

COLORADO GEOLOGICAL SURVEY

Research Notes RN-03

Glacial outburst floods on the Uncompahgre River, Colorado

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ABOUT THIS REPORT

From the abstract:

“Outlet glaciers from the San Juan icefield flowed down the Uncompahgre River valley 23 miles to Ridgway, Colorado. Three major glacial advances are recognized, with each glacier reaching a maximum extent within a half-mile of each other. Ages have not been determined, but suggested ages are Durango, Bull Lake, and Pinedale (Last Glacial Maximum). The Bull Lake and Pinedale glaciers created lakes that ultimately failed catastrophically to produce outburst floods. The Bull Lake flood carried many large flood boulders to Montrose, Colorado, 23 miles down valley. The Pinedale flood occurred when the distal proglacial lake’s morainal dam was breached at two places, perhaps from overtopping. This flood was smaller than the first, but it carried flood boulders nine miles downriver and diverted the river’s course both at Ridgway and at Montrose.”

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COLORADO GEOLOGICAL SURVEY
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GLACIAL OUTBURST FLOODS ON THE UNCOMPAHGRE RIVER COLORADO



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2025

ABSTRACT

Outlet glaciers from the San Juan icefield flowed down the Uncompahgre River valley 23 miles to Ridgway, Colorado. Three major glacial advances are recognized, with each glacier reaching a maximum extent within a half-mile of each other. Ages have not been determined, but suggested ages are Durango, Bull Lake, and Pinedale (Last Glacial Maximum).

The Bull Lake and Pinedale glaciers created lakes that ultimately failed catastrophically to produce outburst floods. The Bull Lake flood carried many large flood boulders to Montrose, Colorado, 23 miles down valley. The Pinedale flood occurred when the distal proglacial lake's morainal dam was breached at two places, perhaps from overtopping. This flood was smaller than the first, but it carried flood boulders nine miles downriver and diverted the river's course both at Ridgway and at Montrose.

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INTRODUCTION

GEOGRAPHY

Floods occurred on the Uncompahgre River that drains the northwest San Juan Mountains in Colorado (fig. 1). The Uncompahgre River flows north from cirques of the San Juan Mountains to its confluence with the Gunnison River, part of the Upper Colorado River Basin. The highest point in the watershed, at the head of East Dallas Creek, is Mt. Sneffels at 14,150 ft (4,315 m) elevation.

The area considered in this report is from Ridgway, where the floods originated, to Montrose. In this report, the morainal hills near Ridgway are informally referred to as the *moraine area*¹ (fig. 2). At Dallas the river flows into the *Uncompahgre Canyon*, capped by resistant sandstone, nine miles long and about 2000—3000 ft wide. At the mouth of the canyon between Eldridge and Colona, the sandstone dips beneath shale, and *Montrose Valley* opens up to 1½ miles wide at Colona and about eight miles wide at Montrose.

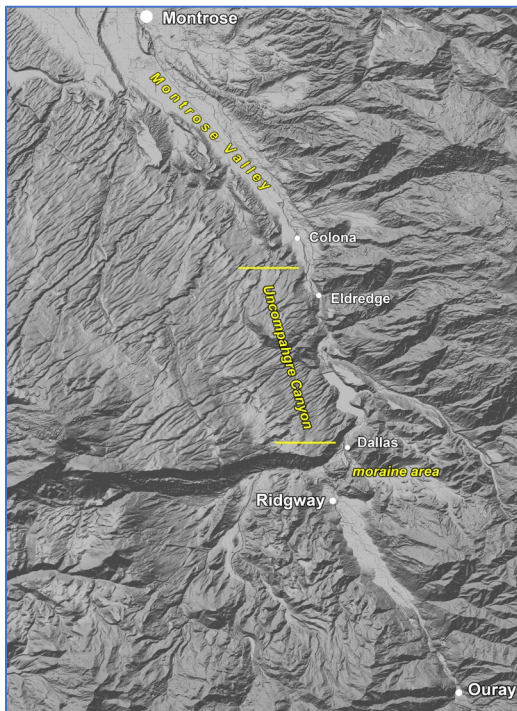


Figure 2—Irregular topography of the moraine area, the restricted Uncompahgre Canyon, and the open Montrose Valley.

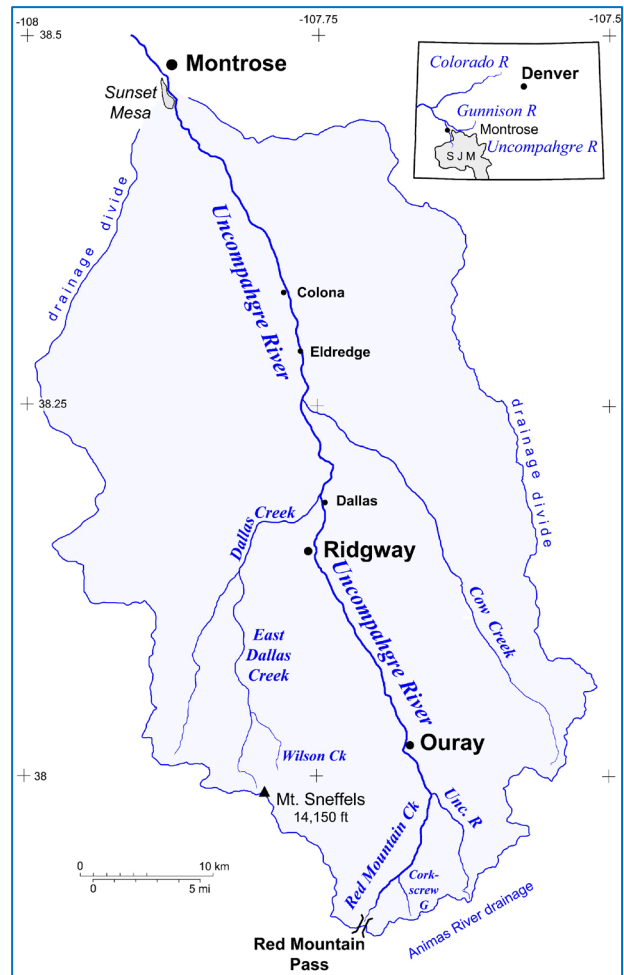


Figure 1—Uncompahgre River drainage basin above Montrose, Colorado, with Uncompahgre River and selected tributaries; inset connects the river to the Colorado River. SJM, San Juan Mountains.

¹ Informal names used in this report for clarity are italicized at first usage.

GEOLOGY

Bedrock geology is relatively unimportant to the flood history of the region, except, as noted above, the constricted Uncompahgre Canyon. The area of the report consists of only Mesozoic sandstones and shales (fig. 3) dipping homoclinally to the north (fig. 4). In the headwaters area of the river, Tertiary volcanic rocks cap Devonian to Cretaceous sedimentary rocks lying on Precambrian metamorphic rocks.

GLACIATIONS IN THE SAN JUAN MOUNTAINS

Glaciers capped much of the San Juan Mountains in an icefield, with one of the outlet glaciers flowing down the Uncompahgre River (fig. 5). The best studied of the San Juan glaciers is the outlet glacier on the Animas River in the contiguous drainage to the south. 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 or three separate advances (Durango 1, Durango 2; Bull Lake 1, Bull Lake 2; Pinedale 1, Pinedale 2, Pinedale 3).

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).

SAN JUAN MOUNTAINS GLACIATIONS			
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

The author mapped bedrock geology in the summers of 1970—1975 and glacial geology in the summers of 1977 and 1978, before the moraine area was developed into residential properties and some of the moraines were modified or removed, and before most of the East Dallas Creek deposits were withdrawn from public access. Additional details and accuracy came with the recent availability of lidar data. Outwash terraces and flood deposits were mapped in 2020—2023.

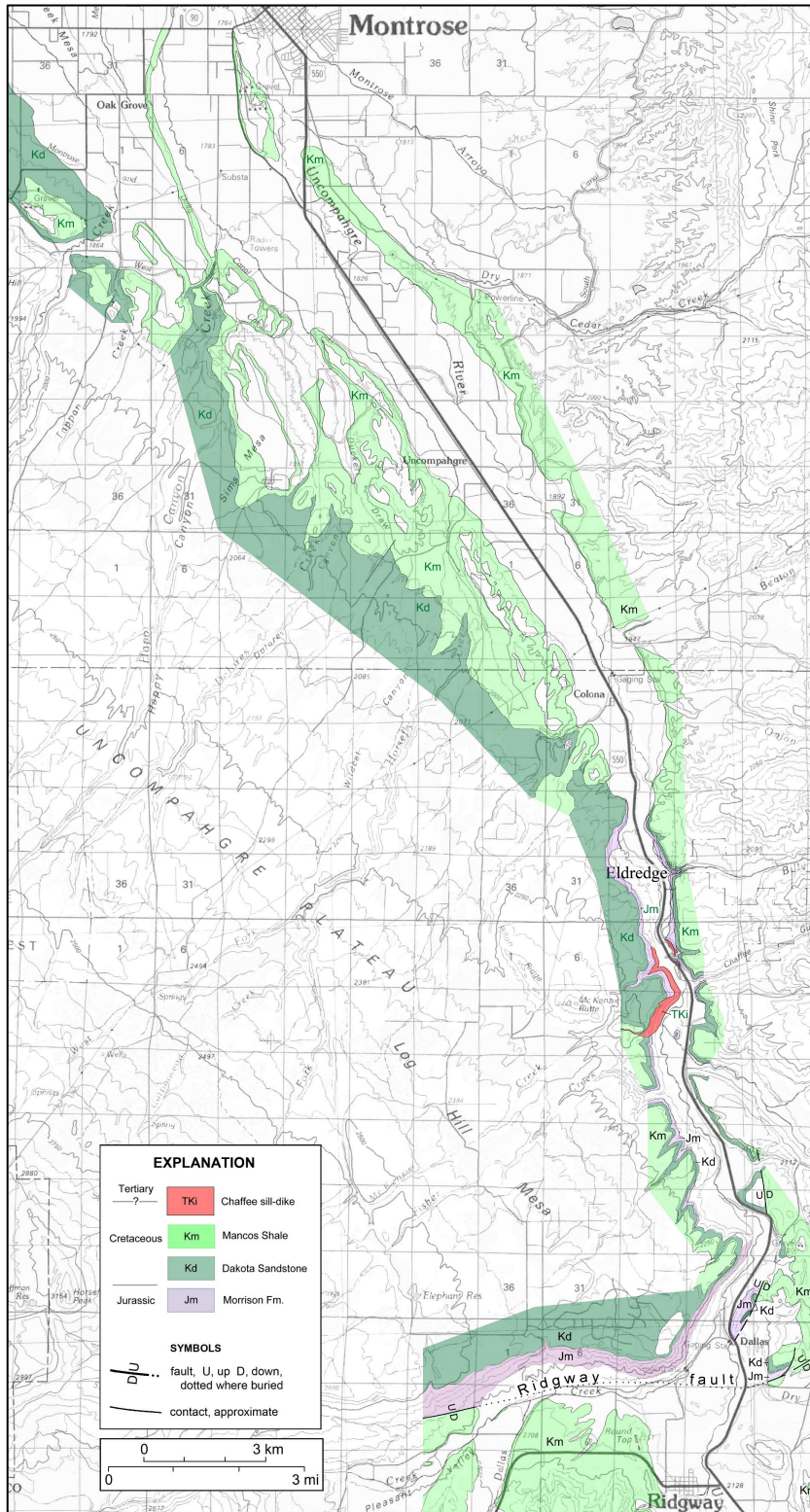


Figure 3—Bedrock geology along the Uncompahgre River. North of Eldredge, geology simplified from Hail (1986, 1987) and Noe et al. (2007). Topographic base maps 1963, 1967.

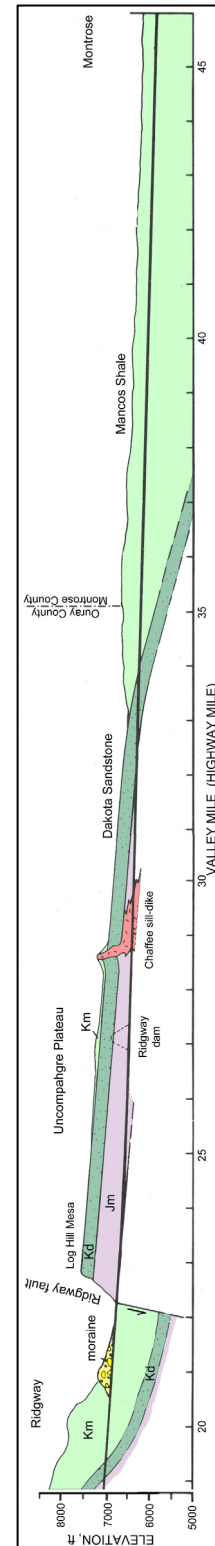


Figure 4—Geologic section along the Uncompahgre River, from Lee et al., 1976. Line of section is highway US 550 in 1976 (fig. 3). Jm, Morrison Fm.; Kd, Dakota Sandstone; Km, Mancos Shale.

GLACIAL GEOLOGY

Glacial deposits on the Uncompahgre River have not been well studied. Early geologists noted moraines at Ridgway (Hills, 1884; Howe and Cross, 1906; Atwood and Mather, 1912, 1932; Atwood, 1915; Cross and Larson, 1935; Sinnock 1978, 1981), but none mapped the moraines in detail. Jarrin et al. (2017) did additional mapping. Some observations were also made on Dallas Creek (fig. 1), a western tributary of the Uncompahgre River (Howe and Cross, 1906; Atwood and Mather, 1932; Richmond, 1954), but no detailed mapping was done there.

The glacial deposits at Ridgway consist of only incomplete lateral and end moraines because of the subsequent outburst floods, but fortunately a more complete record is preserved on a major tributary, East Dallas Creek, discussed below. The glacial deposits in the Uncompahgre River drainage indicate three main advances. None of these deposits has been dated; they are here referred to simply as moraine 1 (m1), moraine 2 (m2, with two pulses, m2a and m2b), and moraine 3 (m3), from oldest to youngest, and their respective outwash terraces are referred to as terrace 1 (t1) to terrace 3 (t3).

I do, however, suggest ages based on relative dating criteria and correlation with the Animas River moraines, because the Uncompahgre and Animas glaciers originated from the same part of the San Juan icefield (fig. 5). Atwood and Mather (1932) mapped moraine 1 as Durango till and grouped the other two together as Wisconsin till (table below). Sinnock (1981) mapped moraine 1 as Bull Lake and grouped the other two together as Pinedale. Jarrin et al. (2017) did not assign ages to the moraines.

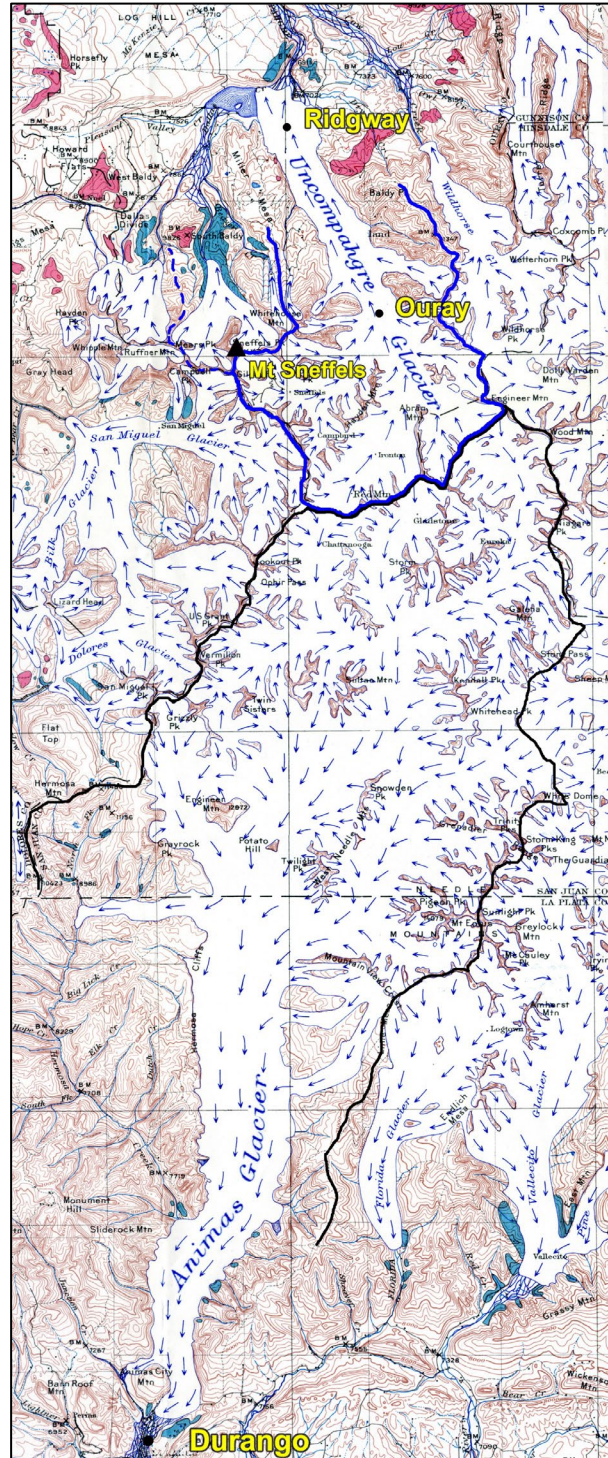


Figure 5—Glacial map of Atwood and Mather, 1932, with glacial divides added: Animas Glacier, black, Uncompahgre Glacier, blue, East Dallas Creek glacier, thin blue dash. Note common starting area for both Animas and Uncompahgre glaciers.

Uncompahgre River Glacial Deposits and Correlations					
this report		Atwood and Mather 1932	Sinnock 1978 1981	Jarrin et al. 2017	
Unit	Age				
rg	Neoglacial ²				
mc	Neoglacial ¹				
m3	Pinedale				gm3 ^{4,5}
m2b	Bull Lake 2	Wisconsin	Pinedale 2 ³	gm4 ⁴	
m2a	Bull Lake 1		Pinedale 1 ³	gm5 ⁴	
m1	Durango	Durango	Bull Lake		

m, moraine; mc, cirque moraine; rg, rock glacier; gm, glacial moraine

¹ at Corkscrew Gulch; cirque moraine soil supports spruce

² lichens only

³ Sinnock refers to older Pinedale as P2 and younger Pinedale as P1

⁴ ages are not assigned

⁵ outwash [Qag3] dated 70—40 ka by OSL

GLACIAL DEPOSITS ON EAST DALLAS CREEK

The most complete glacial record is preserved on East Dallas Creek, a western tributary of the Uncompahgre River (fig. 1). The Uncompahgre glacier and the East Dallas Creek glacier had a common starting area around Mt. Sneffels (fig. 5). Moraines that correlate with those on the Uncompahgre River are well preserved (fig. 6), and a small patch of possible older till is preserved that is not recognized on the Uncompahgre River.

Moraine 1 (m1) is a right lateral moraine showing the first glacier flowed west of South Baldy (fig. 6). Paired lateral moraines of the second glacial advance (m2a) flowed through today's Blaine Draw, and paired lateral moraines of this same glacier (m2b) cross-cut the moraines, indicating the readvancing glacier again changed course down what is the modern East Dallas Creek. The two sets of moraines are at about the same elevation, indicating relatively little time had elapsed between the initial advance and the readvance.

Paired lateral moraines of the third glacial advance, along with a partial end moraine, show this glacier did not extend as far as the earlier glaciers (fig. 6). An anomalously flat area behind the end moraine (Willow Swamp in fig. 6) is suggestive of a proglacial lake. Paired moraines farther up valley (fig. 6) are recessional moraines of this third glacier, as they are at the same height above the creek.

Atwood and Mather (1932) designated the deposit capping South Baldy as Cerro Till, a controversial designation that has been argued since Dickinson (1965) interpreted the type locality of the Cerro Till as a landslide deposit. I interpreted the deposit on South Baldy as a till during a single visit in 1978. Richmond (1954) interpreted it as Cerro Till.

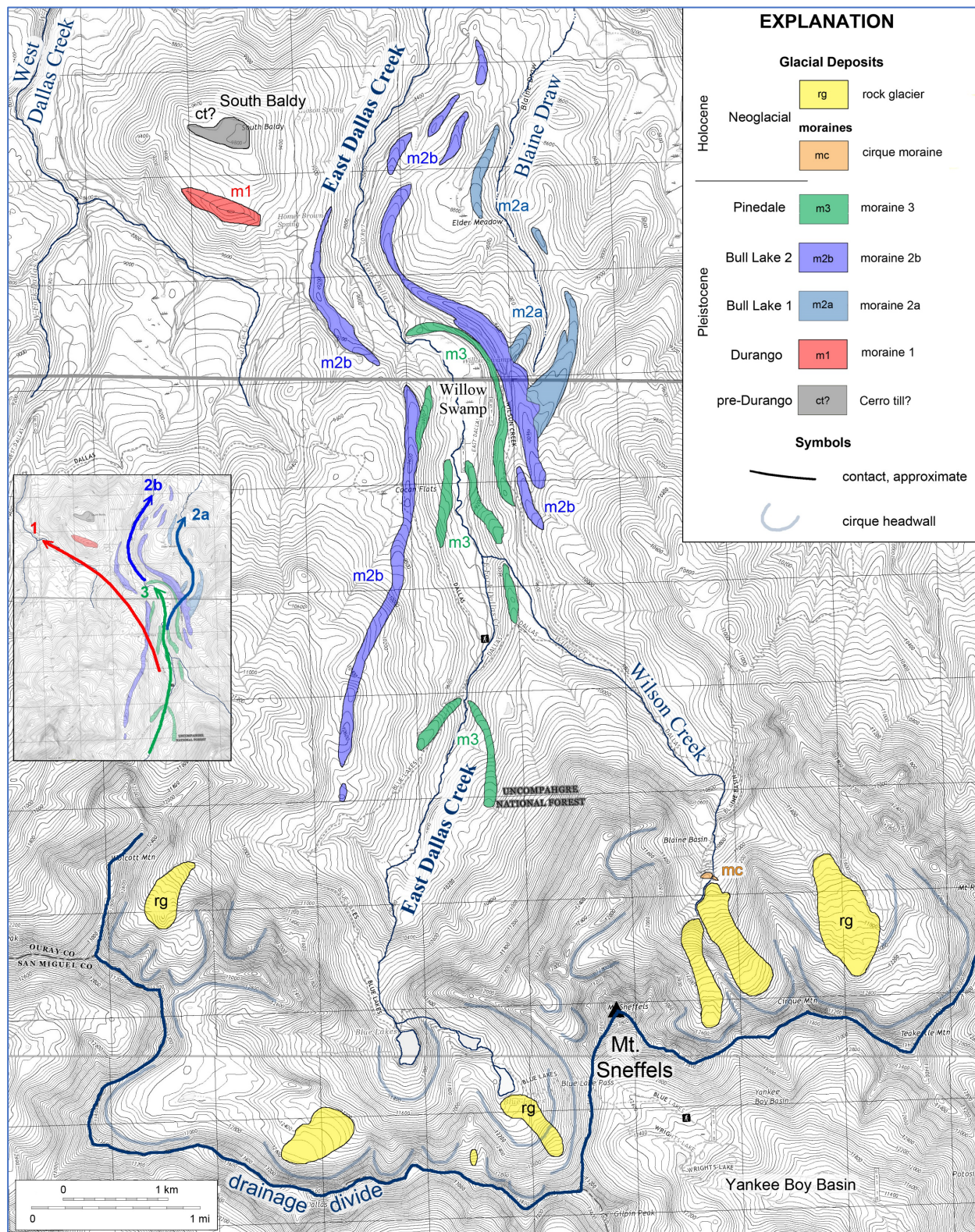


Figure 6—Glacial deposits of East Dallas Creek. Inset shows paths taken by each glacier. Although glacier 2b cross-cut moraine 2a, both moraines are at about the same elevation (see also fig. 9). Cirques and rock glaciers mapped from 1972 NASA color aerial photographs. Cirque moraine on Wilson Creek mapped on same photographs from description by Richmond, 1954. Cirques in Yankee Boy Basin fed the Uncompahgre glaciers (see also fig. 5).

Richmond (1954) also recognized that moraine 2a and moraine 2b *represent two advances of the ice separated by an interval of erosion. The moraines may, therefore, be considered as ... the first and second advances of the Bull Lake stage...* (table below). Richmond considered the youngest moraine, m3, to be Pinedale.

East Dallas Creek Glacial Deposits And Correlations			
this report		Richmond, 1954	Atwood and Mather, 1932
Unit	Age		
rg	Neoglacial	Little Ice Age	
mc	Neoglacial	Temple Lake	
m3	Pinedale	Pinedale 2	Wisconsin
		Pinedale 1	
m2b	Bull Lake 2	Bull Lake 2	Durango
m2a	Bull Lake 1	Bull Lake 1	
m1	Durango		Cerro
ct?	Pre-Durango	Cerro	

m, moraine; mc, cirque moraine; rg, rock glacier; ct?, Cerro Till?

Richmond (1954) also mapped a small cirque moraine on Wilson Creek (mc in fig. 6), a tributary of East Dallas Creek, that he correlated with the Temple Lake stage, which he considered *post-"altithermal" Recent age*. I mapped a similar small cirque moraine at about the same elevation in Corkscrew Gulch, a tributary of the Uncompahgre River near Red Mountain Pass.

Rock glaciers are common in the cirques, both on East Dallas Creek (fig. 6) and other tributary drainage cirques. Richmond (1954) considered these to have *formed during the latest glacial episode from about A.D. 1640 to 1860*.

A remnant of a cirque glacier may have persisted here; Howe and Cross (1906) reported that *ice was seen by Cross in 1895...at the head of a fork of Dallas Creek...it was crevassed and of a characteristic green color*.

GLACIAL DEPOSITS ON THE UNCOMPAHGRE RIVER

Glaciation 1 (Durango)

Only one small fragment of moraine 1 is preserved on the Uncompahgre River, which caps *Dallas East Hill* east of Dallas (figs. 7, 8). Atwood and Mather (1932) also mapped this as Durango. Nothing can be said about the distribution of the glacier other than it reached Dallas.

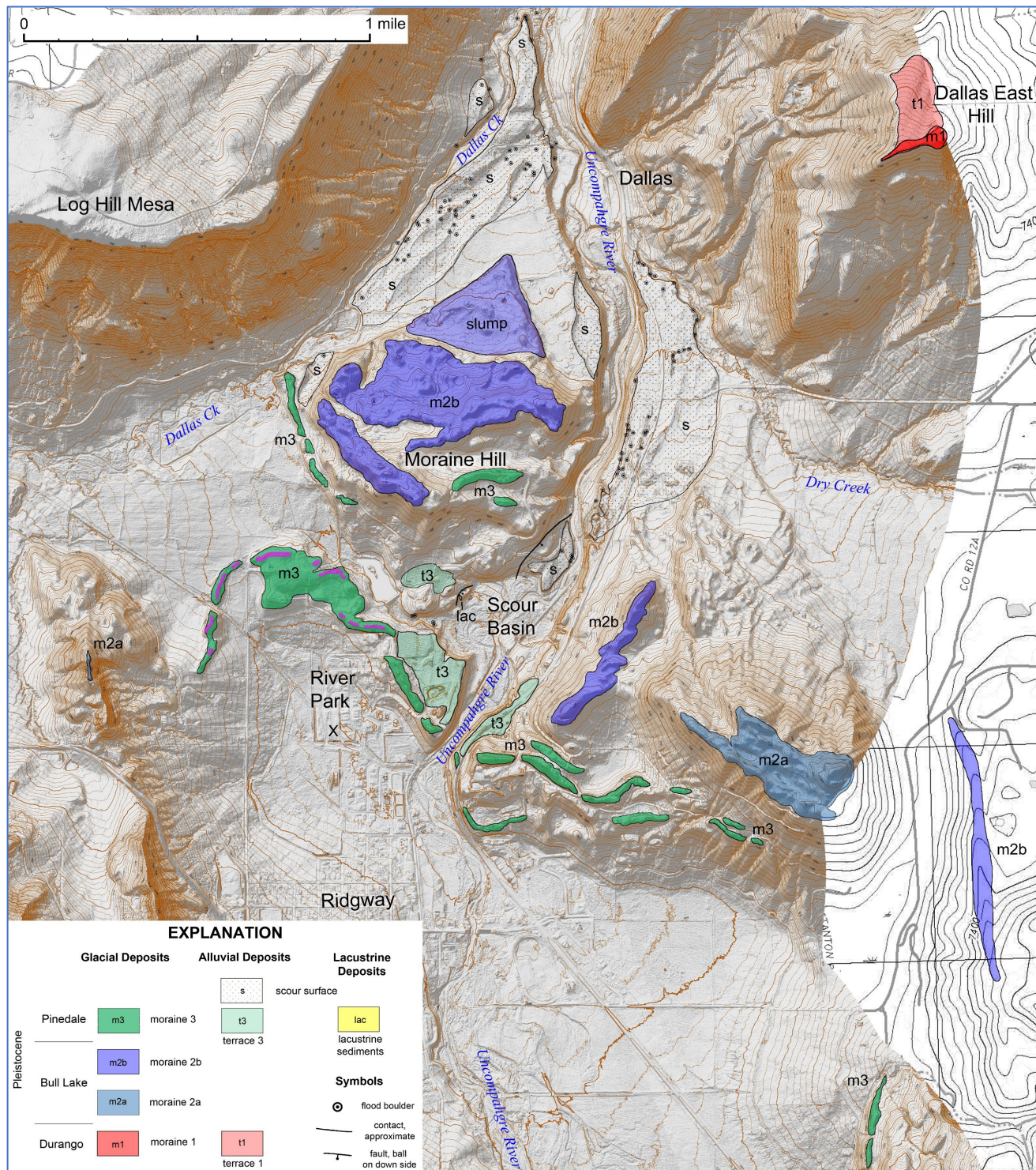


Figure 7—Glacial deposits on Uncompahgre River in moraine area. Lidar contour interval, 5 ft; topo map contour interval, 40 ft. X, shallow excavation into lacustrine sediments; magenta overprint on recessional moraine, reworked lacustrine sediments.



Figure 8—Moraine 1 on Mancos Shale at Dallas East Hill.

A small apron of outwash extends a short distance downstream, which is the start of terrace 1 (t1) (fig. 7, fig. 9). Only two patches of terrace 1 gravels remain in Uncompahgre Canyon, but they are nearly continuous in Montrose Valley down to and beyond Montrose (fig. 9, fig. 10). This forms the highest of a flight of four terraces in Montrose Valley, about 500 ft above the modern Uncompahgre River (fig. 11).

The gravels of terrace 1 are normal main stem gravels, and do not contain flood gravels. Large boulders of resistant ash-flow tuffs occasionally are incorporated in these gravels, but they are always at the base of the gravel and are part of lag boulders widespread in Montrose Valley.

Terrace 1 was correlated with the Florida Gravel of the Animas River by Atwood and Mather (1932; table below). In the Animas River Valley, however, the Florida Gravel is overlain directly by the Lava Creek Ash, whereas in the Uncompahgre River valley this ash is several hundred feet higher than terrace 1 (fig. 9).

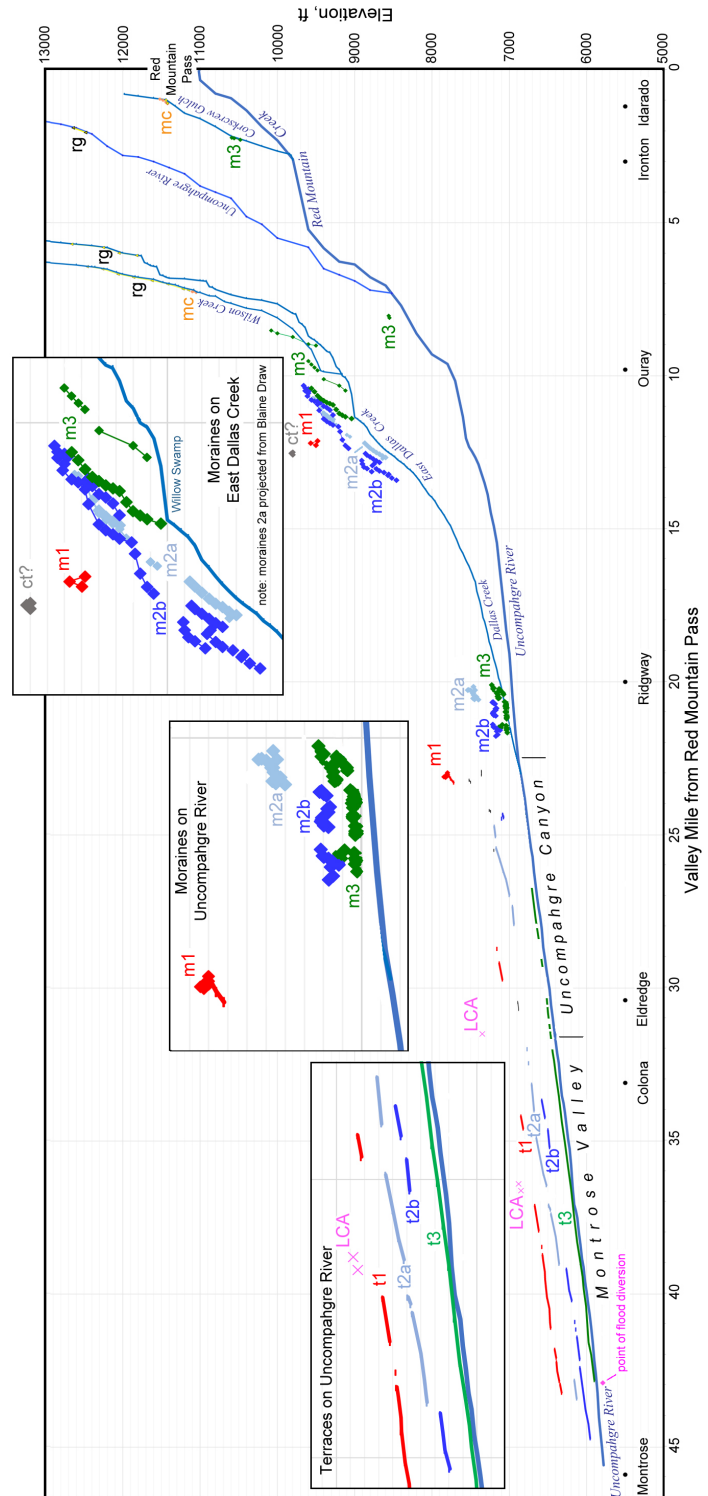


Figure 9—Longitudinal profile of Uncompahgre River and selected tributaries with glacial deposits and outwash terraces. ct?, possible Cerro Till deposit; LCA, Lava Creek Ash; m, moraine; mc, cirque moraine; rg, rock glacier; t, terrace. LCA at mile 31 from Dickinson, 1987; LCA at mile 37 from Noe et al., 2007.

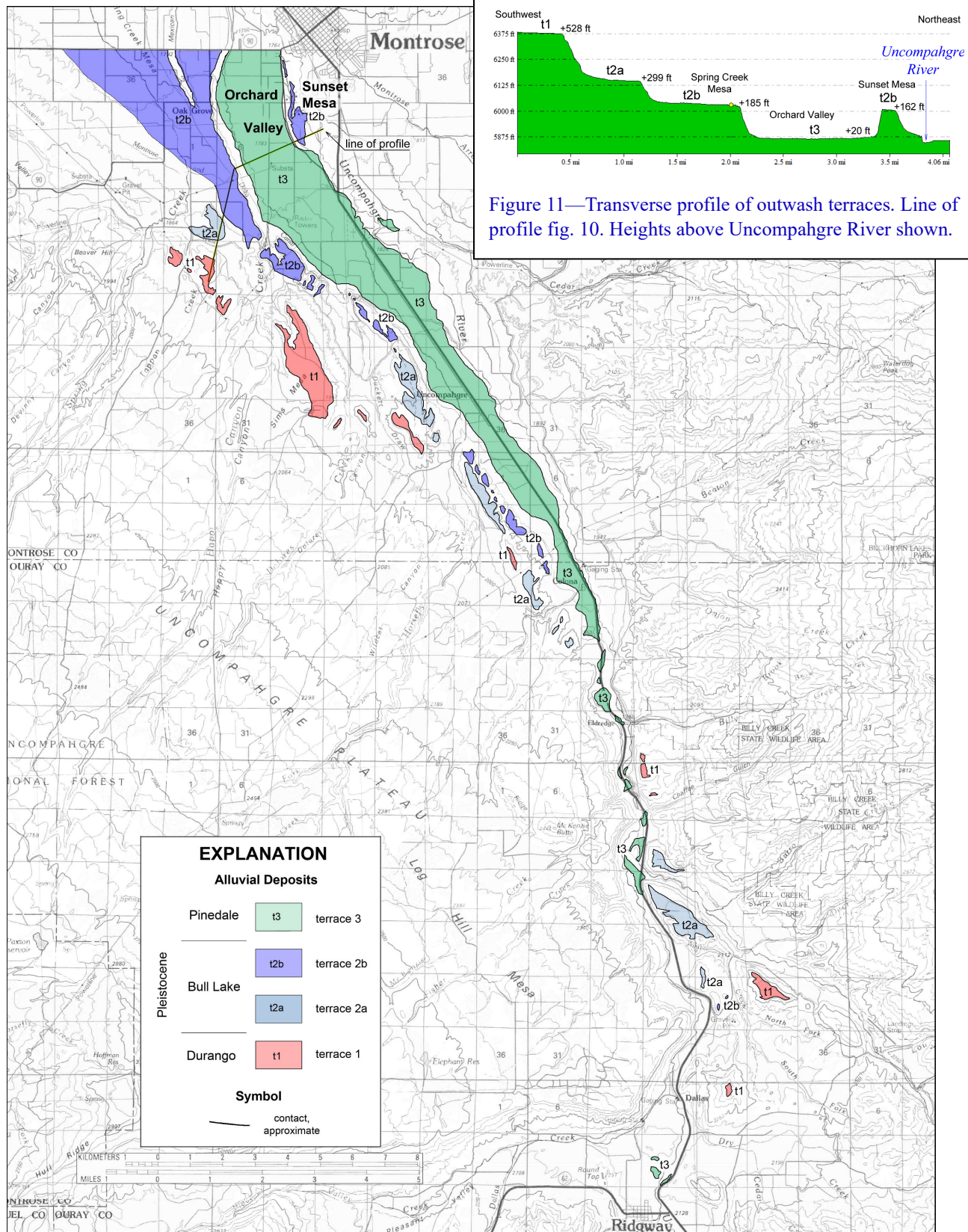


Figure 11—Transverse profile of outwash terraces. Line of profile fig. 10. Heights above Uncompahgre River shown.

Figure 10—Outwash terraces along the Uncompahgre River. t, terrace.

TERRACES of UNCOMPAHGRE RIVER

This Report				Noe et al. ¹ 2007		Atwood and Mather 1932	
Moraine	Terrace	Height	Age	Terrace	Age	Terrace	Age
m3	t3	20'–55'	Pinedale	Qau2	Pinedale	Qwo	Wisconsin
m2b	t2b	200'–260'	Bull Lake 2	Qau3	Pinedale	Qpd	Post-Durango
m2a	t2a	300'–400'	Bull Lake 1	Qau4	Bull Lake	Qdo	Durango
m1	t1	500'–900'	Durango	Qau5	Bull Lake	Qf	Florida Gravel

¹after Sinnock 1978, 1981

Glaciation 2a (Bull Lake 1)

A double right lateral moraine is preserved east of Ridgway, and a small patch of probable till caps Round Top at an equivalent elevation to the west (fig. 7). Given the geometry and height of these deposits, this glacier reached at least to Log Hill Mesa and may have continued farther down the valley of the ancestral Uncompahgre River, which is now the course of modern Dallas Creek. The moraines are sharp-crested and have moderately high boulder exposure.

Outwash from this glacier is not preserved in the moraine area and is found in Uncompahgre Canyon only at the Cow Creek confluence, but a continuous chain of terrace 2a gravels is preserved in Montrose Valley (fig. 10), where the terrace is about 300 ft above the modern Uncompahgre River and about 200 ft below terrace 1 (Figs. 7 and 11). The gravels of terrace 2a are normal main stem gravels, and do not contain flood gravels. Lag boulders are occasionally found at the bottom of the gravel.

Glaciation 2b (Bull Lake 2)

Moraines of this readvancing glacier are better preserved than the older moraines and provide a fairly complete picture of the glacier's configuration (fig. 7). The glacier followed the path of the previous glacier directly to Log Hill Mesa, where it was forced to the right down the ancestral Uncompahgre River (and probably to the left up Dallas Creek). The glacier advanced nearly to Dallas but retreated without forming a terminal moraine. Extensive areas of ground moraine cover the north side of *Moraine Hill*, and multiple sinuous crests top the hill, but no clear end moraine was formed. A minor salient of the glacier cross-cut moraine 2a at Dry Creek (fig. 7).

Outwash from this glacier is not preserved in the moraine area nor in Uncompahgre Canyon, presumably because of the terminal outburst flood, but terrace 2b is continuous in Montrose Valley, where it extended across a valley at least two miles wide at Montrose (fig. 10). The terrace is about 200 ft above the modern Uncompahgre River and about 100 ft below terrace 2a (Figs. 7 and 11). Noe et al. (2017), adopting the age assignments of Sinnock (1978, 1981), considered this terrace to be of Pinedale age, but that would require the 300 ft of downcutting between this terrace surface and the base of t3 gravels

(from boreholes [Noe et al., 2017]) to have occurred *within* the Pinedale and only 100 ft between the Bull Lake and Pinedale glaciations.

Most of the outwash gravels of terrace 2b are normal main stem gravels. At almost every site studied, however, very large boulders are found at, or near, the top of the gravel (fig. 12). These are referred to in this report as flood boulders, a term that indicates they were transported by a catastrophic flood, and they are larger than those that can be transported by normal floods. There is no definitive size above which a given boulder is considered a flood boulder, because it is a function of the local fluvial regime and hydraulic gradient. Along the Uncompahgre River flood boulders are as large as 11 ft in long dimension, whereas the nominal maximum boulder size in river sediments is less than three feet and frequently less than two feet. Flood boulders are observed in the most upstream terrace remnant at Colona, at every site studied down to Montrose, and at the northernmost end of *Sunset Mesa*. No flood boulders are found on Spring Creek Mesa, but the surface gradient there shows that the channel at the time of the flood was at, or near, Sunset Mesa (fig. 11), where flood boulders are ubiquitous.

Two isolated, small patches of gravel with large boulders are two miles north of Dallas (t2b in fig. 10) that may be flood deposits, although too little remains to be certain. At the upstream patch of gravel is a very large boulder, about 40 x 28 x 13 ft, of ash-flow tuff, probably Ute Ridge Tuff (fig. 13). It is tempting to think of it as a flood boulder, which it may be, but it is also possible that it is a lag boulder, because it is within the range of the Ute Ridge eruption (Steven and Lipman, 1976), and lag boulders of ash-flow tuff are common in much of the Uncompahgre River valley.



Figure 13—Boulder of ash-flow tuff may have been transported by flood 1. Boulder is 40 x 28 x 13 ft, view here shows the two lesser dimensions, with rock hammer and water bottle for scale. Boulder might be a lag boulder.



Figure 12—Flood boulders on terrace 2b; (top) flood boulders on northern Sunset Mesa (Figs. 1, 10), (bottom) flood boulder 11 x 6½ x >3 ft near top of gravel on terrace 2b at valley mile 39.3.

The source of the flood, herein referred to as flood 1, was a glacial lake at Ridgway, herein referred to as Lake Uncompahgre 1. No evidence of the lake remains, so it cannot be determined if the lake was a proglacial lake or if the glacier abutting Log Hill Mesa dammed Dallas

Creek to form an ice-dammed lake (as shown on Atwood and Mather's map [1932] [fig. 5]).

Glaciation 3 (Pinedale)

Moraines of this most recent glaciation are also incomplete, but right lateral moraines and a recessional moraine show this glacier still followed a path directly to Log Hill Mesa (fig. 7). Distal moraines are missing, however, due to the ensuing flood. A salient of the glacier moved a short distance northeast from Ridgway toward the east side of Moraine Hill. A well preserved recessional moraine (or possibly a late readvance) was built just downstream from Ridgway that encloses River Park (fig. 7).

A few small deposits of outwash are preserved contiguous with moraines northeast of Ridgway in terrace 3² (fig. 7), but most of the outwash in the moraine area was either washed away in the ensuing flood or was scoured severely and covered with flood deposits (fig. 14). These areas are mapped as scour surfaces, s, in figure 7. Only discontinuous patches of terrace 3 gravels remain in Uncompahgre Canyon, but in Montrose Valley the terrace is continuous from Colona to beyond Montrose (Figs. 9 and 10). In *Orchard Valley* this outwash covers the broad valley floor, because the Uncompahgre River was diverted to the right (east) by the outburst flood and did not incise the gravels to form a terrace (fig. 11).

Terrace 3 is about 40—60 ft high in the moraine area but only about 20—30 ft high at the farthest point downstream that it is next to the river at Montrose. Flood boulders are common on the scoured surface on both sides of Moraine Hill; on the east most, if not all, of this surface was a pediment graded to the ancestral Uncompahgre River west of Moraine Hill (now Dallas Creek). West of Moraine Hill the scoured surface extends all the way to Ridgway Reservoir, so some of this area is scoured terrace 3 outwash.

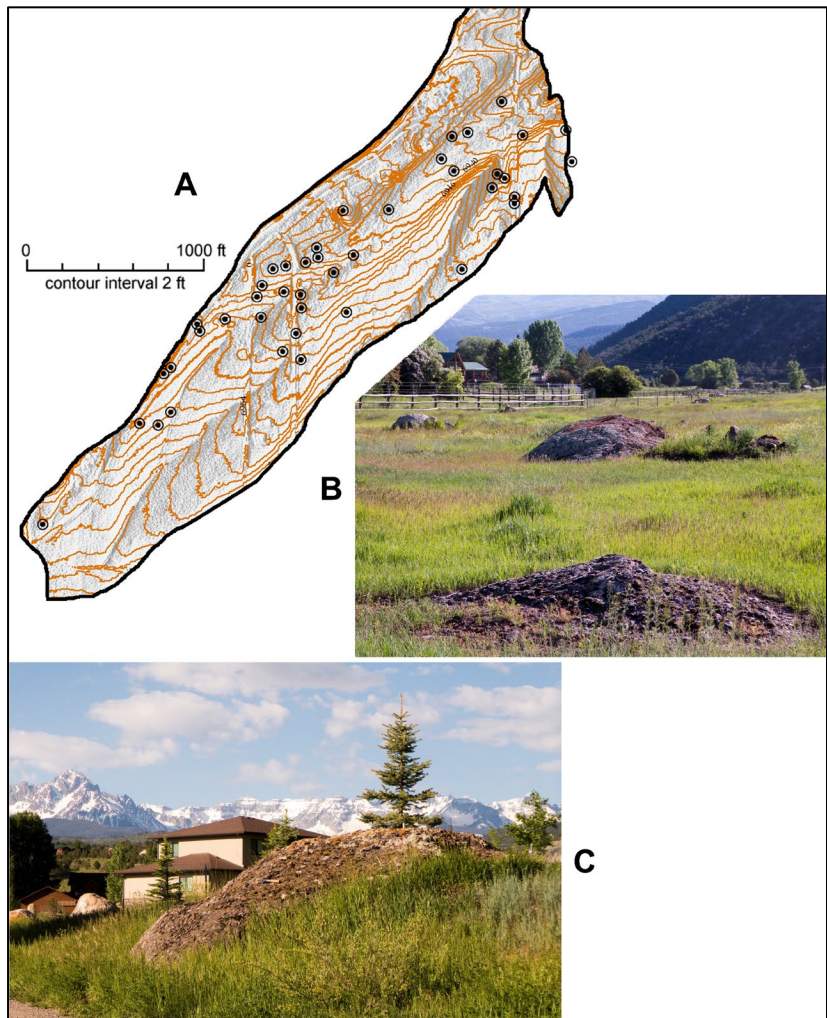


Figure 14—Scour area along Dallas Creek between Moraine Hill and Log Hill Mesa (fig. 7); (A) lidar image of channels scoured into outwash terrace 3 and flood boulders (circled dots), (B) flood boulders in scour channel, (C) length of Telluride Conglomerate flood boulder is 17 ft (note hammer).

² Jarrin et al., 2017, dated this terrace gravel, their Qag3, ca. 70—40 ka by optically stimulated luminescence and post-infrared stimulated luminescence and concluded this was the age of moraine 3.

Flood boulders are at or near the top of terrace 3 gravels in Uncompahgre Canyon (fig. 15), but below the canyon they are uncommon. A few flood boulders were mined in gravel pits 2—3 miles north of Colona, and occasional large boulders are seen in the Uncompahgre River channel through Montrose, but it is difficult to attribute these to the flood rather than as lag boulders. No flood boulders are on the surface in Orchard Valley, and conversations with gravel pit operators suggest there are none in the gravels there at all.



Figure 15—Flood boulders at top of terrace 3 gravels at Eldredge (fig. 1). Long dimensions, near to far, 5 – 6 – 4 – 5 ft.

LACUSTRINE SEDIMENTS

Lacustrine sediments in the moraine area attest to the formation of a proglacial lake, herein referred to as Lake Uncompahgre 2, during recession of the third glacier. Tan lacustrine rhythmites are exposed in only one small outcrop in *Scour Basin* (lac in fig. 7) (fig. 16). The exposure is about 6 ft thick, with neither the base nor the top of the deposit exposed.

The number of sets is approximately 90, with an average thickness of about 2.5 cm, although the thickness of sets is variable. One set consists of a layer of mud and a layer of gypsum crystals and clay (fig. 17). The mud layer is generally light tan, slightly calcareous, clayey silt with traces of fine sand. The gypsum-clay layer is thinner, with gypsum crystals in a dark brown clay matrix.



Figure 16—Tan lacustrine rhythmites in Scour Basin (“lac” in fig. 7).

The mud layers consist of laminated clayey silts with planar laminae 0.2—2.7 mm thick averaging 1.0 mm. Laminae are observed as differences in silt size and/or differences in limonite coloration. Some mud layers have sandy silt or silty sand at the base.

The crystal-clay layers appear to consist of authigenic gypsum crystals and brown clay. The clay appears silky at 40x magnification with no visible silt. Gypsum crystals are clear or pale tan, and occur as single blades, paired interpenetrating blades, or in crystal aggregates (fig. 18).



Figure 18—Gypsum crystals.

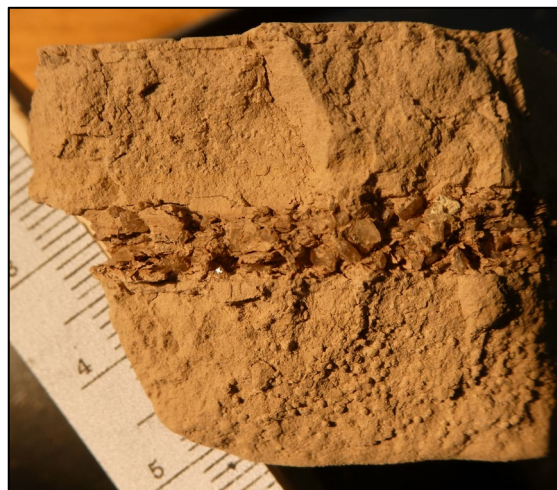


Figure 17—Rhythmite set consists of a layer of tan silt and a thin layer of gypsum crystals and brown clay. Centimeter scale.

No fossils were observed in any of eight washed samples.

A few pebble dropstones are observed, but only at one horizon. Lack of both numerous dropstones and coarse sediments suggests Lake Uncompahgre 2 was a distal proglacial lake (Carrivick and Tweed, 2013).

The mud layers probably represent deposition during ice-free summers, with laminae in the mud layers resulting from variations in runoff. Gypsum-clay layers presumably were deposited during the winter months as suspended clay beneath the ice settled out. Gypsum crystals may have grown only during this quiet time of year.

Gypsum crystals suggest the lake may have been meromictic, or stratified, with the crystals forming in the monimolimnion, or bottom layer of dense, saline water. The modern Uncompahgre River at Ridgway is a calcium sulfate water, but of low salinity, 200—400 TDS (Spahr et al., 2000). Meromixis could have been cryogenic, because the lake was shallow (depth unknown, estimated about 100 ft), and hard winter freezes in the glacial environment might have concentrated dissolved solids. Crenogenesis is also possible, as modern Orvis Hot Springs (Na-Ca SO₄, 2500 TDS) would have been under the lake, although its discharge is small, 10-20 gpm (George et al., 1920, p. 423).

If each set of rhythmites represents one year of deposition, the sediments were deposited over a period of about 90 years. This is a rough, and probably high, estimate, because thin sets may have resulted from early autumn freezes followed by melting prior to full winter icing, or they may represent early spring melting followed by refreezing.

Deposits of similar material cover the Pinedale recessional moraine (magenta overprint on m3 in fig. 7), where they are thick enough to cover all boulders in the till. The deposits are similar in that they are mostly light tan mud containing abraded gypsum flakes and lack fossils. They differ in containing more sand, and no rhythmite sequences are observed, likely because the surface was reworked (no observation was deeper than about two feet).

These lacustrine sediments, considered together, indicate a distal proglacial lake that formed behind the last, Pinedale, end moraine and persisted until the glacier had retreated well beyond the recessional moraine.

Other, quite different, lacustrine sediments occur behind the recessional moraine in River Park. About four feet of dark gray clay were poorly exposed in an excavation (X in fig. 7) along the deep axis of Lake Uncompahgre 2. The clay appears to be massive, but thin bedding or laminae may well exist. The clay is tan-gray to gray, calcareous, fossiliferous, silty clay with abraded gypsum flakes and small amounts of fine to very fine, very well rounded, often frosted sand.

Fossils include snails, clams, reeds or rushes, ostracodes (fig. 19), charophytes (fig. 20), and foraminifers (fig. 21). Four species of ostracodes indicate an environment of shallow freshwater, mainly springs and shallow streams (Brandon Curry, Illinois State Geological Survey, 2023, written communication). One of the ostracodes (*Cypridopsis vidua*) is used as a paleobioindicator of vegetated littoral zones of freshwater lakes or ponds (Echeverria et al., 2019). Charophytes typically live in the littoral zones of freshwater lakes or ponds (Selden and Nudds, 2012, p.186-187).



Figure 19—Freshwater ostracodes.



Figure 20—Charophyte gyrogonites.

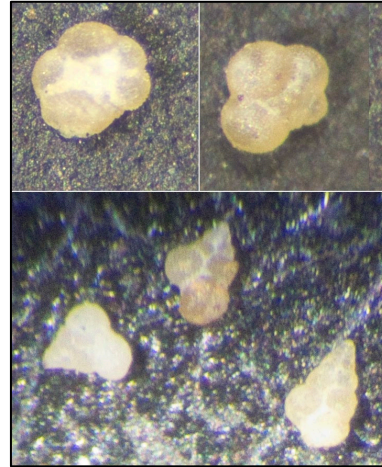


Figure 21—Reworked marine foraminifers.

The foraminifers in these sediments are reworked marine species from the lower member of the Mancos Shale (Kristin McDougall-Reid, U.S. Geological Survey, 2023, written communication). Mancos Shale is the bedrock unit exposed on both sides of the valley at Ridgway (fig. 3).

Taken together, the sediments and fossil assemblage indicate freshwater springs and streams flowing into a shallow lake or pond. This lake or pond clearly postdates Lake Uncompahgre 2 - that is, after flood 2 had drained the proglacial lake.

GLACIAL AND FLOOD HISTORY

During the first glaciation, a glacier advanced to Dallas East Hill, but the solitary deposit precludes knowledge of the configuration of the glacier (fig. 22). Outwash formed what is today terrace 1 that extends intermittently from the moraine at least to Montrose. After retreat, downcutting established the route of the Uncompahgre River to Log Hill Mesa and down what is now Dallas Creek.

The second glacier advanced to Log Hill Mesa, leaving probable paired lateral moraines at Ridgway (fig. 23). Outwash was deposited as terrace 2a at least to Montrose.

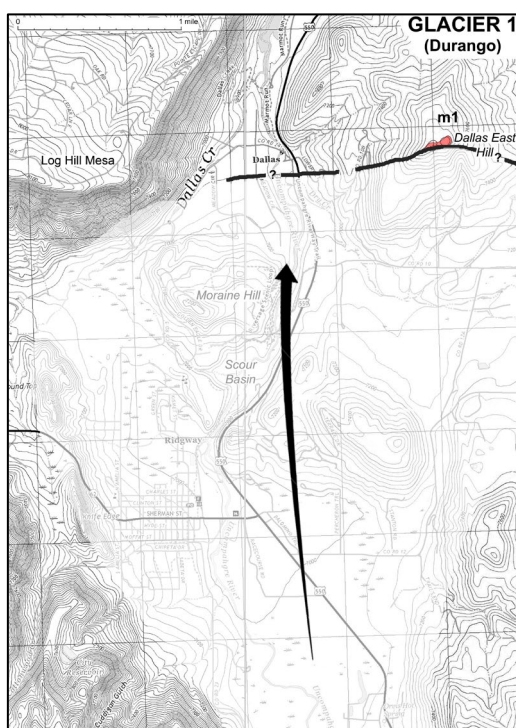


Figure 22—Extent of glacier 1 is poorly constrained by a single small moraine.

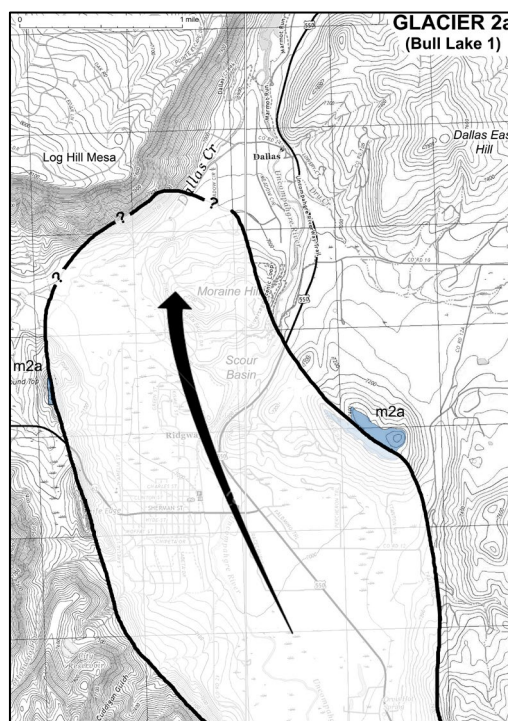


Figure 23—Glacier 2a likely reached Log Hill Mesa as shown by paired lateral moraines.

Following a recession and some erosion, the glacier readvanced again to Log Hill Mesa, where it bulged right and left. It ran almost to Dallas but did not build an end moraine before retreating slightly to build irregular moraines at Moraine Hill (fig. 24). A minor salient cross-cut the lateral moraine from glacier 2a at Dry Creek.

Recession of glacier 2 created proglacial Lake Uncompahgre 1, which extended up the valleys of the Uncompahgre River and Dallas Creek and was fed by both streams (fig. 25). Alternatively, glacier 2

could have formed an ice dam at Log Hill Mesa, damming Dallas Creek to create the lake (fig. 5). Breaching of the morainal dam (or, alternatively, the ice dam) at Log Hill Mesa released all of Lake Uncompahgre 1 as a catastrophic glacial outburst flood that ran down the ancestral Uncompahgre River west of Moraine Hill (today's Dallas Creek) (fig. 25), flushing the outwash from the area below the moraine and from Uncompahgre Canyon, carrying numerous large flood boulders all the way to Montrose.

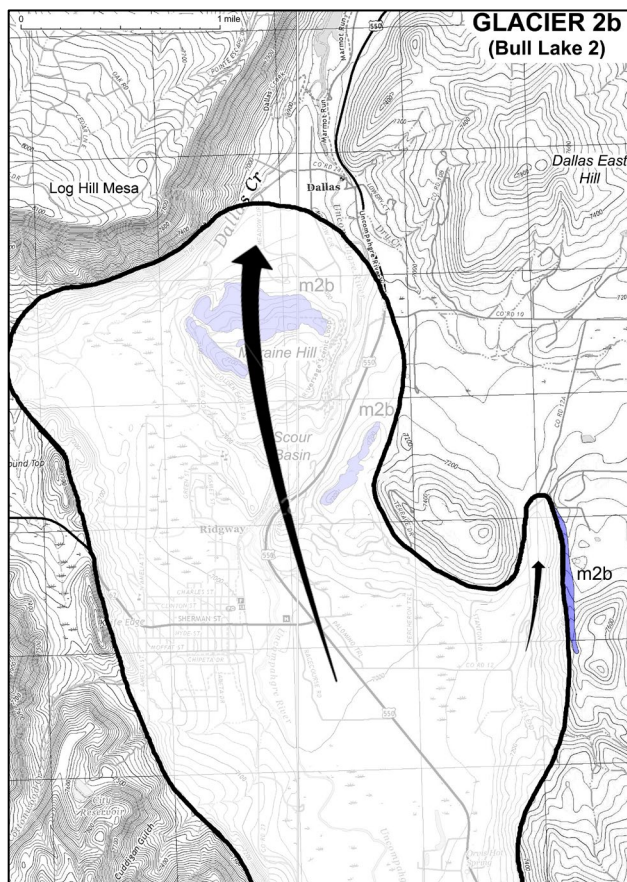


Figure 24—Glacier 2b flowed nearly to Dallas, but retreated to Moraine Hill before building moraines, with a minor salient into Dry Creek drainage.

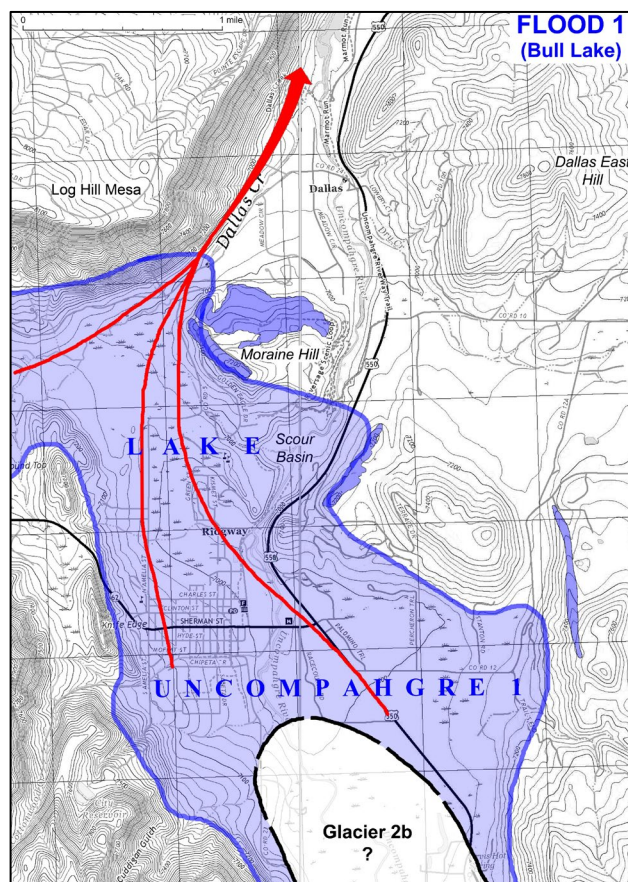


Figure 25—When glacier 2b retreated its moraines dammed the Uncompahgre River and Dallas Creek to form proglacial Lake Uncompahgre 1. The dam failed at Log Hill Mesa causing catastrophic glacial outburst flood 1.

Ground moraine on the north side of Moraine Hill slumped down to the north along a failure plane above the projected Ridgway fault (Figs. 3, 7).

The third, and last, glacier followed the route established by glacier 2 and flood 1 to Log Hill Mesa, with a minor salient northeast of Ridgway toward the east side of Moraine Hill (fig. 26). Outwash was deposited beyond Montrose as terrace 3 and formed the flat floor of Orchard Valley.

Recession of glacier 3 created proglacial Lake Uncompahgre 2, which extended up the valleys of the Uncompahgre River and Dallas Creek and was fed by both streams (fig. 27). Glacier 3 retreated beyond

the lake, pausing briefly to leave a recessional moraine near Ridgway. Lake Uncompahgre 2 was about 150 ft lower and smaller than Lake Uncompahgre 1, with a depth of about 100 ft. The lake persisted about 90 years, during which time lacustrine sediments were deposited on the valley floor and on the recessional moraine. Gypsum precipitation suggests the lake was meromictic.

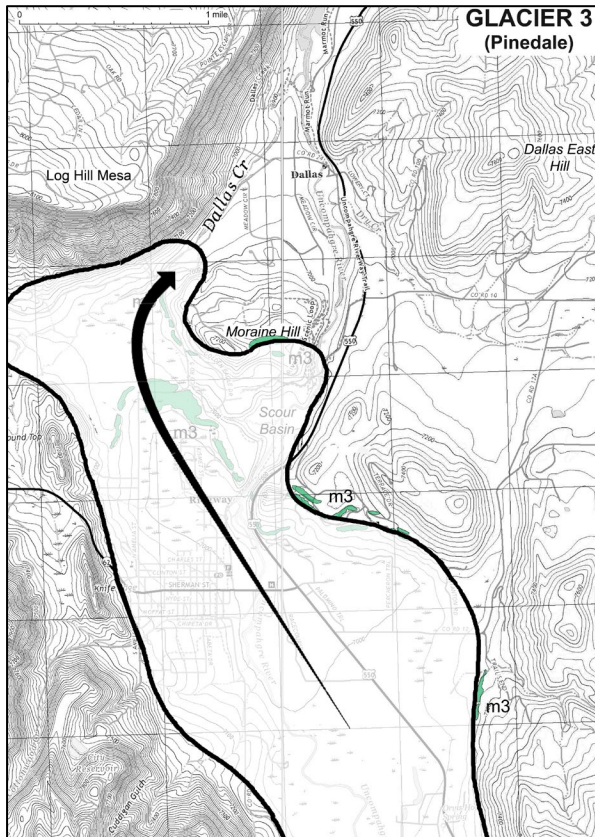


Figure 26—Glacier 3 flowed to Log Hill Mesa and bulged right, with a second salient east of Moraine Hill.

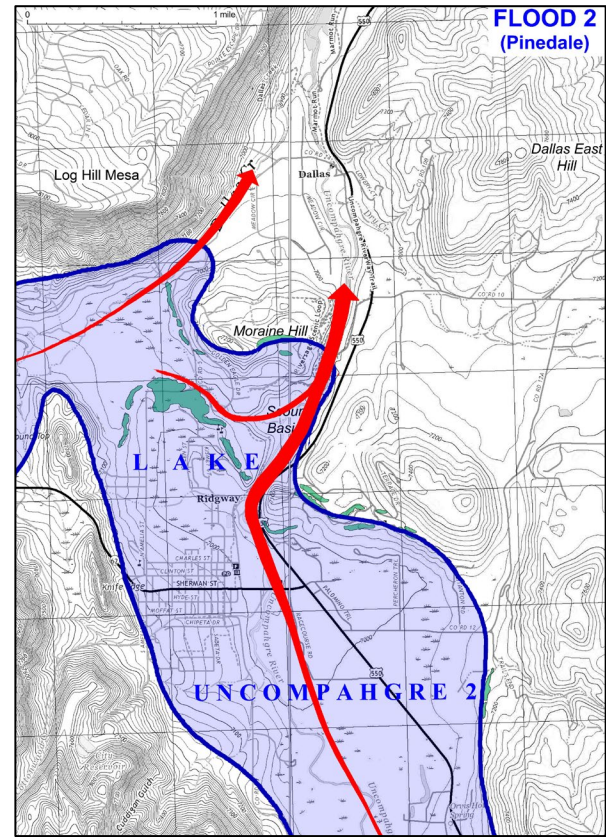


Figure 27—When glacier 3 retreated its moraines dammed the Uncompahgre River and Dallas Creek to form proglacial Lake Uncompahgre 2. After glacier 3 retreated beyond the lake, a surge of water overtopped the morainal dam both at Log Hill Mesa and Scour Basin, leading to a two-prong flood.

A surge of water into the lake overtopped the morainal dam in at least two places, leading to a catastrophic flood release (fig. 27). The source of the inflow surge may have been an upstream dam that failed, perhaps a morainal dam at Willow Swamp on East Dallas Creek (fig. 28) that released a torrent of water into Lake Uncompahgre 2.

Some of Lake Uncompahgre 2 drained at Log Hill Mesa, but most of the lake water, including some backflow from the north part of the lake, tore a new channel at Scour Basin. The flood scoured the outwash surface below the morainal dam and dumped flood boulders down to and into Uncompahgre Canyon.

The new channel cut by the flood east of Moraine Hill became the course of the modern Uncompahgre River at Ridgway.

At Montrose, the flood cut a new channel east of Sunset Mesa, abandoning its wide former channel in Orchard Valley. The flood channel became the course of the modern Uncompahgre River through Montrose.

After flood 2 drained Lake Uncompahgre 2, a small lake or pond formed in what was the deep axis of the paleolake behind the recessional moraine. The freshwater lake was host to snails, clams, sedges or reeds, ostracodes, and charophytes. Streams washed in fossil foraminifers from nearby Mancos Shale outcrops.

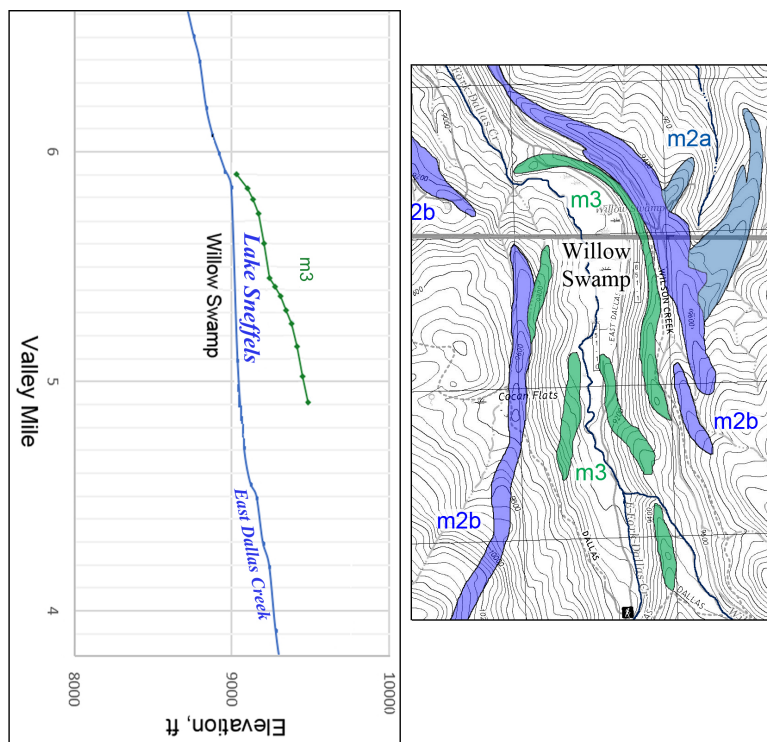


Figure 28—Glacial deposits and longitudinal profile of Willow Swamp on East Dallas Creek, site of a probable proglacial lake and a candidate source for floodwaters into Lake Uncompahgre 2.

CONCLUSIONS

Glaciers ran down the Uncompahgre River valley to the confluence with its tributary Dallas Creek at Log Hill Mesa. Three separate glacial advances reached about the same terminal positions, probably during Durango, Bull Lake, and Pinedale times. Equivalent glaciers advanced along East Dallas Creek, but none came near Log Hill Mesa.

Scant deposits from the first glacial advance (Durango) preclude determination of its actual path and final configuration.

The second glacial advance (Bull Lake) nearly reached Dallas. After a retreat and readvance, the glacier built moraines at Moraine Hill. Glacial retreat left the moraines damming the Uncompahgre River and Dallas Creek to form paleo-proglacial Lake Uncompahgre 1. The glacial dam failed at Log Hill Mesa, resulting in catastrophic flood 1 that carried large flood boulders at least 23 miles down to Montrose.

The third glacial advance (Pinedale) similarly reached Log Hill Mesa. Recession from its end moraine created Lake Uncompahgre 2, a distal proglacial lake similar to, but smaller than, Lake Uncompahgre 1. The lake persisted for about 90 years and was probably meromictic.

The morainal dam failed in at least two places, suggesting overtopping by a surge of water from upstream. Catastrophic flood 2 resulted from breaches both at Log Hill Mesa and at Scour Basin. Flood erosion at Scour Basin cut the channel for the present course of the Uncompahgre River. Flood 2 was smaller than flood 1, but it carried flood boulders through Uncompahgre Canyon, and the flood diverted the river at Montrose from its previous course through Orchard Valley to its present course east of Sunset Mesa.

RELATIONSHIP TO OTHER CATASTROPHIC FLOODS IN COLORADO

Catastrophic outburst floods have also been recognized in valleys of the other outlet glaciers from the San Juan icefield: the Animas River, the Lake Fork of the Gunnison River, the Rio Grande, and Los Pinos River (fig. 29). All the floods were glacial in origin, except perhaps the flood on Los Pinos River, whose origin is unknown. There were also catastrophic glacial outburst floods on the upper Arkansas River.

Animas River Four catastrophic floods ran down the Animas River valley of southwest Colorado during the Pleistocene (Lee, 2025a). Outlet valley glaciers from the San Juan icefield flowed southward down the Animas River valley and reached Durango during the last three glacial advances. Glacial outburst floods resulted from each of these glacial advances, and another, earlier flood likely had a similar origin.

Nested end moraines show each glacier reached the same end point. Upstream from these moraines, a long, flat-floored valley represents the infilled proglacial Lake Durango that formed behind the end moraines as the glaciers receded.

Failure of the morainal dams led to catastrophic draining of the proglacial lakes. The floods ran the length of the Animas River, carrying flood deposits more than 50 miles downstream to the confluence of the Animas River with the San Juan River at Farmington, New Mexico.

Lake Fork of the Gunnison River Glaciers of the San Juan icefield formed in the circular topographic basin of the Lake City caldera and flowed down the Lake Fork of the Gunnison River (Lee, 2025b). Only the latest glacier, the Pinedale,

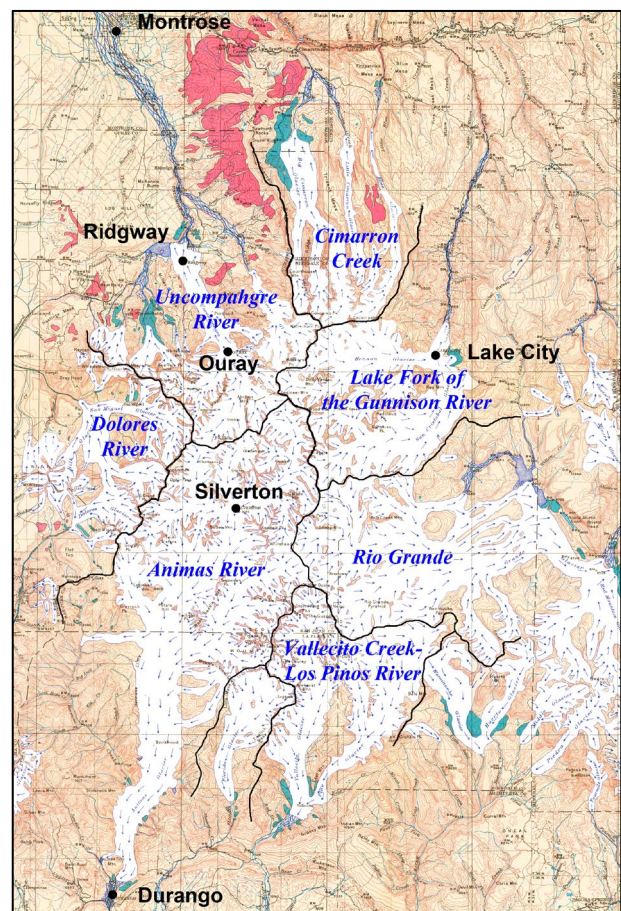


Figure 29— San Juan icefield reconstructed by Atwood and Mather (1932); divides and towns added.

left a record; the glaciers in the basin converged at Lake City and ran about 22 miles down to the north.

A recessional moraine below Lake City dammed proglacial 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. One of the floods left a flood boulder 70 ft above the valley floor.

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, Lake Atwood drained catastrophically twice along ice-bedrock spillways.

Farther down the Rio Grande, the very large glacial Lake Alamosa formed in the closed portion of the San Luis Valley behind a sill of volcanic rock, setting up conditions for a potentially catastrophic flood (Ruleman et al., 2016). Such a flood was suspected but not documented (Machette et al., 2007, p. 76). I see no evidence for such a flood - rather, the alluvial deposits immediately downstream suggest that the incision of the sill and draining of Lake Alamosa was gradual.

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 most 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 led to conditions for an outburst flood. Evidence for the actual dam is lacking, however, so it is possible the flood had a different origin - perhaps a landslide.

The time of the flood is constrained to early to middle Pleistocene, probably early Pleistocene. The Vallecito flood may have been synchronous with the early Pleistocene flood on the Animas River.

Arkansas River The upper Arkansas River valley experienced three glacial outburst floods near Buena Vista (Lee, 2010, 2019). These floods differ from those on the Uncompahgre River, 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, similar to those on the Uncompahgre. The earliest flood on the Arkansas River occurred at about 640 ka (Lee, 2019).

ACKNOWLEDGMENTS

When, in jest, I asked my late friend Tom Russell if he had seen any flood boulders on the Uncompahgre near his home in Montrose, he sent me pictures of large boulders along his driveway! I wasted no time visiting him and learning they were indeed flood boulders, and that initiated this study.

Dick Glanzman provided key insights into the origin of the gypsiferous rhythmites, based on his experience with Siberian lakes.

Critical to understanding the lacustrine sediments at River Park, which I had originally and erroneously thought were deposited in Lake Uncompahgre, was the help provided by Brandon Curry, Illinois State Geological Survey, who identified the ostracodes, and Kristin McDougall-Reid, U.S. Geological Survey, who identified the foraminifers. I am indebted to them for their help.

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