Pleistocene Episodes of Alluvial-Gravel Deposition, Southeastern Idaho

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by

Kenneth L. Pierce[1] and William E. Scott[1]

ABSTRACT

In southeastern Idaho, extensive gravel deposits occur on alluvial fans and along major streams. Gravel deposits of late Pleistocene age occur in each drainage; older gravel deposits form terraces or are buried by the younger gravels. Ages of these deposits are estimated from stratigraphic relations to glacial deposits, sequence relations, degree of soil development, thickness of carbonate coats on stones in soils, thickness and stratigraphy of loess mantles, and radiometric ages. These Pleistocene gravel deposits are characterized by (1) a clast-supported fabric that either is openwork or has a loose sand matrix that generally does not completely fill the spaces between clasts, (2) less than a few percent silt and clay, (3) sorting such that three-fourths of the material in a given exposure is restricted to 4 phi units in the gravel range and even better sorting in individual gravel beds, (4) subhorizontal beds decimeters thick and planar for distances of more than 5 meters, (5) a scarcity of fine-grained beds, and (6) general absence of matrix-supported beds. In contrast, Holocene alluvium is dominantly fine grained and is confined largely to upland valleys and to floodplains. Mudflow deposits are uncommon, except within the mountains and at the heads of small alluvial fans.

These late Pleistocene and older gravels were deposited by streams with sustained seasonal flows probably at least ten times larger than discharges of present streams. Glacial meltwater is only locally a factor in increased discharges because gravels in unglaciated drainages are similar in age and character to those in glaciated drainages. High flows caused by an increase in precipitation do not seem likely because during glacial times the northern Pacific Ocean, which is and was the moisture source for southern Idaho, was colder than at present. Factors thought to be responsible for markedly increased seasonal discharges are (1) a thicker cold-season snowpack resulting from climates as much as 10-15°C colder than present, (2) later and more rapid seasonal melt of this snowpack, and (3) surface runoff, rather than ground-water underflow, of most of this increase in seasonal discharge.

Stabilized rubbly colluvium on mountain slopes suggests that the periglacial conditions of the Pleistocene produced a greater supply of gravelly debris to streams. In contrast, much of the sediment now transported by streams is derived from erosion of loessial deposits that mantle much of the landscape.

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INTRODUCTION

In 1974 when we started our surficial geologic studies in the Basin and Range province[2] of Idaho, we expected to find recent, widespread mudflow and flash-flood deposits forming large alluvial fans. In contrast, we determined that the alluvial fans are largely relict Pleistocene landforms, consisting of well-washed, relatively coarse-grained gravel. This gravel was deposited during discrete episodes that were probably broadly coincident with Pleistocene glacial ages. Holocene sediments are mostly fine grained and are probably largely reworked loess. They are restricted to small deposits along major drainages, where they cover late Pleistocene gravels. This contrast in almost every drainage between the gravel deposition during late Pleistocene time and the mud deposition in Holocene time documents a marked change in stream competency.

In southeastern Idaho, these aluvial gravels are areally much more extensive than glacial deposits and provide a much more visible manifestation of Pleistocene climates. In this report we give examples from sites on and adjacent to the eastern Snake River Plain that illustrate (1) the character and origin of alluvial-fan and main-stream gravels and (2) the evidence for their deposition during gravel-depositing episodes of

[2]For the purposes of this report, we include the Lost River, Lemhi, and Beaverhead Ranges, which lie north of the Snake River Plain, in the Basin and Range province.

Pierce, K. L. and W. E. Scott, 1982, Pleistocene episodes of alluvial-gravel deposition, southeastern Idaho, *in* Bill Bonnichsen and R. M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 685-702.

late Pleistocene and older ages. In addition, we speculate on the conditions that favored gravel deposition during these episodes and offer recommendations for future studies.

Historical observations of flash floods and mudflows on alluvial fans in the Great Basin have led to the inference that these processes are important in the construction of alluvial fans throughout the Basin and Range province. Blackwelder (1928) described the historic Willard mudflow on the alluvial fan at the mouth of Willard Canyon along the Wasatch Front, and noted that mudflow and flash-flood deposits are widespread on alluvial fans in the Basin and Range province. Clayton (1981) studied three fans in southeastern Idaho that showed evidence of late Holocene activity. Although alluvial fans whose surface is underlain by Holocene deposits do occur in southeastern Idaho, they are small and generally restricted to two settings: (1) relatively low-gradient fans of fine-grained alluvium built out onto nearly flat bottomlands of the axial drainages, and (2) very steep fans composed of bouldery deposits derived from precipitous source areas and carried down steep drainages to the fan heads.

Our conclusion that alluvial-fan and main-stream gravels were deposited by streams with sustained flows much greater than at present was first presented in a report on the Raft River Valley (Williams and others, 1974). While we continued our studies in Idaho, Funk (1976) completed a study of sedimentary characteristics of fan gravels in the Birch Creek valley and concluded that these gravels were also deposited by sustained stream flows much larger than at present.

DESCRIPTION OF GRAVEL DEPOSITS

GEOLOGIC SETTING

Quaternary gravel deposits in southeastern Idaho occur both in the basins of the Basin and Range province and on the Snake River Plain (Figure 1). These sites of gravel deposition were formed by middle to late Cenozoic extensional faulting and volcanic activity. Nearby uplifted areas contributed gravel to stream systems that deposited gravels in the basins. The timing and character of gravel deposition appear to have been strongly affected by Pleistocene climate changes. Similar changes in stream regimen in both glaciated and unglaciated drainages provide compelling evidence for climatically induced changes in Pleistocene stream discharges that were unrelated to the direct effects of glaciation.

ALLUVIAL FANS OF UNGLACIATED DRAINAGE BASINS

Raft River Valley

A 10- to 15-kilometer-wide apron of large alluvial fans covers most of the floor of the Raft River Valley, which extends 65 kilometers south from the Snake River Plain to the Utah border (Figure 1; Williams and others, 1974; Pierce and others, in press). Except for parts of the Raft River Range at the south end of the valley, the flanking ranges did not support significant glaciers in Pleistocene time.

Cottonwood Creek fan. A typical alluvial-fan sequence was deposited by Cottonwood Creek near the Raft River geothermal site about 20 kilometers south of Malta (Figure 2). The age sequence of this and other fans can be determined by (1) geomorphic relations, (2) amount of dissection by drainages heading on the fan, (3) degree of soil development, and (4) relations to faults of mid-Quaternary age. The youngest fan deposit of the Cottonwood Creek sequence forms a wedge-shaped, smooth, nearly undissected surface mantled by about 20 centimeters of eolian silt. This fan deposit heads at a distance of 6 to 8 kilometers from the front of the Jim Sage Range. The surface of the fan slopes about 1.3 degrees, and its distal portion is buried by fine-grained Holocene alluvium along the Raft River.

Borrow pits in the youngest fan gravel, 1 kilometer west of Bridge, expose more than 2 meters of gravel. The gravel has a clast-supported (stone-on-stone) fabric; the space between the stones either is filled with sand or is openwork. Fine-grained beds are rare except in soil horizons, and silt and clay are estimated to constitute only a few percent of the deposit by comparison with other gravels analyzed for grain size. We use the term well-washed to reflect this paucity of silt and clay in the gravel beds. The surface soil in this deposit is weakly developed and has similar depth of oxidation and carbonate content as do soils in deposits of the high stand of Lake Bonneville at Kelton Pass, 20 kilometers southeast of Cottonwood Creek. As these Lake Bonneville deposits have been exposed to weathering since the Bonneville Flood, which occurred 14,000 to 15,000 years ago (Scott and others, 1982 this volume), this similarity suggests a late Pleistocene age for the youngest gravels of the Cottonwood Creek fan.

Older gravels of the Cottonwood Creek fan are well exposed in a large gravel pit south of the youngest fan deposit (Figure 2). The older gravels are similar to the younger gravels in having a clast-supported framework in both openwork beds and beds with a matrix of coarse sand (Figure 3). The gravel beds contain almost no silt or clay. Most beds

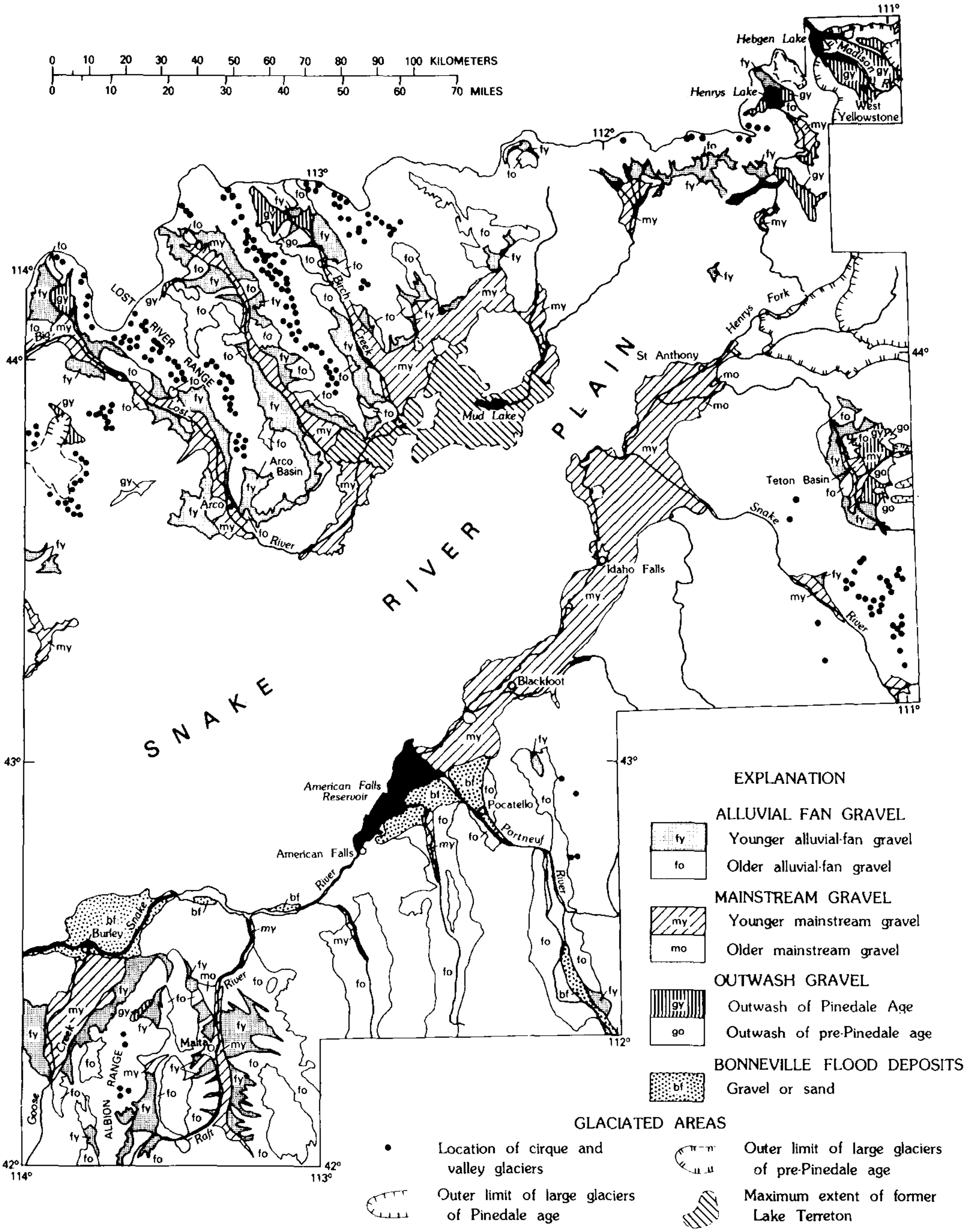


Figure 1. Map showing Pleistocene gravel deposits, glaciated areas, and extent of former Lake Terreton, in southeastern Idaho (modified from Scott, in press and Pierce, 1979).

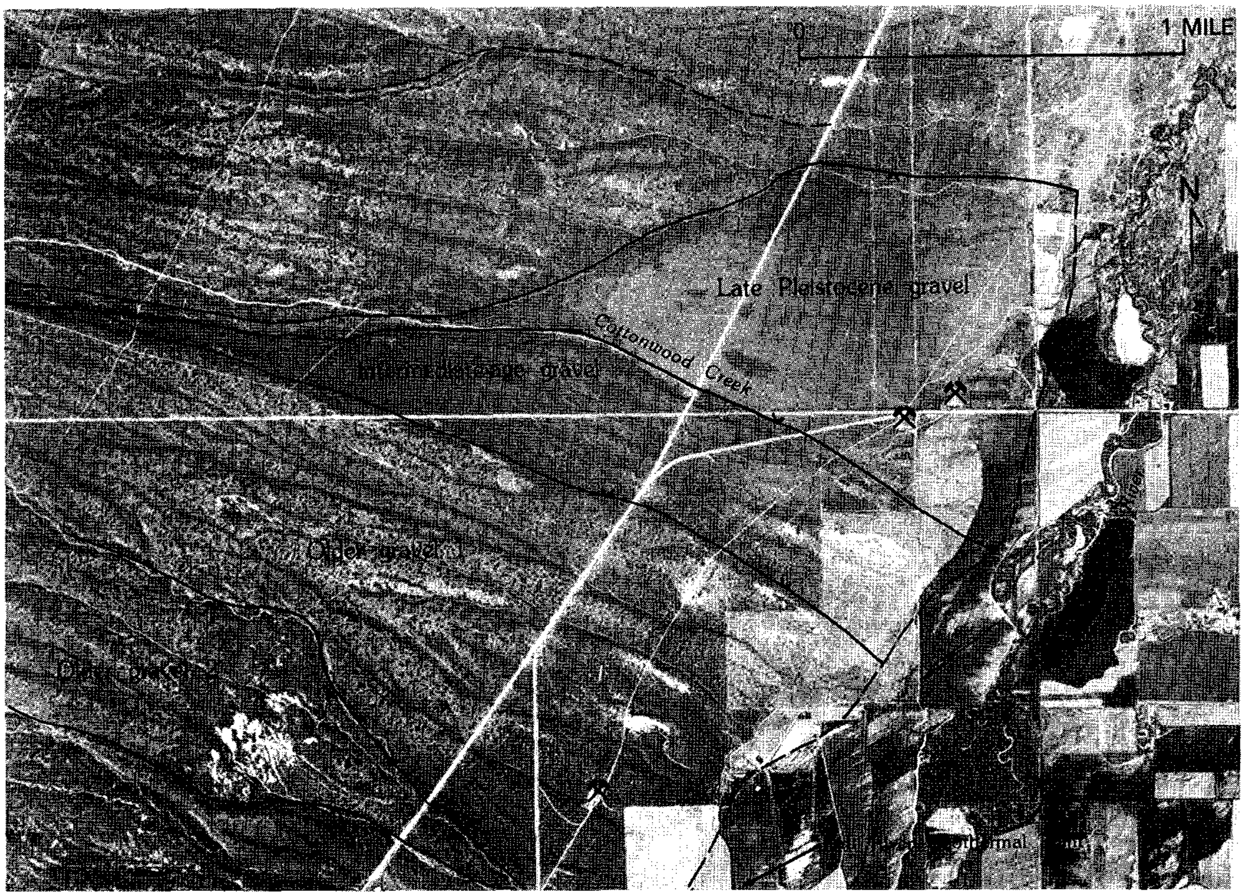


Figure 2. Vertical aerial photograph of Cottonwood Creek fan, Raft River Valley, showing contrast between smooth, wedge-shaped, late Pleistocene deposits and partly dissected older deposits. Age sequence indicated by carets, which are on younger side of contact between deposits of different ages.

are about 0.25 meter thick and are laterally continuous for more than 5 meters. Channels can be seen in cross section; one is about 2 meters wide and 0.5 meter deep. Larger channels probably exist but are difficult to trace in the gravel. Crossbedding is present in some channel deposits. Longitudinal exposures show imbrication of tabular stones. Beds with a muddy matrix were not seen. Boulders as large as 25 by 15 by 15 centimeters are present, and percussion marks are common on large stones of glassy rhyolite. The exposures show an upper gravel about 5 meters thick that partly truncates a silty, calcic soil developed in an older gravel unit.

Holocene deposits of Cottonwood Creek are largely fine grained and are confined to valleys in the Jim Sage Range and to the trench leading from the range to the apex of the youngest fan deposit (Figure 2). During the large spring runoff of 1975, Cottonwood Creek was only about 0.1 meter deep and 0.5 meter wide in the channel at the margin of the youngest fan deposit; the water was clear and was not transporting gravel.

Meadow and Sublett Creek fans. The combined fans of Meadow and Sublett Creeks on the eastern side of the Raft River Valley about 5 kilometers east of Malta (Figures 1 and 4) form large late Pleistocene alluvial fans, yet modern streamflow is generally nonexistent on these fans. These two fans cover about 125 square kilometers and were deposited by streams from the southwestern Sublett and northeastern Black Pine Ranges. Except for sand and loess dunes, the fan surfaces are flat and slope only about 0.5 degree. A loess mantle about 0.5 meter thick facilitates farming of the surface of these fans.

Particle-size analyses by the Idaho Department of Highways of samples from test holes on the fan adjacent to Interstate Highway 84 (Figure 4) show that the gravel is remarkably well washed (Figure 5). The gravel generally contains only 1 to 5 percent silt and clay. Individual samples from the test holes include several beds and have inclusive graphic standard deviations that average -2.4 ± 0.3 (in phi units), indicating they are "very poorly sorted" (Folk, 1968), but this sorting nomenclature is not very useful in making distinctions among alluvial gravel deposits. Individual beds are better sorted than the deposit as a whole and seem to us to be as well sorted as an alluvial gravel in this environment can be. The mean grain size of the gravels decreases down-fan from about 9 ± 3 millimeters (1 S.D.; n=44) 3 kilometers from the fan head to about 5.5 ± 1 millimeters 10 kilometers farther down the fan (Figure 6). The weight percent of gravel larger than 50 millimeters in diameter decreases from about 5 percent to about 0 percent over the same distance (Figure 6).

Soils in these loess-mantled fan gravels are weakly developed. The carbonate-enriched (Cca) horizon is from 0.2 to 0.4 meter thick and locally contains a 1-centimeter-thick cemented layer. Carbonate coats on the undersides of stones in the Cca horizon at three different localities average 0.4 ± 0.3 millimeter, 0.6 ± 0.3 millimeter, and 0.8 ± 0.3 millimeter (Pierce and others, in press). This variation probably reflects differences in the time since the last activity on different portions of the fan, but the three localities are all considered to represent the last episode of gravel deposition.

No Holocene alluvial deposits were found on these two fans. Holocene alluvium of silt to silty gravel is present along the streams within the ranges, and it mantles the floors of the trenches at the fan heads (Figure 4). Stream-gauge records cover only a few years. In the 1966 water year, the maximum recorded discharge of Sublett Creek within the mountains was only 0.08 cubic meter per second (2.7 cubic feet per second), and in the 1965 and 1966 water years, no flow was recorded along Meadow Creek (Thomas, 1967, p. 65, 62).

Fans Near Southern End of Lost River Range

Although the higher parts of the central and northern Lost River Range were glaciated, the southern end of the range was not. The fan gravels in this area consist almost entirely of carbonate rocks.

Arco basin. The broad valley northeast of Arco, here called the Arco basin (Figure 1), is floored by coalescing alluvial fans that almost entirely date from the last episode of gravel deposition. The area covered by these young fan gravels is approximately 50 square kilometers; the size of the drainage basin feeding them is about 100 square kilometers. The surface of the fans is mantled by about 0.5 meter of loess. At present no perennial streams flow through the Arco basin. Carbonate coats on limestone clasts in surface soils are 1.3 ± 0.5 millimeters (1 S.D.) thick at a site near the Big Lost River and 1.0 ± 0.3 millimeter at a site near the head of the basin. These thicknesses of coats on limestone clasts are similar to those in soils in the younger fan gravels and glacial outwash of Pinedale age to the north in the Big Lost River valley (Table 1). The gravels exposed at the outlet of the basin are well washed, containing no more than a few percent silt and clay.

Alluvial fans north of Arco. Sequences of gravel deposits of small alluvial fans of various ages occur at the mouths of the unglaciated drainages on the west side of the southern part of the Lost River Range (Figure 1). At the range front, the older fans are offset by the Arco fault scarp, and younger fans have been deposited on the downdropped side of the fault. The Arco fault scarp is prominently expressed at the foot of this relatively low segment of the Lost River Range that extends for about 15 kilometers north of Arco (Malde, 1971).

The argument for Pleistocene gravel-depositing episodes is somewhat complicated in this area of small fans, because Holocene deposits of angular gravel have accumulated as pods along stream channels where the steep drainages debouch from the mountain front. Nevertheless, exposures of young fan deposits away from the fan heads generally show well-washed gravel with soils and carbonate coats indicating a late Pleistocene age. Only one mudflow deposit was noted in several gravel-pit exposures. Further north in the Lost River Valley at the base of Borah Peak, bouldery mudflows of late Holocene age occur on the surface of the Elkhorn fan (Clayton,

Figure 3. Photograph of gravel beds in older fan deposits of Cottonwood Creek, Raft River Valley. Note coarse-grained gravel beds with clast-supported framework and openwork beds. Pick head is 30 centimeters across.

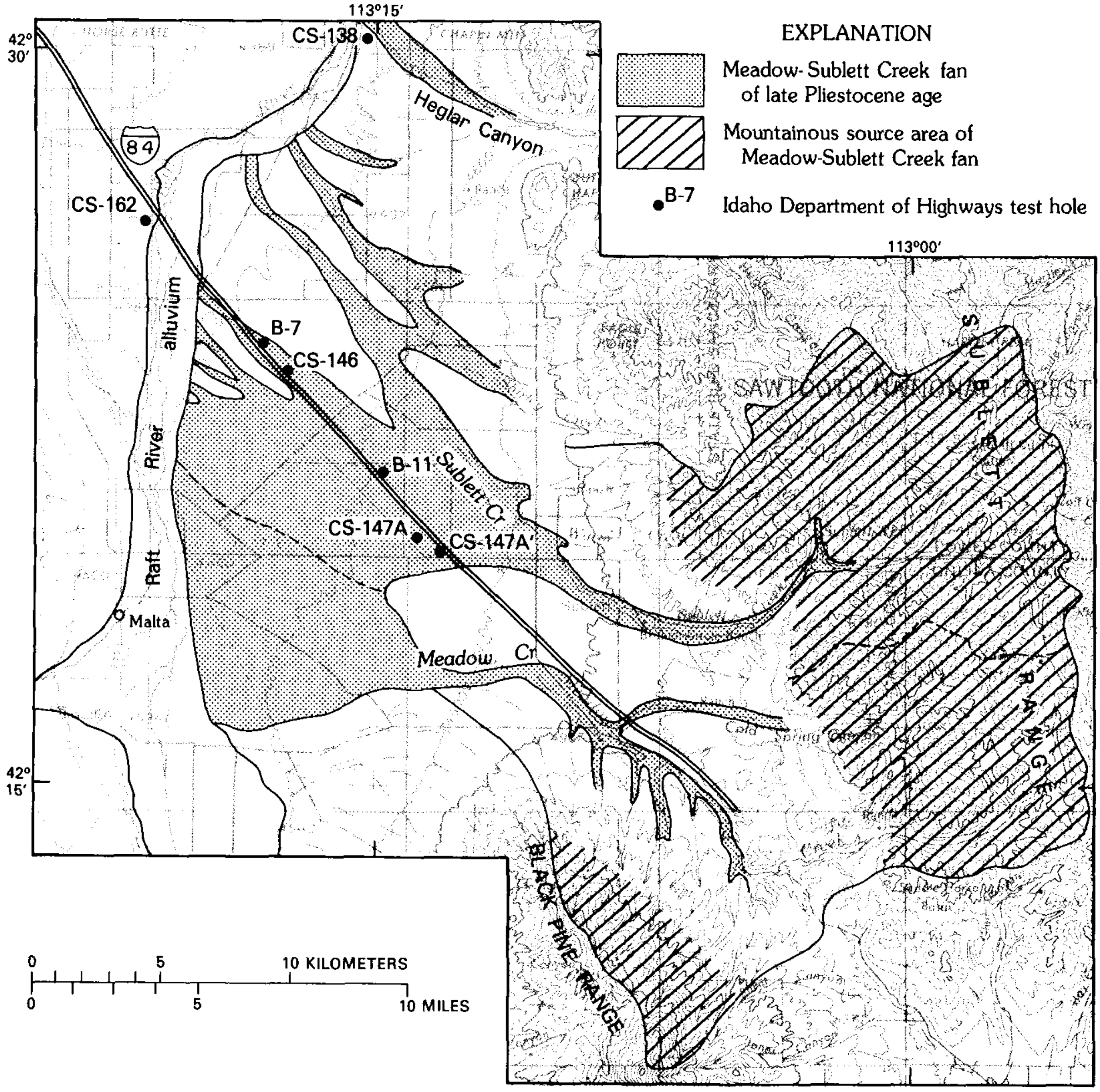


Figure 4. Map of combined alluvial fans of Meadow and Sublett Creeks, Raft River Valley, showing fan deposits of the last episode of gravel deposition.

1981, p. 34). The upper part of this fan slopes 9 degrees and the mountain front draining to the fan abruptly rises 1,500 meters within 5 kilometers of the fan head.

The best evidence that these fans are relicts of Pleistocene conditions comes from the measurement of carbonate coats on stones from the upper part of calcic horizons developed in the youngest fan gravels (section 35 fan, King Canyon fan; Table 1). The coats from the youngest fans are about 1 millimeter thick, about the same as those from outwash and moraines of Pinedale age in a similar climatic environment along Willow Creek, 70 kilometers north of Arco (Table 1). Therefore, the youngest extensive fans near Arco are probably latest Pleistocene, or Pinedale, in age (Table 1). Small deposits having weaker soils with thinner carbonate coats occur along modern drainageways (Table 1); these deposits are probably Holocene in age.

ALLUVIAL FANS OF PARTLY GLACIATED DRAINAGE BASINS

Alluvial fans formed by gravels similar to those of unglaciated drainage basins occur downstream from mountainous source areas that were only partly covered by Pleistocene glaciers.

Ramshorn Canyon Fan

Nearly the entire surface of the Ramshorn Canyon fan in the southern Big Lost River valley (Figure 1, 20 kilometers north of Arco) was formed during the last gravel-depositing episode (Figure 7). The mean thickness of carbonate coats on stones in surface soils from five sites on this fan ranges between 1.0 and 1.3 millimeters, which suggests a Pinedale age (Table 1). Small cirque glaciers occupied less than 10 percent of the Ramshorn Canyon drainage, but during late Pleistocene time, snowmelt from the relatively high, unglaciated terrain of the basin probably contributed much more runoff than melting of the small amount of glacial ice. The vigor of the late Pleistocene streams is reflected in the pattern and size of braided channels on the fan (Figure 7). Loess of late Pleistocene age is thin or absent on the surface of the fan, but small drifts of loess are present in the lee of small fluvially undercut scarps.

Only minor Holocene deposition has occurred on this fan, primarily along a small incised channel (Figure 7). Before 1959, an earthen dam was constructed across this channel, but it was subsequently breached by the stream. A large rockslide of Holocene age has blocked the north fork of Ramshorn Canyon and prevents sediment carried by flash floods from more than half of the drainage basin from reaching the fan head.

Birch Creek Valley

Most of the alluvial fans in the western and

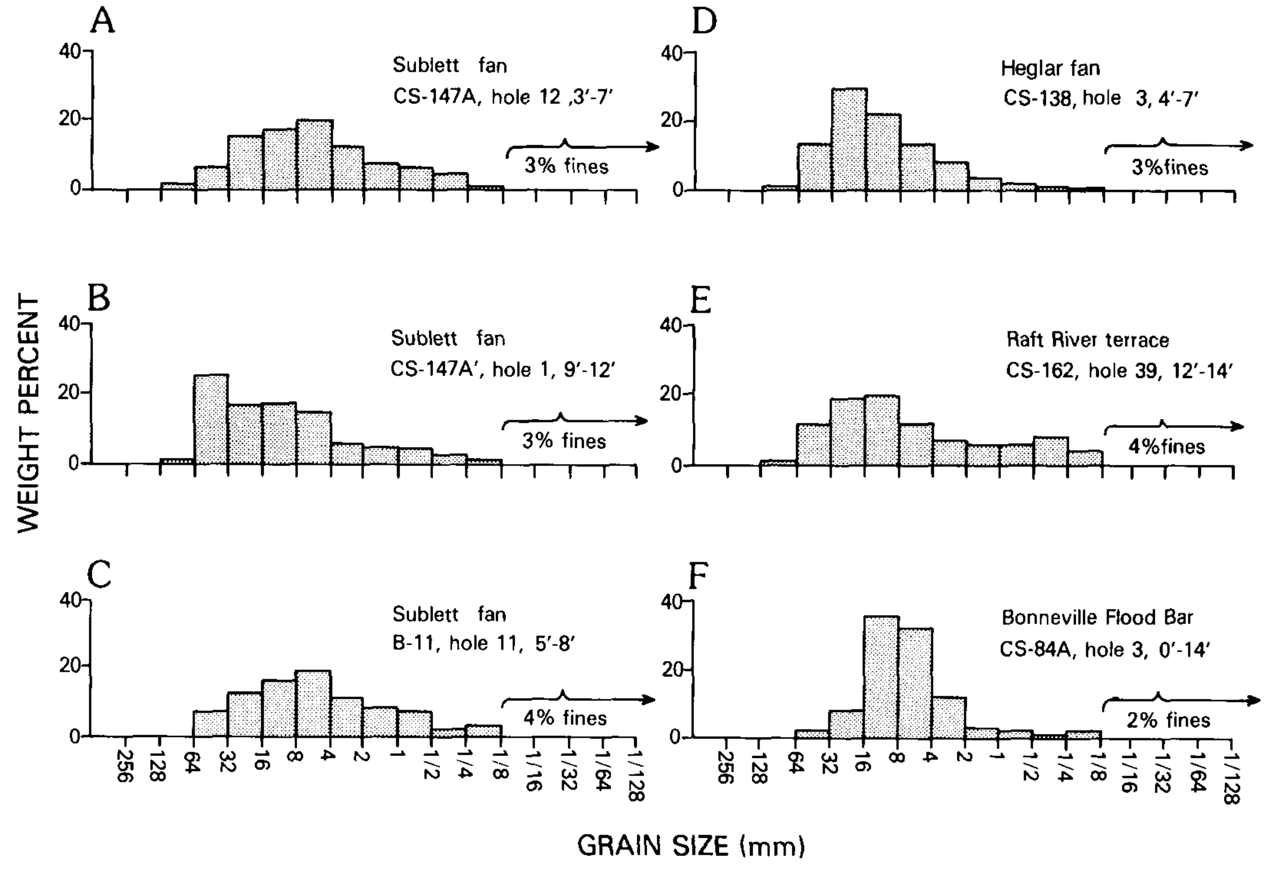


Figure 5. Particle-size distributions of bulk samples of alluvial-fan gravels, Raft River terrace gravels, and Bonneville Flood deposits, Raft River Valley. Grain-size data is derived from cumulative curves plotted from sieve data of the Idaho Department of Highways, Jerome, Idaho.

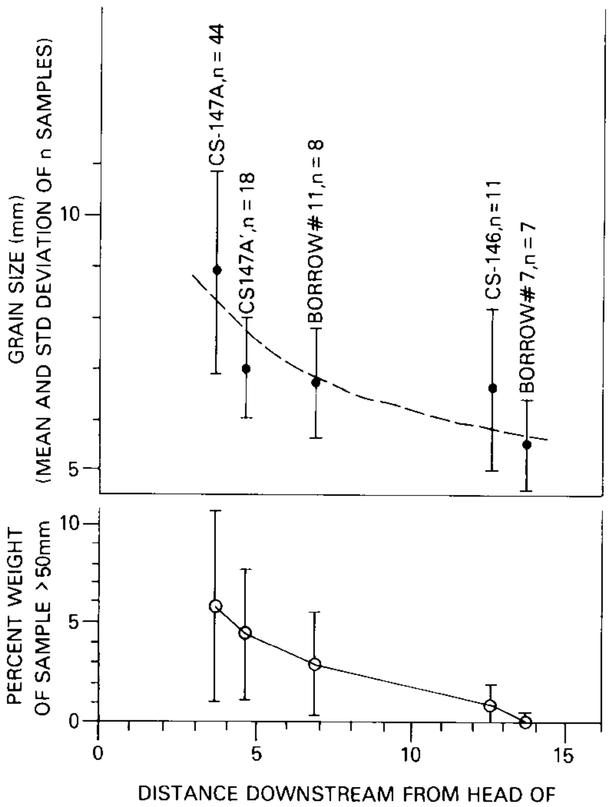


Figure 6. Plot of average grain size and weight percent of gravel coarser than 50 millimeters against distance from the fanhead for the Meadow-Sublett Creek fans, Raft River Valley, Idaho. Trend lines visually fitted. Data derived from cumulative curves plotted from sieve data of the Idaho Department of Highways, Jerome, Idaho.

northern Birch Creek valley (Figure 1) came from drainages that contained valley glaciers, some as long as 6 kilometers (Knoll, 1977). Other fans, particularly those from the southwestern Beaverhead Range, have unglaciated source areas.

Funk (1976) studied the sedimentary characteristics of the fan deposits in the valley and estimated that 90 percent of the fan deposits consist of gravel with clast-supported framework. This clast-supported gravel consists of equal parts of two facies: (A) beds averaging 0.25 meter thick of fining-upward gravel that commonly are openwork in the lower, coarser part and (B) beds of ungraded gravel averaging 0.5 meter thick that commonly have a framework filled with coarse sand.

Funk (1976, Figure 43) also noted two types of bimodal partical-size distributions (Figure 8). In his type I, the sand mode is clearly separate from the gravel mode, whereas in his type II, the two modes overlap (Figure 8). In both types about three quarters of a gravel bed is restricted to 2.3 phi units (Figure 8). Type I gravels are characteristic of braided-stream deposits (Glaister and Nelson, 1974); type II deposits are less definitive but are also characteristic of fluvial environments (Vischer, 1969). Both types result from mixing of bedload and suspended load (70 to 80 percent bedload and 20 to 30 percent suspended load) in a fluvial environment. The dominance of coarse bedload indicates transport under upper-flow-regime conditions (Funk, 1976, p. 127).

Based on the relation of facies, particle-size distributions, bedding features, and fabrics, Funk (1976, p. 130, 144) concluded that deposition of the fan gravels occurred in a high-energy, braided, fluvial system characterized by fluctuating water and sediment discharges, high-regime flow, and rapid aggradation. Deposition occurred mainly in shifting channels and bars of braided streams during waning flows after higher discharges had transported the gravel downstream. According to Funk (1976, p. 144):

> *Well-graded units with a well-developed fabric were probably deposited in bars, whereas poorly sorted units lacking a distinct fabric are most likely channel-fill deposits. Units with intermediate characteristics reflect a combination of channel and bar deposits.*

Debris-flow, flash-flood, or mudflow deposits are conspicuously absent in the alluvial-fan deposits in the Birch Creek valley, although mudflow deposits are present locally in cirques (Knoll, 1977). For the fans in Birch Creek valley, as for alluvial fans elsewhere in southeastern Idaho, the debris-flow model commonly used elsewhere in the Basin and Range province is clearly not appropriate. The alluvial-fan systems are essentially inactive under the prevailing climatic and hydrologic regimes; gravel deposition occurred under conditions of much greater sustained discharge and sediment yield than at present (Funk, 1976, p. 132, 215).

ALLUVIAL FANS OF EXTENSIVELY GLACIATED DRAINAGE BASINS

Alluvial fans downstream from extensively glaciated areas are conventionally interpreted as outwash fans of Pleistocene age. Although the outwash contribution to alluvial fans that had large glaciers in their source areas is important, the fact that unglaciated basins produced similar gravel fans, suggests that, even in glaciated drainages, factors other than outwash deposition were significant in forming gravel fans.

In the ranges north of the Snake River Plain (Figure 1), outwash locally can be traced from moraines of Pinedale age directly to large alluvial fans, such as at (1) Cedar Creek and Willow Creek in the Borah Peak area of the Big Lost River valley

(Scott, in press), (2) Bell Mountain and Spring Mountain canyons in the Birch Creek valley (Knoll, 1977; Funk, 1976, Figure 24), (3) Targhee Creek in the Henrys Lake basin (Scott, in press), and (4) West Yellowstone basin (Pierce, 1979, Figure 35). In addition to these geomorphic relations, soil development and thickness of carbonate coats on stones in Cca horizons (Table 1) suggest that these fan gravels were deposited during the last, or Pinedale, glaciation.

South of the Snake River Plain (Figure 1), outwash can be traced directly from Pinedale moraines to fan gravels at Marsh Creek on the east side of the Albion Range and at Clear Creek on the north side of the Raft River Range. The next range east of the Raft River Valley where glaciers reached the range front is the Teton Range. At the mouth of Teton Canyon, outwash forms both a fan deposit of Pinedale age and a loess-mantled fan deposit of Bull Lake age (Pierce and others, 1982 this volume, Figures 2 and 3).

MAIN STREAM GRAVELS

The main streams deposited extensive gravel fills in late Pleistocene time (Figure 1). The source areas of the Henrys Fork and of the Snake River upstream from Palisades Reservoir contained extensive glaciers; however, other main streams that deposited extensive gravel fills during late Pleistocene time have mountainous source areas in which there was little glaciation. Crude estimates of the amount of unglaciated, mountainous source areas of main streams drainages are: Goose Creek, 99 percent; Raft River, 98 percent; Big Lost River, 90 percent; Little Lost River, 95 percent; Birch Creek, 95 percent; and Snake River downstream from Idaho Falls, 90 percent. Thus, although glaciation in source areas is important to gravel deposition in some main streams, other causes must be involved.

Raft River

Deposits of the Raft River demonstrate a late Pleistocene to Holocene change in stream competency. Excavations and logs of water wells show that gravel with a clean, sandy matrix underlies 3 to 5 meters of fine-grained Holocene alluvium that floors the 1- to 3-kilometer-wide bottomland along the Raft River (Williams and others, 1974; Pierce and others, in press). The gravel probably was deposited by a

Table 1. Mean thickness of carbonate coats (in mm ± 1 S.D.) on limestone clasts from surface soils in alluvial-fan deposits, west side of the Lost River Range. Line of asterisks (*) identifies age of the youngest surface-faulting event on the Arco fault scarp (K. L. Pierce, unpublished data).

LOCATION	AGE								
	Holocene	Late Pleistocene					?	Middle(?) Pleistocene	
		A	B		B′	C			
Willow Creek									
Fan of Pinedale age		1.3 ± 0.2							
Outwash of Pinedale age		1.0 ± 0.4							
End moraine of Pinedale age		1.4 ± 0.4							
Ramshorn Canyon fan		1.2 ± 0.4			2.6 ± 1.5				
		1.3 ± 0.5							
		1.1 ± 0.4							
		1.3 ± 0.4							
		1.0 ± 0.3							
King Canyon fan		0.9 ± 0.3	1.7 ± 0.5	*	1.5 ± 0.7			6.9 ± 2.6	
		1.1 ± 0.4	1.6 ± 0.4	*	2.0 ± 0.6			6.2 ± 2.1	
			1.5 ± 0.5	*	2.1 ± 0.7				
				*	2.2 ± 1.0				
				*	2.3 ± 1.0				
Section 35 fan	0.3 ± 0.3	0.9 ± 0.4	1.7 ± 0.7	*			3.3 ± 1.3	5.0 ± 2.4	10.1 ± 5.4
		0.8 ± 0.8	1.5 ± 0.5	*			2.3 ± 1.1	5.1 ± 1.4	
			1.2 ± 0.6	*			3.2 ± 1.5		
				*			4.3 ± 2.1		
Arco basin		1.0 ± 0.3							
		1.3 ± 0.5							

large braided stream. Flanking these bottom lands are two wide belts of coalescing alluvial fans discussed previously.

The character of the main stream gravel is best seen in exposures of an older but similar gravel of the Raft River in pits north and south of the Interstate Highway 84 crossing of the Raft River (Pierce and others, in press). This gravel contains more medium and fine sand than the fan gravels and has a grain-size distribution that is more clearly bimodal (Figure 5). Mean grain size of gravel in the pits south of Interstate 84 average 7.0 ± 3.4 millimeters (1 S.D.; n=29); about 2 kilometers farther downstream it is 6.8 ± 2.0 millimeters (n=39). The cut-and-fill stratification in the sandy gravels is similar to that seen elsewhere in outwash gravels. The age of this gravel is estimated to be about 150,000 years based on the stratigraphy in the overlying loess mantle that includes two loess units and a strong buried soil developed in the lower loess unit and the upper part of the gravel (Pierce and others, 1982 this volume).

The Raft River is now a small low-gradient stream flowing between banks of fine-grained sediment; it has only minor amounts of gravel in its channel. Between 1947 and 1957, the greatest discharge of the Raft River near Bridge, Idaho, was 30 cubic meters per second (1,090 cubic feet per second) on February 5, 1951, but typical annual peak discharge is between 1.4 and 5.7 cubic meters per second (50 and 200 cubic feet per second) (Thomas and others, 1963, p. 89). The silty, fine-grained sediment that underlies the bottomlands along Raft River is Holocene in age. Carbonaceous material collected from the lower part of this fine-grained unit yielded radiocarbon ages of 8,370 ± 250 and 7,720 ± 250 years (W-3237 and W-3239; Meyer Rubin, written communication, 1975; Pierce and others, in press). A 2-centimeter-thick volcanic ash from 1.7 meters below the surface of this fine-grained unit has characteristics similar to those of the Mazama ash (R. E. Wilcox, written communication, 1975), which is about 6,600 years old. The active meander belt occupies only about one-tenth of the width of these bottomlands. Humic sediment from a depth of 2.9 meters within this belt is 680 ± 200

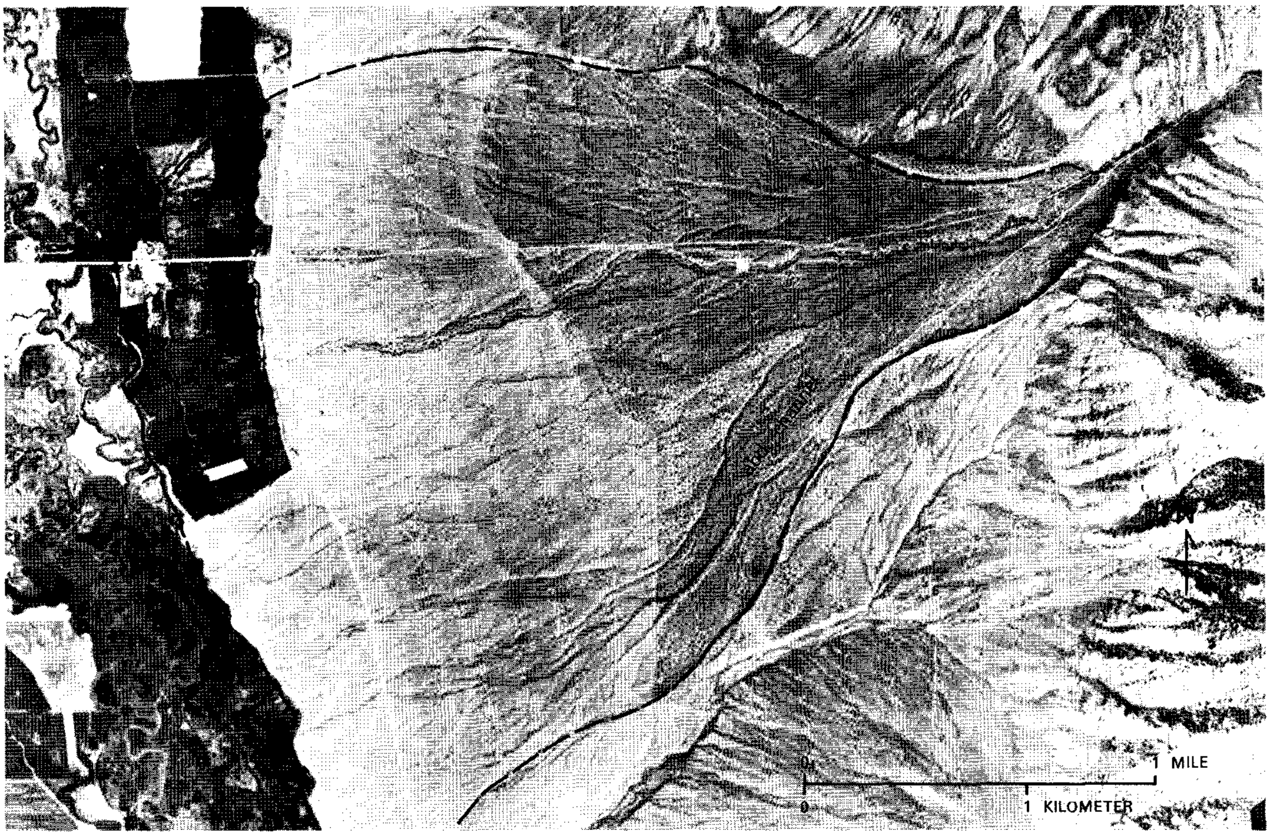


Figure 7. Vertical aerial photograph of the Ramshorn Canyon fan, Big Lost River valley. Dashed line outlines alluvial gravels of late Pleistocene age of Ramshorn Canyon with fresh surface morphology. Note preservation of braided-channel pattern. Based on thickness of carbonate coats, the conspicuous incised channel in center of photograph was abandoned near the close of the last gravel-depositing episode.

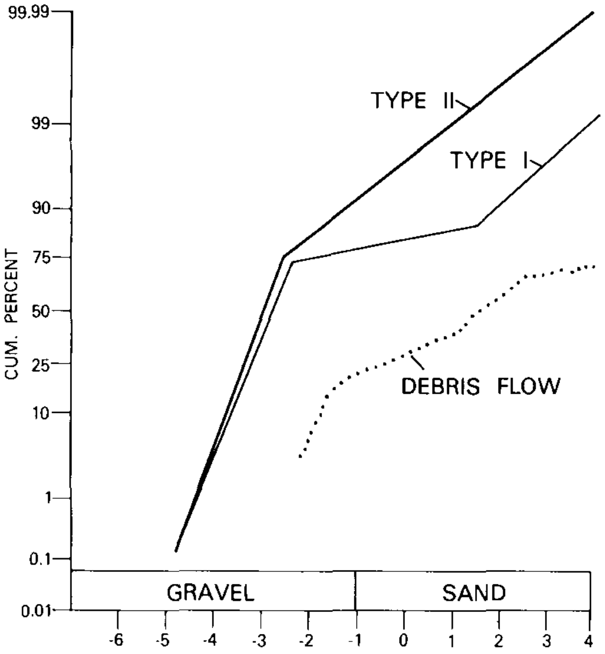


Figure 8. Particle-size distributions for the two types of gravel beds in the fans of Birch Creek valley (after Funk, 1976, Figure 43). Both distributions are bimodal. In both types, the finer fraction is sand, but in type I deposits the sand mode is more distinct from the gravel mode. For comparison, the dotted line is the particle-size distribution of a debris-flow deposit (from Funk, 1976; after Glaister and Nelson, 1974).

years old (W-3065; Meyer Rubin, written communication, 1975). These ages suggest that this fine-grained alluvium accumulated throughout the Holocene and that the underlying gravel is late Pleistocene to perhaps early Holocene in age.

In the Albion Basin to the west of the Raft River Valley, a section of dominantly fine-grained sediment was exposed to a depth of 4.5 meters by gullying of Summit Creek. Well-washed gravel is inferred to lie at a greater depth. A radiocarbon age of 9,280 ± 120 years (W-4966) from the base of this exposure provides a minimum age for the inferred change from Pleistocene gravel to Holocene fine-grained sediment deposition (Pierce and others, in press).

Snake River

An extensive gravel deposit of late Pleistocene age, about 15 kilometers wide and at least 10 meters thick, occurs along the Snake River from St. Anthony to American Falls Reservoir (Figure 1; Scott, in press). Two complimentary effects fostered its accumulation. First, American Falls Lake was dammed by the Cedar Butte Basalt 72,000 ± 14,000 years ago, resulting in elevated base levels upstream until about 14,000 to 15,000 years ago when the Bonneville Flood drained the lake (Scott and others, 1982 this volume; Bright, 1982 this volume). Second, conditions that favored deposition in other areas of nonglacial and glacial gravels at this time also existed along the Snake River. Based on the degree of soil development, the terrace marking the top of this gravel fill is Pinedale in age. Following the draining of American Falls Lake and the change in stream regimen between late Pleistocene and Holocene time, this gravel fill was incised by the Snake River and its tributaries.

Deposits thought to be the result of glacial-outburst floods from Pinedale icecaps on the Yellowstone Plateau occur beneath Egin Bench near St. Anthony and the obsidian-sand plain near West Yellowstone (Pierce, 1979, p. 48-52). These deposits consist of flat-bedded, openwork gravel composed dominantly of obsidian granules. On Egin Bench at Parker, an elongate bar 5 meters high composed of planar, inclined beds demonstrates that floodwaters were at least 5 meters deep across this 10-kilometer-wide section of the Henrys Fork valley.

Downstream from Pocatello, Bonneville Flood deposits floor large areas of the American Falls and Burley basins. Alluvial deposits that postdate the flood are limited in extent along the Snake River and its tributaries, and the flood deposits are little eroded or modified by subsequent fluvial activity. These relations suggest that the most recent episode of Pleistocene gravel deposition was mostly over by the time of the Bonneville Flood.

Big Lost River

The Big Lost River is an influent stream that flows out onto the Snake River Plain and disappears into the underlying rocks and sediments. In late Pleistocene time it transported and deposited gravel and sand much farther out onto the plain (Figure 1). During the Pleistocene, high discharges of the Big Lost River combined with flows from the Little Lost River and Birch, Beaver, and Camas Creeks to maintain Lake Terreton, a large shallow lake on the Snake River Plain (Figure 1). Upstream from Arco, the bottomlands along the Big Lost River are mantled by a meter or more of fine-grained flood-plain alluvium, presumably of Holocene age.

DISCUSSION

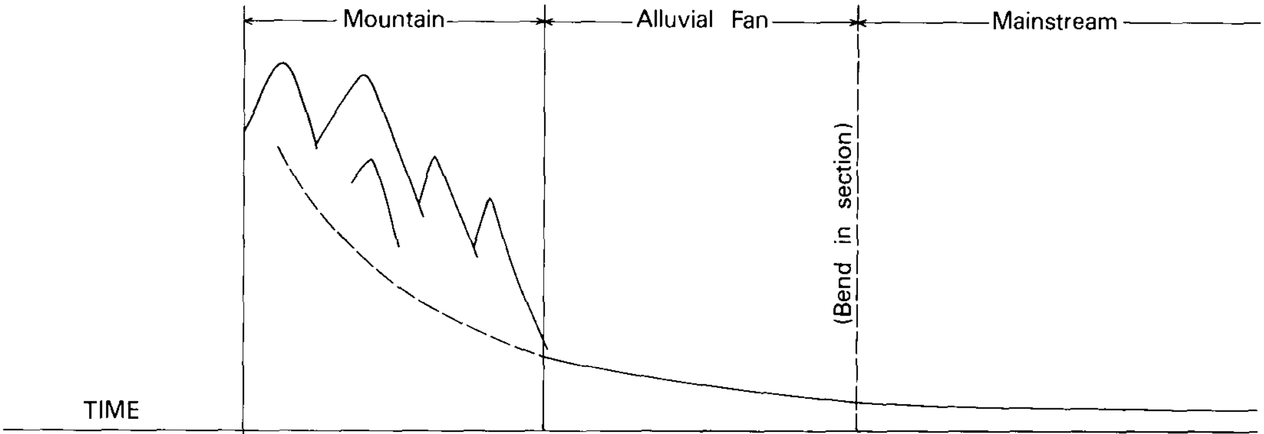
SYNTHESIS OF OBSERVATIONS

Gravel deposition in southeastern Idaho during late Pleistocene time occurred under conditions markedly different from those of the Holocene, as evidenced by the contrast between widespread Pleistocene gravel deposits of fans and alluvial fills and restricted Holocene fine-grained deposits within the same drainage basins (Figure 9). According to Schumm's (1977) classification, these alluvial fans were wet fans at the time of gravel deposition; now they are mostly dry fans and receive little or no sediment.

The youngest extensive deposits of gravel are dated as late Pleistocene, probably between 25,000 and 11,000 years old, because (1) soil development in these deposits is similar to that in deposits of the last, or Pinedale, glaciation, (2) the thickness of carbonate coats on stones in soils in these deposits are similar to those in soils in deposits of the last glaciation, (3) the last gravel-depositing episode was interrupted near its end by the Bonneville Flood, which occurred about 14,000-15,000 years ago, (4) well-washed alluvial gravel deposition in the Raft River Valley and the Albion Basin had ceased by 8,000 to 9,000 years ago and fine-grained alluvium had begun to accumulate on the basin floors, and (5) these gravels are mantled by a small fraction (0.5 meter) of loess unit A that accumulated between 11,000 and about 70,000 years ago (Pierce and others, 1982 this volume).

The presence of glaciers in source areas is not particularly important for the deposition of these alluvial-fan gravels. Morphologically fresh, late Pleistocene fan deposits are present downstream from glaciated as well as unglaciated source areas. A braided channel pattern commonly is well preserved on the youngest fan surfaces (see for example Figure 7). The channel widths of the former streams have not been well defined, but for many of the alluvial fans the width was 10 meters or more. In gravel-pit exposures, beds from 0.2 to 0.5 meter thick can be traced horizontally for distances of more than 3 to 5 meters. Gravelly, braided stream deposits generally indicate abundant sediment supply and high discharges (Ore, 1964).

The fan gravels are similar in appearance, whether the source area was unglaciated, partly glaciated, or extensively glaciated. All have a clast-supported



TIME	Mountain	Alluvial Fan	Mainstream
LATE PLEISTOCENE	RELATIVELY LARGE SEASONAL DISCHARGES AND TRANSPORT OF GRAVEL		
	Large supply of rubble to streams Transport of gravel Fills of alluvium along some large streams	Transport and deposition of gravel Deposition of large fan segment	Transport and deposition of gravel Deposition of major fill
HOLOCENE	RELATIVELY SMALL SEASONAL DISCHARGES AND TRANSPORT OF GRAVEL		
	Small supply of rubble, surface wash of silty soil Local deposition of muddy sediment during storm events Minor incision Tendency to increase stream gradients	Surface erosion of poorly vegetated loessial soil Local deposition near fan head and along entrenched drainage ways Minor incision at toe in response to trimming by mainstream	Deposition of fine sediment Incision of gravel fill along some drainages, no incision on others

Figure 9. Model in which Pleistocene and Holocene conditions are contrasted for a drainage system in southeastern Idaho, consisting of a drainage basin, alluvial fan, and main stream.

framework and show imbrication dipping up-fan. Beds are typically from 0.1 to 0.5 meter thick and are generally planar for distances of more than several meters; low-angle cross stratification is locally discernible. Except for buried soils that separate the gravel sheets of successive episodes, beds with a muddy matrix are scarce, and silt and clay constitute at most only a few percent of the gravel beds. The abundance of loess and Holocene fine-grained alluvium in southern Idaho suggests that enough fine-grained material to form mudflows was available during times of gravel deposition as well as at present. The scarcity of fines and matrix-supported beds in the gravel suggests that final deposition was by vigorous, sustained streamflows. If debris-flow deposits, fine-grained sediments, or more poorly sorted gravels were present initially, they have been almost entirely reworked.

Standard sorting classifications were developed for sand and finer grained sediments and are not particularly useful for gravel deposits. In the Raft River Valley, samples that include several beds from the unglaciated Sublett Creek drainage have inclusive graphic standard deviations of -2.4 ± 0.3 phi units (n=16) and are classified as very poorly sorted (Folk, 1968). In the Birch Creek valley, samples from individual gravel beds of partly glacial drainages have inclusive graphic standard deviations that average -2.2 ± 0.4 phi units (n=23) and are mostly very poorly sorted (Funk, 1976, p. 103; Folk, 1968). About three-quarters of the gravel in beds from the fans of the Birch Creek valley is restricted to a range of 2.4 phi units (a factor of 5 times; Figure 8); most of the remainder is sand that is not abundant enough to fill the pore space between the gravel clasts. Analyses of samples including several different beds of the Sublett Creek-Meadow Creek fan show that about 70 percent of the particles lie within 4 phi units (a factor of 16 times; Figure 5). Thus, although these alluvial gravels are classified mostly as very poorly sorted, they probably are as well sorted as gravel can be in this environment; only beach gravels and some flood gravels are better sorted (Figure 5; Pettijohn, 1957, p. 248). Mudflow and debris-flow deposits generally are more poorly sorted, contain more silt and clay and a wider range of gravel sizes, and are matrix supported (Sharp and Nobles, 1963; Hooke, 1967; Fisher, 1971; Harmes and others, 1975, p. 153).

The last episode of gravel deposition provides a model (Figure 9) for conditions during the deposition of older, similar gravel deposits. Fan gravels having weathering characteristics and loess mantles similar to those of outwash gravels that head in moraines of Bull Lake age in Teton and Birch Creek valleys (Knoll, 1977; Scott, in press; Pierce and others, 1982 this volume) are also inferred to be Bull Lake in age. Thus, older episodes of gravel deposition appear to correlate with older periods of glaciation. However, as during the last gravel-depositing episode, a glacial source was not required for these older episodes; unglaciated drainages produced similar gravels.

Although the degree of soil development and the thickness of carbonate coats help to determine the relative age of the older gravel deposits, correlations among these deposits are much less certain than for deposits of the last episode of gravel deposition. Carbonate coats on stones from soils in fan gravels on the west side of the Lost River Range (Table 1) and from the Raft River Valley show a direct, systematic increase in thickness with age, although the rates of coat accumulation probably vary with lithology, location, and time. The thickness of carbonate coats suggests that the older fan gravels are many times the age of the fan deposits of late Pleistocene age. Gravels about 15,000 years old have coats about 1 millimeter thick on limestone clasts (Table 1; Pierce and others, in press) and about 0.5 millimeter thick on volcanic clasts. Uranium-thorium ages for carbonate coats on limestone clasts near Arco indicate that coats 2 millimeters thick are about 30,000 years old, and that coats 10 millimeters thick are about 170,000 years old (J. N. Rosholt and K. L. Pierce, unpublished data). In contrast, basalt clasts in till estimated to be about 150,000 years old east of Ashton (Pierce and others, 1982 this volume) have carbonate coats only about 3.1 ± 1.3 millimeters thick (n=32).

SPECULATIONS ON CAUSES OF GRAVEL DEPOSITION

In the Basin and Range province of southeastern Idaho, Pleistocene gravels were deposited by streams with greater discharges than present streams. Deposits have been described elsewhere in the Rocky Mountains that show a similar change in stream regimen from gravel deposition in late Pleistocene time to mud deposition in Holocene time. In the Colorado Piedmont, late Pleistocene alluvial deposits are mostly gravel, whereas Holocene alluvium is mostly silt, sand, and clay (Scott, 1965). From a hydraulic analysis of some of these gravel deposits, Baker (1974) determined that both glacial and nonglacial streams had late Pleistocene discharges an order of magnitude greater than present flows. Along streams in the basins of Wyoming, Leopold and Miller (1954) defined stratigraphic units that reflect a change in stream competency; Holocene deposits of the Kaycee Formation, and younger formations, are fine grained, whereas the Pleistocene Arvada Formation is composed of gravel. In central Utah, R. E. Anderson (written communication, 1980) has obtained Holocene radiocarbon ages on alluvial-fan deposits that postdate more gravelly deposits of inferred late Pleistocene age. Along the East Fork River, Wyoming, studies of modern bed-load transport have shown that coarse sand and very fine pebble gravel, but almost no coarser gravel, is being transported, whereas adjacent gravel terraces show that outwash gravel was being transported in late Pleistocene time from the Wind River Range (Leopold, 1982; Meade and others, 1981; Emmett, 1980, p. 7).

The deposition of Quaternary gravels in southeastern Idaho resulted from the combined effects of the climates that prevailed under Pleistocene glacial conditions and geologic processes that produced mountainous source areas and nearby basins of deposition. That late Pleistocene gravels of glaciated and unglaciated drainages are similar argues that climatic effects other than glaciation itself were of major importance.

A simple way to explain these increased stream discharges in southeastern Idaho is to postulate increased precipitation, a mechanism that has commonly been used to explain the filling of pluvial lakes in the Great Basin. Other considerations suggest that this mechanism probably is not applicable. During the last glaciation, the north Pacific Ocean was colder (CLIMAP, 1976) than at present and therefore probably would have provided less moisture for precipitation in the western United States. Consequently, we infer that increased precipitation in southeastern Idaho during this time is unlikely. More likely, the effects of lower temperatures led to increased streamflows by decreasing the evaporation and by altering the magnitude and timing of snowmelt. With today's mean annual precipitation, pluvial Lake Bonneville could have filled to overflowing if mean annual temperatures were only about 7° C colder than at present (McCoy, 1981). Table 2 lists and briefly explains factors that would lead to sustained, seasonal stream discharges much greater than at present. Most of these factors are directly related to how much colder Pleistocene glacial conditions were, compared with the present.

Estimates of the amount of late Pleistocene cooling vary widely. A method commonly used for estimating Pleistocene temperature changes is to multiply the atmospheric lapse rate by the altitudinal difference between past and present snowlines. Such calculations yield commonly accepted estimates that late Pleistocene temperatures in the Rocky Mountains were about 6° C colder than at present (Flint, 1976). However, this simple lapse-rate calculation fails to account for precipitation gradients. If late Pleistocene precipitation and precipitation gradients were the same as at present, snowline changes suggest that mean annual temperatures at that time were 10-15° C colder than at present (Porter and others, in press; K. L. Pierce, unpublished data). Widespread permafrost conditions on the basin floors of Wyoming also suggest similar decreases of late Pleistocene mean annual temperatures (Mears, 1981).

If late Pleistocene temperatures in southeastern Idaho were 10-15°C colder than at present, the consequent changes in the timing and magnitude of peak discharges of streams might readily explain the deposition of gravel without any increase in annual precipitation (Table 2).

In the Snake River basin, snowmelt is responsible for most peak discharges (Thomas and others, 1963, p. 8). Maximum runoff of streams that head above an altitude of 3,000 meters in high, formerly glaciated terrain occurs in June, whereas that of lower altitude basins that were not glaciated occurs typically almost 2 months earlier, in late April (Thomas and others, 1963, p. 56-90). Weather records from the Yellowstone area suggest that a mean annual temperature decrease of about 10° C would delay the time when average monthly temperatures reach above freezing by about 2 months (K. L. Pierce, unpublished data). Thus, with a 10° C cooling, peak discharges from unglaciated basins in southeastern Idaho might occur about June, and peak discharges from glaciated areas might occur in July or August.

Another way to regard the effect of deferred snowmelt relates directly to lower Pleistocene snowlines. During Pleistocene glacial culminations, equilibrium-line altitudes in the western United States were about 900 meters lower than at present (Flint, 1971, p. 468; Scott, 1977; Porter and others, in press). To a first approximation, peak runoff in late Pleistocene time from unglaciated drainage basins in Idaho averaging 2,000 meters in altitude may have occurred at a similar time of year (midsummer) as that in present basins at about 3,000 meters in altitude.

In summary, colder late Pleistocene temperatures would have led to a thicker snowpack that would have melted later in the spring or summer. Because, at this time, the incidence of the sun's rays was more nearly vertical and the days were longer than earlier in the spring, melting would have occurred also at a more rapid rate, thus producing higher sustained peak discharges than at present (Table 2).

Our interpretation of the relation between alluvial-fan deposition and Pleistocene climatic cycles in southeastern Idaho differs in detail from that of Funk and Dort (1977), who concluded:

> *During a single cycle of fan development, it is inferred that erosion was the dominant process acting on the fans until the glacial climate ameliorated, because ice and snow trapped sediment in the drainage basins, effectively reducing sediment yields.*

> *After the ice began to recede, increased sediment loads derived from glacial drift exposed up-valley resulted in deposition of a new fan segment.*

Instead, we conclude that maximum sediment supply and sediment and water discharges are directly associated with full glacial conditions. Both glacial and nonglacial source areas produced similar gravel deposits on alluvial fans in the Birch Creek valley and elsewhere in southeastern Idaho, suggesting that annual snowmelt, not the effects of deglaciation, was the key ingredient causing higher sediment and water discharges.

In addition to increased peak runoff, increased gravel supply (Table 3) was a critical factor in gravel-depositing episodes. Large differences between Pleistocene and Holocene colluvial activity are discernible within the mountains of southeastern Idaho. In mountainous areas that were not glaciated during late Pleistocene time, the slopes are extensively mantled with blocky rubble; stone stripes (Figure 10) and other forms of patterned ground occur widely. This rubble appears to be stable now, but it was last active during the colder climate of the late Pleistocene. Similar features occur on the Snake River Plain and show that periglacial conditions existed at low altitudes in southeastern Idaho at times during the Pleistocene (Malde, 1964; Fosberg, 1965).

Although little deposition of gravel has occurred downstream from the mountain fronts in Holocene time, streams within the mountains currently move some gravel. Historic and older Holocene deposits of gravelly alluvium are present along these drainages, especially at junctions between streams of different orders. Archeological studies in the Cassia Mountains show that 1-2 meters of alluvial sand, silt, clay, and fine gravel have accumulated in about the last 10,000 years, as dated by tool types and by probable 6,600-year-old Mazama ash near the middle of this fine-grained sequence (Green, 1972, Figures 7 and 8).

Furthermore, some streams that are prone to flash floods generated by intense thunderstorms have formed alluvial fans in Holocene time; however, the fans are composed largely of fine-grained sediment. For example, at the northeast end of the Raft River Valley, a fine-grained fan of Holocene age extends onto the Raft River bottoms from the mouth of Heglar Canyon (Pierce and others, in press). This young fan has blocked the Raft River resulting in the

Table 2. Factors tending to increase peak discharges of late Pleistocene streams compared with those of present and Holocene streams.

FACTOR	REMARKS
1. Cooler Pleistocene temperatures	With a mean annual precipitation of 50 centimeters, a change in mean annual temperature from 10° to 0°C would increase total annual discharge by about 4 times (Langbein, 1949; Schumm, 1965) because of decreased evaporation, transpiration, and sublimation.
2. Greater snowpack	In autumn and spring, more moisture would occur as snowfall and less would melt; thus, total water content of spring snowpack would be greater.
3. Snowmelt occurring later in the year	Later in the snowmelt season, days are longer and the incidence of the rays of the sun is more nearly vertical. Both factors would result in more rapid snowmelt and tend to concentrate snowmelt into a shorter interval of time, thus increasing peak discharges.
4. Increased surface runoff	Much of the discharge from drainage basins in southeastern Idaho is now accomplished by ground-water underflow through porous alluvial-fan and stream-channel deposits, but ground-water underflow could accommodate only a small part of any increased discharge. Before alterations by man, about 80 percent of the natural discharge from the Raft River basin was accomplished by ground-water underflow (Walker and others, 1970). If total discharge were increased fourfold and the increase was entirely manifested as runoff, surface runoff would increase twenty-fold.
5. Increased seasonally and permanently frozen ground	Runoff would increase because infiltration would be impeded by either seasonally or permanently frozen ground. Applies mainly to higher altitudes.
6. Glaciers in parts of some drainage basins	Glaciers tend to prolong peak discharges by providing a source of meltwater throughout summer. Glaciers were absent or small in many of the drainage basins that produced gravel deposits in southeastern Idaho.
7. Increased total precipitation	An increase in precipitation seems unreasonable in view of the decreased sea-surface temperatures of the late Pleistocene Pacific Ocean (CLIMAP, 1976), which is the source area for precipitation in southeastern Idaho. An actual decrease in precipitation might be likely if mean annual temperatures were as much as 10-15°C colder.

Table 3. Factors tending to increase the supply of gravel to late Pleistocene streams compared to that of present and Holocene streams.

FACTOR	REMARKS
1. Increased frost action	Frost splitting of bedrock into gravel-sized material, thereby mantling slopes of drainage basins with rubbly colluvium.
2. Increased downslope movement of rubbly colluvium	Frost climate facilitates mass movement of rubble downslope to streams. Solifluction and frost heaving were much more active than at present, especially at intermediate altitudes.
3. Diminished soil erosion	Colder climate creates greater effective soil moisture and consequently greater plant cover, which results in diminished surface erosion of the generally fine-grained soil.
4. Glaciers in parts of some drainage basins	Glaciers tend to augment the amount of both fine- and coarse-grained sediment supplied to streams.

Figure 10. Photograph of inactive stone stripe on hillslope in the Cotterel Range on the west side of the Raft River Valley. The entire upland area is mantled with rubbly colluvium that is generally stabilized by thick turf. Similar rubble mantles the source area of the Cottonwood Creek fan. This site is relatively low in altitude (2,100 meters), below the modern zone of continuous coniferous forest and near the upper limit of junipers.

formation of a marshy area above the fan. Heglar Canyon is subject to rather frequent flash floods. About 10 kilometers upstream from the mouth of Heglar Canyon, a maximum discharge of 55 cubic feet per second was recorded between 1958 and 1966 for a 20-square-kilometer drainage basin (Thomas, 1967, p. 66). A flash flood in July of 1982 flooded part of the fan and moved some gravel down an artificially straightened channel and deposited fine sand and silt on the fan surface. The gravels that were moved in the channel are interbedded with finer grained sediment and are unlike the well-washed gravels of fans of late Pleistocene age.

Under present flow conditions, streams require steeper gradients than those at present for significant gravel transport to the alluvial fans and axial drainages of the depositional basins. Holocene changes in stream profiles appear to be increasing stream gradients by deposition of alluvium along the drainages within the mountains and near the fan heads. Uplift of the mountains relative to the basins also increases gradients. Under the present climate and at present rates of deposition, erosion, and uplift, time in excess of several tens of thousands of years probably will be required for gradients to become steep enough for efficient transport of gravels out into the depositional basins. We infer that this transport might occur primarily by debris flows and mudflows generated by major storm events and thereby differ from the longer sustained streamflows inferred from the Pleistocene gravel deposits. The Tertiary fan glomerates of the western United States that have a fine-grained matrix may provide an example of what gravelly basin-fill sediments would look like that were deposited by debris flows or mudflows under present climatic conditions but on fans having gradients steeper than at present.

However, a new episode of cold climate is likely to occur (Shackleton and Opdyke, 1973; Hays and others, 1976) before the streams have sufficient time to increase their gradients enough to transport gravel to the fans. Increased coarse-sediment supply and greatly enhanced peak discharges on the relatively low-gradient alluvial fans and axial drainages would then cause a new episode of gravel deposition.

RECOMMENDATIONS FOR FUTURE WORK

This report is a by-product of mapping and stratigraphic studies. Specific studies focused on the following aspects of gravel deposition would increase our understanding of the Pleistocene gravels of southeastern Idaho: (1) detailed comparisons of the sedimentary characteristics of alluvial fans from glaciated and unglaciated drainage basins; (2) estimation of late Pleistocene discharges by calculating velocity and discharge from the width, depth, and gradient of preserved channels and the size of transported clasts; (3) hydrologic modeling of discharges produced by snowmelt under climatic conditions appropriate for the glacial climates of the Pleistocene; (4) study of Tertiary fanglomerates and Pleistocene gravels to compare the stream regimens under which each was deposited; (5) determination of times of formation and transport of rubbly colluvium on slopes in the mountains; (6) study of present and older Holocene stream activity within the mountains; (7) dating of Pleistocene gravels older than those deposited during the last episode and comparison of times of deposition with the Quaternary climatic record; and (8) estimate rates of episodic gravel production and deposition based on volumes of gravel deposited during the last gravel-depositing episode.

REFERENCES

Baker, V. R., 1974, Paleohydraulic interpretation of Quaternary alluvium near Golden, Colorado: Quaternary Research, v. 4, p. 94-112.

Blackwelder, Eliot, 1928, Mudflow as a geologic agent in semiarid mountains: Geological Society of America Bulletin, v. 39, p. 465-484.

Bright, R. C., 1982, Paleontology of the lacustrine member of the American Falls Lake beds, southeastern Idaho, *in* Bill Bonnichsen and R. M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26.

Clayton, Janine, 1981, Geomorphology of selected alluvial fans of southeastern Idaho: Idaho State University M.S. thesis, 67 p.

CLIMAP project members, 1976, The surface of the ice-age earth: Science, v.191, p. 1131-1144.

Emmett, W. W., 1980, A field calibration of the sediment-trapping characteristics of the Helley-Smith bedload sampler: U. S. Geological Survey Professional Paper 1139, 44 p.

Fisher, R. V., 1971, Features of coarse-grained, high-concentration fluids and their deposits: Journal of Sedimentary Petrology, v. 41, p. 916-927.

Flint, R. F., 1971, Glacial and Quaternary Geology: John Wiley and Sons, New York, 892 p.

Folk, R. L., 1968, Petrology of Sedimentary Rocks: Hemphill's, Austin, Texas, 170 p.

Fosberg, M. A., 1965, Characteristics and genesis of patterned ground in Wisconsin time in a Chestnut soil zone of southern Idaho: Soil Science, v. 99, p. 30-37.

Funk, J. M., 1976, Climatic and tectonic effects on alluvial fan systems, Birch Creek valley, east-central Idaho: University of Kansas Ph.D. dissertation, 246 p.

Funk, J. M. and Wakefield Dort, Jr., 1977, Quaternary climatic effects on alluvial fan systems, Birch Creek valley, east-central Idaho: Geological Society of America, Abstracts with Programs, v. 9, p. 982-983.

Glaister, R. P. and H. W. Nelson, 1974, Grain-size distributions, an aid in facies identification: Bulletin of the Canadian Petroleum Geologists, v. 22, p. 203-240.

Green, J. P., 1972, Archaeology of the Rock Creek site, Sawtooth National Forest, Cassia County, Idaho: Idaho State University M.S. thesis, 152 p.

Harmes, J. C., J. B. Southerd, P. R. Spearing, and R. G. Walker, 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course No. 2, 161 p.

Hays, J. D., John Imbrie, and N. J. Shackleton, 1976, Variations in the Earth's orbit; Pacemaker of the Ice Ages: Science, v. 194, p. 1121-1132.

Hooke, R. L., 1967, Process on arid-region alluvial fans: Journal of Geology, v. 75, p. 438-460.

Knoll, K. M., 1977, Chronology of alpine glacier stillstands, east-central Lemhi Range, Idaho: Idaho State University Museum of Natural History Special Publication, 230 p.

Langbein, W. B., 1949, Annual runoff in the United States: U. S. Geological Survey Circular 52, 14 p.

Leopold, L. B., 1982, Geologic setting, *in* L. B. Leopold, editor, Field Trip Guidebook: American Geomorphological Field Group, 1982 Conference, Pinedale, Wyoming, p. 4-17.

Leopold, L. B. and J. P. Miller, 1954, A postglacial chronology for some alluvial valleys in Wyoming: U. S. Geological Survey Water-Supply Paper 1261, 90 p.

Malde, H. E., 1964, Patterned ground in the western Snake River Plain, Idaho, and its possible cold-climate origin: Geological Society of America Bulletin, v. 75, p. 191-208.

_______, 1971, Geologic investigation of faulting near the National Reactor Testing Station, Idaho, with a section on microearthquake studies by A. M. Pritt and J. E. Eaton: U. S. Geological Survey Open-File Report, 167 p.

McCoy, W. D., 1981, Quaternary aminostratigraphy of the Bonneville and Lahonton basins, western U. S., with paleoclimatic implications: University of Colorado Ph.D. dissertation, 603 p.

Meade, R. H., W. W. Emmett, and R. M. Myrick, 1981, Movement and storage of bed material during 1979 in East Fork River, Wyoming, USA, *in* T. R. H. Davies and A. J. Pearce, editors, Erosion and Sediment Transport in Pacific Rim Steeplands: International Association of Hydrological Sciences Publication 132, p. 225-235.

Mears, Brainerd, Jr., 1981, Periglacial wedges and the late Pleistocene environment of Wyoming's intermontane basins: Quaternary Research, v. 15, p. 71-198.

Ore, H. T., 1964, Some criteria for recognition of braided stream deposits: Contributions to Geology, University of Wyoming, v. 3, p. 1-14.

Pettijohn, F. J., 1957, Sedimentary Rocks: Harper and Brothers, New York, 718 p.

Pierce, K. L., 1979, History and dynamics of glaciation in the northern Yellowstone Park area: U. S. Geological Survey Professional Paper 729-F, p. F1-F80.

Pierce, K. L., H. R. Covington, P. W. Williams, and D. L. McIntyre, in press, Geologic map of the Cotterel Mountains and the northern Raft River Valley, Cassia County, Idaho: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-1450.

Pierce, K. L., M. A. Fosberg, W. E. Scott, G. C. Lewis, and S. M. Colman, 1982, Loess deposits of southeastern Idaho: age and correlation of the upper two loess units, *in* Bill Bonnichsen and R. M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26.

Porter, S. C., K. L. Pierce, and T. D. Hamilton, in press, Mountain glaciation of the western United States, *in* S. C. Porter, editor, Late Wisconsin of the United States: University of Minnesota Press, Minneapolis, Minnesota.

Schumm, S. A., 1965, Quaternary Paleohydrology, *in* H. E. Wright, Jr. and D. G. Frey, editors, The Quaternary of the United States: Princeton University Press, Princeton, New Jersey, p. 783-794.

_______, 1977, The Fluvial System: John Wiley and Sons, New York, 338 p.

Scott, G. R., 1965, Nonglacial Quaternary geology of the southern and middle Rocky Mountains, *in* H. E. Wright, Jr. and D. G. Frey, editors, The Quaternary of the United States: Princeton University Press, Princeton, New Jersey, p. 243-254.

Scott, W. E., 1977, Quaternary glaciation and volcanism, Metolius River area, Oregon: Geological Society of America Bulletin, v. 88, p. 113-124.

_______, in press, Surficial geologic map of the eastern Snake River Plain and adjacent areas, 111° to 115° W., Idaho and Wyoming: U. S. Geological Survey Miscellaneous Geologic Investigations Map MI-1373.

Scott, W. E., K. L. Pierce, J. P. Bradbury, and R. M. Forester, 1982, Revised Quaternary stratigraphy and chronology in the American Falls area, southeastern Idaho, *in* Bill Bonnichsen and R. M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26.

Shackleton, N. J. and N. D. Opdyke, 1973, Oxygen-isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238—Oxygen-isotope temperatures and ice volumes on a 10^5 to 10^6 year scale: Quaternary Research, v. 3, p. 39-55.

Sharp, R. P. and L. H. Nobles, 1963, Mudflows of 1941 at Wrightwood, southern California: Geological Society of America Bulletin, v. 64, p. 547-560.

Thomas, C. A., 1967, Peak discharges from small drainage basins in Idaho; a basic-data report: U. S. Geological Survey, Water Resources Division, Boise, Idaho, 177 p.

Thomas, C. A., H. C. Broom, and J. E. Cummons, 1963, Magnitude and frequency of floods in the United States, Part 13, Snake River basin: U. S. Geological Survey Water-Supply Paper 1688, 250 p.

Visher, G. S., 1969, Grain-size distributions and depositional processes: Journal of Sedimentary Petrology, v. 39, p. 1074-1106.

Walker, E. H., L. C. Dutcher, S. O. Decker, and K. L. Dyer, 1970, The Raft basin, Idaho-Utah, as of 1966; a reappraisal of the water resources and effects of ground-water development: Idaho Department of Water Administration Bulletin 19, 95 p.

Williams, P. L., K. L. Pierce, D. H. McIntyre, and P. W. Schmidt, 1974, Preliminary geologic map of the southern Raft River area, Cassia County, Idaho: U. S. Geological Survey Open-File Report 74-1126.