COLORADO GEOLOGICAL SURVEY

Research Notes RN-04

Glacial outburst floods on the Lake Fork of the Gunnison River, Colorado

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ABOUT THIS REPORT

From the abstract:

"Glaciers from the San Juan icefield in southwestern Colorado formed in the circular topographic basin of the Lake City caldera and flowed down the Lake Fork of the Gunnison River. Only the latest glacier, the Pinedale, or Last Glacial Maximum, left a record. Pinedale glaciers in the basin converged at Lake City and ran about 22 miles down to the north. A late Pinedale recessional moraine three miles below Lake City dammed a proglacial lake, Lake Hinsdale, that was fed by all streams in the basin. Erosion of the morainal dam at the right abutment led to a glacial outburst flood that scoured the outwash train in the valley below. Much of the moraine remained intact, however, and alluvial fan gravels plugged the outlet gap. Lake Hinsdale persisted until failure of the left abutment caused a second outburst flood that tore out most of the moraine and further scoured the valley below. One of the floods left a large boulder 70 ft above the valley floor."

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COLORADO GEOLOGICAL SURVEY
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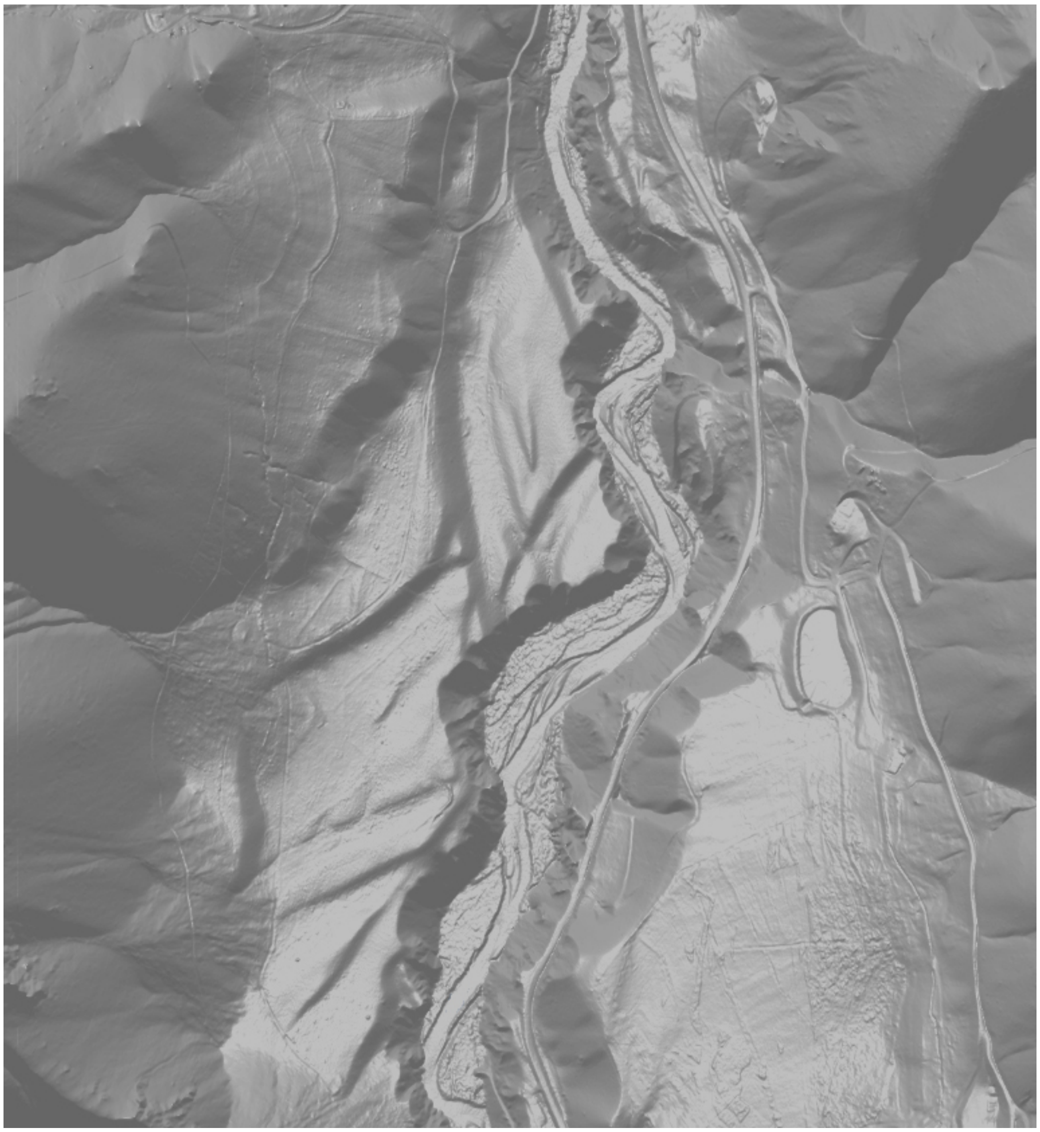
GLACIAL OUTBURST FLOODS

ON THE LAKE FORK OF THE GUNNISON RIVER

COLORADO



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2025

GLACIAL OUTBURST FLOODS ON THE LAKE FORK OF THE GUNNISON RIVER

COLORADO

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FIGURES

ABSTRACT

Glaciers from the San Juan icefield in southwestern Colorado formed in the circular topographic basin of the Lake City caldera and flowed down the Lake Fork of the Gunnison River. Only the latest glacier, the Pinedale, or Last Glacial Maximum, left a record. Pinedale glaciers in the basin converged at Lake City and ran about 22 miles down to the north.

A late Pinedale recessional moraine three miles below Lake City dammed a proglacial lake, Lake Hinsdale, that was fed by all streams in the basin. Erosion of the morainal dam at the right abutment led to a glacial outburst flood that scoured the outwash train in the valley below. Much of the moraine remained intact, however, and alluvial fan gravels plugged the outlet gap. Lake Hinsdale persisted until failure of the left abutment caused a second outburst flood that tore out most of the moraine and further scoured the valley below. One of the floods left a large boulder 70 ft above the valley floor.

INTRODUCTION

Location

The Lake Fork of the Gunnison River ("Lake Fork") drains the north side of the San Juan Mountains in southwestern Colorado as part of the headwaters of the Colorado River (fig. 1). The lone municipality on the river is Lake City, seat of Hinsdale County. The area discussed in this report is a reach of the river valley that extends from Lake City 22 miles down to the north.

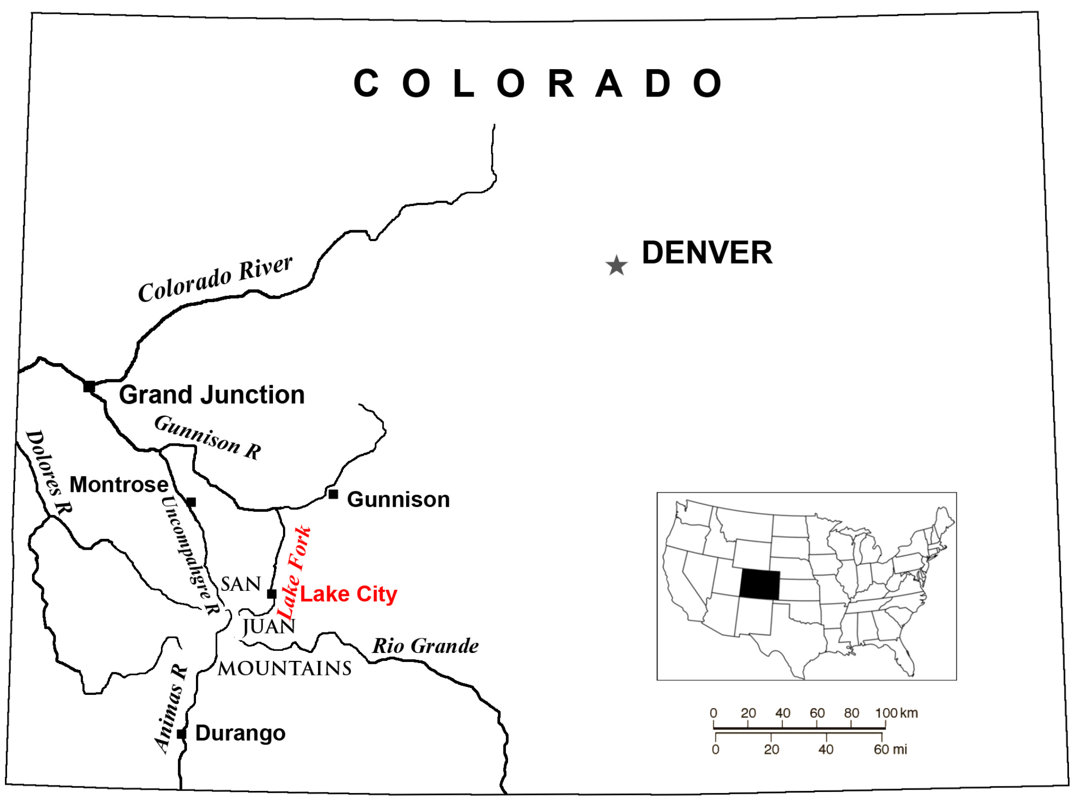

Figure 1 – The Lake Fork of the Gunnison River is part of the Colorado River drainage, as are the other rivers draining the San Juan Mountains except the Rio Grande.

Physical Setting

The drainage area of the Lake Fork consists of a circular basin above Lake City that drains into a narrow, straight valley below (fig. 2). The basin above Lake City is the catchment area for the Lake Fork glacier, and the valley below is the outlet glacial valley.

Five peaks within or on the rim of the basin are above 14,000 ft, with the highest Uncompahgre Peak at 14,321 ft. Arcuate Henson Creek drains the north side of the basin and similarly arcuate Lake Fork drains the south and east sides, with their confluence at Lake City (in this report, valley distances are given with respect to this confluence).

Below Lake City the river runs in a straight, U-shaped valley one to two miles wide for 22 miles, at which point it enters a narrow V-shaped canyon, here called *Head of the Canyon*[1].

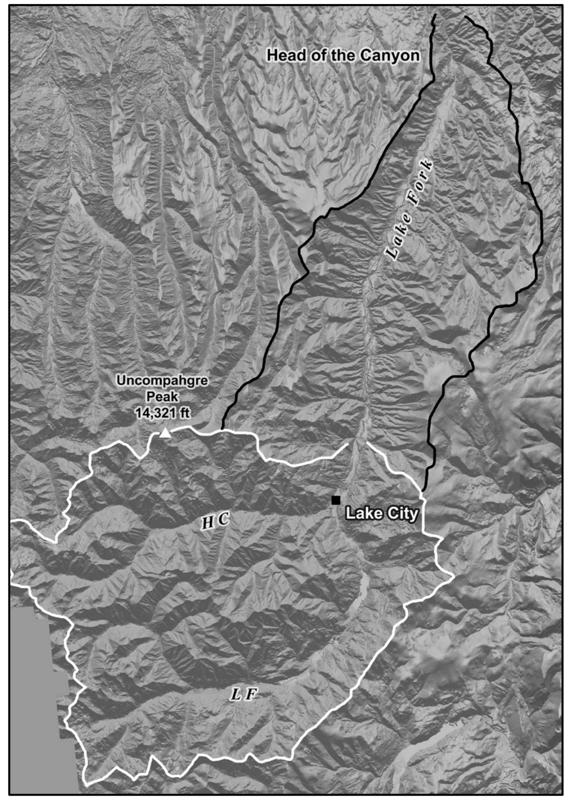

Figure 2 – Lake Fork drainage basin. Area contributing to the Pinedale glacier outlined in white, with addtional area of the modern Lake Fork outlined in black. HC, Henson Creek; LF, Lake Fork.

Geology

The Lake Fork drainage basin is circular because it developed on the Lake City caldera within the Uncompahgre caldera (fig. 3). All the area above Head of the Canyon consists of Tertiary volcanic rocks: late basalt flows capping high plateaus, ash-flow tuffs both within the Uncompahgre caldera and distally, and early intermediate-composition volcanic rocks that make up all the area of interest in this report (fig. 4). These latter rocks include lava flows, cone breccias, and volcaniclastics (Steven and Hail, 1989). It is important to recognize that these rocks are very easily eroded, with downcutting exceeding 100 ft since the end of glaciation. Below Head of the Canyon the river has cut into Proterozoic crystalline rocks.

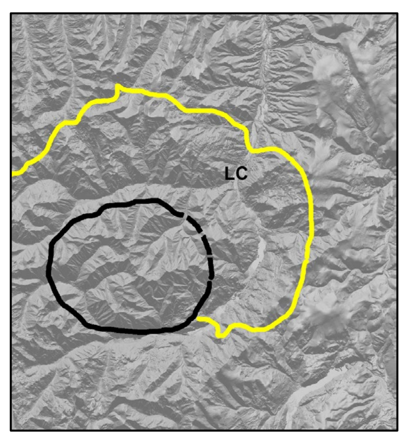

Figure 3 –Topographic rim of the Uncompahgre caldera shown in yellow, Lake City caldera ring fault in black (outlines from Lipman, 1976). LC, Lake City.

Glaciations in the San Juan Mountains

Glaciers capped the San Juan Mountains in an icefield, with one of the outlet glaciers flowing down the Lake Fork valley (fig. 5). The best studied of the San Juan glaciers is the outlet glacier on the Animas River in the contiguous

[1] This is an informal name used here for clarity

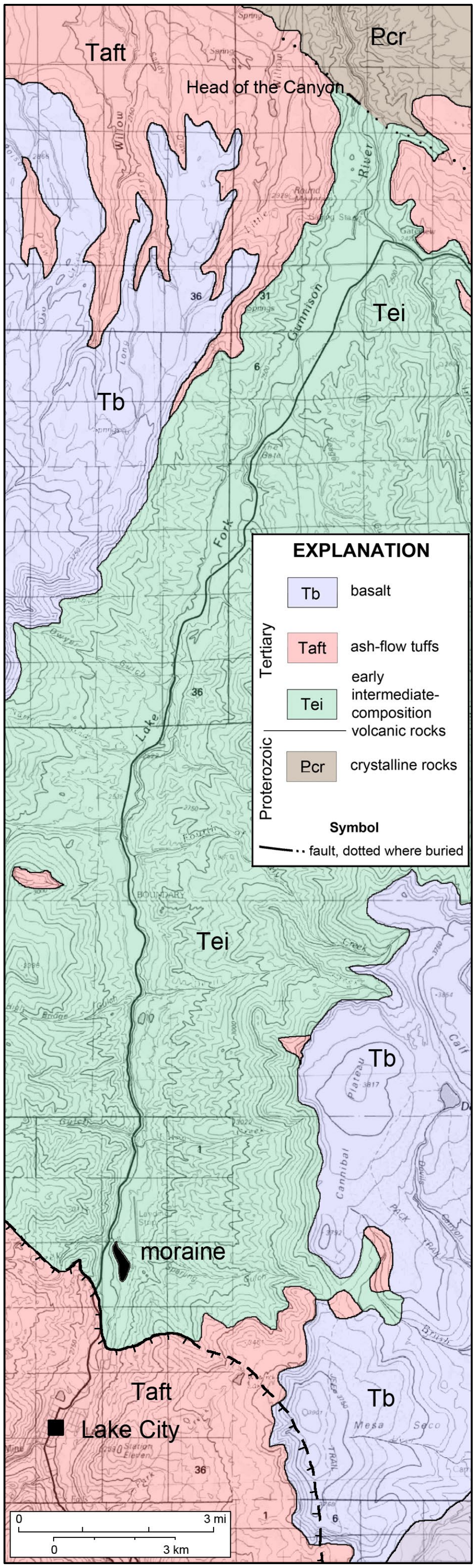

Figure 4 – Geologic map simplified from Steven and Hail, 1989. Hachured line is topographic rim of Uncompahgre caldera (28 m.y.), dashed where covered.

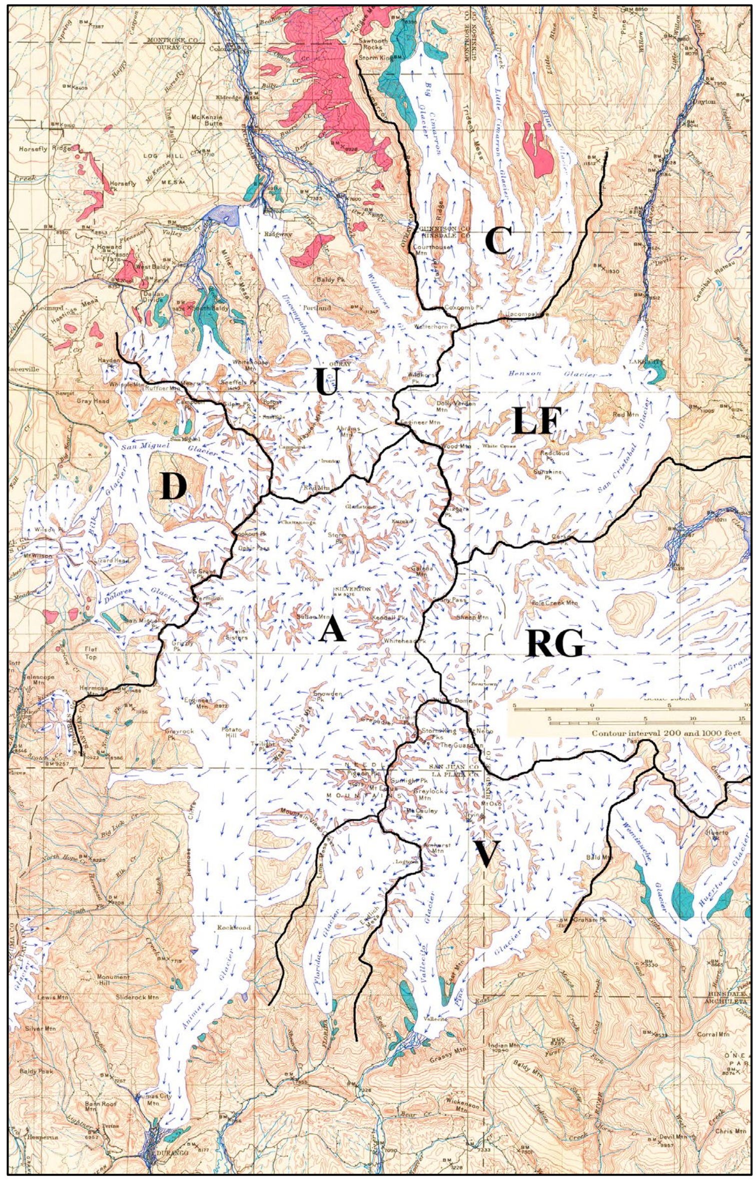

Figure 5 – San Juan icefield mapped by Atwood and Mather (1932) with glacial divides added. Outlet glaciers: A, Animas; C, Cimarron; D, Dolores; LF, Lake Fork; RG, Rio Grande; U, Uncompahgre; V, Vallecito.

drainage to the southwest. Three major glacial advances are recognized at Durango. The age designations for these glaciations, using Rocky Mountain glacial terminology, are Durango for the oldest, followed by Bull Lake and Pinedale (Last Glacial Maximum). Each of the three major glacial advances consisted of two separate advances: Durango 1, Durango 2; Bull Lake 1, Bull Lake 2; Pinedale 1, Pinedale 2 (Johnson and Gillam, 1995; Gillam, 1998; Scott and Moore, 2007).

Following the usage of Johnson et al. (2017, table below) based on the work of Lisiecki and Raymo (2005), Pinedale refers to deposits of the latest major glaciation, approximately 29—14 ka, Marine Isotope Stage (MIS) 2. Bull Lake refers to deposits of approximately 191—130 ka, MIS 6. The Durango glaciation is of less certain age, estimated by Mary Gillam, using calibrated incision rates, to be approximately 374—243 ka, MIS 8—10 (Gillam,1998, tables 7.1, 7.2).

Age	Stratigraphic unit at Durango	Range of absolute age	Marine Isotope Stage
Pinedale	Animas City	~29–14 ka	MIS 2 (Last Glacial Maximum)
Bull Lake	Spring Creek	~191–130 ka	MIS 6
Durango	Durango	~374–243 ka	MIS 8–10

Data from Johnson et al., 2017

This Study

Glacial deposits and outwash were mapped on lidar imagery with 5-foot contour intervals, with field observations made in 2021 and 2022. Field checking was restricted in parts of the Lake Fork valley where properties are held by absentee owners, but this was not a serious limitation, because access was sufficient to characterize the terrace gravels, and the lidar images show the landforms in excellent detail (fig. 6).

GLACIAL GEOLOGY

Prior Studies

Atwood and Mather (1932) mapped glacial deposits in the Lake Fork basin. They mapped Wisconsin-age moraines above Lake City, which included what are today both Bull Lake and Pinedale deposits. They mapped no deposits of Durango age in the basin except two small deposits on hills above Lake City, but both are shown as landslides in the detailed map of Lipman (1976). Lipman mapped moraines within the basin that he described as *glacial moraines of Pinedale age.*

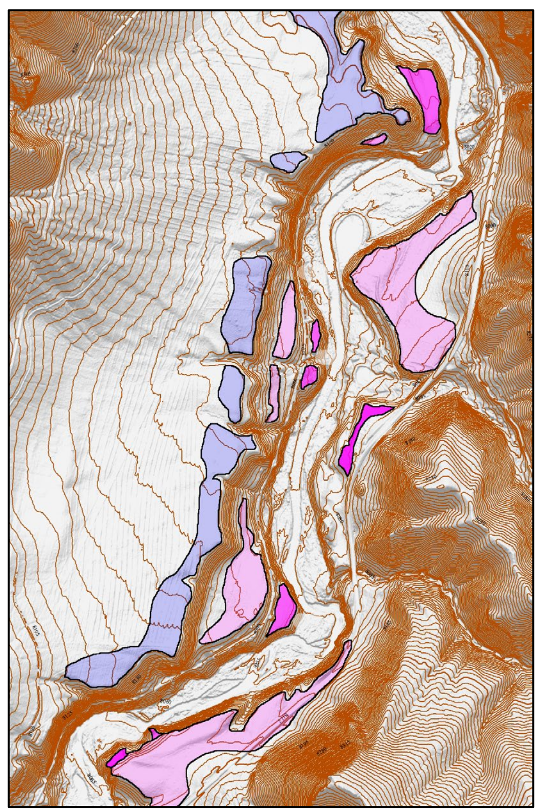

Figure 6 – Lidar image clearly shows three terraces along Lake Fork. Contour interval 5 ft.

Glacial Deposits

Only one glacial deposit remains in the valley below Lake City, a fragment of a multi-crested, valley-transverse moraine (fig. 7). This moraine was considered a terminal moraine of the Lake Fork Glacier by Atwood and Mather (1932, p.72), and it coincides with the maximum extent of the Wisconsin glacier shown on their glacial map (fig. 5). Lipman (1976) mapped the moraine as a Pinedale terminal moraine.

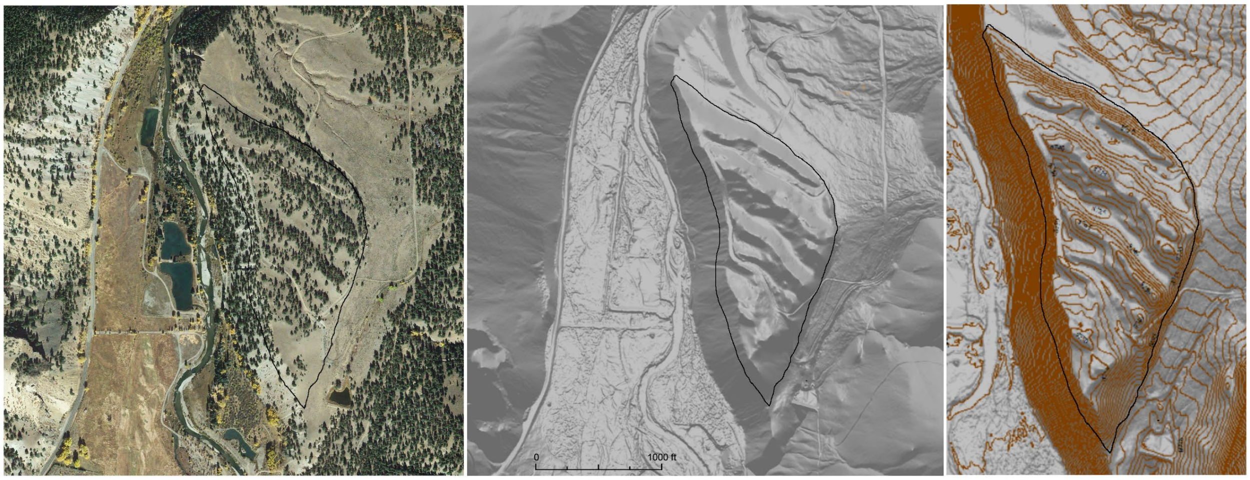

Figure 7 – This moraine remnant is the only glacial deposit remaining in the Lake Fork valley downstream from Lake City. Contour interval 5 ft.

I agree with Lipman's designation of the moraine as Pinedale age. I disagree with both Atwood and Mather's and Lipman's interpretation that it is the terminal moraine of the Pinedale glacial advance, and I argue that the Pinedale glacier flowed to Head of the Canyon. The moraine may be a recessional moraine of the initial Pinedale advance, or more likely, the result of a later Pinedale advance (discussed below). Examination of the topography of Lake Fork valley below Lake City (fig. 2) shows a straight valley with a broad flat floor that extends to Head of the Canyon, a classic pattern for a glacial valley. Transverse valley profiles reinforce this interpretation, showing classic U-shapes above Head of the Canyon and classic V-shapes below (fig. 8).

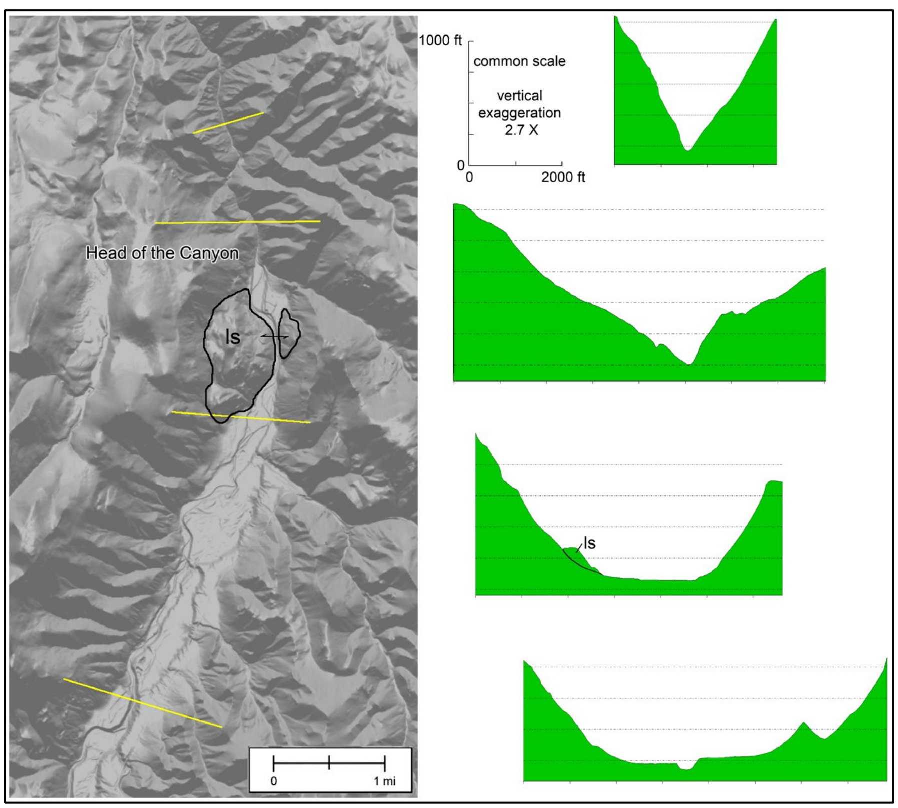

Figure 8 – Transverse profiles show a glacial valley down to Head of the Canyon and a fluvial valley below. ls, landslide.

Further support for this interpretation can be provided by comparing the sizes of the outlet glaciers in the San Juan icefield with their catchment areas (fig. 5). The catchment area of the Lake Fork glacier is comparable to that of the Rio Grande glacier and surpassed only by the

Animas glacier, yet the glacier is shown shorter than any of the other main glaciers. In fact, this stumpy, 3-mile-long glacier would appear to be anomalously undersized. A glacier that extends to Head of the Canyon is more realistic (fig. 9).

Outwash

Two prominent outwash terraces extend down valley from the moraine to Head of the Canyon. The higher terrace, referred to as terrace 1 (t1), extends from about four miles below the moraine nearly to Head of the Canyon (fig. 10). The lower terrace 2 (t2) extends from the moraine to Head of the Canyon. It is 50 to 80 ft lower than terrace 1 (fig. 11), but it was modified by two subsequent outburst floods that scoured and lowered the surface (t2s1 and t2s2, fig. 11).

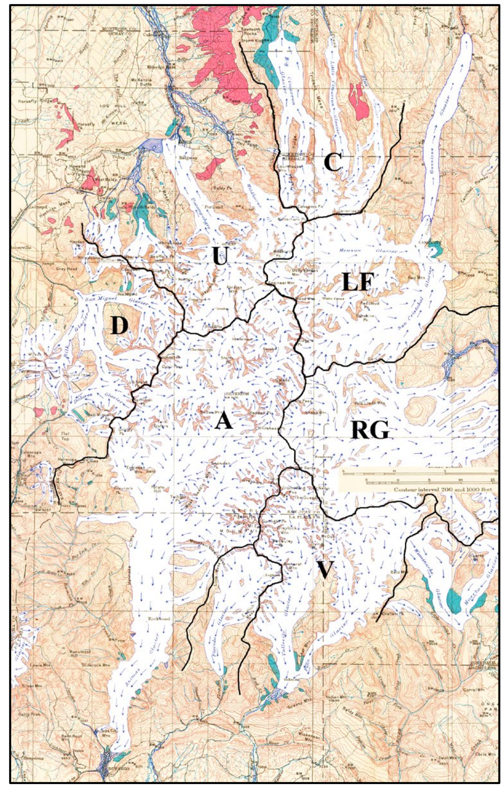

Figure 9 – San Juan icefield of Atwood and Mather (1932) with probable extent of Lake Fork glacier added. Compare with figure 5.

The higher terrace was mapped by Atwood and Mather (1932) as Durango outwash and the lower as Wisconsin outwash. Both terraces were mapped together as Quaternary alluvium by Lipman (1976) and Steven and Hail (1989). I think both terraces are Pinedale age, resulting from the two Pinedale glacial advances, both because of their similar exposure characteristics and their elevations (fig. 11).

Terrace 1, the older, higher terrace, is about 200 ft above the river in the upper reach of the valley and decreases to about 70 ft just above Head of the Canyon (fig. 11). The terrace gravel consists of normal main-stem alluvium, covered with a thin layer of loess and often buried beneath alluvial fans. The only exposure of the gravel is in the abandoned Whinnery gravel pit at valley mile 12 (location in fig. 11) where the gravel is about 25 ft thick (fig. 12). In this crudely stratified boulder-cobble-pebble gravel, boulders are only as large as an estimated 2½ to 3 ft.

Terrace 2 gravels grade to the moraine (fig. 11), and they were deposited down to Head of the Canyon. The depositional gravel surface, however, is preserved only in a seven-mile reach of the valley below the moraine. A continuous one-mile-long terrace surface is immediately below the moraine, two half-mile-long terrace remnants are preserved in expansion reaches of the valley, and seven small, isolated remnants of terrace remain in between (fig. 11). No proper exposures of the gravel have been seen, but from observations of small outcrops the gravels are assumed to be normal main-stem alluvium. At valley mile 8, a few large boulders are on the edge of the terrace.

Two terrace levels can be recognized slightly lower than terrace 2. These have unique surfaces that are erosional surfaces, rather than normal depositional surfaces; they are referred to as scour surfaces and the resulting landforms as scour terraces. The erosion that formed the scour surfaces was not normal stream erosion, but rather instantaneous scouring by glacial outburst floodwaters. Scour surfaces are best recognized on lidar images that show scour channels and anastomosing channel patterns (fig. 13). A transverse valley profile near valley mile 8 (location shown on fig. 11) shows the relationship between terrace 2 (t2), the first, higher scour terrace (t2s1), and the second scour terrace (t2s2) (fig. 14).

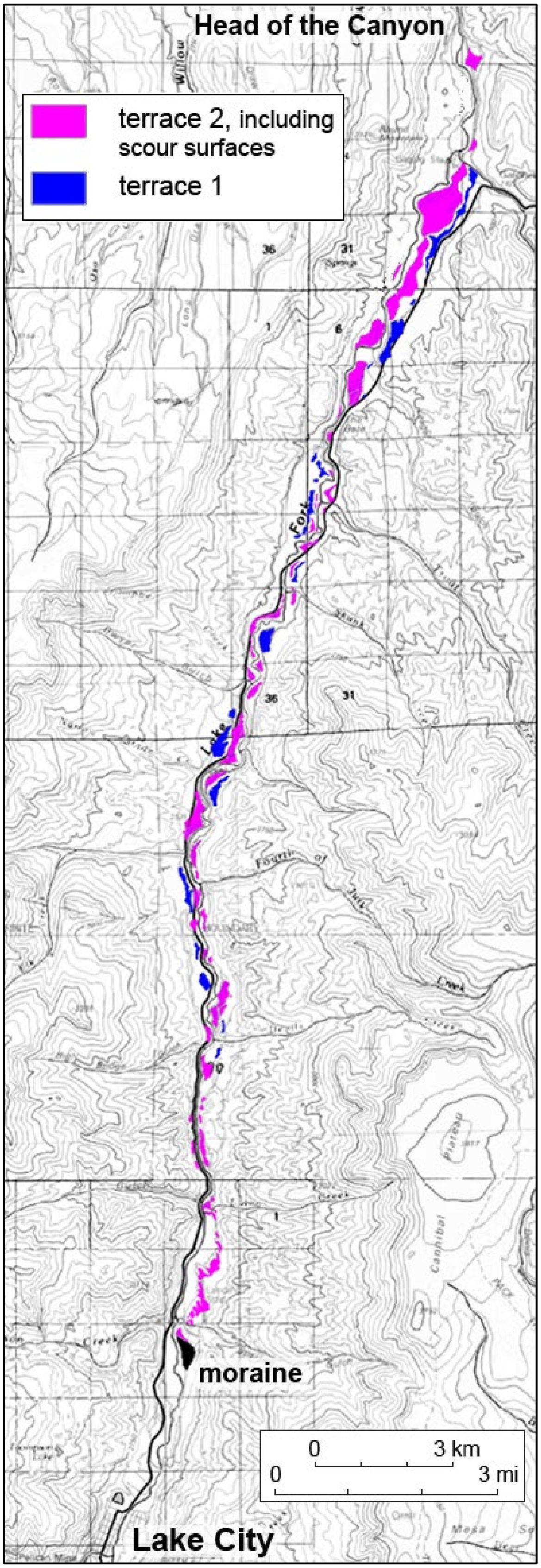

Figure 10 – Outwash terraces of the Lake Fork valley from Lake City to Head of the Canyon.

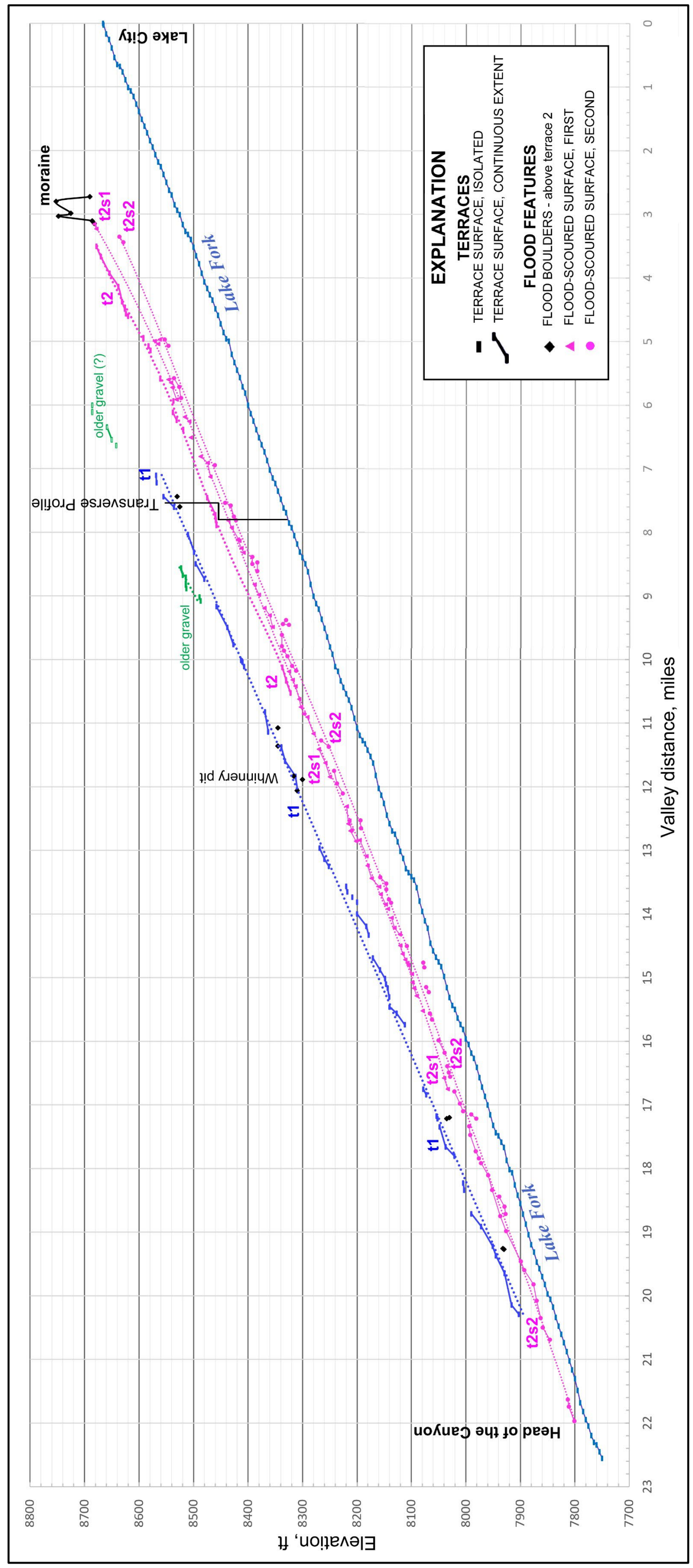

Figure 11 – Longitudinal profile of the Lake Fork with terraces and flood features.

Figure 12 –Outwash gravels of terrace 1 in Whinnery pit at valley mile 12. Boulder at top of gravel is an estimated 2½ ft.

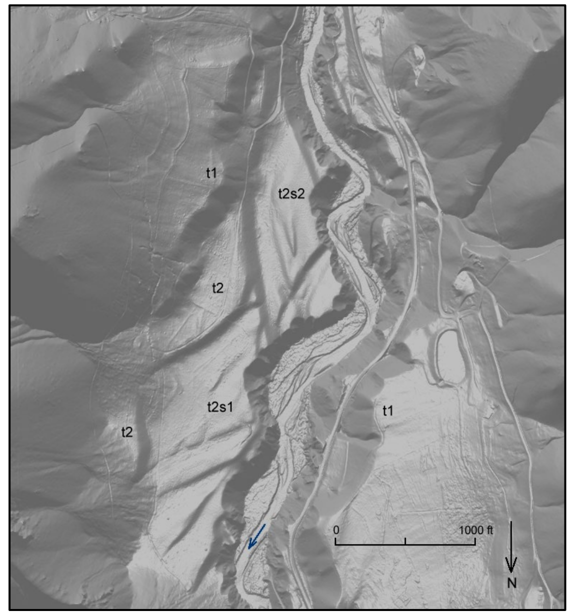

Figure 13 – Scour surfaces are characterized by irregular topography and scour channels that bifurcate both upstream and downstream. Terrace t2s1 is the first scour surface cut into terrace 2 gravels and t2s2 is the second (shaded-relief image has north at bottom so landforms are more easily seen; the same area is shown north-up in the next figure, fig. 14).

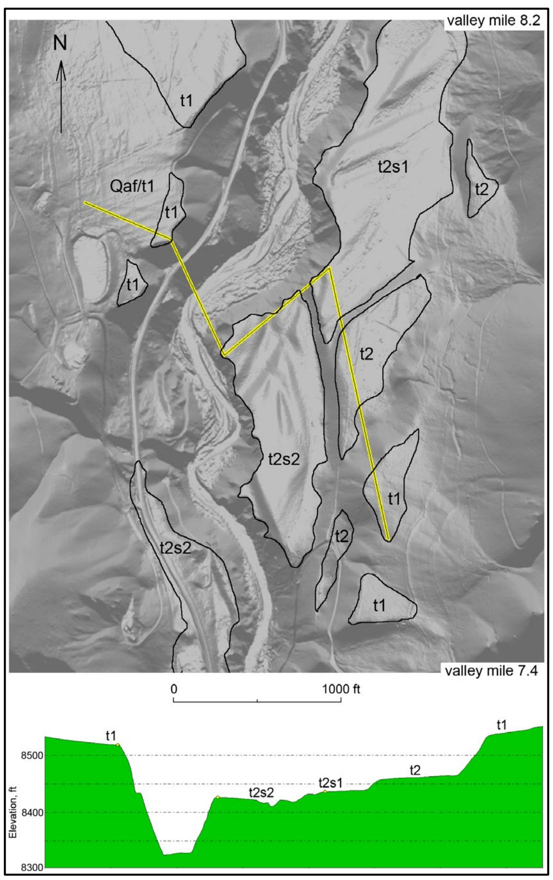

Figure 14 – The first scour surface here cut down into terrace 2 gravels about 20 ft and the second another 10—15 ft, but both surfaces are very irregular. Qaf, alluvial fan.

The first scour surface is about 10 to 30 ft lower than the terrace 2 surface, and the second scour surface is another 10 to 20 ft lower, although there is much variation because the surfaces are irregular. The first scour terrace is adjacent to the moraine and is recognizable down to valley mile17 (fig. 11), whereas the second scour terrace extends from the moraine to Head of the Canyon (fig. 11). In some parts of the valley, scour has nearly reached bedrock (fig. 15).

Flood boulders are common on the scour terraces (boulder in fig. 15, fig. 16). The term *flood boulders*, as used here, refers to boulders much larger than those that can be transported by normal floods and thus must have been transported by much larger (catastrophic) floods. There is no definitive size above which a boulder is considered a flood boulder, because the size is a function of the local fluvial regime and hydraulic gradient. As discussed above and shown in figure 12, the largest boulders in the outwash halfway down the valley are 2—3 ft in diameter, whereas the flood boulder shown in figure 16 (seven miles farther downstream) is an order of magnitude bigger in

Figure 15 – Surface of scour terrace t2s2 is only about eight feet above bedrock at valley mile 9.8.

Figure 16 – Recently excavated flood boulder of ash-flow tuff is 7 x 6 x 5 ft at valley mile 19.6.

volume and weight. When considering boulder sizes, it is helpful to remember that volume and weight of a round boulder increase as the cube of the boulder diameter. For example, one could hold a one-foot diameter spherical boulder of granite, which weighs 87 pounds, whereas a two-foot boulder weighs 698 pounds. Flood boulders along the Lake Fork are as large as 12 ft in long dimension (fig. 17).

Older Gravel
An alluvial terrace remnant about 40 ft above terrace 1, about a half mile long, is at valley mile 9 (fig. 11). The relationship to the outwash terraces is unclear, and the gravel is simply noted as Older Gravel. A correlative terrace two miles upstream (fig. 11) is likely the same, but it has not been field checked.

Atwood and Mather (1932) mapped patches of an even older gravel 300 to 700 ft higher than terrace 1, which they called Florida Gravel. I did not visit these gravels.

Figure 17 – Large flood boulder in borrow pit at valley mile 16.1 is ash-flow tuff 12 x >5 x >4½ ft (trekking poles are 4 ft).

GLACIAL AND FLOOD HISTORY

From glacial records in adjacent drainages, we know there were three major glaciations in the San Juan icefield, but there is no record of the first two in the Lake Fork basin. The only extent moraine in the outlet glacial valley, and only a partial one at that, is the Pinedale moraine just below Lake City at valley mile 3.

Pinedale Glaciation
As discussed earlier, the Pinedale glacier ran to Head of the Canyon before retreating. During retreat all the way back to Lake City or above, it deposited outwash that became terrace 1.

After retreat and some valley deepening, a second Pinedale advance reached only a short distance below Lake City - perhaps about five miles - and retreated without building a moraine to a stasis position at valley mile 3, where it built a multi-crested recessional moraine. During this readvance, outwash deposited down valley became the gravels of terrace 2.

Outburst Floods

As the last glacier retreated into the catchment area, the recessional moraine blocked the Lake Fork to create a proglacial lake, here referred to as Lake Hinsdale. A moraine-bedrock failure occurred at the right abutment that produced glacial outburst flood 1. The flood scoured the surface of the outwash downstream, producing flood scour surface 1. Failure was not complete, however, and at some point the morainal dam held and Lake Hinsdale persisted. The eroded notch was subsequently filled with alluvial fan gravels, creating a unique alluvial fan that diverges downstream (fig. 18).

Eventually, the morainal dam failed catastrophically at the left abutment, and the remaining waters of Lake Hinsdale tore out the left end of the dam and poured down valley as glacial outburst flood 2. Because the canyon is quite narrow and the moraine therefore was relatively short, little material was available to produce flood gravels and relatively few flood boulders were transported downstream. Most of the energy of the flood waters was spent scouring the remaining terrace 2 gravels, producing flood scour surface 2.

The flood magnitude is unknown. A few flood boulders at the edges of terrace 1 (fig. 19) indicate an effective flood depth of about 70 ft. Post-glacial fluvial erosion deepened the valley about 130 ft at the moraine, decreasing to about 30 ft at Head of the Canyon. This erosion left the outwash and flood surfaces as terraces.

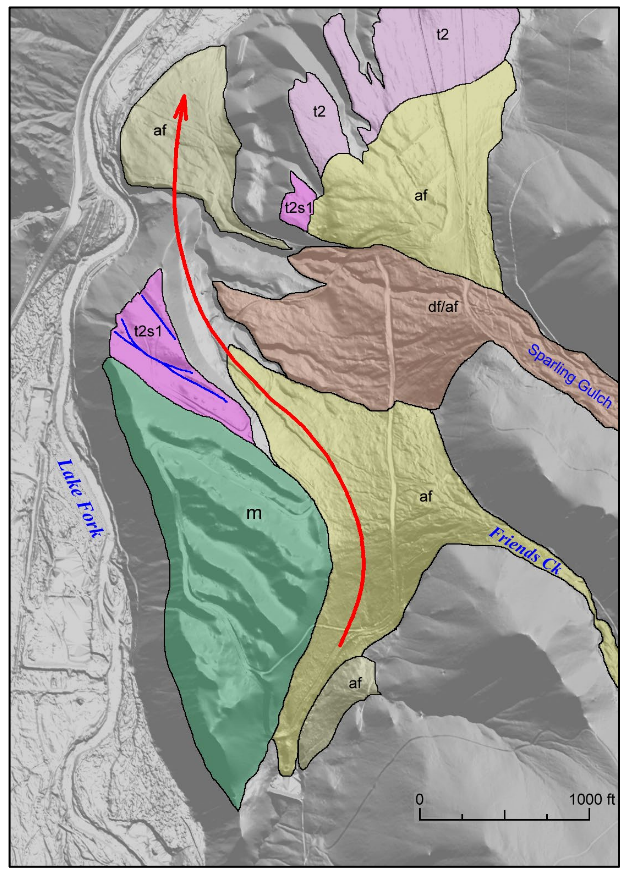

Figure 18 – Geologic interpretation of lidar image of morainal dam area. Red arrow shows probable path of glacial outburst flood 1 from Lake Hinsdale that scoured and eroded terrace 2 gravels. af, alluvial fan; df, debris flow; m, moraine; t2, terrace 2; t2s1, scour terrace 1; blue lines show scour channels.

Figure 19 – Eight-foot flood boulder at the edge of terrace 1 at valley mile 11.4 was deposited by outburst flood about 70 ft above the valley floor.

CONCLUSIONS

Glaciers of the San Juan icefield formed in the circular topographic basin of the Lake City caldera, within the eastern part of the San Juan caldera. The Henson glacier ran along the north rim of the caldera and the Lake Fork glacier followed the south and east rims; the glaciers converged at Lake City and the outlet glacier ran down the Lake Fork.

No deposits of early glaciers on the Lake Fork are known. Only one moraine of the Pinedale glacier remains three miles below Lake City, but indirect evidence indicates an early Pinedale glacier flowed about 22 mi down from Lake City and reached Head of the Canyon. As the glacier retreated, it deposited outwash across the valley.

A readvance of the latest Pinedale glacier reached only about five miles below Lake City before retreating about two miles, where it built a large, multi-crested moraine. As the glacier continued to retreat, the recessional moraine created a dam that formed proglacial Lake Hinsdale, fed by both Henson Creek and Lake Fork.

Erosion along the right abutment caused a failure leading to outburst flood 1 that eroded and scoured outwash deposits downstream. The morainal dam remained intact, however, and the outlet gap was filled with alluvial fan gravels. Lake Hinsdale persisted until ultimate failure along the left abutment led to outburst flood 2, which tore out most of the morainal dam and further scoured the surfaces downstream. Flood magnitude is unknown, but one of the floods left flood boulders about 70 ft above the valley floor.

Postglacial downcutting in the easily eroded bedrock left the Pinedale outwashes and stepped down scour surfaces as terraces.

RELATIONSHIP TO OTHER CATASTROPHIC FLOODS IN COLORADO

Catastrophic outburst floods have been recognized in valleys of other outlet glaciers from the San Juan icefield (fig. 5). All the floods were glacial in origin, except perhaps the flood on Los Pinos River, whose origin is uncertain. There were also catastrophic glacial outburst floods on the upper Arkansas River.

Rio Grande Pinedale glaciers on the Rio Grande impounded glacial Lake Atwood (Leonard et al., 1994). With a volume of about 138,000 acre-ft, the lake drained catastrophically twice along ice-bedrock spillways. Similar to the Lake Fork, both outburst floods occurred during the Pinedale.

Animas River Four catastrophic floods ran down the Animas River valley during the Pleistocene (Lee, 2025a). Outlet valley glaciers reached Durango during the last three glacial advances and formed proglacial Lake Durango. Failure of the morainal dams led to catastrophic draining of the proglacial lakes, carrying flood deposits more than 50 miles downstream to the San Juan River at Farmington, New Mexico. An earlier flood likely had a similar origin.

Uncompahgre River Outlet glaciers flowed down the Uncompahgre River valley to Ridgway (Lee, 2025b). The last two glaciers created proglacial Lake Uncompahgre that ultimately failed catastrophically to produce outburst floods. The Bull Lake flood carried flood boulders at least 23 miles down valley to Montrose. The Pinedale flood occurred when the distal proglacial lake's morainal dam was breached at two places, perhaps from overtopping. This flood diverted the river's course both at Ridgway and at Montrose.

Los Pinos River The catastrophic Vallecito flood, perhaps the largest of all the San Juan floods, ran down Los Pinos River and the San Juan River, carrying flood boulders 72 miles to Farmington, New Mexico (Lee, 2025c). The cause of the flood is unknown, but the likely origin was a glacial outburst flood. Outlet glaciers in the two main forks, Vallecito Creek and Los Pinos River, merged, and the earlier arrival likely dammed the other fork, creating a glacial lake that lead to an outburst flood. The time of the flood is constrained to early to middle Pleistocene.

Arkansas River The upper Arkansas River valley experienced three glacial outburst floods near Buena Vista (Lee, 2019). These floods differ from those on the Lake Fork, however, in the mechanism of dam formation; Three Glaciers Lake on the Arkansas River formed behind tributary glaciers that dammed the main valley and formed ice dams or ice-and-moraine dams. The two most recent glacial outbursts were at the ends of the Pinedale and Bull Lake glacial advances, and the earliest flood occurred at about 640 ka.

ACKNOWLEDGMENTS

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