, later in the day, several strands can be seen to cut grassy alluvial fans just south of Jenny Lake. The highest peak is the Grand Teton (alt. 13,771 ft), south of which are Middle Teton and South Teton, and Buck Mountain. North of the Grand are Mt. Owen and Teewinot.

The Gros Ventre Slide of 1925 is at 4:00 on the south side of the Gros Ventre valley. At about 5:00 is the Ditch Creek (nearer) and Gros Ventre fans of Pinedale age.

From the Gros Ventre drainage in Munger time, a large glacier flowed towards Jackson Hole and sculpted terrain to near upper timberline on Sheep Mountain (4:30). It completely overrode Shadow Mountain (2:00), Blacktail Butte (5:30), and West Gros Ventre Butte (6:00). (3.0)

6.7 Road is on Burned Ridge outwash fan that rises to the northeast. At 2:30 are BR-2 moraines, almost buried in outwash. (1.6)

7.0 About 200 yds (m) to east is low fault(?) scarp in Burned Ridge outwash. (1.3)

8.3 Turn right on gravel road 0.1 mile before the Snake River Overlook for side trip to see the nearly buried moraines of BR-2 age. This would not be a FOP trip without at least one dusty road. (0.0)

8.6 For next mile, the road passes outwash, deeply kettled outwash, and local small moraines rising above road level, all along the Burned-Ridge-3 ice margin (BR-3). To north of us is a 100-ft-high (30 m) drop-off forming a cast of the BR-3 ice margin.

10.0 Take right turn, Lost Creek Ranch Road goes left.

10.5 Climb terrace scarp from BR-3 to BR-2 level.

10.7 Where main road turns left, take right turn onto 2-track road. If road is wet, we will make Stop 1-3 here. See description below.

10.9 Center of long trough representing an outwash-buried BR-2 ice margin.

11.1 **Stop 1-3, BR-2 moraines, nearly buried by outwash.** Stop adjacent to Burned Ridge moraine (see annotated aerial photo). We may have to turn around by backing up the 2-track side road to the east. Climb up onto moraine to west, formed mostly of Pinyon-type quartzite, with some Tensleep Sandstone, Absaroka volcanic rocks, Huckleberry Ridge Tuff (from nearby exposure in and adjacent to landslide 1 mile to the northeast).

Note that the moraine we are standing on and another a little upvalley from here, are both completely buried by outwash at their eastern and western margins. The main source of this outwash was the ice-marginal Spread Creek, which traversed the ice margin from near Togowotee Pass to here. Alluvial fans first BR-1, then BR-2, and finally BR-3 age were built southward and westward into the east side of Jackson Hole from where the ice-marginal Spread Creek escaped its confined position between the Burned Ridge ice margin and the Mt Leidy Highlands. *The BR-2 and BR-3 fans probably filled a depression like that behind the present BR-3 ice margin.*

Annotated aerial photograph showing surficial geologic relations just west of **Stop 1-4** at the Snake River Overlook. The present Snake River is located where the Triangle X-2 lake spilled over the low point at the seam between the west-sloping fan deposited by the ice-marginal Spread Creek of Burned Ridge (BR) age, and the southeast fan from the Spalding Bay west channelway of Hedrick Pond (HP) age. Hedrick Pond ice locally advanced through the landform known as Burned Ridge. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July, 1979.

Annotated aerial photograph showing surficial geologic relations near **Stops 1-3, 1-4, and 1-5**. Moraines of Burned Ridge age (BR) are largely buried by aggradation of 200-300 ft of quartzite rich outwash largely supplied by the ice-marginal Spread Creek. Hedrick Pond (HP) moraines and outwash are north of and about 100 ft lower than Burned Ridge outwash. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 14, 1979.

Outwash aggradation of 200 ft (60 m) or more is common near the glacial terminus in northern Jackson Hole. Most of this outwash consists of cobbles of Pinyon-type quartzite which crops out extensively in the drainage basins of Buffalo Fork, Pacific Creek, and Spread Creek. These quartzites occur in poorly indurated conglomerate of both Paleocene (Pinyon Fm.) and Cretaceous (Harebell Fm). They were supplied in great abundance by glacial/fluvial erosion/transport to the ice margin where their abundance and coarse size resulted in this extensive aggradation and steepening of stream gradients.

Downvalley from here near the valley margin, you can see a large kettle. Another large kettle is out of sight about an equal distance further downvalley. That kettle marks the BR-3 ice margin, whose moraines on the floor of Jackson Hole are entirely buried by outwash.

Return to U.S. 26, make right turn, and then turn left into the Snake River Overlook.

Snake River Overlook to Moran Junction

0.0 **Stop 1-4, Snake River Overlook** (alt. 6,905 ft; 2,105 m, Snake River alt. 6,620 ft; 2,018 m). We are standing on BR-3 outwash, and BR-3 moraines locally rise above outwash across the highway and across the river. Stones in this moraine and those to the south are dominated by roundstones of Pinyon-type quartzite with lesser amounts of Paleozoic limestone, Pennsylvanian sandstone, Mesozoic sandstone, Eocene andesitic rocks, and Precambrian crystalline rocks. The drop-off to the north of the BR-3 moraine is a depositional, ice-contact slope formed at the BR-3 ice front Here on the BR-3 fan, the channels and slope trends to the west indicating a dominant depositional rather than tectonic signal. The BR-2 ice margin is 1.6 mi (2.6 km) to south, and the BR-3 ice margin is 2.2 (3.5 km) to south. The Burned Ridge moraines here were deposited by the Buffalo Fork lobe. The outwash is largely from the ice-marginal Spread Creek (see Stop 1-3). Across the river and inside (north of) the Burned Ridge moraines is outwash of Jackson Lake age in The Potholes channelway. Looking down the Snake River, the prominent inset terrace level (flood flume) is the lowest level eroded by multiple floods of Jackson Lake age. Nearby at the next stop (Stop 1-5), Hedrick Pond outwash levels are about 6,800 to 6,830 ft (2,073-2,082 m). The eroding bluffs seen above the Snake River expose a gray gravel mantled by loess(?), overlain by a yellow gravel, overlain in turn by a gray gravel of Jackson Lake age.

The Burned Ridge outwash fan of the ice-marginal Spread Creek slopes to the west here (Love and Montagne, 1956). Although this surface has probably been tilted by downdropping on the Teton fault, such tilting was probably small compared to the original depositional slope shown by westward stream-channel patterns on the annotated aerial photos. (9.3)

0.5 Deadmans Bar turn off. We are now at the level of Hedrick Pond outwash and moraines. Optional parking area for small groups but not the FOP. (8.8)

0.9 **Stop 1-5, Hedrick Pond Till exposed in bluffs of Snake River.** Park well off highway on right side and carefully cross highway. Hike due north 1,500 ft (500 m) past east end or Hedrick Pond moraine and across kettled Hedrick Pond outwash (6,800-6,830 ft; 2,073-2,082 m) to a high exposure in the Snake River bluffs (see annotated aerial photo). This Hedrick Pond outwash gravel and sand overlies and interfingers with till of Hedrick Pond age. The following section is exposed along the ridge line:

Thickness in ft (m), and description

16 (5), Gravel with scattered lenses of flow till. Bedded , but beds discontinuous. Surface kettled.

6 (1.8), Diamicton, flow till

11 (4.3), Gravel

11 (3.4), Sand, cross bedded

2.5 (0.8), Gravel

80 (24.1), Diamicton, muddy sand matrix with scattered pebbles, locally wispy bedding. The diamicton is rich in fines and poor in gravel, and was probably eroded from lake sediments that accumulated in the Triangle X-1 lake (the pre-Hedrick Pond lake) that extended from the Snake River overlook to Moran Junction, and up the Buffalo Fork valley from there. Glacial flow across this muddy-bottomed lake is probably responsible for the low gradient of Hedrick Pond ice, which is about one-half that of Burned Ridge ice in the same area. Diamicton deposited near ice as either a lacustral till or mudflow. Below the diamicton is a covered interval and an older gravel near river level.

Hike back to U.S. 89 noting the BR-3 outwash level well above the Hedrick Pond level, cross highway carefully, and continue north. (8.4)

1.7 **Hedrick Pond**, a deep kettle-lake for which the Hedrick Pond phase is named, is briefly visible on the right beyond the forested moraine. All the benches and moraines in this area below the much higher BR-3 outwash are of Hedrick Pond age. (7.6)

2.0 Lake sediments an altitude of 6,720 ft. A small delta front of a local drainage similar to that at Stop 1-6 is to the left of the road. (7.3)

2.2 Light-gray lake sediments are exposed in roadcut. (7.1)

2.5 Lake sediments to east (right) of the Triangle X-2 lake. The nearly white color reflects ash reworked from the ash-rich Teewinot Formation (Miocene). (6.8)
2.7 More lake sediments at the front of Triangle X-2 fan-deltas. Fan-delta fronts descend in altitude from about 6,800 to 6,720 ft (2,073-2,048 m), reflecting a progressive lowering of the outlet near Deadmans Bar. (6.6)
3.2 **Stop 1-6, Triangle X-2 Lake sediments.** Note escarpment just before Triangle X Ranch road representing delta front of larger drainage. Turn right on road to Triangle X Ranch, go through gate and park on right side of road for walk south to badlands terrain. Here is a fine-grained, deltaic sediment rich in reworked ash from the Teewinot Formation. This deltaic sediment locally has dips of up to 11° along the delta front. Note multiple levels of delta front where we are standing, in area of ranch buildings, and on forested slope south of here.

The bluffs on the far side of the Snake River expose gravel over sandy and silty, deltaic lake sediments resulting from progradation of outwash fan/deltas from the Snake River lobe of Jackson Lake age. An alluvial fill (or terrace) of the Snake River did not occupy the area southeast of the Snake River; the gravel bench across the river has no terrace counterpart on this side of the river. The Hedrick Pond ice margin forms the kame bench just above us, and the BR-3 ice margin is above that. (6.1)
3.9 Road to Cunningham Cabin on left. (5.4)
4.2 On the right, about 10 ft (3 m) above the wetlands, is a strandline platform formed at the highest level of the Triangle X-2 lake. (5.1)
4.8 Gravel road on east (right) goes up the late Holocene Spread Creek alluvial fan on the south side of Spread Creek hill, which is at 12:00-2:00. (4.5)
5.5 Bridge across Spread Creek, aptly named due to continued alluviation of quartzite-rich gravel. The south side of Spread Creek hill is a high, remarkably linear scarp more than 200 ft (60 m) high, which has been considered to be either a post-glacial fault scarp (Love and Love, 1983, p. 293), or a fluvial facet undercut by Spread Creek as it aggraded and built its alluvial fan against this hill (3.8)
5.8 Wolff Ranch road, optional side trip to see top (alt. 6,780 ft; 2,067 m) of Pleistocene Spread Creek delta built into the Triangle X-2 lake. (3.5)
6.3 Road descends across low scarp from surface of lowest(?) fan-delta of Spread Creek (6,750 ft; 2,057 m) near Wolff Ranch to the older Holocene alluvial fan of Spread Creek. This older Spread Creek fan was deposited when Spread Creek flowed around the east end of Spread Creek hill and deposited the fan that heads near 2:00. This fan is mantled by locally derived mud transported by local drainages after Spread Creek changed its course. This mud-mantled fan is irrigated and produces lush grass. (3.0)
7.1 Optional Stop 1-5b. Triangle X-2 lake sediments exposed (1989) in the bluffs and bottom of the Snake River. Park on the shoulder in the middle of a straight section of highway. To the east on the north side of Spread Creek hill, Hedrick Pond moraines slope up a valley separated only by a low divide from Buffalo Fork, indicating Buffalo Fork lobe had receded well upvalley by Hedrick Pond time. Hike about 1/4 mile west to a meander bend of the Snake River to observe the following stratigraphic section exposed in river bluffs (from top down):

7 ft (2 m), Clayey alluvium with a prominent humic buried soil at its base and a less prominent buried soil in the middle. Deposited by muddy discharges across the older part of the Spread Creek alluvial fan.

11 ft (3.5 m), Snake River gravel with basal erosional unconformity. Holocene or late glacial in age.

8 ft (2.5 m), Gray, laminated lake sediments These sediments were deposited near the center of the Triangle X-2 lake. They also extend to the river bottom and may extend more than 300 ft (100 m) deeper and fill a basin scoured by the Buffalo Fork glacial lobe in Burned Ridge time.

Return to vehicles and proceed north. (2.2)
7.8 Triangle X-2 lake sediments exposed in the banks on the far side of the Snake River. (1.5)
8.5 Gravel road on right just after descending a scarp from the mud-mantled fan of Spread Creek onto the bottomlands of Buffalo Fork. (0.8)
9.1 Bridge across Buffalo Fork. (0.2)
9.3 Moran Junction. Continue straight ahead (east) up Buffalo Fork on U.S. 287. Beaches and deltas of Triangle X-2 lake at 6,820 north of small community at Moran. (0.0)

Moran Junction to Togowotee Mountain Lodge

0.0 Go east on U.S. 287 up the valley of Buffalo Fork. (16.5)
0.7 Low terraces of the Buffalo Fork on right. Road ahead climbs up onto backfill deposits of stop 1-7. (15.8)
1.3 **Stop 1-7, kame morainal backfill of Pacific Creek lobe into Buffalo Fork valley.** Park in unpaved area to right of road and walk to south to overlook backfill deposits. As shown on the annotated aerial photo, the aligned ridges in the

Annotated aerial photograph showing surficial geologic relations near **Stop 1-6**. Local stream deltas were built into the Triangle X-2 lake as the lake and its threshold at Deadmans Bar lowered from about 6800 to 6720 ft. The Triangle X-2 lake occupied the large basin excavated by the Buffalo Fork lobe in Burned Ridge (BR) time and briefly reoccupied by an advance in Hedrick Pond (HP) time. Northwest across the Snake River, outwash fans of Jackson Lake age prograded across fine sediments of the Triangle X-2 lake. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 14, 1979.

kame moraines trending up into the valley of the Buffalo Fork in Jackson Lake time. Across Buffalo Fork and about 500 feet (150 m) higher, Hedrick Pond moraines slope up Buffalo fork, indicating the Pacific Creek lobe reached this level when Buffalo Fork ice had receded well upvalley. During Burned Ridge time, Buffalo fork ice covered nearly all the terrain visible up Buffalo Fork. This ice was more than 1,500 ft (500 m) thick, and excavated a scour basin probably much deeper than the unconsolidated fill of >100 ft (30 m) determined by shallow drill holes. (15.2)

1.9 Kame gravels overlain by lake sediments. The lake sediments were deposited when the Pacific Creek lobe dammed the valley of the Buffalo Fork in Jackson Lake time while the kame moraines seen at Stop 1-7 were being deposited. On the divide to the north (between Buffalo Fork and Pacific Creek), remarkably well expressed glacial scour features demonstrate the overflow of Pacific Creek ice into the lower, ice-free valley of Buffalo Fork in Hedrick Pond time. (14.6)

2.1 Sign "Leaving Grand Teton National Park". Note the wide, alluviated, un-terraced valley of the Buffalo Fork, suggesting continued filling of a glacial-scour basin. (14.4)

2.2 Kame gravel benches above road on north (left) deposited against backfill of Pacific Creek lobe in Hedrick Pond time. (14.3)

2.7 Bridge across Lava Creek. Note large alluvial fan built onto bottomlands. (13.8)

3.5 Buffalo Valley Road on left. Stay on U.S. 287 and note morainal deposits that represent the backfill moraine advance of Pacific Creek lobe up the Buffalo Fork valley in Hedrick Pond time. This approximates the upvalley advance of the backfill moraines that were 500 ft (150 m) above the valley floor at Stop 1-7. (13.0)

3.6 Bridge across the Buffalo Fork. We now drive on the mile-wide bottomlands of the Buffalo Fork, above a deep scour basin excavated by the Buffalo Fork lobe in Burned Ridge time. This scour basin extends downvalley all the way to the Snake River Overlook (Stop 1-6). (12.9)

4.8 To north is the Heart Six Ranch (red roofs) nestled on west-sloping benches of extensive kame gravels deposited alongside the recessional Buffalo Fork lobe(?). (11.7)

5.6 KOA Campground sits on wide bottomlands of Buffalo Fork. At 10:00 is Mt Randolph. A glacial scour lake and morainal embankments within 150 ft (50 m) of its top demonstrates Burned Ridge ice levels to 8,840 ft (2,695 m). Between the valley floor and that level, kame deposits form ten's of ice-contact benches. (10.9)

8.0 Hatchet Motel. (8.5)

8.2 Gravel road on right (Flagstaff Road) traverses much of the glacial terrain near the southern margin of the Buffalo Fork lobe, including the ice-marginal Spread Creek. Lily Lake, the site of some of Cathy Whitlock's cores, is also in this area.

8.5 Bridge across Blackrock Creek. We start to climb to higher terrain above Buffalo Fork (The Blackrock erosion cycle of Blackwelder, 1915). (8.0)

10.0 Terrain to right (south) was all glaciated by Buffalo Fork lobe in Burned Ridge time (The Buffalo Glaciation of Blackwelder, 1915, the term abandoned by Richmond in 1976, p. 363). The road crosses active landslides and other terrain that could landslide. (6.5)

11.7 Start of outcrops of conglomerates formed of Pinyon-type quartzite. (4.8)

13.0 Road on left goes to Turpin Meadows 950 ft (290 m) below there along the Buffalo Fork. Turpin Meadows is at the head of filled scour basin that ends near the Snake River. Overlook (Stop 1-4). (3.5)

14.6 Open area with Pinedale morainal topography. (1.9)

15.8 **Stop 1-8 where highway crosses post-glacial scarp of "new" basin-and-range fault.** Park as far to right as possible in paved parking area on south (right) side of highway. **Carefully** cross highway and walk through woods along top of scarp to old road. This fault is down to the east, and has a sag-pond at its foot (Love and Love, 1982). The scarp is about 30 ft (10 m) high, has a maximum scarp angle of about 40°, and can be traced locally in the immediate area for about 1,000 ft (300 m). Its north-south orientation is not appropriate for landsliding or sackungen into drainages to north and south. It is part of a set of scarps that are recognized for at least 2 miles (3 km) to the southsoutheast. A related fault 1 mile (1.5 km) south-southwest of here down-drops a large moraine crest of Munger age 70 ft (20 m). This new faulting is part of an overall pattern thought to be associated with eastward migration of the Yellowstone hotspot (Pierce and Morgan, 1992).
Carefully recross U.S. 289 and continue to east. (0.7)

16.5 Togowotee Mountain Lodge to north (left). (0.0 millage for return trip)

16.9 Large backfill morainal plug on right. We will come back to this for Stop 1-8, but will drive upvalley so we can see Blackrock Meadows, turn around, and easily park in the turnout on the north side of the road.

17.4 Note kettles at upper end of backfill plug.

17.7 Pull right and make U-turn using end of Flagstaff Road. Please note upvalley from here the large, flat-bottomed stretch of Blackrock Creek

Annotated aerial photograph showing surficial geologic relations near **Stop 1-7**. The Pacific Creek lobe advanced up Buffalo Fork valley in both Hedrick Pond (HP) and Jackson Lake (JL) time, indicating the Buffalo Fork lobe was much smaller than it had been in Burned Ridge time. The Pacific Creek lobe flowed south and scoured the divide in the northern part of the photo, perpendicular to westward flow during Burned Ridge (BR) time. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 15, 1979.

named Blackrock Meadows. This is a valley glaciated in Burned Ridge time as indicated by Pinedale moraines 500 ft (150 ft) above the meadows and by striated Absaroka volcanic bedrock across the valley from here. Following this in Hedrick Pond? time, Blackrock Meadows was then blocked and backfilled with lake and other sediment. Recessional Pinedale moraines occur along the edge of the meadows where deposited by glaciers from cirques immediately north of the meadows, and at upper end of Blackrock Meadows where fed by a small icecap in the Togwotee Pass area.

17.7 After U-turn, proceed west on U.S. 287 and retrace route.

18.6 **Stop 1-9, to Buffalo Fork lobe backfill of Blackrock Meadows in Hedrick Pond(?) time.** Park in paved parking area on north (right) side of road and **carefully** cross the highway. From here we get a distant view of Jackson Hole and the Teton Range about 30 miles (20 km) to the west. In that direction we are looking along the southern margin of the Buffalo Fork lobe and its ice-marginal Spread Creek drainage that sloped from here down to the Burned Ridge moraines we saw earlier in the day at Stops 1-3 and 1-4. The Blackrock Meadows are 0.5 to 3 miles upstream from us and are part of a glaciated valley that trends towards us from the southeast.

During full-glacial Burned Ridge time, the Buffalo Fork lobe headed mostly north of us, in three large valley draining the Absaroka Range. In addition, a glacier flowed out of the Blackrock Meadows area and joined the larger Buffalo Fork lobe. Evidence for a Pinedale glacier flowing down the Blackrock valley consists of sharp-crested Pinedale moraines that extend to as much as 500 ft (150 m) above Blackrock Meadows and fresh glacial striations and rat tails streamed out from pebbles in Absaroka volcanic bedrock indicating westward ice flow out of Blackrock Meadows. This outflow from Blackrock Meadows is assigned a Burned Ridge age, because this was when the Buffalo Fork lobe was largest.

We are standing on a kettled, thick morainal plug built across the valley of Blackrock Creek. This deposit connects with moraines that rise northward to and beyond the constructed overlook on the far side of the highway. At the time of deposition, Blackrock Meadows appears to have contained a lake with local glaciers terminating in on its eastern and northern sides. The age of this backfill is inferred to correlate with Hedrick Pond time, after the Buffalo Fork lobe had receded from its maximal size in Burned Ridge time. Exposures into this backfill moraine can be seen 1,500 ft (500 m) southeast of here where Blackrock Creek has cut deeply into this backfill. They consist of lake sediments, sands, and gravels more than 100 ft (30 m) thick.

Buffalo Fork flows in a deep valley 2 miles (3 km) north and 1,500 ft (460 m) below where we are standing. This high bench was attributed by Blackwelder (1915, p. 312) to the Blackrock erosion cycle, named for Black Rock Meadows. Blackwelder inferred the height above drainage to represent erosion post-dating deposition of these glacial deposits, and thereby inferred they pre-date the Bull Lake glaciation. He thereby named the Buffalo glaciation for the adjacent Buffalo Fork (Blackwelder, 1915, p. 328). Unfortunately, this height above drainage simply reflects the thickness of the Buffalo Fork lobe, and not a deposit that pre-dates 1,500 ft of incision into the landscapes we are standing on by the Buffalo Fork.

End of road log for Day 1. Retrace route to Moran Junction, Gros Ventre Junction, and to your lodging for the night.

Day 2, Central and Northern Jackson Hole

0.0 **Start at 8:00 AM, entrance road to Gros Ventre Campground,** Grand Teton National Park. Please line up the carpool vehicles on the right side of the road leading out of the campground. Arrange to carpool using vehicles that can carry the most people, and please have no vehicles with less than 4 people. *We will not start until all vehicles have at least 4 people.* The lucky person that gets the front right seat, also gets the honor of being the official guidebook monitor and is responsible to see that someone informs the driver and others of what is in the guidebook.

For road log of first part of Day 2, see *Day 1, Gros Ventre Campground to Gros Ventre Junction, and then Gros Ventre Junction to Moose Junction.*

Inner Road--Moose Junction to Jackson Lake Junction

0.0 **Moose Junction.** Turn west (left), onto "inner road" through Grand Teton National Park. Then descend through terrace flight to the Snake River, passing entrance road to Dornan's on right. (24.1)

0.4 **Bridge across Snake River.** Many of the float trips from Deadmans Bar or Pacific Creek end just upstream from here. (23.7)

0.5 **Park Headquarters** on low terrace of Snake River. (23.6)

0.9 **Entrance station,** Grand Teton National Park (GTNP). Climb a small terrace scarp at the entrance. (23.2)

1.0 Climb another small terrace scarp. (23.1)

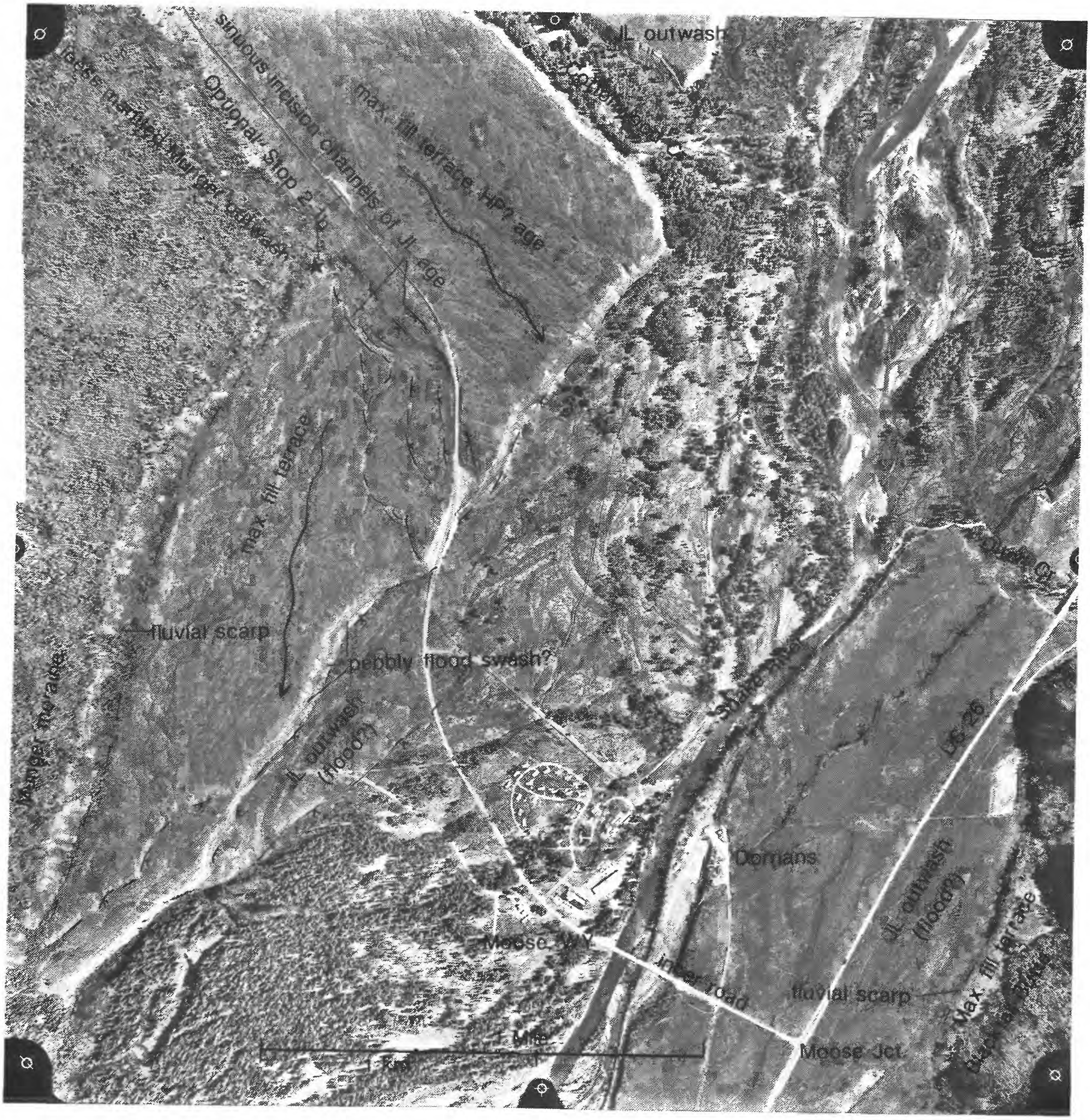
1.3 Base of large terrace scarp. Sorted pebble gravel on lower third of terrace scarp seems to characterize edges of "flood flume" upstream from here. Next the road climbs through a sinuous set of incision channels of later Jackson Lake age. (22.8)
1.9 Climb onto the top of Pinedale fill terrace, here of Jackson Lake? age. (22.2)
2.2 **Windy Point Turnout. Optional Stop 2-1b.** This stop made optional for much seen from this stop can be also seen from the fault scarp at Stop 2-2). From the turnout, note the view of Teton Range and outwash surfaces rising to the north . Then walk south of road, across head of local incision terraces and up scarp 100 ft (30 m) high onto loess mantled bench of Munger recessional deposits (see annotated aerial photo).

Large granitic boulders suggest a till in the scarp, and suggest glacial transport from the Teton Range, perhaps by a glacier confluent with ice from the north and northeast. The planar nature of the loess mantled surface at the top of the scarp indicate the till was probably plainated by Munger outwash. An auger hole near here went through about 6 ft (2 m) of loess and then into a buried soil with a red B-horizon with 30 percent clay in parent material of mixed loess and pebbly sand. The outwash surface trends southeast towards us, but at its western end it now has a slope to the west apparently due to back tilting towards the Teton fault in post-Munger (Bull Lake) time.

From the top of the scarp, the following features can be seen (generally from south to north, right to left): (1) Gros Ventre Buttes overridden by Munger ice, and the upper limit of Munger ice near the top of the Snow King Ski area, (2) airport on terrace of Jackson Lake age which correlates with fill terrace at base of scarp we are standing on, (3) loess mantled terrace extending from south end of Blacktail Butte to Stop 1-1, (3) Sheep Mountain behind Blacktail Butte with upper limit of Munger ice near tree line, (4) Gros Ventre slide of 1925, (5) in foreground, sinuous incision channels of glacial-age Cottonwood Creek as it attempted to keep up with incision of Snake River into its fill terrace during Jackson Lake time, (6) Shadow Mountain-Mount Leidy highlands, nearly all overridden by Munger ice, (7) Burned Ridge moraines, at head of outwash terraces, (8) Antelope flats with ice-marginal Spread Creek fans of BR-1, BR-2, and BR-3 age, (9) the closer part of Antelope Flats where Hedrick Pond outwash slightly trims the Spread Creek fan and forms more planar, south sloping surface, (10) the Snake River valley inset into the Pinedale fill terrace with its prominent cut terrace ("flood flume") that merges down valley with the top of the Pinedale fill terrace, (11) the Dogleg moraine of Hedrick Pond age that extends east from a prominent timbered scarp to join the Burned Ridge landform and is fronted by Hedrick Pond outwash forming the fill terrace (highest terrace) of the Spalding-Bay-west channelway, (12) the Spalding-Bay-west outwash fan that heads at a scarp cut into the Dogleg moraine and has a sequence of terraces of Jackson Lake age inset into the highest fill terrace of Hedrick Pond age, (13) Timbered Island which similar to the forested area behind us, with loess on a buried soil in outwash at its near end, and Teton till with 5 m boulders at its north end, and (14) the fill terrace between us and Timbered Island which is of Jackson Lake age.

Note that we can not see the Tetons from here, which from a glacial geologic point of view is appropriate because, although the Tetons are breathtakingly alpine, they were of minor importance in glaciation of Jackson Hole, which resulted from ice buildup in the much larger area of high terrain to the north and northeast.

Return to Windy Point Turnout. Continue northwest towards Tetons (You truly can't miss them). Straight ahead are the Taggart Lake moraines, which were burned by a lightning-started forest fire in 1985 accompanied by much fire-spalling of the morainal boulders. (21.9)
2.9 **Beaver Creek,** the original GTNP Headquarters. Continue on fill terrace, here of Jackson lake age. (21.2)
3.8 **Cottonwood Creek.** This creek loses water into the permeable outwash and in autumn and winter dries up between here and the Snake River. (20.3)
4.0 Gravel road on right. This 2-track road goes many miles along the Snake River bluffs and comes out near South Landing. (20.1)
4.7 **Timbered Island,** south end is Munger outwash rich in Pinyon quartzite with a buried soil on it mantled by about 8 ft (2.5 m) of loess. View ahead of Teton Glacier on north (right) side of Grand Teton, and a high Little Ice Age moraine in front of it. (19.4)
6.8 Road makes broad left turn on outwash of Jackson Lake age. On right is north end of Timbered Island which has 5 m boulders in Munger till from Tetons although fabric studies (Harrington, 1985) indicate glacial flow from northeast. This remnant may represent an interlobate recessional moraine between Snake River and Teton ice. (17.3)
7.1 **Lupine Meadows Junction.** Those climbing the Grand Teton park at end of this road. (17.0)
7.9 **South Jenny Lake Junction,** for store, ranger station, boat rides, and campground. Moraine system that holds Jenny Lake is closer to road as we travel north past the junction; note forested



Annotated aerial photograph showing surficial geologic relations near **Optional Stop 2-1b**. Linear scarps are associated with the maximum fill terrace. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 11, 1979.

moraine with granitic boulders, outside of which is trench of ice-marginal drainage flowing around moraines from north. (16.2)

8.9 Scattered trees where road crosses lowest of Spalding-Bay-west channelways. Jenny Lake moraine set that is outside those pointed out above is locally exposed in forest on left. This older moraine set is mostly buried by quartzite-rich outwash of Jackson Lake age. (15.2)

9.3 Climb up terrace sequence on west side of channelway. Mount Moran is flat topped peak with its Falling Ice Glacier facing southeast. (14.8)

10.8 **North Jenny Lake Junction,** turn left. We are on terrace of Hedrick Pond age and the road ahead descends onto terraces of Jackson Lake age. All these terraces are rich in Pinyon-type quartzite even though they are in front of moraines of the Snake River lobe rich in granitic rocks from the Teton Range. (13.3)

11.5 **Cathedral Group Turnout, Optional Stop 2-1c.** See annotated aerial photo. View of the fault scarp on the Teton front about 120 ft (35 m) high. Offset of the surface is 65 ft (19 m), formed by Pinedale slope deposits and a cascade of Pinedale morainal debris from a slab glacier on the Teton front. The turnout is on outwash of Jackson lake age rich in quartzite from northeastern Jackson Hole. The slope and channel pattern of outwash trend obliquely toward the Teton front, defining a source to the northeast at the Spalding-Bay-west channelway. The direction of stream flow (see annotated aerial photo) suggests filling of a tectonic depression created by down-dropping on the Teton fault. Post-depositional tilting of this surface has probably occurred, but is of lesser magnitude than the original depositional slope.

Walk 600 ft (200 m) north from the turnout to forested moraines of Jackson Lake age. Note here the boulders of Precambrian rocks from the Teton Range deposited along the western side of the Snake River lobe. Quartzite cobbles are common in the outwash in front of the moraine, but are uncommon in the moraine itself. If one follows the moraine crest both north and south of here, there are places where the moraine crest descends below the level of the outwash, indicating burial of the ice margin by strongly aggrading outwash debouching from the glacier margin at Spalding Bay. Much of this outwash may be from the exhumation of the Jackson Lake basin in post-Burned Ridge time. (12.6)

12.3 String Lake area. (11.8)

12.4 **Stop 2-1, faulting and moraines near String Lake.** Turn left into String Lake parking area. See annotated aerial photo. Hike across bridge over String Lake Creek which flows into Jenny Lake half a mile south of here. Note upstream at threshold of String Lake line of boulders marking an outer moraine of Jenny lake that in the parking area has been covered by outwash of Jackson lake age from the Spalding Bay west channelway. As you hike the trail, this outer moraine forms the ridge nearest String Lake. and the trail crosses into the inner moraines around Jenny Lake.

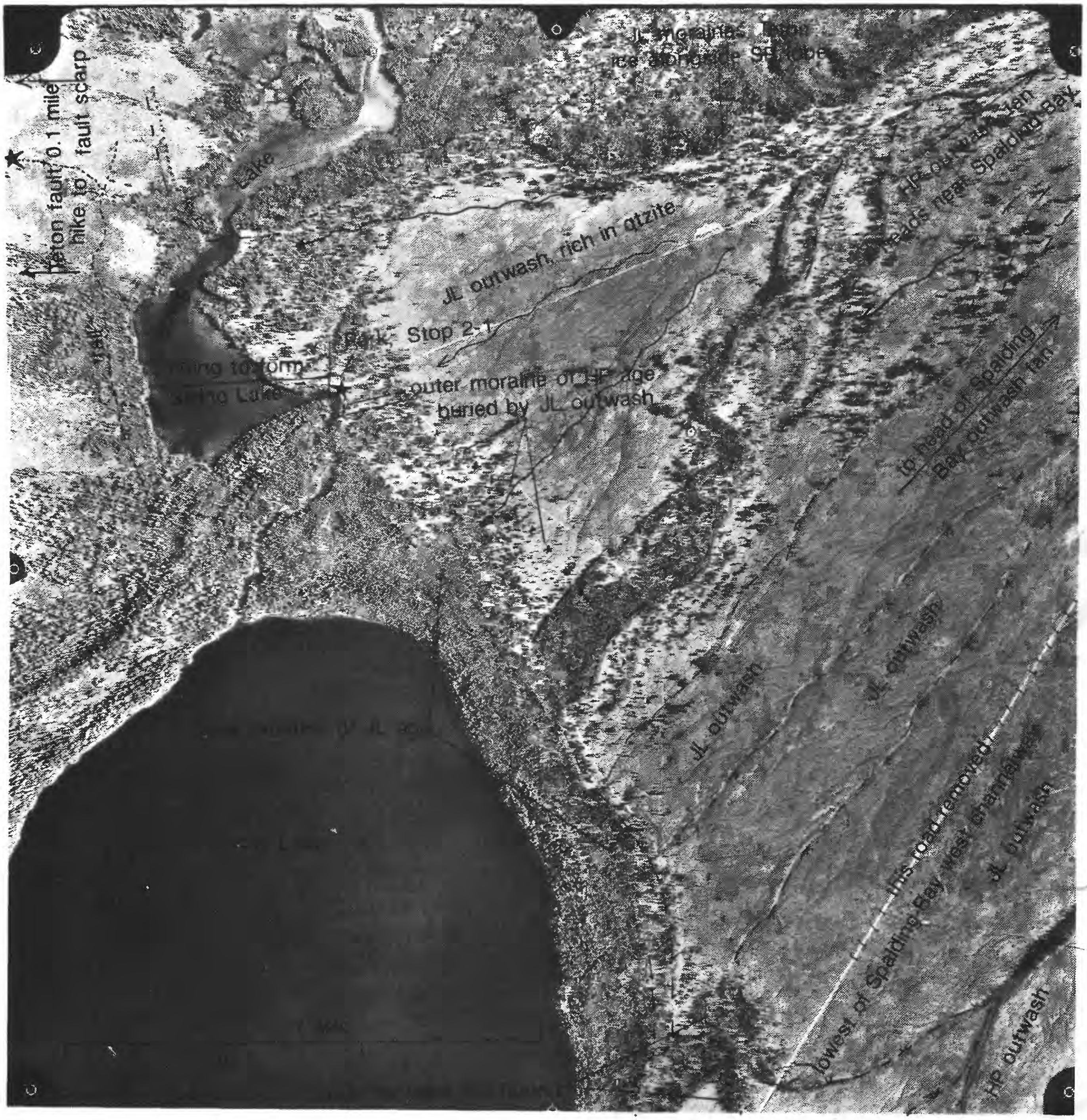
After hiking 0.3 miles (0.5 km) and just past a small ice-block depression, turn north (right) on trail towards Indian Paintbrush Canyon and follow trail as it climbs up and over the outer Jenny Lake moraines.

Upon leaving forest, you enter an open area. In the spring of 1986, trees and snow littered this area and extended out into String Lake, where they can still be seen. The avalanche scar extends up a steep slope to moraines around Laurel Lake 600 ft (180 m) above. This steep slope was formed by a cascade of morainal debris coming to rest at its angle of repose after being delivered to the snout of a Pinedale glacier in the Laurel Lake basin. The avalanche came down the canyon above Laurel Lake, crossed the lake, overrode the moraines enclosing the lake, and rushed all the way out onto String Lake, plucking out mature trees along the way.

String Lake is a shallow, pan-like lake only about 5 ft (2 m) deep, which on sunny summer days is the warmest lake around for swimming. In Jackson Lake time, a large outwash stream headed at the upper end of String Lake. The outlet is 2,000 ft (600 m) further away from the Teton fault than is the west lake shore. Tilting of Jackson Hole into the Teton fault would submerge the western part of the lake area more than its outlet, thus backflooding this glacial stream course and converting it into a lake.

Leave avalanche runout and continue north through forest and then into meadow formed on large conical fan. Above the fault scarp, this drainage is deeply incised; on the benches at the edge of the gulch are moraines of a Pinedale slab glacier. We will cross the conical fan on trail to seam between two fans, and at large Douglas Firs, start hike up to fault scarp. Climb 250 ft (75 m) to base of fault scarp through meadows swept free of large trees by avalanches.

At the base of the fault scarp is a partially filled graben with a preserved lip a few feet high. Clock directions referenced to Mt Leidy at 12:00, which is conical peak across the valley and just left of white scars of Teewinot Fm. From here you can see the following: (1) the fault scarp about 113 ft (34 m) high with a middle half as steep as 39^{0} and with surface offset of 63 ft (19 m) (Gilbert and others, 1983), (2) lakes, from south to north, Jenny, String, Leigh Lake, and Jackson; (3) moraines at the



Annotated aerial photograph showing surficial geologic relations near **Stop 2-1**. Downdropping of Jackson Hole increases towards the Teton fault (just beyond west margin of photo). The outwash fan that heads at Spalding Bay has deposited more than 200 ft of outwash, burying older Pinedale moraines east of Jenny Lake. Depositional slopes of this outwash trend obliquely towards the Teton fault. Low-sun angle aerial photograph from U.S. Bureau of Reclamation, taken July 11, 1979.

southern margin of the Teton-Snake River lobe at the narrows of String Lake at 1:30; (4) large outwash fan that heads (11:00) at Spalding Bay west channelway and forms the fill terrace (Hedrick Pond age) and incised channelways (Jackson Lake age) that extend past Timbered Island at 2:00; (5) on the far side of this fan, Burned Ridge with its moraines of both Burned Ridge and Hedrick Pond age; (6) Antelope flats and ice-marginal Spread Creek outwash fan that heads at 12:00 just below the white scars that fronts and buries Burned Ridge moraines there. The position of the three glacial lobes is as follows, from right to left (1) Buffalo Fork lobe from 10:-11:30 heading in the high Absaroka Range, (2) from 10:00 to 11:00, highlands between Buffalo Fork and Pacific Creek including Mt. Randolph and Gravel Mountain, (3) Pacific Cr. lobe near 10:00, (4) from 9:00 to 10:00, Pilgrim Creek highlands that were invaded and surrounded by ice but not traversed by ice, and (5) out of sight at 8:00, the Snake River lobe. The Gros Ventre slide is at 1:30; Sheep Mountain with its Munger limit near tree-line at 2:00. Return to parking area. (11.7)

12.4 Leave **String Lake parking area** and turn left. Drive up outwash terrace of Jackson Lake age. The terrace slopes obliquely towards the Teton front, very close to parallel to the braided channel pattern on the terrace. Unfortunately, this slope of the terrace can not be used to indicate tilting of the terrace into the Teton fault.

14.0 **North Jenny Lake Junction** (new position on new road alignment) on Hedrick Pond outwash forming fill terrace. (10.1)

14.5 Descend into channelway with 2 main terrace steps. (9.6)

15.3 **Head of Spalding-Bay-west channelway.** (This channelway had to be renamed when road relocations moved the North Jenny Lake Junction away from here). Dogleg moraine of Hedrick Pond age forms smooth landform 100 ft (30 m) high that extends for 1.3 mi (2 km) to east where it joins the Burned Ridge landform at an right angle, hence our name Dogleg moraine. One-half mile (1 km) to the northeast through the forest and 200 ft (60 m) below is Spalding Bay. This is a typical height of outwash above Jackson Lake, and reflects the buildup of quartzite-rich outwash at the fronts of Pinedale glaciers. (8.8)

15.5 Note deep kettles on both sides of road in pitted outwash of Jackson Lake age. For the next mile, the road traverses a extensively pitted outwash surface that drained eastward towards the Potholes channelway, and carried outwash after the western channelway was left high and dry. (8.6)

16.7 Moraine 150 ft (50 m) to left of road is of Jackson lake age and that 1,200 ft (400 m) to right is of Hedrick Pond age. (7.4)

17.0 Head of the **Potholes channelway,** whose lowest level is here at 6,820 ft (2,080 m). Deep kettles occur near the road, but fluvial character of landscape of this collapsed topography is readily apparent on aerial photos, especially fluvial scarps between terrace levels. (7.1)

Climb up though pitted terrace sequence.

17.6 **Mount Moran Scenic Turnout** on north side of road on highest outwash level of Jackson Lake age. (6.5)

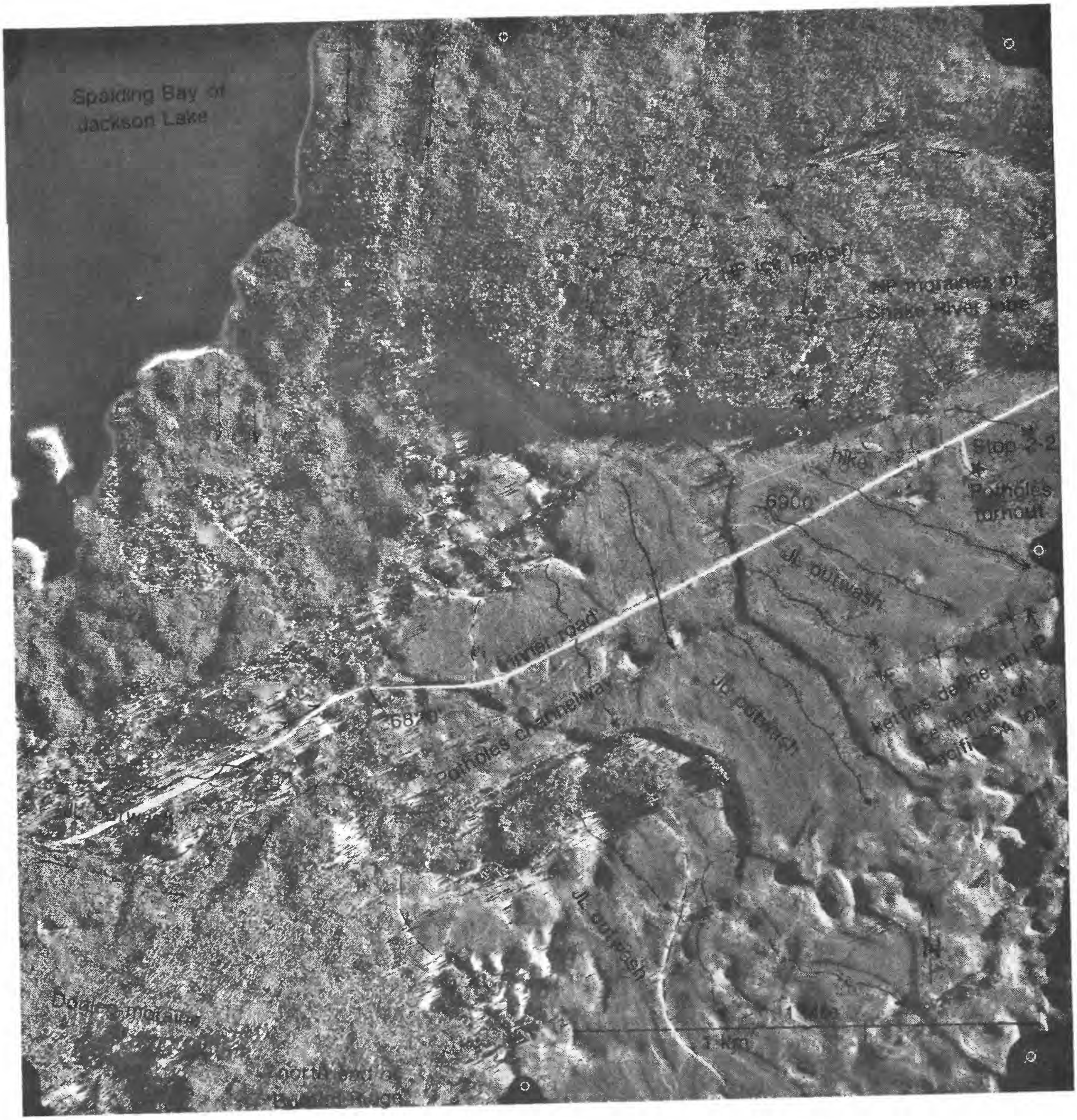
17.9 Climb onto inwash maximum fill terrace of Hedrick Pond age. (6.2)

18.3 **Stop 2-2, Potholes Turnout,** on south side of road shown on annotated aerial photo. This terrace surface outwash of oldest Jackson Lake age deposited by the Spalding Bay sublobe of the Snake River lobe. The tree-covered knobs to the east and kettles to the southeast define the western margin of the Pacific Creek lobe during Hedrick Pond time. The kettles in the outwash near and north of us were from the maximum advance of the Spalding Bay sublobe which also left moraines on the south side of the forested hills to the north to which we will hike.

We are standing near the margin of a basin excavated by Buffalo Fork ice in Burned Ridge time. Prior to Hedrick Pond time this basin held the Triangle X-1 lake, whose extent is poorly known but probably extended from where we are standing south to the BR-3 moraine, southeast to the Triangle X Ranch, and northeast to well up the Buffalo Fork. The biggest difference in the extent of ice between Hedrick Pond and Jackson Lake time occurred in this basin: it was entirely filled in Hedrick Pond time whereas in Jackson Lake time the Pacific Creek lobe extended only into its northeastern margin, and the Snake River lobe into its northwestern margin.

The northern half of Burned Ridge has moraines of the Spalding Bay sublobe draped around both its east and west sides. An advance of Hedrick Pond ice through a breach in Burned Ridge occurs between 0.9 and 1.5 mi (1.4 km-2.3) of the Snake River. The margins of this breach are marked by appropriately configured small moraines of Hedrick Pond age, and the west side is marked by aligned kettles concentric about the breach. The breach may have been the post-Burned Ridge valley of Buffalo Fork at a level more than 150 ft (50 m) below the present topography. This is one of the oddest set of glacial geologic relations we have seen.

Cross the road and walk on the kettled outwash 1/4 mi (1/2 km) towards Mt. Moran, and



Annotated aerial photograph showing surficial geologic relations near **Stop 2-2**. In spite of extensive kettles and collapse, fluvial features of the Potholes channelway are clearly recognizable. In Hedrick Pond time, the Snake River lobe advanced into the potholes area, depositing moraines along its *northern* margin on the wooded hill in the northeast part of the photo. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, July 14, 1979.

then climb about 60 ft (20 m) up onto complex glacial landform we consider to be Burned Ridge mound of glacial debris mantled by a veneer of Hedrick Pond moraines.

From the viewpoint one can see: (1) the highest terrace of kettled outwash of Jackson lake age deposited against the Pacific Creek lobe, (2) the Burned Ridge moraine, which has small, south-descending moraines of Hedrick Pond age deposited on it, (3) the Potholes channel of Jackson Lake age, and (4) across the Snake River the Burned Ridge and the lower gradient Hedrick Pond levels.

The Potholes channelway headed on east side of Spalding Bay sublobe and extended southeast into the Triangle X Lake and, when the lake had filled and the outlet at Deadmans Bar had lowered, flowed into the Snake River. From the channel head to the Snake River, the Potholes channelway is marked by deep kettles which for about half the way to the Snake River are aligned in belts concentric about the head of the channelway. These are thought to represent buried margins of Hedrick Pond ice from the Spalding Bay lobe.

Walk back into woods, and traverse for several hundred yards (meters) one of a set of small moraines deposited by Hedrick Pond advance on the north side of the Spalding Bay sublobe. These moraines slope east, and are asymmetric with a steeper, cobbly proximal side about 10 ft (3 m) high and a gentle distal side. Return to the Potholes parking area, and continue north (right) on inner GTNP road. (5.8)

18.7 Road climbs onto outwash fan of Hedrick Pond age from ice front on east side of the same upland as Stop 3. (5.4)

18.8 Road starts descent into **South Landing channelway** by crossing several terrace scarps of Jackson Lake age. (5.3)

19.5 **South Landing channelway**, lowest point (alt. 6,860 ft/2,090 m). (4.6)

19.6 **South Landing turnout, Optional Stop 2-3b,** on north side of road. On the northeast side of the parking area, climb up onto a moraine deposited near the confluence of the Snake River and Pacific Creek lobes in Jackson lake time. The moraine has erratics of Pinyon-type quartzite, Huckleberry Ridge Tuff, and Precambrian crystalline rocks. The viewpoint overlooks the South Landing outwash channelway, with multiple terrace levels indicating progressive incision during Jackson Lake time. Across the sewage ponds at the margin of Jackson Lake, an esker ridge at lake level indicates a pressurized subglacial jet of water that flowed up the slope and fountained at the head of this channelway. The outwash fan continues a couple of miles to the southeast, where it built a prograding delta into the Triangle X-2 Lake. Deposits that accumulated on the north side of the Pacific Creek lobe that came around the south side of Signal Mountain form the tree-covered knobs to the south and southeast. Return to inner road, and continue north (left) driving on glacial deposits inside the limit of Jackson Lake age. (4.5)

19.9 **Signal Mountain Road.** Optional 10 minute drive for spectacular views of Jackson Hole but without enough parking for the FOP. (4.2)

21.6 **Signal Mountain Lodge.** This arm of Jackson Lake is formed by a deep scour basin with 125 ft (40 m) of water and several times that amount of sediment (Smith and others, in press). This scour basin was excavated by the Pacific Creek lobe in Burned Ridge time. (2.5)

22.4 Pond in recessional ice-marginal channel of Jackson Lake age. (1.7)

22.7 **Jackson Lake Dam.** The south end of the concrete section is founded on 2 Ma Huckleberry Ridge Tuff, whereas the long dike to the north is built on unconsolidated sediments at least 600 ft (180 m) thick (Gilbert and others, 1983), filling scour basin excavated by the Pacific Creek lobe in Burned Ridge time. The upper 100 feet (30 m) of these sediments contain sand beds found to be subject to liquefaction were an earthquake to occur on the Teton fault. This dike section of the dam was completely rebuilt in the late 1980's at a cost of $82 million. The liquefiable sediments were strengthened by a combination of dynamic compaction by dropping a 30 ton weight repeatedly from a height of 100 ft (30 m) and by in situ injection and auger mixing of cement to form concrete pilings.

After descending from dam road traverses near boundary between the Pilgrim Creek fan (Willow Flats) and a low terrace of the Snake River. (1.4)

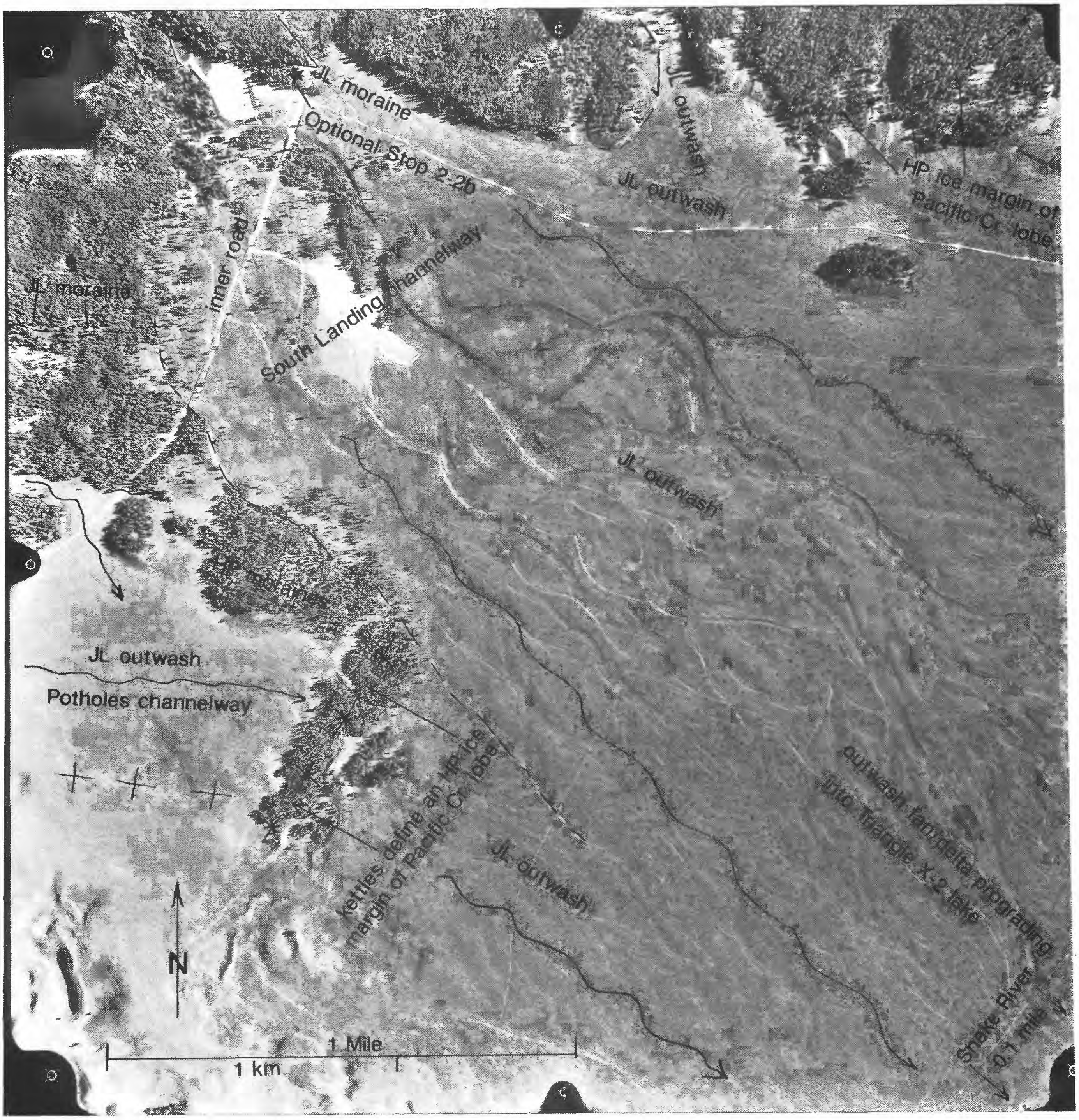
24.1 **Jackson Lake Junction.** (0.0)

Jackson Lake Junction to north end of Jackson Lake

0.0 Head north on U.S. 89 & 287 from Jackson Lake Junction. (11.4)

0.3 Road climbs onto gravel bench we interpret to be a delta built into a late glacial lake at an altitude of 6,820 ft (2,080 m). (11.1)

0.5 **Stop 2-3, Willow Flats-Christian Pond-Signal Mountain area.** Turn right onto narrow paved road and park on outwash gravel surface built into Jackson Lake when at the 6,820 ft level when held in by the threshold just downstream from Pilgrim Creek. Climb up onto a ridge of kame gravel north of the parking area and observe: (1) kame topography deposited around Snake River lobe of



Annotated aerial photograph showing surficial geologic relations near **Optional Stop 2-2b**. Note the fresh fluvial morphology of the South Landing channelway. This channelway contrasts with the potholes channelway in being nearly free of kettles. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, July 14, 1979.

recessional Jackson Lake age that extends from the ridge north to the Christian Pond area; (2) Willow Flats to the west on the post-glacial Pilgrim Creek alluvial fan, on which is built the Jackson Lake Dam; (3) Jackson Lake Lodge and Willow Flats overlook on the outwash/delta of a 6,840 to 6,820 ft alt. lake (2,085-2,080 m); and (4) Lunch Tree Hill to the northwest , built on a recessional moraine of Jackson lake age.

Traverse the kame ridge to the east and note: (1) development of kame terrace (alt. 6,950 ft/2,120 m) between Christian Pond and Emma Matilda Lake required simultaneous presence of Pacific Creek lobe on the east side and Snake River lobe on the west side of the kame terrace during recessional Jackson Lake time; (2) 2 and 5 Ma tuffs on Signal Mountain dipping 11° and 22° into the Teton fault but the 9-10 Ma Teewinot Formation in the area dips the same as the percent Ma tuff (22°), suggesting fault activity is younger than 5 Ma (see Love and Love, 1983, p. 310 for additional information on Signal Mountain area); (3) the location of a glacial scour basin north of Signal Mountain, which extends as much as 600 ft (189 m) below the Jackson Lake Dam; (4) Pilgrim Mountain to the north, with an upper limit of the Snake River lobe at an altitude of about 8,100 feet (2,470 m), just below the 8,274-ft (2,520 m) crest; (5) large kame benches and terraces (alt. 7,600-7,200 ft/2,320-2,200 m) built along the margin of the Snake river lobe from Pilgrim Peak to the eastern side of Pilgrim Creek; (6) the Pacific Creek glacial lobe, which reached an altitude of about 8,800 ft (2,680 m) between Whetstone and Gravel Mountains and flowed into Jackson Hole from the high country in and near southern Yellowstone National Park. Follow the power lime back down to the road, drive back to U.S. 89, and turn north (right). (10.9)

0.7 **Christian Creek Bridge,** with a kame hill on the south side and kettled outwash on the north side. (10.7)

0.9 **Jackson Lake Lodge turnoff**. Travel on kame terrace that heads at a recessional ice margin. This kame terrace seems to end in a delta at 6,800 ft (2,075 m) level of Jackson Lake near Stop 2-4. Half a mile away on the right, note the flat topped "two-sided" kame terrace that flowed at its elevated position between the Snake River and Pacific Creek lobes in recessional Jackson Lake time. (10.5)

1.7 Descend from kame terrace to large **Pilgrim Creek fan** of Holocene age. (9.7)

2.8 Kame not yet buried by Pilgrim Creek fan. (8.6)

2.9 **Pilgrim Creek Bridge.** Note wide swath of unvegetated gravel indicating seasonally active alluviation by Pilgrim Creek. The Holocene Pilgrim Creek fan is quite large, as much as 13 mi (20 km) long and 7 mi (10 km) wide, about 1/3 the size of its drainage basin. Above the head of the fan, the Pilgrim Creek highlands were surrounded by glaciers in Pinedale time. Glaciers and meltwater streams fed sediment over divides into the Pilgrim Creek headwaters. The outlet from this drainage basin was dammed by ice just south of Pilgrim Peak. This giant sediment trap accumulated glacial outwash/inwash more than 400 ft (130 m) thick, which have been incised to angle-of repose slopes, thus explaining the volume of Holocene alluvium. (8.5)

3.4 **Pilgrim Creek Road** on north (right), goes up to Teton Wilderness boundary at head of Pilgrim Creek fan. Pilgrim Peak rises 1,390 ft (425 m) above here, and Pinedale ice reached within 100 ft (30 m) of its summit. Note the kame deposit embankments 600 ft (180 m) high (and thick?) that extend east from Pilgrim Peak marking the margin of the Snake River lobe that blocked the Pilgrim Creek drainage in Jackson Lake time. Kame terraces extend to an equal height on the east side of Pilgrim Creek. (8.0)

4.2 Kame deposits rising above gravel plain. (7.2)

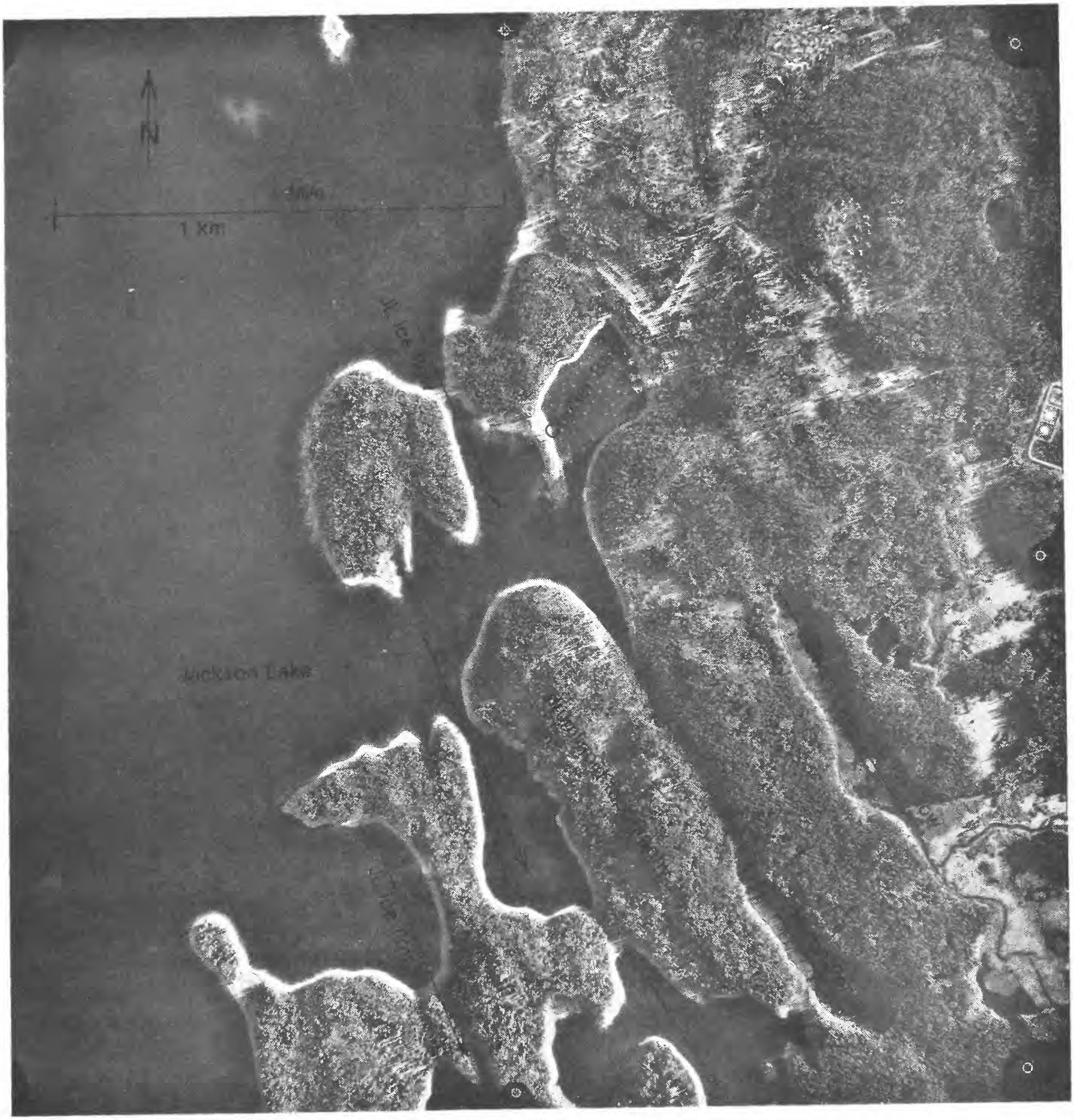
5.4 **Coulter Bay Village turnoff.** See annotated aerial photo showing strong drumlinoid topography formed by scour during Hedrick Pond and Jackson Lake time of Burned Ridge deposits. (6.0)

6.2 **Leeks Marina turnoff. Optional Stop 2-3b.** Drumlinoid topography is well expressed between the highway and the eastern side of Jackson Lake as well as on most of the islands in the lake. This strongly drumlinoid topography was formed by overriding of south-southeast-flowing Snake River lobe. At this site, reservoir wave action is needed to expose the deposits that form the core of these drumlinoid hills. Pinyon-type quartzite is abundant in the overridden deposit, yet is not present in the upflow area of the Snake River lobe. Thus the overridden deposit is thought to have been deposited by the Pacific Creek lobe in Burned Ridge time. In this case, the terminus of the Snake River lobe was well north of here, and the outwash-bearing Snake River flowed between here and the Teton front. (5.2)

7.3 Views of lake through forest from high point in drumlinoid topography. (4.1)

8.9 Small parking area that was the access for archeological studies at the Lawrence site. Roadcut just beyond exposes gravel rich in Pinyon-type quartzite (not found upflow in the Snake River lobe) and yet no Yellowstone tuff (which forms most of the immediately upflow area of the Snake River lobe). This material was most likely transported here in Burned Ridge time by the

Annotated aerial photograph showing surficial geologic relations near **Stop 2-3**. Extensive outwash gravels (kames, eskers(?), and deltas) occur in this area, including a kame terrace that accumulated between the Snake River (SR) and Pacific Creek (PC) lobes. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 14, 1979.



Annotated aerial photograph showing surficial geologic relations in the Coulter Bay area, and like that at **Optional Stop 2-3b.** The Snake River lobe overrode and streamlined older deposits of outwash and till along the eastern side of Jackson Lake. Quartzite is common and tuff is rare in these older deposits, indicating deposition by the Pacific Creek rather than Snake River lobe, probably in Burned Ridge time. Low sun-angle aerial photograph from U.S. Bureau of Reclamation, taken July 14, 1979.

Sample No. 88-WY-2025
Classification: Typic Argiallbolls
Location: Arizona Creek Fan, N. Jackson Hole
Parent Material: Pleistocene Arizona Creek gravel capped by fines
Native vegetation: Lodgepole pine, Englemann spruce
Elevation: 6800 feet

Soil description at Stop 2-4 in abandoned sand pit at edge of Pleistocene delta of Arizona Creek. Delta prograded into Jackson Lake when it was at about 6800 ft ((2073 m) in later Jackson Lake time.

Pedon Description

Horizon	Depth	Boundary	Color		Texture	Structure	Consistence		Clay Films	Lime	Pores	Roots	Notes
	cm		Dry	Moist			Moist	Wet					
O	5-0												
A	0-7	cs	10YR5/2	10YR3/2	l-(12)	2vf & fgr	fr	ss,sp	none	none	--	--	
BA	7-18	cs	10YR5/2.5	10YR3/3	l-(12)	2fsbk-2fgr	fr	ss,sp	none	none	3vf	--	1
Bw	18-45	cw	10YR5/2.5	10YR3/3	l-(12)	1msbk	fr	ss,sp	none	none	3vf	--	1 and 2
E	45-60	cw	10YR6/2	10YR4.3/2.5	l-(10)	1csbk-1msbk	fi	ss,sp	3	none	3vf,2f	--	2
EB	60-80	aw	E-10YR6.5/2 B-10YR3/3	E-10YR5/2 B-10YR3/3	l-(14)	2msbk	fi	ss,sp	4	none	3vf&f	--	3
2EB	88-92	cw	same	same	vgrcl	2fsbk	fi	s,p	6	none	3vf&f	--	5
2CB	92-155	as	--	10YR4/3	gr	structureless	loose	so,po	7	none	--	--	7
3CB	155-230	cw	--	10YR3/2	s	structureless	loose	so,po	8	none	--	--	8
3C	230-250	--	--	10YR3/3	cs	structureless	loose	so,po	none	none	--	--	

1-Many krotovinas.
2-Very few gravels.
3-Few thin clay film bridges.
4-5 lamellae 5mm thick; moderately thick clay films occur on lamellae; in matrix clay films occur in spots, 25% of area.
6-Continuous moderate clay films on 60% of area.
7-Open worked gravel with soil coatings of moderately thick clay films.
8-About 10 lamellae 0.5-2mm thick.

Pacific Creek lobe, which has abundant Pinyon-type source area and essentially Yellowstone tuffs. (2.5)

10.2 **Stop 2-4.** Turnoff on 2-track road or park along highway just beyond (north) Arizona Creek. In the creek bank, sandy gravel several meters thick overlies compact till. The outwash gravels form a fan/delta graded a higher level of Jackson Lake (alt. 6,810 ft/2,976 m), about 75 ft (23 m) above the natural level of Jackson Lake. The till is not especially rich in quartzite and contains(?) Yellowstone tuff, indicating deposition by the Snake River lobe.

Cross road and walk out to sand pit at edge of the Arizona Cr. fan delta. The soil profile (see separate page for soil description) can be easily seen in the edge of the pit. Of particular note are up to 10 or so reddish, clay lamallae that occur between depths of 4 and 6 ft (1.5 and 2 m). Reddish lamallae were found at depths of over a meter in all the soil pits dug in forested areas on Pinedale deposits of till and loess. At this site, deep wetting (flushing?) associated with melting of about 5 ft (1.5 m) snowpack carried clays to such depths, forming a B & C horizon. These lamallae represent the translocated-clay part of the B-horizon. Soil pit or descriptions to only 3 or even 5 ft (1 to 1.5 m) would miss this important, time related aspect of these soils. Return to vehicles and continue north. (1.2)

10.5 Meadow on Arizona Cr. fan/delta. (0.9)

11.0 Picnic area (0.4)

11.4 **Stop 2-5.** Large parking strip on Jackson Lake side of road. If the reservoir is down to levels below 6,740 ft (2,055 m), we will see the Holocene geology and archeology associated with the Snake River delta, as follows. (1) The Teton fault occurs near lake level across from us. (2) The axis of the deep scour trough formed by the Snake River lobe during Hedrick Pond and Jackson Lake time. Water in this trough is 400 ft (120 m) deep, and the sedimentary fill is a equal thickness, yielding a total depth of about 800 ft (250 m) (Smith and others, in press). This trough extends upvalley from us and at this position is probably at least 500? ft (150? m) deep. (3) Immediately in front of us is "ridge and basin terrain" resulting from deformation of deltaic sediments filling the deep glacial-scour basin. Middle Archaic points are found on the ridges, suggesting an age of about 3,000-5,000 yr B.P. The best explanation so far is shaking and perhaps liquefaction caused by an earthquake on the Teton fault, perhaps about 4,000 years ago. (4) Indian Island, which is in the western part of the Lawrence site. About 4 beach levels ranging from 6,753 to 6,745 ft (2,060-2,055 m) have paleoindian points on them, suggesting an age of 8,000 yr B.P or greater. The beach level at 6,745 ft (2,055 m) has McKean points both on and in? it, suggesting an age of 3,000-5,000 years, and also has hearths in? and on it suggesting ages in the same range. (5) Near Gull Island are two 2 beach sets deposited on meander scrolled delta sediments that extend lakeward of the beaches. This suggests a submergence event, probably by an earthquake on the Teton fault. The younger beach set has hearth in and on it indicating deposition between 1500 and 2000 yr B.P. (5) Between the areas described in 2 and 4 is the "meander belt" section also marked by an abundance of archeological sites, mostly dated between 1200? and 1700 yr B.P., and including a cabin attributed to Beaver Dick Leigh. In 1974, a forest fire burned much of the slope on the west side of Jackson Lake. Return to vehicles and backtrack to Jackson Lake Junction. (0.0)

Jackson Lake Junction to Moran Junction

0.0 **Jackson Lake Junction,** continue straight ahead (east). (4.0)

0.5 Start of "Oxbows", which are deep, tranquil loops of the Snake River separate from the gently flowing main stem further to south. (3.5)

0.9 Oxbow loop comes close to the road. (3.1)

1.6 **Stop 2-6, if enough time.** Turn right into large parking area. This is a favorite wildlife viewing spot. At the edge of the meadow east of here is a barrier beach of late Jackson Lake age dammed to this level by the bedrock threshold where Pacific Creek joins the Snake. The lush, flat meadows below this barrier beach are the bottom of the associated lake. The water in the Oxbows is locally deep (15 ft, 5 m). This deep, tranquil stretch of the Snake River may result from backtilting on the Teton fault, elevating the bedrock threshold just downstream from where Pacific Creek joins the Snake. (2.4)

1.8 Crest of the barrier beach off in forest to right (south)(alt. 6,800 ft/2,070 m). (2.2)

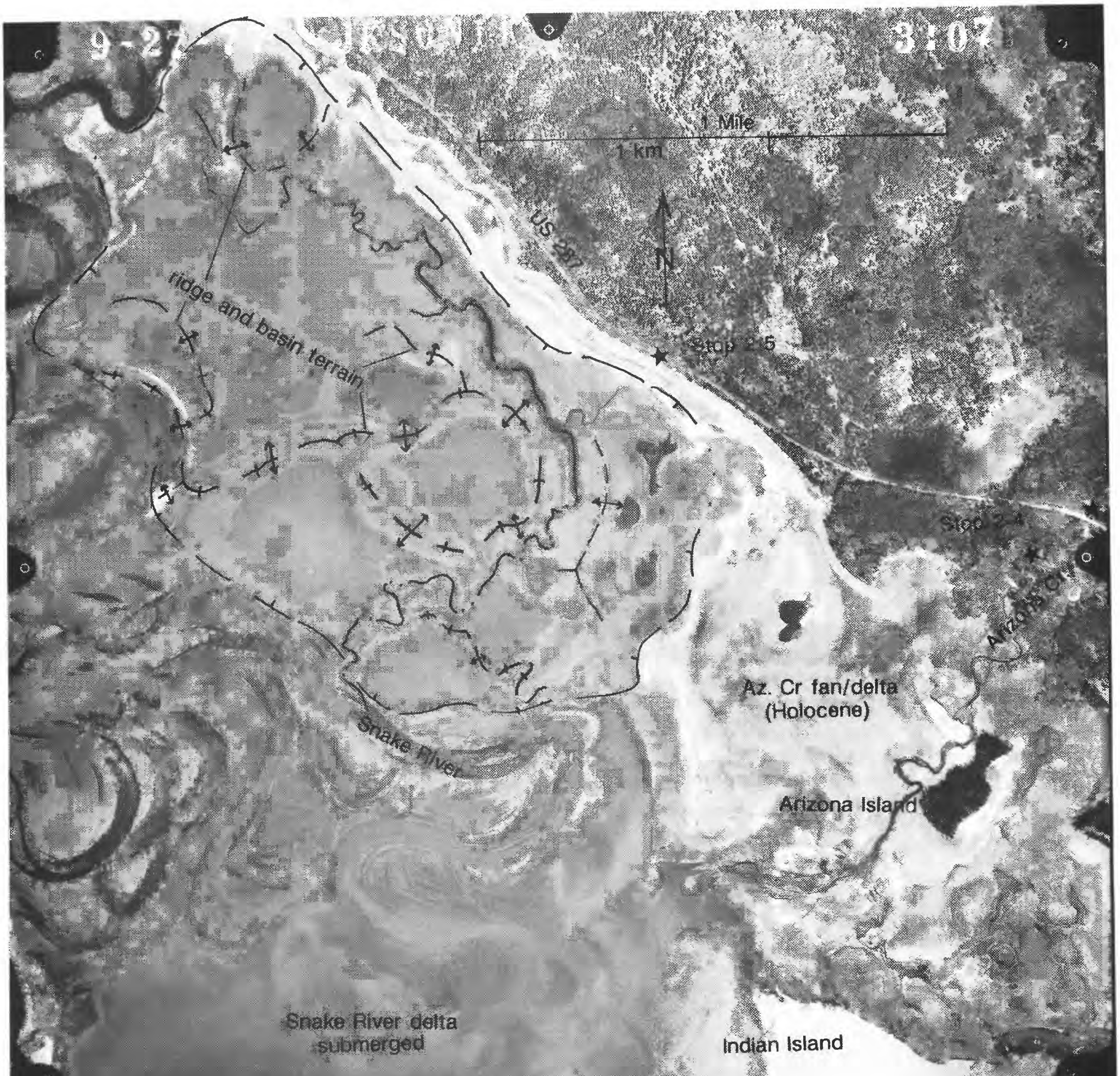
2.0 Pond between barrier beach and Pacific Creek fan. (2.0)

2.4 Highest remnant of Pacific Creek fan apparently incised after it overtopped bedrock threshold near mouth of Pacific Creek. (1.6)

2.8 Inset terrace dissecting Pacific Creek fan after lake threshold removed and lake lowered. (1.2)

3.1 **Pacific Creek,** which joins Snake River just upstream from bedrock threshold. (0.9)

3.2 Bedrock threshold formed of Mesaverde Formation (Love and Love, 1983, p. 310) between the Jackson Lake and Triangle X basins above road (alt. 6,800 ft; 2,070 m), 80 ft (25 m) higher than present river. (0.8)



and stop 2-4

Annotated aerial photograph showing surficial geologic relations near **Stop 2-5**. At the time of the photo, the reservoir only flooded part of the natural Jackson Lake delta. West of Stop 2-5, deltaic sediment has been deformed into a ridge and basin terrain, perhaps as a result of shaking during an earthquake on the Teton fault. The Lawrence site is east of Indian Island. Aerial photograph taken at relatively low water, September 27, 1977.

3.8 **Entrance station,** Grand Teton National Park (GTNP). (0.2)
4.0 **Moran Junction** (turn left to return to southern Jackson Hole. This section of road is given under Day 1, but in the reverse direction). (0.0)

Day 3, Southern Jackson Hole

This day will focus on the Munger (Bull Lake?) glaciation, which filled all of Jackson Hole. At one time, we considered naming this the Jackson Whole glaciation. We plan to finish by early afternoon.
0.0 **Start at 8:00 AM, entrance road to Gros Ventre Campground,** Grand Teton National Park. Please line up the carpool vehicles on the right side of the road leading out of the campground. Arrange to carpool using vehicles that can carry the most people, and please have no vehicles with less than 4 people. *We will not start until all vehicles have at least 4 people.* The lucky person that gets the front right seat, also gets the honor of being the official guidebook monitor and is responsible to see that someone informs the driver and others of what is in the guidebook.

Proceed southwest to Gros Ventre Junction

Gros Ventre Junction to Jackson

0.0 Gros Ventre Junction. Head south (left) on U.S. 26. (6.5)
0.5 Gros Ventre River. Stony deposits of 1927 Gros Ventre flood near present channel. Climb up onto low Pinedale terrace. (6.0)
1.0 Climb up onto Munger gravel mantled by loess resting on a buried soil. Turn left on dirt road and proceed through gate into Elk Refuge to **Stop 1, Buried soil on Munger glacial deposits mantled by Pinedale loess.** Drive 0.9 mi (1.5 km) across loess-mantled outwash fan drainages on east side of Jackson Hole to gully of abandoned irrigation ditch from Gros Ventre River to Flat Creek. Note the vegetation and soils indicating this is a relatively dry part of Jackson Hole.

The upper gully walls still expose loess on a buried soil developed on Munger glacial deposits. Details of the stratigraphy exposed when the gully walls were fresh as described and mapped by Love is given in Richmond and others (1965, p. 40-42). The area north of where we park exposes mostly till, consistent with a suggestion of a moraine loup across the valley. The area to the south of where we park exposes outwash, consistent with the flat bench.

About 1 km northeast of here along the same ditch, the Shooting Iron Formation (Love and others, 1992) is exposed. Studies of the vertebrate fauna by Barnosky (1985) indicate a Blancan age. Return to vehicles and backtrack to U.S. 26 and turn south (left). (5.5)
1.4 Entrance to Overlook for Grand Teton National Park. Road is on central part of Munger outwash fan. Scarps between terrace and channel pattern indicate this is an alluvial fan of the Gros Ventre River. To west, it slopes beneath Pinedale alluvium To east, it rises to where it is truncated by either a fault (Love and others, 1992), undercut by Flat Creek (our preferred explanation), or reaches its original ice margin position.

We are headed towards East Gros Ventre Butte with West Gros Ventre Butte to the right of it. Both are streamlined by overriding Munger ice and Munger glacial scour probably extends well below the present valley bottoms around these buttes. (5.1)
2.0 Descend from Munger gravel to Flat Creek lowlands
2.2 Roadcut shows loess mantle on Munger gravel. (3.7)
2.6 Roadcut on west exposes remnant of fan gravel of Gros Ventre River of Munger age, mantled by loess. Note Flat Creek wetlands along lower part of the mostly dry Flat Creek alluvial fan of Pinedale age. The Flat Creek glacier of Pinedale terminated at canyon mouth to east, and was about 12 miles (19 km) long, as long as any Pinedale valley glaciers in the Tetons. (3.4)
4.3 Flat Creek Motel, where thick loess exposures indicate base level of Flat Creek here at the end of the Munger glaciation was no higher than its present level. (1.7)
5.7 Flat Creek Bridge. Jackson is built on an alluvial fan of Cache Creek (Love and Albee, 1972), of probably Pinedale age. This fan has pushed Flat Creek westward and pinned it against East Gros Ventre Butte. Cache Creek produced only small Pinedale glaciers, but was extensively backfilled with Munger ice. The upper limit of Munger glaciation is well shown by till and erratics at the top of the ski area on Snow King Mountain on the south side of Jackson (Qg2 of Love and Albee, 1972).

The size of the wetlands upstream from here have increased this century, perhaps because of a combination of damming effect of the bridge and alluviation of the material eroded from a deep gully where an irrigation ditch dropped 140 ft (40 m) from the Gros Ventre River to Flat Creek. (0.3)
6.5 End of segment at Mercill and Cache at start of Truck route avoiding congestion near the Jackson Town Square. (0.0)

Jackson to Munger bench at Squaw Creek

0.0 Mercill and Cache. Turn west (right) on Mercill and follow Truck route signs. (10.8)
0.1 Turn south (left) on Millward. (10.7)
0.3 Turn west (right) on Broadway. (10.5)
0.6 Veer left at stoplight on U.S. 26. Note exposures in area of thick loess with buried soil on Munger age terrain. (10.2)
1.0 Roadcuts here and elsewhere in this part of Jackson Hole dug into steep colluvial slopes expose a steeply stratified sequence of talus and loess, with buried soils. (9.8)
2.8 Light at High School Road. Enter South Park underlain by Pinedale outwash that came down Flat Creek and the valley between East and West Gros Ventre Buttes. Here this maximum Pinedale fill terrace is only 10-20 ft (3-7 m) above the Snake River. (8.0)
3.6 Stratified colluvial sequence involving flagged colluvium (scree), loess, and buried soils. (7.2)
4.5 Side valleys through this area have two distinct ages of alluvial fans: a higher fan of Munger age mantled by loess on a buried soil, and a undissected fan of Pinedale age. (6.3)
5.8 Inset alluvial fan of Pinedale age. (5.0)
6.2 Climb up onto higher fan of Munger age. (4.6)
6.5 Pinedale outwash beneath the bottomlands of the Snake River. (4.3)
8.0 **Game Creek.** Munger outwash spilled into the headwaters of Game Creek from a low divide with Cache Creek and built terrace remnants as much as 400 ft (120 m) above the present small drainage. (2.8)
8.6 **Snake River bridge.** Note maximum Pinedale fill terrace is only 10-15 ft (3-5 m) above the Snake River here, more than a order of magnitude different than near the Pinedale end moraines to the north. (2.2)
9.6 Turn east (left) at end of broad left curve of highway. Continue across one lane, metal bridge. (1.2)
10.0 Turn north (left) onto old highway after road climbs up dugway. (0.8)
10.3 Contorted Munger gravels and lake sediments in roadcut. (0.5)
10.8 **Stop 3-2, Snake River bluffs just downstream from Squaw Creek.** Center of large roadcut with contorted gravels, sands, and lake sediments of Munger age. Turn vehicles around and park on Snake River side of road. These deposits were mapped as Qg2 by Love and Love (1978), which is largely equivalent to the Munger glaciation.

This stop has two general areas of interest. One is the contorted ice contact stratified drift, including an overturned fold in gravel, and rapid changes in material from silts to gravels.

The other is the buried soil complex at top of the bluffs 400 ft (120 m) above river level (see separate pages for description of buried soil complex as well as surface soil). From the top of the bluffs we can see other benches at this level, and loess mantled ridges we think are Munger moraines. The buried soil complex has as many as three soils in it. Such buried soil complex with three soils occur on Munger deposits only at sites in the optimal position to receive loess deposition, adjacent to the Snake River and bluff positions. Farther away from the river only two or one soil can be recognized at this stratigraphic position. This is similar to the loess/soil sequence noted in Czechoslovakia (Kukla, 1970; and Kukla and Koci, 1972) . From top down in the buried soil complex, the soils are thought to represent oxygen isotope stages 5a, c, and e, and the loesses in which the soils are developed are thought to represent stages b, c and the end of stage 6.

Return to vehicles and take route back to Jackson staying on the main street (Broadway) well past the green at the town center until you reach the entrance to the Game Refuge. (0.0)

Jackson to higher overlook above Curtis Canyon Overlook

0.0 Start at Entrance to Game Refuge at west end of Broadway. Travel 0.7 mi northward near edge of Cache Creek alluvial fan of Pinedale age built into the Flat Creek lowland. Pinedale glaciers at the head of Cache Creek were only 2 miles (3 km) long. This lowland was probably excavated by Munger ice whose surface was 1,500 ft (450 m) thick above us.
0.5 Road makes left turn around alluvial fan complex consisting of higher fan of Munger recessional age and inset Pinedale fan
1.3 South end of Miller Butte with outcrops of Madison Limestone. Miller Butte is a bedrock mass streamlined by flow of overriding Munger ice in a manner similar to East and West Gros Ventre Buttes. Two stage fan complex on right.
3.6 Section-corner north (left) turn on alluvial fan of Twin Creek.
4.6 East (right) turn near eastern side of large alluvial fan of Flat Creek. This large alluvial fan fills most of the Flat Creek lowland, and heads at the edge of this lowland in the end moraine area of the 12-mile-long (19 km) Flat Creek glacier of Pinedale age.
5.1 Road climbs onto alluvial fan of Sheep Creek, which is steeper than that of Flat Creek. The Pinedale glacier of Sheep Creek was about 5 mi

Sample No. 78-WY-2014
Classification: Typic Cryoboroll
Location: Skunk Creek and Porcupine Creek, S. of Jackson Hole
Parent Material: Loess
Native vegetation: Mountain big sagebrush and Idaho fescue
Elevation: 6330 feet

Soil description on flats above Stop 3-2, included because the surface soil is eroded there. This thick post-glacial (Pinedale) soil is typical of moist sites in loess. Pinedale loess here nearly 6 m thick above the buried soil complex exposed at Stop 3-2.

Pedon Description

Horizon	Depth	Boundary	Color		Texture	Structure	Consistence		Clay Films	Lime	Pores	Roots	Notes
	cm		Dry	Moist			Moist	Wet					
A1	0- 15	cs	10YR3.8/2	10YR2.8/1	sil	2fgr	fr	ss,sp	none	none	3vf&f,1m&c	3vf&f,1m&c	
A2	15- 35	cw	10YR4.2/2	10YR2.8/1.6	sil	2m&fgr	fr	ss,sp	none	none	3vf&f,1m&c	3vf&f,1m&c	
BA	35- 58	cw	10YR4.6/2	10YR2.4/2	sil	1cpr - 1m&cs	fi	ss,sp	2-none	none	3vf&f,2m&c	3vf&f,1m&c - 2	
Bw1	58- 85	cw	10YR5.7/3	10YR3/3	sil	2cpr	fi	ss,sp	3	none	3vf&f,2m&c	2vf,1f	3
Bw2	85-110	aw	10YR6/3	10YR3.4/3	sil	1pr - 1m&csb	fi	ss,sp	4-none	none	3vf&f,2m&c	2vf,1f	4
Bk1	110-130	cw	10YR5.8/2.8	10YR3/3	sil	1csbk	fi	ss,sp	none	es	3vf,2f,1m	2vf,1f	
Bk2	130-154	cw	10YR7/2.9	10YR5/2.6	sil	massive	fi	ss,sp	none	es	3vf,2f	2vf	
Bk3	154-190	gw	10YR8/2.2	10YR6/2.8	sil	massive	fi	ss,sp	none	ev	2vf	1vf	
Bk4	190-210	gw	10YR7.3/2	10YR5.3/3	sil	1cpl-m,17	fi	ss,sp	none	ev	2vf,1f	1vf	
C	210-255	ci	10YR7/2	10YR5/3.3	sil	massive-soft	fr	ss,sp	none	es	2vf,1f	1vf	

2-Bleached silt grains occur on top of ped faces.
3-Thin continuous clay films at top of prisms, becoming patchy below. Also ped faces have thick coatings of bleached silt grains.
4-Thick coatings of bleached silt grains on ped faces.
17-Platy structure may be due to solifluction or flowage and freezing at time of deposition.

This soil was described from a backhoe pit. The first buried soil, not included here, starting at 255cm has a weakly developed profile and the C horizon extended to a depth of 582cm.

Sample No: 88-WY-2027
Classification:
Location: Snake River Bluff South of Squaw Creek.
Parent Material: Loess
Native vegetation:
Elevation: 6290 feet

Description of buried soil complex in bluffs at Stop 3-2. Locally three buried soils can be recognized, inferred to represent the three oscillations of oxygen isotope stage 5. See description on previous page (Sample 78-WY-2014) for uneroded surface soil. Note that loess unit at uneroded site is nearly 6 m thick, much thicker than the 2 m exposed in this eroding bluffs site.

Pedon Description Refer to site 78-Wy-2014 for surface soil.

Horizon	Depth	Boundary	Color		Texture	Structure	Consistence		Clay Films	Lime	Pores	Roots	Notes
	cm		Dry	Moist			Moist	Wet					
3Ab	196-211	c	10YR7/3	10YR5/3	sil-(15)	4	fr	ss,sp	none	e	3vr,3f,2m	--	5
3ABb	211-225	c	10YR6/3	10YR4/3	sil-(18)	4	fr	ss,sp	none	es	3ve,3e,2m	--	6
3Bt1b	225-255	c	7.5YR5.5/4	7.5YR4.5/4	sil-(20)	4	fr	ss,sp	none	em	3vf,3f,2m	--	6
3Bt2b	255=282	c	10YR6/3.5	10YR4/4	sil-(16)	1msbk	fr	ss,sp	none	em	3ve,3f,2m	--	6

Footnotes for above portion of soil profile.

4-Structure compressed and breaks as massive material.
5-Few pores filled with lime; 2cm thick dark humic band visible 50m to north.
6-Many pores filled with lime.

Horizon	Depth	Boundary	Color Dry	Color Moist	Texture	Structure	Consistence Moist	Consistence Wet	Clay Films	Lime	Pores	Roots	Notes
3Bkb	282-296	c	7.5YR8/2	10YR6/3	sil-(16)	1	fr	ss,sp	none	ev	3vf,3f,2m	--	2
4Bw	296-341	c	10YR6/4	9YR4/4	sil-(15)	1	fr	ss,sp	none	em	3vf,f,m	--	3
4Bk	341-346	c	7.5YR8/2	10YR6/3.5	sil-(16)	1	fr	ss,sp	none	ev	3vf,f	--	4
5Bt1b	346-381	g	10YR6/3	7.5YR3.5/4	sil-(18)	1	er	ss,sp	5	em	3vf,2f,m	--	6
5Bt2b	381-431	g	10YR5/3.5	7.5YR3/3	sil-(20)	1	fi	ss,sp	5	e	3vf,2f	--	7
5Bt3b	431-466	g	9YR6/3.5	7.5YR3/3	sicl-(28)	1	fr	ss,sp	9	eo	3f	--	8
5Bkb,B,	466-616	--	10YR4/3	--	--	--	--	--	--	--	--	--	10

1-Structure compressed and breaks as massive material.
2-Lime is disseminated throughout.
3-Many pores lined with white lime.
4-Increase in stones; zone of lime accumulation and pebbles.
5-Thin continuous clay bridging.
6-Many pores coated with lime; many very fine pebbles.
7-Lime coats some pores; boulders and some pebbles extent 3/4 of the way up in horizon.
8-Few lime coatings in pores; noncalcareous between veins.
9-Moderate continuous clay films.
10-Bouldery, very gravelly, cobbley zone with pendants of lime strongly cemented, conglomerated, very hard gravelly material with irregular zones of silt loam soil that is 10YR4/3 color. Lithology is mixed but limestone is highly weathered and spalls off into powdery material. Other rock material such as andesite or basalt is highly weathered. Mixed silty soil is strongly effervescent. On spur to south 1.5 m of K horizon cemented gravels represents end member in K-horizon development.

(8 km) long and flowed at nearly right angles to the flow of Munger ice which left the strong northwest-southeast topographic alignments we will see at the next stop.

5.9 Road turns east (right) and starts climb. Sheep Creek fan heads in gorge to north (left). Slopes ahead are covered with Munger till mantled, where gentle enough, by Pinedale loess.

6.7 Switchback.

7.2 Curtis Canyon turnout for overlook. Continue on main road, climbing through terrain with strong southwest alignment formed by ice molding and ice-marginal stream erosion in Munger time.

8.1 Switchback to left

8.5 **Stop 3-3, Munger glacial terrain and overview of Jackson Hole.** Turnout on left 500 ft above the Curtis Canyon Overlook. Park vehicles in grassy area and walk northwest onto grassy knoll. See annotated aerial photo. At this site, we can stand on well-preserved glacial terrain of Munger age, view much of the extent of Munger glaciation that filled Jackson Hole, and look up Jackson Hole to view the Pinedale outwash and moraines that terminated 30 miles (50 km) shy of the Munger (Bull Lake) limit.

The strong southwesterly grain to the local topography is the result of both (1) southwest flow of Munger ice whose upper limit is shown by till and erratics 1,200 ft (360 m) above us, and (2) ice-marginal meltwater erosion forming multiple "valleys" that descend to the southwest and are inset into the general northwesterly slope. Erratics are mostly of Tensleep Sandstone and Madison Limestone, with some Absaroka volcanics and Pinyon-type quartzite. The abundance of Paleozoic rocks and paucity of Absaroka volcanics and quartzite reflect the Flat Creek and Gros Ventre ice-streams which would have constituted this side of the larger Jackson Hole glacier. The ice-marginal valleys in this area reach depths of 30-300 ft (10-100 m) (topographic reversals from regional slope). One of the deepest is Curtis Canyon immediately southwest from here. The deep canyon immediately north of us is formed by Sheep Creek which has been eroding a rocky canyon into the Munger glacial terrain.

The view from here includes (generally from north to south): (1) Burned Ridge moraines and outwash overlapped down valley by successively younger Hedrick Pond (on Antelope Flats) and Jackson outwash (at airport); (2) Blacktail Butte and the hills of the National Elk Refuge overridden by Munger ice, with the loess-mantled Munger fan of the Gros Ventre River at the left end of the Elk Refuge hills; (3) below that the large Pinedale outwash fan of Flat Creek; (4) Pinedale moraines along the front of the Teton Range, including the interconnected Phelps Lake-Open Canyon-Granite Canyon complex and post-glacial scarps of the Teton fault cutting these moraines and other surficial deposits, (5) the Gros Ventre Buttes streamlined by overriding Munger ice, (6) above these buttes on the far side of Jackson Hole, Phillips Ridge where the Munger glacial limit is well defined at 8,100 ft (2,470 m); the large ridge between Twin Creek and Cache Creek, where Munger ice spilled across U-shaped divides but did not completely fill the Cache Creek valley on the far side.

Return to vehicles, and backtrack roadlog to Elk Refuge-Jackson boundary. To avoid congestion drive on Broadway for 1.0 miles, turn north (right) on Bruun and go straight until street west (left) turn and goes to stoplight on Cache Street. Turn north (right) on Cache.

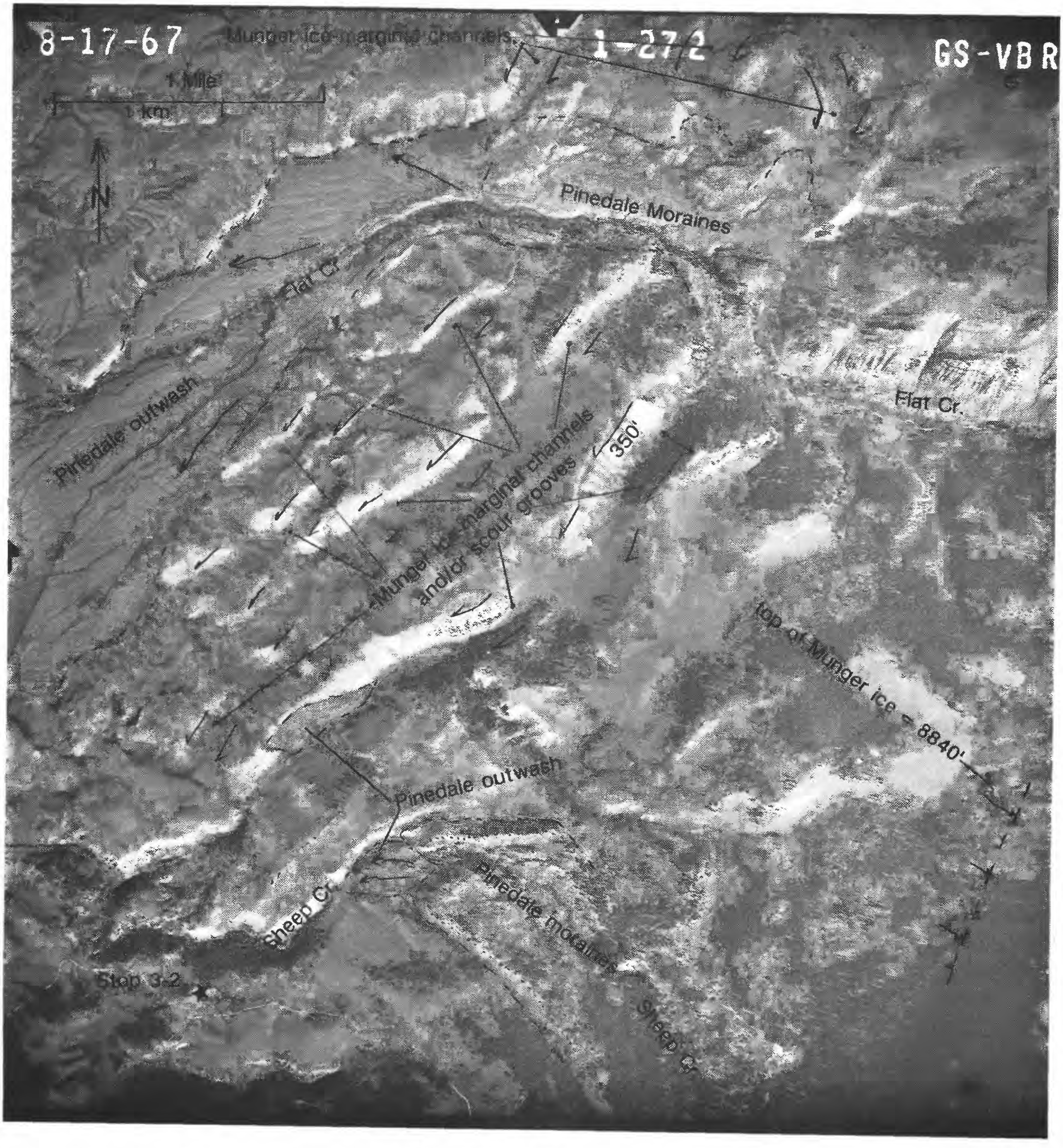
Retrace route from Jackson to Gros Ventre Junction (road log, first part of Day 3). Turn east (right) at Gros Ventre Junction and retrace route to Gros Ventre Campground

Gros Ventre Campground to Gros Ventre Slide

0.0 Entrance road to Gros Ventre Campground Continue east and climb a succession of Pinedale teracettes of the Gros Ventre River. A geologic map in Love and Love (1988) shows the area we will be traversing. The area Sizable valley glaciers existed on the south side of the Gros Ventre valley and generally terminated near the valley axis.

0.5 Road is now on large **Pinedale alluvial fan** of Gros Ventre River that splits and flows down both sides of Blacktail Butte. The Pinedale fan that goes down the north side of the Gros Ventre is younger than the terraces adjacent to the present course of the Gros Ventre.

The high, steep, slope of Blacktail Butte adjacent to the Pinedale outwash fan of the Gros Ventre River is proposed to have been formed by **"fluvial faceting"** When the channel of the aggrading Gros Ventre River on the older fan intersected Blacktail Butte, the river course was downstream from there "pinned against" the Butte, resulting in undercutting of it to form the 700 ft (200 m) high, angle-of-repose fluvial facets. By similar argument, the south side of Blacktail Butte was steepened by fluvial faceting when the loess-mantled terrace was formed in early Wisconsin(?) time. Formation of these facets by faulting is considered less likely, in part because no scarps on a few meter scale are observed on any of the small alluvial cones at the base of these scarps. These "fluvial facets" are best viewed when driving west on the return trip. (7.6)



Annotated aerial photograph showing surficial geologic relations near **Stop 3-3**. Glacial landforms of Munger age are well preserved and displayed in this area, including ice-marginal channels and recessional moraines. The Jackson Whole glacier of Munger age was 2600 ft thick here. During recession of this glacier, ice-marginal streams (Flat Creek, the Gros Ventre River, and others) cut canyons hundreds of feet deep. Aerial photograph taken August 17, 1967 by U.S. Geological Survey, .

2.3 Road makes north (left) turn in **Kelly**. Note the Yurts occupied by a counter culture group. (5.8)
3.5 Turn right onto Gros Ventre Road. (4.6)
3.9 **Kelly Warm Springs** on right is a swimming and bathing area from high volume springs that issue from the Teewinot Formation (Love and Love, 1988).

On the north side of the road are the lowest of an extensive set of **ice-marginal inwash gravel terraces** deposited against the receding margin of Munger ice by the glacial Gros Ventre River and by Ditch Creek (the next drainage to the north). For the next 1.5 miles, the road climbs through a succession of such inwash fans representing higher and slightly older recessional ice-margin positions. Their number and size probably reflects the high volume of sediment delivery by the Gros Ventre River and Ditch Creek, rather than an long pause in glacial recession. At that time, large areas had just deglaciated and an abundant supply or gravel rich in Pinyon-type quartzite was available from erodible slopes. These gravels are locally mantled by more than 10 ft (3 m) of loess, mostly of Pinedale age. (4.2)
4.6 Log cabin from the movie "Shane". Loess mantled inwash fan gravels form multiple sloping benches. (3.5)
5.2 Road makes gentle right turn and crests (alt 6,900 ft/2,100 m) in the inwash gravels. The open slopes ahead extending to the skyline 500 ft (150 m) above have a sequence of **Munger recessional moraines** that slope east into the valley of the Gros Ventre River. Munger deposits extend above the wooded hills on the skyline.

These recessional deposits are well below the limit of Munger ice. Although nor visible from here, south of here on Sheep Mountain, Munger scour features and erratics? of the glacier flowing out of the Gros Ventre valley extend to an altitude of at least 9,600 ft (2,930 m) and perhaps 10,000 ft (3,000 m). Under full-glacial conditions, a large glacier flowed out of the Gros Ventre valley and joined the Munger glacier in Jackson Hole. (2.9)
5.8 **Enter Bridger Teton National Forest.** The benches on north (left) are on inwash kame gravels. On the right (south) are boulder deposits of the 1927 Gros Ventre flood. (2.3)
7.3 **Stop 3-4 in unpaved parking area** where road turns left. If muddy we will go to optional Stop 3-1b further up the road. The roadcut exposes some of the backfill deposits resulting from blockage of the Gros Ventre by Munger ice in Jackson Hole. See annotated aerial photo.

Walk down to the knob to see the following: (1) the Gros Ventre landslide deposit of 1925 and its source area, (2) the breach of the landslide when the landslide-dammed lake filled and rapidly eroded the threshold in 1927, and (3) boulder deposits if the 1927 Gros Ventre flood, (4) the older Devils Elbow slide a mile downstream from the Gros Ventre slide (Love and Love, 1988, p. 5-6).

The Munger glaciation covered everything in view. Up the Gros Ventre valley from here are glacial, alluvial, and lacustrine deposits assigned by Love (in press) to the Leidy Formation. These thick deposits extend from the valley floor up to heights of 600? ft (200? m) and are described in a number of measured sections of Leidy Formation (Love, in press). These deposits are probably associated with the following sequence of events: (1) blockage of the Gros Ventre valley by advancing Munger ice from Jackson Hole thus forming a lake with alluviation around its margins at the same time as local glaciers advanced towards the valley center, (2) eventual buildup of ice to fill the Gros Ventre valley and convert it into a source area in full-glacial Munger time, and (3) a phase similar to #1 in which the central part of the Gros Ventre valley was deglaciated whereas recessional Munger ice in Jackson Hole was still extensive enough to block the valley mouth and create a second lake. (0.8)
7.6 View for the few. Ice-contact deposits deposited near margin of recessional Munger ice backfilling the Gros Ventre valley. (0.5)
8.1 **Parking area for viewing the Gros Ventre slide** built on slide material. Interpretative signs about the slide, but trees have masked the view. (0.0)
8.8 **Optional Stop 3-4b** in large gravel parking area if scheduled stop is muddy. Good site for view of Lower Slide Lake, the Gros Ventre Slide, and the main part of the Gros Ventre valley.
Return to entrance to Gros Ventre Campground. You will get a better view of the inferred fluvial facets (described at mile 0.5) as you drive across the Pinedale fan of Gros Ventre River.
End of FOP field trip at Gros Ventre Campground. **Congratulations,** *you have survived another FOP field trip.* See you next year!

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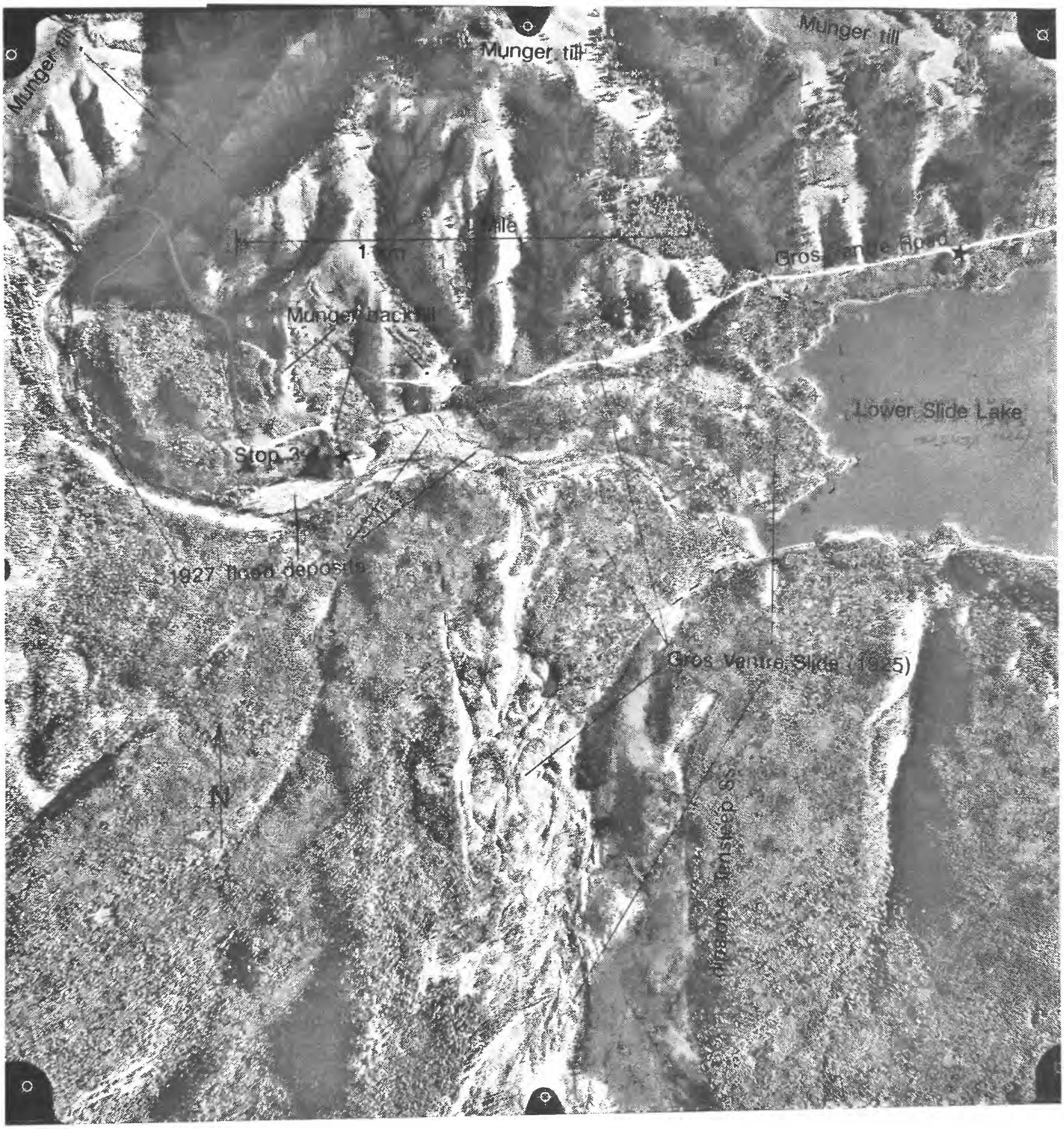

Annotated aerial photograph showing surficial geologic relations near **Stop 3-4**. The slide occurred on a dip slope of upper Paleozoic rocks on June 23, 1925 and created a lake about 200 ft deep, which partially drained on May 18, 1927, producing a flood. Low-sun angle aerial photograph from U.S. Bureau of Reclamation, taken July 15, 1979.

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HOLOCENE VEGETATION AND CLIMATE OF GRAND TETON NATIONAL PARK AND VICINITY

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Pollen records from Hedrick Pond and other lakes in Grand Teton National Park (GTNP) and Yellowstone National Park (YNP) provide information on the vegetational and climatic changes that have occurred during the last ca. 18,000 years (Fig. 1). The chronology for these records is based on radiocarbon-age determinations and the presence of Mazama ash and Glacier Peak ash in most sites. Hedrick Pond is exceptional in that Mazama ash was absent in the core, and the late-glacial ash is apparently not from Glacier Peak (A. Sarna-Wojcicki, pers. comm.).

The vegetational history of the last ca. 18,000 years is divided into five major phases (Fig. 2; Whitlock, in press): (1) Prior to 11,500 yr B.P., meadow communities with birch (Betula), willow (Salix) and juniper (Juniperus) were widespread in the GTNP/YNP region. The pollen assemblage most closely resembles the modern pollen rain of alpine vegetation today. This implies that upper treeline was at least 600 m lower and annual temperatures were 5-6°C less than at present. (2) Engelmann spruce (Picea engelmannii) was present near Hedrick Pond as early as 14,500 yr B.P.; however, it did not spread northward into YNP until 11,500 and 10,500 yr B.P. The development of spruce parkland throughout much of the region implies increased summer temperatures and greater winter precipitation after 11,500 yr B.P. (3) The third phase occurred between 10,500 and 9500 yr B.P. when subalpine fir (Abies lasiocarpa) and whitebark pine (Pinus albicaulis) moved into northern GTNP and YNP. At this time, the forest closely resembled the subalpine forest of GTNP/YNP today.

The vegetational history of the Central Plateau of YNP is somewhat different during the period from 11,500 to 10,000 yr B.P. While subalpine parkland was present elsewhere at this time, the rhyolite plateau was unforested and covered by Artemisia (probably sagebrush), Gramineae (grass), and other herbs. Apparently, the poor soil conditions that limit spruce, fir, and whitebark pine in the Central Plateau today also prevented the development of subalpine forest in late-glacial time.

The fourth phase began between 10,000 and 9500 yr B.P, when pollen of Pinus contorta (lodgepole pine) was first abundant in the sediments of all sites. The development of lodgepole pine forest suggests continued warming within the region. Between 9500 and 5000 yr B.P., lodgepole pine,

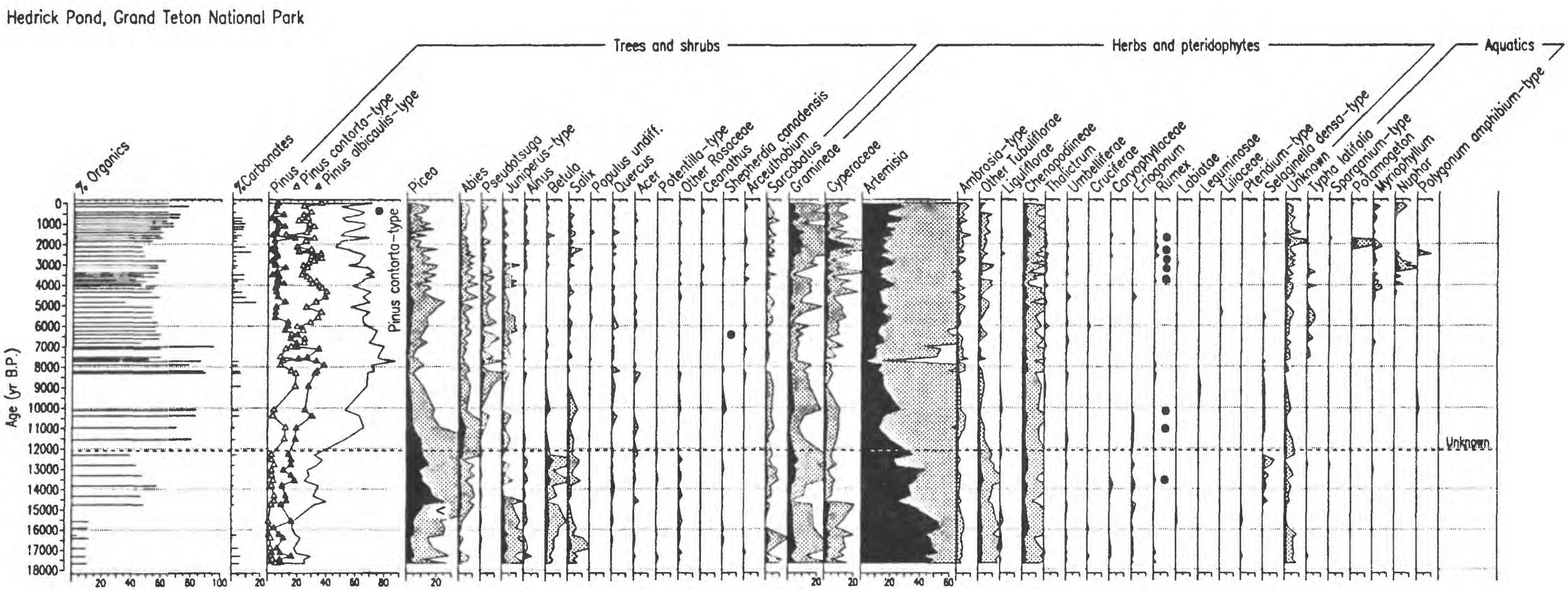
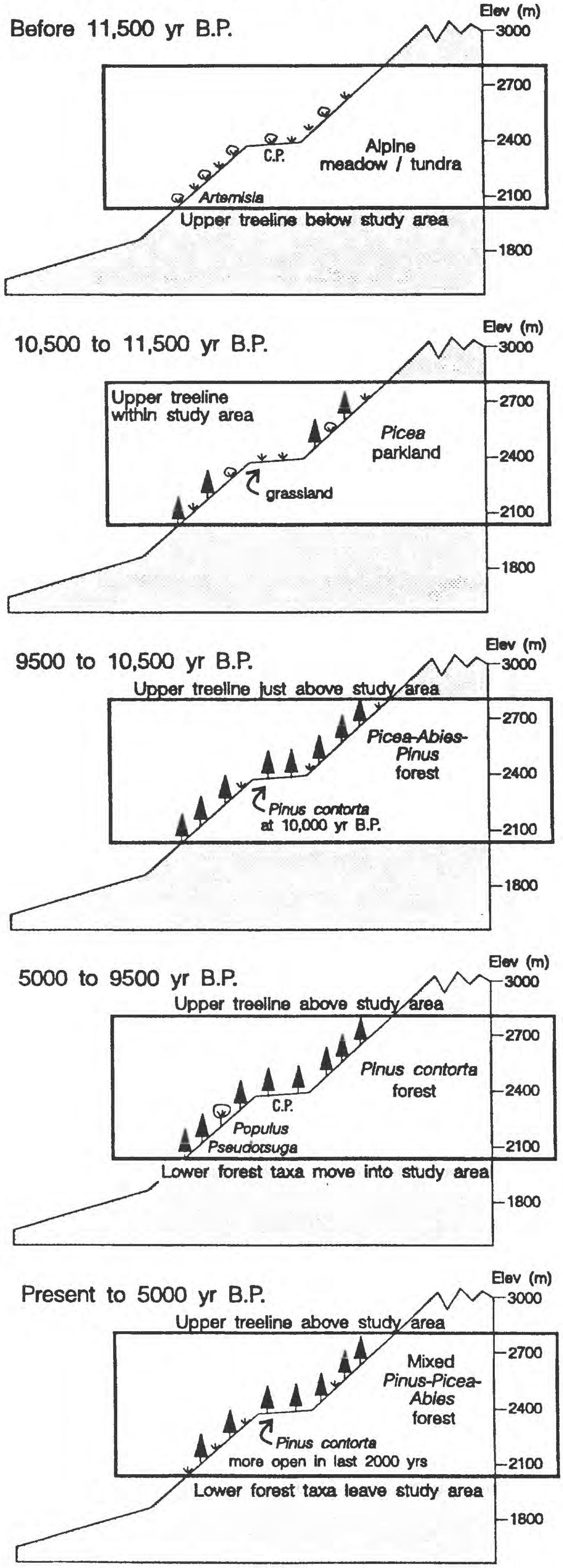


Figure 1. Pollen percentage diagram from Hedrick Pond, Grand Teton National Park. Data are plotted against years before present (yr B.P.). Black circles indicate the presence of plant macrofossils at a particular depth in the core. (From Whitlock, in press).

Figure 2. Major phases of vegetational history of the study area reconstructed from pollen data. C.P. = Central Plateau. (From Whitlock, in press).



Douglas-fir (Pseudotsuga) and aspen (Populus) grew above their present altitudinal range. The climate during this interval was probably warmer and drier climate than that of today and fires were more frequent. (5) In the last 5000 years, spruce, pine, and fir have become more prominent in the vegetation, except on the Central Plateau, where a closed forest of lodgepole pine has persisted to the present day. The shift towards more-closed forest and wet-loving communities is ascribed to the onset of cooler wetter conditions in the late-Holocene.

The major changes in the climate history of the GTNP/YNP region appear to be a response to large-scale changes in the climate system that affected the northwestern U.S. as a whole. The nature of these large-scale changes is suggested in paleoclimatic simulations with general circulation models (COHMAP, 1988; Kutzbach and Guetter, 1986; Thompson et al., in press). Three hemispheric climatic controls were particularly significant with respect to the climate of the GTNP region. The first was the direct effect of the Laurentide ice sheet on Northern Hemisphere temperatures. The ice sheet depressed temperatures by 4-10^{o}C in the northern middle latitudes (Kutzbach and Guetter, 1986). The second control was the latitude of the jet stream, as governed by the size of the continental ice sheet. During full-glacial conditions the southern branch of the jet stream was shifted south of its present position, causing the northwestern U.S. to be drier than today. As the Laurentide ice retreated, the jet stream moved northward and winter storms increased in the GTNP region. The third control was the amplitude of the seasonal cycle of solar radiation, which was greater between 12 and 6 ka (Kutzbach and Guetter, 1986). Summer radiation was higher by 10% during the early Holocene and resulted in higher temperatures and decreased effective moisture. It also led to an expansion of the eastern Pacific subtropical high pressure system, which intensified summer drought in the northwestern U.S. Summer radiation decreased in the late Holocene, and the GTNP region became cooler and wetter.

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