DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 95

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

1915

DAVID WHITE, CHIEF GEOLOGIST

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

EOCENE GLACIAL DEPOSITS IN SOUTHWESTERN COLORADO.

By Wallace W. Atwood.

INTRODUCTION.

At the northwest base of the San Juan Mountains, not far from the village of Ridgway, Colo., there is a series of exposures that include a remarkable section of glacial till, which is overlain by formations of early Tertiary age. These exposures were found in September, 1913, while I was conducting an areal geologic survey of the southwest quarter of the Montrose quadrangle. The areal work was being done with a class of advanced students from the University of Chicago, and credit for collecting many of the data presented in this report is due to these able and enthusiastic young men. The party consisted of Messrs. F. B. Plummer, Frank Selfridge, W. J. Coleman, H. R. Bennett, M. M. Leighton, Walter R. Miller, L. E. Wells, Lloyd Le Duc, and V. L. Wooten. Messrs. Bennett and Miller first located what is now referred to as the type section, and they, with Mr. Le Duc, were with me when the material was first recognized to be of glacial origin and to be buried beneath Tertiary formations. Mr. Kirtley F. Mather, who is assisting me in the physiographic survey of the San Juan district, also aided in working out the characteristics and age of these glacial deposits.

After the completion of the work with the student party physiographic studies were continued in this area under the auspices of the United States Geological Survey, and at the close of the season Mr. Whitman Cross joined me and critically examined several of the best sections. I feel especially indebted to Mr. Cross for his very careful analysis of the available field data and for his judgment that the overlying Tertiary formations, with which he is so familiar, have been correctly recognized.

PHYSICAL GEOGRAPHY.

The area within which these early Tertiary glacial deposits have been found is in the foothill belt at the northwest base of the mountains, in the same region where three distinct stages of Pleistocene glaciation among the mountains were demonstrated in 1912.[1]

At the south margin of this area are the precipitous slopes of the high mountains. Many of the summits rise to altitudes of over 13,000 feet, and Sneffels Peak, the highest peak in this mountain front, attains 14,148 feet. At the north is a bold escarpment, bounding the southern face of the Uncompahgre Plateau. To the west are Hastings Mesa and Howard Flats, both of which are broad, flat-topped areas somewhat below the level of the Uncompahgre Plateau, and far below the mountain summits to the south. The valley of Dallas Creek and its tributaries occupies the central portion of the area, and the dissection of this area by these streams has developed a topography of late maturity and uncovered many of the exposures to be described in detail in this paper. The conspicuous topographic features in the central portion of the area, between the mountains and the plateau escarpment, are West Baldy, South Baldy, and Miller Mesa. West Baldy rises somewhat boldly above the generally even surface of Howard Flats. South Baldy is a dome-shaped mountain in the upper portion of the Dallas Valley. Miller Mesa is at the eastern margin of the area and adjoins the valley of Uncompahgre River. In many of the escarpments of this mesa the Eocene till is exposed.

Dallas Creek drains eastward into Uncompahgre River, which is the master stream on the northwest slope of the range. The Uncompahgre rises far south of the region under

[1] Atwood, W. W., and Mather, K. F., Evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains of Colorado: Jour. Geology, vol. 20, pp. 385-409, 1913.

consideration among high mountains, and flows northward, skirting the east base of Miller Mesa and the Uncompahgre Plateau. The western portion of the area is drained by Leopard Creek and its tributaries, and Leopard Creek joins the Dolores. All the streams of this area are tributary to Colorado River.

DESCRIPTIVE GEOLOGY.

MESOZOIC SECTION.

The Mesozoic section here exposed includes, from the top downward, the Mancos shale, the Dakota sandstone, and the series of sandstones and shales belonging to the McElmo formation. These formations decline northward with very gentle dips, but are broken by a great east-west fault a short distance north of Ridgway. The block north of this fault line has been elevated relative to that at the south, and the elevated block is a portion of the Uncompahgre Plateau. The Mancos shale is preserved below the capping of the glacial drift in Horsefly Peak, near the southern margin of that plateau, but most of the surface of the great table-land is formed by the Dakota sandstone, and the slope of the surface corresponds very closely to the inclination of the sandstone. In the escarpment bordering the plateau, below the Dakota sandstone, the McElmo formation is exposed. South of the fault escarpment, in the valley of Dallas Creek, the dominant formation is the Mancos shale, which also forms the basal portion of Miller Mesa. To the west the Dakota sandstone forms the surface of much of Howard Flats and of portions of Hastings Mesa, but there are remnants of Mancos shale upon these upland surfaces, and in each locality where any of the earliest of the Pleistocene glacial deposits are present small areas of the shale are preserved beneath those glacial deposits.

CENOZOIC SECTION.

TERTIARY ROCKS.

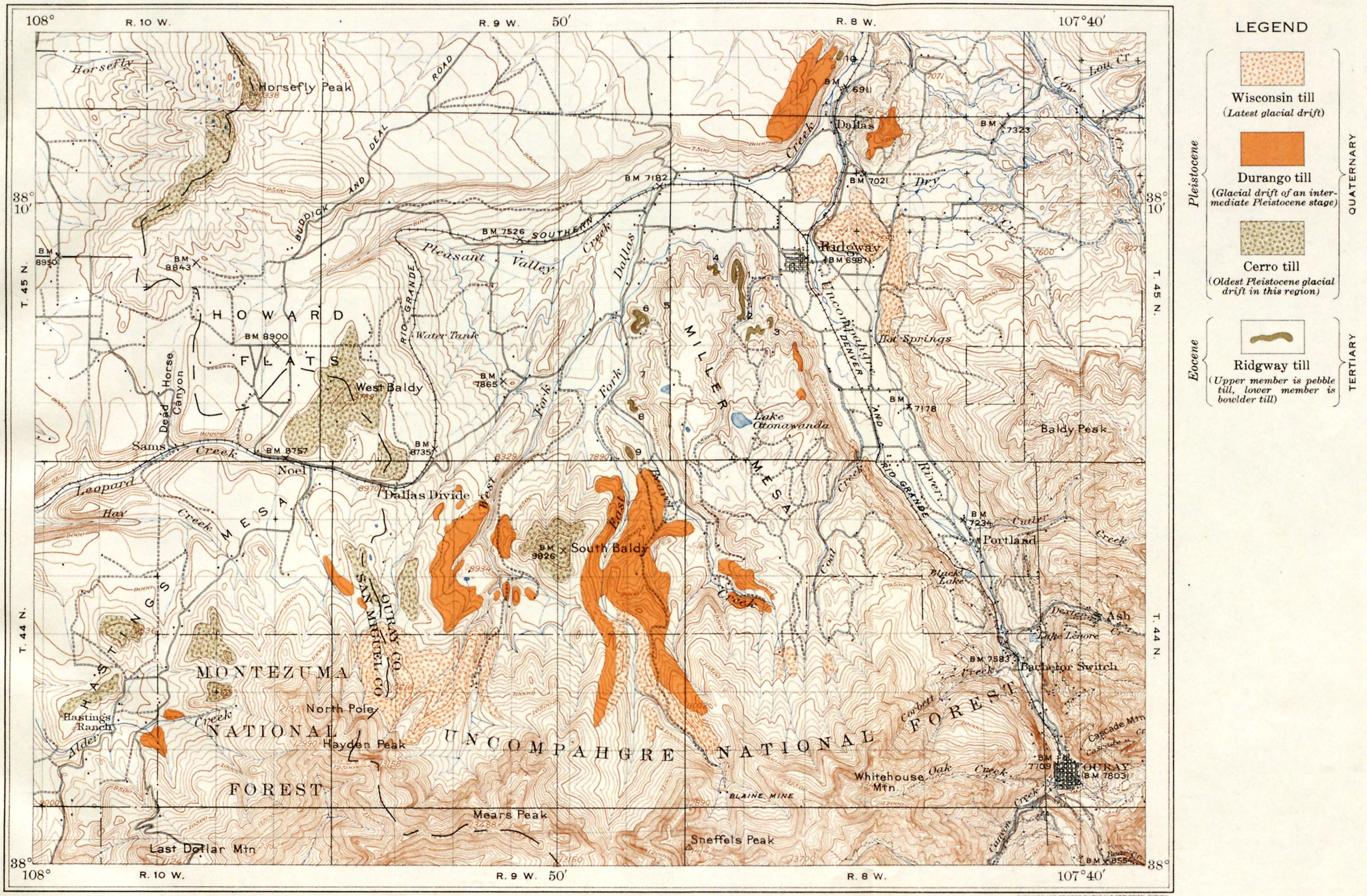
Above the Mesozoic section the geologic succession differs from place to place within the area. The Eocene till, where found, rests unconformably upon the Mancos shale. The till is usually overlain unconformably by the Telluride conglomerate, which, in turn, is overlain unconformably by the San Juan tuff. Locally the Telluride conglomerate or the San Juan tuff rests upon the Mancos shale. At the south margin of the area the San Juan tuff is buried by great thicknesses of later Tertiary volcanic rocks of the Silverton and Potosi volcanic series.

The Telluride conglomerate and the basal portion of the San Juan tuff extend northward over Miller Mesa, to which the tuff forms a resistant capping. The upper volcanic series probably extended much farther northward, but they have since been removed by erosion.

PLEISTOCENE FORMATIONS.

The three distinct Pleistocene drift sheets which have been recognized in the San Juan region must be frequently referred to in this paper and in all subsequent reports on the glacial studies of these mountains. For convenience in description the following names have been selected:

The oldest known Pleistocene drift sheet in this region will be called the Cerro till. The name Cerro is selected from Cerro Summit, near the north margin of the Montrose quadrangle, at which there are heavy glacial deposits of this earliest Pleistocene stage. The Pleistocene glacial deposits of the intermediate stage will be called the Durango till. A little northeast of Durango, a city on the south slope of the range in the valley of Animas River, there are heavy morainic deposits of this intermediate stage. These deposits rest on a high rock bench. They retain a distinct morainic topography and are associated with extensive outwash deposits of the same age. They are readily distinguished from the later glacial deposits which rest upon the valley floor several miles upstream. In the Montrose quadrangle deposits of Durango till occur on the hilltops east and west of the village of Dallas, which is about 3 miles north of Ridgway, also near the headwaters of Dallas Creek, and a short distance to the southeast of Dallas Divide. The most recent Pleistocene glacial deposits in the region will be referred to



Base from Montrose topographic atlas sheet

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

MAP OF SOUTHWESTERN PART OF MONTROSE QUADRANGLE, COLORADO

Showing distribution of Eocene and Pleistocene glacial deposits

Geology by Wallace W. Atwood

Scale $\frac{1}{125000}$

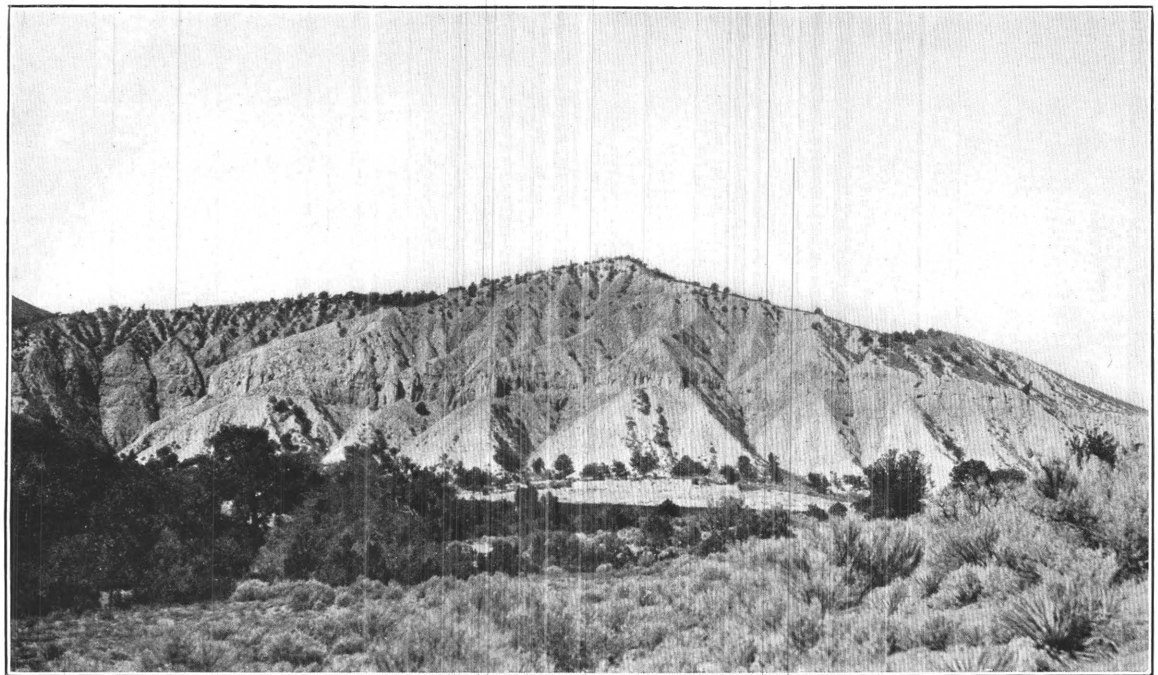
1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

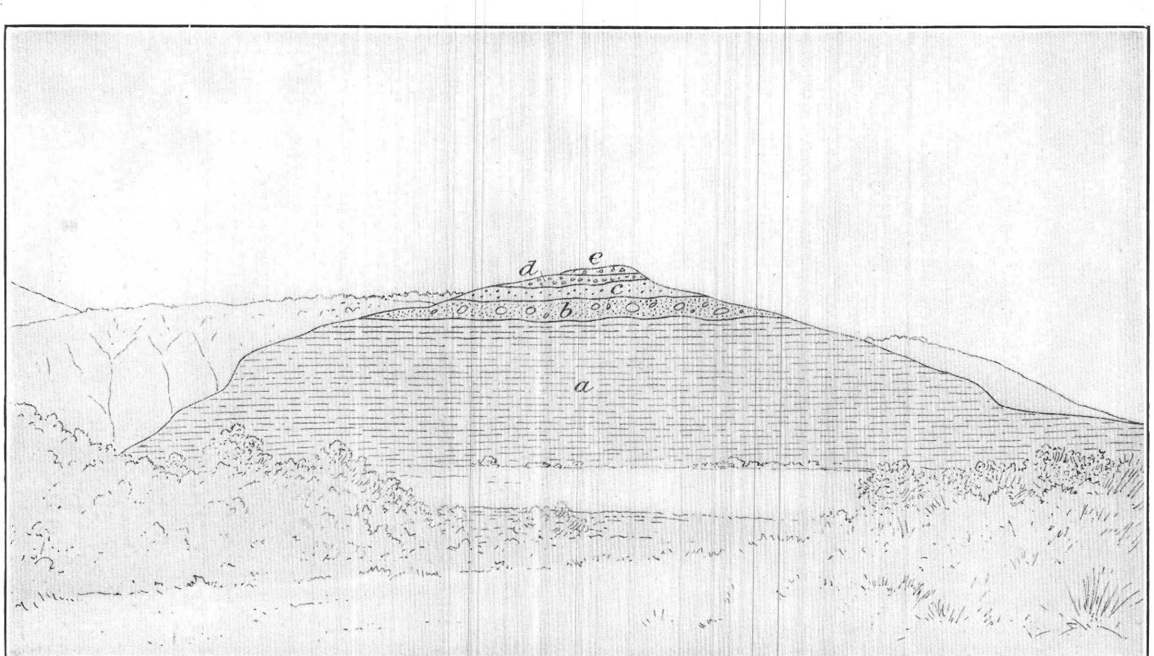
Contour interval 100 feet.

Datum is mean sea level.

1915



A.



B.

RIDGWAY TILL AT THE TYPE LOCALITY, 1 MILE WEST OF RIDGWAY, COLO.

For explanation of diagram see p. 16.

as the Wisconsin till, in accordance with a usage already established in describing the latest of the till sheets in the Rocky Mountains. The correlation of the deposits of the last glaciers in the Rocky Mountains with those of the last great continental ice sheet has been established in the study of the deposits at the east base of the Rocky Mountains near the Glacier National Park,[1] but the correlation of the deposits of the pre-Wisconsin glaciers in the Rocky Mountains with the pre-Wisconsin drift sheets of the Central States is uncertain, and hence the local names Cerro and Durango are introduced.

The Pleistocene glacial deposits within this area are at the surface and must not be confused with the buried glacial deposits to be herein described. The remnants of the Cerro till, or oldest known Pleistocene glacial deposits of this region, are at widely separated localities, on the higher portions of the lowland country. Thus, West Baldy and South Baldy are both capped with the Cerro till. Certain of the higher hills rising above Hastings Mesa are also so capped, and Horsefly Peak, a prominent feature on the Uncompahgre Plateau, rising to an elevation of 10,338 feet above the sea level, or about 2,500 feet above the bordering plateau surface, is also capped with Cerro till. The moraines of the Durango or intermediate Pleistocene glacial stage occur in association with the modern valleys or canyons just north of the San Juan range. They are distinctly below the level on which the Cerro till was left, and yet farther down the valleys than the deposits left by the ice of the last or Wisconsin glacial stage. The accompanying map (Pl. I) furnishes the essential data on the distribution of these Pleistocene glacial deposits within the area under consideration.

The Cerro morainic deposits, now preserved in scattered remnants on certain hilltops, exhibit many characteristics of great age. They rest upon an erosion surface, most of which has been carried away by streams since the ice of this earliest Pleistocene stage melted. The wide distribution of these remnants and the vast stretches of country which have been deeply dissected since these deposits were made point most impressively to the great age of these moraines. Furthermore, these deposits within the area under consideration are composed very largely of volcanic rocks, which once capped the mountain summits to the south but which are now almost entirely missing from the range. It is clear that the basins in which the Cerro glaciers formed have been obliterated by subsequent erosion. The distribution of these glacial deposits is furthermore suggestive of a valley system quite different from that of the present day. The present remnants of Cerro till are not opposite the mouths of the modern canyons. Many of them are opposite the mountain spurs, at localities that ice coming from the mountain canyons of to-day could not reach. This relationship also points to the great antiquity of these deposits. Furthermore, these oldest Pleistocene moraines do not contain an abundance of bowlders from the older formations which have been uncovered as the dissection of the range has gone on. By this means it is possible to distinguish the Cerro moraines from those of the Durango and Wisconsin stages. The oldest Pleistocene deposits are much weathered, and stream erosion has nearly obliterated all signs of morainic topography in them.

The moraines of the two later Pleistocene stages (Durango and Wisconsin) are associated with the modern canyons, and some of them extend but a few miles down the valleys from the great amphitheatral basins where the glaciers formed. In the valley of Uncompahgre River, at the east margin of this area, the terminal moraines of the Durango and Wisconsin stages have been recognized a short distance down the valley from the village of Ridgway. In the smaller valleys west of Miller Mesa the later glaciers were but a few miles in length. They failed to reach the broad lowland area of the Dallas Valley.

RECENT DEPOSITS.

Since the last Pleistocene glaciers melted away the streams have distributed vast quantities of sand and gravel over their flood plains, and these lowlands stretch far off to the northwest, beyond the margin of the range. Locally there has been some land sliding, and a number of torrential fans have been developed.

[1] Alden, W. C., Pre-Wisconsin glacial drift in the region of Glacier National Park, Mont.: Geol. Soc. America Bull., vol. 23, pp. 687-708, 1912. Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, 1906.

EOCENE TILL.

TYPE SECTION.

GENERAL FEATURES.

The section 1 mile west of Ridgway, at the locality where the Eocene till was discovered, has been selected as the type section. The locality is marked as No. 1 on Plate I. It is within plain view from the Ridgway station platform, and the term Ridgway till has therefore been adopted for this formation. The cliff in which the till is exposed (see Pl. II) contains the Mancos shale (*a*) at the base. Overlying the shale unconformably is a section (*b*) 80 to 100 feet thick which exhibits all the usual characteristics of glacial till. This section appears from a distance as a distinct yellow band. Above the yellow band, resting upon an uneven erosion surface, is a dark slate-colored stratum (*c*), which, on careful examination, has also been found to be a glacial till. The upper till sheet is overlain by a layer of the Telluride conglomerate (*d*), which varies in thickness from 70 feet at the south (left-hand) end of the section shown in Plate II to 10 or 15 feet at the north end of the section. Above the Telluride conglomerate, also upon an erosion surface, is a remnant of San Juan tuff (*e*) having a thickness of at least 30 feet.

The spur in which this type section is exposed is so nearly separated from the main part of Miller Mesa that the section above described may be traced around the north end and on the west side, so that it is perfectly clear that the formations extend through this spur. The section thus described continues, with some variations in the thickness of the different formations, southward along the face of the Miller Mesa escarpment for fully a mile. At the southernmost exposure (locality No. 2), which, however, may not be the southern limit of these formations in the mesa, the section is somewhat different from that at the type locality and is described on page 18.

RIDGWAY TILL.

Lower or bowlder member.—The lower till sheet at the type locality contains an abundance of stones which range in size from tiny pebbles to bowlders 15 feet in diameter. These stones vary in composition, like the rock formations in the core of the San Juan Mountains, beneath the great volcanic cap which was added to the mountain area in Tertiary time. They include many varieties of porphyries, granites, some volcanic tuff, quartzites, sandstones, limestones, and conglomerates. The harder, crystalline bowlders, the pink and purple quartzites, and the volcanic rocks came from the core of the range, but the softer sandstones, limestones, light-colored quartzites, and conglomerates were plucked by the ice from the upturned sedimentary strata at the north base of the range. These stones have been derived from formations which range in age from the pre-Cambrian to and including the Upper Cretaceous. The bowlders of tuff came from a volcanic series older than any of those which form the present great mass of the San Juan Mountains. The San Juan tuff overlies the Telluride conglomerate, which in turn overlies the glacial deposits.

The tuff deposits that contributed material to the Ridgway till seem to have belonged to an early and rather local extrusion. These tuffs were largely removed by erosion before the Telluride conglomerate was laid down, for such material is rarer in the conglomerate, all through the western San Juan Mountains, than it is in the known exposures of Ridgway till. The San Juan tuff, which reaches a thickness of 3,000 feet near Ouray, is composed mainly of transported material similar in petrographic character to the fragments of tuff in the till. But the source of the San Juan tuff was a great volcanic mass erupted, soon after the Telluride conglomerate was laid down, in the area which supplies the Telluride materials. These facts fix the general time relations of the Ridgway glacial epoch to the volcanic history of the San Juan Mountains.

The pink and purple quartzites came from the pre-Cambrian Uncompahgre formation, now well exposed near Ouray and up the canyon of Uncompahgre River. Most of the limestones were derived from the Devonian or Carboniferous formations which are also now exposed near Ouray. A vast quantity of red sandstone and conglomerate was gathered by the ice from the Cutler (late Carboniferous) and Dolores (Triassic) formations. These formations must have been exposed but a few miles south of the localities where the Eocene drift is now located. They are well exposed to-day in the Uncompahgre Valley, between Ridgway and Ouray. The white quartzites are from the Dakota sandstone, which is locally a distinct quartzite.

A great many of these stones show distinct signs of ice action. Small striated stones are abundant (see Pl. III, *B*) and subangular forms are conspicuously common. Many of the huge bowlders are distinctly striated, and in certain of the great masses of red conglomerate from the Cutler formation, the exposed surfaces of the limestone pebbles carry striæ. The abundance of striated stones found on the exposed surface of this till may seem somewhat surprising, and it should be explained that as the underlying Mancos shale is rapidly washed away, the glacial drift is continually falling, and therefore, at this locality, continuously presenting a fresh exposure. The discovery of other striated stones in this till may be safely expected for many years to come.

The matrix of this lower or yellow till is sand and clay, and it is quite probable that most of the clay was derived from the underlying Mancos shale. The sand may have come from various formations. The conspicuous yellow color of this lower layer of glacial till is characteristic of every exposure of this member throughout the area. The yellow coloring is not confined to the surface, but evidently continues throughout the section. It appears to be due to the oxidation of the iron minerals associated with the matrix of this till. If this oxidation proceeded from the top throughout the mass, which has a thickness of at least 90 feet, it would seem to indicate that this member was at the surface during an exceedingly long period of time. Possibly the material as gathered by the ice had this extreme yellow color.

In texture this drift is exceedingly firm. It stands with a slope so steep that it is difficult to work around the hill on foot at that horizon. In places the large stones, or bowlders, have acted as preserving caps, and the rain erosion has developed great earth pillars 6 to 8 feet in height, each with its bowlder cap. Certain of these earth pillars are shown in Plate III, *A*. Throughout the finer matrix of this till there is an abundance of small stones, many of which have been beautifully polished and striated.

Upper or pebble member.—The upper member of the Ridgway till is strikingly different from the lower member. When first examined, it was thought to be a layer of clay without stones or pebbles. In color it so closely resembles the Mancos shale that it was suggested in the field that it might be a part of that formation. This hypothesis was, however, very promptly abandoned, for it was somewhat unreasonable to think that there was a glacial epoch in southwestern Colorado during a period of marine invasion. Again a lacustrine origin was considered, but it is quite certain that this material is unstratified. I was for some time in great doubt as to what its true origin might be. The absence of large stones, such as characterized the drift sheet just below, seemed to exclude the idea of another glacial deposit. That the same ice which brought the bowlder till could have contained or carried this upper sheet of material seemed improbable. It also seemed unlikely, if ice had brought the upper material, that it could have had the same source as the ice which deposited the bowlder till. It was certainly strange that ice could have moved over the bowlder till without gathering some large stones. However, on very careful search, several small but distinctly striated pebbles were procured from this upper sheet. When a mass of this material could be broken out and carefully examined, it was found that the distribution of the tiny stones and pebbles was similar to that in the typical deposit of glacial till, the only difference being that the stones were much smaller. These characteristics have been found to persist in the several exposures of this upper member, and it is quite clear now that the material is a glacial deposit, and the term "pebble till" is suggested as appropriately descriptive of it. This upper member is not so deeply weathered as the lower member, but the upper 6 or 8 feet seems to be somewhat leached, as if that portion had been exposed to the air for some time and affected by the usual processes of weathering.

The stones in the pebble till are so small that no attempt has yet been made to identify them and determine their source, but further studies of these deposits may make it possible to procure collections that will help to determine the source of the drift. As the examination of the several exposures progressed a few larger stones, the largest 2 or 3 inches in diameter and one stone 6 inches in diameter, were found in the pebble till. The striking characteristics, however, of this upper member are an absence of large stones, a firm clay matrix, an unstratified condition, and striated pebbles.

FORMATIONS OVERLYING THE EOCENE TILL.

Telluride conglomerate.—The Telluride conglomerate, which overlies the upper till member at the type locality, contains many pebbles 4 inches or less in diameter and a few stones as much as 10 inches in diameter. The matrix is sandy, with some fine gravel. The formation is cemented and stands with a nearly vertical face. It has a general pink color and closely resembles other exposures of this well-known formation of the San Juan Mountains. It was, however, a notable surprise to find distinctly striated stones in this conglomerate. It is of course clear that the formation is of later age than the underlying glacial deposits, and the streams which laid down the Telluride conglomerate must have drawn in part upon glacial deposits for their materials. Possibly some of the stones in the conglomerate were not carried far, and that would account for the preservation of glacial striæ on stones transported by water.

San Juan tuff.—The San Juan tuff overlies the Telluride conglomerate at the Ridgway type section and forms the capping of the spur in which the section occurs. The material is quite evidently of volcanic origin, and most of the fragments are angular. They vary from dust to blocks 8 feet in diameter. It is possible to detect distinct lines of bedding in this exposure of the tuff. It has a gray, slate-colored appearance, is much broken from weathering, and seems at places to have settled irregularly since it was deposited. There is very little rounded material in this exposure of the tuff, but otherwise it resembles the San Juan tuff which has been fully described by Cross in the geologic folios on the San Juan district.

OTHER SECTIONS.

The other exposures about the rim of the mesa may now be described somewhat briefly, for the different formations retain their marked characteristics, but at most of the several localities one or another of the formations included in the type section is missing. The numbers used in the descriptions represent corresponding numbers on Plate I.

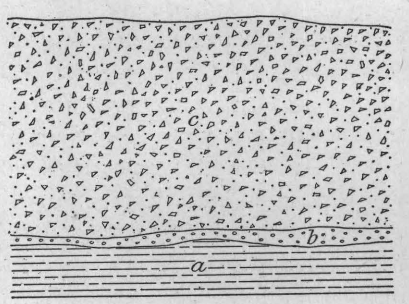


FIGURE 2.—Geologic section at locality No. 2 near Ridgway, Colo. *a*, Mancos shale; *b*, pebble member of Ridgway till, 6 feet; *c*, San Juan tuff.

Locality No. 2 is at the extreme south end of the exposure which contains the type section, but it is fully a mile distant from the type section. It is on the west wall of Pleasant Valley. At this point the Mancos shale is exposed at the base. (See fig. 2.) Above it is about 6 feet of the upper or pebble till, in which a number of striated stones were found. Overlying the pebble till is the San Juan tuff fully 200 feet thick. The missing members in this section are the bowlder till and the Telluride conglomerate. The Telluride conglomerate was not recognized, although there was a narrow band of pinkish material at the base of the San Juan tuff, which suggested that possibly a little of the Telluride was left there. The pebble till thickens toward the north and within a few rods in that direction it is underlain by bowlder till.

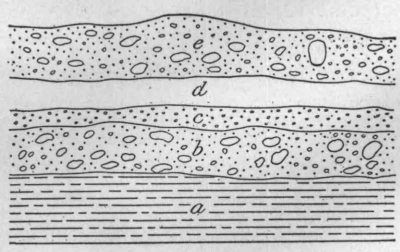
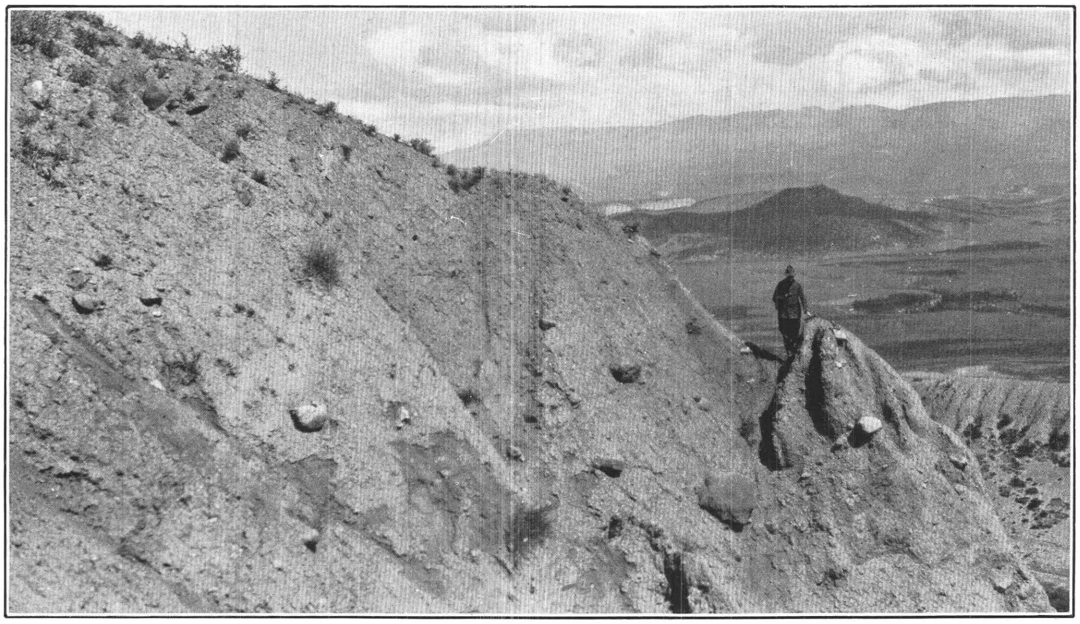
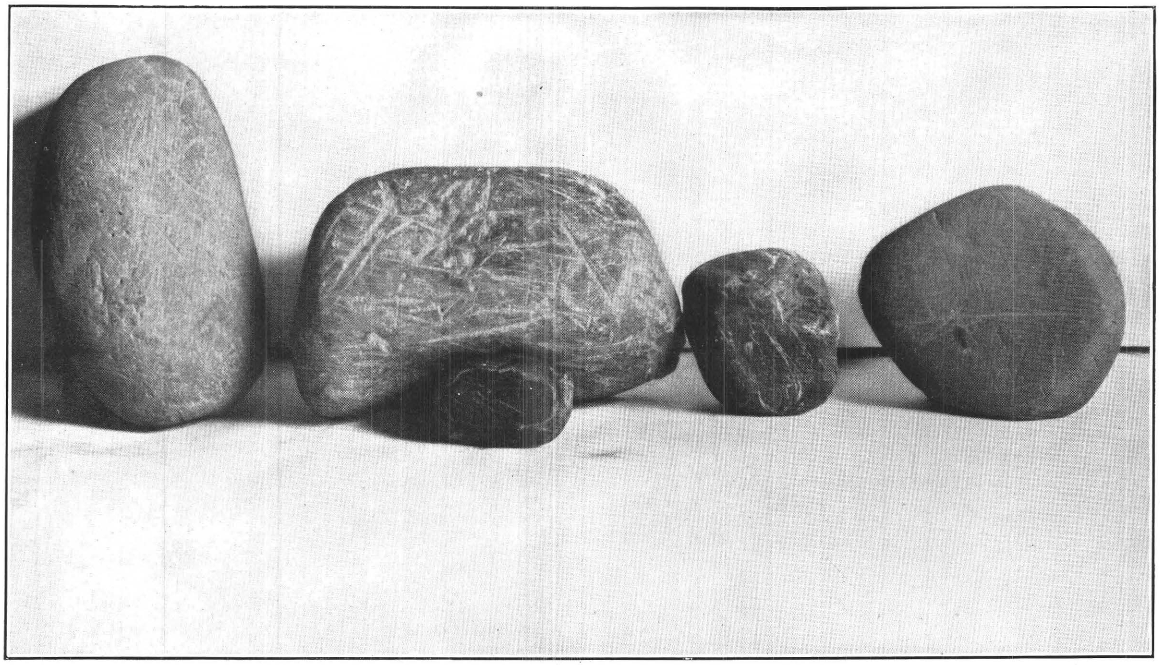


FIGURE 3.—Geologic section at locality No. 3 near Ridgway, Colo. *a*, Mancos shale; *b*, bowlder member of Ridgway till, 40 feet; *c*, pebble member of Ridgway till, 15 feet; *d*, obscured, 15–20 feet; *e*, Pleistocene glacial till of Durango stage.

Locality No. 3 is nearly east of No. 2, about three-quarters of a mile south of Ridgway, on the west side of the Uncompahgre Valley. Here a thickness of 40 feet of the yellow bowlder till overlies the Mancos shale and is in turn overlain by 15 feet of the pebble till. (See fig. 3.) The immediate covering of the pebble till is obscured. Possibly some San Juan tuff is present at that horizon, but there are no satisfactory outcrops. The surface of the hill or ridge is mantled with Pleistocene till of the Durango stage.



A. DETAILED VIEW OF THE BOWLDER MEMBER OF THE RIDGWAY TILL AT THE TYPE LOCALITY, 1 MILE WEST OF RIDGWAY, COLO.



B. STRIATED STONES FROM THE RIDGWAY TILL AND TELLURIDE CONGLOMERATE.

The second stone from the right came from the Telluride conglomerate.

Locality No. 4 is about half a mile west of No. 1. The Mancos shale is exposed at the base. (See fig. 4.) No bowlder till is present, but there remains at least 30 feet of the pebble till, with its usual characteristics. Telluride conglomerate is lacking, and the pebble till is overlain by the San Juan tuff, which reaches to the surface of the mesa.

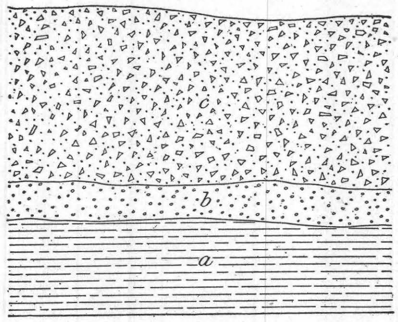


FIGURE 4.—Geologic section at locality No. 4 near Ridgway, Colo. *a*, Mancos shale; *b*, pebble member of Ridgway till, 30 feet; *c*, San Juan tuff, 90 feet.

Locality No. 5 is on the west side of Miller Mesa, southwest of No. 4. At this point the Mancos shale is overlain immediately by Telluride conglomerate, and that in turn by San Juan tuff. (See fig. 5.) The section does not contain the glacial formations, but their absence at this point is significant and will be discussed elsewhere (p. 23). The Telluride conglomerate at this locality contains striated stones.

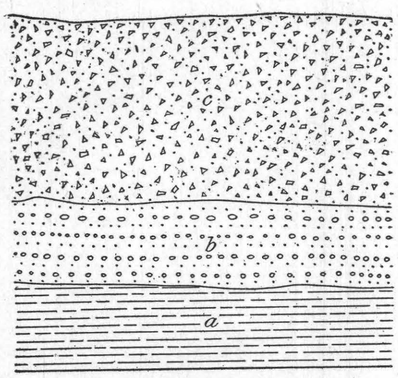


FIGURE 5.—Geologic section at locality No. 5 near Ridgway, Colo. *a*, Mancos shale; *b*, Telluride conglomerate, containing striated pebbles; *c*, San Juan tuff.

Locality No. 6 is on the west side of Miller Mesa, due west of No. 2 and just across a small valley from No. 5. It is in a small outlier from the main part of the mesa. Here the type section is repeated, with the exception of the upper capping of San Juan tuff. (See fig. 6.) The Mancos shale is at the base and is succeeded by 30 feet of bowlder till overlain by 20 feet of pebble till, and this in turn by 40 feet of the Telluride conglomerate. At this locality the bowlder till contains a great deal of waterworn material. It is quite possible that the deposit represents a local pocket in the older of these Eocene till sheets, where water had much to do with the deposition of the material. At this locality no striated stones have yet been found in this lower member. In the overlying pebble till striated stones have been found, and a few such stones have also been found in the Telluride conglomerate, which overlies the glacial deposits.

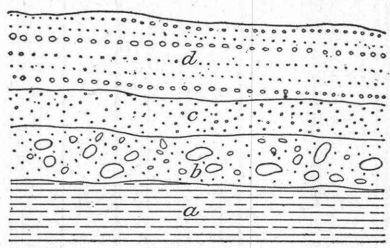


FIGURE 6.—Geologic section at locality No. 6 near Ridgway, Colo. *a*, Mancos shale; *b*, bowlder member of Ridgway till, 30 feet; *c*, pebble member of Ridgway till, 20 feet; *d*, Telluride conglomerate, with striated pebbles, 40 feet.

At locality No. 7, at the rim of the mesa, there is an excellent exposure of the San Juan tuff, and below that fully 300 feet of Telluride conglomerate, in which striated stones have been found. Below the Telluride is the Mancos shale. (See fig. 7.) This section, therefore, resembles that at locality No. 5. It is without glacial formations, but very near to the localities where the glacial material remains.

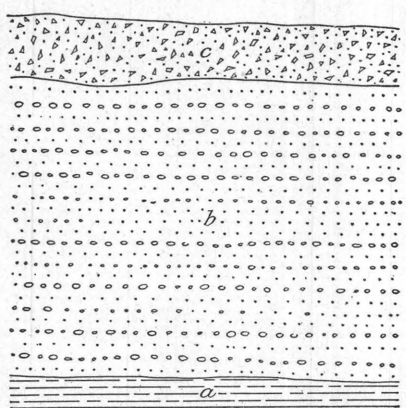


FIGURE 7.—Geologic section at locality No. 7 near Ridgway, Colo. *a*, Mancos shale; *b*, Telluride conglomerate, with striated pebbles; *c*, San Juan tuff.

Locality No. 8 is about a mile south of No. 7, just south of an east-west dike, which causes the road to make a distinct bend toward the west at that point. At this locality the entire type section is repeated. (See fig. 8.) The Mancos shale is exposed at the base, followed by the bowlder till with its usual characteristics, the pebble till, the Telluride conglomerate, and the San Juan tuff.

Locality No. 9 is about a mile south of No. 8, in a prominent hill a short distance west of Beaver Creek. This hill is not to-day a part of Miller Mesa, and the glacial material forms its capping. (See fig. 9.) In this respect this locality differs from all others, for the deposit which is interpreted to be Eocene till is not buried. Its physical and lithologic characteristics are, however, identical with those of the bowlder till in the lower part and the pebble till in the upper part. It is with confidence interpreted as a remnant of the Eocene till, from which the covering of Telluride conglomerate and San Juan tuff has somewhat recently been removed. It might be asserted that this particular hill may have been overridden by the earliest of the Pleistocene glaciers, but in reply it may be urged that the composition of this till and the fact that it has two distinct members make it quite distinct from the deposits of the Cerro stage. The absence of the great latite bowlders which characterize the glacial deposits of the Cerro stage would seem to put it in another geologic epoch. If the interpretation is correct, the latite flows which contributed so largely to the Pleistocene glaciers were not present in the San Juan Mountains at the time the Eocene till was gathered. The intermediate and latest Pleistocene glaciers did not reach the summit of this hill.

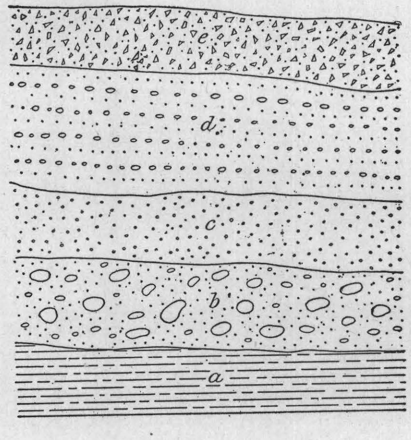


FIGURE 8.—Geologic section at locality No. 8 near Ridgway, Colo. *a*, Mancos shale; *b*, bowlder member of Ridgway till; *c*, pebble member of Ridgway till; *d*, Telluride conglomerate; *e*, San Juan tuff.

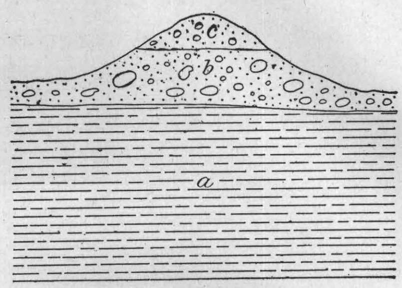


FIGURE 9.—Geologic section at locality No. 9 near Ridgway, Colo. *a*, Mancos shale; *b*, bowlder member of Ridgway till; *c*, pebble member of Ridgway till.

Locality No. 10 is about 4 miles northeast of No. 1. It is on the southeastern rim of Log Hill Mesa, a portion of the great Uncompahgre Plateau. The exposure is on the face of the cliff bordering the Uncompahgre Valley, about a mile north of the Dallas railway station. Upon the surface of Log Hill Mesa in this vicinity is a thin mantle of glacial drift which was deposited during the Durango stage of the Pleistocene epoch. The formation is in a small hill or knob on the mesa (see fig. 10 and Pl. IV), and the section exposed there includes, from the top downward, the following formations:

Section at locality No. 10.

	Feet.
San Juan tuff	80–90
Telluride conglomerate	4–10
Bowlder member of Ridgway till	40
Mancos shale	70–80
Dakota sandstone.	
McElmo formation.	

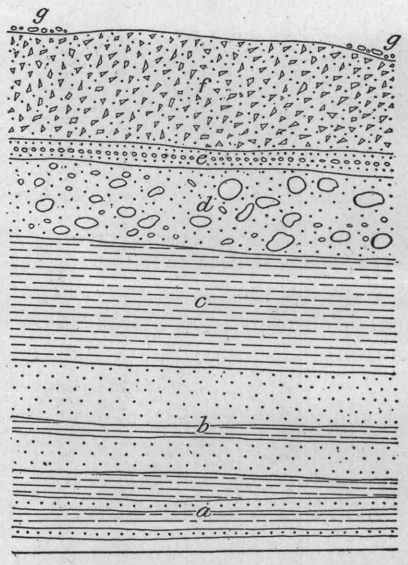
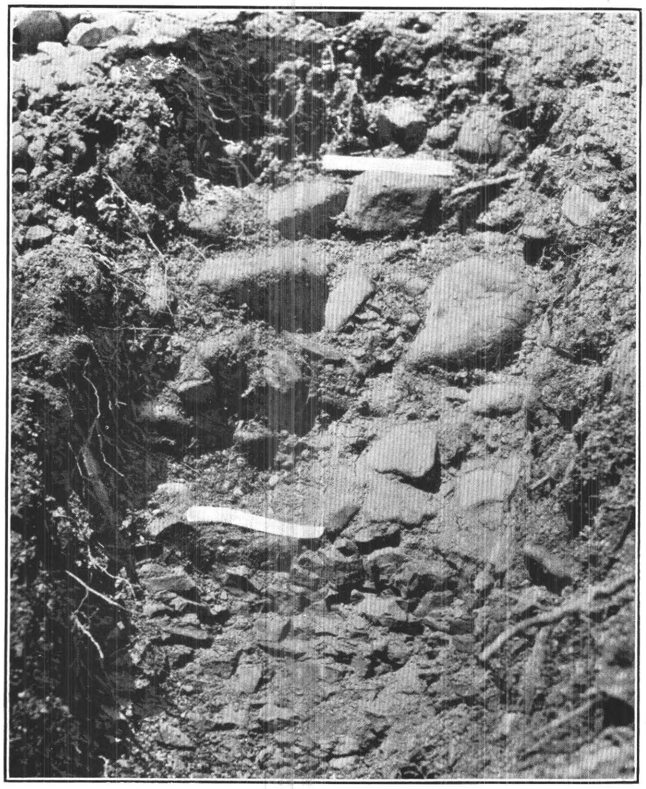


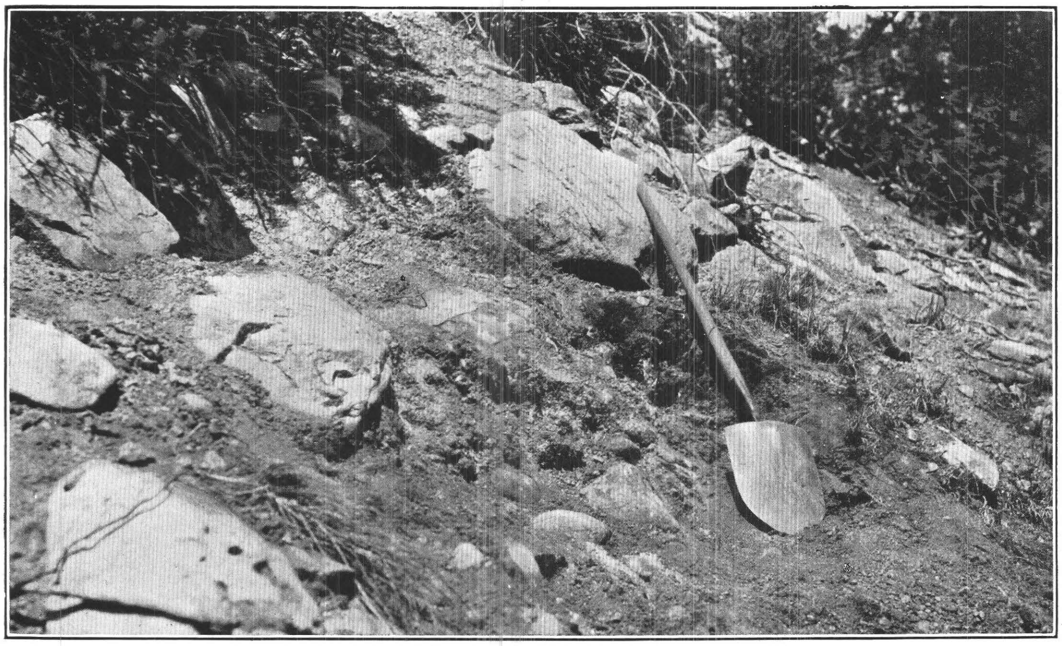
FIGURE 10.—Geologic section at locality No. 10 near Ridgway, Colo. *a*, McElmo formation; *b*, Dakota sandstone; *c*, Mancos shale; *d*, bowlder member of Ridgway till; *e*, Telluride conglomerate; *f*, San Juan tuff; *g*, glacial bowlders of the Pleistocene Durango till.

This exposure is of special interest, for it is the most northern locality at which the Ridgway till has been found and is the one locality not immediately associated with Miller Mesa where this older glacial drift is known to occur. The preservation of the older drift at this place is readily accounted for by the heavy mantle of San Juan tuff and Telluride conglomerate. The exposures on the cliff were not altogether satisfactory, and it was found necessary to clear away with pick and shovel the loose material throughout the section described, so as to prove beyond doubt the presence of a layer of till beneath the Telluride conglomerate at this locality. The Ridgway till here, as at many



A. SECTION IN BOWLDER MEMBER OF RIDGWAY TILL AT LOCALITY NO. 10 NEAR RIDGWAY, COLO.

The till immediately underlies the Telluride conglomerate. Distance between white marks is about 8 feet.



B. SECTION IN BOWLDER MEMBER OF RIDGWAY TILL AT LOCALITY NO. 10 NEAR RIDGWAY, COLO.

All loose material was removed and glaciated bowlders exposed.

other localities, differs from the Pleistocene drift of the region in not including any material contributed from the later Tertiary volcanic rocks of the San Juan Mountains. It contains representatives from the earlier volcanic rocks and an abundance of bowlders from the sedimentary beds. The section where the loose surface material was cleared away did not show any of the pebble till

SOURCES OF THE RIDGWAY TILL.

Lower or bowlder member.—The composition of the lower or bowlder till member makes it perfectly clear that this material was gathered in the San Juan Mountains, south and southeast of the locality where it is now exposed. The stones in the drift are just such as are exposed in the core of the range. The large tuff bowlders resemble the tuff bowlders in the San Juan tuff, but it is apparent that they came from a volcanic formation which was much earlier than the San Juan tuff and which yielded many of the bowlders contained in that formation. It is evident from other studies carried on by Cross that there was a period of volcanism earlier than that which began with the formation of the San Juan tuff.

Upper or pebble member.—The source of the upper or pebble till member is not so clear. If it came from the San Juan Mountains, it is very strange that it does not also contain large bowlders, or at least an abundance of stony material. If the ice which brought the pebble till moved far over a surface mantled by the bowlder till, it would seem that it should have gathered a great deal of stony material. The source of the pebble till, as exposed in these localities, seems to have been chiefly the Mancos shale. The area in which the Mancos shale was exposed at the surface during Eocene time was to the north or northeast of Ridgway, in the direction of Vernal Mesa and the West Elk Mountains. If ice had come from that direction to the vicinity of Ridgway, it would have traveled the last 30 or 40 miles of its course over a surface of Mancos shale, and as most of the glacial drift of any one locality is usually of local origin, that would account for the character of the material in the pebble till. The contrast between the bowlder till and the pebble till suggests distinct glaciers, either from a single center at distinct times in the history of glaciation or from distinct centers. It appears most likely that the earliest Eocene ice which invaded the Ridgway territory must have come from the south, and that later, after that ice had retreated, and perhaps disappeared, and after a long period of weathering and erosion had elapsed, other ice invaded this same region from another direction. Possibly this other direction was the northeast, the ice coming from the region of the West Elk Mountains.

AGE OF THE RIDGWAY TILL.

The position of the Ridgway till upon the Mancos shale makes it evident that it is late Cretaceous or younger, but the Mesaverde formation overlay the Mancos shale at the time of the first uplifting of this mountain area, at the close of the Cretaceous period. The Ridgway till was therefore not deposited until after the close of Cretaceous time, and not until the Mesaverde formation had been entirely eroded from the vicinity of Ridgway.

The Telluride conglomerate, which rests upon the Ridgway till at several localities, has been referred by Cross [1] to the Eocene. It therefore appears that the Ridgway till is of early or mid-Eocene age.

EOCENE GLACIERS.

The facts thus far presented lead to the inference that the earlier Eocene ice may have been of an alpine type and descended from an early generation of San Juan Mountains, bringing vast quantities of coarse, stony material to the foothills of a range of mountains that has long ago disappeared. If the pebble till was brought by ice from the north and northeast, and if that ice formed in mountains, it must have come a distance of fully 40 miles and, in early Eocene time, probably moved over a surface of slight relief. Such ice could not have been a true mountain or alpine glacier. It would suggest the presence of a piedmont glacier, or possibly a local ice sheet, in Colorado in early Tertiary time.

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1899.

PROBABLE FURTHER EXTENSION OF THE EOCENE TILL.

The distribution of these Eocene glacial deposits at the northwest base of the San Juan Mountains suggests the possibility that other remnants of the Ridgway till may be found at other localities about the base of the range. Furthermore, if the mountains which existed in early Tertiary time in the San Juan region contained glaciers, it is more than likely that other mountain areas of early Tertiary time, in Colorado and throughout the Cordilleran province of North America, also contained glaciers. If the suggestion of a somewhat distant origin for the ice which deposited the pebble till is correct, it would seem that the Eocene glaciers in the Cordilleran province may have been more extensive than the Pleistocene glaciers of that region and possibly had dimensions commensurate with those of local ice sheets. Certainly many of the early Tertiary conglomerates of the western portion of the continent should be examined to determine whether they may not be of glacial origin, and the discovery of glacial deposits of Eocene age in the western mountain areas may henceforth be expected. It seems reasonable to suggest that if there were such extensive glaciers in the Cordilleran province of North America in early Eocene time, there may have been glaciers on lower lands within the continent at the same time, the conditions thus simulating those of the Pleistocene epoch.

SUMMARY OF AVAILABLE FACTS PERTAINING TO THE RIDGWAY TILL.

It is appropriate now to sum up the characteristics of the Eocene glacial deposit as they have been determined from the various localities described and to present a brief statement of the available facts pertaining to this formation.

1. The Ridgway till is divisible into two members.
2. The lower member is distinctly a bowlder till.
3. This lower member appears to have been deeply weathered, perhaps weathered throughout its maximum known thickness of 90 feet.
4. The lower member contains an abundance of striated stones.
5. Wherever it has been found this lower member rests upon Mancos shale.
6. The stones in the lower or bowlder till have certainly come from the San Juan Mountain area to the south.
7. The upper member is appropriately described as a pebble till.
8. It appears to have been subject to a much shorter period of surface weathering.
9. Most of the upper till sheet is clay, which was probably derived from areas where the Mancos shale was exposed at the surface.
10. At certain localities the lower member, or bowlder till, is missing and the pebble till is present.
11. There was probably an erosion period after the deposition of the bowlder till and before the deposition of the pebble till.
12. At certain localities the pebble till is missing and the bowlder till is present.
13. At most localities the Telluride conglomerate overlies these glacial deposits, but in places it is absent and the overlying formation is the San Juan tuff.
14. At one locality (No. 9) the bowlder and pebble till sheets are present, but not the Telluride conglomerate nor the San Juan tuff. At this locality the pebble till is at the summit of the hill.
15. Striated stones have been found in the pebble till.
16. Striated stones, presumably from the Ridgway till, have been found in the overlying Telluride conglomerate at several localities.
17. At some localities within the area bounded by the exposures of the Ridgway till the Telluride conglomerate rests upon the Mancos shale. At these localities the Telluride conglomerate has been found to contain striated stones.
18. The exposures described are within an area 8 miles long in a northeasterly direction and 2½ miles wide in a northwesterly direction. The areal extent of the region within which the deposits have thus far been found is about 20 square miles.
19. All but one of the exposures are about the margin of the Miller Mesa, and it is quite probable that there may be somewhat extensive remnants of the Ridgway till buried within the mesa.
20. The surface of the Mancos shale beneath the till is too loose and soft to have received or retained glacial striæ.

GEOGRAPHIC HISTORY SINCE THE CLOSE OF THE MESOZOIC ERA.

With the discovery of evidence of early Eocene glaciation in the San Juan district, it is of some interest to review the geographic history of this region.

At the close of the Mesozoic era and the opening of the Cenozoic era there were mountain-making movements which affected the entire Rocky Mountain province of North America, and the great dome which was then formed in the San Juan area was at once subjected to vigorous erosion. As the mountain mass rose erosion began, and as the great dome was more and more deeply dissected a mountain topography must have been produced, and those mountains may be thought of as the first generation of the San Juan range. (See fig. 11.) During the period of mountain growth there was some volcanism. Many porphyritic intrusions and the deposition of the great volcanic tuffs which made contributions to the Ridgway till date back to this period. The Eocene till indicates that during the dissection of these early San Juan Mountains ice formed in the range and descended to the bordering lowlands. Possibly ice formed in neighboring ranges and approached the San Juan Mountains, and possibly there were distinct glacial epochs in that period of glaciation.

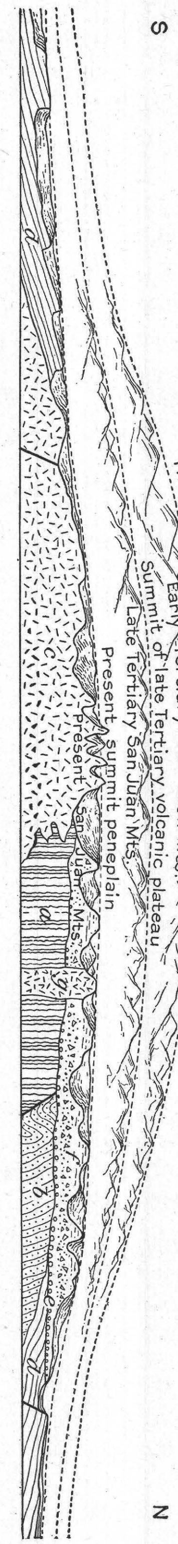


FIGURE 11.—Diagrammatic cross section showing the physiographic evolution of the San Juan region since the beginning of Tertiary time. *a*, Pre-Cambrian schist and gneiss; *b*, Algonkian quartzites; *c*, Pre-Cambrian granitic intrusion; *d*, Paleozoic and Mesozoic rocks; *e*, Ridgway till and Telluride conglomerate; *f*, middle and late Tertiary volcanics; *g*, Tertiary intrusives.

After the retreat and disappearance of the early Tertiary ice, stream erosion continued, and the western portion of the San Juan Mountain area was reduced to a surface of slight relief which may be thought of as a peneplain.[1] This peneplain bordered on the west a higher area of mountainous character, which supplied the material for the Telluride conglomerate. The deposition of gravels upon this peneplain surface was probably due to some uplift and rejuvenation of the streams in the eastern portion of the range. After the deposition of the Telluride conglomerate there was further erosion in the range, and then came the three great epochs of volcanism, the San Juan, the Silverton, and the Potosi. During these epochs of volcanism a great volcanic plateau was developed. By this time the Miocene epoch had been reached and possibly passed, and with the quieting down of volcanic activity began the erosion and dissection of the volcanic plateau. During this period of dissection another generation of San Juan Mountains were carved, this time out of volcanic débris and great lava flows. (See fig. 11.)

Recent physiographic studies of the range have led to the recognition of a summit peneplain in the San Juan region (see fig. 11), so it would appear that the first dissection stopped at a plain which is now represented by many of the summit areas within the region. The San Juan Mountains that were first carved out of this great volcanic plateau should then be thought of as surmounting those of to-day. Perhaps, if replaced, they would rise 3,000 or 4,000 feet above the present summits. (See fig. 11.)

With the redoming of the area, which involved the warping or doming of the summit peneplain, another cycle of erosion was begun. Valleys were again formed, and in these valleys snows collected which in time formed glaciers that advanced to the lowlands bordering the range. These earliest Pleistocene glaciers retreated and disappeared. The range continued to be uplifted, and the streams were so rejuvenated that they cut great canyons below the broad troughs occupied by the Cerro glaciers. Again climatic changes favored the formation of ice among the summits, and that ice (the Durango glaciers) descended through the main canyons to the foothills and later retreated and disappeared. The canyons were still more deeply cut into the mountain mass, and then climatic conditions favorable for glaciation once more returned and the Wisconsin or third series of Pleistocene glaciers formed and descended through the great canyons, nearly as far as those of the Durango stage. These glaciers have now disappeared, and there

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), 1905.

is no true glacier ice remaining in the region to-day, but the streams are vigorously dissecting the mountain mass to still greater depths. The vigor of that work is illustrated in many a sharp, V-shaped notch cut below the depth of ice action. The débris taken from the mountain area is being distributed along the great valleys leading away from the range.

The ice gouging in the three successive Pleistocene stages and the vigorous stream work during the interglacial intervals and since the last melting away of the ice suggest somewhat continuous mountain growth in this region during late geologic time.

OTHER GLACIAL EVIDENCE.

Before closing this report it may be appropriate to refer briefly to other glacial deposits made at different times in the history of the earth. The accompanying table presents some data as to these deposits and indicates that glacial conditions have existed at many times and at very many places on the earth. The records of pre-Cambrian glaciation are found in Norway and Canada and perhaps indicate early Huronian or Proterozoic age, though probably not exactly the same age in the two countries. The glacial deposits recorded from China are known to be either Lower Cambrian or pre-Cambrian, for Cambrian strata immediately overlie the glacial till. There is some reason for believing that the early deposits of Australia may be pre-Cambrian. Some doubtful evidence of glaciation is afforded by the Devonian of England, but the records of Devonian glaciers in South Africa are more certain. The record of late Carboniferous (Permian) glaciation comes from South Africa, Australia, Tasmania, South America, India, the East Falkland Islands, England, Germany, and the Boston Basin in Massachusetts. In New Zealand there is evidence of glacial ice action during Triassic time. Doubtful indications of Cretaceous and Eocene glaciation come from Italy, and the record herein reported is derived from a study of the Eocene till in southwestern Colorado. The Icelandic glacial records are of Miocene age, and there are Miocene deposits in Italy which may be of glacial origin. The Pleistocene record is found in all the high mountains of the world, in great lowland areas in North America and Europe, and in the Arctic and Antarctic regions. Since Pleistocene time glacial conditions have continued in many parts of the world and are still present at high altitudes and in high latitudes.

An inspection of the table should also bring out with some emphasis the occurrence of glacial epochs at the opening of each of the great eras of geologic time. Possibly the pre-Cambrian records are separated by periods of time as long as the Paleozoic or Mesozoic eras, which intervened between later records of ice action. This distribution of glacial records in the history of the earth appears to have some real significance and recalls the profound studies of T. C. Chamberlin on the causes of glacial climates. Each great geologic era was closed by a great physical revolution, which brought vast areas above the sea and therefore subjected those areas to the processes of weathering and erosion. By such revolutions the areal extent of the seas was reduced and the distribution of lands and seas changed. These changes have undoubtedly been great factors in determining the climates of the earth. They have affected the movements of ocean currents and the distribution of precipitation and of different temperatures. Possibly these great physical changes have had so profound an influence upon the climates of the different portions of the earth that they have been fundamental causes of the great glacial epochs. The lesser glacial epochs may have been associated with periods in which lofty mountains were being made. The glacial records surely suggest a field of most significant research.

Geologic and geographic distribution of reported evidence of glacial deposits.

Geologic time scale.			Geographic distribution.
Cenozoic.	Quaternary.	Recent.	High latitudes. High altitudes.
		Pleistocene.	Northern North America. Northwestern Europe. High latitudes. High altitudes.
	Tertiary.	Pliocene.	
		Miocene.	Iceland.[a] Italy.[b] Italy.[c]
		Oligocene.	
		Eocene.	Southwestern Colorado.[d] Italy.[b]
Mesozoic.	Cretaceous.		Italy.[b]
	Jurassic.		
	Triassic.		New Zealand.[e]
Paleozoic.	Carboniferous.	Permian.	South Africa.[f] South Australia.[g] West Australia.[h] Tasmania.[i] South America.[j] India.[k] East Falkland Islands.[l] Boston Basin, Mass.[m] Germany.[n] England.[o]
		Pennsylvanian.	
		"Mid-Carboniferous."	Oklahoma.[p]
		Mississippian.	
	Devonian.		Doubtful evidence from England.[q] South Africa.[r] Canada.[s]
	Silurian.		
	Ordovician.		
	Cambrian.		China.[t] Australia.[u]
Proterozoic.			Canada.[v] Norway.[w]

Footnotes on page 26.

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