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Fire and Ice in Central Idaho: Modern and Holocene Fires, Debris Flows, and Climate in the Payette River Basin, and Quaternary and Glacial Geology in the Sawtooth Mountains

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

Edited by Kathleen M. Haller and Spencer H. Wood

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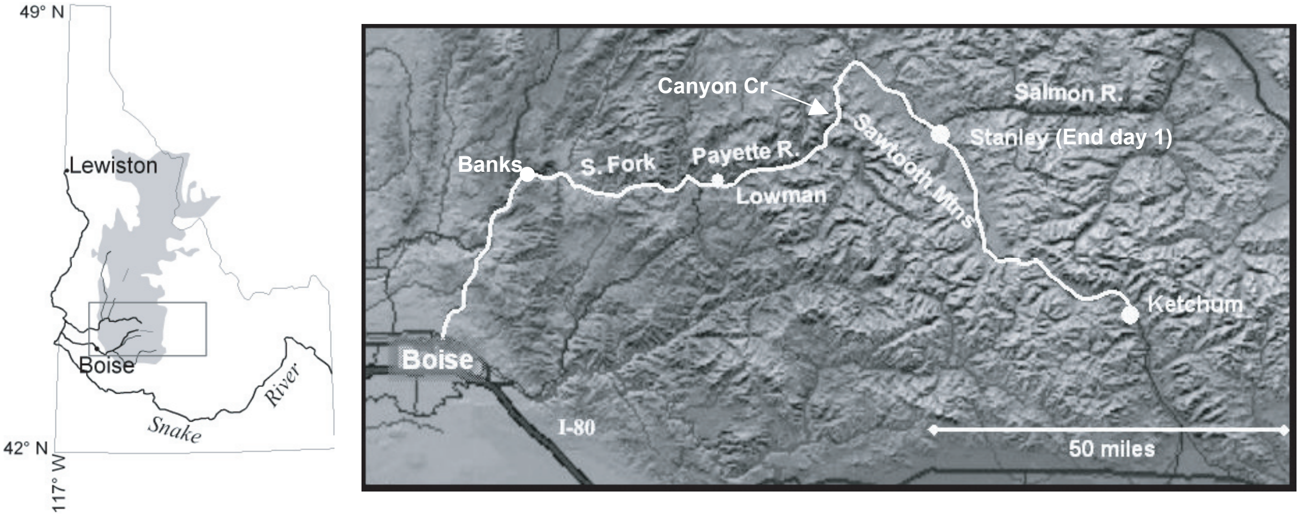

Figure 1. Map showing approximate location of the field-trip area within the State of Idaho and enlargement of field-trip route to right of state map. Gray shading on the state map shows the outline of the Idaho batholith. The trip will depart from Boise, travel up the main stem Payette River, turn east at Banks up the South Fork Payette Canyon, and continue up Canyon Creek into the Stanley Basin, ending day one in Stanley. Day two of the trip will examine glacial features near lakes on the eastern side of the Sawtooth Mountains and continue over Galena summit into the town of Ketchum.

Fire and Ice in Central Idaho: Modern and Holocene Fires, Debris Flows, and Climate in the Payette River Basin, and Quaternary and Glacial Geology in the Sawtooth Mountains

By Jennifer L. Pierce[1], Grant A. Meyer[1], Glenn D. Thackray[2], Spencer H. Wood[3], Kari Lundeen[4], Jennifer A. Borgert[5], and Eric Rothwell[3]

Introduction

This 2-day trip will highlight recent fire and storm-related debris flows in the Payette River region, Holocene records of fires and fire-related sedimentation events preserved in alluvial fan stratigraphic sequences, and geomorphology and geology of alpine glaciations in the spectacular Sawtooth Mountains and Stanley Basin of central Idaho. Storm events and associated scour following recent fires in the South Fork Payette basin have exposed Holocene fire-related debris-flow deposits, flood sediments, and other alluvial fan-building deposits that yield insights into Holocene environmental change. Moraine characteristics and sediment cores from the southeastern Sawtooth Mountains and Stanley Basin provide evidence of late Pleistocene alpine glaciation. A combination of these glacial records with reconstructions of regional equilibrium line elevations produces late-glacial paleoclimatic inferences for the area.

Day one of the trip will examine recent and Holocene fire-related deposits along the South Fork Payette River; day two will focus on alpine glaciation in the Sawtooth Mountains (fig. 1). A description of the scope, methods, results and interpretation of the South Fork Payette fire study is given below. Background information on late Pleistocene alpine glaciation in the eastern Sawtooth Mountains is presented with the material for day 2 of the trip.

The road log for day 1 of the trip begins at Banks, Idaho, and ends in Stanley, Idaho. Stop locations are shown on figure 2. At Stop 1, we will provide an introduction to interpretation of alluvial fan stratigraphic sections, and discuss the Boise Ridge fault. At Stops 2–4 (Hopkins Creek, Deadwood River, and Jughead creek), we will examine recent debris-flow deposits and Holocene alluvial fan stratigraphic sections. At Stop 5 (Helende Campground), we will look at a series of well-preserved Holocene and Pleistocene terraces and at Stop 6 (Canyon Creek), we will briefly inspect fire-related deposits in higher-elevation alluvial fan stratigraphic sections.

The road log for day 2 begins at Stanley, Idaho, and ends in Sun Valley, Idaho. Stop locations are shown on figure 2. Stop 1, at Redfish Lake, will focus on regional equilibrium line altitude reconstructions and on the general pattern of late Pleistocene glaciation on the eastern flank of the Sawtooth Mountains. Stop 2 will be at Pettit Lake, where we will examine the moraine sequence and discuss relative weathering criteria and moraine groupings. At Stop 3, near Alturas Lake, we will discuss lake sediment coring, moraine chronology, and implications for latest Pleistocene paleoclimatic inferences. Stop 4 will be a brief stop at Galena Summit for an overview of the Sawtooth Mountains and a discussion of ice accumulation patterns. The trip will end at a set of moraines in the Trail Creek valley, near Sun Valley, where we will examine moraine morphology and weathering rind data that constrain the moraine ages.

South Fork Payette Fire Study

Introduction

Fire is an important agent of geomorphic change in forested mountain landscapes (Swanson, 1981; Wells, 1987; Parrett, 1988; Benda and Dunne, 1997; McNabb and Swanson, 1990; Meyer and others, 1995; Meyer and Wells, 1997; Cannon and others, 1998; Cannon and Reneau, 2000). Greatly increased surface runoff and decreased slope stability after severe fires often produce floods, debris flows, and massive sediment transport. In recent years, a number of "catastrophic" fires have burned through conifer forests of the Western

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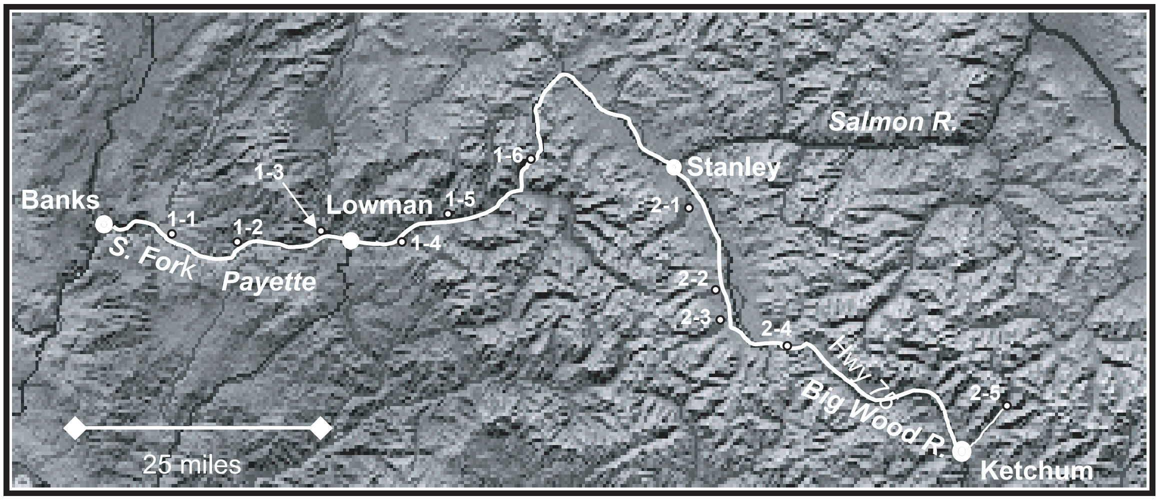

Figure 2. Approximate locations of field-trip stops. Stops on the first day of the trip along the South Fork Payette River focus on fire-related deposits in alluvial-fan stratigraphy, and include Stop 1-1 (Garden Valley fault), 1-2 (Hopkins Creek), 1-3 (Deadwood River), 1-4 (Jughead creek), and 1-5 (Helende Campground). The second day of the trip examines evidence of late Pleistocene alpine glaciation in the southeastern Sawtooth Mountains at Redfish Lake (2-1), Petit Lake (2-2) Lost Boots marsh (2-3), Galena Summit (2-4), and concludes with a study of moraine characteristics along Trail Creek (2-5) outside of Ketchum, Idaho.

United States, promoting concerns about soil erosion, accelerated sedimentation and other impacts to aquatic ecosystems, and hazards to human development. In 2002, wildfires burned over 7 million acres across the United States (National Interagency Fire Center, 2003), from the moist fir and hemlock forests of the Pacific Northwest, to the dry ponderosa pine forests of Arizona and New Mexico.

Fire data for the past 30 years reveal that although the annual acreage burned has not increased, the total number of large, severe fires has increased, and three of the largest fires ever recorded in the United States have occurred in the last 12 years (National Interagency Fire Center, 2003). In many ponderosa pine (*Pinus ponderosa)* forests in the Western United States, fire suppression, logging, and grazing are thought to have caused unprecedented increases in tree densities in post-settlement times (Cooper, 1960; Swetnam and Baisan, 1996; Covington and Moore, 1994; Arno and others, 1995; Fule and others, 1997). The resulting buildup of fuels due to fire suppression, and decrease in the availability of fine fuels for frequent surface fires due to grazing may account for the increase in fire size and severity (Swetnam, 1993; Covington and Moore, 1994; Grissino-Mayer and Swetnam, 2000; Kipfmueller and Baker, 2000), and a corresponding apparent increase in fire-related erosional events. Likewise, in central Idaho, tree-ring records show that although fire frequency decreased significantly within the 1900s, fire severity and magnitude increased in ponderosa pine and Douglas-fir *(Pseudotsuga menziesii)* forests late in the century (Steele and others, 1986; Barrett, 1988; Barrett and others, 1997).

In many ponderosa pine forests, recent stand-replacing fires contrast with frequent, low-intensity fires during presettlement times, as shown by tree-ring fire-scar studies. Climate is a primary control on fire regimes, however, and using the prefire suppression record to define reference conditions and management goals for the warmer and drier present may not be justifiable. The tree-ring fire-scar records begin during the Little Ice Age (LIA), a time of widespread minor glacial advances and generally cooler climate ca. 1200-1900 AD (*e.g.*, Grove, 1988; Luckman, 2000; Grove, 2001; Esper and others, 2002). Following the LIA, marked warming occurred in the late 1800s–early 1900s and the late 20th century (Jones and others, 1999; Mann and others, 1999). Geothermal data from boreholes provide a record of past fluctuations in surface temperatures. Temperature reconstructions from these data show a 1° C increase in temperature over the last 5 centuries, with half of that increase occurring during the last century (Pollack and others, 1998). Therefore, at least some of the observed increase in magnitude and severity of fires may be the result of a warming climate and severe droughts.

With the exception of data reported by Meyer and others (1995), little is known about changes in fire regimes and rates of slope erosion, how those changes relate to climate, and whether or not recent catastrophic fires truly are extraordinary in Holocene times. Fires and fire-related floods and debris flows are recorded in alluvial fans as burned soil surfaces and charcoal-rich deposits. Although alluvial-fan deposition is discontinuous in both space and time, fan deposits provide records of events in specific small basins, contain datable materials and, unlike lakes, are ubiquitous in mountain landscapes. The episodic nature of deposition on alluvial fans can be offset by compiling the records from tens to hundreds of individual stratigraphic sections, yielding a detailed history for the region.

On this trip, we will view the effects of recent large debris-flow and flood events in the South Fork Payette River region, in both burned and unburned mountain drainage basins. Depositional and erosional features yield evidence of flow processes and geomorphic controls. Deposits also provide analogs to aid in interpretation of Holocene fan stratigraphy. We will examine a number of the dated alluvial-fan stratigraphic sections that are being used to develop a detailed record of fire-related sedimentation events in the South Fork Payette region and to estimate long-term sediment yields at selected locations. We also will consider how changes in the magnitude and frequency of fire-related sedimentation may relate to regional climate change. Insights are gained through comparison and contrast of the Payette record with similar data from the cooler, high-elevation lodgepole-pine forests of Yellowstone National Park (Meyer and others, 1995).

Study Area

The Idaho batholith

The Idaho batholith covers approximately 41,000 km^2 in central Idaho and western Montana (fig. 1) and is part of a chain of large intrusive bodies that extend inland along western North America (Hyndman, 1983; Clayton and Megahan, 1986). Limited dating using K-Ar and Rb-Sr methods indicates that the large southern Atlanta lobe of the batholith was intruded between about 95 and 65 Ma (Armstrong, 1974; Kiilsgaard and others, 2001). The batholith in the South Fork Payette study area is composed mainly of biotite granodiorite and muscovite-biotite granite (McCarthy and Kiilsgaard, 2001). Fission-track data suggest the Atlanta lobe of the batholith lay at a shallow depth and was relatively unaffected by tectonism during most the Cenozoic, despite active Basin and Range extension around its margins, and was then unroofed by rapid denudation over the last 10 Ma (Sweetkind and Blackwell, 1989). The batholith is intruded by Eocene stocks and batholiths ranging in composition from gabbro to younger granite that likely are related to the Eocene Challis Volcanics (Kiilsgaard and others, 2001). Shallow emplacement and rapid cooling of these Eocene plutons caused widespread (>10,000 km^2) meteoric-hydrothermal alteration of the batholith granitic rock (Criss and Taylor, 1983). Tertiary rhyolitic to andesitic dikes ranging in width from a few centimeters up to approximately 100 m cross cut all plutonic rocks and generally are more resistant than the weathered batholith granite. The majority of these dikes strike northeast, likely associated with the northeast-trending pattern of regional faults in the central Idaho area (Kiilsgaard and others, 2001).

The batholith granitic rock in the Payette River region is highly weathered and altered, and surface and road-cut exposures show decomposed granite to depths of over 10 m. Drill cores from the Arrowrock Reservoir site on the Middle Fork Boise River reveal biotite oxidation and feldspar hydrolysis to depths of over 600 m (J.L. Clayton, 2003, written commun.). The present suite of hot springs along the South Fork Payette River, however, represents nonmagmatic, fracture-controlled hydrothermal systems (Druschel and Rosenberg, 2001).

A belt of north-south trending, late-Cenozoic normal faults runs along the west side of the Idaho batholith (Hamilton, 1962). The east-facing escarpments and west-dipping footwall blocks of these faults contrast with predominantly west-facing escarpments and east-dipping footwall blocks of faults east of the batholith (Wood and Clemens, 2002). The Boise Ridge fault forms a prominent east-facing escarpment across the lower South Fork Payette valley.

Geomorphology

The South Fork Payette River canyon is deeply incised within a lower-relief upland and features steep slopes (20–40°) and high local relief (~500 m) (figs. 2 and 3). Broad trough valleys with floors mantled by till and outwash deposits characterize the glaciated headwaters (Stanford, 1982). Below the last-glacial terminal position near Grandjean, the valley floor has a generally narrower but variable width. Fluvial-terrace surfaces with tread-surface heights between 1 and 20 m above current bankfull level are common except within the canyon between Lowman and Gallagher Creek, and fluvial gravels locally exist as high as 185 m above the current channel. Bedrock strath surfaces predominate in constrained reaches of more resistant bedrock, whereas in broader segments bordered by floodplain or fluvial terraces, small valley-side alluvial fans store some of the sediment produced from tributary basins. Granular disintegration of weathered Idaho batholith granitic rocks has produced abundant grussy colluvium on unglaciated slopes along the canyon. Soils on hillslopes in the South Fork Payette area are coarse textured and typically have A and oxidized C horizons underlain by weathered granitic bedrock (Clayton, 1979). Soils on hillsides are poorly developed due to high erosion rates and lack significant accumulations of clay and other fine-grained material (Clayton, 1979); however, fines are locally abundant in areas of strongly altered bedrock.

Between Lowman and the Gallagher Creek area, the South Fork Payette River enters a higher gradient canyon, with steep valley walls and few preserved terrace surfaces. Below Gallagher Creek, the valley is characterized by high bedrock strath terrace surfaces about 20 m, 15 m, and 10 m above the incised modern channel. At Garden Valley, abrupt widening of the valley floor to about 2 km likely is related to late Cenozoic movement on the Boise Ridge fault (Wood, 2004).

Climate and Vegetation

Pacific-derived moisture from winter cyclonic storms accounts for most of the annual precipitation, whereas occasional localized convective storms occur during summer months. Annual rainfall data show that between 1896 and 2002, 39 percent of mean-annual precipitation in the study area occurred between November and February, while only 13 percent of the mean-annual precipitation fell between June

Figure 3. Looking west along South Fork Payette River, note steep valley slopes within the canyon, with higher elevations in the distance typified by more moderate relief. The mixed ponderosa pine and Douglas-fir forests on the north-facing slopes versus the sparsely forested rangeland on south-facing slopes reflect the strong aspect control on vegetation in this area.

and August. At Lowman, the mean annual temperature is –5° C, and about 60 percent of the total precipitation comes as snowfall. Mean-annual precipitation in the study area varies from approximately 60 cm at lower elevations to approximately 80–100 cm or more at higher elevations. Snowmelt produces a majority of the runoff, but rapid thaws and large storms sometimes generate major winter floods (Meyer and others, 2001). A pronounced summer dry period is conducive to frequent fires, especially at lower elevations.

The South Fork Payette study area includes several different climatic and ecologic zones determined largely by elevation and aspect. On south-facing slopes in the lower basin (below ~900 m), the valley vegetation is typified by shrubs, grasses, forbs, and sparse ponderosa pines. At elevations between 900–1,400 m, open ponderosa pine forests cover south-facing slopes and mixed pine, and Douglas-fir forests are found on north-facing and wetter sites. Higher elevations above about 2,200 m are typified by ponderosa pine and Douglas-fir forests on south-facing slopes and mixed spruce, Douglas-fir and pine forests on north-facing slopes (fig. 3). Palmer Drought Severity Index (PDSI) calculated for the study area (climate region 4) shows that drought severity has increased over the period of instrumental record (statistically significant at the 95 percent confidence interval) between 1895 and 2002, with extended periods of drought from 1928–1937, 1987–1995, and 1999–2003. During the same period, mean summer temperature (June–August) in Idaho climate division 4 increased by approximately 0.3° C (fig. 4). The periods 1901–1925 and 1951–1975 were generally wetter periods with cooler summers, and relatively small areas burned in the Boise National Forest (~140 and 170 km^2, respectively). In contrast, 1926–1950 and 1976–1996 are periods when large areas burned (~1,270 and 1,650 km^2) and include prolonged droughts with generally warmer summers.

Recent Fires, Storms, and Erosional Events

From July 15–27, 1989, lightning ignited 335 fires in the Boise and Payette National Forests. The Lowman fire ultimately burned over 186 km^2 of ponderosa pine and Douglas-fir forest until it was put out by cooler temperatures and higher humidity in the early fall of 1989. Eight years later, between December 20, 1996, and January 4, 1997, the South Fork Payette basin received approximately 11 inches of rain on melting snow. This event caused widespread flooding and culminated in numerous slope failures in colluvial hollows on New Year’s Day (Meyer and others, 2001).

A previous study documenting the colluvial failures resulting from the 1997 storm in the South Fork Payette area showed that of the 246 failures inventoried, approximately 75 percent occurred in areas burned in 1989, and about 25 percent occurred on unburned but unforested south-facing slopes (Shaub, 2001). The majority of the colluvial failures (92 percent) occurred below 1,588-m elevation, which may indicate a threshold for frozen ground at the time of this event (Shaub, 2001). These colluvial failures led to sediment-charged sheetfloods and debris flows in tributary channels of the South Fork Payette, incision of tributary fans, and damage to roads and buildings.

Fire-Related Geomorphic Processes

Fire promotes sedimentation events such as debris flows and floods via two distinct sets of processes (Meyer and Pierce, 2003). Saturation-induced failures result when infiltration of heavy rainfall, snowmelt, or rainfall on areas with high-saturation antecedent conditions cause failure of colluvium. Fire increases the likelihood of failure because of diminished root strength after decay. The difficulty of measuring root cohesion and its importance relative to other factors in slope stability (*e.g.*, Schmidt and others, 2001) makes it difficult to positively identify fire as the primary cause of failure. Reduced infiltration, typically caused by post-fire water repellency and(or) surface-sealing of soils (Robichaud, 2000), provides an additional mechanism for generating major sedimentation events following fire. Greatly increased overland flow picks up abundant sediment through sheetwash, rilling, and gully erosion, such that sediment-charged flows ranging from flash floods to debris flows are produced through progressive sediment bulking (Meyer and Wells, 1997; Cannon and others, 2003). Post-fire surface runoff typically is generated by high-intensity precipitation, as in summer convective storms, and can readily erode the cohesionless grussy colluvium of the Idaho batholith (Megahan and Molitor, 1975).

Sedimentation on Alluvial Fans

The range of possible depositional processes on alluvial fans includes debris flow, hyperconcentrated flow, sheetflood, and streamflow. Deposit facies produced by these flow types have been recognized and defined by previous studies based on their sedimentology and morphology. Debris flows are non-Newtonian fluids with high sediment concentrations, where the water and fine sediment move together in a single fluid slurry. Characteristic features of debris-flow deposits include very poor sorting, marginal levees, a lack of internal stratification and a fine-grained matrix between clasts. The matrix may flow out on deposition, or may have later been washed out of the deposit (Pierson and Costa, 1987; Costa, 1984, 1988; Blair and McPherson, 1994; Meyer and Wells, 1997). Noncohesive debris flows contain low percentages of silt and clay. This lack of fines can reflect the character of available sediment in the basin and is a common characteristic of the grussy, generally clay-poor regolith in the South Fork Payette region. Hyperconcentrated flows also are non-Newtonian flows that are transitional between Newtonian water flow (streamflow of Pierson and Costa, 1987) and debris flows. Hyperconcentrated flows have a measurable but low yield strength from particle interactions, and turbulence is damped relative to water flows (Pierson and Costa, 1987). Poorly sorted deposits that are unstratified or weakly stratified with internal grading patterns and a sand and pebble-dominated texture often characterize hyperconcentrated flows deposits in the South Fork Payette region. Streamflows are Newtonian highly turbulent flows with sediment concentrations that are too low to produce a yield strength and leave stratified deposits (Pierson and Costa, 1987). Sheetfloods are unconfined streamflows that spread over fan surfaces (Blair and McPherson, 1994; Meyer and Wells, 1997). Sheetflood deposits typically contain well-developed, graded surface-

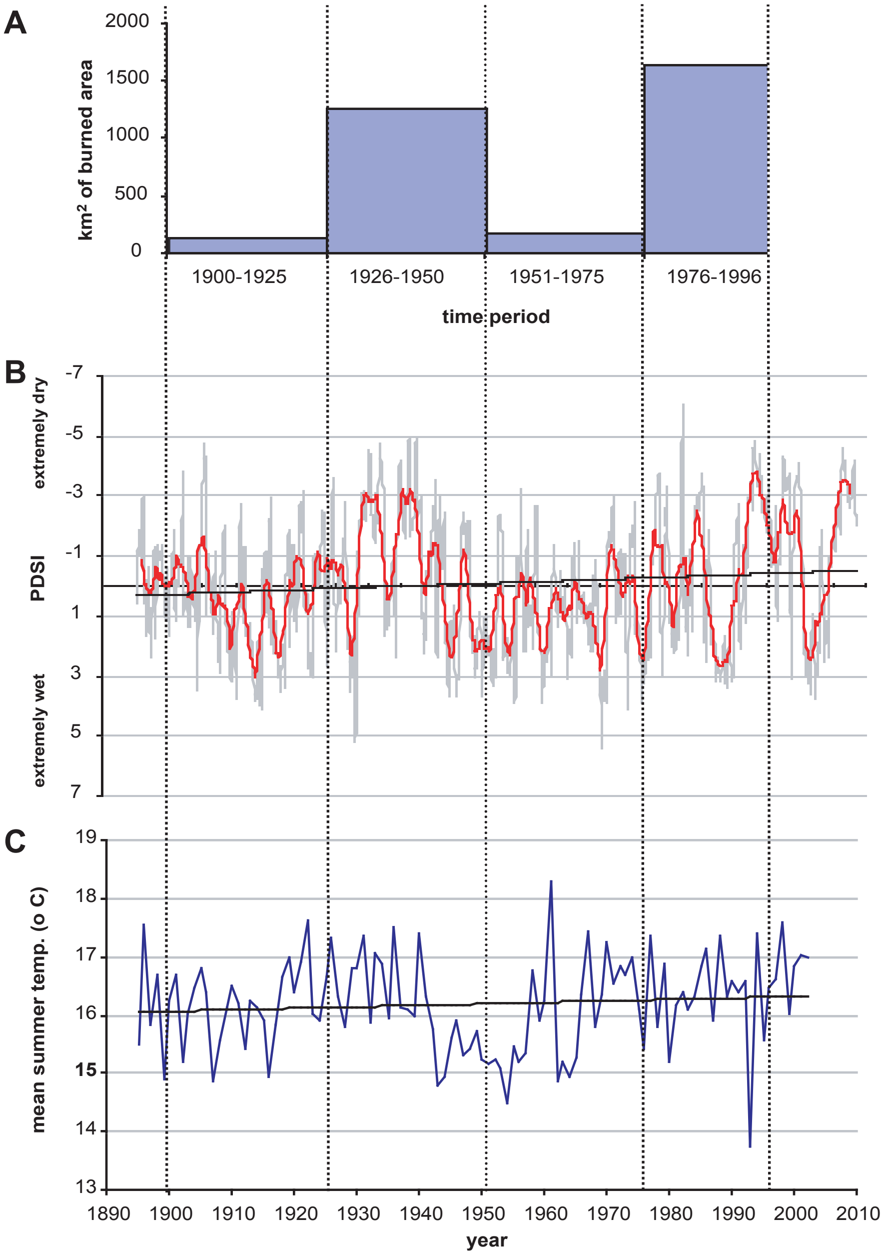

Figure 4. (A) Approximate number of square kilometers of area burned in the Boise National Forest between 1900–1997 (Strom and others, 1998) is shown as a bar graph. (B) Palmer Drought Severity Index (PDSI; top graph) for Idaho division 4, where the light gray lines show monthly PDSI values; and the black line shows a 20-month moving average of PDSI values. (C) Idaho division 4 mean summer (June–August) temperature from 1895–2003. Trendlines show increase in mean summer temperatures (~0.3° C) and a decrease in PDSI (~0.8 units) over the 20th century.

parallel stratification, and are better sorted than debris flows or hyperconcentrated flow deposits. Streamflows confined within fan channels often generate coarse, imbricated deposits. Streamflow and sheetflood deposits are relatively well sorted and clast supported with features such as sorting and clast imbrication indicating suspension- and traction-transport processes.

Methods

We described alluvial-fan stratigraphy and sampled charcoal for ^{14}C dating from sites in the South Fork Payette and North Fork Boise River basins of central Idaho. Field examination of deposit sedimentary structures, sorting, clast size and content, proportions of sand, silt, and clay in the fine (<2 mm) fraction of the deposit, boundary characteristics, color, and the presence of buried soils were used to determine variations in deposit characteristics. Fire-related deposits were distinguished based on the presence of abundant angular charcoal fragments or dark mottles of charcoal or charred material. Buried burned-soil surfaces are characterized by discrete, laterally extensive layers approximately 0.5–5-cm thick, composed predominantly of fine charred organic material representing the forest litter layer. In the South Fork Payette area, these incipient buried soils usually do not display distinct soil development other than a thin, weak A horizon (sometimes with silt enrichment) underlying the charred organic layer. If the burned surface is not disturbed by bioturbation and erosion before deposition of overlying sediment, this indicates that the depositional event occurred soon after a fire, and thus is likely related to fire.

Individual units within alluvial fan stratigraphic sections also were differentiated by deposit characteristics and thickness. Debris-flow units with abundant coarse angular charcoal that generally are coarser grained than other units in a stratigraphic section and comprise at least 20 percent of the thickness of the section are classified as “major events.” These deposits most likely represent high-severity burns. Deposits that are clearly related to fire, but do not meet the above criteria are classified as “small events.”

Dating Methods

Charcoal samples were radiocarbon dated at the NSF-Arizona Laboratory using accelerator mass spectrometry (AMS). To avoid dating samples of inner heartwood and bark from older trees that have “inbuilt” ages significantly older than the fires that burned them (Gavin, 2001), small twigs,

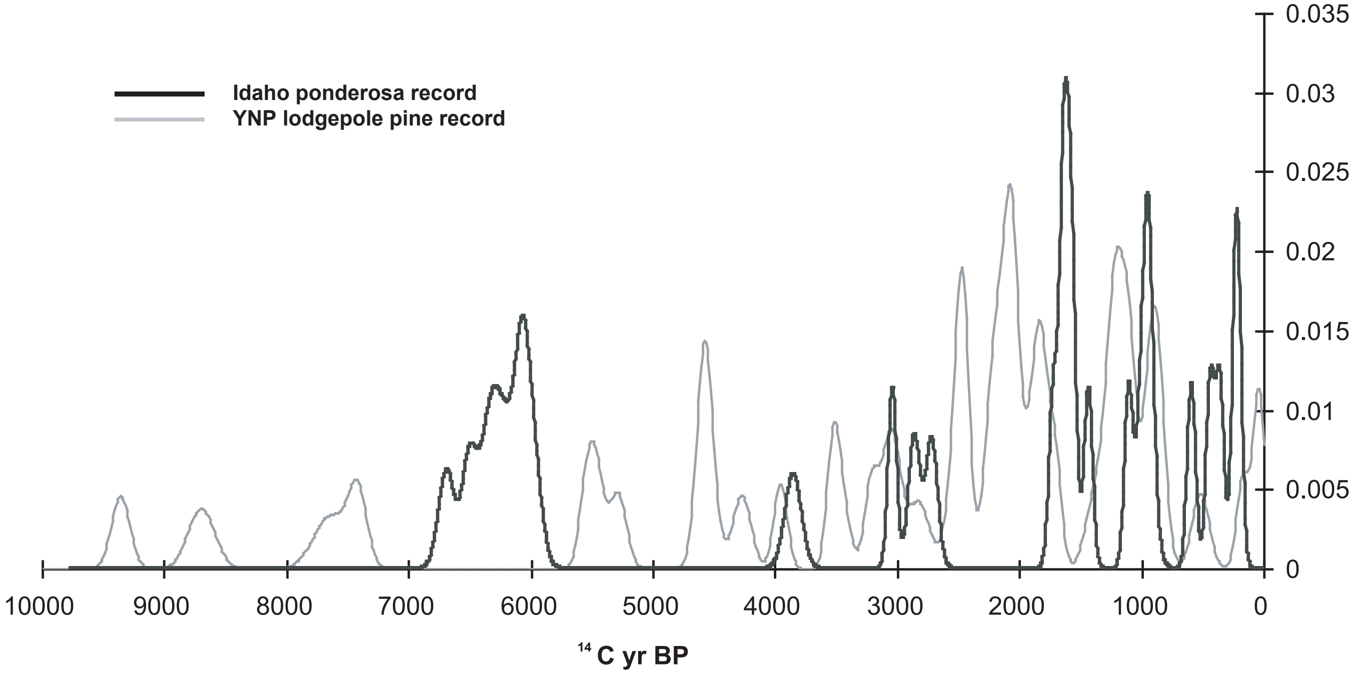

Figure 5. Probability distributions of 26 individual radiocarbon ages and their analytical uncertainty for alluvial-fan sites from the South Fork Payette Idaho study area (black line). Yellowstone (YNP) data (gray line) are from Meyer and others (1995). Preliminary data in the Idaho ponderosa record show peaks during the “Little Ice Age” (LIA) between about 750–50 cal yr BP when fire-related sedimentation in YNP is at a minimum. Both records show the probability of fire-related events at one maximum centered about 1,000 ^{14}C yr BP, which corresponds with Medieval Climatic Anomaly (MCA) between about 750–1,050 cal yr BP. Most of the fire-related events in the Idaho study area that occurred during the MCA were major fire-related debris-flow events (criteria described in text), while the LIA is characterized by frequent but minor fire-related sedimentation events in Idaho.

cone fragments, needles, and seeds were selected where possible. Individual charcoal fragments were selected for dating to avoid mixing of charcoal ages; rootlets were removed manually and acid and base washes were used to remove soluble organic contaminants. Identification of charcoal macrofossils was used when possible to determine the type of vegetation burned, and to aid in paleoclimatic interpretation.

Inverted dates (those with ages significantly older than underlying age(s) in a sequence) can be caused by bioturbation, deep burning of roots, reworking of older charcoal from existing soils or deposits, or large inbuilt ages. Analysis of radiocarbon dates within their stratigraphic context and careful selection and handling of samples limits error from these sources. For multiple ages obtained within the same deposit, the youngest age was assumed to have the least inbuilt age and to be the most accurate. Radiocarbon ages (^{14}C yr BP) were calibrated to calendar years (cal yr BP) using the program CALIB 4.3 (*e.g.*, Stuiver and Reimer, 1993).

Preliminary Results and Interpretation

Figure 5 summarizes preliminary sample results from ten dated alluvial fan sections. These results show several periods of frequent fire-related sedimentation in the South Fork Payette area at ca. 200–600 cal yr BP, 900–1,000 cal yr BP, 1,300–1,600 cal yr BP, 2,800–3,100 cal yr BP, and 6,600–7,400 cal yr BP. The majority of these events produced relatively minor sheetflood and small debris-flow deposits, consistent with the limited erosional response typical of low- to mixed-severity fires (Lavee and others, 1995). The relatively frequent fire-related events 200–600 cal yr BP occurred during the Little Ice Age in the South Fork Payette region. This and most of the other peak periods of fire-related sedimentation frequency in Idaho correspond to times of relatively few fire-related sedimentation events in Yellowstone National Park (fig. 5). Minima in fire-related sedimentation in the high-elevation Yellowstone forests occur during relatively cool, wet periods, when fire spread is inhibited by fuel moisture (Meyer and others, 1995). In the more xeric Idaho study area, these may be times when effectively wetter conditions allow abundant grass growth, fueling frequent low-severity fires during the typical summer drought.

Evidence of large, fire-related debris flows ca. 900 cal yr BP is found at site LO10 (Stop 4), and at the higher elevation GJ2 site (Stop 6). A ca. 900 cal yr BP forest fire also was dated at the Deadwood River archeological site (Stop 3) (Reid, 2001). These events occurred during the so called “Medieval Warm Period”, or Medieval Climatic Anomaly 1,050–750 cal yr BP, a time of locally warmer temperatures and(or) episodes of severe drought in some regions (Bradley and others, 2003). Widespread and severe multi-decadal droughts occurred in the Western United States between 1,050–750 cal yr BP (Stine, 1994; Woodhouse and Overpeck, 1998; Benson and others, 2002). This also was a time of major fire-related debris-flow activity in Yellowstone (Meyer and others, 1995) (fig. 5) and of increased fire activity in a variety of northwestern United States conifer forests (Whitlock and others, 2003). These data suggest that in Idaho ponderosa forests, occasional large, stand-replacing fires may be typical during warmer and drier times.

Additional dating of fire-related sedimentation in the Payette River area is pending, and results will be presented on the field trip. We will use these data to test the hypotheses of relations between climate, fire, and sedimentation presented above. This understanding will allow better predictions of the impact of probable future climate warming on fire regimes in ponderosa pine forests.

Acknowledgments

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Figure 6. Large boulders and matrix material from Staircase rapids debris flow, September 2001. Debris from channel on north side of South Fork Payette crossed road (note cars on left side of photo) and flowed into main stem Payette River out of photo to right (photo credit: Spencer Wood, Boise State University).

ROAD LOG—DAY 1

Mileage		
Cum.	Inc.	
		Depart from Boise, Idaho, and take State Highway 55 approximately 45 miles to the town of Banks, Idaho.
0.0	0.0	(lat 44°05'9"N., long 116°06'53"W.) Town of Banks. Turn right onto the Banks-Lowman Road and reset your odometer.
0.7	0.7	(lat 44°05'0"N., long 116°06'7"W.) 1997 debris flows from tributaries on the north side of the South Fork Payette raised local base levels in this area, drowning trees upstream of "Slalom Rapids," and significantly changing main-stem channel morphology. Stratigraphy of the small tributary junction alluvial fan exposed by the 1997 event shows a series of Holocene sheetflood and fire-related debris-flow deposits.
2.8	2.1	(lat 44°06'6"N., long 116°04'46"W.) "Staircase Rapids" debris flow. Debris flows from the tributary on the north side of the South Fork Payette blocked the road and partially dammed the mainstem river in September 2001 and again in May 2002 (fig. 6). Large boulders (>2 m) from this event have significantly altered channel habitat (and kayaking runs) in this reach, and provide another example of how tributary debris-flow events exert longer-term effects on mainstem channel morphology. Conversely, other recent debris flows from tributary drainages on the South Fork Payette (Jughead creek, Hopkins Creek) have provided significant (>15,000 m^3) amounts of sediment to mainstem channels (Meyer and others, 2001), but have limited effect on local channel morphology because they lack boulder-sized clasts.
10.1	7.3	(lat 44°05'53"N., long 115°57'48"W.) Pull into the parking lot of the Garden Valley St. Jules Catholic Church on north side of road and park. View of the Boise Ridge fault across Garden Valley to the southwest.

Stop 1-1. Garden Valley: Late Cenozoic Faulting on the Boise Ridge Fault, Idaho

By Spencer Wood

From the settlement of Banks, the highway parallels a steep reach of the South Fork Payette River with many rapids. The river is confined to a deep granite gorge for 6 mi and then breaks out into the expansive Garden Valley with low hills and alluvial flats. This dramatic change in scenery is a result of late Cenozoic movement on the Boise Ridge fault. The Quaternary geology and geomorphology of this valley and the fault deserve a detailed study. The rich placer gold deposits of Boise Basin to the south and the proximity of a seemingly active fault near urban Boise are topics that invite further investigation. What follows is a summary of related earlier work and some casual roadside observations.

The Boise Ridge fault is a down-to-east, normal fault, north-striking (006º), 900-m-high physiographic escarpment (figs. 7 and 8). The escarpment can be traced for a distance of 45 km. At the southern end, near the North Fork of Robie Creek, the fault appears to terminate against the Kelly Gulch fault (fig. 9). The surface traces become indistinct and are lost in an area of dense timber, brush cover, and thick grus (Kiilsgaard and others, 1997). The northern end has not been mapped, but appears he Boise Ridge fault is one of several north-south trending faults that occur in a belt along the west side of the Idaho batholith (Hamilton, 1962). These faults typi-

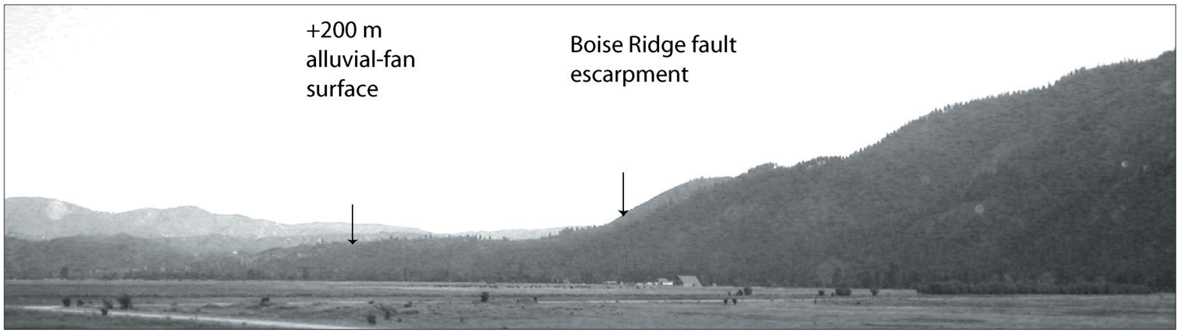

Figure 7. The Boise Ridge fault escarpment and the 1,130-m (3,700-ft) elevation alluvial-fan surface. The fan surface is 200 m above the alluvial flats of Garden Valley. Top of the ridge on the upthrown block of the fault is at 1,980-m (6,500-ft) elevation. View is to the south from the highway at Garden Valley.

Figure 8. Faceted spurs along the southwest side of Garden Valley. View is to the southwest from the highway.

cally are spaced 10 to 20 km apart, and all have down-to-east displacement and west dipping fault blocks (fig. 10).

The footwall is the fault block to the west. The top of the ridge to the west is a much dissected old surface of granitic rock, pervasive over the Idaho batholith mountains, at about an elevation of 2,500 m (8,000 ft) (Anderson, 1935). Movement on the fault interrupted stream drainages and created the intermontane basin of Garden Valley and the gold placers of Boise Basin to the south. The gold-rich alluvium in Boise Basin was studied by Lindgren (1898), and although he recognized the fault origins of these basins, he did not show the fault on a map. Alfred Anderson in 1934 described geomorphic features and recognized the faceted ridges along the fault (fig. 8). In his 1947 study, he mapped the fault and discussed the offset of Columbia River Basalt and associated sediments in the basins. I quote here from his 1934 paper:

> *"Where the scarp bounds the west side of Garden Valley it is even more striking, for it involves a relief difference of from 3,000 to 3,500 feet. The faulting temporarily blocked the Payette River and caused deposition of gravels in the basin on the upstream side. But as in the case of the Deadwood fault, the river has carved a profound canyon across the tilted block range across its path."*

Kiilsgaard and others (1997) mapped the fault south of Garden Valley and document 580 m of displacement on the Columbia River Basalt of Hawley Mountain (fig. 9). On the downthrown eastern block are discontinuous patches of lacustrine and coarse fluvial sediment some of which is interbedded with basalt; however, much of the sediment clearly overlies the basalt in the Boise Basin (Forester and others, 2002). No basalt is known from the Garden Valley basin-sediment section. The sediment is deformed, and various steep dips occur near the fault. The sediment section overlying the granite probably does not exceed 100 m in thickness. On account of the association of the sediment with

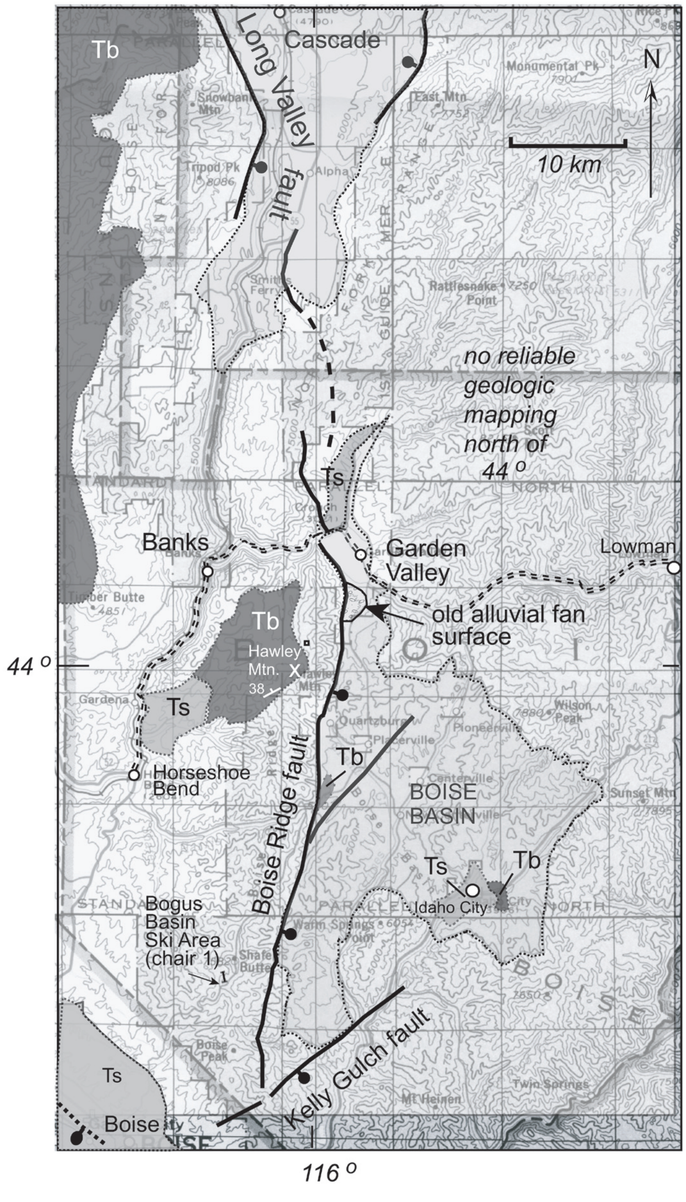

Figure 9. Geologic map of the Boise Ridge fault. The Boise Basin and Garden Valley basin areas are outlined and shaded. Tb, Columbia River Basalt and Ts, Miocene sediments of intermontane basins including what previous workers have called the Payette Formation. Most of the area is Mesozoic granitic rocks of the Idaho batholith and shallow intrusive rocks of Eocene age (partly from Kiilsgaard and others, 2001).

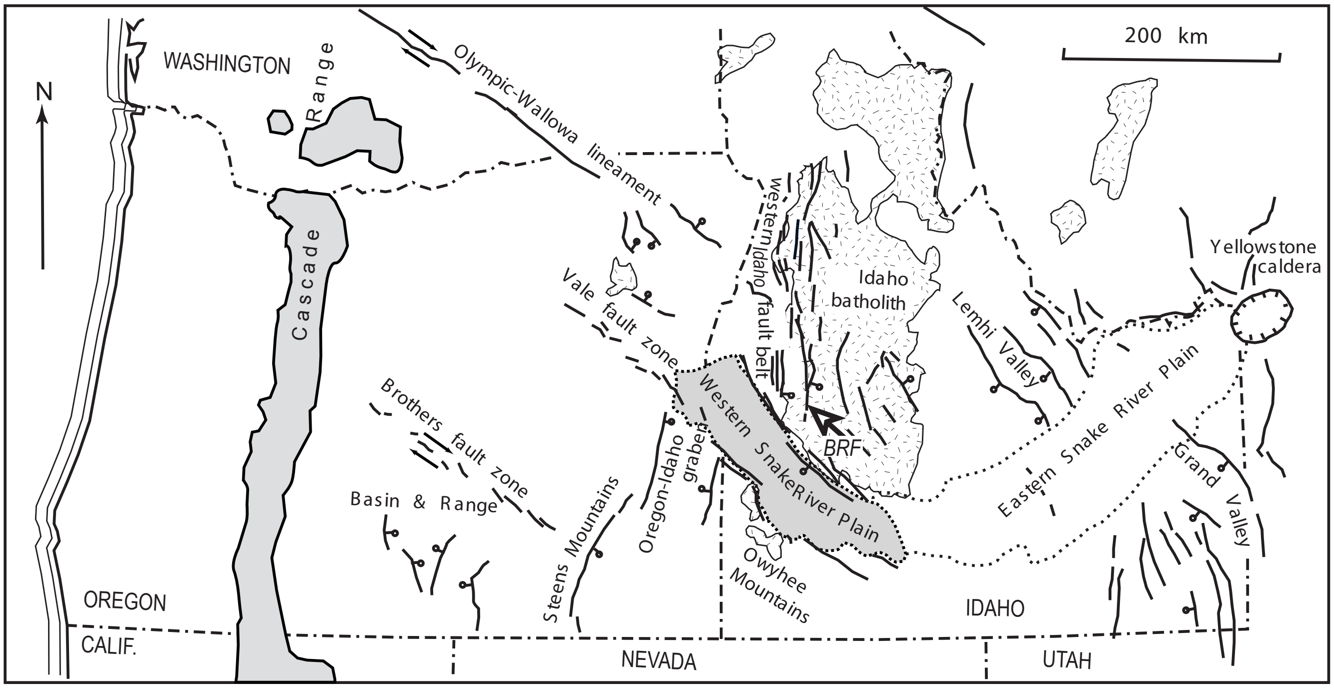

Figure 10. Location of the Boise Ridge fault (BRF) within the north-south trending western-Idaho fault belt. Late Cenozoic faults within the belt, and also the batholith mountains including the Sawtooth fault, are mostly east-facing escarpments with west-dipping footwall blocks. This contrasts with most faults east of the batholith, which have west-facing escarpments, east-dipping footwall blocks, and a more northwesterly trend (adapted from Wood and Clemens, 2002).

the Columbia River basalt in the Boise Basin, this sediment in Garden Valley has been called the Payette Formation (Fisher and others, 1992; Gibbons, 1995; Kiilsgaard and others, 1997, 2001). Kirkham (1931) originally defined the Payette Formation by its association with the basalt, but it is unlikely it was ever a continuous blanket over the area. More likely, these are just intermontane basin sediments, probably of different ages, confined to fault basins and subsequently preserved on down-dropped blocks. Miocene flora described by Smith (1941) and volcanic ash correlations by Forester and others (2002) indicate an age of 11.3 Ma for similar sediments overlying basalt in Boise Basin.

On the north side of the highway, just west of the bridge over the Middle Fork, sediments are dipping 15-20° to the southwest and are faulted by planes striking 315° and dipping 40° northeast consistent with the trend of the Boise Ridge fault.

An impressive section of alluvial-fan sediments stands as a terrace surface at the south end of the valley, west of the Alder Creek Road (fig. 9). The upper surface of the deposits is at elevation 1,130 m (3,700 ft), 180 m above the valley floor. In recent road cuts associated with the Crosstimber Ranch development, biotite-bearing granitic boulders of the deposit have disintegrated and can be cut with a spade. Weathering rinds on aphanitic basalt cobbles are 3 mm or more. Such thick rinds on basalt indicate an age of at least middle Pleistocene or older (Coleman and Pierce, 1986). This section of fan sediments appears to lap upon, and very likely is faulted against granite of the Boise Ridge block to the west. This depositional surface has been partly excavated away by the South Fork. The granite-strath surface beneath the fan deposits (which has not been mapped in detail) appears to be at elevation 975 m (3,200 ft), about 50 m above the bed of the South Fork Payette River. Clearly these deposits warrant further study if one is to understand the history of movement on the fault.

The classic faceted spurs along the fault and the steep mountain front attest to the youthful nature of the fault escarpment. Late Quaternary (the last 125,000 years) movement likely has occurred on the fault, but little is known of the slip rate. A minimum vertical slip rate is obtained by dividing the offset of Miocene basalt and sediment (14–11 Ma) by the 900 m of physiographic offset or the 600 m stratigraphic offset, giving 0.04 to 0.08 mm/yr. This minimum slip rate approaches the 0.1 mm/yr of better-documented active normal faults (dePolo and Anderson, 2000) of the Great Basin and Basin and Range.

Mileage Cum.	 Inc.	
18.5	8.4	(lat 44°02'56"N., long 115°15'18"W.) Carefully pull off along the south side of road opposite the abandoned house and buildings to the north. At Stop 2, we will examine

sheetflood deposits from the 1997 New Year's Day storm event, as well as older dated fan stratigraphy exposed along the Hopkins Creek channel. If time permits, we will walk down the fan on the south side of the road, over the 1997 deposits, to the terrace gravels, placer workings, and modern bedrock strath of the South Fork Payette.

Stop 1-2. Hopkins Creek

By Jennifer Pierce, Grant Meyer, Spencer Wood

Overview

In the January 1, 1997, storm, the 0.58 km^2 Hopkins Creek basin experienced intense rain on melting snow that triggered colluvial failures, floods, and debris flows (Meyer and others, 2001). In this unburned south-facing grassland basin, failure of 15 individual colluvial hollows and erosion of material stored in channel and alluvial-fan sediments yielded 16,100 m^3 of erosion, equivalent to about 42,000 Mg/km^2 (Meyer and others, 2001). Sheetflooding over the Hopkins Creek fan partly buried many buildings of this homestead. The elderly woman residing here at first refused to be evacuated but later was rescued by neighbors. Small tributary fans such as this one have been popular sites for ranch and summer home development throughout central Idaho, but are subject to major flood and debris-flow hazards, especially after fire. The Hopkins Creek fan extends over a 24-m-high terrace tread that is deeply buried by fan sediments. Below, an 18-m-high bedrock strath covered with 2 m of alluvial material has been disturbed by placer mining. The Hopkins Creek fan probably also buries and obscures older terraces of the South Fork Payette River in this area.

Holocene fire and sedimentation record at Hopkins Creek

The 1997 event also exposed a record of Holocene fires and sedimentation in the stratigraphy of the upper Hopkins Creek alluvial fan (fig. 11). The lower part of the exposed sequence shows an approximately 1-m-thick dark, cohesive, clast-poor deposit with dates of 1,772±43, 1,722±43, and 1,651±41 ^{14}C yr BP. A change from a more clay-rich sandy loam texture at about 170 cm, and an increase in the percentage of clasts suggests a possible depositional boundary between the 1,722±43 and 1,651±41 ^{14}C yr BP ages, but also could be indicative of a facies change within the same depositional event. An oxidized sheetflood unit with a concentration of charcoal at the base of the unit, dated at 1,100±43 ^{14}C yr BP, overlies the lower unit(s). The overlying clast-rich debris flow deposit provides a very distinct depositional change; this charcoal-poor unit is dated at 411±31 ^{14}C yr BP. This in turn is overlain by thin sheetflood deposits dated at 197±43 ^{14}C yr BP, and the 1997 sheetflood and debris flow deposits at the top of the unit.

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30.5	12	(lat 44°04'45"N., long 115°39'28"W.) Intersection with Deadwood Road. Turn left onto

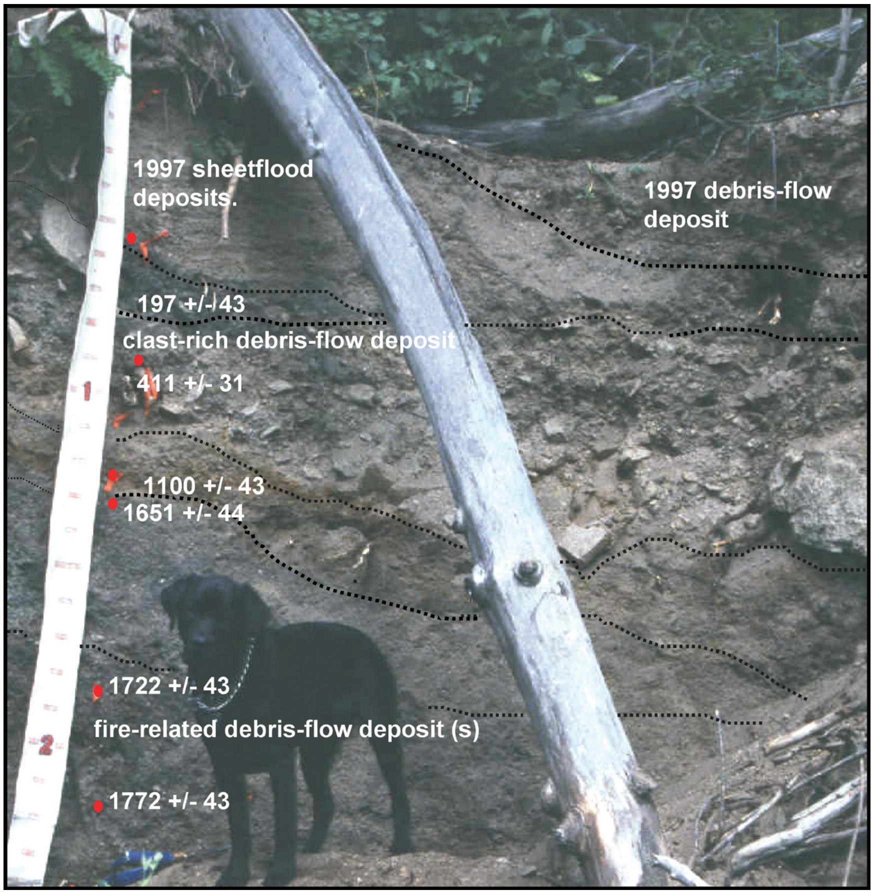

Figure 11. Alluvial-fan stratigraphy exposed at Hopkins Creek. Dates on figure are in radiocarbon years BP. Deposit characteristics are described in the text. This section generally is more charcoal poor than upvalley sections, likely due in part to the fewer trees in the basin. Charcoal macrofossils identified from this section were almost all from hardwood (riparian) species, although ponderosa pine needles were found near the base of the deposit.

Figure 12. Deadwood River with debris from August 22, 2003, storm event. Debris flows from tributary streams Slaughterhouse Creek and Slim Creek temporarily dammed the Deadwood (note mud and debris above channel on far side of Deadwood River) and trapped a family camping in the area.

the Deadwood Road and drive up gravel road approximately 2.7 km (1.7 miles) to Slaughterhouse Creek on the left (west) side of the road. Park on the side of road. Slim Creek is approximately 500 m upstream, also on the west side of the road.

Stop 1-3. Recent Debris Flows Along the Deadwood River

By Jennifer Pierce and Grant Meyer

On the afternoon of August 22, 2003, the Lowman area received approximately 1.25 inches of rain, likely more at this location. The adjacent basins of Slim Creek (6.0 km^2), Slaughterhouse Creek (~3.6 km^2), and Deadwood Jim Creek (2.0 km^2) all produced major debris-flow events, which appear to have originated at the very tops of the watersheds as rilling from overland flow on locally steep (~40°) slopes accumulated sediment and converged in tributary channels to produce debris flows (fig. 12). The debris flow temporarily dammed the Deadwood River and backed up water and debris

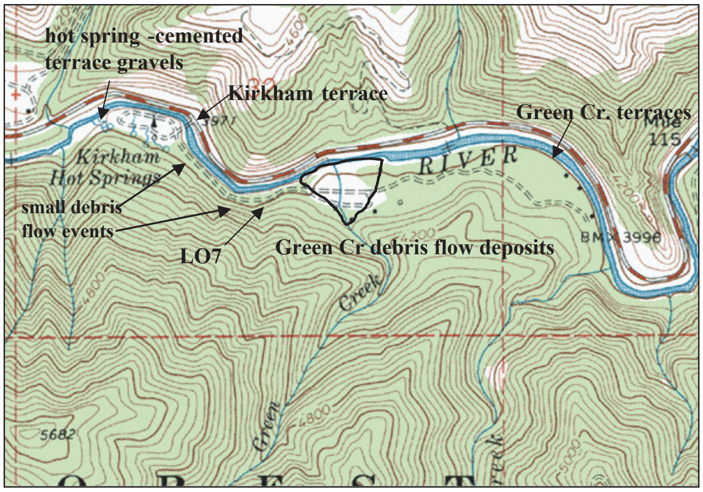

Figure 13. Map showing locations of site LO7, Green Creek, and cemented terrace gravels at Kirkham Hot Springs. Estimated area of deposition of 1997 debris flow at Green Creek is shown by triangle-shaped feature on figure.

at Slim Creek about 1.5 km upstream to Pigeon Flats (Kari Grover-Wier, August 2003, personal comm.).

Archeological sites on low terraces in Deadwood Campground area contain abundant charred ponderosa pine wood, which provides evidence for a ca. 900 cal yr BP forest fire (Reid, 2001). The timing of this event coincides with evidence of other major fire-related debris flows at a variety of elevations in the Payette area ca. 900 cal yr BP.

Mileage Cum.	Inc.	
33	2.5	Return to junction of the Deadwood Road and the Banks-Lowman Road and turn left.
36.5	3.5	(lat 44°4'57"N., long 115°36'44"W.) At intersection of Banks-Lowman road and Highway 21, turn left on to Highway 21 towards Lowman Ranger Station.
37.5	1.0	(lat 44°4'34"N., long 115°35'48"W.) Lowman Ranger Station on right. Terrace sequence below station with tread heights of about 1.5 m, 3.0 m, 6.3 m and 10.5 m above the current channel bankfull level. On the 1.5-m terrace are large (meter-scale) subangular boulders in a cigar-shaped bar deposit, which could either have been deposited during a major flood on the main stem Payette or could be deposits from a major debris-flow event originating from the tributary (LO25) on the opposite side of the river from the terrace. Alluvial-fan site LO25 contains a series of fire-related sheetflood and debris-flow deposits with dates on selected units of 3,479±30, 2,796±44 and 2,072±36 ^{14}C yr BP. The highway is on the 10.5-m terrace tread, with an approximately 25-degree slope up to the 20-m terrace (USFS residential area).
39.5	2.0	(lat 44°4'26"N., long 115°33'44"W.) We now are driving through the area that was extensively burned in the 1989 Lowman fire. Terraces on south side of river, across from "Burnt Pines" store, have terrace-tread heights of 5.3 m, 8.2 m, 13.5 m, and 16.5 m. Variable bedrock strath heights of 4.5–5.5 m are present in this reach, upstream past Kirkham Campground. In this study, bedrock strath terraces are differentiated from other terraces by either exhumed bare bedrock strath, or bedrock strath covered by less than 2 m of gravel and cobble fill.
40.5	1.0	(lat 44°4'23"N., long 115°32'42"W.) Kirkham Hot Springs on south side of river. Cobble- and boulder-rich alluvial fill terraces above the hot springs are partially cemented by hot-spring deposits (fig. 13).
41.5	1.0	(lat 44°4'21"N., long 115°31'38"W.) During the 1996-1997 storm event, failures of colluvial hollows produced debris flows in the Green Creek and nearby small steep tributary drainages of the South Fork Payette (fig. 13). Debris-flow deposits of grussy material from a large debris flow in Green Creek itself extend onto the 18- and 10-m terraces, filling the road with sediment, and transporting a large water tank. The Green Creek fan progrades out onto

Figure 14. Alluvial-fan stratigraphy at site LO7. Dashed lines show depositional breaks. Ages are in radiocarbon years BP, shovel for scale, approximate depth of section is 3 m.

a series of gravel and cobble-rich fill (?) or fill-cut (?) terraces.

At site LO7 (fig. 13), Holocene alluvial-fan deposits are exposed by incision of the fan during the 1997 events. The LO7 fan contains a series of multiple debris-flow deposits, most of which date between about 2,700–2,900 ^{14}C yr BP, with the exception of the lowest date of about 6,050 ^{14}C yr BP (fig. 14). The 2,911±99 and the approximately 6,049±55 ^{14}C yr BP events are considered 'major events' based on criteria previously described. The upper unit(s) contain multiple layers of charcoal concentrations that form prominent dark layers in the stratigraphy. These may represent lower energy deposits between pulses of a single event (note lower date of 2,788±57 ^{14}C yr BP).

45.5 4.0 (lat 44°4'24"N., long 115°30'41"W.) East of Archie Creek Road, (near milepost marker 79), turn right into the informal campsite area and park. At this site, we will examine deposits from the 1997 event at Jughead creek and discuss how estimated sediment yields from this event and the event at Hopkins Creek compare with other estimates of sediment yields in this area. We also will examine early Holocene alluvial-fan stratigraphy exposed in perched fan of Jughead creek and the alluvial-fan stratigraphy at site LO10 on the north side of the highway.

Stop 1-4. Jughead Creek and Site LO10: Recent Debris-Flow Events and Holocene Alluvial-Fan Stratigraphy

By Jennifer Pierce, Grant Meyer, and Spencer Wood

During the New Year's Day 1997 storm, a massive slab of colluvium slid from a broad hollow in the Jughead creek basin, (fig. 15), which was burned in the 1989 Lowman fire. A rather boulder-poor debris flow resulted, with maximum velocity at the basin mouth estimated at between 12 and 25 m/s (Meyer and others, 2001). This extremely rapid debris flow crossed the Payette River, and despite strongly divergent flow, climbed terraces on the north side up to nearly 7 m above the river's bankfull level. Many ponderosa pines on the terraces were removed by the flow, and a few "bayonet trees" knocked partly over are still visible. The flow deposited a broad lobe of material that was ringed by logs concentrated at the flow front (Meyer and others, 2001), although woodcutters have removed some of the original logjam. The sediment yield from the Jughead creek basin (0.50 km^2) is estimated at 14,600 m^3 (Meyer and others, 2001). Erosion in Hopkins Creek (~42,000 Mg/km^2) and Jughead creek (~44,000 Mg/km^2) was similar, suggesting burned forested areas respond similarly to unburned rangelands after tree root strength in burned forested areas decreases.

Figure 15. This large colluvial failure at Jughead creek produced about 40 percent of the total eroded volume of the 1997 debris flow event (Meyer and others, 2001). Spencer Wood (circled) in bottom left for scale.

Early Holocene alluvial-fan stratigraphy, and comparisons of sediment yields at different time scales

An early Holocene alluvial-fan stratigraphic section at Jughead creek contains between 10 and 24 thin, charcoal-rich sheetflood deposits and burned soil surfaces that were formed between 7,400 and 6,600 cal yr BP (Meyer and others, 2001). The recurrence interval for the fire-related events is estimated

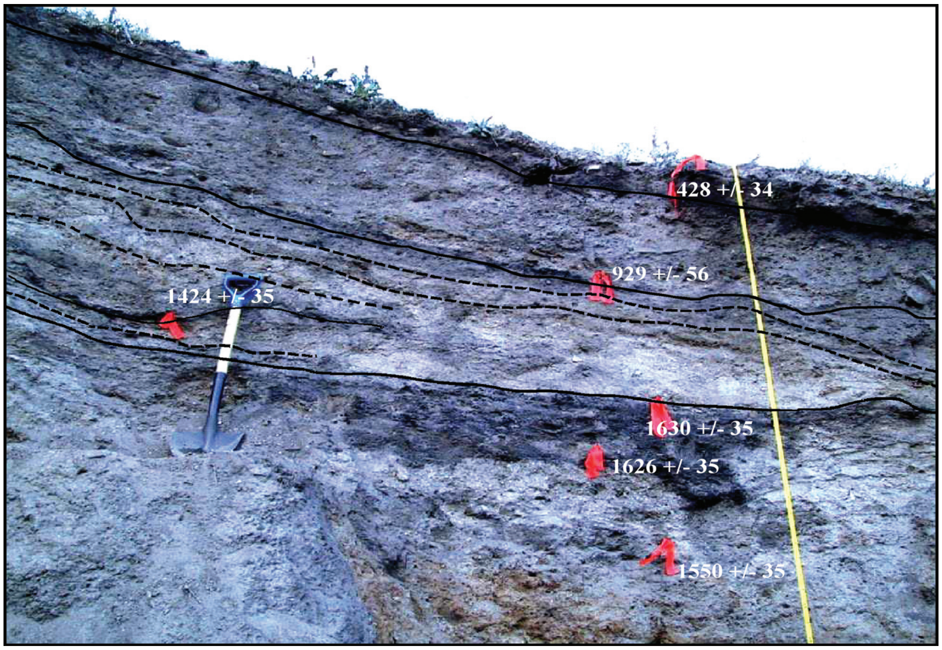

Figure 16. Incised alluvial fan at site LO10, exposing Holocene burned soil surfaces (solid lines) and deposit boundaries (dashed lines). Ages on figure are given in radiocarbon years BP. The debris-flow deposit above the burned surface dated at 929±56 ^{14}C yr BP is a single, large, debris-flow deposit; while the sequence is characterized by multiple sheetflood deposits between 1,630±35 ^{14}C yr BP and 929±56 ^{14}C yr BP. The lowest debris-flow deposit with a mottled dark appearance also is likely a single event, where the age of 1,550±35 ^{14}C yr BP represents the most accurate date (least inbuilt age) for the deposit.

to be 33–80 years, depending on how many events are interpreted as stemming from fires. Since not all fire-related events are recognizable in the stratigraphic record, and since low-severity surface fires may not produce sedimentation events, this represents a minimum recurrence interval for fires. These small fire-induced sheetfloods occurred with a much higher frequency than observed for fire-induced events at any site in Yellowstone (Meyer and others, 1995), and imply frequent, low-severity fires.

The stratigraphic section in the early Holocene fan shows a conformable sequence of roughly parallel contacts between sheetflood deposits and burned soil surfaces with no erosional breaks or inset channel deposits (Meyer and others, 2001). We assume, therefore, that this fan section accurately records the volume of sediment deposited during this time period. Assuming a typical cone-shaped fan morphology, the sediment yield during the time period between 7,400 and 6,600 cal yr BP was calculated to be approximately 16 Mg/km^2/yr (Meyer and others, 2001). This evidence of frequent, small, fire-related events is consistent with the regime of frequent, low-intensity fires thought to be characteristic of Idaho ponderosa pine forests (Steele and others, 1986). The estimated sediment yield is similar to short-term sediment-yield estimates in Idaho batholith watersheds of 2.7-30 Mg/km^2/yr (Clayton and Megahan, 1986). The sediment yields from the 1997 erosion events, however, are orders of magnitude greater than the early Holocene record, and are equivalent to several thousands of years of background sediment yield. In order to account for the 10,000-yr average Idaho batholith sediment yields of approximately 112 T/km^2/yr (Kirchner and others, 2001), events as large as the 1997 events could only occur about once every 400 years. Compared to the Holocene average, erosion rates during the 7.4- to 6.6-ka interval were unusually low, suggesting fluctuating sediment yields.

Fluvial terraces

Terrace-tread heights at the Jughead debris-flow site are approximately 3.2 m, 5.4 m, and 7.0 m above bankfull level. All terraces appear to be fill-cut terraces; no bedrock straths are seen outcropping at this location. Less than 500 m downstream, however, bedrock is exposed at bankfull, covered with 4.8 m of sandy alluvial gravels, and bedrock can be seen in the current channel in the Jughead creek area. This indicates that the current stream is close to bedrock in this reach, or that the

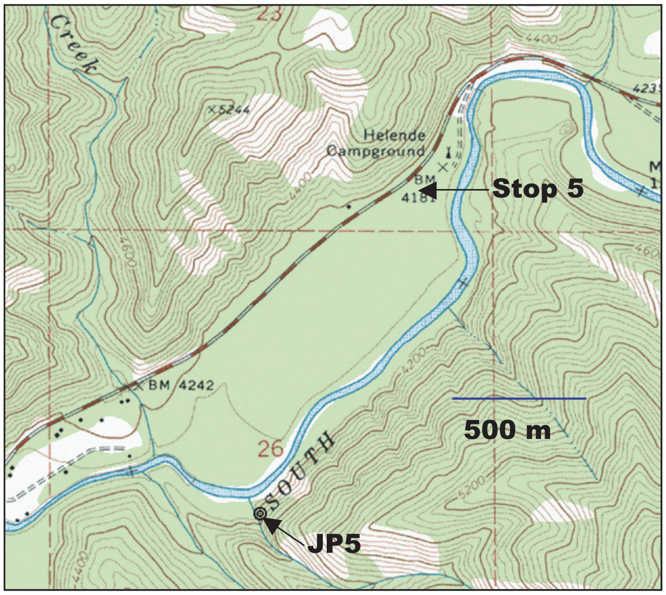

Figure 17. Location of Stop 5 at Helende Campground and the JP5 alluvial-fan site.

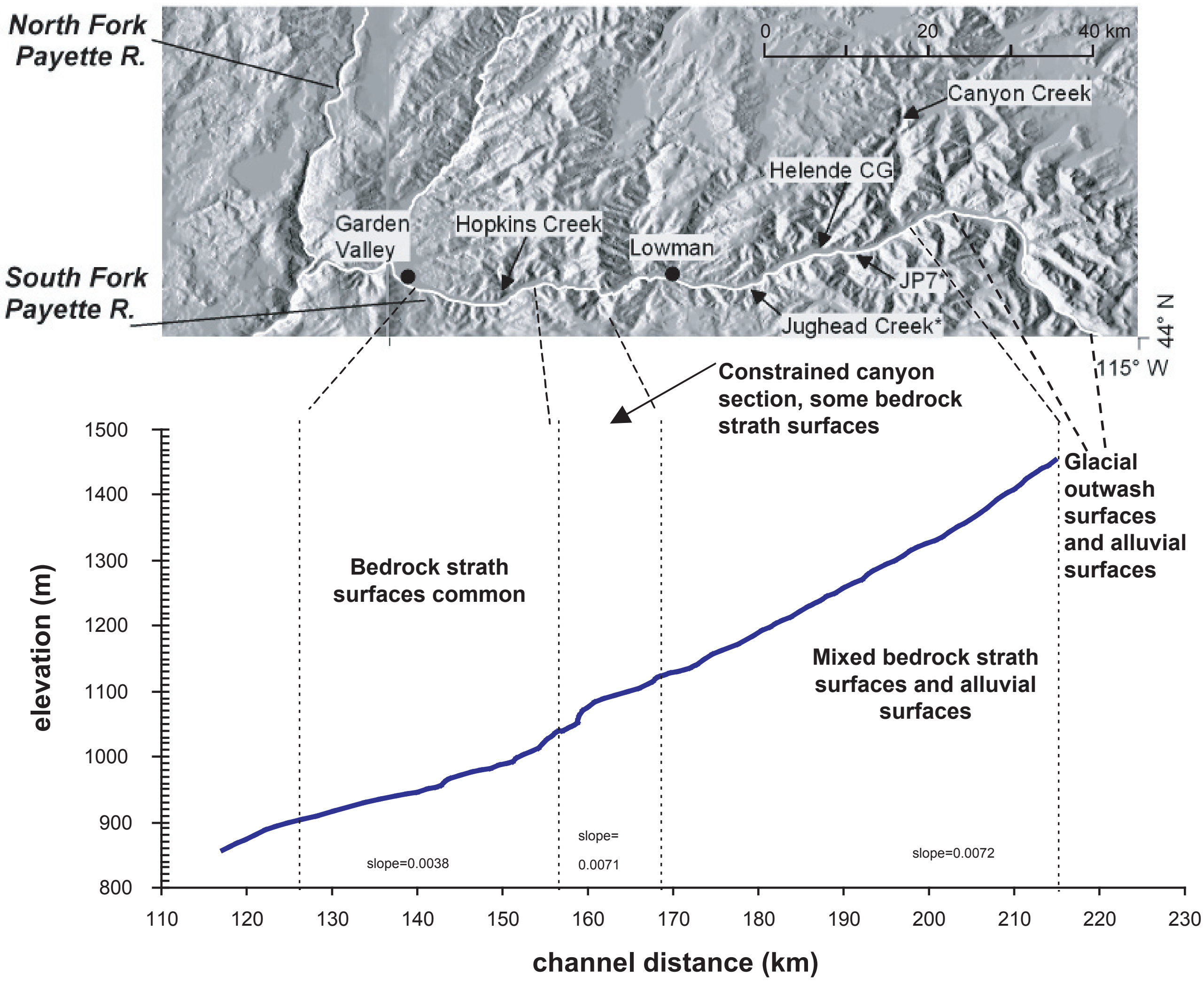

Figure 18. Locations of terrace study areas referred to in text. Asterisks (*) denote locations of radiocarbon-dated terraces.

bedrock channel may be covered with only a few meters of alluvium. Alluvial-fan sediments from the early Holocene fan at Jughead creek were deposited on the 5.4-m terrace tread. A basal date from the fan sediments of 6,495±60 ^{14}C yr BP (~7,425 cal yr BP) provides a minimum age for the 5.4-m terrace gravels underlying the alluvial-fan deposits (Meyer and Pierce, 2003).

Site LO10

Radiocarbon dates from the LO10 site, a south-facing drainage across the South Fork Payette River from Jughead creek provide a later Holocene (ca. 1,500 cal yr BP through present) record of fire-related sedimentation events (fig. 16). In this fan sequence, the 1989 burned soil surface is covered with only a few centimeters of washed debris-flow deposit from 1997. During the 1997 event, the proximal fan became deeply incised, and most of the volume of the debris-flow was deposited on the medial to distal end of the fan, creating a new fan lobe. This fan contains distinct burned soil surfaces at 428±34 ^{14}C yr BP and 929±56 ^{14}C yr BP, underlain by multiple deposits dating between approximately 1,550±35 ^{14}C yr BP, and 929±56 ^{14}C yr BP (fig. 16). The 929±56 ^{14}C yr BP (ca. 907 cal yr BP) burned soil surface is distinct, continuous, and exhibits little sign of bioturbation or post-fire disturbance. A relatively thick, continuous, charcoal-rich debris-flow deposit overlies the burned soil surface; all these characteristics indicate this likely is a fire-related debris flow. Evidence of a ca. 907 cal yr BP fire also is found at the GJ2 site, over 30 km upstream. This corresponds to the

Medieval Warm Period (1,050–750 cal yr BP) and also was a time of major fire-related debris-flow activity in Yellowstone (Meyer and others, 1995). The time period between 1,308–1,529 cal yr BP seems to represent a period of more frequent small sedimentation events, as seen at the Hopkins Creek site, at sites downstream near Banks, Idaho, and at nearby sites PL, LO13, LO33, and LO30. This record of frequent small fires corresponds with a time of little fire-related fan deposition in Yellowstone (Meyer and others, 1995), and the coldest phase of the approximately 1,400 yr cycle of ice-rafted debris in the North Atlantic (Bond and others, 1997).

Mileage		
Cum.	Inc.	
48.6	3.1	(lat 44°04'45"N., long 115°39'28"W.) Stop 5: A preliminary characterization of Holocene terraces of the South Fork Payette River and JP5 fan site. Turn right into Helende Campground area and follow paved road into campground and park in campsite parking. Restrooms available. At this stop, we will discuss preliminary work on Holocene terraces of the South Fork Payette River, then we will continue down a dirt road to examine alluvial-

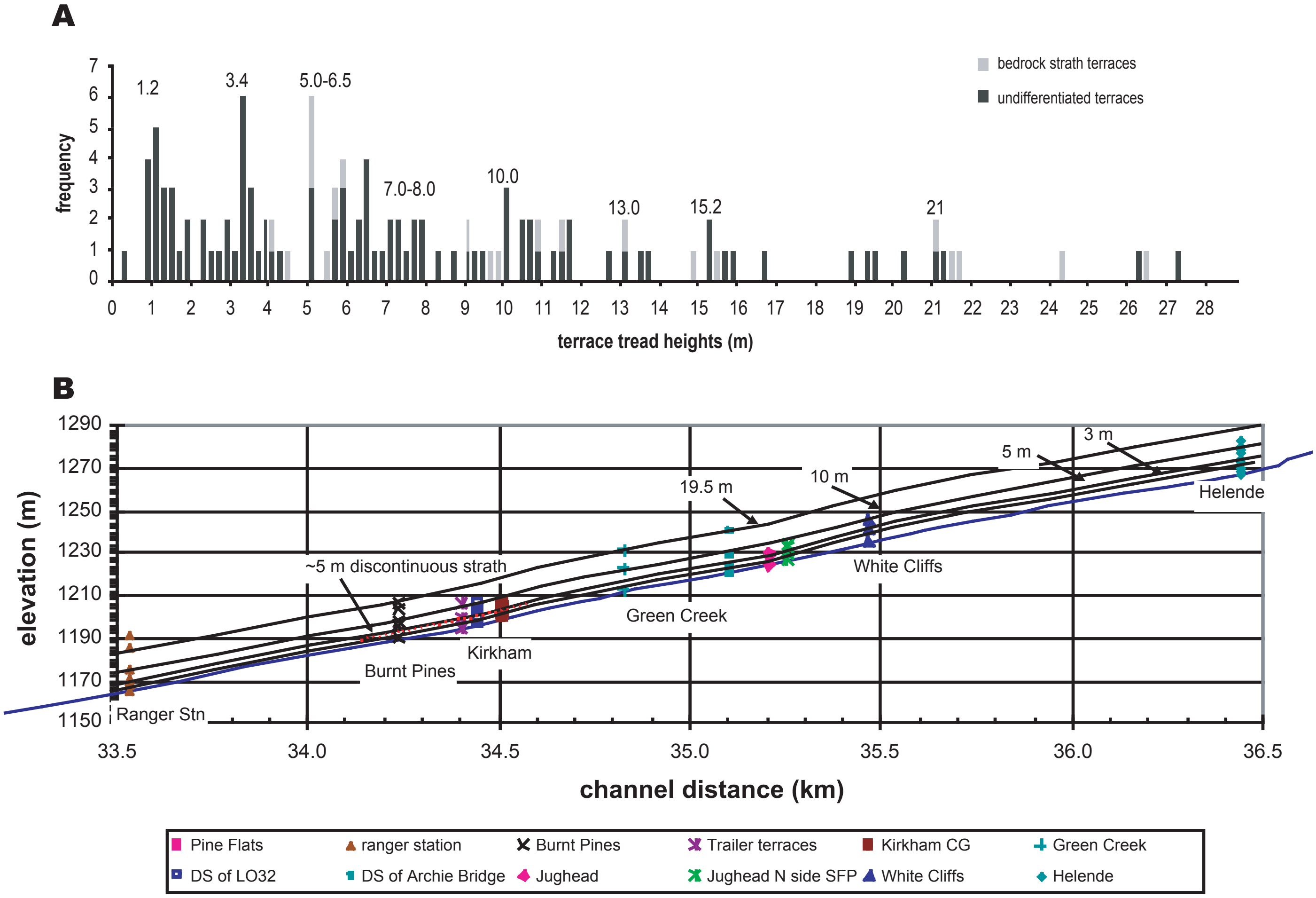

Figure 19. (A) Histogram of South Fork Payette terrace-tread heights above bankfull. For the purpose of this figure, bedrock straths have been defined as tread surfaces with less than 2 m of fill on bedrock. Some undifferentiated terraces are fill-cut into glacial terrace material. Numbers above histograms indicate preliminary groupings of major modes of terrace heights in meters. (B) Longitudinal profile of the South Fork Payette River between the Lowman Ranger Station and Helende Campground. Locations of measured terrace-tread heights above bankfull are denoted with symbols. Lines show tentative correlations assuming constant terrace-tread height, which are unsupported at present.

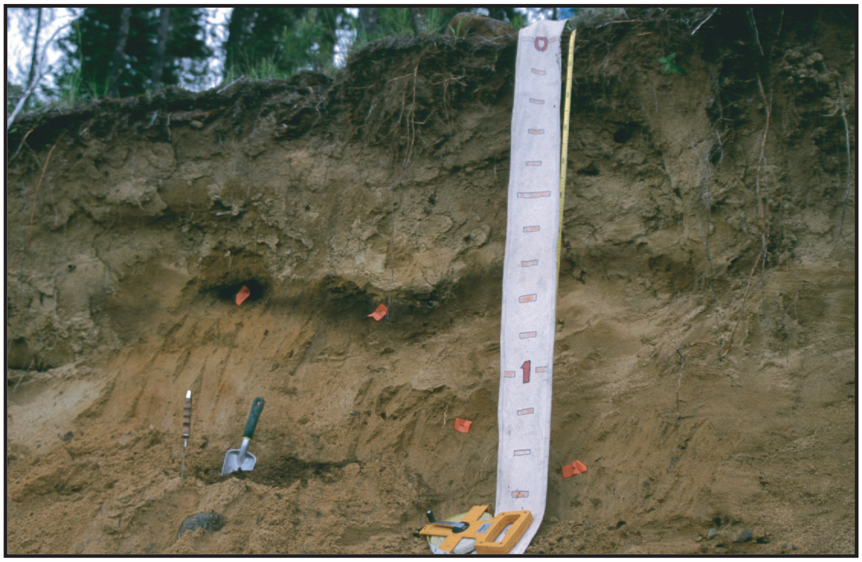

Figure 20. Site JP7, 3.2-m terrace tread, with radiocarbon samples from fine-grained channel-fill deposit at 0.8 m depth.

fan stratigraphy at a location across the South Fork Payette River (fig. 17).

Stop 1-5. A Preliminary Characterization of Holocene Terraces of the South Fork Payette River and JP5 Fan Site

By Jennifer Pierce and Grant Meyer

The South Fork Payette River valley features a well-formed sequence of fluvial terraces, especially between the last-glacial ice margin near Grandjean and Lowman (fig. 18). Although fluvial gravels can be found at heights of 180 m above the current channel, this study focuses on the terraces with treads of less than 15 m in height that likely are late glacial or postglacial in age (Stanford, 1982). The following is a preliminary description of terrace characteristics, terrace-tread heights above bankfull level, and when possible, radiocarbon ages of material collected from fine-grained overbank or slackwater deposits.

Description of South Fork Payette River terraces

The gravel and cobble-rich terraces with terrace-tread heights of about 20 m likely are glacial fill terraces, containing an estimated 10 m thickness of fill material. In the South Fork Payette area above Lowman, terrace exposures near the Lowman Ranger Station, Green Creek, and Helende Campground contain gravel- and cobble-fill material. Locally, in reaches of more resistant bedrock or bedrock "fins" extending down to the channel, bedrock straths underlie the 20-m terraces. In the lower South Fork Payette below the canyon section, bare bedrock straths at about 20 m, or bedrock at about 18 m covered by approximately 2–3 m of fill are common (fig. 18). In general, bedrock strath terraces typify the section of the valley below the canyon section, with terrace-tread heights of about 20 m, about 15 m, 11-13 m, and 9-10 m above local bankfull levels. The upper section of the drainage has a combination of bedrock strath terraces in higher gradient reaches or reaches of locally more

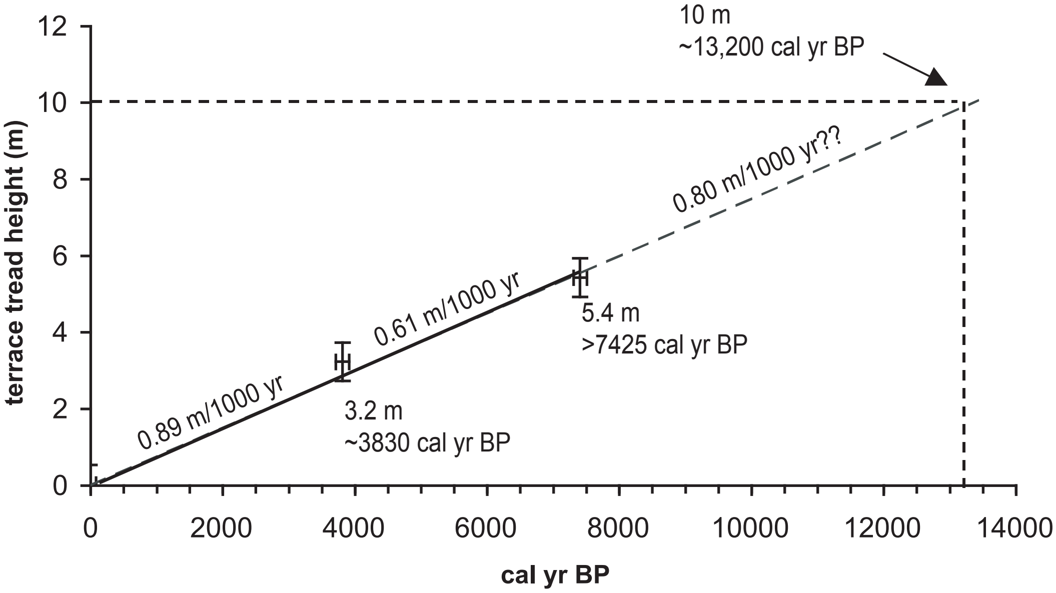

Figure 21. Estimated incision rates from radiocarbon ages of terrace treads given in calibrated years BP. Two sigma variation in ages given by x-axis error bars; 0.5 m variation in terrace height given by y-axis error bars. Estimates of incision rates calculated between individual points using calibrated radiocarbon ages, and change in terrace-tread height. Assuming constant incision rates, a rough age estimate for 10-m terrace of ~13,200 cal yr BP was calculated by extending the linear trendline fitted to dated terrace heights.

resistant bedrock (*i.e.*, at Kirkham Campground), and glacial fill (?) terraces and late-glacial and post-glacial fill-cut (?) terraces in wider valley sections. In some wider reaches (*i.e.*, at Jughead creek area, Lowman Ranger Station, Helende Campground) terraces are preserved on the north side of the valley, and the active, bedrock-bottomed channel of the South Fork Payette River is confined against hillslopes and small terrace remnants on the southern side.

Terrace-tread heights

Hand-level surveying of terrace tread heights in the South Fork Payette valley from the Warm Springs Creek down to Garden Valley shows that terrace heights form several apparent groups (fig. 19). The major modes in terrace-tread heights center around 1.2 m, 3.4 m, 5.0-6.5 m, and 10.0 m above current bankfull (fig. 19A). The range of tread heights between about 5.4 m and 6.8 m makes this grouping more ambiguous. Some of this variation is due to a variety of bedrock strath heights around 5.5 m, although there is a fairly consistent fill-cut terrace height at 6.6 m. Figure 19B shows the locations of surveyed terrace heights between Lowman Ranger Station and Helende Campground and correspondence of terrace-tread heights within the reach. The terrace heights surveyed in this relatively short valley distance provide information on possible terrace-tread correlations within this specific area; more data on other sections of the South Fork Payette are needed to make further inferences about general terrace-tread heights within the upper basin.

Figure 22. Cluster of large boulders, perhaps from a large flood event, on the 11-m terrace-tread surface at Helende Campground. The boulder surfaces are extensively pitted (~5 cm deep), but the high weathering rates of the batholith granitic rock make calibration of weathering characteristics difficult.

Dating of terrace deposits and estimated postglacial incision rates

At site JP7, upstream from Helende campground an age of 3,535±45 ^{14}C yr BP (~3,830 cal yr BP) was obtained from a large charcoal fragment collected from fine-grained channel fill deposits 0.8 m below the top of a 3.2-m terrace-tread surface (fig. 20). Similar fine-grained deposits are not uncommon in the approximately 3-m terrace from the Jughead creek area to site JP7. A basal radiocarbon age of 6,495±60 ^{14}C yr BP (~7,425 cal yr BP) from the inset alluvial fan of Jughead creek also provides a minimum age for the 5.4-m terrace gravels underlying the alluvial-fan surface (Meyer and Pierce, 2003). Although the approximately 10-m terrace surface has not been dated, an age of approximately 13,200 yr was hypothesized, assuming incision rates have been constant over Holocene time scales. These data provide an average Holocene incision rate of about 0.076 m/k.y. for approximately13,000 yr (fig. 21). More data are needed from the South Fork Payette terraces to consider relations between fan sedimentation and terrace formation. Meyer and others (1995) found that most tributary sedi-

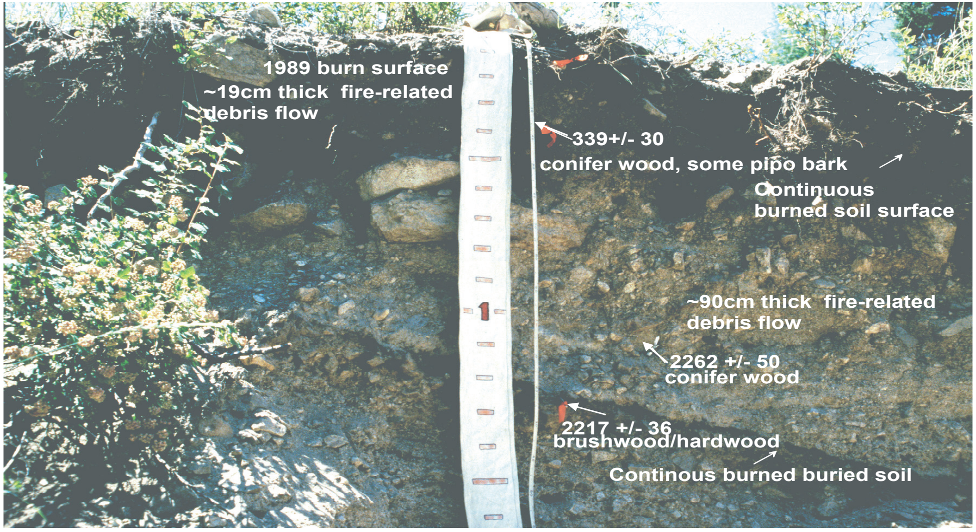

Figure 23. Fan stratigraphy exposed at site JP5. Dates are in ^{14}C yr BP, with major features of the deposit noted on the photo.

ments in glacial trough valleys of Yellowstone remain stored in fans for long periods and are worked downstream during periods of increased flow in the mainstem streams. Since the tributary fans of the South Fork Payette drainage are more proximal to the mainstem river than fans in the wider glacial valleys of Yellowstone, sediment supply in the Payette River may be more closely tied to hillslope erosion and deposition on fans.

In the Helende Campground area, a series of terraces with tread heights of 1.3 m, 3.3 m, 7.3 m, 6.1 m, 10.0 m, 11.5 m, 12.5 m, and 15.5 m are preserved on the north side of the South Fork Payette River. Higher terrace surfaces are also present, but were not mapped or measured in this area; the terraces less than 10 m in height are likely fill-cut terraces, while the higher terraces of glacial age are likely fill terraces. An additional feature of note is the cluster of large (~4-m-tall) boulders on the 11.5-m terrace, near the campground (fig. 22). Other large (>1 m b-axis) boulder deposits are found on a 10.4-m terrace about 1.5 km upstream from Helende Campground (site JP12). The boulders at the campsite likely were deposited during a large flood event.

Alluvial-fan stratigraphy at site JP5

The tributary stream at site JP5 is located on the south side of the South Fork Payette, downstream of the campground, and just downstream of the steep granite cliff opposite the Helende terrace surfaces (fig. 23). The storm event of 1997 deposited material on top of the perched fan, crossed the South Fork Payette River depositing material on the other side, and then deeply incised the tributary channel exposing fan material, channel deposits, and weathered bedrock in the channel wall.

This section contains a very prominent, continuous burned buried soil surface (115 cm below the top of the section), with a weak A horizon extending for approximately 10 cm below a burned O horizon. The burned surface, which contains abundant fine charred material, is in abrupt contact with an overlying 90-cm-thick fire-related debris flow (fig. 23). Based on these characteristics, the debris flow is interpreted as being a sedimentation event related to the fire that burned the underlying surface. The debris-flow deposit is clast rich (~40 percent), and the lack of variation in color, sorting, or texture indicates this is a single event. The radiocarbon ages of 2,217±36 ^{14}C yr BP for the burned surface, and 2,262±50 ^{14}C yr BP for the deposit are statistically indistinguishable, and well within the range of possible “inbuilt age” and analytical error. The timing of this event (~2,280 cal yr BP) falls within a time of increased fire-related sedimentation in Yellowstone (Meyer and others, 1995), and high fire frequency in mountain hemlock forests of British Columbia (Hallett and others, 2003).

The ca. 2,280 cal yr BP debris-flow event is overlain by another distinct continuous burned soil surface at 30-33 cm depth, dated at 339±30 ^{14}C yr BP. Fire-related sedimentation events are common in the Payette study area during this time period, which coincides with low fire activity in Yellowstone. This event is in abrupt contact with an approximately 19-cm-thick charcoal-rich debris-flow deposit, which appears to be an event associated with the underlying burned surface.

Mileage		
Cum.	Inc.	
0.0	0.0	Reset odometers when exiting Helende Campground. Turn right onto Highway 21.
6.8	6.8	(lat 44°07'24"N., long 115 °20'35"W.) Terraces at Warm Springs station, across from MacDonald Creek. Alluvial terrace-tread heights above bankfull level of 0.8 m, 2.1 m, 2.6 m, 8.9 m characterize surfaces upstream of a major valley constriction. Bedrock strath

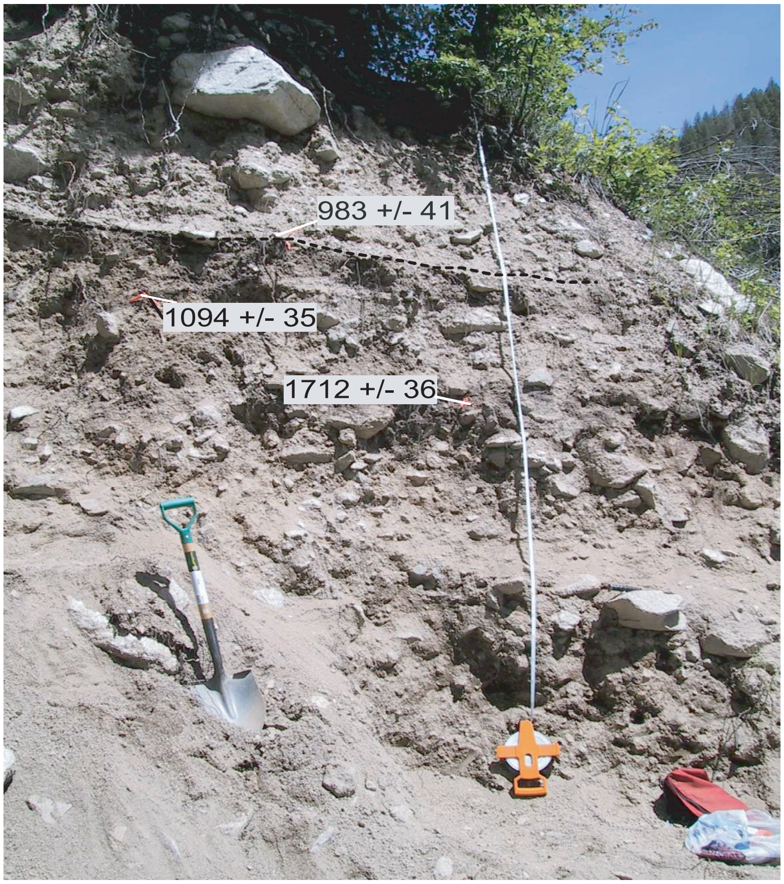

Figure 24. Alluvial-fan stratigraphy of site GJ2, showing multiple clast-rich debris-flow deposits. This site, and other high elevation (over ~1600 m) mixed conifer sites lack high-frequency fire-related debris-flow deposits. Site GJ2 contains a prominent burned soil surface and fire-related debris flow dated at about 930 cal yr BP (983±41 ^{14}C yr BP).

		terraces with tread heights of 5.6 m, and 6.6 m, and alluvial terraces with tread heights of 11.1 m and 21.0 m characterize the downstream, constricted section.
8.7	1.9	(lat 44°04'45"N., long 115°39'28"W.) Abundant clast-rich debris-flow deposits of Chapman Creek can be seen in main channel to right.
12.8	4.1	(lat 44°10'32"N., long 115 °14'48"W.) Emile Grandjean historic sign and view of the glacial landscapes of the western Sawtooth Mountains. Deposits from three glaciations can be found in the upper South Fork Payette River valley, informally named by Stanford (1982) the Penrod Creek (pre-Bull Lake?), Camp Creek (Bull Lake?), and Grandjean (Pinedale?) glaciations.
~14	~1.2	The area burned in the August 14–20, 2003, Canyon Creek Fire can be seen for the next several miles. Keep a lookout for fire-related debris-flow activity in tributaries of Canyon Creek and post-fire erosion on hillslopes.
16.6	2.6	(lat 44°13'13"N., long 115 °13'56"W.) Pull off along right side of the road and walk along to the fans exposed near the west side of the road.

Stop 1-6. High-Elevation Alluvial-Fan Stratigraphy

By Jennifer Pierce and Grant Meyer

Alluvial-fan sites GJ2 and GJ1, in the high elevation (~1700 m) mixed conifer forest, provide a record of fire-related debris-flow events. Unlike lower elevation fan sites in the study area, deposits at these sites do not contain fine-grained sheetflood or hyperconcentrated flow deposits, but instead are dominated by boulder rich, massive debris-flow deposits (fig. 24). Both GJ1 and GJ2 contain a fire-related debris flow event ca. 907 cal yr BP (928 ^{14}C yr BP at site GJ1 and 983±41 ^{14}C yr BP). These events are very similar in age to the fire-related debris-flow event at site LO10, also dated at ca. 907 cal yr BP, and the approximately 900 cal yr BP burned ponderosa pine found at the archeological site along the Deadwood River (Reid, 2001).

Mileage Cum.	Inc.	
~23	~8.4	(lat 44° 18'22"N., long 115°13'51"W.) Banner Summit.
~47	~24	(lat 44° 12'41"N., long 114°56'42"W.) Stanley, Idaho.

End Day 1

References

Anderson, A.L., 1934, A preliminary report on recent block faulting in Idaho: Northwest Science, v. 8, no. 2, p. 17–28.

Anderson, A.L., 1935, The valley of Grimes Creek in the Payette Canyon, Idaho: Journal of Geology, v. 43, p. 618–629.

Anderson, A.L., 1947, Geology and ore deposits of Boise Basin, Idaho: U.S. Geological Survey Bulletin 944-C, 319 p.

Armstrong, R.L., 1974, Geochronometry of the Eocene volcanic-plutonic episode in Idaho: Northwest Geology, v. 3, p. 1–15.

Arno, S.F., Harrington, M.G., Fiedler, C.E., and Carlson, C.E., 1995, Restoring fire-dependent ponderosa pine forests in western Montana: Restoration Management Notes, v. 13, p. 32–36.

Barrett, S.W., 1988, Fire suppression’s effects on forest succession within a central Idaho wilderness: Western Journal of Applied Forestry, v. 3, p. 760.

Barrett, S.W., Arno, S.F., and Menakis, J.P., 1997, Fire episodes in the inland Northwest (1540–1940) based on fire history data: Odgen, Utah, USDA-Forest Service, Intermountain Research Station, General Technical Report INT-GTR-370, 17 p.

Benda, L., Dunne, T., 1997, Stochastic forcing of sediment supply to channel networks from landsliding and debris flow: Water Resources Research, v. 33, p. 2849–2863.

Benson, L., Kashgarian, M., Rye, R., Lund, S., Paillet, F., Smoot, J., Kester, C., Mensing, S., Meko, D., Lindstrom, S., 2002, Holocene multidecadal and multicentennial droughts affecting northern California and Nevada: Quaternary Science Reviews, v. 21, p. 659–682.

Blair, T.C., McPherson, J.G., 1994, Alluvial fan processes and forms, *in* Abrahams, A.D., and Parsons, A.J., eds., Geomorphology of desert environments: London, Chapman and Hall, p. 344–402.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I., and Bonani, G., 1997, A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates: Science, v. 278, p. 1257–1266.

Bradley, R.S., Hughes, M.K., and Diaz, H.F., 2003, Climate in medieval time: Science, v. 302, p. 404–405.

Cannon, S.H., Gartner, J.E., Parrett, C., and Parise, M., 2003, Wildfire-related debris-flow generation through episodic progressive sediment-bulking processes, Western USA, *in* Rickenmann, D., and Chen-lung, C., eds., Debris-flow hazards mitigation—Mechanics, prediction, and assessment: Rotterdam, Milllpress, p. 71–82.

Cannon, S.H., Powers, P.S., and Savage, W.Z., 1998, Fire-related hyperconcentrated and debris flows on Storm King Mountain, Glenwood Springs, Colorado, USA: Environmental Geology, v. 35, no. 2–3, p. 210–218.

Cannon, S.H., and Reneau, S.L., 2000, Conditions for generation of fire-related debris flows, Capulin Canyon, New Mexico: Earth Surface Processes and Landforms, v. 25, p. 1103–1121.

Clayton, J.L., 1979, Soil and bedrock properties—Weathering and alteration products and processes in the Idaho batholith: Odgen, Utah, USDA Forest Service Research Paper 237, 35 p.

Clayton, J.L., and Megahan, W.F., 1986, Erosional and chemical denudation rates in the southwestern Idaho batholith: Earth Surface Processes and Landforms, v. 11, p. 389–400.

Colman, S.M., and Pierce, K.L., 1986, Glacial sequence near McCall, Idaho—Weathering rinds, soil development, morphology, and other relative-age criteria: Quaternary Research, v. 25, p. 25–42.

Cooper, C.F., 1960, Changes in vegetation, structure, and growth of southwestern pine forest since white settlement: Ecological Monographs, v. 30, p. 129–164.

Costa, J.E., 1984, Physical geomorphology of debris flows, *in* Costa, J.E., and Fleisher, P.J., eds., Developments and applications of geomorphology: Berlin, Springer-Verlag, p. 268–317.

Costa, J.E., 1988, Rheologic, geomorphic, and sedimentologic differentiation of water floods, hyperconcentrated flows, and debris flows, *in* Baker, V.R., Kochel, R.C., and Patton, P.C., eds., Flood geomorphology: New York, John Wiley & Sons, p. 113–121.

Covington, W.W., and Moore, M.M, 1994, Southwestern ponderosa forest structure—Changes since Euro-American settlement: Journal of Forestry, v. 92, p. 39–47.

Criss, R.E., and Taylor, H.P., 1983, An $^{18}O/^{16}O$ and D/H study of Tertiary hydrothermal systems in the southern half of the Idaho batholith: Geological Society of America Bulletin, v. 94, p. 640–663.

dePolo, C.M., and Anderson, J.G., 2000, Estimating the slip rates of normal faults in the Great Basin, USA: Basin Research, v. 12, p. 227–240

Druschel, G.K., and Rosenberg, P.E., 2001, Non-magmatic fracture-controlled hydrothermal systems in the Idaho batholith—South Fork Payette geothermal system: Chemical Geology, v. 173, p. 271–291.

Esper, J., Cook, E.R., and Schweingruber, F.H., 2002, Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability: Science, v. 295, p. 2250–2253.

Fisher, F.S., McIntyre, D.S., and Johnson, K.M., 1992, Geologic map of the Challis 1° x 2° quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-1819, scale 1:250,000.

Forester, C.S., Wood, S.H., and Nash, B.P., 2002, An 11.8±0.2 Ma silicic volcanic ash in the Miocene Payette Formation, Boise Basin, Idaho: Geological Society of America Abstracts with Programs (Rocky Mountain Section), v. 34, p. A-48.

Fule, P.Z., Covington, W.W., and Moore, M.M., 1997, Determining reference conditions for ecosystem management of southwestern ponderosa pine forests: Ecological Applications, v. 7, p. 895–908.

Gavin, D., 2001, Estimation of inbuilt age in radiocarbon ages of soil charcoal for fire history studies: Radiocarbon, v. 43, p. 27–44.

Gibbons, A.B., 1995, Tertiary sedimentary rocks of the Payette Formation (Miocene) and the lower part (Miocene and Pliocene) of the Idaho Group, Hailey 1° x 2° quadrangle and vicinity, west-central Idaho: U.S. Geological Survey Bulletin 2064-K, 9 p.

Grissino-Mayer, H.D., and Swetnam, T.W., 2000, Century-scale climate forcing of fire regimes in the American Southwest: The Holocene, v. 10, p. 213–220.

Grove, J.M., 1988, The Little Ice Age: New York, Methuen, 498 p.

Grove, J.M., 2001, The initiation of the “Little Ice Age” in regions round the North Atlantic: Climatic Change, v. 48, p. 53–82.

Hallett, D.J., Mathewes, R.W., and Walker, R.C., 2003, A 1000-year record of forest fire, drought and lake level change in southeastern British Columbia: The Holocene, v. 13, p. 773–783.

Hamilton, W.B., 1962, Late Cenozoic structure of west-central Idaho: Geological Society of America Bulletin, v. 73, p. 511–516.

Hyndman, D.W., 1983, The Idaho batholith and associated plutons—Idaho and western Montana, *in* Roddick, J.A., ed., Circum-Pacific plutonic terranes: Geological Society of America Memoir 159, p. 213–240.

Jones, P.D., New, M., Parker, D.E., Martin, S., and Rigor, I.G., 1999, Surface air temperature and its changes over the past 150 years: Reviews of Geophysics, v. 37, p. 173–199.

Kiilsgaard, T.H., Stanford, L.R., and Lewis, R.S., 2001, Geologic map of the Idaho City 30x60-minute quadrangle, Idaho: Idaho Geological Survey Map 29, scale 1:100,000.

Kiilsgaard, T.H., Scanlan, T.M., and Stewart, D.E., 1997, Geologic map of the Boise Basin vicinity, Boise, Ada and Elmore Counties, Idaho: Idaho Geological Survey Map M–7, scale 1:50,000.

Kipfmueller K.F., and Baker W.L., 2000, A fire history of a subalpine forest in south-eastern Wyoming, USA: Journal of Biogeography, v. 27, p. 71–85.

Kirchner, J.W., Finkel, R.C., Riebe, C.S., Granger, D.E., Clayton, J.L., King, J.G., and Megahan, W.F., 2001, Mountain erosion over 10 yr, 10 k.y., and 10 m.y. time scales: Geology, v. 29, p. 591–594.

Kirkham, V.R.D., 1931, Revision of the Payette and Idaho Formations: Journal of Geology, v. 39, p. 193–239.

Lavee, H., Kutiel, P., Segev, M., and Benyamini, Y., 1995, Effect of surface roughness on runoff and erosion in a Mediterranean ecosystem—The role of fire: Geomorphology, v. 11, p. 227–234.

Lindgren, W., 1898, The mining districts of the Idaho Basin and the Boise Ridge, Idaho: 18th Annual Report of the U.S. Geological Survey, pt. 3, p. 617–619.

Luckman, B.H., 2000, The Little Ice Age in the Canadian Rockies: Geomorphology, v. 32, p. 357–384.

Mann, M.E., Bradley, R.S., and Hughes, M.K., 1999, Northern hemisphere temperatures during the past millennium—Inferences, uncertainties, and limitations: Geophysical Research Letters, v. 26, p.759.

McCarthy, J.H., and Kiilsgaard, T.H., 2001, Soil gas studies along the trans-Challis fault system near Idaho City, Boise County, Idaho: U.S. Geological Survey Bulletin 2064, http://geology.cr.usgs.gov/pub/bulletins/b2064-11/.

McNabb, D.H., and Swanson, F.J., 1990, Effects of fire on soil erosion, *in* Walstad, F.D., Radosevich, S.R., and Sandberg, D.V., eds., Natural and prescribed fire in Pacific Northwest forests: Corvallis, Oregon State University Press, p. 159–173.

Megahan W.F., and Molitor, D.C., 1975, Erosional effects of wildfire and logging in Idaho, *in* Watershed Management Symposium: Logan, Utah, American Society of Civil Engineers, Irrigation and Drainage Division, p. 423–444.

Meyer, G.A., and Pierce, J.L., 2003, Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho—A long-term perspective: Forest Ecology and Management, v. 178, p. 89–104.

Meyer, G.A., and Wells, S.G., 1997, Fire-related sedimentation events on alluvial fans, Yellowstone National Park, U.S.A.: Journal of Sedimentary Research, v. A67, p. 776–791.

Meyer, G.A., Pierce, J.L., Wood, S.H., and Jull, A.J.T., 2001, Fires, storms, and erosional events in the Idaho batholith: Hydrological Processes, v. 15, p. 3025–3038.

Meyer, G.A., Wells, S.G., and Jull, A.J.T., 1995, Fire and alluvial chronology in Yellowstone National Park—Climatic and intrinsic controls on Holocene geomorphic processes: Geological Society of America Bulletin, v. 107, p. 1211–1230.

National Interagency Fire Center, 2003, Wildland fire season overview, accessed 8/26/03 at *http://www.nifc.gov.*

Parrett, C., 1988, Fire-related debris flows in the Beaver Creek drainage, Lewis and Clark County, Montana: U.S. Geological Survey Water Supply Paper W-2330, p. 57–67.

Pierson, T.C., and Costa, J.E., 1987, A rheologic classification of subaerial sediment-water flows, *in* Costa, J.E., Wieczorek, G.F., eds., Debris flows/avalanches: Geological Society of America Reviews in Engineering Geology 7, p. 1–12.

Pollack, H.N., Huang, S., and Shen, P., 1998, Climate change record in subsurface temperatures—A global perspective: Science, v. 282, p. 279–281.

Reid, K.C., 2001, The prehistory of fire in the Idaho Rockies: Idaho Yesterdays, v. 45, no. 3, p. 3–13.

Robichaud, P.R., 2000, Fire effects on infiltration rates after prescribed fire in North Rocky Mountain forests, USA: Journal of Hydrology, v. 231–232, p. 220–229.

Schmidt, K.M., Roering, J.J., Stock, J.D., Dietrich, W.E., Montgomery, D.R., and Schaub, T., 2001, The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range: Canadian Geotechnical Journal, v. 38, p. 995–1024.

Shaub, S., 2001, Landslides and wildfire—An example from the Boise National Forest: Boise, Idaho, Boise State University, unpublished M.S. thesis, 85 p.

Smith, H.V., 1941, A Miocene flora from Thorn Creek, Idaho: The American Midland Naturalist, v. 25, p. 473–523.

Stanford, L.R., 1982, Surficial geology of the upper South Fork Payette River area, south central Idaho: Idaho Geological Survey Technical Report 82-7.

Steele, R., Arno, S.F., and Geier-Hayes, K., 1986, Wildfire patterns change in central Idaho's ponderosa pine-Douglas-fir forest: Western Journal of Applied Forestry, v. 3, p. 76–80.

Stine, S., 1994, Extreme and persistent drought in California and Patagonia during medieval time: Nature, v. 369, p. 546–549.

Strom, B., Nutt, G., McConnaughey, D., and Lancaster N., 1998, Historic Large Fires in Boise National Forest (1900-1997), SW IDAHO ECO-GIS, Boise, Idaho, available online at *http://inside.uidaho.edu/data/bnf/bnf/utm/metadata/histfire_bnf_bnf.htm.*

Stuiver, M., Reimer, P.J., 1993, Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program: Radiocarbon, v. 35, p. 215-230.

Swanson, F.J., 1981, Fire and geomorphic processes, *in* Mooney, H.A., Bonnicksen, T.M., Christensen, N.L., Loctan, J.E., and Reiners, W.A., eds., Fire regimes and ecosystem properties: Washington, D.C., USDA Forest Service General Technical Report WO-26.

Sweetkind, D.S., and Blackwell, D.D., 1989, Fission-track evidence of the Cenozoic thermal history of the Idaho batholith: Tectonophysics, v. 157, p. 241–250.

Swetnam, T.W., 1993, Fire history and climate change in giant sequoia groves: Science, v. 262, p. 885–889.

Swetnam, T.W., and Baisan, C.H., 1996, Historical fire regime patterns in the southwestern United States since AD 1700, *in* Allen, C.D., ed., Proceedings of the second La Mesa Fire Symposium, 29–30 March 1994, Los Alamos, New Mexico, USDA Forest Service General Technical Report, RM-GTR-286, p. 11–32.

Wells, W.G., II, 1987, The effect of fire on the generation of debris flows, *in* Costa, J.E., and Wieczorek, G.F., eds., Debris flows/avalanches: Geological Society of America Reviews in Engineering Geology 7, p. 105–114.

Whitlock, C., Shafer, S.L., Marlong, J., 2003, The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management: Forest Ecology and Management, v. 178, no. 1–2, p. 5–21.

Wood, S.H., 2004, Stop 1-1. Garden Valley—Late Cenozoic faulting on the Boise Ridge fault, Idaho: this volume.

Wood, S.H., and Clemens, D.M., 2002, Geologic and tectonic history of the western Snake River Plain, Idaho and Oregon, in Bonnichsen, B., White, C.M., and McCurry, M., eds., Tectonic and magmatic evolution of the Snake River Plain volcanic province: Idaho Geological Survey Bulletin 30, p. 69–103.

Woodhouse, C.A., Overpeck, J.T., 1998, 2000 years of drought variability in the central United States: American Meteorological Society, v. 79, p. 2693–2714.