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PROCEEDINGS OF WORKSHOP XXVIII - ON THE BORAH PEAK, IDAHO EARTHQUAKE - VOLUME B to appear in Volume B

Field Guide and Map to Accompany the Research Papers

This volume contains a self-guided field excursion of the spectacular surface faulting features, landslides, and sand boils that formed during the 1983 Borah Peak, Idaho, earthquake. Three annotated topographic maps that are referred to in the guide as Plates 1-3 are located in the map flap of this volume. The field guide is ancillary to the collection of research papers that are contained in Volume A of this report.

FAULT SCARPS, LANDSLIDES AND OTHER FEATURES ASSOCIATED WITH THE BORAH PEAK EARTHQUAKE OF OCTOBER 28, 1983, CENTRAL IDAHO: A FIELD TRIP GUIDE

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INTRODUCTION

The M_s 7.3 Borah Peak earthquake of October 28, 1983 was the first earthquake in the Intermountain Seismic Belt to produce surface faulting since the Hebgen Lake, Montana earthquake in August, 1959. The Borah Peak earthquake provides an excellent opportunity to study the effects of and hazards posed by a major earthquake in the Intermountain Seismic Belt. Fortunately, it occurred in a sparsely populated area where damage and injuries were minimal considering the size of the earthquake. The results of studies of this earthquake will hopefully improve our understanding of the mechanics of other Intermountain Seismic Belt earthquakes, the variations and severity of ground motion, the hazards posed by surface faulting and earthquake-induced mass movements, and engineering and land-use modifications that might minimize the damage from similar earthquakes in more populous areas.

An impressive zone of fault scarps and surface ruptures, about 36 km long, formed during the earthquake (Crone and others, 1985). The earthquake epicenter was near the south margin of Thousand Springs Valley (fig. 1). The scarps and ground ruptures occur primarily along the Lost River range-front fault that separates Thousand Springs Valley and Warm Springs Valley from the Lost River Range to the northeast (fig. 1). The largest scarps and very complex patterns of ground breakage occur along the fault at the northeast margin of Thousand Springs Valley between Elkhorn Creek on the southeast and Arentson Gulch on the northwest. This field guide will focus on the characteristics of scarps and ground ruptures in this area and the types of geologic data that have been used to document the directions and amount of near-surface movement on the fault. At Doublespring Pass road, a trench across the fault scarp was excavated, mapped and backfilled in 1976, prior to the earthquake. During the earthquake, the surface faulting reactivated the preexisitng fault planes and exposed a cross section of the trench in the new scarps. In September, 1984, the new trench was excavated adjacent to the 1976 trench to examine the patterns of the new surface faulting and changes in the stratigraphic relationships caused by the earthquake.

In addition to the scarps and surface ruptures, the earthquake caused numerous landslides and rockfalls, and immediate radical and substantial long-term changes in the groundwater hydrology. This trip visits one of the more dramatic landslides, a complex rotational slump-debris flow at Birch Springs. The last stop is at Chilly Buttes where spectacular but temporary large-volume springs, sand boils and fissure eruptions formed large craters and produced local flooding.

FIELD TRIP ROAD LOG

Log starts at the west entrance of Sawtooth National Forest, northeast of Sun Valley on the Trail Creek road (State Route 75; Forest Route 51).

Cum. Miles	Int. Miles	Description
0.0	0.0	Entering Sawtooth National Forest. Sign on right.
1.4	1.4	Road to Corral Creek on right. The lower half to two-thirds of the hills on both sides of Trail Creek Valley in this area are composed of argillaceous rocks of the Devonian Milligen Formation. The upper part of these hills are klippen (erosionally isolated remnants) of Pennsylvanian and Permian Wood River Formation that was thrust over the Devonian rocks (Dover, 1981).
1.7	0.3	Antelope Creek on left.
4.3	2.6	Wilson Creek trail on right. Ahead, the road crosses the first of several imbricate thrust faults between here and Trail Creek Summit. Upvalley from this thrust fault, argillaceous, sandy and calcareous rocks of the Pennsylvanian and Permian Wood River Formation are exposed along the sides of the road. These rocks are part of the upper plate of this first thrust fault (Dover, 1981).
5.6	1.3	About 25 m^3 of rock fell onto the road in this area from the steep slopes to the right (Keefer and others, 1985)
6.3	0.7	Limestones of the Pennsylvanian and Permian Wood River Formation are exposed in the roadcuts on the right (Dover, 1981).
7.0	0.7	During the earthquake along this part of the road, limestone blocks slid down dip slopes and boulders up to 0.3 m in diameter moved down steep talus slopes and onto the road. Locally, cracks formed in the road fill (Keefer and others, 1985). In this area, the road crosses several closely-spaced imbricate thrust faults of the Pioneer thrust fault system. Rocks in these thrust sheets are Ordovician, Silurian and Devonian in age and are composed of black, carbonaceous argillite and shale of the Phi Kappa Formation and silicious metasiltstone and very fine grained quartzite of the Trail Creek Formation (Dover, 1981).
8.8	1.8	Trail Creek Summit. Entering Challis National Forest and the drainage of Summit Creek.
9.7	0.9	Park Creek Campground on left. The road has just crossed the sole thrust of the Pioneer thrust fault

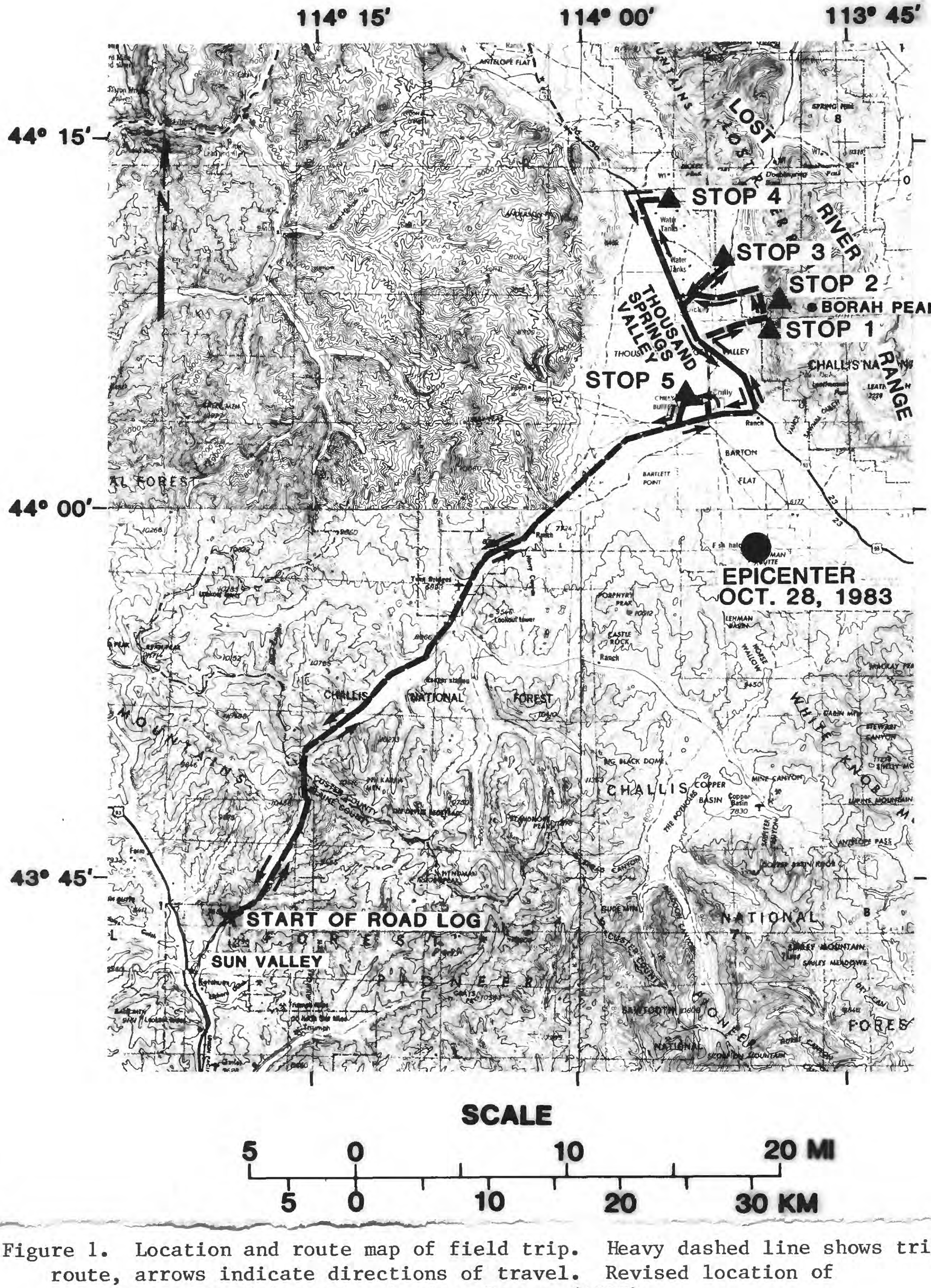

Figure 1. Location and route map of field trip. Heavy dashed line shows trip route, arrows indicate directions of travel. Revised location of epicenter of M_S 7.3 earthquake from Dewey, (1985).

		system. The bedrock in the valley wall to the left is Mississippian Copper Basin Formation. Bedrock in the valley wall to the right is Eocene quartz monzonite of the Summit Creek stock. The stock is part of the intrusive complex of the Pioneer window (Dover, 1981).
11.1	1.4	Exposure of Eocene quartz monzonite on left (Dover, 1981).
11.8	0.7	Big Fall Creek on left.
12.4	0.6	Phi Kappa Campground on right and the valley of Phi Kappa Creek behind the campground. About 0.7 mi up the valley is the Phi Kappa mine, one of the more productive mines in the area, that produced about $175,000 worth of lead, zinc and silver (Dover, 1981).
13.0	0.6	In this area, rocks fell onto the road from the steep talus slopes on the left (Keefer and others, 1985).
16.0	3.0	Kane Creek road on the right. The imposing peak at the head of Kane Creek Valley is Devils Bedstead (11,000 ft). Near the head of the valley, Precambrian gneiss and lower Tertiary? to Upper Cretaceous? granodiorite are exposed in the Pioneer window, an area in the central Pioneer Mountains where the rocks beneath the thrust sheets have been exposed by erosion (Dover, 1981).
16.7	0.7	Crossing North Fork of the Big Lost River. Road up the North Fork is on the left. The hillslope to the left is argillite, sandstone and granule conglomerate of the upper clastic unit of the Mississippian Copper Basin Formation (Dover, 1981). Mapping by Evenson and others (1982) indicates that during the maximum extent of the Copper Basin glaciation (tentatively correlated with Bull Lake glaciation), ice lobes from the North Fork Valley, Summit Creek Valley and Kane Creek Valley merged and flowed downvalley to about this point.
19.3	2.6	Road to the right follows the East Fork of the Big Lost River into Copper Basin. Locally, earthquake-induced landslides occurred in talus along both sides of the valley (Keefer and others, 1985). During the Copper Basin glaciation and Potholes glaciation (tentatively correlated with Pinedale glaciation) ice from Wildhorse Canyon, a side valley, formed a dam near the mouth of the East Fork. Upvalley from the dam, Glacial Lake East Fork filled to as much as 120 m deep (Evenson and others, 1982).
19.9	0.6	Deep Creek on left. Outcrops beyond the creek are latites, andesites and rhyodacites of Eocene Challis Volcanics (Rember and Bennett, 1979).
20.3	0.4	Crossing North Fork of the Big Lost River.
21.6	1.3	Road up Twin Bridges Creek on left.
21.9	0.3	Crossing Twin Bridges Creek. Lost River Range is in the distance at 1:00. Borah Peak is the high point on the left skyline.
22.5	0.6	Lake Creek on left. The bedrock here is Mississippian Copper Basin Formation(?) (Rember and Bennett, 1979).

24.4	1.9	Garden Creek Campground on right.
26.2	1.8	A seismic profile and drilling shows alluvial fill in this part of the valley to be about 23 m thick (Crosthwaite and others, 1970).
28.9	2.7	Grant Creek on right.
29.1	0.2	Swensen Basin on left at 9:00-10:00.
29.6	0.5	Swensen Butte is at 10:00 and Bartlett Point at 2:00. Borah Peak is ahead at 12:00. Saddle in the range at 10:00-11:00 is Doublespring Pass. Entering Thousand Springs Valley. White Knob Mountains are in the distance at 2:00-3:00.
33.3	3.7	Sage Creek-Howell Canyon road on the left. Elkhorn Creek, close to the southernmost end of ground breakage associated with the earthquake, is straight ahead.
33.7	0.4	Chilly Buttes at 10:00. In the vicinity of the bedrock promontory at 3:00 on the south side of the river, numerous boulders of Challis Volcanics more than 1 m in diameter were dislodged from the near-vertical cliffs and rolled or bounced as much as 60 m beyond the distal margin of the talus slopes below. Collisions between the boulders produced rock fragments that flew distances of several meters. The 80-m-high cliffs are broken into pinnacles by sets of open joints (Keefer and others, 1985).
34.4	0.7	Road to Chilly Buttes on left. Chilly Buttes, at 9:00, was the site of groundwater eruptions and sand boil formation immediately after the earthquake. The trip will visit these features at the last stop.
35.8	1.4	Road to Chilly townsite on left. The epicenter of the main shock on October 28 was a few kilometers to the south (fig. 1).
37.8	2.0	Crossing Thousand Springs Creek. The day after the earthquake, this creek was nearly flowing over the road in part because of the increased groundwater flow from the eruptions near Chilly Buttes. From this point northward to Whiskey Springs (pl. 1), a zone of fissures, formed by lateral spreading of the distal parts of the alluvial fans, extends about 1.2 mi (2 km) along the margin of the valley (Youd and others, 1985).
38.1	0.3	Junction with U.S. Highway 93 (U.S 93). TURN LEFT. The tree-lined channel of Elkhorn Creek is at 11:00. Small cracks formed during the earthquake on the hillslopes on the south side of the creek. A large new spring, now dry, formed in the bottom of the valley near the projected trace of the fault on the north side of the creek.
38.6	0.5	At the top of the hillslope at 3:00, a series of uphill-facing scarps formed (pl. 1). These scarps are thought to result from gravity-induced, deep-seated rock creep (sackungen) in which the entire hillslope has settled downward and spread laterally toward Thousand Springs Valley. If this interpretation is

		correct, these scarps are earthquake related but are not true tectonic scarps (Crone and others, 1985).
39.3	0.7	Whiskey Springs lateral spread (pl. 1). A large lateral spread extends along the highway for the next 0.3-0.4 mi (0.5-0.6 km). Fissures at the headwall of the spread, locally more than 1 m wide and 3 m deep, are in the sagebrush about 30 m to the right of the road. To the left of the road, sod in the marshes was thrust upward and outward at the toe of the spread. The road pavement was disrupted in several places and the roadway and underlying ground was displaced more than 1 m westward in the middle of the spread (Youd and others, 1985).
40.3	1.0	Chilly Buttes at 9:00-10:00 in the valley. Dickey Peak at 2:00.
42.8	2.5	Access road to Borah Peak and Cedar Creek indicated by small sign on the right. TURN RIGHT. Dirt road ahead.
43.1	0.3	Cross cattle guard. Road curves to left. After the curve, the newly-formed scarp is highly visible as a light-colored scar on the treeless slope at the base of the range at 2:00. This slope is formed by the left-lateral moraine formed by a late Pleistocene glacier that flowed down Cedar Creek Valley. The summit of Borah Peak (12,662 ft), the highest summit above the moraine, is composed of Silurian Laketown Dolomite and Devonian Jefferson Dolomite (Ross, 1947). The broad, flat alluvial surface about 100 m above the base of the hills is capped by the Donkey fanglomerate of post-Oligocene and pre-upper Pleistocene age (Ross, 1947). The low saddle in the Lost River Range at 11:00 is Doublespring Pass. Dickey Peak is at 10:00 and the tree-covered bedrock hills of Willow Creek Summit are at 9:00-10:00. The road over the Summit is visible at 9:00.
45.1	2.0	The scarp straight ahead displays the pattern of right-stepping offsets between adjacent segments.
45.8	0.7	Scarp crosses Birch Springs-Cedar Creek road. Park on right side of the road, cross the creek, and walk uphill approximately 100 m to the southeast to Stop 1.

STOP 1: BIRCH SPRINGS DEBRIS FLOW

(modified from Keefer and others, 1985)

A complex rotational slump-debris flow occurred at the end of a probable Bull Lake(?) moraine (K. L. Pierce, 1985, written commun.) at this site. The debris flow contained an estimated 100,000 m^3 of poorly sorted morainal material and covered approximately 4 hectares. The slightly arcuate scarp at the head of the landslide is about 250 m long (fig. 2) and up to 5 m high. Upslope from the scarp, there is a zone of subparallel cracks. For approximately 50 m downslope from the scarp, the landslide consists of numerous back-rotated slump blocks, some of which are partially disintegrated. Further downslope, the landslide material is progressively more disrupted and, at the distal end, the landslide consists of four debris flows, each several hundred meters long. The debris flows are composed of numerous lobes, some of which flowed around islands of undisturbed ground. The toes of the flows are a few tens of centimeters high.

The debris flows extended over the fault scarp (fig. 2) showing that they postdate the formation of the surface rupture. The morphology of the debris flows and splash marks 1.2 m high on the trees suggest that the debris flowed rapidly, at least several tens of meters per hour.

The presumably low strength of the saturated morainal material, temporarily elevated pore pressures caused by the strong shaking, and/or changes in groundwater flow due to faulting probably contributed to initiating the landslide.

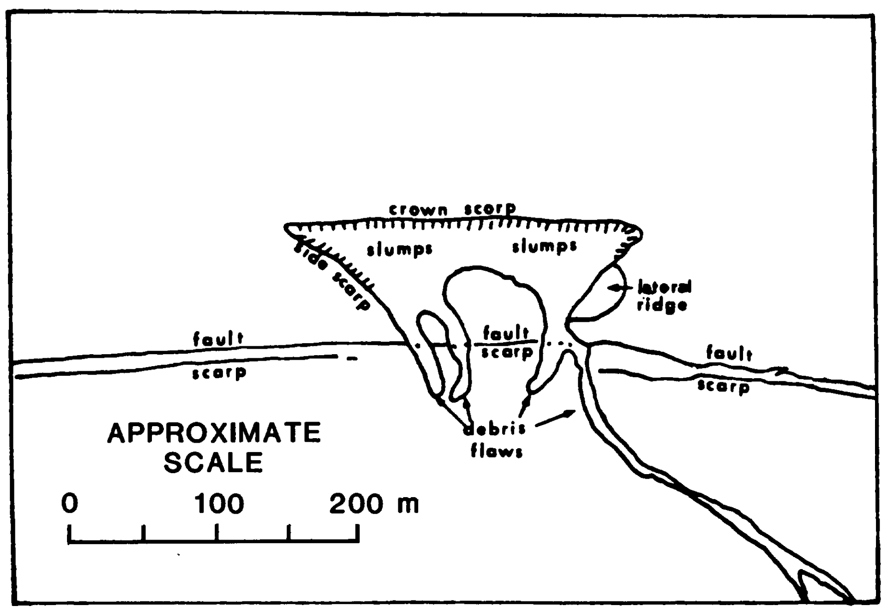

Figure 2. Schematic drawing of oblique view of Birch Springs debris flow. View is generally to the east. (From Keefer and others, 1985).

Return to vehicles

STOP 2: TRAVERSE OF FAULT SCARPS FROM CEDAR CREEK TO ROCK CREEK

The next part of the trip involves a one-mile-long foot traverse northwestward along the Lost River fault from Cedar Creek to Rock Creek. The scarps present along this part of the range front display the characteristics and complex patterns of ground breakage that typify much of the surface faulting.

The most striking feature of these scarps is the complex pattern of ground breakage produced by the main scarp and the multiple synthetic and antithetic scarps. The height of individual scarps often varies rapidly along strike. Commonly, en echelon scarps form the pattern of right steps between adjacent segments that is typical of left-lateral strike-slip motion.

The 1983 surface faulting produced a well-developed graben along this part of the fault zone that varies in width from a few tens to more than 100 m. Most of the new surface faulting was superimposed on preexisting synthetic and antithetic scarps. At a large unnamed drainage midway between Cedar Creek and Rock Creek (pl. 1), pre-1983 surface faulting had formed a broad graben that channeled the westward flowing drainage along the graben and caused it to flow northwestward along the range front. During the Borah Peak earthquake, most of the faults, including the antithetic faults, were reactivated, redefining the topographic expression of the graben.

The largest net throw (vertical component of slip) along the fault zone, 2.5-2.7 m, was measured just southeast of Rock Creek (pl. 1). The measurements of throw compensate for the effects of local warping and backrotation, antithetic faults, and complex ground breakage adjacent to the fault. In this area, grooves, formed by clasts as they were dragged along the fault plane in the colluvium, were locally preserved near the base of the free face of some of the larger main scarps. The rake of these grooves showed that the net slip averaged 17 cm of sinistral slip for every 100 cm of dip slip. The near-surface fault plane dips 60^{o}-80^{o} to the southwest. Cultural features confirmed that the surface faulting had a sinistral slip component. At Rock Creek, a concrete irrigation ditch, now destroyed by construction, had a geometrically reconstructed sinistral displacement of 0.43 m and 2.90 m of vertical displacement. About 30 m north of Rock Creek, a fence line that trends oblique to the scarps also has a distinct sinistral displacement.

The influence of the grain size, shape, and sorting of faulted materials on the morphology of the newly formed scarps is especially well demonstrated at a site about 80 m north of Rock Creek. Here the main, west-facing scarp is about 2.5 m high and, where formed in poorly sorted gravelly colluvium with a silty matrix, the free-face of the scarp is nearly vertical ($\sim 78^{o}$) to overhanging. About 10 m away, the same scarp, formed in moderately well-sorted cobble gravels, had raveled to an angle of repose of 30^{o} to 37^{o} within one day after the earthquake. Monuments have been established at this and several other sites along the system of fault scarps to monitor the degradation of the scarps.

Vehicles will rendezvous with the field trip at Rock Creek.

53.5	7.7	Cumulative mileage for shuttle of vehicles from start of hike at Cedar Creek to rendezvous at Rock Creek. Route and mileage for the shuttle includes: return to U.S. 93 (2.8 mi), TURN RIGHT (North) on the highway, follow highway 1.8 mi to the Doublespring Pass road turnoff (pl. 1), TURN RIGHT (Northeast) onto Doublespring Pass road, proceed northeast for 0.4 mi to the end of the fence on the right side of the road, TURN RIGHT onto the Rock Creek dirt road at the end of the fence (pl. 1) and follow it 2.7 mi to the mouth of Rock Creek canyon and rendezvous with the trip. Return to Doublespring Pass road.
56.2	2.7	Junction of Rock Creek road and Doublespring Pass road. TURN RIGHT on Doublespring Pass road. The road is on a glacial outwash surface of Pinedale (late Pleistocene) age (Scott, 1982).

58.4 2.2 Fault scarps cross Doublespring Pass road. Park near the site of the old road and walk northwest about 65 m to the trench site.

STOP 3: FAULT SCARPS AND TRENCH SITES AT DOUBLESPRING PASS ROAD

One is impressed with how faithfully the 1983 scarps followed the many preexisting scarps at this location. Just north of the road, trench studies and pre-1983 aerial photographs both show a well-developed horst within the graben adjacent to the main scarp. During the Borah Peak earthquake, the fault at the main scarp and the smaller faults bounding the horst were all reactivated.

The amount of ground breakage within the graben is also impressive. In addition to the multiple scarps, the ground surface is broken into numerous randomly tilted blocks up to several meters in across, perhaps caused in part by the violent shaking and by subsidence into the graben.

The net throw at this site is 1.56 m (Stein and Barrientos, 1985) with a noticeable amount of left-lateral slip. The lateral component can be observed at the old Doublespring Pass road where drainage ditches along the sides of the road are displaced to the left across the fault zone.

Trenching studies of prehistoric fault scarps are valuable sources of paleoseismic data for earthquake risk assessments, yet often the interpretations of stratigraphic relationships in trenches permit several plausable scenarios of the faulting history. The rare circumstances of a previously mapped trench being ruptured by a subsequent earthquake at Doublespring Pass road presented a unique opportunity to document the effects of multiple surface faulting events on stratigraphic relationships. David Schwartz of Woodward-Clyde Consultants, Walnut Creek, California, with support from the U. S. Geological Survey, excavated a trench across the 1983 scarps immediately adjacent to the 1976 trench.

Detailed mapping and interpretation of relationships in the post-earthquake trench are still in progress but several important observations about the behavior of the Lost River fault at this site are already clear (fig. 3). The trench contains strong evidence for one major pre-1983, post-Pinedale age surface faulting event. Many small 1983 scarps, some only a few tens of centimeters high, overlie pre-1983 shear zones indicating that even very small displacement faults were reactivated during the Borah Peak earthquake, and that the pattern of 1983 ground breakage was nearly identical to the breakage associated with the pre-1983 surface faulting event. Furthermore, stratigraphic relationships in the trench show that the amounts of 1983 dip-slip displacement on most of the faults were similar to those associated with the pre-1983 earthquake. Similarities in the amounts of displacement and in the pattern of ground breakage imply that the magnitude of pre-1983 earthquake was probably similar to the Borah Peak earthquake.

A second trench excavated by David Schwartz, located about 220 m south of Doublespring Pass road, unexpectedly exposed a water-saturated sequence of clays, silty clays and silty sands beneath 2.6 m of outwash gravels. The fine-grained sediments may predate the Pinedale outwash gravels, or they may be Pinedale-age overbank slackwater deposits between interfluves. The fault plane in this trench has a more gentle dip than the fault plane formed in gravels in the trench to the north. The more gentle dip of the fault plane in this trench is probably the result of lower shear strength in the fine-grained, water-saturated sediments.

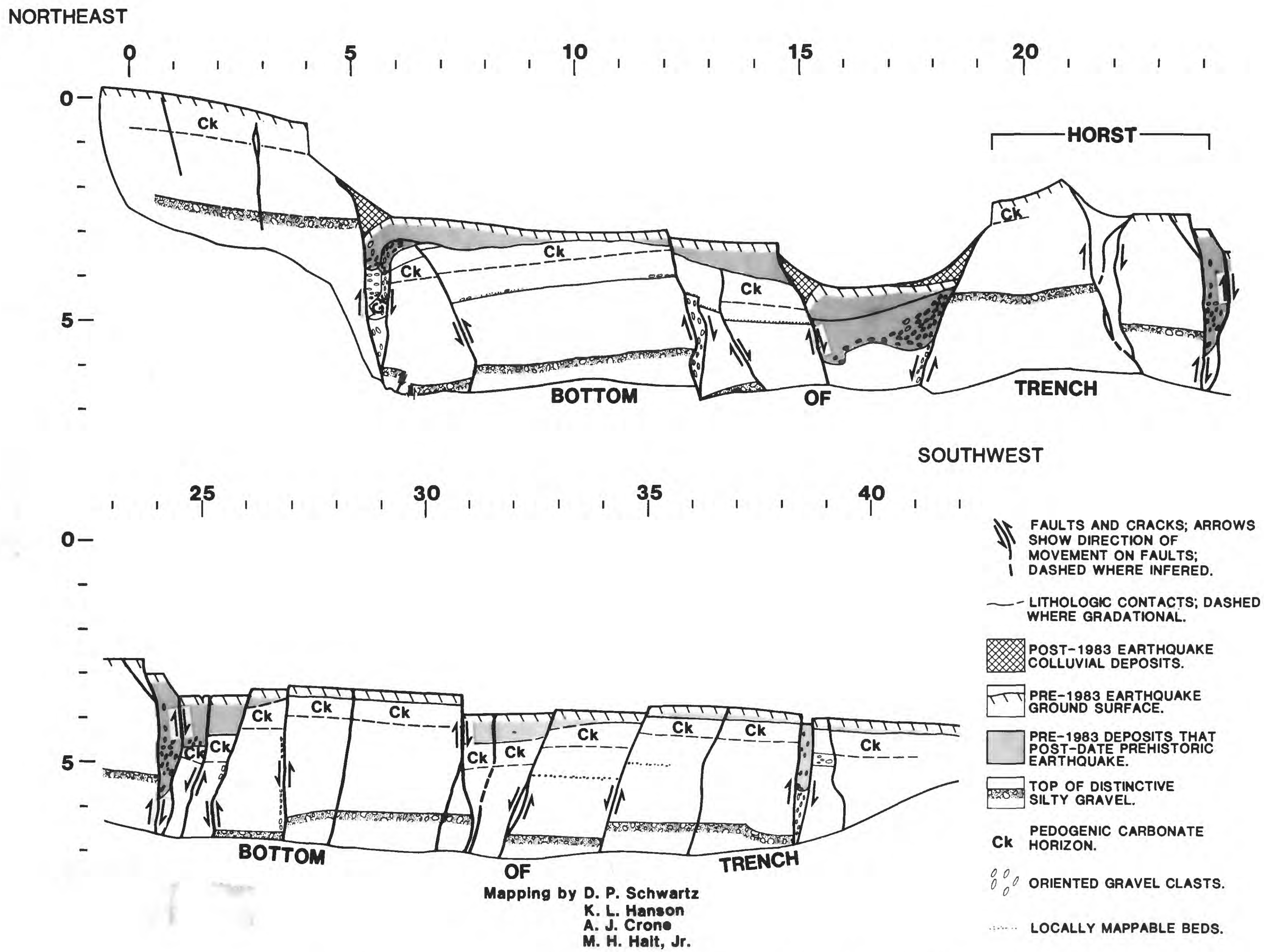

Figure 3. Preliminary diagram of stratigraphic relationships in the post-earthquake trench near Doublespring Pass road. Map shows south wall of trench. Scale is in meters with no exaggeration. Compare with pre-earthquake trench log in Figure 7.

The following section describes the stratigraphy, structure and interpretation of the pre-earthquake trench excavated at this site in 1976 by M. H. Hait, Jr., U.S. Geological Survey.

DOUBLESPRING PASS ROAD TRENCH

by

M. H. Hait Jr.

Introduction

Before 1983, the primary evidence of geologically young tectonic activity in the Basin and Range area of Idaho north of the Snake River Plain was fault scarps that displaced Quaternary deposits along range-front faults. These scarps provided the impetus for geologic studies of the history of Quaternary movement on the associated faults. In 1976, as part of these studies, a trench was excavated across a pre-historic fault scarp along the Lost River fault just north of the Doublespring Pass road (Hait and Scott, 1978). This trench was one of five excavated prior to the Borah Peak earthquake across prominent, youthful-looking fault scarps in the area (fig. 4).

The Doublespring Pass road trench was excavated during July, 1976 in NE $1/4$, SW $1/4$, SW $1/4$, Sec. 28, T. 10N., R 22E. (pl. 1), about 65 m northwest of the Doublespring Pass road (fig. 5a), Custer County, Idaho. Near the trench site, the grade of the Doublespring Pass road steepened noticeable as it crossed the fault scarp about 4 km northeast of U. S. 93.

The scarp was expressed as a continuous, subdued, southwest-facing, 1.6-km-long step that interrupted the smooth slope of the Willow Creek alluvial fan where the fan becomes wider as it emerges from the Lost River Range (pl. 1). Northwest of the fan, the scarp passed east of a bedrock knob ("West Spring block" on pl. 1) and continued to the northwest. Southeast of the trench site, the scarp coincided with a series of aligned springs and groves of alder and willow trees. Farther southeast, the scarp followed the general trend of the southwest base of the Lost River Range.

On the Willow Creek fan, the face of the fault scarp was generally more cobbly and pebbly with less vegetation than the adjacent fan surface. At the trench site, a graben on the downthrown block adjacent to the main fault scarp supported a relatively luxuriant growth of sagebrush. Between the trench and the aligned springs 0.6 km to the southeast, the fault zone contained subtle, right-stepping horsts and grabens, suggesting a component of left-lateral slip. Profiles across these features (figs. 5a, 5b) show the range in slope angles and the magnitude of vertical offsets on the scarps along this part of the fault zone.

General Surface Age Relations

Figure 6 is a schematic northwest-southeast profile, generally parallel to the trend of the fault scarp, that summarizes some of the geomorphic features in the vicinity of the scarp. North of Doublespring Pass road, the faulting postdates a high terrace (1) and the main outwash surface (2), as well as the downstream ends of sidevalley fans (3) that bury parts of both (1) and (2). South of Doublespring Pass road, the fault scarp postdates a possible old channel of Willow Creek (4) and a meander belt (5) in the bottom of the old channel. The pre-1983 channel of Willow Creek (6) was entrenched in the meander belt. Features (1)-(6) converge upstream toward a narrower part of the valley near Freighter Spring (pl.1). Future work near the spring may establish the overlapping age relations of these features.

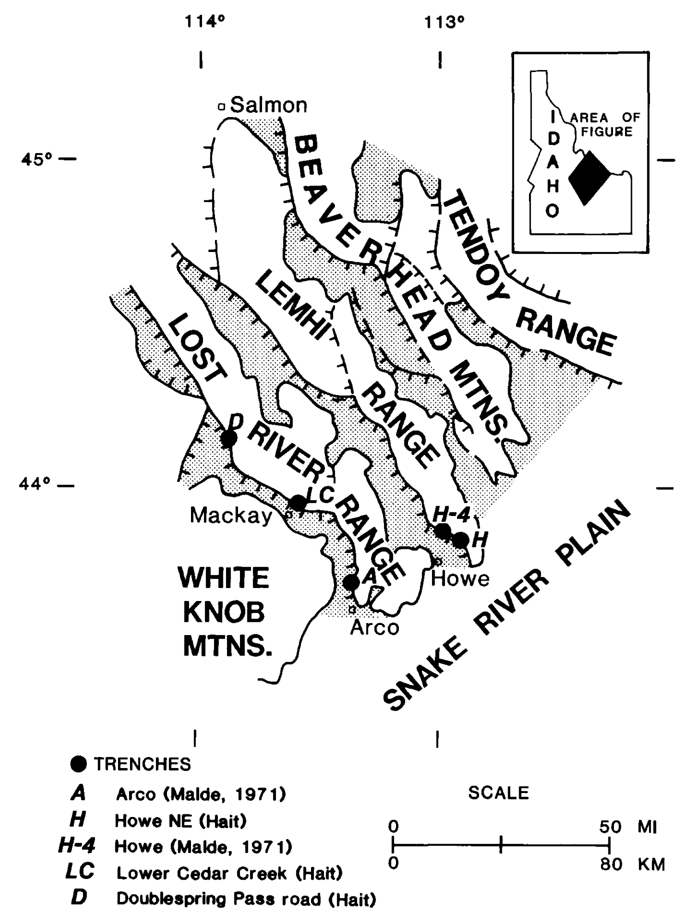

Figure 4. Location of fault scarps that have been trenched in east-central Idaho. Alluvial valleys are stippled. Normal faults shown by hachured lines; hachures on downthrown side.

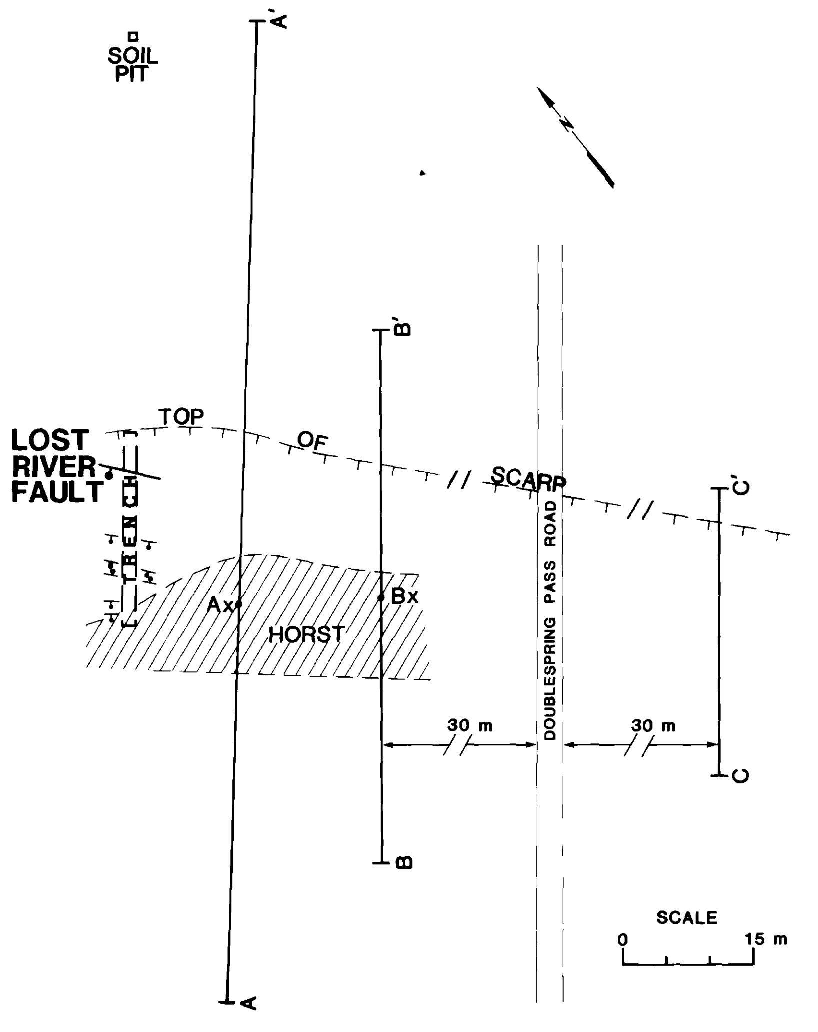

Figure 5a. Detailed map of Doublespring Pass road trench site. Profiles A-A′, B-B′ and C-C′ are shown in figure 5b. The soil exposed in the soil pit, described by W. E. Scott, is schematically shown in figure 8.

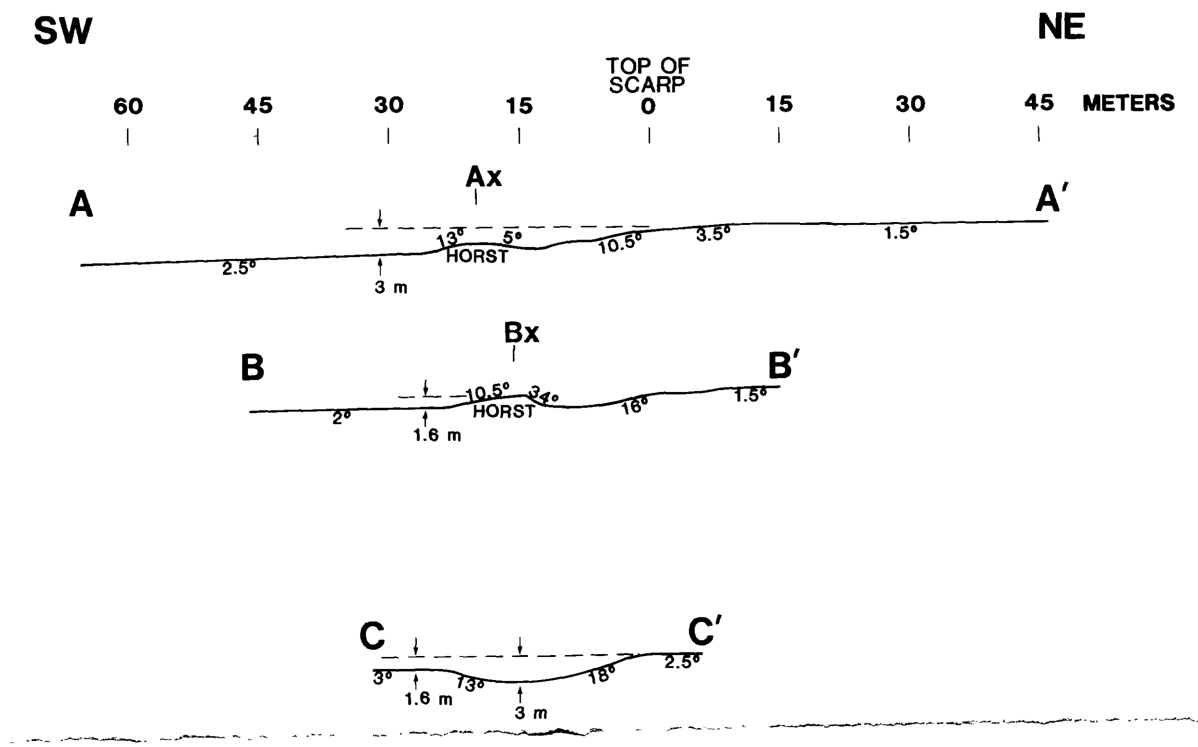

Figure 5b. Topographic profiles of the fault scarp near Doublespring Pass road prior to the 1983 earthquake. Location of profiles shown in figure 5a. No vertical exaggeration.

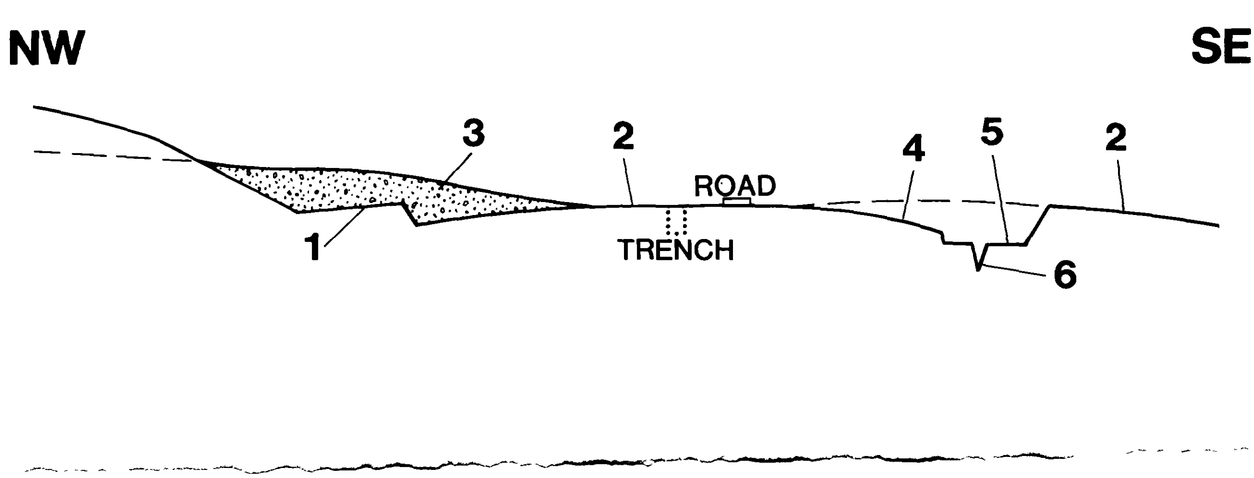

Figure 6. Schematic diagram of general relationships of geomorphic surfaces in the vicinity of the Doublesprings Pass road trench. Surfaces (1) through (6) are discussed in the text. Surfaces are not to scale.

Stratigraphy of the Trench

The trench (fig. 7) exposed a sequence of poorly- to well-bedded outwash gravels containing fine- to medium-grained sand stringers. The gravel beds were generally continuous through the trench.

Unit 1, thickness unknown, is poorly stratified gravel with enough fine sand and silt matrix to retain some moisture and give the unit a subtle muddy appearance.

Unit 2 is a prominent bed of well sorted pebbles, 30-37 cm thick with minor sand matrix.

Unit 3, the well-bedded upper part of the gravel sequence, includes a 25-45-cm-thick bed of pebbles that were stained yellow-ocher from oxidized iron. The uppermost gravel of unit 3 contains a buried soil (fig. 8) that has a cumulative thickness of about 70 cm. The buried soil in similar in development to Pinedale age soils in a soil pit on the outwash fan and on the Doublespring moraine (fig. 8) which is located about 6 km to the north-northeast (Hait and Scott, 1978; Scott, 1982). The soils at each of these sites are characterized by weakly calcareous, cambic B horizons about 20 cm thick and by 15-40-cm-thick C horizons with stage I-II carbonate development (W. E. Scott, 1984, written commun.).

Unit 4 is colluvium, composed of reddish-brown pebbly silt, deposited disconformably at the top of unit 3 between faults B and J.

Unit 5 is unsorted gravel that filled in around toppled blocks of units 3 and 4 that fell into the deep graben between faults I and J.

Unit 6 is compact, dark brownish silt locally preserved in the deep graben between faults I and J. It is apparently unconformable above the fill and toppled blocks in the graben.

Unit 7 is post-faulting colluvium, 15-90 cm thick, consisting of massive, tan, pebbly silt. It buries eroded edges of the faulted gravel and could be mapped from the northeast end of the trench to within 3 m of the southwest end.

Subsurface Evidence of Faulting

Steeply inclined to vertical disturbed zones representing both faults and in-filled cracks were mapped (A-M on figure 7). The faults and cracks have a variety of forms: curved with variable widths (I, M); en echelon right-stepping (E, F) and left-stepping (C); branching (J,K,L) and rejoining to enclose antithetic blocks (B) or horses (G).

The differential movement in the fault zones produced greater mixing of sand and gravel than in the cracks. Mixing in the cracks is caused only by infilling from slumping and collapse. Crack C had openings along its length about 5 cm or more wide that extended back into the trench wall at least 7-10 cm. They probably formed where loosened pebbles dropped into the crack, lodged against the walls, and formed a bridge.

Sequence of Events

The following sequence, listed from youngest to oldest, was deduced from stratigraphic/structural relationships in the trench and from geomorphic relationships in the vicinity of the fault scarp (fig. 6). Faults and cracks are assigned capital letters as shown in Figure 7; subscripts on faults denote possible recurrent movement. This sequence may overestimate the number of faulting events. Some of the events interpreted below may be based on evidence that resulted from settling or slumping of blocks, and may not be the result of actual tectonic movements.

Sequence of Deposition or Faulting Event	Description or Comment
Fault G_2, cracks E, F?, H	
Unit 7	colluvial silt
Faults J_2, I_2	
Unit 6	compact silt
Unit 5	fills in around toppled units 3 and 4
B_2, G_1, I_1, J_1	major surface faulting event; perhaps displacement also on C, D, E, F, H, K, L, M
unit 4	silt plus side valley fans to north and meander belt to south
Fault B_1	small thrust jostles unit 3 followed by normal antithetic block; unit 4 seems unaffected
unit 3	Pinedale outwash gravel; carbonate soil forms at top
unit 2	Pinedale outwash gravel
Fault A	cuts unit 1 with unknown displacement, overlapped by unit 2
unit 1	Pinedale outwash gravel

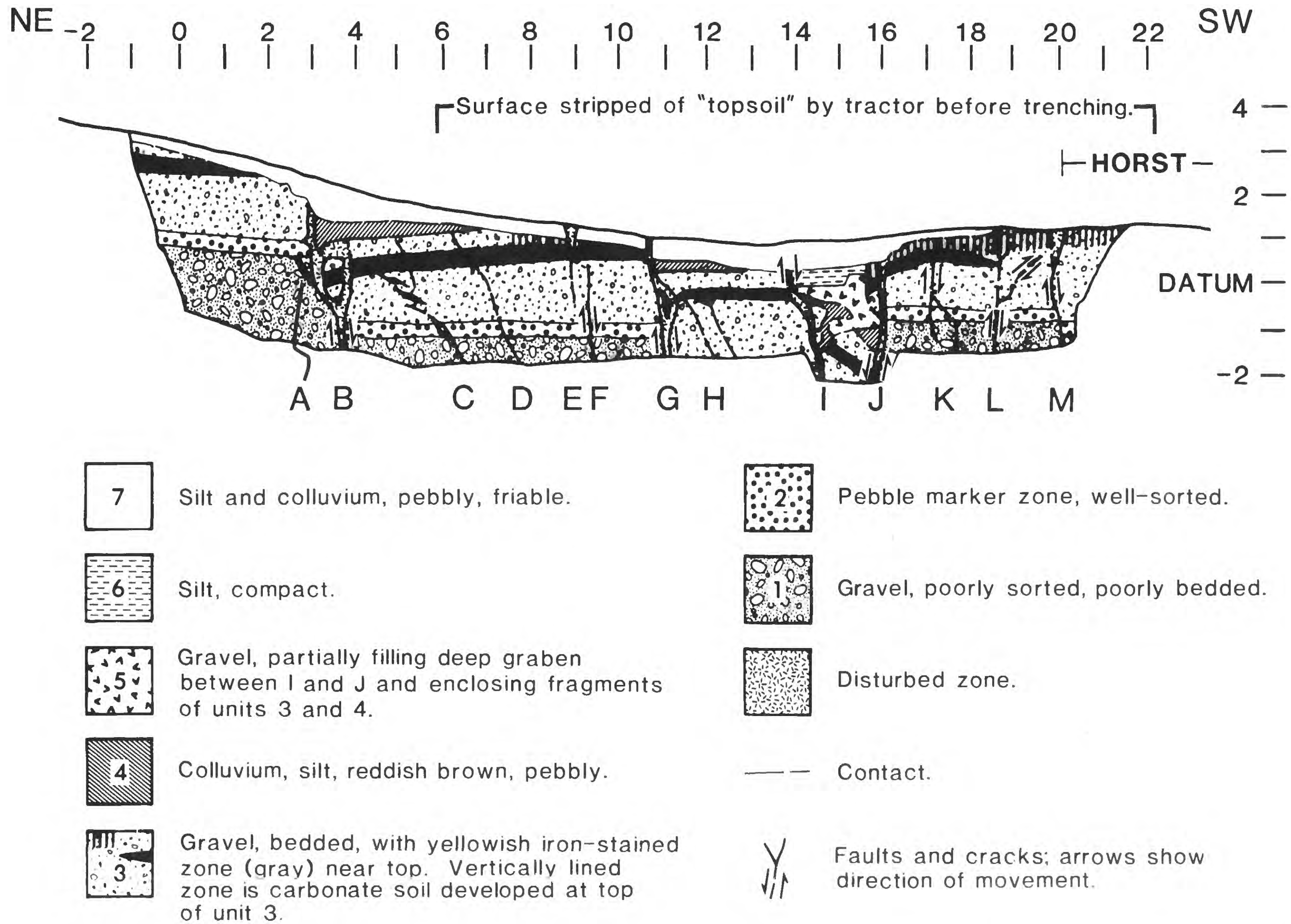

Figure 7. Generalized log of Doublespring Pass road trench. The stratigraphy (1-7), faults and cracks (A-M), and the sequence of events interpreted from relationships in the trench are discussed in the text. North wall of trench was mapped. Trench log has been reversed to have same perspective as log in Figure 3.

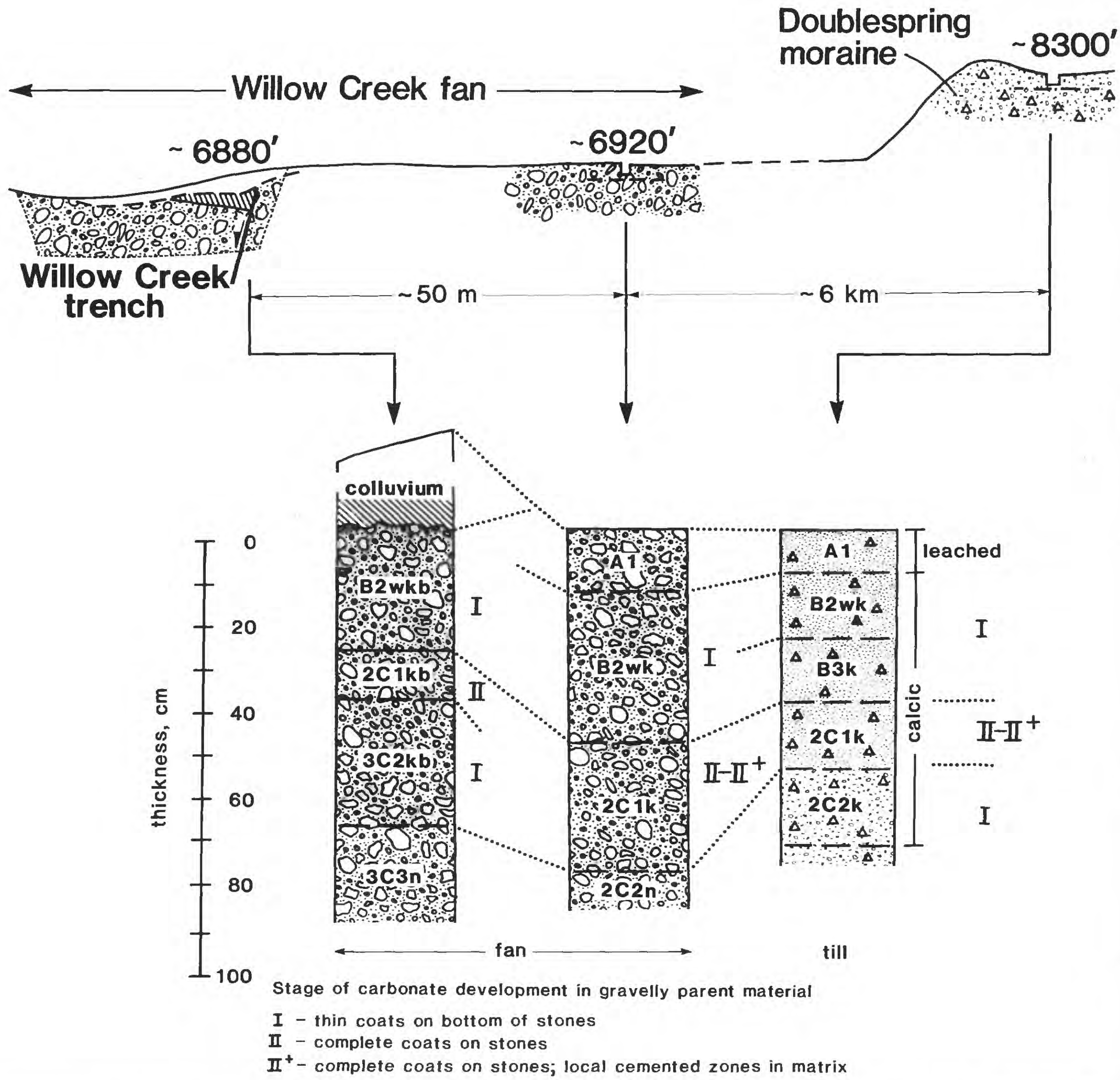

Figure 8. Schematic diagram of soil profiles developed on upper Pleistocene deposits in the area near the Doublespring Pass road trench. Location of the soil pit near the trench is shown in figure 5a. Soils data modified from W. E. Scott (1984, written commun.).

Return to vehicles. Proceed southwest on Doublespring Pass road toward U.S. Highway 93.

61.0 2.6 Junction of Doublespring Pass road with U. S. 93. TURN RIGHT. The historical sign on the right notes that Borah Peak was named after William E. Borah who was known as the "Lion of Idaho" and served in the U. S. Senate from 1907 to 1940. Dickey Peak (11,141 ft), at 2:00, is composed of limestones of the Upper Mississippian Middle Canyon and Scott Peak Formations

		(B. A. Skipp, 1984, oral commun.). The lowest shrub and brush covered hill at the edge of the valley between 2:00 and 3:00 is the "West Spring block" (pl. 1), composed of folded, fractured and sheared limestones of the Scott Peak Formation (Skipp, 1985). Recent mapping shows that the block is an isolated piece of bedrock, separated from the bedrock in the main range by a fault that has produced at least 200 m of stratigraphic omission (Skipp, 1985). Note the abundant small bedrock outcrops and the different appearance of the hill compared to the surrounding hills. Willow Creek Summit hills are at 11:00.
65.8	4.8	Road to Arentson Gulch. TURN RIGHT. 1983 scarps traverse the southwest flank of Dickey Peak between 10:00 and 11:00.
66.3	0.5	Road turns left through the fence. Stop here.

STOP 4: DICKEY PEAK AND ARENTSON GULCH OVERVIEW

From this view, the fresh scarps extending across the flank of Dickey Peak are obvious. One of the few places where bedrock has been exposed in the new scarps occurs on the west slope of Dickey Peak (pl. 2). At least three sets of slightly weathered slickensides are present on the bedrock surfaces. Based on their degree of preservation in the limestone bedrock, the slickensides are probably Quatenary in age; none of them appeared to be fresh enough to be the product of movement during the 1983 earthquake. The rake of the slickensides show that, in addition to the dominant dip-slip component, net slip directions from past movements on the fault plane have had both left- and right-lateral slip components.

Looking to the north, one can see west-trending scarps cutting across the hillslopes above Arentson Gulch (pl. 2). These scarps are part of the western segment of the fault scarps (the Arentson Gulch fault of Wallace, 1984) that diverge from the Lost River fault northwest of Dickey Peak. At Arentson Gulch, there is 1.4 m of throw and 0.6 m of sinistral slip on the fault. Westward, the displacement on the scarp diminishes and new ruptures are expressed mostly as a northwesterly-trending alignment of downhill-facing, arcuate scars, probably incipient landslides. Locally, there are offsets in valley floors and across ridgecrests.

Along the Lost River fault, there is a 4.8 km-long gap in 1983 surface faulting (pl. 2) that starts about 2 km northwest of where the western section diverges away from the range front. Quaternary fault scarps are locally present in this gap, indicating that surface faulting has occurred in the gap in the past. Northwest of the gap, scarps with up to 1 m of throw, occur along the Lost River fault (pls. 2 and 3), commonly as a single 1983 scarp on a preexisiting scarp.

Return to the vehicles, turn around and return to the main highway.

66.8	0.5	Junction of Arentson Gulch road and U. S. 93. (Note: BE SURE GATE IS CLOSED). TURN LEFT.
71.6	4.8	Doublespring Pass road on left. Continue straight.
73.4	1.8	Road to Birch Spring-Borah Peak. Continue straight.
76.5	3.1	Approaching Whiskey Springs lateral spread.

77.7	1.2	Junction of Trail Creek Road. TURN RIGHT. Chilly Buttes at 1:00.
78.0	0.3	Crossing Thousand Springs Creek.
79.9	1.9	TURN RIGHT on dirt road toward Chilly townsite. Elkhorn Creek at 3:00.
80.5	0.7	TURN LEFT toward Chilly Buttes. Buttes are straight ahead.
81.3	0.7	Crossing zone of linear fissures that extend north-northwestward toward Chilly Buttes. The fissures were 10 to 15 m long and only 5 to 10 cm wide.
81.6	0.3	Intersection with Chilly Buttes road. TURN RIGHT. Borah Peak at 2:00.
81.7	0.1	Notice the numerous fissures and craters in the fields at 2:00-3:00.
81.9	0.2	Pull off to the right side of the road and park.

STOP 5: CHILLY BUTTES GROUNDWATER ERUPTIONS AND SAND BOILS
(modified from Waag, 1985; Youd and others, 1985)

Immediately after the earthquake, violent eruptions of groundwater from the limestone bedrock on the flank of Chilly Buttes and from the adjacent alluvial plain created spectacular sand boils and huge temporary springs. The vigorous flow erupting from the alluvial plain, reportedly spewed water 4 to 6 m into the air, and left numerous craters, some more than 6 m in diameter and more than 2 m deep (fig. 9). The flowing water transported limestone clasts with maximum dimensions of 15 to 20 cm. The stratigraphy exposed in the wall of a 3 m by 5 m wide crater shows that the sediment deposited during the eruption was 25 to 35 cm-thick. Following the earthquake there were at least 47 craters larger than 0.6 m and 19 larger than 6 m. The largest crater was 22 m in diameter and about 5 m deep. Some of the craters existed prior to the earthquake and were reactivated during the event.

During the seismic shaking and for at least 48 hrs after, water at high artesian pressures erupted from solution-widened fractures in the limestone on the flank of the butte. The washout and fracture at this site can be traced upslope for at least 175 m. The highest eruption is about 30 m above the valley. No measurements of the flow of water from the fractures are available but elutriation of all but the largest clasts and the 4 m depth of the washout trench show that the velocity and volume of water were substantial.

Return to vehicles and turn around.

82.1	0.2	Road to Chilly townsite on left. Continue straight.
82.6	0.5	Road joins from right. Continue straight.
83.3	0.7	Junction with Trail Creek Road. TURN RIGHT. Return to Sun Valley and conference center.

END OF ROAD LOG

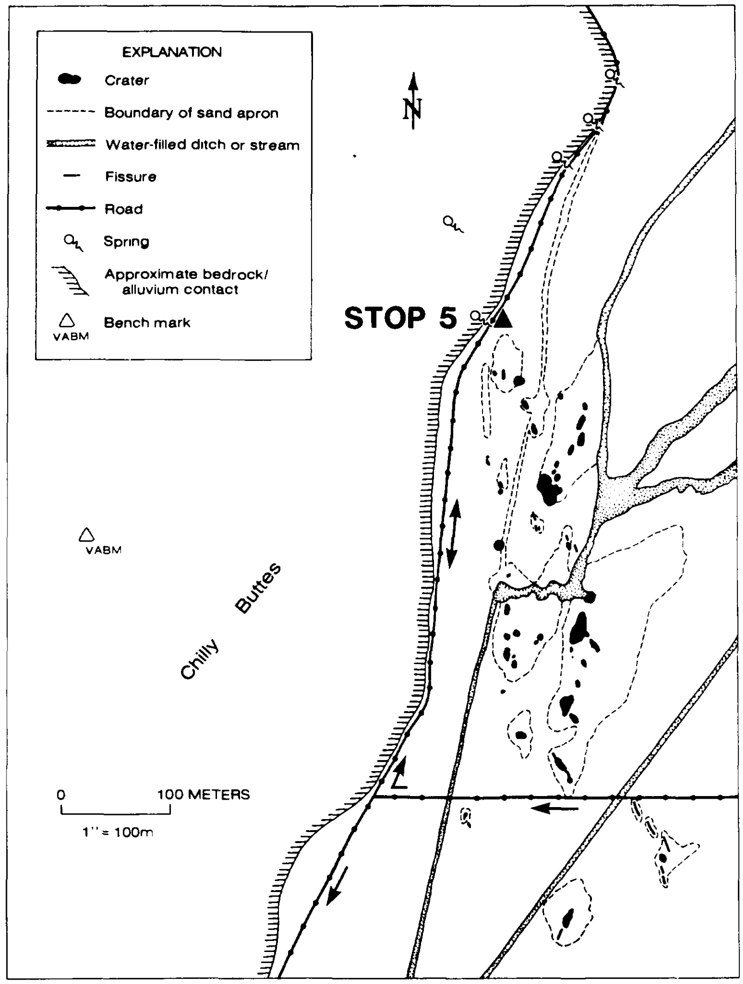

Figure 9. Generalized map of Chilly Buttes areas showing craters and areas covered by ejected sediment (modified from Youd and others, 1985). The buttes are composed of Paleozoic limestone.

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