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1981, pp. 113-120. https://doi.org/10.56577/FFC-32.113

in:

Western Slope (Western Colorado), Epis, R. C.; Callender, J. F.; [eds.], New Mexico Geological Society 32 nd Annual Fall Field Conference Guidebook, 337 p. https://doi.org/10.56577/FFC-32

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GLACIAL MORAINES, TERRACES AND PEDIMENTS OF GRAND VALLEY, WESTERN COLORADO*

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INTRODUCTION

This paper discusses a set of late Pleistocene landforms in the Grand Valley of western Colorado (fig. 1). More detailed discussion is available in Sinnock (1978).

The Grand Valley is a broad lowland underlain by Mancos Shale and stretching from near Montrose, Colorado to Price, Utah. The floor of Grand Valley is ubiquitously characterized by multileveled pediments and/or terraces veneered with thin Pleistocene gravels. Within the study area, the Book Cliffs, Grand Mesa, West Elk Mountains, Black Canyon uplift, and San Juan Mountains form the northeastern boundary of the valley and the Uncompahgre Plateau gently rises from the southwestern edge of the valley. Locally the valley is the site of master drainage lines and associated glacial moraines and terraces; in other places only ephemeral drainage channels and associated pediments characterize the valley floor.

LATE PLEISTOCENE TILLS

Glacial moraines in the Ridgway Basin are the most useful chronologically determinative landforms in the study area. Three distinct

*Field activities were performed during the summers of 1976 and 1977 while the author was attending Purdue University. Preparation of this rnnni icrrint % A / c Clinnnrtrarl by thP I I nPrIA rtment of Fruargy

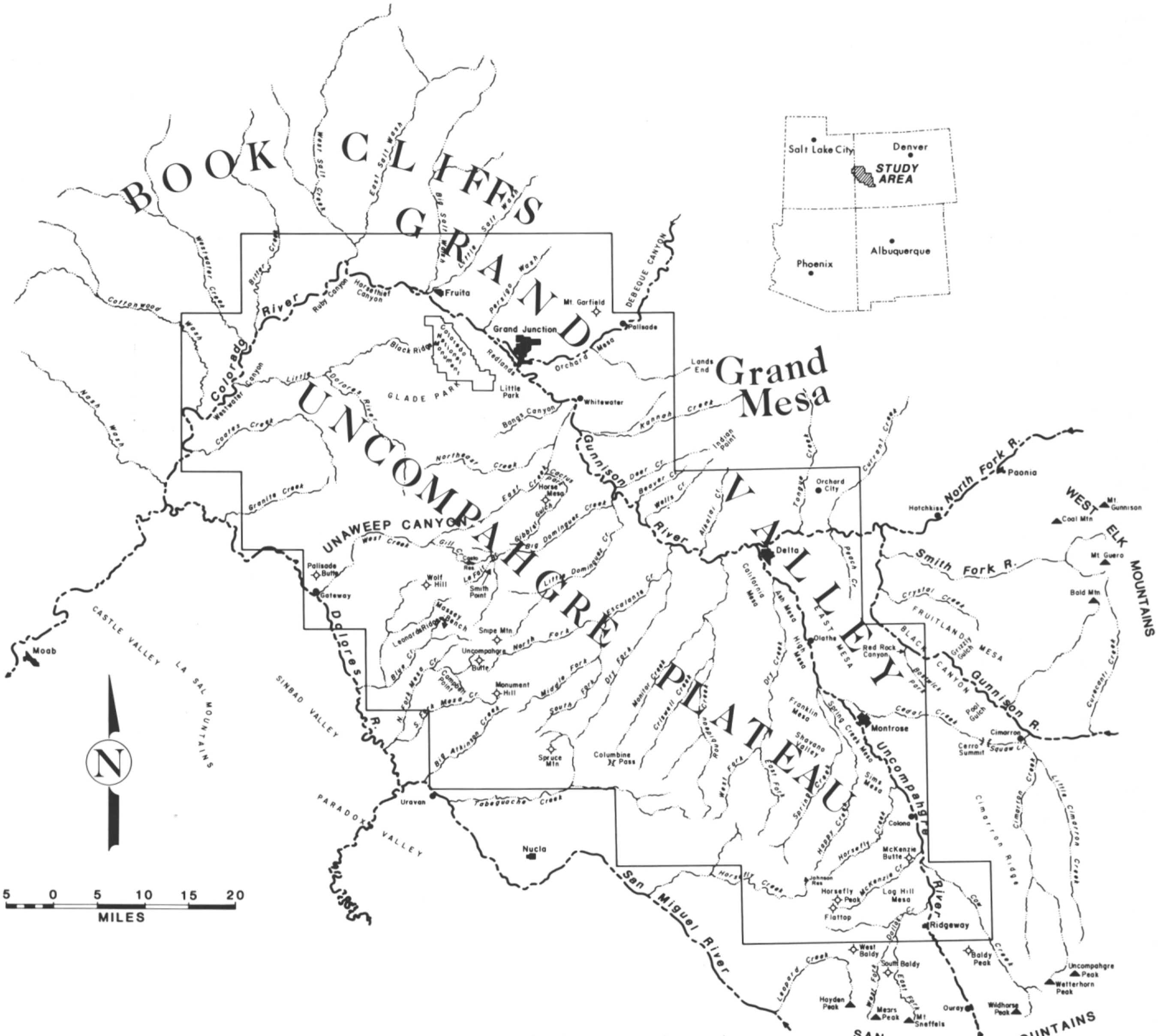


Figure 1. Geographic features in the study area.

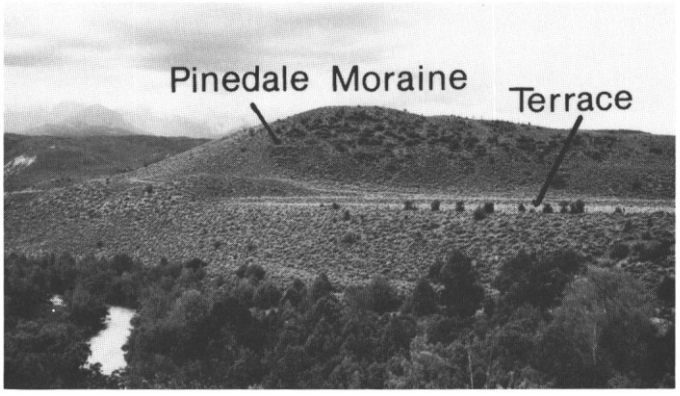


Figure 2. Youngest Pinedale moraine and associated terrace near Ridgway. View is south from SE ¼, Sec. 4, T.45N., R.8W.

and a fourth indistinct moraines are located north of the town of Ridgway. The two lowest, and presumably youngest, are located about one mile* north of town. Two higher and older morainal deposits terminate one to two miles farther north.

The younger two moraines are relatively undissected, possess hummocky topography, kettles, kames, and eskers, and sit 50 to 200 ft above the river (fig. 2). The youngest is a thin (50 to 100 ft), broad, rather flat belt of till that surrounds 200 ft-high hills of the next older moraine. Two correlative lateral moraines extend south from Ridgway along the slopes of Baldy Peak on the east side of the Uncompahgre Valley. The younger lateral moraine is "nested" within the older. However, the fact that the younger terminal moraine surrounds the base of the older and extends farther down the valley suggests that the last glacial advance breached the older moraine, perhaps during an ice surge. The thickness of the ice was probably less than during the previous advance because the top of the younger till deposits occurs at lower elevations than the older till. Similar dissection and weathering on the two young moraines suggests that they were deposited at about the same general time. Original depositional forms such as hummocky terrain, kettles, and so forth, do not occur on the older sets of moraines in the Ridgway Basin. These moraines are dissected by small streams and gullies and are significantly modified by mass wasting. The older moraines are 400 to 600 ft above the present river level and are difficult to distinguish from one another. A deposit mapped as outwash by Atwood and Mather (1932) caps a small hill one mile north of the largest deposit of the older till. Recent gravel-pit operations on the hill exposed an ice-contact mixture of till and outwash. This hill is therefore believed to represent the fourth and oldest moraine in the Ridgway Basin. A till deposit along the southeast edge of Log Hill Mesa on the Uncompahgre Plateau is thought to be a lateral moraine of this oldest till. No correlative lateral moraines have been identified upstream from Ridgway.

The Ridgway area tills were first described by Howe and Cross (1906) as a single suite of relatively recent moraines. Richmond (1954) mapped two Pinedale and two Bull Lake moraines along Dallas Creek, upstream from Ridgway. Tweto and others (1979) mapped all of the moraines near Ridgway as Bull Lake and Pinedale in age. Moraines in the Animas Valley near Durango were formed by glaciers flowing southward from the same ice caps above Ridgway. These till assemblages have been correlated (Richmond, 1965) with Pinedale, Bull Lake and the Sacagawea Ridge glaciations of the Wind River Mountains in Wyoming (Blackwelder, 1915; Holmes and Moss, 1955; and Richmond, 1948). Atwood and Mather (1932) also believed that three major glacial episodes are recorded in the tills around the San Juan Mountains. They mapped the resultant deposits, from youngest to oldest, as "Wisconsin," "Durango," and "Cerro" tills. Atwood and Mather's (1932) map shows both the Pinedale and Bull Lake moraines of Richmond (1965) in the Durango area as Wisconsin age and his Sacagawea Ridge moraine as Durango age. At Ridgway, Atwood and Mather mapped the two youngest tills as Wisconsin and the two older as Durango.

Thus, it is fairly certain that the moraines of the Ridgway Basin are Pinedale and Bull Lake deposits. The two freshest represent two separate Pinedale advances; the older two, Bull Lake advances.

PRE-BULL LAKE TILL

Another much older set of till deposits occurs on Horsefly Peak, Flat Top, West Baldy and South Baldy along a line from the San Juan Mountains to Horsefly Peak and along the flank of Cimarron Ridge in the Cerro Summit area. Howe and Cross (1906) described the deposit at Horsefly Peak and noted the absence of quartzites, paucity of San Juan Tuff breccias, and abundance of Potosi and Hinsdale volcanic clasts. Exposures of Hinsdale basalt presently are absent in drainage basins of the western San Juan Mountains. The Potosi Series is a thin, narrow ridge former, almost completely eroded from the region. San Juan Tuff currently comprises the greatest area of surface exposure in the Mt. Sneffels region. Howe and Cross concluded, and I concur, that the till on Horsefly Peak was deposited when most slopes of the San Juan Mountains were formed on volcanic units now absent or significantly reduced in surface area.

Atwood and Mather (1915) named this deposit the Cerro Till and later (1932) cited Hills (1884) as first recognizing its glacial origin. This interpretation seemed generally acceptable until Dickinson (1965a, 1965b) concluded that the Cerro till at this type locality at Cerro Summit was landslide debris. At about the same time Mather and Wengerd (1965) described massive Bull Lake-age landslide deposits in the Ridgway area. However, agatized rhyolite, granite, and basalt clasts occur at the surface throughout the region mapped as landslide by Dickinson. These same clasts, especially agatized rhyolite and basalt, are abundant at Horsefly Peak. Certainly the northern and western slopes of Cimarron Ridge (the Cerro Summit region) have wasted by downhill slumping, sliding and argilliturbatonal creep, but the material that is landsliding is mostly till.

Because of confusion surrounding the name "Cerro Till," I herein informally refer to the deposit as the Horsefly Peak Till. It is the only till of pre-Bull Lake age noted in the study area. At Cerro Summit, it occurs about 1,000 ft above the lowest nearby graded pediments. At Horsefly Peak, it is about 3,000 ft above the Ridgway Basin and rests on a fault-produced ridge probably formed after deposition of the till. Richmond (1965) mapped glacial deposits only 300 to 350 ft above the Animas River near Durango as Sacagawea Ridge age. Topographic form and weathering characteristics of the "Sacagawea Ridge" moraines resemble in many respects morainal material near Ridgway considered herein as Bull Lake. However, if Richmond's age assignments near Durango are correct, the older moraines in the Ridgway basin may be as old as Sacagawea Ridge age, making the Horsefly Peak Till at least as old as Cedar Ridge events in the Wind River Mountains. Descriptions of the Sherwin Till (Blackwelder, 1931) on the east flank of the

*English units of measurement are used throughout this paper because the source data from topographic maps are so expressed.

Sierra Nevada indicate similarity between the Sherwin and Horsefly Peak tills. Both are found on upland surfaces, deeply weathered, sparsely strewn with very large boulders, and considerably more extensive than younger, in-valley tills. The Bishop Tuff which overlies the Sherwin Till has been dated as 0.7 m.y. old (Dalrymple and others, 1965). If the Horsefly Peak Till correlates with the Sherwin, it is probably older than the Sacagawea Ridge, supporting correlation with Cedar Ridge glaciation. If true, and if the older moraines in Ridgway Basin are Bull Lake, then moraines of Sacagawea Ridge age are absent from the northwest flank of the San Juan Mountains.

This discussion indicates some. uncertainty concerning stratigraphic correlation of Pleistocene events in the Rocky Mountain region. However, a set of relative age relationships in the northwest San Juan Mountains is evident: four "younger" in-valley tills and associated outwash terraces and at least one "older," upland till occur. All "younger" tills are about the same general order of magnitude in terms of moraine size, vertical separation, and downvalley extent. The Horsefly Peak Till, on the other hand, is quite different from the younger tills in all these respects. It is vertically separated from the other tills by thousands rather than hundreds of feet and covers broad areas, suggesting piedmont glaciation.

TERRACES

Each glacial advance produced an outwash train of downstream terraces. Near Montrose four distinct terrace levels are apparent. These terraces merge with similar terraces along the Gunnison and farther, with those along the Colorado River. The terraces thus correlate with Pinedale and Bull Lake glacial events.

The Uncompahgre River flows northward from the moraines near Ridgway and enters a small canyon entrenched through the southeastern tip of the Uncompahgre Plateau at McKenzie Butte, a dome formed around an intrusive dike. Near the town of Colona, Grand Valley heads and rapidly expands to nearly 12 mi in width, a dimension maintained for about 80 mi in a downstream direction. From Colona to Delta the Uncompahgre River flows along the approximate center of the valley. Outwash terraces from the glacial moraines of Ridgway form broad mesas (Sims, High, Spring Creek, Ash, and California) that rise southwestward from the river as four steps, the uppermost lapping onto the flank of the Uncompahgre Plateau. Terrace gradients parallel the northwest trend of the valley (fig. 3), and their surfaces comprise one of the largest irrigated row crop regions in western Colorado.

The four terrace levels are easily recognized between Delta and the moraines. Near the moraines, they are separated by sharp 100 to 150 ft-high interterrace scarps. The terraces merge toward Delta, where they are only about 50 to 75 ft apart, a separation generally maintained downstream along the Gunnison and Colorado rivers to Moab and perhaps beyond. The lowest terrace merges with the present floodplain of the Uncompahgre River near Olathe. From Colona to Delta converging terrace gradients average about 50 ft per mile; from Delta to Grand Junction, they slightly diverge and slope about 5 to 10 ft per mile.

Terrace surfaces are generally underlain by a layer of fine-grained, windblown or slackwater deposits resting on coarse-grained fluvial sand and gravels, which, in turn, rest on Mancos Shale and older rocks. The uppermost, fine-grained deposits are absent in some places. In others, they are overlain by slopewash, fan or pediment deposits. Along the Uncompahgre River, the terrace gravels and cobbles are entirely comprised of San Juan Mountain-provenance volcanic, carbonate and quartzite clasts. Rounding of originally joint-controlled triclinic forms toward triaxial indicatrices generally occurs in a downstream direction along with size diminution of the clasts. Downstream from Delta, terrace

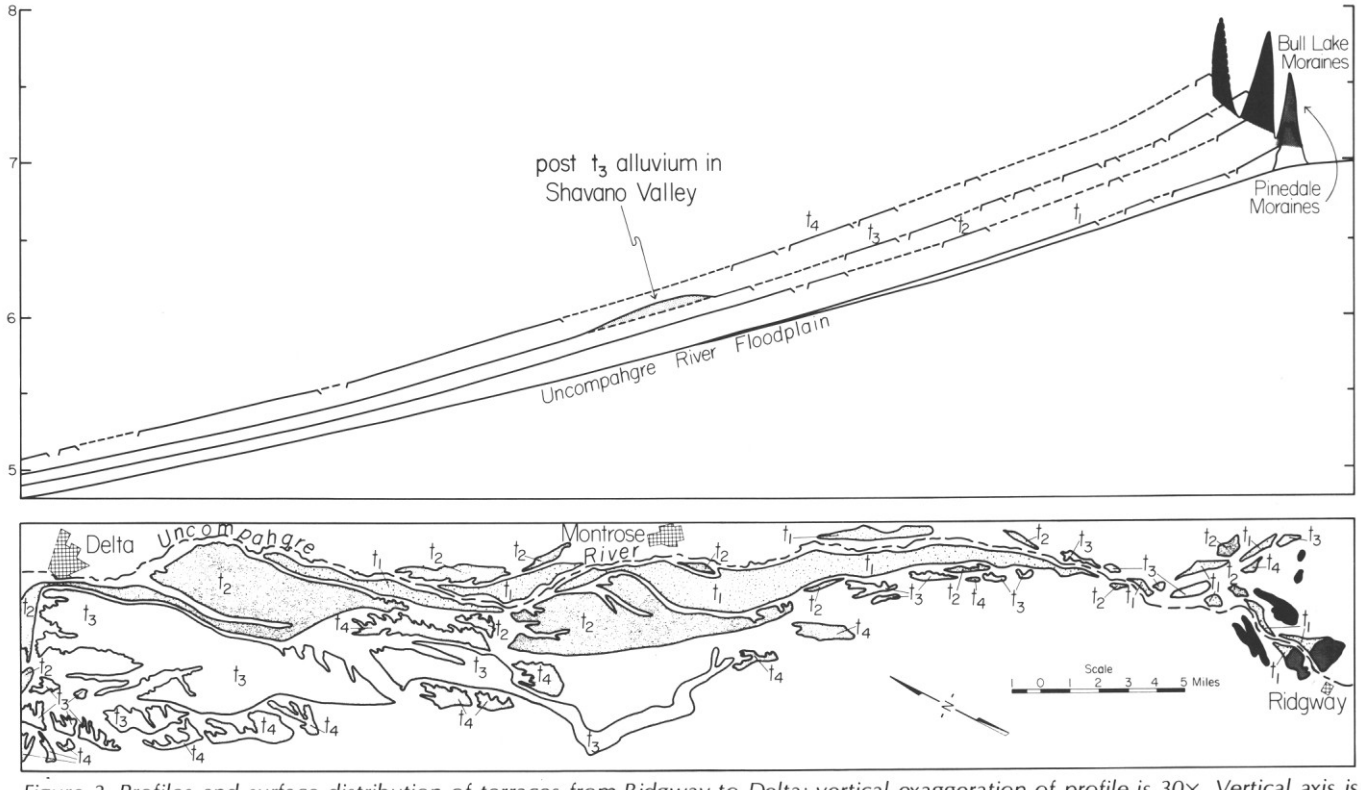


Figure 3. Profiles and surface distribution of terraces from Ridgway to Delta; vertical exaggeration of profile is 30×. Vertical axis is elevation in thousands of feet.

gravels include more varied rock types from the headwaters of the Gunnison and North Fork Rivers. Thickness of terrace deposits ranges from about 2 to 30 ft along the Uncompahgre River.

Terraces and pediments similar to those along the main trend of Grand Valley occur in a large embayment extending up the Gunnison and its North Fork from Delta to Paonia.

Below Delta the Gunnison flows east, out of the center of Grand Valley, and cuts into the flank of the Uncompahgre Plateau. There it bends back to the northeast and enters a canyon 600 to 800 ft deep along the lower slopes of the plateau. Scattered patches of terrace remnants are perched on the canyon walls throughout the canyon. The river emerges at Whitewater before reoccupying a smaller canyon for about five more miles downstream. Where the Gunnison reemerges into the Grand Valley, it joins the Colorado River, which flows into the study area from the northeast.

In the apex of the confluence broad outwash terraces again are found and join terraces entering the area along the southeast side of the Colorado River. South of the confluence, the terraces lap onto the plateau's dipping flank (fig. 4) in a manner similar to those between Delta and Colona. Along the Colorado National Monument fault zone, the terraces sharply truncate drag folds below the fault scarp (fig. 5) and comprise the Redlands region near Grand Junction.

On the right bank of the Colorado near Grand Junction, a 2.5 mi-wide, very flat, undissected slip-off plain slopes gradually toward the river. The river hugs the southern edge of this broad lowland where it flows at the base of an 80 ft-high cliff separating the river 'rom the first terrace level. The towns of Grand Junction and Fruita are sited on this low, sloping plain. Along with the terraces, this area comprises another major irrigated region in Grand Valley. Four miles west of Fruita, the Colorado crosses the northwest extension of the Monument uplift zone and occupies a canyon entrenched 1,000 ft below walls capped with Dakota Sandstone. As along the canyon of the Gunnison River between Delta and Whitewater, isolated terrace patches occur on the canyon walls (fig. 6). The valley terraces have long been recognized. Nelson and (olbe (1910) mapped the soils of the terraces along the Uncom-)ahgre Valley as the Mesa Series. From geologists' perspectives Atwood and Mather (1932) described and mapped the terraces as)utwash trains from Wisconsin through Cerro glacial episodes. (nobel and others (1955) mapped the Mesa, Hinman, and Genola

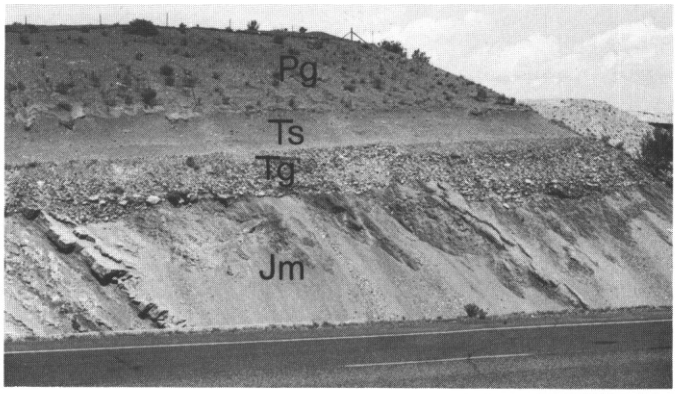


Figure 5. Terrace sands (Ts) and gravels (Tg) truncating tilted Jurassic sandstones and shales (Jm) and overlain by pediment gravels (Pg) derived from the Colorado National Monument. View is northwest from CO-340 south of Fruita.

;oil series near Grand Junction and described them as derived terace material from old river alluvium. Lohman (1965) recognized and briefly mentioned the terraces in the Redlands but chose not to include surficial deposits on his geologic map of the Grand Junction area. Tweto and others (1979) mapped the terraces throughout Grand Valley as Pinedale and Bull Lake age alluvium.

Terrace outwash associated with the Horsefly Peak Till occurs throughout the uplands of the Uncompahgre Plateau northwest of Horsefly Peak. Old outwash gravels occur at Columbine Pass, in the headwaters of Dry Creek and Roubideau Creek and in Cactus Park (Cater, 1965; Lohman, 1961). All these deposits are interpreted as remnants, perhaps reworked, of an outwash train associated with the Horsefly Peak Till. Their origin is discussed in more detail in the companion paper of this guidebook (Sinnock, this guidebook).

Howe and Cross (1906) first recognized the gravel deposits on the uplands of the Uncompahgre Plateau and thought they were outliers of the Horsefly Peak Till. Atwood and Mather (1932) agreed. Hunt (1969) interpreted the Horsefly Peak Till and associated outwash gravels as Miocene-age fluvial gravels. Richmond (1965) described the Bridgetimber, Bayfield and Oxford gravels of Atwood and Mather (1932) as evidence of very early glaciations in the San Juan Mountains. Marshall (1959), Williams (1964), and Tweto and others (1979) mapped them as Mancos Shale. Cater (1965) and Lohman (1961) interpret the gravels in Cactus Park as reworked Plio-Pleistocene gravels of the Gunnison River.

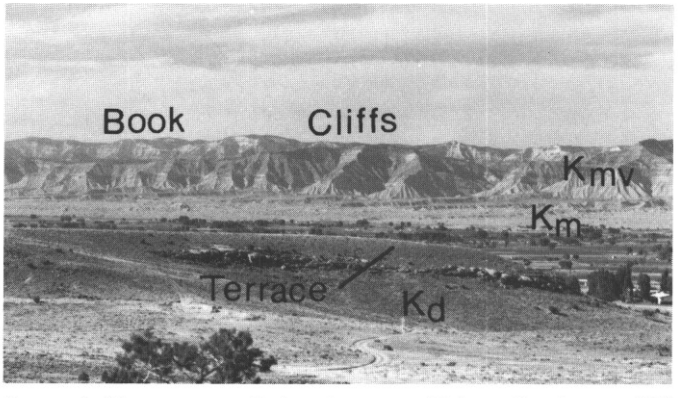


Figure 4. Terrace gravels lapping onto Dakota Sandstone (Kd) along the lower flank of the Uncompahgre Plateau near Grand Junction. Note pediments at the base of the Book Cliffs. View is northwest from SE ¼, Sec. 18, T.15N., R.1W.

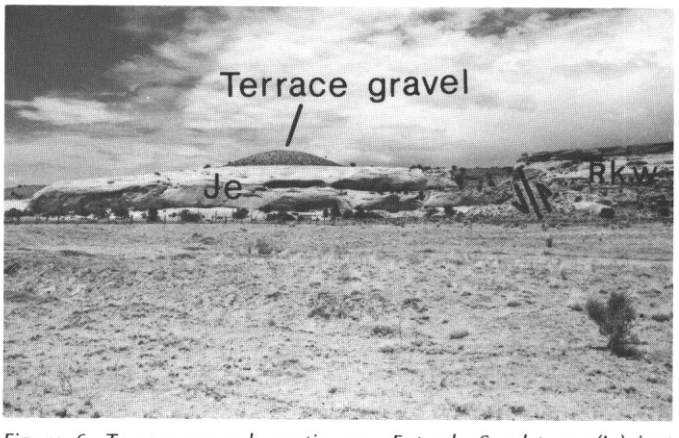


Figure 6. Terrace gravels resting on Entrada Sandstone (Je) just south of Westwater Canyon. Rkw is Triassic Kayenta and Wingate formations. View is northwest in NE¼, Sec. 36, T.21S., R.24E.

Terrace Genesis

The terraces between Ridgway and Fruita correlate with glacial episodes in the San Juan Mountains. The two older terraces and pediments are Bull Lake age, the two younger are Pinedale. Yeend (1969) maps and assigns identical ages to terraces and pediments along the Colorado River Valley upstream from De Beque Canyon. Local variations of glacial behavior make resulting terrace and pediment sequences difficult to correlate among the headwater regions of glacial valleys in the Southern Rocky Mountains, but those along the master streams are buffered from the effects of these variations and permit a glimpse at the nature of regional, fluvio-glacial events.

Homoclinal migration of master drainage inherited from pre-Bull Lake time (Sinnock, this guidebook) continued into the late Pleistocene. Episodic glacio-fluvial regime changes superposed their effects on this continuing landform evolution. The result created a situation ideal for preservation of terraces along the Uncompahgre River.

At the outbreak of late Pleistocene glaciation, the Uncompahgre River was at the present position of the highest terrace (see Figure 11, companion Sinnock paper). Thereupon commenced a sequence of events similar to those outlined by Richmond (1962) for terrace formation during glacial cycles.

As the climate cooled, precipitation in the highlands increased but did not yet form ice. Desert valleys remained dry, but master streams swelled and the rivers incised. As ice began to form in the highlands, frost-riving and other periglacial phenomena increased sediment production. Streams were required to carry greater loads and began to spread out as anastamosing channels and alluviate the valleys, forming the terrace deposits. Blocked by the 2° dip slope of the Uncompahgre Plateau to the southwest, the widening terraces spread to the northeast on low, pediment slopes graded to the river. This tended to block the river's return to its former position. The permeable gravels deposited in the wake of the shifting river tended to absorb enough of the river's flow to cause additional sediment to be dropped, nudging the river to continue migrating northeastward onto lowermost pediment slopes.

At glacial maxima, end moraines formed and a general equilibrium obtained whereby neither significant erosion nor alluviation occurred along the terraces, though both sediment load and runoff were at their greatest levels during the glacial maxima. The river maintained its position along the northeast edge of the newly formed outwash plain. During the retreating phases of glacial pulses, discharge decreased, exposing more sandbars. Loess deposits and sand dunes formed upon the terrace surfaces. At glacial minima, equilibrium between sediment supply and transport capacity again obtained but along a meandering stream with attendant slackwater areas which locally deposited finer grained fluvial sands upon the coarser terrace gravels. Major incision awaited readvance of the ice, which is consistent with the fact that the elevation difference between the merging lowest terrace and present floodplain is small even near the moraines. The merger of the low terrace with floodplain along the Uncompahgre River also may be due in part to retarded incision rates of the Gunnison River where it encounters the Precambrian surface in the middle part of its canyon along the plateau flank.

Incision attendant with glacial cycles lowered the floodplain and created the elevated terraces southwest of the river. Incision passed through the outwash gravels and into the underlying Mancos Shale. If the Dakota Sandstone were encountered during incision, the river shifted northeast along the resistant sandstone surface. However, perhaps by coincidence, the ratio of the width of the terraces to interterrace vertical separation is approximately equal to the cotangent of the angle of structural dip. Hence, incision during each episode returned the riverbed almost exactly to the level of the Dakota-Mancos contact.

Between Delta and Whitewater, remnants of all four terraces are found within the Gunnison Canyon, demonstrating that this canyon began forming before the first advance of late Pleistocene glaciers. Similar terrace deposits indicate pre-glacial incision along Horsethief-Ruby-Westwater Canyon of the Colorado River.

Terraces near Grand Junction tell a slightly different story of late-Pleistocene river wanderings. The Colorado River, in contrast to the Uncompahgre River, did not significantly change its geographic position in the Grand Junction area throughout the Pleistocene. It maintained its position and general elevation during early uplift of the Uncompahgre Plateau, but only its position during and after the final uplift phases. Another difference is that the Colorado River flowed (and flows) almost normal to strike, and sustained lateral migration upon a resistant stratigraphic horizon could not occur. Therefore, lateral movement of the river tended to be oscillatory rather than directional. The relations between the terraces and slip-off plain from Palisade to Fruita support this inference.

The higher terraces along this stretch are reduced to very small patches. Remnants of the higher terraces are restricted to a band about one mile wide south of the lowest terrace. Only the lowest terrace occupies significant area. It follows the river on the southeast between Palisade and Grand Junction, and on the southwest between Grand Junction and Fruita. Two levels of slip-off plain extend along the north side of the river as distinct belts, each about 2.5 mi wide. Although the upper one is highly dissected by small arroyos, its boundaries are clear. Thus, the slip-off slopes rather than the terraces form the broad expanse of late Pleistocene surfaces in the Grand Junction area.

This situation was caused by geographic oscillation of the Colorado River at the same time that the four broad terraces formed near Montrose as the Uncompahgre River migrated northeastward. The Colorado River deposited outwash on its valley floor during glacial advances and migrated northward onto the lower reaches of pediments below the Book Cliffs in a manner similar to that described for the Uncompahgre River. This forced the river northward as it emerged from De Beque Canyon. Because no stratigraphic surface disposed continued migration in a northward direction after alluviation ceased, the river returned to its former course during incision by sliding back toward the south, cannibalizing its own terrace deposits and shaving into the Mancos Shale. The net result is a suite of small, uncannibalized terrace patches south of the river and gentle, riverward sloping slip-off surfaces on Mancos Shale north of the river. Because incisional slip-off commenced from the northern edges of the terraces, elevations at the upper parts of the slip-off slopes match the terrace elevations south of the river. Current incision by the Colorado River has not completely cannibalized the lowest terrace, so a broad remnant remains northeast of the river. Earlier terraces were almost completely consumed, thus their widths are diminished to very narrow bands.

Near Montrose the second terrace level above the river is about one and one-half to two times as wide as the first. Near Grand Junction, the upper slip-off plain extends twice the distance from the Colorado River as the lower. This suggests that the second terrace near Grand Junction was originally about twice as wide as the first. Therefore, it is reasoned that the first Pinedale glacial advance was more intense than the second, an inference supported by the

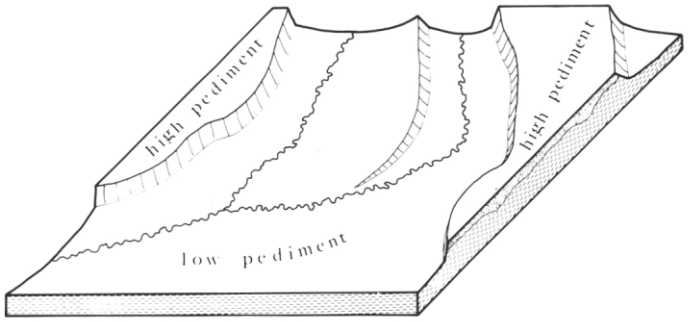


Figure 7. Schematic diagram demonstrating how scarp may separate parts of the same (low) pediment level and be as high as interpediment scarps separating pediments (high and low) of different ages.

relative sizes of the two Pinedale moraines in Ridgway Basin. BE cause the relationship among terrace widths is similar along botl the Colorado River and Uncompahgre River, the relative intensit of separate Pinedale advances was probably regional, at least ii the Southern Rocky Mountains.

PEDIMENTS

Four pediment levels occur northwest of the rivers in Graft Valley and are counterparts to the four valley terraces. Local ferences in pediment elevations make precise correlations chi ficult. For example, pediments may form simultaneously along stream and one of its tributaries (fig. 7). If pedimentation consume the uplands between the streams, separate pediments graded ti the same level will meet along a divide separating the two streams. If one stream is closer to the divide than the other, an it terpediment scarp will separate the two correlative pediment! Such a scarp may be almost as high as one which separates ped ments formed during two separate epochs. Conversely, two ped ments of different ages may have the same general elevation. Not withstanding, the overall association of four major pediment level with the four terrace levels is evident. The lowest and still activ pediment merges locally with the lowest terrace and floodplair Higher pediment surfaces merge with the elevations of corrE sponding terraces (fig. 8).

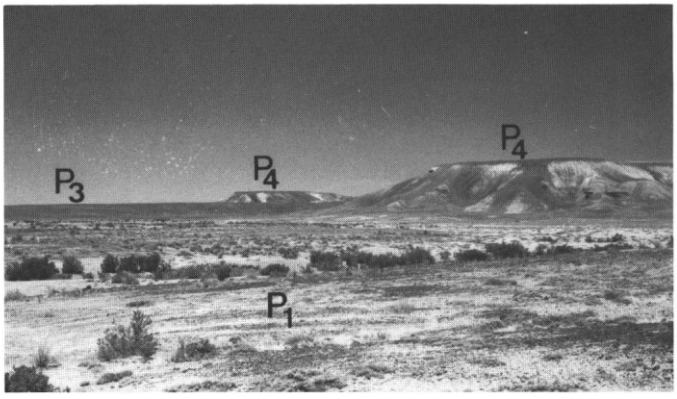


Figure 9. Pediments between Delta and Whitewater; dark layer of basalt gravel caps higher pediments. Lower pediment (P_1) has no gravel cap. View is northwest from NE ¼, Sec. 36, T.4S., R.97W.

From Delta to Colona the cliffs along the northeastern side of Uncompahgre River Valley are capped by Mesozoic shales and sandstones and possess no source rocks amenable to survival as pediment gravel deposits. Therefore, pediment gravel veneers are thin or absent and Mancos Shale generally forms the pediment surfaces. Remnants of older pediments are reduced to narrow ridge crests, many of which have been eroded below their original levels, yielding extensive badland terrain devoid of old pediment surfaces. The lowest pediment near Montrose grades to the floodplain or lowest terrace of the Uncompahgre River and creates an extensive lowland known as East Mesa. At the south end of Grand Valley near Colona, a few high-level pediments are well preserved where they are capped with a protecting gravel derived from volcanic rocks of Cimarron Ridge.

Between Delta and Grand Junction the upper pediments slope toward the river from the southern flank of Grand Mesa as wide, smooth, concave surfaces (figs. 9, 10). Pediment surfaces are commonly capped with a layer of permeable gravels composed of poorly sorted clay to boulder-sized deposits about 0 to 40 ft thick. Basalt clasts derived from Grand Mesa are sub-angular to well-rounded and range from about one inch to three feet in diameter. Pediments in Grand Valley are generally best preserved where

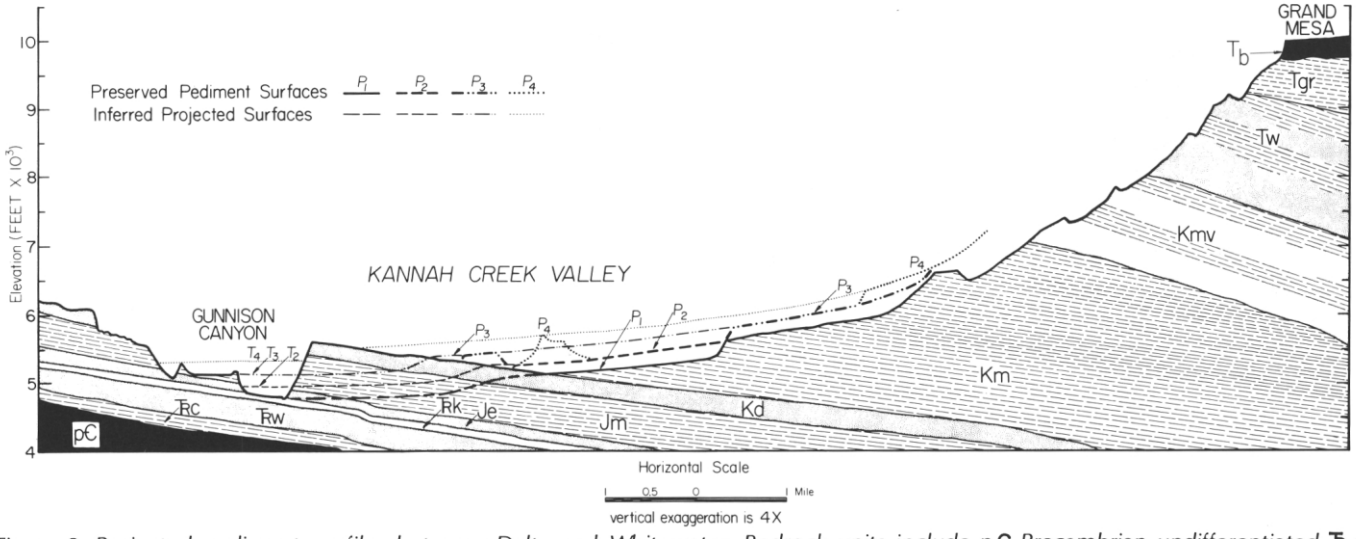


Figure 8. Projected pediment profiles between Delta and Whitewater. Bedrock units include p€ Precambrian undifferentiated, Rc Chinle, Rw Wingate, Rk Kayenta, Je Entrada, Jm Morrison, Kd Dakota, Km Mancos, Kmv Mesaverde, Tw Wasatch, Tgr Green River, and Tb Tertiary basalts.



Figure 10. Pediments at the base of Grand Mesa. View is north from NW ¼, Sec. 23, T.3S., R.2E.

such permeable, thick deposits mantle their surfaces, causing local inversions of topography during successive periods of pedimentation.

The lowest pediment possesses no basalt-gravel cover. It forms a strike valley nestled at the contact between the Dakota Sandstone and Mancos Shale and grades topographically and stratigraphically upward into the lower slopes of Grand Mesa. The strike valley is two to three miles northeast of, parallel to, and perched 200 to 300 ft above the Gunnison River where it is entrenched into the flank of the Uncompahgre Plateau. Wells, Beaver, Deer, and Kannah creeks drain the lower pediment along short, steep ravines that breach the canyon wall. A small cuesta formed by the Ferron Sandstone Member of the Mancos Shale rises 50 ft above the surrounding pediment, bifurcating it into a pair of parallel, strike valleys graded to the same level. Near Delta and Whitewater, the lower pediment merges along strike with the Gunnison floodplain. Northwest of Kannah Creek, the pediments swing around the Lands End promontory of Grand Mesa, eventually grading toward terraces along the southeast side of the Colorado River downstream from De Beque Canyon.

Northwest of the river, pediments occur between the Book Cliffs and the slip-off plain at Grand Junction and are poorly preserved. Badlands in Mancos Shale dominate the landscape. The badlands and dissected pediments commence abruptly at the base of the Book Cliffs and grade to the slip-off slope where they are equally abruptly truncated at their lower ends. For about five to eight miles northeast from Mt. Garfield, the Book Cliffs are very smooth and conspicuously devoid of deep serration by obsequent streams. Incision by the streams increases to the northwest, together with better preservation of higher pediments. Northeast of Fruita, the upper pediments are well preserved, although extensive badland areas still occur (fig. 4). This pattern continues essentially unchanged as the valley and bounding Book Cliffs swing to the southwest around the northwestern end of Uncompahgre Plateau and out of the study area. The pediment terrain drains south to the river along ephemeral streams which breach the rim of Westwater Canyon, a situation analogous to that between Whitewater and Delta.

The pediments in Grand Valley have not been so clearly recognized as distinct landforms as have the terraces. Because they generally are not used for irrigated row crops, soils mapping in Grand Valley has not included much of the pedimented terrain. Yeend (1969) concluded that pediments west of Grand Mesa were either terraces or low lying moraines. Tweto and others (1979) map the pediments as pre-Bull Lake surficial deposits of unspecified origin.

Pediment Genesis

Pediments flanking Grand Mesa indicate an alluviation-incision cycle similar to that of the terraces. Grand Mesa was covered by an ice carapace during four late Pleistocene events correlated with two Bull Lake and two Pinedale episodes (Yeend, 1969). Meltwater flowed from Grand Mesa to the Gunnison River along many pedimented washes in Grand Valley. Clasts from the basalt cap of Grand Mesa were mixed with meltwater and detritus from underlying shales and sandstones to form a muddy slurry of clays, sand, gravel, and large basalt boulders. This slurry oozed down the slopes of Grand Mesa and onto the pediments as pro-glacial mudflows forming the deposits that mantle all but the lowest pediment. Local depressions on the pediment surfaces suggest that ice blocks were incorporated in the slowly moving slurries, which upon melting created small kettle-like depressions.

During both the major rivers' incisional phase and interglacial times, the lowest pediment eroded headward along the washes graded to the rivers. Because pediment development occurred during inter-glacial conditions, no large mudflow deposits were supplied to the headward-expanding pediments. During subsequent glacial conditions, the mudflow deposits accumulated upon the pedimented surfaces. This accounts for the absence of mudflow deposits on the lowest pediment surface which is veneered only with sand and a very thin layer of small broken basalt cobbles derived from the mudflow deposits on older pediments.

Near Montrose and Grand Junction, no mudflow deposits comparable to those below Grand Mesa occur on the upper pediments because no glaciers or resistant caprocks existed in headwater regions. In these regions, pedimentation probably has occurred continuously throughout the late Pleistocene and perhaps earlier. Incisional episodes along the master streams formed pediment knickpoints that migrated headward by processes described by Bryan (1932, 1940). Thus, the graded pediment levels simultaneously migrated headward. This generally creates a situation whereby older pediments occur near the cliffs and younger pediments near the master stream.

CONCLUSION

A distinct set of landforms composed of river terraces and cliff-flanking pediments characterizes the floor of Grand Valley from Colona to Fruita. The terraces form four separate levels that generally rise toward the lower slopes of the Uncompahgre Plateau, whereas the correlative four pediments are dispersed throughout the lowlands at the base of the Book Cliffs, Grand Mesa, Black Canyon uplift and Cimarron Ridge. The four levels correspond, from oldest to youngest, to two separate glacial advances during each of Bull Lake and Pinedale times. The degree of preservation of the terrace and pediment forms is directly related to the infiltration capacity of the gravels veneering their surfaces. When the gravels are at least in part derived from headwater igneous or metamorphic terrain, the resulting deposits predispose the forms to preservation, contrary to those surfaces veneered with thin gravels derived from sedimentary rocks. The general northeastward migration of the landform assemblage (terraces, river, pediments, and cliffs from southwest to northeast) contributed to conditions which facilitated the formation and preservation of the four terraces and associated pediments.

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