Bulletin 50

Debris-Flow Origin of High-Level Sloping Surfaces on the Northern Flanks of Battlement Mesa, and Surficial Geology of Parts of the North Mamm Peak, Rifle, and Rulison Quadrangles, Garfield County, Colorado

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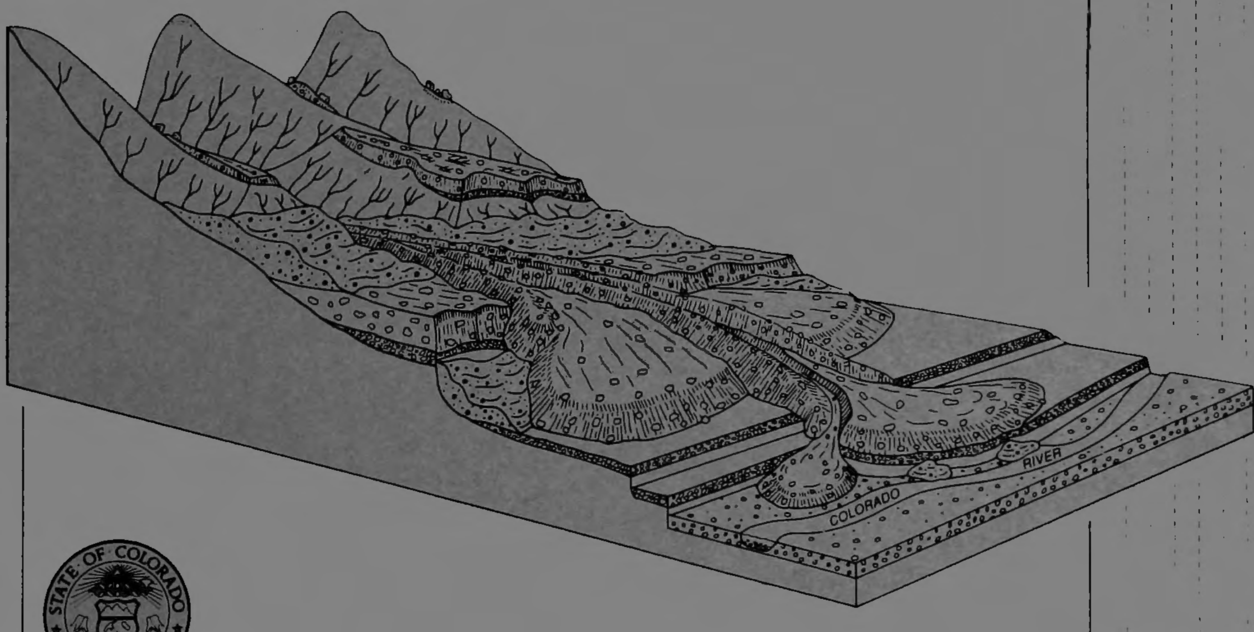

Colorado Geological Survey
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By Bruce K. Stover

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Abstract

A diverse assemblage of surficial geologic deposits is present in the Colorado River valley near Rifle on the northern flanks of Battlement Mesa. These include alluvium, colluvium, landslide deposits, debris-flow deposits, and eolian deposits ranging in age from Late Pliocene to Holocene. The most significant discovery is the recognition that extensive high-level sloping surfaces, originally mapped and described as gravel-veneered pediments flanking Battlement Mesa, are instead the remnants of huge, ancient debris-flow fans. These debris flows buried bedrock surfaces and Colorado River deposits beneath 35 to 70 m of clayey, matrix-supported, bouldery material. Large masses of colluvium and landslide debris which mantled the upper slopes of Battlement Mesa periodically formed these massive debris flows which traveled up to 12 km downslope before coming to rest in the valley. The largest individual debris-flow fan investigated in this study is estimated to have contained at least 850 million cubic meters of debris, which covered an area of about 17 sq km to an average depth of 50 m.

Field studies and stereoscopic-photogeologic interpretation were used to map the surficial geology of part of the northern slope of the mesa and adjacent river valley in order to develop a stratigraphic framework for interpretation of the debris-flow stratigraphic framework for interpretation of the debris-flow deposits, and the geologic and geomorphic processes which formed them. Four different levels of Colorado River terrace gravel are used to subdivide the debris-flow deposits into five units ranging in age from Late Pliocene to Holocene. Interpretations of debris-flow stratigraphy in the present valley axis suggest that ancient debris flows often entered and sometimes crossed the Colorado River.

The constructional nature of the surfaces of debris-fan remnants perched high on the valley slopes above the river requires revision of previous studies which attempted to use these surfaces to project former Colorado River levels, or interpret rates of downcutting. This work suggests that a more accurate estimate of the former river position associated with an individual debris-fan surface would closely approximate the present position that debris-fan remnant occupies on the valley slope. The heights of buried main-stream terrace gravels above the Colorado River should be used to more accurately calculate rates of downcutting through Quaternary time.

Finally, existing geologic maps should be revised to depict these high surfaces as colluvial debris-fans, rather than pediments mantled with alluvial outwash gravels.

Chapter 1

Introduction

Aerial-photographic interpretation and field studies have revealed that deposits on high-level, gently sloping surfaces south of the Colorado River between Rifle and Parachute are not pediment gravels, as previous work has stated; rather, internal characteristics of the deposits and morphology of the surfaces suggest they are remnants of large-scale debris flows which flowed down the northern slopes of Battlement Mesa. The existence of several levels of debris-flow remnants associated with main- stream terrace-gravel deposits implies that this happened more than once, and suggests that there may have been a cyclicity to these events. This study was developed to investigate these deposits in more detail, and determine their role in the geomorphic development of the area.

Geographical Setting

The study area is located in west-central Colorado in Garfield County, along the northern slopes of Battlement Mesa, near Rifle. The study area includes parts of the North Mamm Peak, Rifle, and Rulison U.S.G.S 7.5-minute quadrangles (Figure 1). Battlement Mesa is a prominent highland reaching an altitude of 3,048 m that borders the study area on the south. The towering Roan Cliffs (3000-m altitude) border the area on the north, soaring to heights almost 1,220 m above the river valley within a distance of 6.5 km (Figure 2). In contrast, the flanks of Battlement Mesa are much smoother and more gently sloping, and are nearly devoid of precipitous cliffs.

Access to the area is provided mainly by dirt roads which wind upward from Interstate 70 and other principal paved roads along the valley bottom. Much of the higher ground is public land that includes White River National Forest, Naval Oil Shale Reserve No. 5, and U. S. Bureau of Land Management lands. Private agricultural property makes up the majority of the lower slopes and valley bottom.

The climate in the area is arid to semi-arid. Mean annual precipitation is 25 to 30 cm per year at Rifle, but the top and upper slopes of Battlement Mesa receive up to 50 cm of precipitation per year (U.S. Weather Bureau). These slopes support heavy stands of aspen and pine. Snowmelt is intense in spring, and thunderstorms are frequent during the summer months.

Geologic Setting

Bedrock units in the area consist of the Wasatch, Green River, and Uinta Formations, all of Tertiary age. The Wasatch Formation consists of up to 1,768 m of claystone and siltstone, with thin interbedded lenses of channel sandstone and conglomerate (Donnell, 1961, 1969). This formation was deposited during the Paleocene and early Eocene by major rivers during subsidence of the Piceance Basin. Outcrops occur throughout the lower slopes and valley bottom, the most spectacular being those of the Roan Cliffs. Composed dominantly of incompetent, poorly indurated rocks, the Wasatch Formation is notoriously unstable in steep to moderate slopes undercut by streams, or where saturated by perched ground water or runoff.

The Green River Formation was deposited in a vast lake which occupied a closed depression in a structural basin the Eocene (W. H. Bradley, 1925). It intertongues with the upper part of, and conformably overlies the Wasatch Formation, and is divided into two main parts. The lower part consists

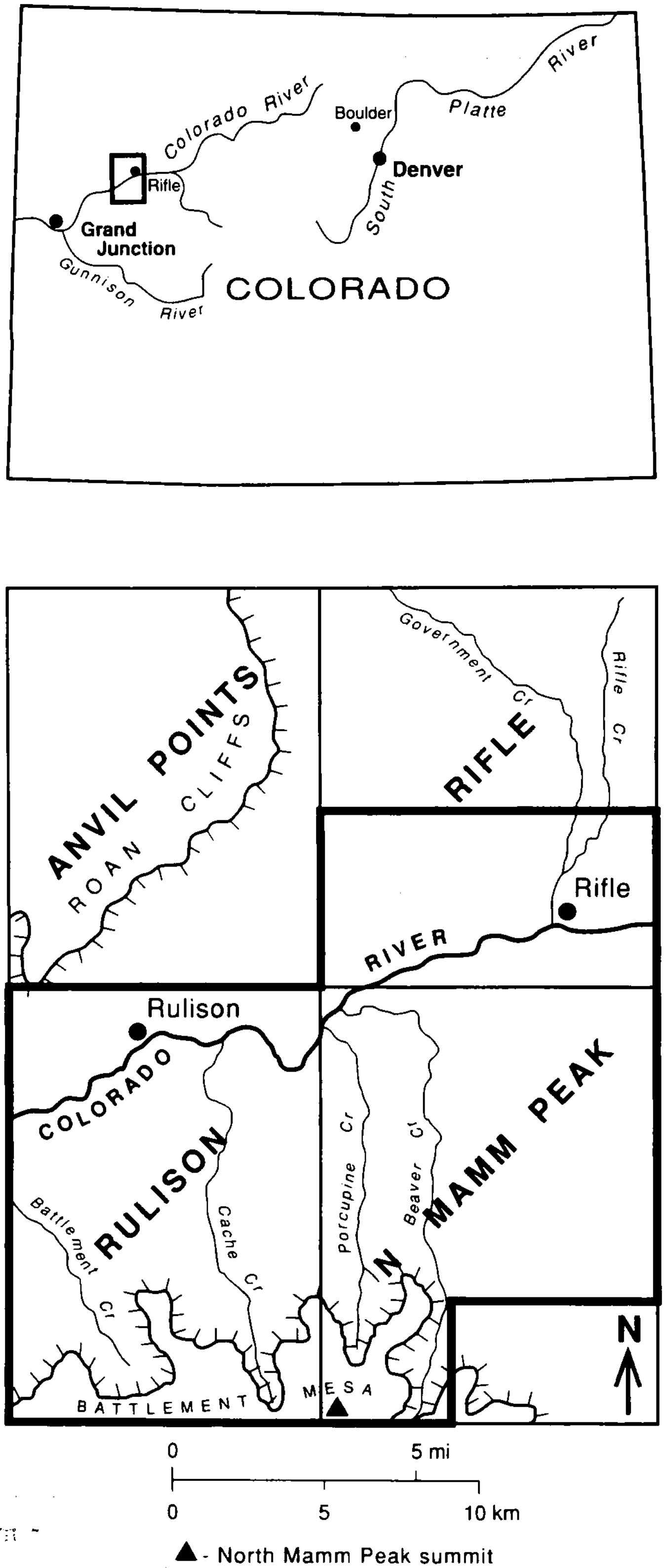


Figure 1. Index map of Colorado (top) showing showing Garfield County and index map of Garfield County (bottom) showing the U.S.G.S. 7.5-minute quadrangles and the study area covered on Plate 1.

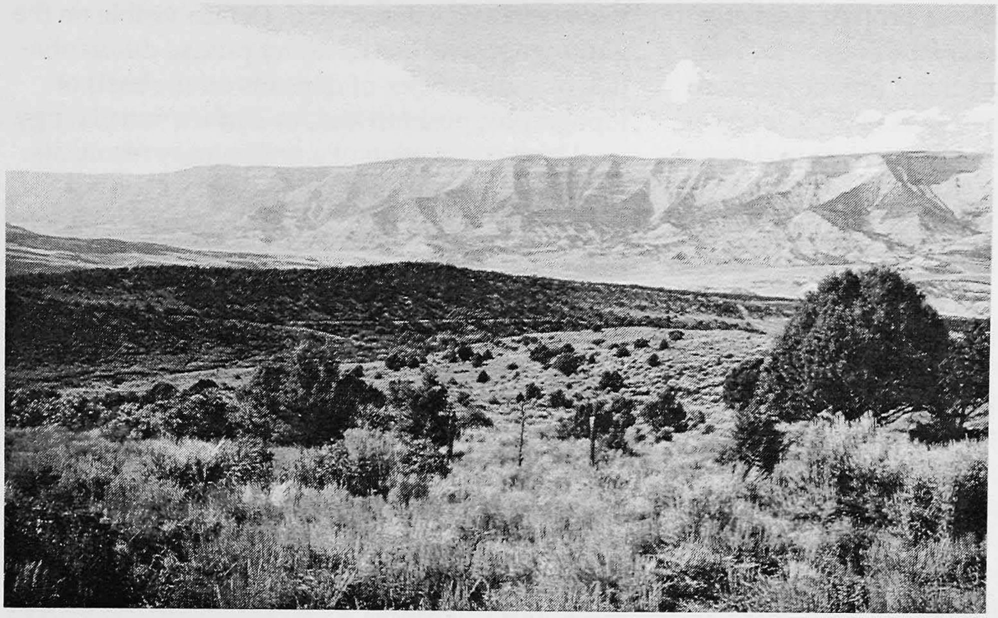


Figure. 2. View of Colorado River Valley in study area, looking northwest. Roan Cliffs are in the distance, and the gentle slopes in the foreground and at left are the footslopes of Battlement Mesa.

of over 610 m of lacustrine shale, sandstone, and marlstone that make up the Anvil Points, Garden Gulch, and Douglas Creek Members respectively (Donnell, 1961, 1969). The upper part is made up of the Parachute Creek Member which consists of 370 m of oil shale and marlstone deposited under anoxic conditions at the bottom of the lake. The richest oil shale zone is the "Mahogany Ledge," a laterally persistent and easily identifiable unit that makes up part of the Roan Cliffs, and occurs in scattered outcrops on the sides of Battlement Mesa.

Above the Green River Formation is a 300-m-thick sequence of fluvial arkosic sandstones, siltstones, and subordinate marlstones known as the Uinta Formation. These rocks were previously designated the Evacuation Creek Member of the Green River Formation. They conformably overlie the oil shale and were deposited by westward flowing streams in Eocene time after the lake dried up.

Unconformably overlying the Uinta Formation on Battlement Mesa is an unnamed unit of soft, white, variegated claystone, 15 to 150-m thick. This claystone is overlain by basalt flows that were erupted from fissures. The basalts have been K-Ar dated at between 7.5 and 8.5 m.y., and are associated with the regional basic volcanism in northwestern Colorado which occurred between 7 and 24 m.y. (Larson et al., 1975; E. E. Larson, 1983, written comm.).

The basalt flows in the study areas once created an extensive plateau to the south and east, but do not appear to have extended farther north than 8 or 10 km from the present position of the summit of Battlement Mesa. Most of this basalt plateau has been eroded away.

Structurally, the study area lies on the southern edge of the Piceance Basin of northwestern Colorado. Regional bedrock dips are gentle to the north-northwest towards the center of the sedimentary basin, with no faults or major folds known in the study area.

Previous Surficial-Geological Studies

A large part of the study area was studies and mapped by Yeend (1969), who concentrated mainly on the glacial geology of Grand Mesa and the mass-wasting processes that destroyed much of the basalt-capped plateaus of Grand and Battlement Mesas. He also discussed briefly the extensive sloping surfaces on the north side of Battlement Mesa, and interpreted them as remnants of large pediments. His map is at a scale of 1:96,000, and necessarily generalizes the surficial geology of the study area. Donnell and Yeend (1968) had previously published open-file geologic maps of the North Mamm Peak and Rulison 7.5-minute quadrangles. These maps do not show any more detail than the map published by Yeend (1969).

With the exception of Yeend (1969), the only other work on surficial geology has been in the form of unpublished preliminary engineering-geologic reports conducted for a proposed ski area near Doghead Mountain and Holms Mesa, Rulison quadrangle. In 1974 the consulting firm of Amuedo and Ivey, Denver, mapped the area in order to determine geologic hazards and constraints to ski-area development. Their mapping was taken primarily from the previous work of Yeend and Donnell, with some new interpretations of the sequences of debris flows and mudflows.

R. M. Kirkham, consulting geologist, also mapped parts of the study area near Doghead Mountain in 1980 for a proposed ski-area development. The unpublished report included a small scale geologic map and detailed descriptions of the debris-flow and colluvial deposits in the area. His work departed somewhat from that of Yeend (1969), and describes in detail the debris-flow mechanisms operating in the existing drainages.

The present study area is only part of a regional engineering surficial-geologic-mapping project I conducted for the Colorado Geological Survey under a grant from the U.S. Geological Survey Energy Lands Program (Project No. 1-9500-01301). This particular area was chosen for thesis study because of an interesting new interpretation of some of the landforms, deposits, and processes which I developed during work on the regional project.

Methods and Scope of Study

This study is mainly a field mapping project to delineate deposits and interpret the geologic history of a relatively large area. Detailed study of high-quality natural-color 1:24,000 stereoscopic aerial photographs was the major technique used to map the surficial deposits. The photographs, flown in the fall of 1978, were obtained from the U.S. Bureau of Land Management. Landforms were mapped on the photographs and then transferred to U.S.G.S. 1:24,000 topographic base maps. Mapping units were tentatively designated. Details visible on the photographs facilitated rather precise differentiation of similar types of deposits on the basis of topographic position and/or surface morphology.

Upon completion of a preliminary reconnaissance map, the area was field checked during the summer and fall of 1982 to determine contact locations, and sedimentologic character of the deposits. This resulted in a greater subdivision of mapping units, and the delineation of units that could not be recognized solely from photographic interpretation. In particular, alluvial-bedrock contacts were traced out, and the provenance and nature of alluvial units were studied. Tracing float of non-locally-derived gravel of the Colorado River resulted in the discovery of buried terrace gravels beneath debris-flow deposits. These terrace deposits are often traceable on aerial photographs by a vegetation anomaly which occurs along their basal contact, due to groundwater issuing from the gravels. The resulting lush deciduous vegetation contrasts starkly with the native arid-land grasses, sagebrush, and sparse pinion and juniper. Debris flows were examined in detail at key exposures where crosscutting relationships with underlying main-stream terrace deposits could be studied. Most contacts were located from field investigation, and only in a few remote areas not actually traversed were surficial deposits mapped directly from the aerial photographs.

This study does not include detailed laboratory analyses of sediments or semi-quantitative relative-dating studies. Qualitative properties relating to the relative ages of deposits are noted where they were observed in the field or on aerial photographs. Because the study attempts to cover a sufficiently large area to effectively depict the relationships between processes and deposits, lab work, detailed soil descriptions and relative weathering studies were beyond the scope of this work.

Chapter 2

Descriptions of Surficial Mapping Units

Introduction

Surficial-geologic deposits have been subdivided into mappable units defined either by sedimentologic character, landform morphology, or elevation above the local datum (Colorado River); in most cases, all three criteria were used. Where relative ages could be determined by field relations, further subdivision of deposits of similar type or origin was possible.

Sedimentary criteria include clast provenance (main stream versus side stream deposits), matrix- versus clast-supported deposits, sorting, degree of clast roundness, and the qualitative degree of weathering or soil development on a deposit. Distinctive morphologies of debris-flow levees, landslides, alluvial fans, and river terraces were used to map the extent of these deposits. The relative degree of muting of originally rough debris fans through surface weathering and loess accumulation appears to increase with age, and aided in distinguishing various ages of these deposits.

Elevations of main-stream terrace deposits buried beneath debris fans are important markers, and were used to subdivide debris-flow mapping units. Several distinct terrace levels occur throughout the area.

This section describes the various surficial mapping units, and the processes that formed the deposits. Important relationships between certain ages and types of deposits are also discussed. Examples of relative dating localities are listed in Table 1. Deposits of similar origin are grouped together, and units of successive chronologic age are described from youngest to oldest so that inferences on the origins of older deposits can be made. Symbols for each unit are also given in parentheses for reference to the map. All of the deposits in this study are of Quaternary age unless otherwise specified as Neogene.

Table 1. Locations of stratigraphic exposures, soils, and relative weathering localities for further relative dating studies

Map No.	Description
	Soil or Relative Weathering Study Localities
1	Weathered terrace gravel exposure in mtg
2	Basalt boulders on surface of Grass Mesa
3	Soil developed on colluvium on slope of Grass Mesa possessing a stage IV carbonate horizon
4	Poorly exposed soil along road cut in Taughen-baugh Mesa (mdf) possibly containing well developed carbonate horizon
5	Basalt boulders on surface of lower, younger debris flows
6	Basalt boulders on surface of Flatiron Mesa, a Neogene aged surface
7	Buried soil sequence in gravel pit and prospect trench showing stratigraphy which suggests a debris flow crossed the Colorado River
8	Soil developed in debris-flow levee which overrides part of Morrisania Mesa
9	Basalt boulder weathering locality, lower debris-flow unit
10	Basalt boulder weathering locality, middle debris-flow unit
	Stratigraphic Exposure Localities
1	Upper debris-flow unit resting on upper Colorado River terrace gravel deposit
2	Lower debris-flow unit resting on lower terrace gravel deposit of Colorado River
3	Lower debris-flow unit resting on lower terrace gravel unit north of the Colorado River exposed in gravel pit

Table 1. Continued.

Map No.	Description
4	Neogene debris flow or colluvium resting on Tertiary rocks exposed at top of cliffs at head of Porcupine Creek
5	Neogene debris flow or colluvium resting on high, narrow drainage divide.
6	Neogene debris flow resting on Neogene Col orado River terrace gravel
7	Middle debris-flow unit resting on middle terrace gravel deposits
8	Upper debris-flow unit resting on upper terrace gravel deposit
9	Upper debris-flow resting on Wasatch bedrock
10	Claystone exposed beneath Tertiary basalt lava flows on Battlement Mesa

River and Stream Alluvium

General Description of Deposits

Alluvial deposits of gravel, sand, silt, and clay occur in floodplain and terrace deposits throughout the area. The deposits were transported by running water and are generally well sorted, stratified, and clast-supported. They vary in thickness from 0.2 m to over 15 m. Two facies are recognized: deposits of the Colorado River, and those of tributary side streams.

Colorado River alluvium contains greater than 75 percent clasts that have been transported into the area from sources far to the east. Common lithologies include granite, gneiss, porphyritic andesites and rhyolites, red sandstones and siltstones, quartzite, and limestone. The majority of gravel clasts are well rounded, smooth, and relatively competent. Fresh main-stream alluvium appears dominantly gray in color, and the color of clasts varies with lithology. Clast provenance is the key to identifying old main-stream terrace deposits.

In contrast, side-stream deposits contain less than five percent non-locally-derived clast lithologies, and consist almost entirely of gravels derived from Tertiary rocks which are widely exposed in the area. Clasts are less rounded and composed of relatively incompetent shaley tan to brown sandstone, siltstone, and marlstone. Tributary streams draining Battlement Mesa are the exception; they contain as much as 85 percent locally derived, sub-rounded to rounded gray, black and red basalt clasts. Gravelly side-stream units contain a much higher percentage of silt and clay than main-stream gravels, and are of a uniform brown, tan, or black color in outcrop.

No dating control on the deposits is available within the study area. The nearest tentatively correlated chronosequence of main-stream terraces is at Carbondale, 70 km upstream (Piety, 1983). There, outwash terraces from 15–40 m above the Roaring Fork River are thought to be of Pinedale age, and terraces 60–80 m above the river are believed to be of Bull Lake age (Piety, 1983). Age estimates are greater than 20,000 years for Pinedale deposits, and 140,000 to 150,000 years for Bull Lake deposits (Porter et al., 1983). The Pearlette type-0 ash, dated elsewhere at 600,000 year B.P. (Izett et al., 1982), occurs in a gravel terrace 90–100 m above the river at Carbondale. Tectonic complications in the Carbondale area make correlations even short distances up or downstream tentative at best, and lack of work between Carbondale and Rifle further complicates any attempt at correlating terrace deposits 7 km away.

Yeend (1969) reported a carbon-14 date of 19,730 plus or minus 500 years B.P. on organic material within an alluvial fan deposit at the mouth of Wallace Creek, 15 km downstream of the study area. It is not known how the fan deposit relates to main-stream terraces near Rifle, but it appears from field relations at the locality that the fan postdates a main-stream terrace deposit which is 53 m above the Colorado River.

Main-stream alluvial deposits in this study are subdivided into gross chronologic units based on their elevation above local base level, degree of weathering, and field relations with other deposits. No attempts are made to relate any of these units to terraces or absolute dates up or downstream. Tentative regional correlations must await more detailed soils and relative weathering studies of the terrace and debris-flow deposits.

Flood Plain Alluvium

(fpa) Alluvial deposits of this unit are mapped solely on the basis of their positions in the flood plain of the Colorado River and its major tributary streams. The first prominent terrace scarp, about 5 m high, defines the edge of the flood plain. The deposits in the Colorado River flood plain are unweathered, range in size from cobbles to clay, have well-rounded clasts, and range from 2–15 m in thickness.

Youngest Terrace Deposits

(ytg, yta) Deposits that constitute the first prominent terrace above the flood plain are mapped as young terrace gravels and alluvium. The deposits range in size from cobbles to clay, and underlie low terraces 2–6 m above the flood plain. They generally range from 3 to 6 m in thickness. Up to 3 m of pebbly sand, silt, and clay often overlie well-sorted sandy gravel along the Colorado River; they are considered to be overbank deposits.

Two facies are recognized. The symbol ytg is used for deposits of 75 percent or greater gravel, and yta for deposits dominated by fine sand or silty alluvium. The latter are most common along local tributary streams. Multiple arroyo-fill deposits common in many smaller tributaries are also included in the yta unit.

Lower Terrace Gravel of the Colorado River

(ltg, tgb) Terraces 40 to 53 m above the flood plain that contain abundant igneous and metamorphic clasts of pebble to cobble size characterize the lower terrace gravel of the Colorado River (ltg). The gravels are generally well sorted, unweathered, and constitute an important aggregate resource in the area; in places they are overlain by as much as 10 m of alluvial silt and sand, and loess (Figure 3). Subordinate well-sorted sand lenses commonly occur within the gravels. The gravel varies from 1 to more than 8-m thick, and rests on bedrock of the Wasatch Formation. The extent of the gravel towards the valley margins is difficult to map accurately because of the overlying silt and loess deposits. This terrace gravel can be traced along the river valley throughout the mapped area and serves as an important stratigraphic marker for interpretation of debris-flow sequences, several of which have overridden and buried parts of the terrace.

Springs flow all along the contact of the gravel with the underlying relatively impermeable Wasatch Formation along the western side of Taughenbaugh Mesa. The groundwater contributes to landsliding and other slope failures by saturating sloughed colluvial deposits along the steep slopes that border

Figure 3. Lower terrace gravel of the Colorado River exposed in a gravel pit near Rifle. Note thick silt and loess deposits which overlie the gravel at this locality.

the mesa-top. Along the northern margins of this mesa, groundwaters saturated with $CaCO_3$ have locally cemented the gravels into resistant ledges.

In places the gravel contains large polished and smoothly sculpted basalt boulders 2 and 3 m in diameter, and is mapped as tgb (Figure 4). These boulders are derived from debris flows which entered the valley axis, and because of their size, have probably not moved far from their original depositional position in the river valley. The boulders were likely angular to sub-angular when deposited, and have since been rounded in the river.

Fine-Grained Terrace Alluvium

(ta) Deposits of gray-to-tan alluvial sand, silt, and clay, from 5-to 10-m thick, overlie the lower terrace gravels along the Colorado River in the northern part of the map area near Rifle. These are probably overbank deposits. Occasional thin, well-sorted, pebble and sand lenses are characteristic of these fine-grained alluvial units.

Reddish-brown loess 1-to-2 m-thick mantles the alluvium and is included in the unit, since more detailed field work would be necessary to distinguish the two. Although the silt and loess stand in vertical banks along terrace margins and drainages, they are extremely susceptible to erosion, hydrocompaction, piping, and bank-caving. This deposit forms the smooth surfaces of Prefontaine and Graham Mesas near Rifle.

Middle Terrace Gravel of the Colorado River

(mtg) A third terrace gravel deposited by the Colorado River is present along the valley about 120 m above the present river channel. The gravel occurs on high benches and caps the upper parts of Graham Mesa (Figure 5). This terrace deposit is much less extensive than the younger gravel described above. The gravel ranges in thickness from 5 to 9 m and rests on the Wasatch Formation. Compared to the younger gravels, it is more weathered, with 20 to 30 percent rotted or unsound granitic clasts, and has a visibly greater accumulation of calcium carbonate in the sandy matrix and on clast bottoms, approximating stage III morphology (Gile et al., 1966). The matrix has oxidized, creating a brownish-yellow stain on the majority of clasts in outcrop.

Upper Terrace Gravel of the Colorado River

(utg) The oldest Quaternary terrace gravel of the Colorado River is approximately 200 m above the valley and crops out on the edges Grass and Holms Mesa. The gravels are preserved only where buried by debris-flow deposits. The clasts are well-rounded igneous and metamorphic lithologies; more resistant finer-grained lithologies such as metaquartzites and amphibolite-gneisses are qualitatively more abundant than they are in younger

Figure 4. Large basalt boulders of unit tgb, polished and smoothed by the Colorado River. Boulders are approximately 2.5 m in length; hammer handle is 30 cm.

Figure 5. Terrace gravel of unit mtg in an excavation on Graham Mesa, near Rifle. Gravel is slightly cemented with pedogenic $CaCO_3$ and contains 20 to 30 percent grusified granitic clasts.

gravels. At a locality 10 km east of the area the gravel is at the surface and is extremely weathered, with 40 to 45 percent rotted or unsound granitic clasts, and accumulations of calcium carbonate on clast bottoms visibly thicker than those in lower terrace deposits (Figure 6).

Groundwater flows associated with permeable buried terrace deposits suggest that this gravel unit, although buried beneath debris flows, is quite extensive. Landslides and mass wasting along the margins of the mesas are the result of the saturation of colluvium and other slope deposits by ground water. Wherever landslides occur around the margins of a mesa, a buried main stream or fan gravel, acting as a local aquifer, can often be found.

Neogene Terrace Gravel of the Colorado River

(Ntg) A 5-to 8-m-thick terrace deposit of well-rounded gravel with non-locally-derived metamorphic and intrusive-porphyry clasts is present on the slopes of Flatiron Mesa 610 m above stream level. It is overlain by a 60-m-thick debris-flow deposit that forms Flatiron Mesa. This deposit is probably late Pliocene in age, as suggested by the 600 m of downcutting that has occurred since the terrace deposit

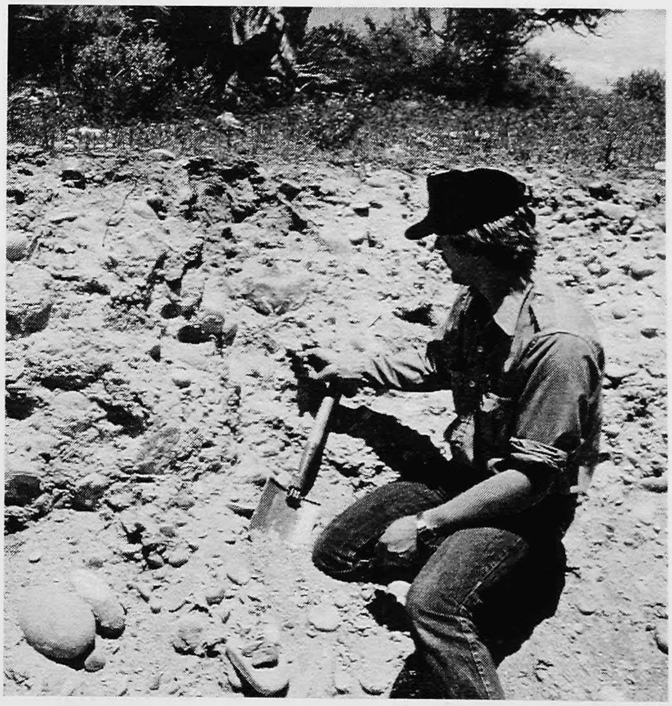


Figure 6. Upper terrace gravel of the Colorado River exposed east of study area in sec. 23, T. 6 S., R. 92 W. Gravel is extremely weathered and contains 40 to 45 percent grusified granitic clasts. Note thick pedogenic $CaCO_3$ coats on the bottoms of sound clasts.

was buried by the debris flow. Larson (1975) dated a basalt flow 46 km east of the area near Glenwood Springs which rests on a main-stream terrace deposit. The basalt, K-Ar dated at 8 m.y. B.P., apparently flowed into a former valley, which is now some 300 m above the local base level.

The gravel is poorly exposed and its thickness difficult to estimate, but it can be traced in the float around the northern perimeter of the mesa at the pronounced break in slope where landslide deposits flank the steep mesa margin. It appears to rest on Wasatch bedrock, and is overlain upslope by a fan gravel, which, in turn, is overlain by a debris flow.

Groundwater flow is not associated with this gravel as it was with the younger buried gravels. The reason for this is that Flatiron Mesa has been cut off and isolated above the surrounding drainage basin; with no upland drainage basin, groundwater flows are significantly reduced. Past groundwater flows are suggested by the mass of inactive landslides around Flatiron Mesa. These may have been active at a time in the past when Flatiron Mesa was connected to the local drainage system of Battlement Mesa.

Alluvial-Fan and Pediment Deposits

General Description of Alluvial-Fan Deposits

Alluvial-fan deposits occur at several levels throughout the study area. The deposits are recognized by their fan-shaped topographic expression. They consist of subangular-to-subrounded 0.5-to 1-m boulders and slabby pieces of locally derived sandstone, marlstone, and basalt in a dominantly clast-supported matrix of cobbles, gravel, sand, silt, and clay. The deposits are usually poorly sorted, but some show moderately well-sorted layers and lenses of sand, pebbles, and gravels.

The sediment source area for the fans directly influences the lithology of the deposits. Alluvial fans from the Roan Cliffs north of the Colorado River are devoid of basalt, whereas those emanating from drainages that head on Battlement Mesa contain up to 85 percent basalt clasts (Figure 7). Marlstone slabs are common in most fan deposits, but tend to disintegrate rapidly into masses of chips. Well-rounded non-locally-derived gravel clasts are rare but do occur in some fan deposits. These clasts may have been eroded from higher terrace deposits and incorporated into the fan deposits, or they may represent interfingering of river gravels with alluvial-fan gravels.

Most alluvial-fan deposits in the study area are actually composites of alluvial deposition and debris-flow deposition, with the former predominant. Examination of 3-m-deep fanhead trenches revealed occasional debris-flows interbedded with alluvial deposits, and several small debris flows were observed on surfaces of some large fans.

The different alluvial-fan mapping units are based on the relation of the fan to the stream that deposited it, the degree of dissection, relationship to terrace gravel, and height above streams (Figure 8). Relative age as well as the relative hazard associate with the fan surface are implicit in this scheme, which is interpreted from aerial photographs.

Active Fan Deposits

(af) Fans which have evidence of recent deposition, as shown by lack of established master drainages and vegetation, are mapped as active fan deposits. They occur at the base of steep, actively eroding gullies and canyons, and lack a fanhead trench. There is no permanent drainage traversing the fan, indicating that the flows deposit sediments

Figure 7. Alluvial-fan gravel composed of basalt from Battlement Mesa resting on Wasatch Formation bedrock.

randomly across the fan surface (Figure 8-*A*). Distal margins are smooth andeven, commonly filling over and burying depressions or gullies in the underlying surface. Proximal areas are littered with large boulders and cobbles, and often contain loose blocky sieve deposits.

A second type of active fan deposit occurs on more extensive fans where the bottom of the fan head trench approaches the surface of the fan. Here, large flows that were confined to the trench farther upstream spread out onto the fan surface, depositing sediment of all sizes. This type of active fan deposit is common to the coalescing fans north of the Colorado River along the base of the Roan Cliffs.

Young Alluvial Fan Deposits

(yaf) Fans of this next older category are large and exhibit well-formed fanhead trenches and established master channels (Figure 8-*B*). These fan surfaces are less hazardous because most destructive flows are confined to the incised master drainage and the active fans at the lower end of the trench. The inactive part of the fan is covered with mature vegetation and weathered surface boulders, suggesting that a relatively long time has elapsed since the last depositional event took place. The large size of the fans is probably a function of the rapid erosion of the incompetent poorly indurated sediments of the Wasatch and Green River Formations in the Roan Cliffs.

Some degree of chance that a severe flash-flood event could be diverted from the master channel still exists on these fans. This may even occur on upper and mid-fan areas if the channel is not deeply entrenched, particularly if it makes a sharp bend. A large flash-flood could obstruct the abrupt bend with debris, overtop the channel, and continue on a new course across the surface of the fan.

Old Alluvial Fan Deposits

(ofg) Old alluvial-fan deposits have been isolated by stream downcutting and are no longer related to the present drainage regime. They occur in two situations. In one, the fans have been incised enough to reveal their contacts with underlying deposits or bedrock, and climax vegetation communities are common (Figure 8-*C*). In the other, the fan gravels crop out on valley walls and are overlain by debris flows. These latter deposits are mapped on the basis of their clast-supported character versus the matrix-supported debris-flow deposits. Several of these buried deposits seem to contain more non-local clasts than are found in younger alluvial fan gravels.

In places it is difficult to distinguish between alluvial fan and pediment deposits. Fan deposits,

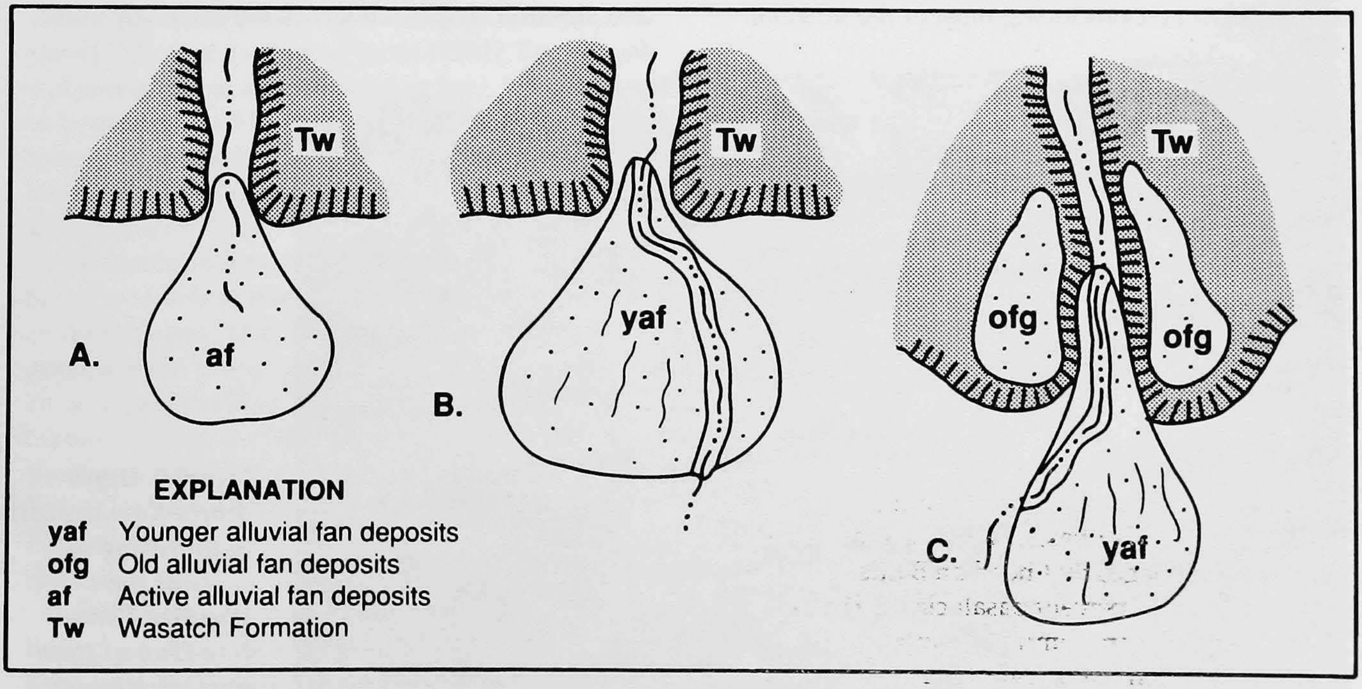


Figure 8. Schematic diagram of alluvial fan mapping units discussed in text.

however, have a larger maximum clast size, and a significantly greater thickness.

Pediment Alluvium

(pa) Thin deposits of locally-derived poorly-sorted gravelly alluvium that form gently sloping surfaces are mapped as pediment alluvium. Nowhere do the deposits attain a thickness of more than 2 to 3 m. The deposits consist of sandstone and marlstone lithologies that are subangular to angular, are dominantly clast supported, and similar in nature to coarse-grained alluvial-fan sediments. Pediment deposits are commonly veneered by 0.5 to 1 m of eolian sand and loess, which can be mapped separately where vegetation patterns permit interpretation of contacts.

All pediment alluvium is north of the Colorado River below the Roan Cliffs and rests on surfaces cut on the Wasatch Formation. Pediment alluvium was not found on any of the high surfaces bordering the slopes of Battlement Mesa, although Yeend (1969) showed it to be quite extensive.

Debris-Flow Deposits

General Description and Discussion of Deposits

Mass wasting on a truly grand scale is the dominant geologic process responsible for creating many of the deposits and producing most of the unusual geomorphic surfaces on the north side of Battlement Mesa. The characteristic landforms are called "mesas" because they are elevated, smooth, gently sloping surfaces. In the past these landforms have been interpreted as pediments mantled with outwash gravels graded to former positions of the Colorado River (Yeend, 1969). In contrast, sedimentologic studies and aerial-photogeologic landform analysis suggest that these isolated high surfaces are the remains of large ancient debris flows that traveled down the flanks of Battlement Mesa into the ancestral river valley below, locally burying a pre-existing landscape. Five ages of these deposits, all having similar properties, have been identified in the study area.

Debris-flow deposits are strikingly different, in both landform morphology and sedimentary character, from the other surficial deposits in this study. The deposits are matrix supported and lack bedding, sorting, or sedimentary structures (Figure 9). Basalt blocks ranging from 0.5 to 4 m in length occur scattered throughout a matrix of yellowish-white silt and clay. Boulders are angular to subangular and show very little rounding or other evidence of alluvial transport. The largest blocks seem to be concentrated near the surface and along the sides of a deposit. Large (0.5 to 1.5 m) angular slabs of weak, fissile shale and marlstone are also present, supported in the clayey matrix.

The sedimentologic character of these deposits, and size and shape of bedrock blocks, some quite

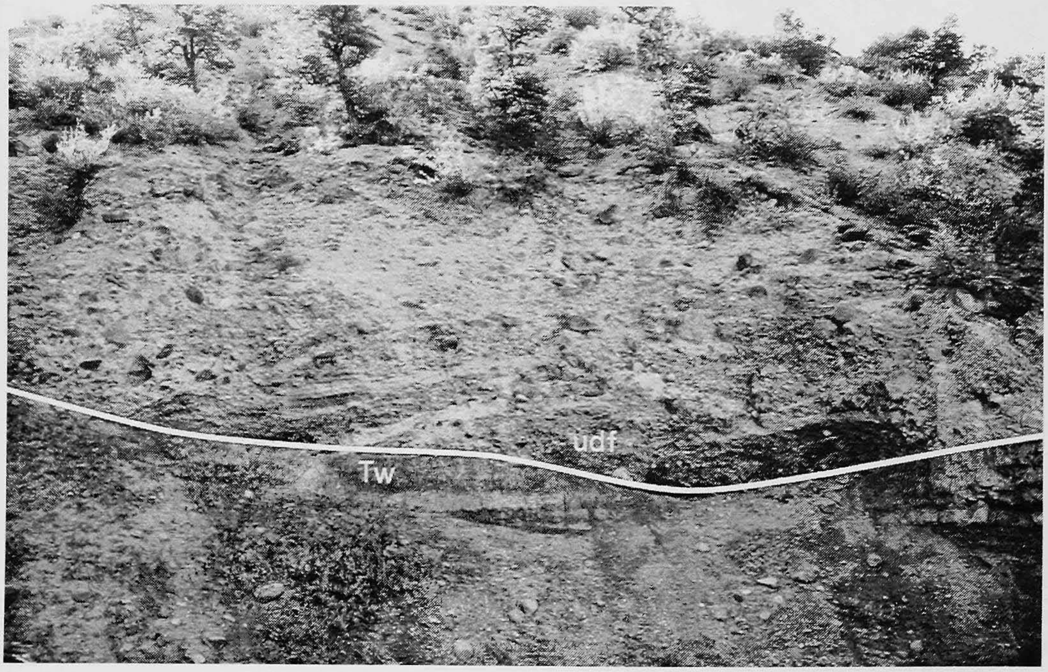


Figure 9. Upper debris-flow deposit (udf) resting on shale of the Wasatch Formation (Tw) at Ramsey Gulch (stratigraphic locality 9).

incompetent, are better explained by debris-flow transport than by alluvial processes. Alluvial processes cannot account for the absence of sorting and bedding of these matrix-supported deposits. High velocity alluvial flows would have flushed away the finer-grained material, leaving a clast-supported cobble boulder deposit such as those that make up alluvial fans or river deposits. In addition, flows at flood stage capable of transporting such blocks would rapidly break off corners and chunks, producing more rounded boulders such as those deposited by floods north of Buena Vista, Colorado (Scott, 1975), and in mountain streams draining the Front Range (Bradley and Mears, 1980).

The sediment characteristics described above closely correspond to those of other debris-flow deposits that have been observed and studied (Sharpe and Nobel, 1953; Bagnold, 1954; Johnson, 1970; Fisher, 1971; Rodine and Johnson, 1976; Varnes, 1978; Costa and Jarret, 1981). Clearly, these deposits are the results of rapid flowage of slurries of water, mud, and rock behaving as high-density bingham fluids (Johnson, 1970).

The morphology of debris-flow deposits is helpful in their recognition. The flows have a characteristic fan shape in plan view, often bi- or multilobate. The distal margins of many debris fans have been lost due to erosion by the Colorado River and landsliding, creating somewhat truncated fan shapes. Lateral levees that border the paths of individual flows are similar to those discussed by Johnson (1970), and Costa and Jarret (1981). The magnitudes of some of the flows (12 sq km), have resulted in levees up to 30 m high which resemble glacial moraines. The levees crosscut one another and are useful for interpreting sequences and relative ages of debris-flow lobes.

A common feature associated with older flows is a pile of debris that forms an elongate conical hill at the fan apex. This feature is believed to mark the approximate former position of the canyon mouth from which the flow spewed. It was probably formed during the final moments of viscous flow as the deposit came to rest, causing the last bit of debris still flowing in the constricted canyon to pile up behind the newly formed fan. The present shape of the hill is probably due to subsequent erosion.

Debris flows are 10-to-70-m thick and have buried pre-existing topography (Figure 10). A drillhole west of the study area on Lucas Mesa penetrated over 70 m of debris-flow material overlying Wasatch bedrock (W. R. Junge, personal commun., 1983). The thickness of the deposits can be highly variable within short lateral distances, because of the topography they buried. The deposits have a smoothing effect (Johnson, 1970), and no evidence of the nature of the underlying topography is reflected by the surfaces of the deposits. The great thicknesses of these deposits clearly indicate that they are constructional, and that the smooth-sloping upper surfaces of the "mesas" have not been formed by pedimentation processes, as was once suggested (Yeend, 1969). Rather, the smoothness is the result of lateral down-wasting of originally rough furrows and ridges, and loess deposition which has veneered the debris fan surfaces.

The immense volumes of some of these debris flows are difficult to imagine, and much field work was directed toward trying to determine whether certain deposits were produced as single large flows, or by multiple events. In most cases, the morphology and stratigraphy of the fan lobes and crosscutting levees suggests the former. The amount of material contained by the debris flow remnants

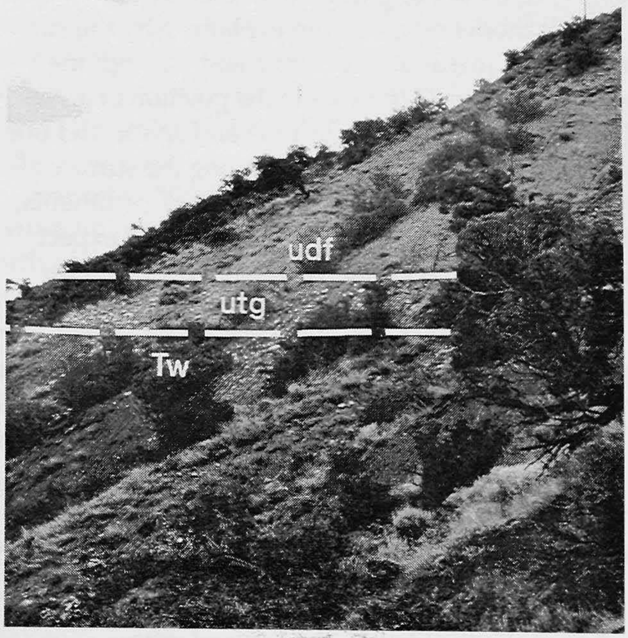


Figure 10. Upper terrace gravel of the Colorado River buried 70 m beneath the surface of Grass Mesa (Skyline). Gravel rests on the Wasatch Formation.

comprising Grass Mesa alone is estimated to be at least 850 million cubic meters. Due to erosion, it is difficult to estimate the total area this debris fan once occupied, but based on the remaining shape of the deposit, it may have involved half again as much material as is present in Grass Mesa.

Debris-flow deposits have an armoring effect because their blocky boulder-studded surfaces are difficult to erode (Madole, 1982). Once these deposits dry out and set up, they are often more resistant than the underlying soft Tertiary claystones and sandstones, and tend to protect these latter rocks from erosion.

The surfaces of individual debris fans can be related to the elevation of the Colorado River gravels they buried during deposition (Table 1). Projecting gradients of preserved debris-fan surfaces down to the present valley axis to estimate the former position of the Colorado River, and thereby rates of downcutting, has little meaning. The slopes of debris-fan surfaces often do not reflect that of the underlying topography, and are more a function of an individual deposits consistency and flow rheology (Johnson, 1970). In most cases, the river was near or occupying the elevation of the buried main-stream gravels at the time of debris-flow deposition. If dates for the debris fans are obtained, a more accurate estimate of downcutting rates can be made by using the heights of these old gravels above the river.

This model of formation explains why the surfaces of the mesas are not accordant through the area. Each "mesa" represents the position of an individual debris-flow fan in time and space, and one would not expect accordance among the surface elevations of such deposits. If these were pediments, as considered by Yeend (1969), one would expect widespread surfaces that correlated on elevation throughout the area. In fact, Yeend (1969) puzzled over this lack of accordance throughout the area, as it was not predicted by his interpretation.

Although the surfaces of individual fans are not accordant, the flows can be broadly grouped into five age groups. The relative ages are based on the former approximate position of the Colorado River valley when the flows were deposited, as indicated by the level of river gravel that they bury, by qualitative ranking of the degree of surface smoothness, and stratigraphic relationships with younger debris flows. The debris flow units are similar to each other sedimentologically, and would be difficult to distinguish on age if it were not for the different levels of terrace gravels that they overlie.

Young Debris Flows

(ydf) The youngest debris flows occur on the flood plain of the Colorado River. Similar debris flow deposits also occur on the upper reaches of the Porcupine Creek fan, where the creek emerges from the steep confining canyon walls (Figure 11). The flows are relatively small, a few hectares in size, and do not exhibit well-formed lateral levees. Their surfaces are rough and hummocky. Chiefly, they are the products of flash floods and, perhaps, rapid snowmelt, where large quantities of water are available to saturate debris that collects along sideslopes and the normally sluggish creek bottoms. Because these fan surfaces are directly associated with existing drainages, they are still subject to hazardous debris-flow events.

Lower Debris Flow Deposits

(ldf, rcf) An extensive area of coalescing debris flows occurs along the lower slopes of Battlement Mesa. Individual flow deposits crosscut one another,

Table 2. Debris-fan surfaces and associated main-stream terrace-gravel deposits.

	Debris-Flow Unit	Terrace gravel Underlying Debris-Fans	Elev. of Terrace Gravel above Colorado River (m)	Names of Debris-fan Surfaces
Youngest	ydf	ytg-ytd	2–6	—
	ldf-rcf	ltg-tgb	40–53	Western Taughenbaugh Mesa
	mdf	mtg	110–125	Morrisania Mesa, eastern Taughenbaugh Mesa
	udf	utg	207–216	Holms Mesa, Grass Mesa
Oldest	Ndf	Ntg	610	Flatiron Mesa, Log Mesa

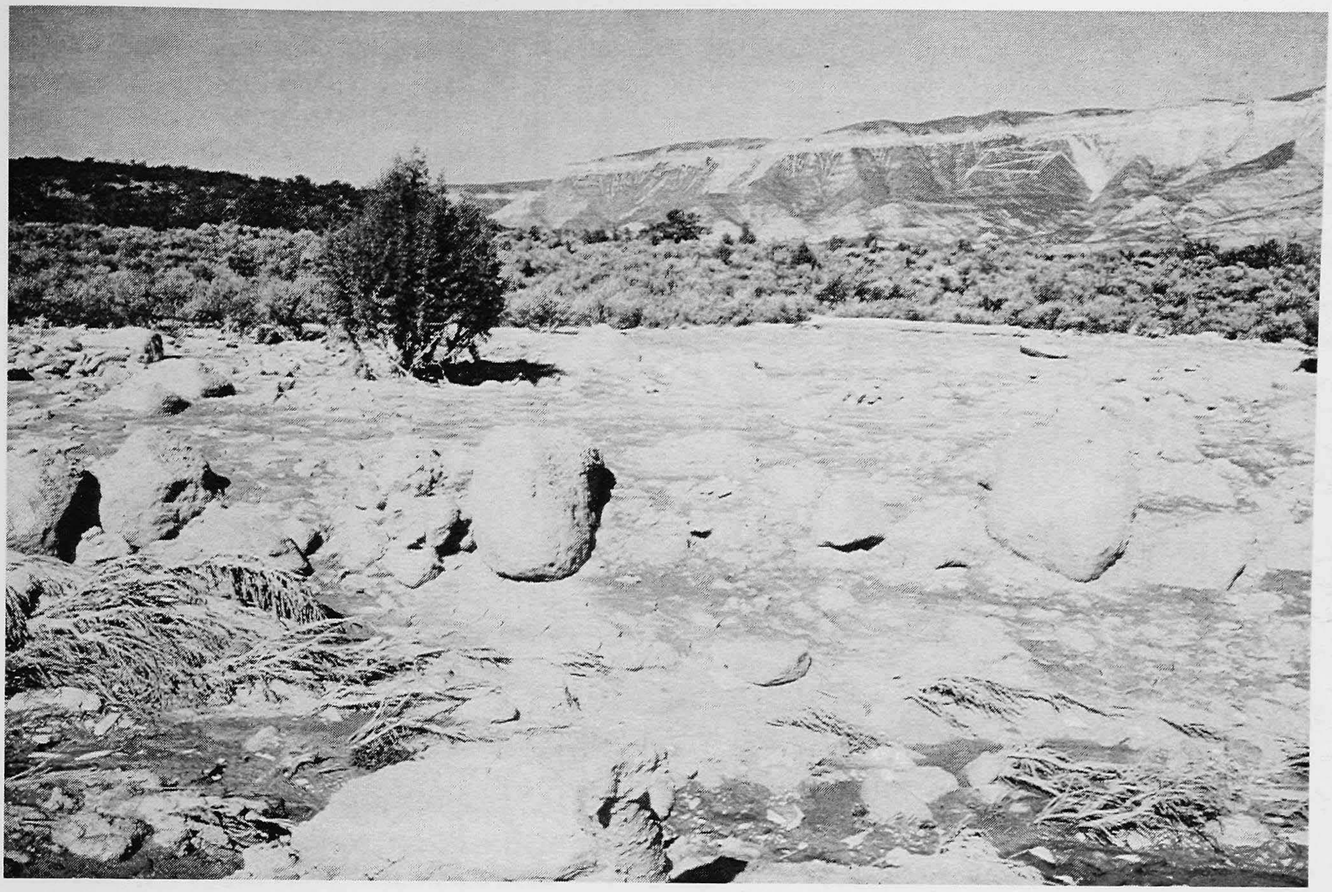


Figure 11. Three-week-old debris flow deposit (ydf) on Porcupine Creek fan. Note mud on branches of Juniper tree which indicates depth of debris (1.5 m) during flow. Photograph taken September 21, 1982.

and large lateral levees often mark the paths the flows followed (Figure 12). These flows began on the side slopes of Battlement Mesa in drainage basins that had previously produced large debris flows. This sequence of flows has buried the lower terrace gravel (ltg, tgb) in many places, and at one locality (stratigraphic locality 3), stratigraphic evidence and field relations suggest that the debris impounded the Colorado River for a short period of time.

Debris flows of this unit exhibit the best preserved depositional morphology in the area. Levees are well preserved, giving the deposits a rough irregular topography. The surfaces of the flows are littered with angular slabs and blocks of basalt ranging in size from 0.5 to greater than 3.5 m in large dimension. Many boulders protrude through the thin patchy loess which veneers the fan surfaces.

Individual fans in this unit are up to 4 sq km, and their associated levees can be traced upslope for 5 km. The largest fans are estimated to contain approximately 80 million cubic meters of debris. Deposits of such size were possibly initiated during a past wetter climate that resulted in the saturation of large colluvial slope-failure complexes and previously deposited debris flows mantling the slopes of Battlement Mesa. Roughly 40 m of downcutting by the Colorado River has occurred since the first flows of this group buried the lower river terrace. Portions of this unit were

Several debris-flow deposits derived from colluvium on the lower slopes of the Roan Cliffs occur north of the Colorado River; they are mapped as unit rcf. These debris flows consist of slabs of sandstone, marlstone, and shale in a fine-grained, matrix-supported deposit. The flows were derived from clayey colluvium of the Wasatch Formation that is present on the lower slopes and in gullies draining the Roan Cliffs, and appear to have occurred when large thicknesses of colluvium were saturated and mobilized.

It is not known how these deposits correlate with the debris flows on the south side of the valley. However, on the basis of topographic position and stratigraphic relations to alluvial fans along the base of the cliffs, they are tentatively included as a facies of the lower debris flow unit (ldf).

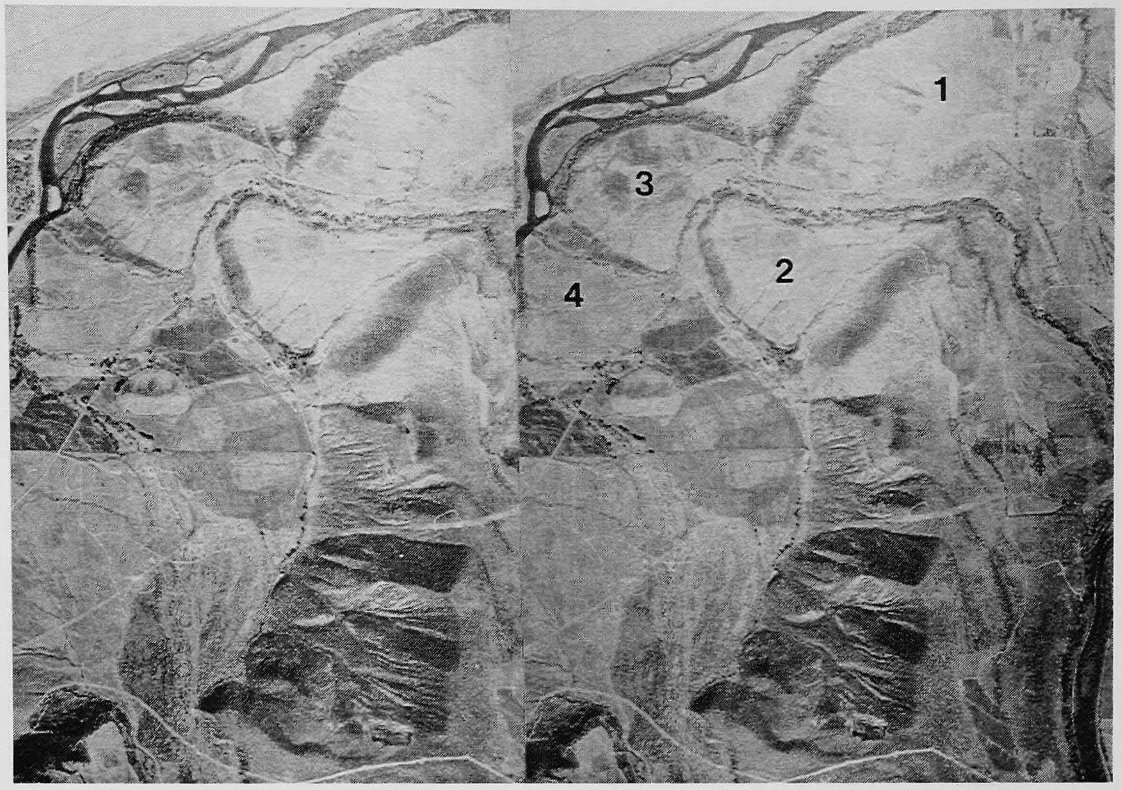


Figure 12. Stereo pair aerial photographs showing successive debris-flow fans formed by flows moving down Beaver Creek to valley axis. Colorado River is in the upper left corner. Numbers on fans show flow sequence; 1 is oldest. North is toward top of figure previously mapped as mudflows of Pinedale age by Yeend (1969). (BLM 24CN CO77F, photographs 1-8-185 and 1-8-186)

Middle Debris Flows

(mdf) Debris-flow deposits (mdf) that bury the middle terrace gravel unit (mtg) are older than the lower debris flows because about 60 m of downcutting occurred between the deposition of the two debris-flow units. The surfaces of these flows are somewhat smoother in appearance, and often have a thicker loess veneer (0.5 m) relative to the lower debris flows.

Upper Debris-Flow Deposits

(udf) A third group of old debris-flow deposits occupies the middle to upper slopes of Battlement Mesa. Fans in this group were originally about 11 to 17 sq km and are 10 or 12 km downslope of the source area. The large extent of these surfaces probably led earlier workers to call on pedimentation processes to form them. Holms Mesa and Grass Mesa are examples of debris fans of this unit. Debris flows of this magnitude were generally not recognized in the literature until the early 1970s (Johnson, 1970; Fisher, 1971), and this may explain why such a mechanism was not considered during earlier work in the area.

About 60 m of debris-flow material overlies the upper terrace gravel (utg) on Holms Mesa (stratigraphic locality 1). This terrace gravel, lying 207 m above the river, is believed to correlate with a gravel 216 m above the river that crops out beneath Grass Mesa 16 km upstream (stratigraphic locality 9), suggesting that Grass and Holms Mesas are of similar relative age. Average debris thickness at Grass Mesa is 50 m (stratigraphic locality 10).

Soils developed in colluvium on the slopes of these mesas can be used to put approximate limits on the age of these deposits. A strongly developed soil on a colluvial slope near the surface of Grass Mesa (Figure 13) possesses a stage IV carbonate horizon (km) (Gile et al., 1966). This suggests that the colluvium around the sides of these eroded fan remnants has been in place for a substantial length of time, perhaps on the order of 500,000 years

(Machette, 1982; Machette and Steven, 1982). The soil may owe some of its strong development to its position on the edge of the mesa where seepage of carbonate saturated groundwater may have been active. Additional soil studies are necessary to determine if the observed development is representative of soils on the upper surface of Grass Mesa.

The upper surfaces of these old flows are commonly mantled with a meter or less of reddish-brown loess. Large protruding boulders are quantitatively less common than on younger flows, giving these older surfaces a smoother appearance relative to the younger flows.

Neogene Debris-Flow and Colluvial Deposits

(Ndf) Unsorted, unstratified, matrix-supported, basalt-boulder deposits similar in sedimentologic character to younger identifiable debris-flow deposits cap high drainage divides and form the highest sloping surfaces peripheral to Battlement Mesa. The materials on narrow drainage divides are poorly exposed but differ from the other deposits in that much of the finer clayey matrix has been washed away, leaving the basalt blocks on high narrow ridges between drainage basins (Figure 14). These boulders have been described as lag gravels by workers in the area (Kirkham, 1980).

Flatiron Mesa is the largest Neogene debris-fan remnant. The surface of the mesa has a gentle uniform northwestward slope and is composed of basalt gravel and boulders mixed with platy fragments of laminated pedogenic(?) calcium carbonate in a white clayey matrix. The deposit is about 50 m thick in one exposure where it overlies a river terrace gravel (Ntg, stratigraphic locality 7). There are relatively few protruding basalt blocks on the surface; most are essentially flush with the ground (Figure 15). Loess veneers some parts of the mesa, but there is generally much less of it than on the lower debris-fan remnants, possibly due to the high position relative to probable loess sources in the valley. The debris-flow morphology of these deposits is not everywhere well preserved, but enough of the fan shaped surfaces remain to enable convincing comparisons to younger flows. Flow levels are missing, however, probably due to erosion or lateral-downwasting.

The age of these oldest debris-flow and colluvial deposits is thought to be Neogene. Between 600 and 900 m of downcutting has occurred since they were deposited. Larson et al. (1975) dated a basalt flow 46 km east of the area near Glenwood springs which rests on a main-stream terrace deposit. The basalt, K-Ar dated at 8 m.y. B.P., apparently flowed into a former valley, and about 300 m of downcutting followed extrusion of the flow.

Figure 13. Strongly developed carbonate soil (km, at least stage IV) on colluvial slopes of Grass Mesa (soil locality 3). Basalt clasts have been pushed apart during carbonate accumulation.

Other Mass Wasting Deposits

Colluvial Slope-Failure Complexes

(csf) Other types of mass wasting deposits can be identified on aerial photographs in the study area. Thick deposits of unconsolidated clayey colluvium containing basalt fragments mantle much of the upper slopes and summit areas of Battlement Mesa and are mapped as complex slope-failure deposits. Accumulations of this material occur in local valleys where it appears to clog the drainages with deposits of unconsolidated debris up to 30-m thick. Several mass wasting processes probably helped form these deposits, including slumping, debris flows, and solifluction.

There is no dominant process, but rather a complex interaction of slope-failure mechanisms that

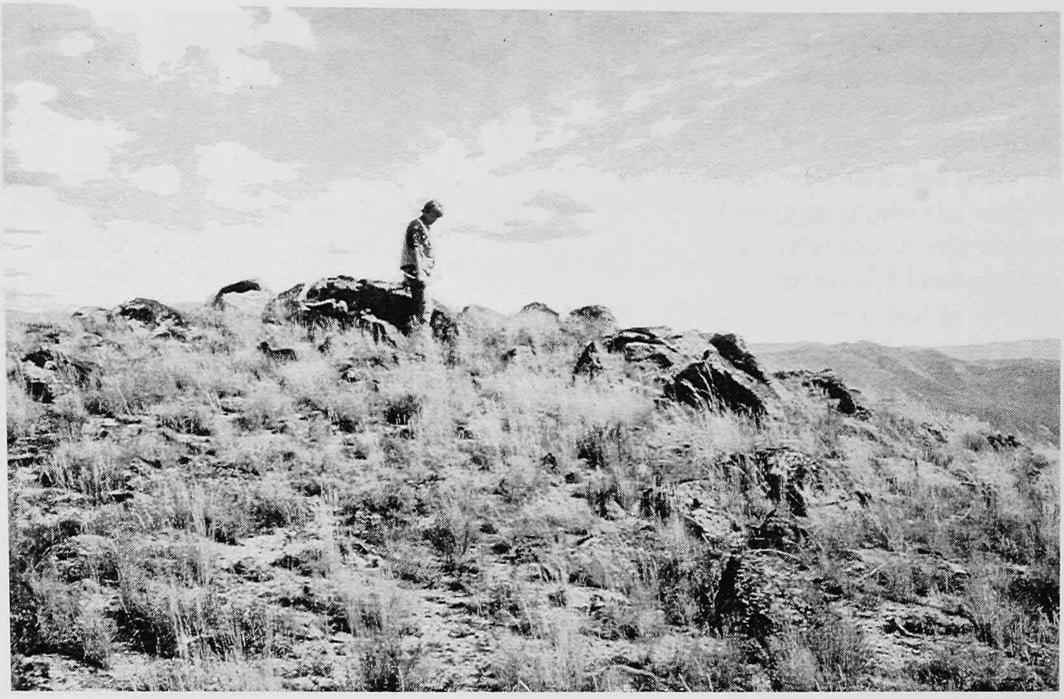


Figure 14. Basalt boulders of debris flow origin matrix has been washed away. (Ntg) resting on narrow drainage divide. Clayey

Figure 15. Basalt boulder 4.5 m long on surface of Log Mesa (Ntg).

are gradational to one another and not easily separable. In many areas these deposits grade valleyward into debris-flow units, indicating that some of these are the source materials for debris flows.

Basalt Block Fields and Boulder Streams

(tbs) Extensive hummocky areas of large angular basalt blocks derived from the break up of volcanic flows are present on the summit of Battlement Mesa (Figure 16), and extend down several local drainages. The deposits average 6 m in thickness and overlie incoherent claystone. Failure of the claystone gives rise to creep or rapid flowage. These deposits merge downslope into colluvial slope-failure complexes, and contacts between the two are gradational. Large slumped blocks of basalt flows are included in this unit.

Talus

(t) Talus deposits of loose, angular rock debris occur throughout the higher elevations in the study area. Most deposits are composed of marlstone and sandstone derived from cliffs in the Green River Formation. Large accumulations, such as those below cliffs at the head of Porcupine Creek, are up to 15 m thick and possess a well-defined stratification. Oil shale in these thick talus piles appears to have undergone spontaneous combustion or rapid

Figure 16. Basalt boulder field on top of Battlement Mesa. North Mamm Peak in left background is the only remnant of in situ basalt in the study area.

oxidation, resulting in bright red and orange "clinker" deposits of burned oil shale, similar in appearance to burned coal-waste piles.

Landslide, Earthflow, and Slump Deposits

(ls, als) Landslide debris of various ages covers much of the lower and middle slopes of Battlement Mesa. Deposits consist of a heterogeneous mixture of angular to subangular rock debris of all sizes in a fine-grained matrix. Lithology of the entrained debris reflects the nature of materials involved in the slope-failure process. The term landslide is used to include all types of rotational, translational, and slumping failures (Varnes, 1978), exclusive of debris flows. Morphologic expression of landslides is so apparent on aerial photographs that identification and mapping is comparatively simple (Rib and Liang, 1978).

Two age categories of this deposit, both composed of similar materials, are mapped to distinguish between active and inactive landslide areas. Recent or active landslides (als) are identified by ground-water flow within the slide materials or at the slide scarp, disrupted vegetation, fresh scarp morphology, tension cracks, and burial of pre-existing structures or surfaces.

Older landslide deposits (ls) cover extensive areas on the slopes of Battlement Mesa, and most often involved failure of previously deposited debris flows. An example of this type of landslide deposit surrounds Flatiron Mesa, where the original slide scarps form cusps along the edges of the remaining surface. Most of the larger, more extensive landslide deposits are presently stable, probably due to dryer soil moisture conditions which prevail under present climatic conditions, and lower slope angles. However, disturbances or changes such as road cuts and crop irrigation have reactivated landsliding locally.

Colluvium and Slope Wash

(csw) Angular rock fragments in a fine-grained matrix derived from downslope gravitational transport and sheetwash have accumulated on slopes and valleys throughout the area. Deposits vary in thickness from 1 to 5 m, with locally thicker wedge-shaped accumulations in swales and valley bottoms. With the exception of steep slopes and cliffs, the Green River and Wasatch Formations are usually covered by such a colluvial veneer. This unit is mapped only along valley bottoms and at the base of slopes where it is at least 1-m thick.

Colluvium and slope wash can be identified on aerial photographs where they have a subtle masking or smoothing effect on slopes, or where wedge-shaped deposits occur on toe slopes and in low lying areas. On aerial photographs, it is usually difficult to distinguish the fine-grained colluvium and slope wash of the Wasatch Formation from eolian deposits, and field observation is necessary to separate the two.

Eolian Sand and Loess

(es) Mantling all but the highest surfaces in the study area are thin patches of light-reddish-brown silt and fine sand. Thicknesses vary from 0.5 to 2 m. This appears to be loess derived from wind erosion of local deposits. It locally attains thicknesses of 3 to 5 m on some east-facing leeward slopes and valleys. In several places, the sandier facies forms small dunes 1-to 2-m high along the valley axis.

The loess is mapped only where it was thick enough to bury other surficial deposits by a meter or more. It often fills local valleys and leeward areas, producing a smoothed appearance on aerial photographs. Thicker accumulations often do not support pinion and juniper trees, so that the deposits in particular areas can be mapped according to the boundary between sagebrush and wooded areas.

Bog and Peat Deposits

(bog) Small accumulations of organic-rich muck and peaty deposits in local sag ponds and poorly drained areas on the upper slopes and summit of Battlement Mesa are mapped as bog deposits. These small marshy areas are usually water-filled during most of the year, but dry up during late summer and fall. Most occur as small closed depressions within the hummocky landslide terrain on higher, wetter areas of Battlement Mesa.

Man-Made Deposits

Radioactive Uranium and Vanadium Mill Tailings

(UVT) Two piles of purplish colored, finely-ground silty hazardous radioactive uranium and vanadium mill tailings are present in the study area. Both are located within the floodplain of the Colorado River near Rifle, and constitute extreme environmental problems due to their proximity to the local populace, and the potential for serious pollution of the river. A 100-year flood would introduce toxic materials into the river, causing severe pollution of the river. The tailings are susceptible to wind erosion, and have contaminated adjacent surface soils within several hundred meters of the piles. Radiation levels associated with the piles are dangerously high, and efforts are currently being made to relocate and properly dispose of the tailings (W. R. Junge, personal commun., 1982).

Tertiary Bedrock Units

Sedimentary Bedrock Units

(Tw, Tgu, Tuc) Sedimentary bedrock exposures are mapped as either Tertiary Wasatch (Tw), or Green River and Uinta Formations (Tgu), all of which have been described previously. It was not necessary to subdivide the Green River and Uinta Formations for the purposes of this study; however, an unnamed claystone unit of the Uinta Formation underlies the basalt flows of North Mamm Peak about 150 m below the summit, and is mapped separately (Tuc). This claystone unit is important because it can be used to determine the original thickness of the basalt flows, and it is the main pre-basalt unit responsible for causing the mass wasting processes on Battlement Mesa. Good exposures of the claystone are found in deeper gullies and swales within the basalt block fields around North Mamm Peak (stratigraphic locality 11).

Volcanic Basalt Flows

(Tb) Undisturbed volcanic basalt forms the pinnacle of North Mamm Peak. This isolated knob is all that remains of the once more extensive basalt-capped plateau in the study area, which is estimated to have been approximately 150 m thick at this locality. Individual flows differ in composition and petrology yielding a variety of basalt types. Colors include black, gray, brown, and red. Most flows have a vesicular texture, with vesicles elongated in the direction of flowage.

Much of the basalt has not developed good weathering rinds for use in relative dating. One probable reason is the extremely vesicular texture of the majority of flows. A more likely reason is that the high pH of the calcareous clayey matrix enclosing the basalt detritus inhibits the formation of weathering rinds on basalt boulders and cobbles (K. L. Pierce, oral commun., 1983).

Even if the basalts did have good weathering rinds, I do not believe they would be useful in dating debris flow deposits. Younger debris flows do not necessarily contain fresh clasts when deposited. Much of the material incorporated into younger flows has been derived from older flows and landslide deposits, so that it would be difficult to determine if a basalt clast's rind was representative of the age of deposition, or if it was older and had been reworked into a younger deposit. Weathering rind data is thus not expected to produce any useful trends; however, this conjecture needs to be tested.

Chapter 3

Interpretationof Surficial-Geologic History

Summary of Events

The oldest unit important to surficial-geologic history is the basalt that caps Battlement Mesa. During the last stages of eruptive activity, about 7.5 m.y. ago, basalt flows from south of the area forced the Colorado River north into roughly its present position, in a valley about 1200 m above present base level (E. E. Larson, personal commun., 1983). By late Pliocene time, the Colorado River was flowing through the area in a valley some 610 m above present stream level. Basalt-capped Battlement Mesa bordered the river on the south, about 2500 m higher above the valley floor.

Regional tectonic uplift (Tweto, 1975) resulted in continual downcutting by the Colorado River throughout the Late Pliocene and Quaternary. As downcutting progressed, headward erosion by tributary streams began to undercut the extensive basalt plateau, and a wide river valley was rapidly excavated in the soft Tertiary sediments. Landsliding of the undercut basalt and underlying incompetent claystone produced large volumes of clayey, boulder-laden debris around the margins of the plateau. After initial breakup of the flows, their blocky surfaces trapped large quantities of precipitation and this could have saturated the relatively impervious underlying clay strata. Greater soil moisture during the Pleistocene also could have been a contributing factor to landsliding and mass wasting of the basalt plateau.

Periodically, massive debris flows occurred along the flanks of the plateau. Some debris flows could have started when huge toreva blocks of basalt and claystone on the edge of the plateau failed, and slid down the steep upper slopes. Once liquified, the material could flow down existing drainages as a high-density bingham fluid[1], rafting basalt blocks and incorporating more slope debris as it traveled.

Below canyons the debris flows spread out and formed huge fans (Johnson, 1970). Alluvial fans, main-stream terraces, and the floodplain of the Colorado River were covered with muddy, bouldery debris tens of meters thick. These flows often forced the river to a course farther north around the newly deposited fan lobe. Larger flows or flows at particularly narrow areas of the Colorado River valley crossed the river completely, creating natural dams which were subsequently breached. Other flows may have entered the river and followed it downstream for short distances.

The degree of erosional isolation and subsequent preservation of an individual flow would have depended on the length of time which elapsed before the next great debris flow occurred in the parent drainage (Figure 17). Following one of these large debris flows, the drainage down which the debris traveled often became filled with debris (A—A', Figure 17-*A*) in narrower parts of the drainage just behind the fan apex (Johnson, 1970). The rough topography of debris at the fan apex often deflected the stream to one side of the fan surface, preventing it from flowing across the newly deposited fan (Figure 17-*A*). Subsequent downcutting and headward erosion continued along the newly aligned stream, and if downcutting continued long enough during inter-flow periods, the deeper stream valley could conduct the next large debris-flow around the previous fan lobe, effectively isolating it from the

[1]A high-density slurry which does not behave as a liquid, having a central "plug" or "raft" of rigid debris moving at a uniform velocity. The "plug" of rigid debris can thus support and transport very large boulders.

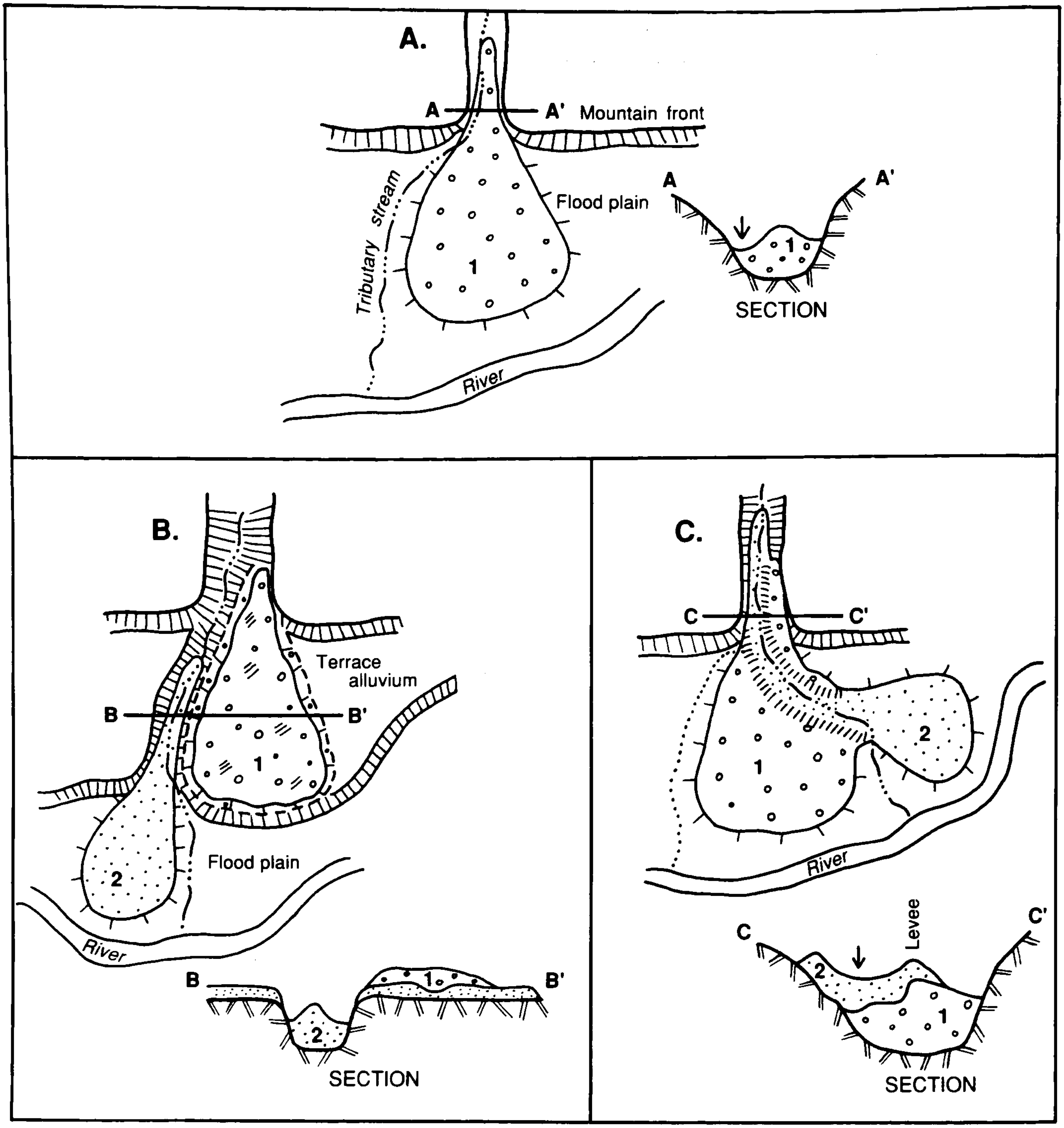


Figure 17. Simplified diagram illustrating the effects of both different recurrence intervals between flow events and rate of stream incision on preservation of debris-fan surfaces in the landscape. A) debris flow 1 occurs in tributary drainage and flows onto flood plain. New topography deflects stream (arrow in section) to one side of fan. B) tributary stream becomes deeply incised prior to next major debris flow (2), isolating fan surface 1 in landscape. C) major debris flow (2) occurs before stream has incised (thin arrow in section) and spills across fan surface 1, rerouting stream across older surface within new levees.

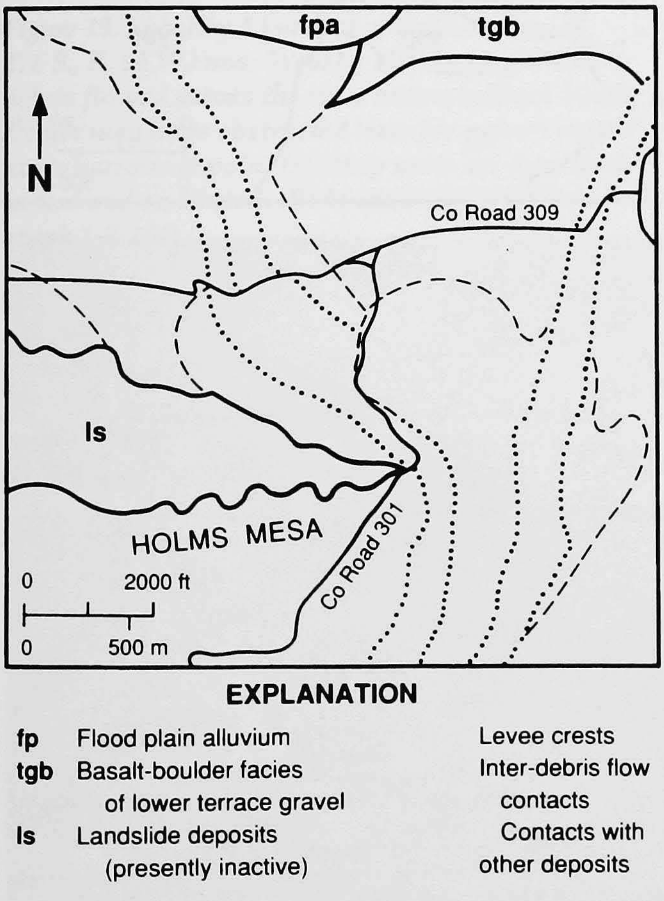
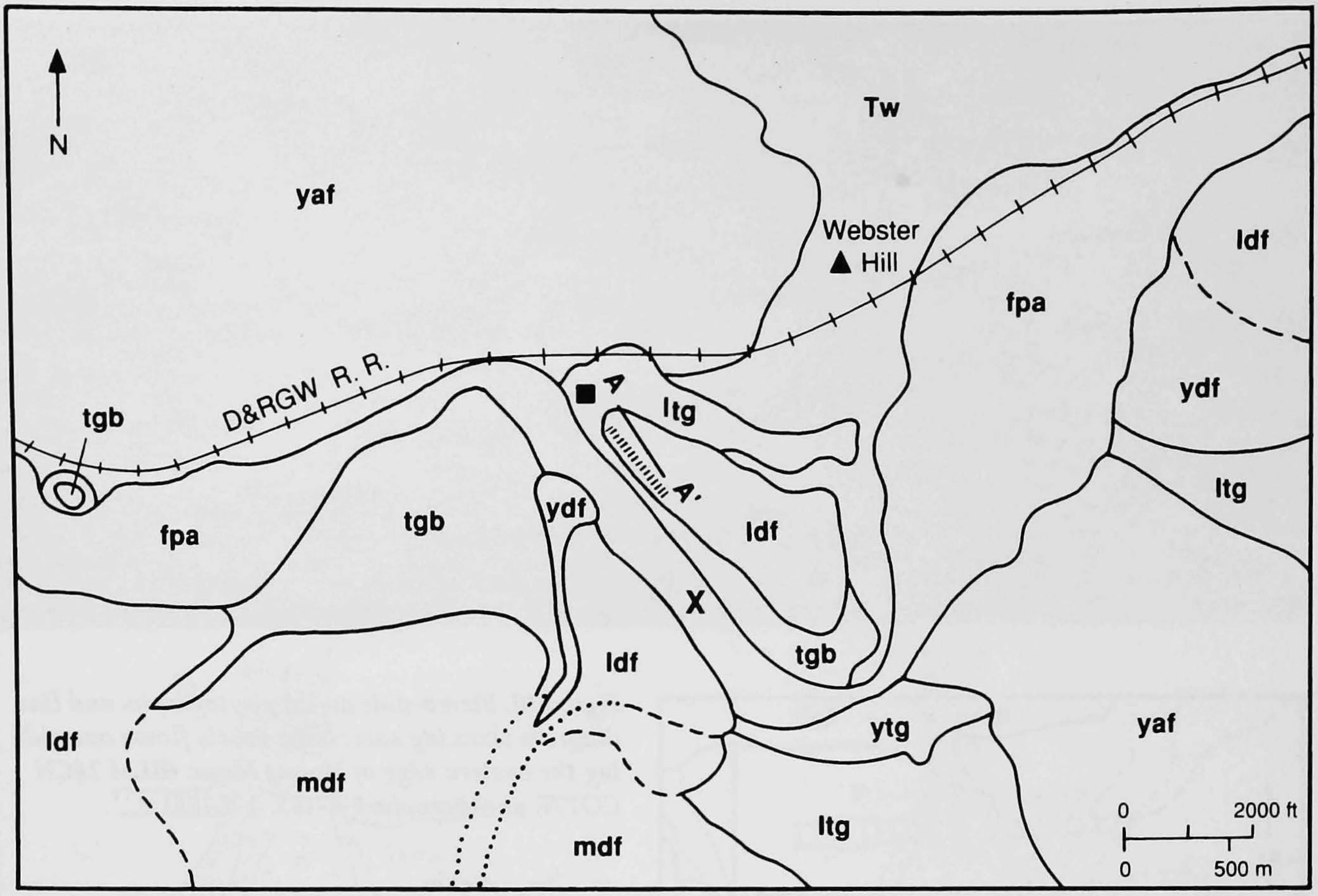


Figure 18. Stereo-pair aerial photographs and line diagram showing successive debris flows overriding the eastern edge of Holms Mesa. (BLM 24CN CO77F, photographs 1-8-183, 1-8-184)

active depositional regime (Figure 17-*B*). In this way, surface drainage was prevented from reworking or removing some debris fans, thus preserving the fan surfaces in the landscape.

Other debris-fan remnants suggest that the tributary stream may not have had sufficient time to downcut enough to guide subsequent debris flows away from the initial debris fan. Rather, the flows spilled across the older fan surface (Figure 17-C). Examples of this are the multiple debris-flow events which flowed across parts of the older fans of Holms and Morrisania Mesas (Figure 18). Relatively smaller successive flows were confined within levees across the older fan surfaces, and eventually they too spread out to form fans.

The debris-flow mechanisms described above began in the Pliocene and continued to operate throughout the Quaternary, consuming large sections of the basalt-capped highland to the south. As the primary basalt-toreva-block source was reduced to complex landslide deposits, and backwasting produced gentler slopes, and thus terrain less susceptible to massive failures, successive debris-flow events diminished in size, and probably in frequency. Younger flows were derived mainly from older debris-flow and landslide deposits that became unstable due to the continuing undercutting and headward erosion in tributary streams draining Battlement Mesa.


N
Tw
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Hill
ldf
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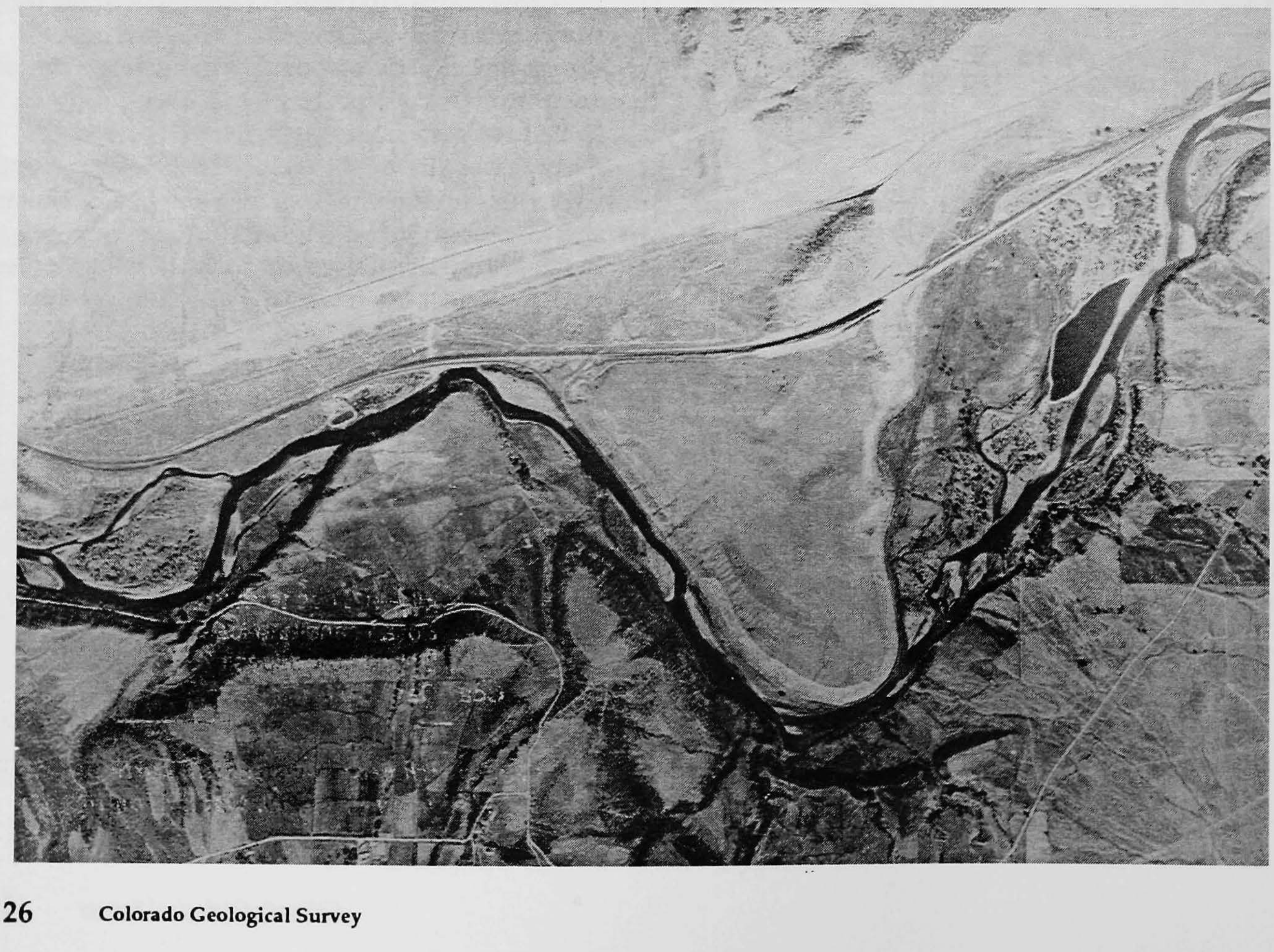


EXPLANATION

fpa Flood plain alluvium
ytg Younger terrace gravels
ltg Lower main-stream terrace gravel
tgb Basalt-boulder facies of lower terrace gravel
ydf Younger debris flow
ldf Lower debris-flow deposits, **ldf₁** is oldest
mdf Middle debris-flow deposits, **mdf₁** is oldest
yaf Younger alluvial fan deposits
Tw Wasatch Formation

X Debris may have obstructed river for a short period at its narrowest point

■ Location of gravel pit
——— Line of section in Fig. 20
ıııııııııııııııı Trench
– – – – – – Inter-debris flow contact
· · · · · · · · · · Levee crest

Figure 19. Locality 4 km east of Rulison (sec. 28, T. 6 S., R. 94 W.) near Webster Hill (triangle) where debris flowed across the river onto a bedrock bench. Debris may have obstructed river for a short period at its narrowest point (x). Map units are described in text and on Plate I. (BLM 24CN CO77F, photograph 1-8-184)

Quaternary History of Lower Debris Flows Near Rulison

A most significant stratigraphic succession 4 km east of Rulison suggests that a large debris flow crossed the Colorado River near a southward projecting bedrock high known as Webster Hill (Figure 19). Debris-flow deposits rest on a high point north of the present river. Lack of rounding of basalt clasts which are supported in a fine-grained matrix, coupled with a lack of Colorado River gravels, suggests that the river did not occupy the high point after deposition of the debris flow. Part of a debris fan that may have been contiguous with the above debris-flow deposit is present directly south across the river channel.

A gravel pit and prospect trench expose a stratigraphic section (Figure 20) that suggests that the debris flow crossed the river and came to rest on a terrace on the north bank. The gravels in the terrace are Colorado River gravels; they are the oldest surficial deposits at this locality, and they are overlain by fine-grained alluvium and loess. In the upper part of the loess is a calcic soil with a well developed Bt horizon, and a carbonate horizon with stage III morphology (Gile et al., 1966). More loess overlies the soil, and the upper unit is the debris-flow deposit. The hiatus represented by the soil suggests

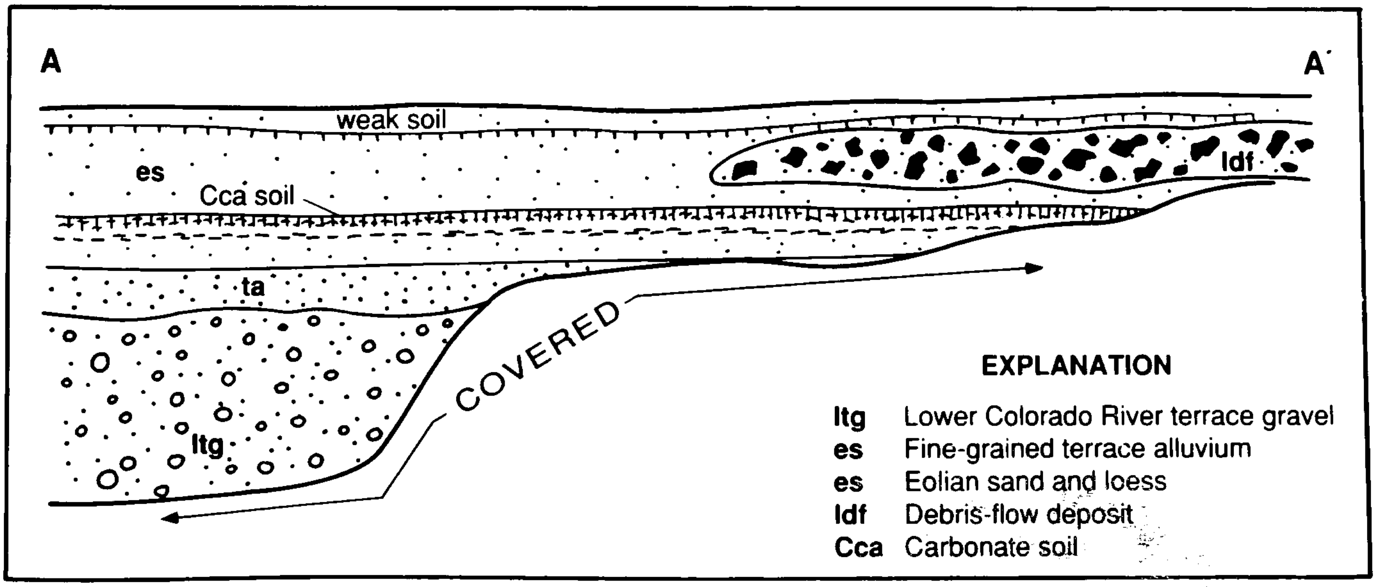
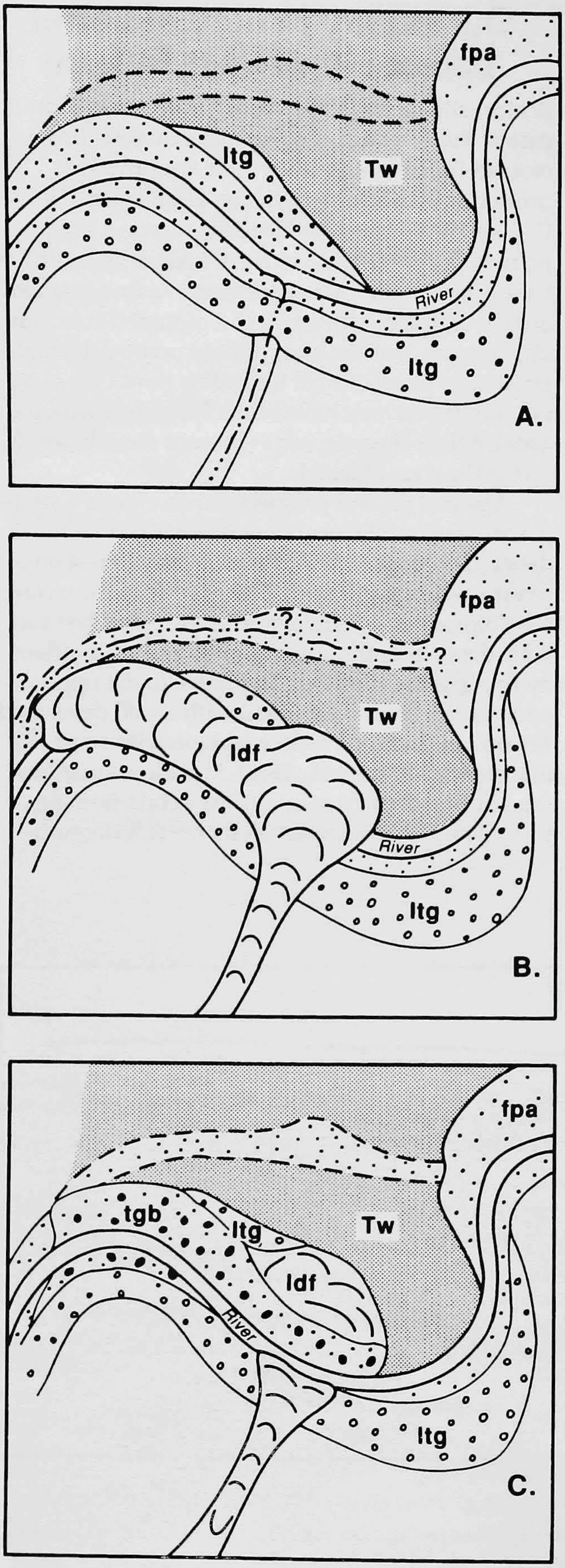


Figure 20. Sketch of stratigraphic section exposed in gravel pit and trench near Webster Hill, north of Colorado River (NW¼ sec. 28, T. 6 S., R. 94 W.). Section orientation shown on Figure 19. Not Drawn to scale.



EXPLANATION

fpa	Flood-plain alluvium
ltg	Lower main-stream terrace gravel
tgb	Basalt-boulder facies of lower terrace gravel
ldf	Lower debris-flow deposits, $\mathbf{ldf_1}$ is oldest
Tw	Wasatch Formation

Figure 21. Sketch of interpretation of events from stratigraphy exposed in gravel pit and trench, and field mapping. A) pre-debris flow landscape, river is entrenched several meters below terrace deposits (ltg). B) debris flow (ldf) flows into river, spilling onto part of terrace deposit north of river, then flows downstream in valley axis 0.5 km. Dashed lines outline possible(?) spillway location where part of river may have flowed. C) River has flushed out fine debris leaving boulders in tgb unit, and downcut to present level of stream.

that the river was entrenched below the terracelevel when the debris flow was deposited (Figure 21-*A*). The debris-flow materials contain large angular basalt boulders mixed with rounded river cobbles, all in a poorly sorted matrix; perhaps the latter were derived from the flood plain as the debris flow crossed the river. A lower main-stream terrace forms the edge of the point along the edge of the point along the river, and contains many large (2.5–3-m diameter) basalt boulders of debris flow origin (unit tgb). The boulders have been smoothed and rounded by the river, but have not had all their pedogenic(?) $CaCO_3$ coatings worn off (Figure 4), indicating that boulders deposited in the valley axis by the debris flow have not moved far from their original site of deposition. This natural rip-rap explains why the Colorado River is so narrow (40 m) at this locality.

The debris appears to have flowed onto the terrace north of the river during a major debris-flow event which poured millions of cubic meters of mud and rock into the river valley. As the debris became diluted with river water and lost much of its original viscosity and strength, it probably began to flow downstream in the valley below the terrace (Figure 21-B). The debris on the terrace was thus left stranded above the river. An east-west trending valley lies northeast of the gravel pit 54 m above the river, and is floored with thin patch deposits of river gravels veneered by loess. The valley could have been a spillway through which part of the river flowed during the time the main channel was obstructed by the debris-flow materials.

Eventually, the finer grained matrix of the obstructing debris in the river was flushed away, leaving behind large basalt boulders in the flood plain. These boulder-laden flood plain deposits are now preserved above the present river as the tgb terrace gravel facies (Figure 21-C).

Other interpretations of the Webster Hill locality are possible. The strong development of the buried soil beneath the debris flow suggests that the un-reworked debris flow resting on the terrace gravels may have been perched on the peninsula above the flood plain prior to a younger debris flow that entered the river, and now its only remains are the reworked basalt boulders of unit tgb. This means that the debris fan on the south bank of the river is not part of the one on the high point north of the river, suggesting that the latter debris is the remains of a much older event no longer preserved on the south side of the valley axis. A better understanding of the history of this locality must await more detailed soils, stratigraphic, and relative dating studies.

Regardless of the details, it appears that large debris flows that started on the middle and upper flanks of Battlement Mesa often reached the river and sometimes crossed it. The huge masses of debris, once set in motion, rarely stopped before reaching the lowest points in the landscape (Rodine and Johnson, 1976).

Chapter 4

Summary and Conclusions

The results of this surficial-mapping project suggest that debris flows are important geologic agents responsible for shaping the "mesa" landscape of the north slopes of Battlement Mesa. The gently sloping "mesa" surfaces, previously interpreted as pediments overlain by outwash gravels are, in fact, the surfaces of old debris-flow fans, which have been muted and smoothed through time (Figure 22).

Study and comparison with well-preserved younger debris flows in the present valley axis is the strongest evidence for the above interpretation of the older higher surfaces. The deposits and stratigraphic relations of younger debris-flow deposits mirrors that for the older "mesa"-forming flows.

A crude cyclicity of major debris-flow periods is suggested by the positions of debris-flow remnants on the present flanks of the valley. The surfaces of these individual flows cannot be correlated as the remains of a once continuous surface as was previously attempted, but do suggest cycles of debris-flow events with respect to former river positions. The cycles are probably related to a combination of geologic and climatic factors that periodically resulted in massive debris flows off the sides of Battlement Mesa.

Many levels of debris-flow deposits other than those present may have existed in the past. If there were others, it would suggest that the debris flows occurred more continuously in closer cycles, or that no cyclicity was involved. It is difficult to determine if there were any additional debris-flow levels because of the extensive landsliding and erosion that has occurred on the valley slopes.

Debris flows of the type above did not occur from the upper Roan Cliffs. There is no evidence that the incompetent, unnamed claystone unit was ever present here, and thus geologic conditions were not as conducive to massive debris flows. Also, the Roan Plateau is about 750 m lower in altitude than Battlement Mesa, and may not have experienced the same precipitation and climatic conditions which prevailed there in the past.

The constructional nature of the huge debris-flow deposits that created the sloping surfaces peripheral to Battlement Mesa urges caution in the use of these surfaces as time or river position indicators. The pre-debris flow landscape present when the surfaces were formed lives buried under 20 to 70 m of debris. Gradients of these constructional surfaces should not be used to project former river levels or rates of downcutting, because the gradients are more a function of the physics of high-density debris flowage, and often are not related to the underlying surfaces.

The former valley elevation at the time when an individual surface was formed more closely corresponds to the present position of the lower edge of that surface on the slopes of Battlement Mesa. If dates can be obtained for some of these debris-fan surfaces, accurate rates of Colorado River downcutting could be calculated using the elevations of buried main-stream terrace gravels within the debris-flow sequence.

Further detailed relative weathering studies are needed to more confidently determine ages of depositional units, and for correlation with other Quaternary deposits in the region. Future studies should include soil carbonate-horizon development, carbonate coating development on cobbles and boulders, surface-boulder weathering studies, and perhaps weathering rind studies on some types of basalt clasts found within the debris flows (Birkeland, 1974). An appendix describing field locations of soil profiles and key stratigraphic exposures useful in further studies is included, and these locations are plotted on the map.

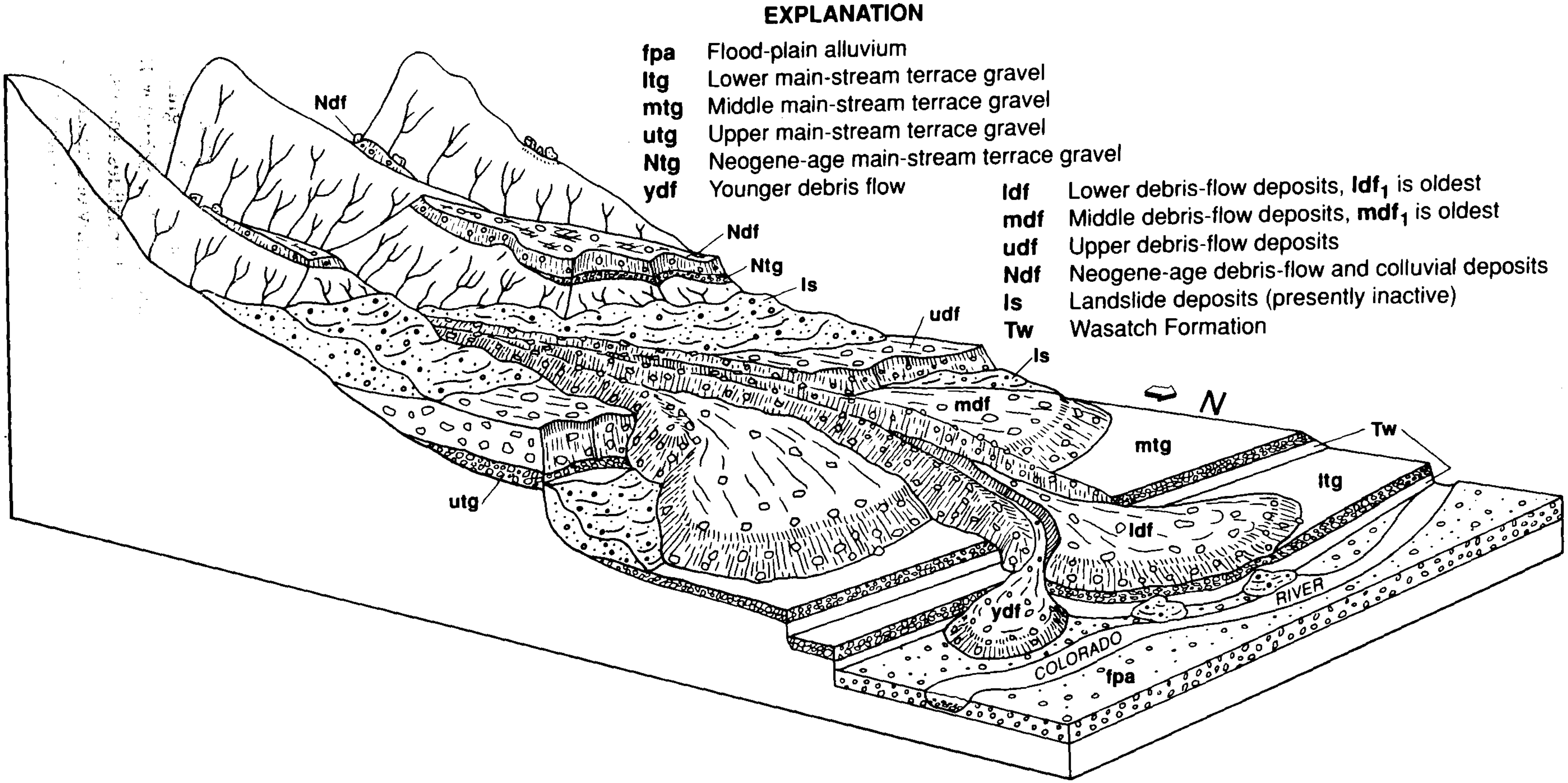


Figure 22. Idealized block diagram showing relationships among constructional and erosional landforms and the succession of debris-flow and alluvial deposits in the Colorado River valley area.

Selected References

Amuedo and Ivey Consultants, 1974, Preliminary engineering geology report, Buffalo Basin project, Garfield County, Colorado: Denver, Colo., Amuedo and Ivey Consultants unpublished report, job no. 7318.

Bagnold, R. A., 1954, Experiments on a gravity-free dispersion of large solid spheres in a Newtonian fluid under shear: London, Royal Society Proceedings, ser. A, v. 41, p. 49–63.

Birkeland, P. W., 1974, Pedology, weathering, and geomorphologic research: New York, Oxford University Press, 285 p.

Bradley, W. C., and Mears, A. I., 1980, Calculations of flows needed to transport coarse fraction of Boulder Creek alluvium at Boulder, Colorado: Geological Society of America Bulletin, pt. II, v. 91, p. 1057–1090.

Bradley, W. H., 1925, A contribution to the origin of the Green River Formation and its oil shale: American Association of Petroleum Geologists Bulletin, v. 9, no. 2, p. 247–262.

Donnell, J. R., 1961, Tertiary geology and oil-shale resources of the Piceance Creek basin between the Colorado and White Rivers, northwestern Colorado: U.S. Geological Survey Bulletin 1082-L, p. 835–891.

_____, 1969, Paleocene and Lower Eocene units in the southern part of the Piceance Creek basin, Colorado: U.S. Geological Survey Bulletin 1274-M, 18 p

Donnell, J. R., and Yeend, W. E., 1968a, Geologic map of the Rulison quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Map, scale 1:24,000.

_____, 1968b, Geologic map of the North Mamm Peak quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Map, scale 1:24,000.

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

Izett, G. A., and Wilcox, R. E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek ash beds (Pearlette Family ash beds) of Pliocene and Pleistocene age in the Western United States and southern Canada: U.S. Geological Survey Miscellaneous Investigations Map I-1325, scale 1:4,000,000.

Johnson, A. M., 1970, Physical processes in geology: San Francisco, Freeman and Cooper, 577 p.

Kirkham, R. M., 1980, Geotechnical evaluation of the proposed Rifle ski area: Boulder Colorado, Thorne Ecological Institute, unpublished report.

Larson, E. E., Ozima, M., and Bradley, W. C., 1975, Late Cenozoic basic volcanism in northwest Colorado and its implications concerning tectoniand origin of the Colorado River system, in Curtis, Bruce, ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoirs 144, p. 155–178.

Machette, M. N., 1982, Morphology, age, and rate of accumulation of pedogenic $CaCo_3$ in calcic soils and pedogenic calcretes of the southwestern United States (abs.): Geological Society of America, 78th Annual Meeting, Cordilleran Section Abstracts with Programs, v. 14, no. 4, p. 182–183.

Machette, M. N., and Steven, T. A., 1982, Geologic map of the northwest one-quarter of the Beaver 15-minute quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1445, scale 1:24,000.

Madole, R. F., 1982, Surficial geologic map of the Craig $1/2° \times 1°$ quadrangle, Moffat and Routt Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-1346, scale 1:100,000.

Piety, L. A., 1981, Relative dating of terrace deposits and tills in the Roaring Fork Valley, Colorado: Masters Thesis, University of Colorado, Boulder.

Porter, S. C., Pierce, K. L., and Hamilton, T. D., 1983, Late Wisconsin mountain glaciation in the western United States, in Porter, Stephen, ed., Late-Quaternary environments of the United States: University of Minnesota Press, p. 71–111.

Rib, H. T., and Liang, Ta, 1978, Recognition and identification (of landslides): in Schuster, R. L., and Krizek, R. J., eds., Landslides: analysis and control: National Academy of Sciences, Transportation Research Board, Special Report 176, p. 34–79.

Rodine, J. D., and Johnson, A. M., 1976, The ability of debris, heavily freighted with coarse clastic materials, to flow on gentle slopes: Sedimentology, v. 23, p. 213-234.

Scott, G. R., 1975, Reconnaissance geologic map of the Buena Vista quadrangle, Chaffee and Park Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-657, scale 1:62,500.

Sharpe, R. P., and Nobels, L. H., 1953, Mudflows of 1941 at Wrightwood, southern California: Geological Society of America Bulletin, v. 64, p. 547–560.

Tweto, Ogden, 1975, Laramide (Late cretaceous-Early Tertiary) orogeny in the Southern Rocky Mountains, in Curtis, Bruce, ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoirs 144, p. 1–44.

_____, 1979, Geologic map of Colorado: U.S. Geological Survey State Geologic Map, scale 1:500,000.

Tweto, Ogden, Moench, R. H., and Reed, J. C. Jr., 1978, Geologic map of the Leadville 1° x 2° quadrangle, northwest Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-999, scale 1:250,000.

U. S. Weather Bureau, 1982, Annual rainfall data, Rifle and Grand Mesa, Colorado.

Varnes, D. V., 1978, Slope movement types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides: analysis and control: National Academy of Sciences, Transportation Research Board, Special Report 176, p. 11–33.

Whitney, J. W., 1981, Surficial geologic map of the Grand Junction 1° x 2° quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1289, scale 1:250,000.

Yeend, W. E., 1969, Quaternary geology of the Grand and Battlement Mesas area, Colorado: U.S. Geological Survey Professional Paper 617, 50 p.