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PHYSIOGRAPHY AND QUATERNARY GEOLOGY OF THE SAN JUAN MOUNTAINS, COLORADO

BY

WALLACE W. ATWOOD

AND

KIRTLEY F. MATHER

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PHYSIOGRAPHY AND QUATERNARY GEOLOGY OF THE SAN JUAN MOUNTAINS, COLORADO

By Wallace W. Atwood and Kirtley F. Mather

Chapter 1.—INTRODUCTION

GEOLOGIC WORK IN THE SAN JUAN MOUNTAINS

The scenic beauty, rugged contour, and great variety of geologic phenomena displayed by the San Juan Mountains of southwestern Colorado have lured to that region many geologists, both professional and amateur, as well as countless laymen. Serious geologic studies in these mountains seem to fall historically into three periods. The first of these covers the work of the geologists and topographers of the United States Geological and Geographical Survey of the Territories. Field studies were prosecuted under the general direction of F. V. Hayden in this region from 1869 to 1876, and the results obtained were published among the monographs of the Hayden Survey. The second period of geologic examinations began in 1887, when Whitman Cross undertook investigations of certain of the mining districts in the San Juan region, which by that time had attracted much attention in the mining world. The results of this second series of studies have appeared from time to time as folios of the Geologic Atlas and reports on the economic geology of the mining districts, published by the United States Geological Survey between 1899 and 1910. Gradually the concept of the geologic problems was changed. Instead of considering individual mining districts as the units of investigation it became apparent that the San Juan region must itself be the unit. In 1908 Mr. Cross drafted plans for the completion of the San Juan studies on this enlarged basis. His aim was to arrange for the publication of papers on different subjects rather than one huge monograph on the region as a whole.

As the work progressed it was found necessary to give more and more time to the study of topographic forms and the geology of surficial deposits. In a letter dated June 13, 1908, Mr. Cross wrote:

> The physiographic development of the San Juan area, from the end of the volcanic accumulations in later Tertiary time to the present, including glaciation during several epochs and the final production of the present topography, is another major subject. I wish to see that subject adequately discussed in a manner comparable with the treatment contemplated for the other parts of the geology.

Thus began the third phase of geologic studies. Each of the great problems, such as the volcanic history, the stratigraphy, and the physiographic development, has been handled as a unit and, so far as possible, under the direction of a specialist in the particular subject.

In February, 1909, Wallace W. Atwood agreed to take the responsibility of the study of the physiography and Quaternary geology of the San Juan region in cooperation with Mr. Cross. Allen D. Hole had previously made special studies, under the direction of R. D. Salisbury, of the glacial phenomena of the western portion of the region. Some of the results of his work have been published independently. The unpublished material is incorporated in the present report. Ernest Howe, who for several years had been associated with Mr. Cross, had been giving especial attention to the surficial deposits and glacial features. As a result of his work two papers have been published, one on glaciation and one on landslides. In addition a large amount of unused information had been procured, some of which has been incorporated in this report.

Mr. Atwood joined Mr. Cross in the field for a few weeks during the summer of 1909, most of which was spent in the higher mountains of the San Cristobal quadrangle. Systematic mapping was begun in 1910, with Kirtley F. Mather as assistant. Mr. Mather has remained associated with Mr. Atwood throughout the subsequent work in field and office. Field work was conducted each summer for several years except in 1912. In 1917 demands upon the Geological Survey for concentration of all its energies on subjects connected with the World War interrupted the work in the San Juan region, and it was not resumed until 1920, when Mr. Atwood was again able to continue the San Juan studies. At this time Mr. Mather was engaged in geologic work in South America; but in the summer of 1922 both geologists were again in the San Juan region. Finally, in the summer of 1924, Mr. Atwood spent a month in revisiting critical localities and extending the physiographic studies into adjacent ranges of the southern Rocky Mountain system for purposes of correlation.

Each winter, following a summer season in the field, office work was prosecuted as opportunity afforded. This work involved the compilation of data upon the maps, the revision of notes, and the preparation of special reports. The writing of the final report was begun in 1923 and completed in 1925.

At several stages during the progress of work in the field preliminary statements of results thus far obtained have been made. These statements in a measure record the growth of the ideas and knowledge of the authors during the 13 years of field work. They are listed in the bibliography of North American geology.[1]

ACKNOWLEDGMENTS

It is a pleasure to record our grateful acknowledgments to many geologists and fellow workers, whose hearty support and cordial cooperation have made possible the completion of this work. The late C. W. Hayes was chief geologist at the time that we began our studies in the San Juan region, and he, in company with many other members of the Geological Survey, gave us most cordial support and many useful suggestions. M. R. Campbell has at all times shown an especial and most appreciative interest. Special thanks are due to Arthur Keith, F. L. Ransome, and Sidney Paige, who in turn have had the responsibility of directing this work while in charge of the section of western areal geology. We are glad also to express our appreciation to Waldemar Lindgren, David White, and W. C. Mendenhall, who, as chiefs of the division of geology, have at all times given us the staunchest support.

Most especially, however, we wish to acknowledge the cooperation and enthusiastic support of Whitman Cross, which have won the lifelong appreciation of both authors. His intimate knowledge of the geology of the San Juan region has been of inestimable value in the discussion of physiographic problems. We wish, also, to record our appreciation of the hearty cooperation which has been given by Mr. Cross's associates and assistants, among whom we would mention specifically E. S. Larsen, the late J. Fred Hunter, and C. S. Ross.

Arthur Iddings rendered very efficient service as field assistant during the seasons of 1915 and 1916. Robert E. Webb and Preston E. James ably assisted Mr. Atwood in the season of 1920, and Ralph G. Lusk served capably as assistant to Mr. Mather in the season of 1922. Finally we wish to express our thanks to a score or more of camp helpers who have shared the pleasures and hardships of life in camp and of moving with a pack outfit through the high mountains.

[1] Nickles, J. M., U. S. Geol. Survey Bulls. 746 and 823.

METHODS OF WORK

Although this study of the San Juan Mountains has been essentially physiographic, we have tried, as far as possible, to keep our field methods fundamentally geologic. Throughout much of the area we have attempted to recognize and map all formations of Quaternary age. Thus we have kept constantly in mind the preparation of an areal geologic map on which all Quaternary formations would be accurately and adequately portrayed. This aim has involved the survey of practically every square mile of the San Juan region, for Quaternary débris is likely to be present in almost any part of the region.

The mapping of the Quaternary formations has been paralleled by the mapping of physiographic surfaces. The physiographer must analyze all surfaces in a region under survey, classifying them so far as possible genetically. A peneplain, for example, is a definite though not necessarily a horizontal surface, comparable to the surface of a bed of rock. Rock strata may be folded or faulted; similarly a peneplain may be deformed and thus rendered difficult to trace. At places it may be buried beneath younger deposits. With this idea in mind, the remnants of peneplains or other graded erosion surfaces recognized in the field were mapped as such wherever they form the surface of the country.

In many places between the remnants of a highly elevated peneplain and the beds of the master streams may be found intermediate graded surfaces which represent the floors of valleys during cycles of erosion that were interrupted before completion. These surfaces may be considered to mark definite physiographic horizons. They are best developed in the larger valleys and may be entirely lacking in the vallays of smaller tributaries. As a rule, the remnants of these intermediate surfaces have a somewhat dendritic form as they follow the valleys. Although they are not so continuous nor generally so extensive as a peneplain or a rock stratum, these intermediate levels should be recognized by the physiographer in the field and may, if care is used, be denoted on his map. Between the peneplain remnants and the intermediate levels there are slopes that were being developed while the streams were working to the successive base levels of erosion. These slopes are significant physiographic surfaces; they should be recognized in the field, and they may also be indicated on a good topographic map. Below the most recent surfaces which have been brought to grade the slopes as a rule are being sculptured in the process of development of the modern flood plains and drainage channels. These slopes are related to the modern valley bottoms in much the same way as the upper slopes are related to the abandoned levels. At many localities the intermediate valley floors of earlier cycles have been entirely obliterated, and the younger slopes extend up the hill to blend into the higher slopes of the ancient peneplain surface. Here there is physiographic unconformity. Two physiographic surfaces, separated in origin by an interval of time and by the development of another physiographic surface, thus come into contact with each other. Such physiographic unconformity may be clearly appreciated in the field and may be represented on an areal physiographic map.

The physiographer who has this conception of his task will classify all surfaces of the land, and with care may represent on a map the remnants of each surface, whether it is flat or inclined. The making of the map certainly adds definiteness to the field work, and when it is completed the graphic form of representation is of great value in making clear the several stages of erosion that have marked the history of the region studied. With this in mind, our field work included the drafting of a physiographic areal map more or less similar to the geologic areal map showing Quaternary formations. Thus, at all times our attention was focused upon the necessity of explaining the origin of each of the land forms observed and of discovering the sequence of events in the physiographic history of the region. The second half of this task obviously involved a careful examination of the relations between the physiographic surfaces and the geologic structure of the underlying rocks. It was early discovered that certain geologic formations had each its own individual and characteristic topographic expression. It therefore became necessary for us to know in considerable detail the bedrock geology of the areas surveyed. It was in this phase of our work that the close cooperation and frequent conferences with Mr. Cross and his associates proved to be of the greatest value.

The constant application of geologic methods to the physiographic studies helped greatly in the interpretation of the varied features of the landscape. Day by day we consciously strove to interpret each individual feature. A mountain peak would be satisfactorily interpreted only when the relative importance of various agents of erosion—atmospheric, fluviatile, glacial, etc.—had been estimated; at the same time knowledge of its relations to graded surfaces, peneplains, mature valleys, or modern canyons was obviously essential to an adequate statement of its origin. Each mountain canyon presented an individual problem, involving the presence or absence of glaciers and the relations between its erosion and the development of quondam graded surfaces. As a rule, the foothills presented problems in the relations between erosion and structure, with the omnipresent question of erosion cycles constantly before us. A bench or shoulder on a hillside or terraces within the valleys were eagerly sought as clues to the solution of the many problems of mountain history. Each such surface must be explained before one could be satisfied with his work. Undrained depressions, because obviously not the result of normal stream erosion, were likewise considered hints toward the solving of problems, as well as challenges to our intelligence.

All these phases of our work dealt solely with inanimate nature. The true physiographer has learned, of recent years especially, to look upon his science as having most intimate connection with man and his activities. Thus we welcomed the opportunity of observing at first hand the relations between the physiography of mountain, plateau, or valley and the human settlement and life in the region. The changing trend of human interest in this vast area, with its varied resources and climate, was indicated by abandoned mining camps near timber line or by busy ditching machines engaged in the extension of the net work of irrigation canals in the valleys among the foothills. Nearly every day's work had its reward in some new discovery concerning the geographic factor in human life or some added bit of information to strengthen a previously established principle. Thus the physiographer retains fully as much of human interest in his work as the mining geologist with his constant emphasis upon economic resources.

Chapter 2.—GENERAL GEOGRAPHY

LOCATION AND EXTENT OF THE REGION

The area under consideration in this report includes the San Juan Mountains and a large extent of surrounding plateaus and lowlands in the southwestern part of Colorado and the adjacent part of New Mexico. The rugged peaks and lofty ridges of the San Juan Mountains occupy an area 90 miles long from east to west, with an average width of 70 miles from north to south. With the exception of the far southeast corner of the mountains, which extends a few miles southward into New Mexico, all are within the State of Colorado. They lie between longitudes 106° and 108° west. The northern outposts touch latitude 38° 15′ north, and the southern margin near the east front of the range is close to 36° 30′.

The name San Juan is applied, however, not only to these mountains but to the adjacent plateaus, extending for great distances to the south, southwest, and west. Thus local usage justified the application of the name "San Juan country" to the entire southwest corner of Colorado, the southeast corner of Utah, the northeast corner of Arizona, and the northwest corner of New Mexico. The region thus includes in Colorado Montrose, San Miguel, Ouray, Dolores, San Juan, Montezuma, La Plata, Archuleta, Conejos, Hinsdale, Mineral, and Rio Grande Counties, the southern part of Gunnison County, and the southwest half of Saguache County; in New Mexico much of San Juan County and the north third of Rio Arriba County; in Arizona the northeast corner of Apache County; and in Utah much of San Juan County. The mountains with the neighboring plateaus cover an area of 20,000 square miles. The general geographic relations of this great area are indicated in Plate 1.

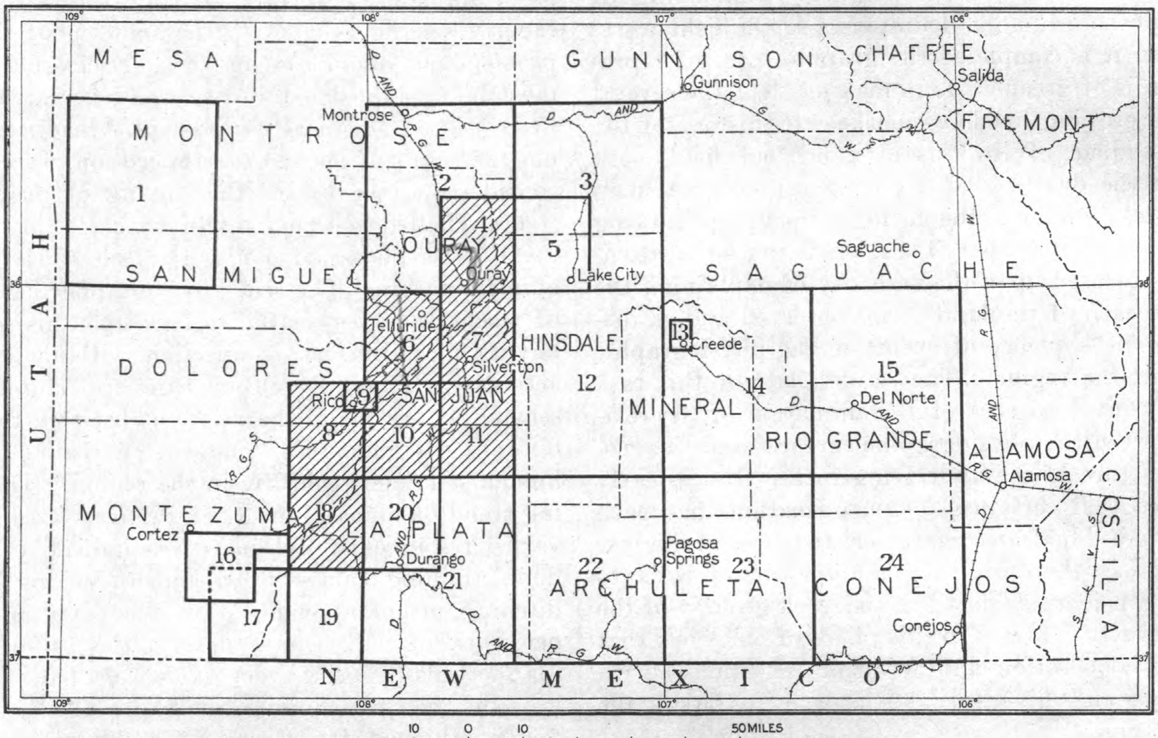


FIGURE 1.—Index map of southwestern Colorado showing locations of quadrangles covered by geologic folios (shaded) and by topographic maps. 1, Paradox Valley; 2, Montrose; 3, Uncompahgre; 4, Ouray; 5, Lake City; 6, Telluride; 7, Silverton; 8, Rico; 9, Rico district; 10, Engineer Mountain; 11, Needle Mountains; 12, San Cristobal; 13, Creede and vicinity; 14, Creede; 15, Del Norte; 16, Mesa Verde National Park; 17, Soda Canyon; 18, La Plata; 19, Red Mesa; 20, Durango; 21, Ignacio; 22, Pagosa Springs; 23, Summitville; 24, Conejos

TOPOGRAPHIC MAPS

Practically all of this vast area was mapped by the topographers of the Hayden Survey, but for detailed physiographic studies the Hayden maps are not of very great service. Much of the region, however, has now been surveyed by the topographers of the United States Geological Survey. The topographic maps that had been prepared prior to 1924 are indicated on Figure 1.

More recently the Pagosa Springs quadrangle (immediately north of the San Cristobal quadrangle) has been surveyed for publication on a similar scale, but the map was not available during the progress of our field work.

These accurate and detailed topographic maps embrace an area of about 9,500 square miles and cover practically all of the San Juan Range with general overlaps beyond the mountain front on all sides except the southeast. The only gaps in the composite San Juan map, based on these detailed surveys, are a 15-minute quadrangle north of the Rico and west of the Telluride quadrangle, and two 30-minute quadrangles east of the Uncompahgre and north of the Creede and Del Norte quadrangles. At present the best available maps of these areas are those of the Hayden Survey and of the United States Forest Service.

That portion of the southeastern extension of the San Juan Mountains in New Mexico south of the Conejos quadrangle which is included in the Carson National Forest has been surveyed by the United States Department of Agriculture. The data thus obtained have served as the basis for preliminary contour maps on a scale of approximately 2 miles to the inch with a contour interval of 100 feet. Photographic reproductions of these maps were available for field work in 1922. Although not so accurate as the maps made by the topographers of the Geological Survey, they served adequately as a base for mapping during the somewhat hasty survey made in that portion of the San Juan region. A few miles south of the Conejos quadrangle is the small Rio Brazos Canyon area, about 10 miles long from east to west and 7 miles wide from north to south, which has been surveyed by the Geological Survey on a scale of approximately 1 mile to 1⅓ inches with a contour interval of 50 feet. Similarly a small portion of the San Luis Valley, a few miles east of the San Juan Mountains, has been mapped on a large scale with great accuracy by the Bureau of Reclamation. Its area is within that of the topographic map of the San Luis Valley,[1] on a scale of approximately 3 miles to the inch, with contour intervals of 10, 50, and 200 feet. This map covers the portion of the San Luis Valley which is within the State of Colorado.

In addition topographic maps on a scale of approximately 4 miles to the inch, with a contour interval of 200 feet, are available for much of the plateau country in New Mexico, Arizona, and Utah. Of the areas covered by these maps, the Abajo quadrangle in Utah, the Canyon de Chelly quadrangle in Arizona, and the Chaco and Largo quadrangles in New Mexico abut more or less closely against the San Juan region. These maps, however, are merely redrawn from the Hayden sheets and are scarcely accurate enough for detailed physiographic work. Finally the excellent topographic map, a model of its kind, which covers the area included in the Mesa Verde National Park should be mentioned. This gives a remarkably faithful representation of the peculiarities displayed by the topographic features of the San Juan plateaus beyond the mountain front.

AREA SURVEYED IN PREPARATION FOR THIS REPORT

In the progress of our work it has been found necessary to make field studies which may be roughly grouped in three categories: (*a*) Detailed physiographic mapping, with careful survey of all geologic deposits of Quaternary age; (*b*) generalized physiographic mapping, with reconnaissance survey of geologic deposits of Quaternary age; (*c*) reconnaissance examination and correlation of physiographic features and Quaternary geology. The area surveyed in detail according to the first of these three categories is approximately coextensive with the published topographic maps on the 15-minute or 30-minute scale. Surveys of this nature cover almost 10,000 square miles. The region examined more hastily and embraced within the second category amounts to a little more than 1,000 square miles. It includes the northern part of the Pagosa Springs quadrangle, a portion of the Mesa Verde National Park, a small area north of the Montrose quadrangle covered by maps drawn by the engineers of the Gunnison irrigation project, most of the Rio Brazos Canyon area, and certain other areas both north and south of the quadrangles mapped by the Geological Survey.

Several trips have been made beyond the area for which suitable maps were available, with the purpose of gathering data for correlating studies in various parts of the San Juan region and furnishing a basis for comparison of the San Juan history with that of surrounding regions. As a result areas aggregating about 6,000 square miles have been covered by reconnaissance surveys. These trips included an expedition southwest from Mancos, a journey from Mancos northward skirting the western front of the San Juan Mountains and terminating at Ouray, brief journeys west of the Montrose quadrangle on the Uncompahgre Plateau, an examination of the northern part of the quadrangle north of the Creede, a trip across the San Luis Valley from Del Norte to the west front of the Sangre de Cristo Range, a brief examination of the west front of that range from Blanca Peak south to Taos, several traverses across the Rio Grande Valley in northern New Mexico and a journey down that valley as far as Santa Fe, a reconnaissance of the central portion of the Pagosa Springs quadrangle, a trip

[1] Siebenthal, C. E., U. S. Geol. Survey Water-Supply Paper 240, pl. 1, 1906.

down the Los Pinos River south of the Ignacio quadrangle to its junction with the San Juan and thence across the plateau to the Animas, and two reconnaissance expeditions into the adjacent "Navajo country" of northwestern New Mexico, one of which covered the area between Farmington and Gallup.

After the completion of the field work in the San Juan region Mr. Atwood spent a month during the summer of 1924 in other ranges of the southern Rocky Mountain system with the purpose of attempting a correlation of the physiographic development of the several mountain groups. This involved a review of the work of Davis,[2] Lee,[3] and others in the Front Range and a brief visit to the Sawatch Range and South Park.

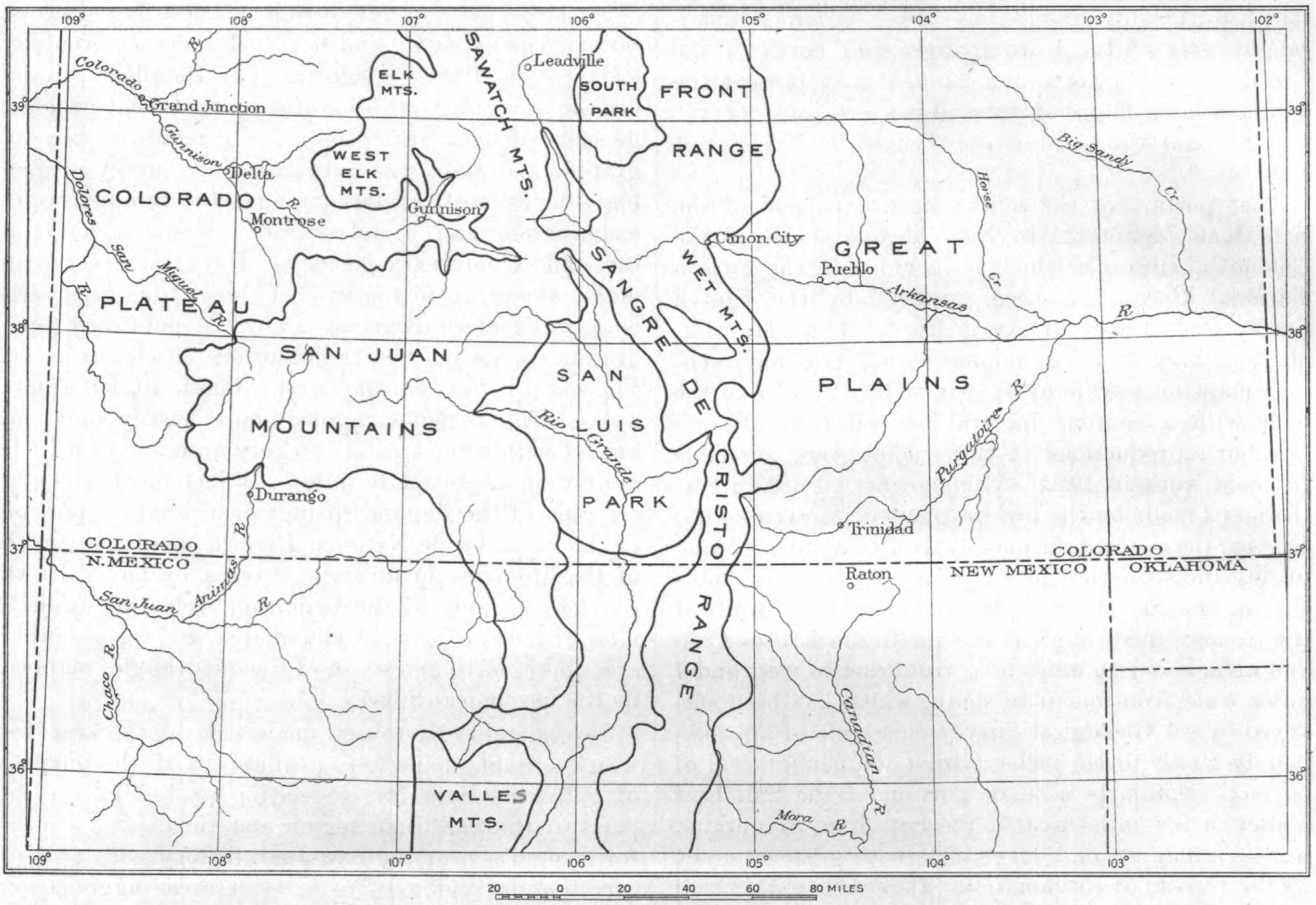


FIGURE 2.—Physiographic provinces of southwestern Colorado and northwestern New Mexico

GENERAL PHYSIOGRAPHIC RELATIONS

The general relations between the San Juan area and adjacent parts of the Rocky Mountain region are indicated on Figure 2. The San Juan Mountains form an outlying group of the southern Rocky Mountains, situated at the west margin of the continuous belt of mountain ranges that extends from central New Mexico northward through Colorado to southern Wyoming. The rest of the San Juan region falls in the physiographic province ordinarily referred to as the Colorado Plateaus.

The San Juan Mountains are a well-defined group of high, rugged mountains, almost entirely surrounded by lowlands or plateaus. The northern limit of the group encroaches upon the valley of the Gunnison River, which trends westward from Marshall Pass to join the valley of the Colorado River at Grand Junction. The Gunnison Valley is generally rather broad and is nearly everywhere bordered by plateaus, which gradually increase in height toward the West Elk Mountains to the north and toward the San Juan Mountains to the south. Thus along their north margin the San Juan Mountains are separated by a distance of at least 20 miles from the next range of the Rocky Mountains. Only at the northeast is there a line of hills, the Cochetopa Hills, which bridge the gap and in a sense tie the San Juan group to the Sawatch Range and thence to other ranges of the Rocky Mountains.

At the east the San Juan Mountains are everywhere separated widely from the eastern range of the Rocky

[2] Davis, W. M., The Colorado Front Range, a study in physiographic presentation: Assoc. Am. Geographers Annals, vol. 1, pp. 21–84, 1911.

[3] Lee, W. T., Peneplains of the Front Range and Rocky Mountain National Park, Colorado: U. S. Geol. Survey Bull. 730, pp. 1–17, 1922.

Mountains by the San Luis Valley, a meridional trough extending from a point only a few miles south of Salida, Colo., nearly to Santa Fe, N. Mex. East of this great valley the Sangre de Cristo Range is the southern extension of the Front Range of the Rocky Mountains.

At the western margin of the San Juan Mountains there are three more or less isolated mountain groups—the La Plata Mountains, the Rico Mountains, and, in somewhat the same category, Mount Wilson and its neighbors, which, although separate from the San Juan group in a geologic sense, are so closely situated that it is customary to include them as part of the San Juan Mountains. From these western summits one may look for scores of miles across the neighboring lowlands and plateaus and see on the far horizon isolated mountains, mostly of laccolithic origin, which rise near the Utah-Colorado boundary line.

The southeast margin of the San Juan Mountains extends southward into New Mexico, where the mountains decline in height and gradually give place to low country. At 40 miles south of the Colorado line the broad valley of the Chama River intervenes between the San Juan Mountains and the next group on the south, the compact Valle Mountains, 20 to 30 miles south of the San Juan Mountains and a similar distance west of the Rio Grande.

Thus the San Juan Mountains may be briefly described as bounded on the north by the Gunnison Valley, on the east by the San Luis Valley, and on the southeast by the valley of the Rio Grande and its tributary, the Chama River, while on the west and southwest the mountains rise boldly above the adjacent portions of the Colorado Plateaus.

The San Juan Mountains.—An adequate physiographic study of the San Juan Mountains must necessarily include an examination into the relations between the mountains and the contiguous lowlands on all sides. Local usage applies the name San Juan not only to the mountains but to the adjacent portions of each of the bordering lowlands. The physiographer's extension of the term "San Juan region" to include all the area of mountains and adjacent lowlands is therefore justified. The relief features of the region, as thus defined, run the entire gamut from lofty mountain peaks through every variety of foothill, mesa, plateau, or butte to valleys that range from precipitous canyons to broad, gently sloping intermontane basins.

Although no one of the peaks among the San Juan Mountains bears the unique distinction of being the loftiest in the United States or even in the State of Colorado, the number of summits that fall short of this distinction by only a few score feet is considerable. There are at least 13 mountains with altitudes of more than 14,000 feet. The highest is Uncompahgre Peak (pl. 4, *A*), 14,306 feet above sea level, situated near the north margin of the mountains, 10 miles northwest of Lake City. Second in height is Mount Wilson (pl. 4, *B*), 14,250 feet above the sea, which is also near the mountain front but on the west margin, 12 miles southwest of Telluride. The third is San Luis Peak, 14,149 feet high, in the northwest corner of the Creede quadrangle, near the heart of the range. Next comes Sneffels Peak (pl. 5, *B*), 14,143 feet above sea level, and likewise at the very margin of the mountains, 7 miles west of Ouray. The next in order are Window Mountain, 14,084 feet; Mount Eolus, 14,079 feet; Sunlight Peak, 14,053 feet; Redcloud Peak, 14,050 feet; an unnamed peak near Mount Eolus, 14,030 feet; Wilson Peak, 14,026 feet; Sunshine Peak, 14,018 feet; Wetterhorn Peak, 14,017 feet; and Handies Peak, 14,008 feet. Crowding close behind these leaders are more than a score of peaks with altitudes close to 14,000 feet, most of which are near the center of the range, in the general vicinity of Silverton.

The forms of the individual mountain peaks are extremely varied. The more characteristic or noteworthy summits are described at greater length in a subsequent chapter. Here it is sufficient to call attention to the fact that many are sharp-pinnacled crests of the type to which the term "needles" is spontaneously applied. Uncompahgre Peak is a truncated pyramid with a large triangular surface at the summit. Many are pyramids with fairly sharp points; Mount Wilson and Rio Grande Pyramid are characteristic. Others of the higher summits are wide, flat areas; the Continental Divide at several places traverses broad upland meadows, as in the northeast corner of the Needle Mountains quadrangle. A few of the summits are broadly rounded.

As might be expected in a mountain group of so great extent as the San Juan, individual portions are known by local names. The north front, west of Ouray, is locally referred to as the Sawtooth Mountains, because of its extremely serrate sky line. The group of peaks culminating in Mount Wilson at the west front is sometimes called the San Miguel Mountains, inasmuch as it is drained by the headwaters of the San Miguel River. The group of sharp-pointed peaks south of Silverton is known as the Needle Mountains, and one long line of these has been named the Grenadier Range. As already mentioned, the mountains around Rico and the La Plata Mountains, 20 miles farther south, are in reality separate units grouped with the San Juan Mountains merely because of their proximity.

The mountains between the Rio Grande and the Saguache River, at the northeast, are known as the La Garita Mountains. Still farther north the Cochetopa Hills, at the east side of the San Juan Mountains, connect them by way of Marshall Pass with the Sawatch Range. The mountains in the vicinity of the Conejos River, near the southeast margin, are sometimes referred to as the Conejos Mountains. Finally, the long southward extension of the San Juan Mountains along the west side of the Rio Grande Valley in New Mexico is designated the Tusas Mountains.

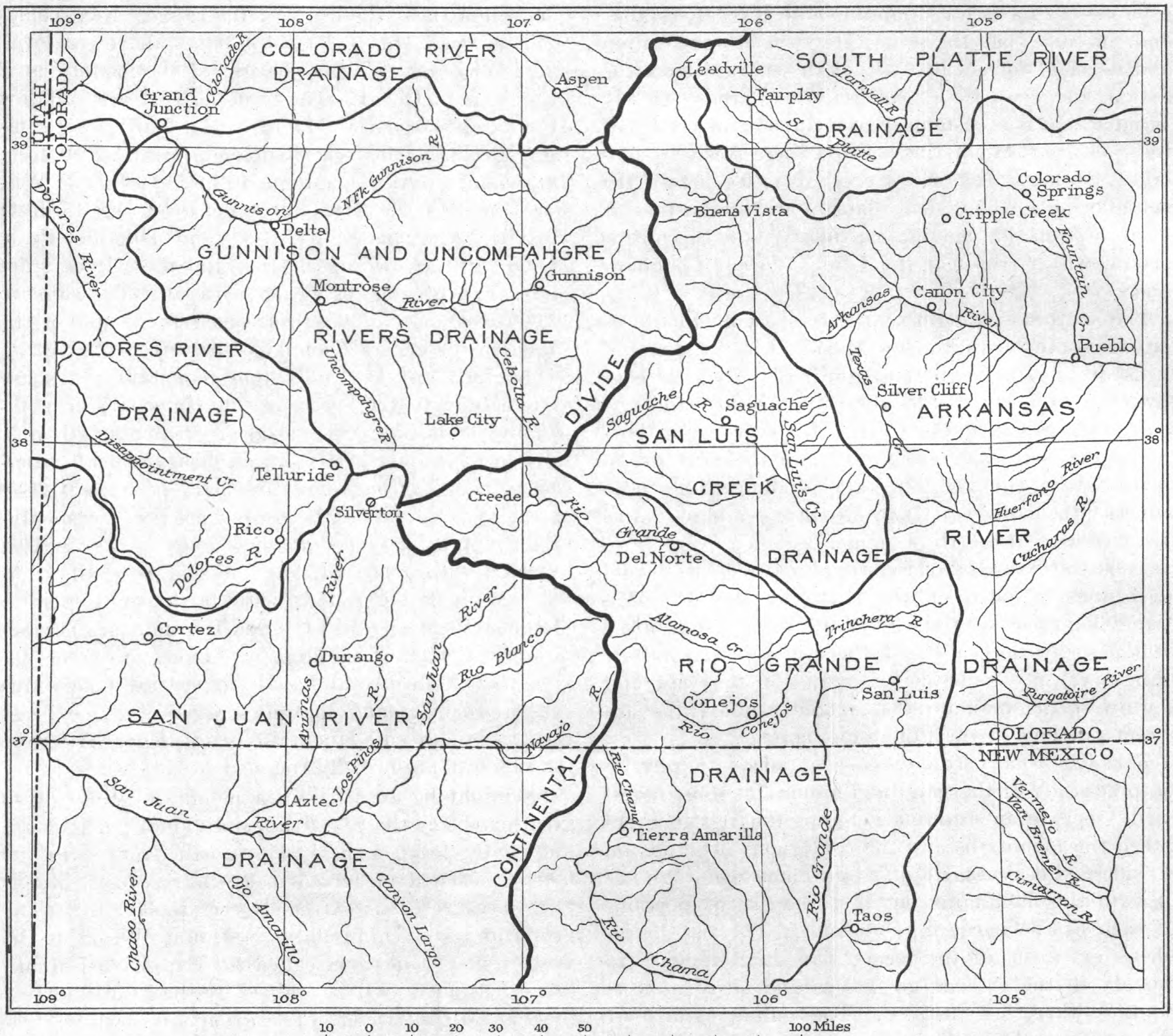


FIGURE 3.—Major drainage systems of the San Juan Mountains

Drainage.—The master streams and main drainage basins of the San Juan region are indicated on Figure 3. Many of the rugged, lofty summits are in close proximity to the Continental Divide, separating the drainage of the Rio Grande, which empties into the Gulf of Mexico, from that of the Colorado, which empties into the Gulf of California. This divide enters the San Juan region at the northeast and may be traced from Marshall Pass southward along the crest of the Cochetopa Hills to the mountain summits immediately north of Creede. Thence it continues far to the west across the north half of the San Cristobal quadrangle. Curving southward, the Continental Divide traverses the southeast quarter of the Silverton quadrangle and the northeast quarter of the Needle Mountains quadrangle. Thence it swings sharply toward the east, crosses the south half of the San Cristobal quadrangle, and bends southward across the southwest corner of the Creede quadrangle. It passes diagonally from a point near the northwest corner of the Summitville quadrangle to a point near the southeast corner of the same quadrangle, whence it continues southward into New Mexico west of Chama.

The larger tributaries of the Rio Grande in the San Juan Mountains have U-shaped profiles as a result of recent glacial erosion. Others, more commonly the smaller ones, are V shaped in cross section, an indication of the present vigor of stream erosion. The master streams are in most parts of the range working at levels 5,000 or 6,000 feet below the adjacent summits. All the longer streams traverse rocks of varying resistance to erosion, and hence show varied types of topography at different places along their courses.

In general, the valleys of the master streams display a radial plan, extending outward from the central part of the mountains toward their margins. As a rule the upper courses of these valleys within the mountains are deep, narrow, and rugged canyons. In the marginal belt of foothills the canyons broaden and become shallower, and the valley sides are deeply dissected and broken. Beyond the foothills the streams traverse a belt of lowland and the valleys take on the characteristics of old age. At 20 or 30 miles from the mountain front each of the streams of the Colorado drainage system plunges into a narrow canyon, through which it traverses the dissected mesas of the Colorado Plateaus. The Rio Grande, on the other hand, continues for a long distance upon the flat floor of the intermontane basin known as the San Luis Valley.

Plateaus.—Except on the east and north the San Juan Mountains are bordered by the Colorado Plateaus. Of these the Mesa Verde, southwest of the La Plata Mountains, is typical. (See pl. 5, *A*.) It is a dissected plateau, carved by running water into long, narrow strips of flat upland separated by steep-walled, narrow canyons. Near the mountains the plateau surfaces are generally between 7,000 and 8,000 feet above sea level, and the canyons traversing them are in places as much as 1,000 feet deep. Southward and westward from the mountains the plateau surfaces decline gradually with slopes of 10 to 30 feet to the mile, but, as the streams have a similar gradient, the canyons between the uplands maintain approximately the same depth.

The extensive plateau that stretches for scores of miles northwestward from the mountain front between the Uncompahgre-Gunnison and San Miguel drainage basins is known as the Uncompahgre Plateau. South of it, in the drainage basin of the San Miguel River, is the deeply carved, much dissected San Miguel Plateau. Next in line at the southwest is the Mesa Verde, east of which are many isolated uplands overlooking the Mancos River and its tributaries. Still farther east, a short distance south of the San Juan Mountains, the northern rim of the plateaus drained by the San Juan River is known locally as the Mesa Mountains.

CLIMATE

Climatic conditions in the San Juan country are as varied as the topographic features. Precipitation is heavy on the slopes of the higher mountains, but is much less in the peripheral belt of lowland and scanty in the adjacent plateau country. Ordinarily the mountain trails are snow-bound from October to May. Generally after the last heavy falls of snow in early June there is a period of four or five weeks of comparatively clear weather. Then during the typical short summer of the high mountains there are almost daily thunderstorms, which break early in the afternoon. Again in September there may come another short spell of clear weather before the first heavy snows of the fall. Snow generally accumulates at the higher altitudes to depths of 8 or 10 feet, and snow banks persist from winter to winter in sheltered nooks at altitudes of 12,000 and 13,000 feet.

The temperatures in the mountains are those typical of all such regions, where because of altitude the atmosphere is comparatively rare. Sunshiny days may be even uncomfortably warm and nights as uncomfortably cool. The camper in the mountains should always be provided with an abundance of woolen blankets for his bed and heavy sweaters for evenings and cloudy days. The prevailing winds blow from the southwest, hence precipitation is greater and storms more frequent on the southern and western slopes of the mountains than on the northern and eastern slopes. Local breezes, however, seem to be controlled rather definitely by the topographic features. The up-valley breeze of the forenoon invariably gives way to the down-valley breeze of the late afternoon and evening.

HUMAN RELATIONS

Settlements.—Although as a whole the San Juan Mountains are very sparsely settled, there are in the mountains a number of towns of considerable size, which owe their prosperity to the development of the mineral resources of the region, and in the adjacent lowland several even larger communities, where agricultural development has gone forward in recent years with accelerating pace. Among the mountain towns are Ouray, which in 1930 had a population of 707; Telluride, a city of 512; Silverton, 1,301; Rico, 447; Lake City, 259; and Creede, 384. In the lowland group the leaders are Montrose, with 3,566 inhabitants, on the north side of the mountains, and Durango, with 5,400 inhabitants, on the south side. Of lesser importance are Mancos, at the southwest, with a population of 646, and Pagosa Springs, at the south, with 804. Monte Vista, with a population of 2,610, and Del Norte, with 1,410, are near the margin of the San Luis Valley, on the east side of the mountains.

All these towns are connected by railways, but there is no rail route directly across the mountains. Instead, the range is encircled by railroads, mostly narrow gage, from which long spurs extend up the larger river valleys almost to the center of the mountains. These railways are all a part of the Denver & Rio Grande Western system.

National forests.—The San Juan Mountains are generally covered with a magnificent forest growth, and practically all of the mountainous country is within the boundaries of the national forests. These tracts are so administered by the Forest Service as to yield the greatest benefits from their varied resources. Certain areas are set apart for sheep grazing, and others as cattle lands. Timber is marked for cutting by expert foresters. Trails and roads have been constructed, bridges built, and camp sites designated. In every conceivable way the forests have been made the "people's playground."

A. SUMMIT REGION IN THE MIDST OF THE SAN JUAN MOUNTAINS

View north from saddle east of Dolly Varden Mountain. In the distance, at right, is Uncompahgre Peak (14,306 feet); in the middle is Wetterhorn (13,589 feet). Much of the rolling surface is at or near the San Juan peneplain horizon. High peaks are monadnocks; deep canyons represent the work of streams and valley glaciers during two later cycles of erosion. Photograph by Whitman Cross.

B. MOUNT WILSON

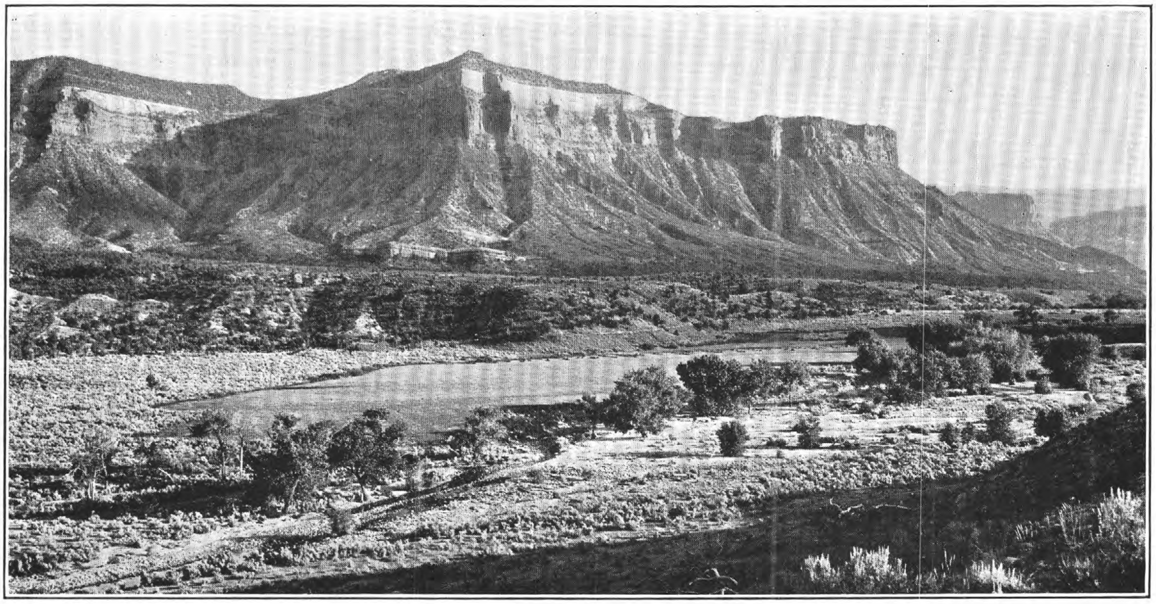
Mount Wilson, 14,250 feet above sea level, is in a group of rugged peaks near the western margin of the San Juan region. Although separated from the San Juan Mountains by wide valleys, the Wilson group has been throughout its geologic history intimately related to the San Juan Mountains. Photograph by Whitman Cross.

A. MESA VERDE FROM THE NORTHEAST

View from a high position south of Mancos, showing the bold escarpment of Mesa Verde and the dark forest on top in left background. At the north end (right) the mesa rises about 1,000 feet above the lowland of the Mancos River Valley. Photograph by Whitman Cross.

B. SNEFFELS PEAK

This peak is a mass of diorite and gabbro cutting up through the bedded volcanic series. This view was taken from the saddle west of Stony Mountain. Sneffels Peak (14,143 feet) is the highest peak in the bold mountain front at the northwest margin of the range. It is a conspicuous monadnock. Photograph by Whitman Cross.



A. LA PLATA SANDSTONE

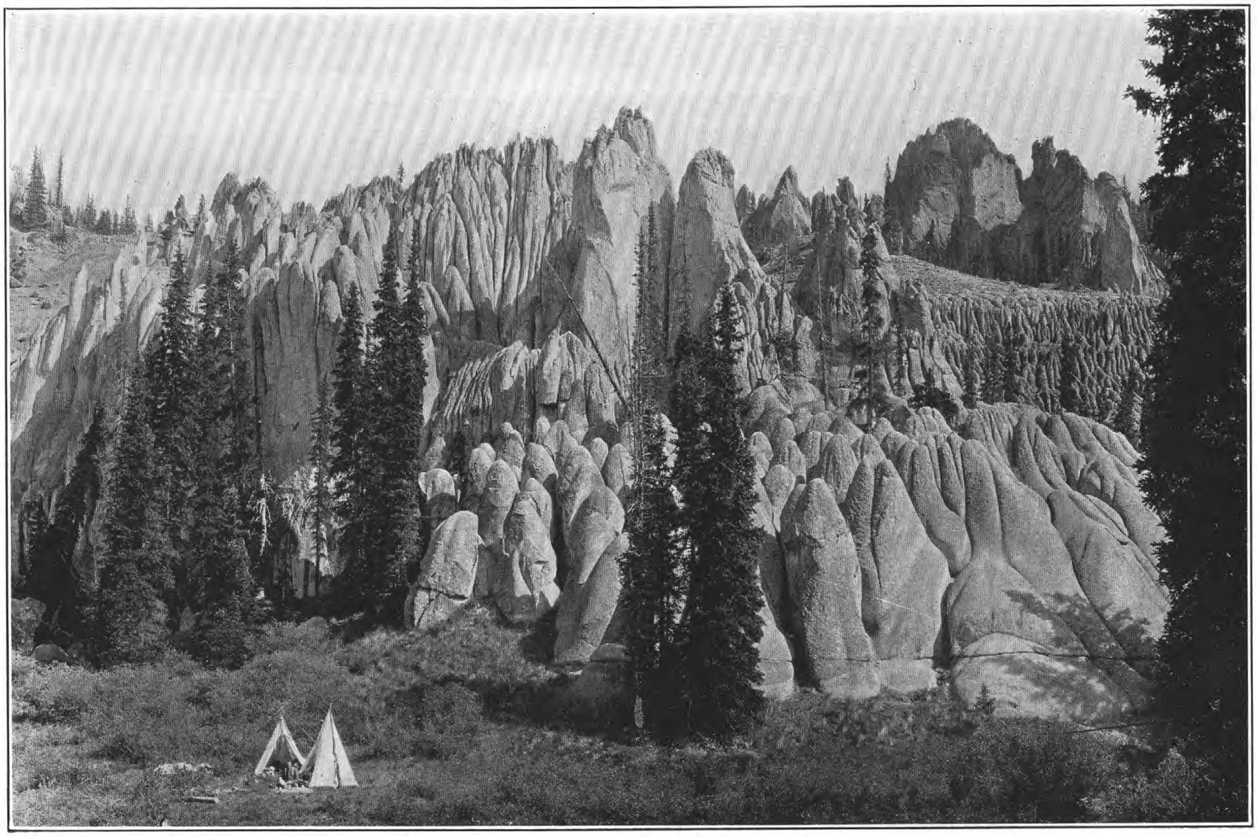
The light-colored band at the top of the cliffs represents the Jurassic La Plata sandstone. Beneath it occur the Dolores (Triassic and Jurassic?) and Cutler (Permian) formations. The view was taken in the valley of the Dolores River. Photograph by Whitman Cross.

B. HERMOSA FORMATION

The bold cliffs at the left are composed of the Hermosa formation. The view was taken from the top of the cliffs west of the Ignacio Reservoir, looking northwestward toward Engineer Mountain and Potato Hill. Photograph by Whitman Cross.

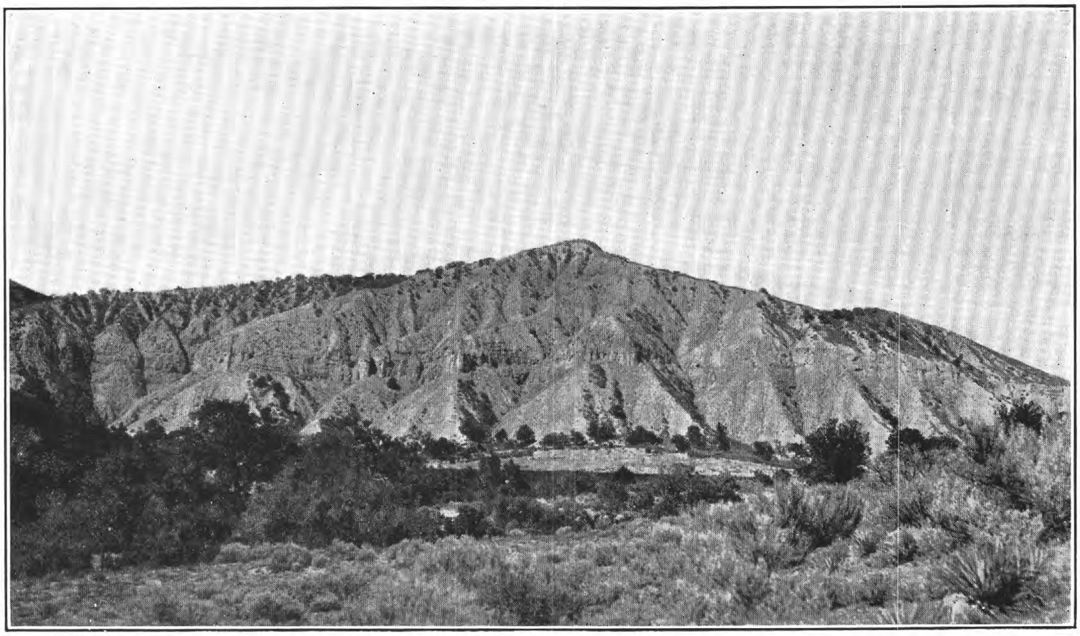
A. NORTHWARD-DIPPING STRATA IN THE UNCOMPAHGRE VALLEY AT OURAY

The clearly defined layers are of Paleozoic and Mesozoic age. They were uplifted and arched at the end of the Mesozoic era. Overlying the sedimentary rocks are thick accumulations of volcanic rocks. The village of Ouray is located on a torrential fan. Photograph by Ernest Howe.



B. PINNACLES AND MINARETS OF TUFF AT WHEELER NATIONAL MONUMENT

These fantastic forms are due to differential weathering of a fine-grained volcanic tuff.



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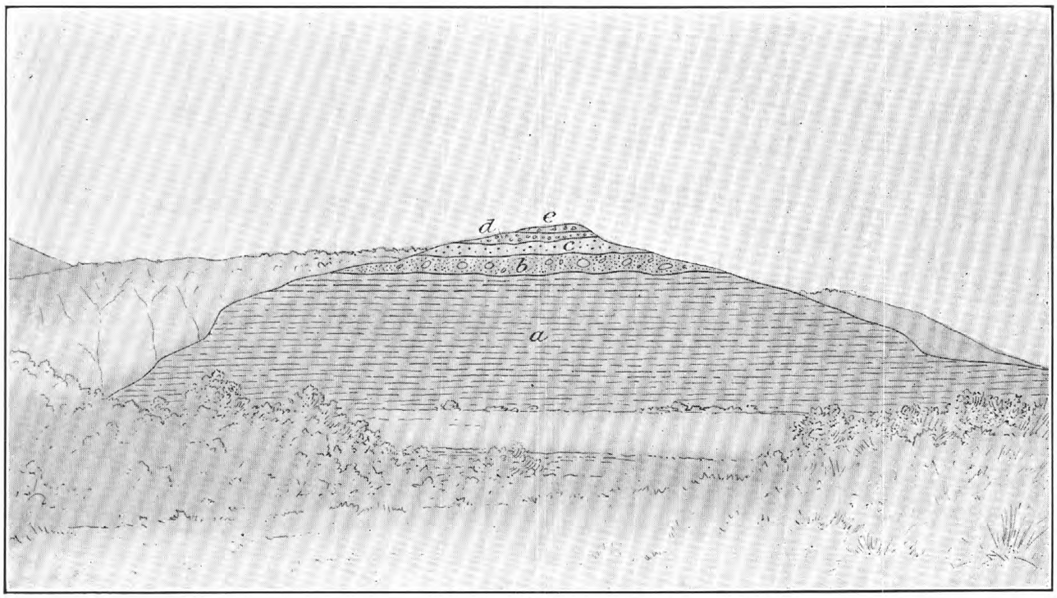
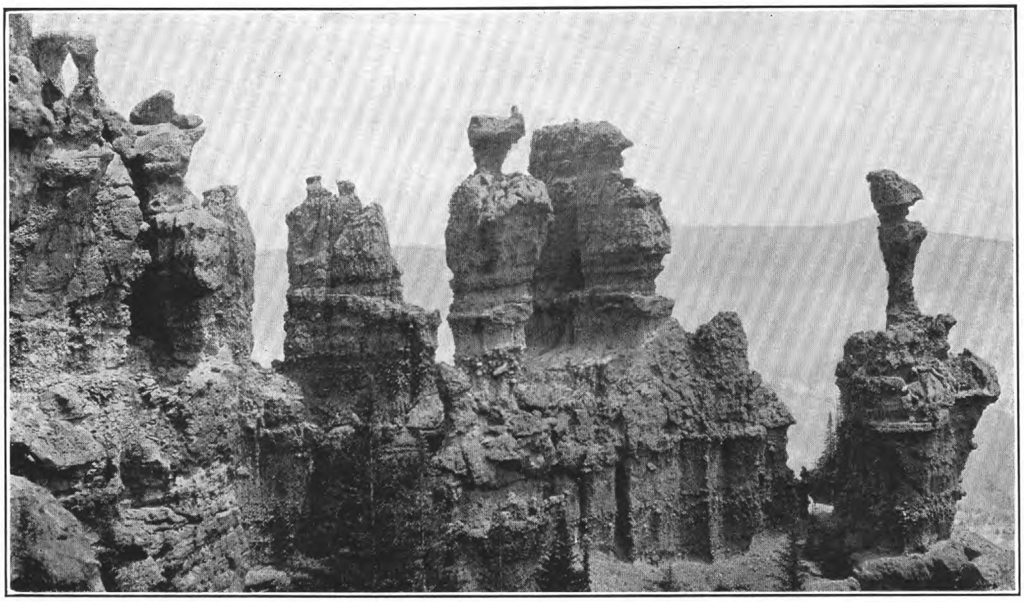


B

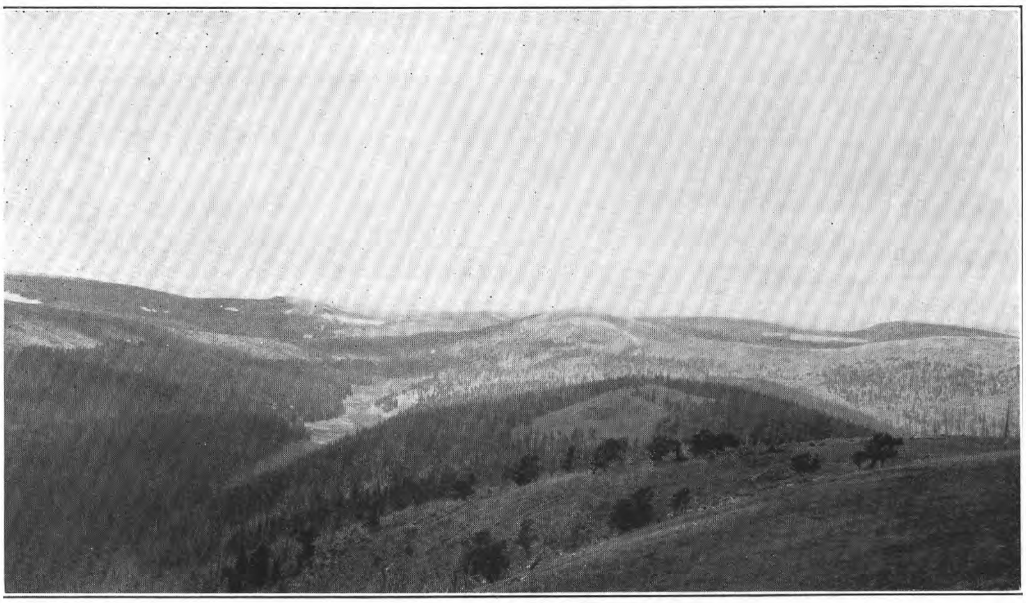
RIDGWAY TILL AT TYPE LOCALITY, 1 MILE WEST OF RIDGWAY

a, Mancos shale; *b*, yellow glacial till; *c*, dark slate-colored glacial till; *d*, Telluride conglomerate; *e*, San Juan tuff.



A. WEATHERING OF VOLCANIC TUFF-BRECCIA

The hoodoolike forms have resulted from the weathering of a mass of volcanic breccia on a canyon wall.



B. EASTERN SUMMITS OF SAN JUAN MOUNTAINS NEAR HEAD OF LA GARITA CREEK, CREEDE QUADRANGLE

Known as Mesa Peak, Bowers Peak, and Boot Mountain. Although each reaches an altitude greater than 12,500 feet, they are in striking contrast to the serrate summits and jagged divides found at similar altitudes in the central and eastern portions of the same mountain range. Remoteness from the major streams and deficiencies in rainfall explain the absence of notable dissection since the broad valleys were carved, during the Florida cycle of erosion. The broad uplands and rounded summits are remnants of the San Juan peneplain.

Chapter 3.—PRE-QUATERNARY HISTORY OF THE SAN JUAN MOUNTAINS

To comprehend the present topography and the more recent geologic history of the San Juan region it is necessary to have a clear picture of the nature of the rocks and the succession of events responsible for their present distribution. In every part of the area the physical features of mountains, valleys, plateaus, and mesas are closely related to the underlying terranes, each of which has its own individual expression in surface features. The present distribution of the many varieties of rocks, each of which has impressed specific characteristics upon the landscape, is the result of a long chain of events and can be understood adequately only in the light of these events. It is therefore necessary at an early stage in this report to depict the background against which are thrown the occurrences of more recent ages, the real subject matter of this paper.

It happens that in the San Juan region the geologic record is unusually extensive and inclusive. Here are exposed rocks of all ages from some among the oldest yet identified in the earth's crust to those of most recent origin. There are, to be sure, many gaps in the record, but viewed in its entirety it can not fail to convey an impression of the remarkable completeness with which the events of geologic time are here recorded.

Fortunately, also, this particular region has been subjected to long and careful examination by many of the most expert of American geologists. As indicated in Chapter 1, the region has for many years been under critical examination by the United States Geological Survey. Under the leadership of Whitman Cross, geologists of that organization have explored all parts of the region and in a large number of publications have placed the facts there obtained before the public. It is our purpose at this time to summarize in convenient though probably somewhat sketchy form this great mass of data in order that it may be readily available to serve as an introduction to the body of this report.

For further details concerning this portion of San Juan history and for descriptions of the great mass of observed phenomena on which the conclusions are based the reader is referred to the reports already published or now in process of publication. Among them the following will probably prove to be of greatest value:

Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 13–26, 1915.

Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1899; La Plata folio (No. 60), 1899; Rico folio (No. 130), 1905; Engineer Mountain folio (No. 171), 1910.

Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 634–679, 1907.

Cross, Whitman, The Triassic portion of the Shinarump group, Powell: Jour. Geology, vol. 16, pp. 97–133, 1908.

Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), 1905; Needle Mountains folio (No. 131), 1905; Ouray folio (No. 153), 1907.

Cross, Whitman, and Howe, Ernest, The Red Beds of southwestern Colorado: Geol. Soc. America Bull., vol. 16, pp. 447–498, 1905.

Cross, Whitman, and Larsen, E. S., Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90, pp. 39–50, 1914.

Cross, Whitman, and Larsen, E. S., The Tertiary history of the San Juan Mountains, Colo. (in preparation).

Emmons, W. H., and Larsen, E. S., A preliminary report on the geology and ore deposits of Creede, Colo.: U. S. Geol. Survey Bull. 530, pp. 42–65, 1913.

Emmons, W. H., and Larsen, E. S., Geology and ore deposits of the Creede district, Colo.: U. S. Geol. Survey Bull. 718, 198 pp., 1923.

Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, 1903.

Hunter, J. F., Pre-Cambrian rocks of Gunnison River, Colo.: U. S. Geol. Survey Bull. 777, 1925.

Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: U. S. Geol. Survey Bull. 478, 1911.

Larsen, E. S., and Hunter, J. F., Melilite and other minerals from Gunnison County, Colo.: Washington Acad. Sci. Jour., vol. 4, pp. 473–479, 1914.

PRE-CAMBRIAN HISTORY

Rocks of pre-Cambrian age compose the great massif of the Needle Mountains and adjacent peaks, in the southwestern part of the San Juan Mountains, and also the greater part of the mountain prong that extends far southward into New Mexico from the southeast corner of the main mass. Similar terranes underlying younger formations have been laid bare in the deeper canyons in many other parts of the region. These rocks are obviously the basement complex upon which the younger sediments and volcanic materials have been laid.

The pre-Cambrian formations may be grouped into three series, and the pre-Cambrian history of this region is divisible into three long epochs, each of which was terminated by episodes of profound crustal movement.

The earliest rocks of which there is any record in the San Juan region are the crystalline schists and gneisses that form the walls of the canyon of the Animas River in the Engineer Mountain, Needle Mountains, and Silverton quadrangles. Similar rocks are exposed in and near the Black Canyon of the Gunnison River, along the northern margin of the San

Juan region, and in the far southeast extension of the San Juan Mountains, as well as in other parts of the region.

These schists and gneisses are intruded by the Twilight granite, a large batholith now exposed in the West Needle Mountains, which culminate in Twilight Peak. A somewhat similar gneissose granite forms innumerable sheets in the walls of the Gunnison Canyon, and elsewhere in the pre-Cambrian complex other masses, presumably contemporaneous with it, may be observed. These extensive intrusions of granitic magmas were probably accompanied by mountain building and were certainly followed by a long period of erosion, which must have been accompanied by deposition, but of the resulting rocks almost none now remain. They are to-day chiefly represented by quartzite and ironstone pebbles in the Vallecito conglomerate and by quartzite inclusions in the Irving greenstone. From the abundance of these pebbles and fragments it is reasonable to assume that strata of considerable thickness must have then accumulated in or near the Needle Mountains. The accumulation of these sediments was accompanied or followed by the second great episode of igneous activity in this region. The injection of basic igneous magma and the accompanying metamorphism produced a complicated series of schists and greenstones to which the name Irving greenstone has been applied. Associated with these schists and greenstones are a few bands of quartzite, in part mashed and schistose, whose structural relations and origin are obscure. The Irving greenstone is best exposed in and near the southeast corner of the Needle Mountains quadrangle, where it forms the walls of Vallecito Canyon and composes Irving Peak, as well as certain neighboring summits toward the east. The crustal movements also elevated the region sufficiently to permit its widespread degradation, and thus an episode of crustal movement, mountain building, and subsequent erosion brought to an end the second of the three pre-Cambrian epochs.

The detritus resulting from long-continued erosion in the interval succeeding the metamorphism of the Irving greenstone supplied the materials for the next younger series of sediments. These materials were obtained from all previously existing terranes and hence consisted dominantly of quartzite, greenstone, schist, and gneiss débris. At first the fragments were coarse, and the Vallecito conglomerate was accumulated. This formation, with its pebbles of vein quartz, purple quartzite, bright jasper, dark amphibolite, greenstone, gray hematite, and chloritic chist, is of special interest to the student of more recent phenomena along the southern slopes of the range. It crops out only in the canyons of Vallecito Creek and the Los Pinos River, near the southeast corner of the Needle Mountains quadrangle, and the distribution of tho easily recognized boulders derived from it and now spread widely over the adjacent lowlands forms a valuable key to the Quaternary history of the region. As erosion progressed, finer materials were deposited, and sedimentation continued without interruption for a very long period. The thick series of quartzites and schists thus formed is known as the Uncompahgre formation and is the most widely distributed of all the pre-Cambrian terranes. It appears at the surface of a large area in and near the Needle Mountains, forms a part of the wall of Uncompahgre Canyon near Ouray, has been recognized at the center of the Rico dome, is trenched by the Piedra River in the Pagosa Springs quadrangle, reappears along the stream courses north of the Cochetopa Hills in the far northeastern portion of the San Juan region, and is exposed along the slopes of the Brazos Valley and in the higher summits near the southeast corner of the range. The distribution of the resistant boulders of purplish quartzite derived from this formation by stream and ice erosion has proved of great assistance in deciphering the more recent history of the region.

The metamorphism of the Uncompahgre quartzites and schists was followed by the intrusion of many granitic batholiths with numerous dikes and apophyses. The largest of these is the Eolus granite, of which Mount Eolus and its neighbors among the Needle Mountains are formed. Another is now exposed about the headwaters of the Los Pinos River in the southwest quarter of the San Cristobal quadrangle. Other bodies of similar age and nature have been trenched by the Piedra River between Sand Creek and First Fork, in the Pagosa Springs quadrangle. Although most of these intrusive rocks consist of granite, more basic material was injected at some localities. Of the rocks thus formed the granodiorite, near the junction of Virginia Creek with the Florida River, in the Needle Mountains quadrangle, and the gabbro, near the southeast corner of the Engineer Mountain quadrangle, are typical.

This igneous activity was accompanied or followed by great orogenic movements that deformed and uplifted the entire San Juan region. Thus was started a long period of erosion which marked the transition from pre-Cambrian to Paleozoic time and ended the third of the pre-Cambrian epochs. Gradually the entire southwestern part of Colorado was reduced well toward base-level, and a peneplain of almost continental proportions was developed. In the beveling process each of the pre-Cambrian rocks was exposed in one place or another at the surface of the nearly level plain and in positions suggestive of the vicissitudes through which it had passed.

PALEOZOIC HISTORY

PRE-DEVONIAN TIME

Very little is known concerning the early Paleozoic history of the San Juan region. In all probability during much of Cambrian, Ordovician, and Silurian time it was part of a large land area. The extensive denudation that marks the transition from pre-Cambrian to Paleozoic time developed a surface of slight relief before the end of the Cambrian period. The lower undulations of this surface were for a time covered by ocean waters. The subsidence was not general, however, for certain parts of the land remained above the sea; these supplied the materials for the deposition in the adjacent shallow basins of the first of the Paleozoic formations, the Ignacio quartzite. This is an extremely variable formation, generally less than 100 feet in thickness, consisting of quartzite with subordinate amounts of sandy shale and conglomerate. This formation contains only scanty fossils, which suggest but can not be said to prove its reference to the Upper Cambrian, the epoch to which it is generally assigned. Only a few small remnants of this formerly widespread formation now exist. These are found chiefly on the southwestern margin of the central pre-Cambrian area, in the Engineer Mountain and Needle Mountains quadrangles. Here the Ignacio beds rest with great unconformity upon the pre-Cambrian complex and are overlain with comparative conformity by middle Paleozoic formations.

DEVONIAN TIME

The rocks next younger than the Ignacio quartzite carry fossil fishes regarded as of Upper Devonian age and indicate that at this time there was a widespread submergence of the entire San Juan region. The strata of the Elbert formation, the earliest deposits then laid down, consist of impure limestone or limy sandstone and shale; these are overlain by the richly fossiliferous marine limestone that forms the basal part of the Ouray limestone.

CARBONIFEROUS TIME

Mississippian epoch.—The Mississippian epoch began at a time when the entire San Juan region was a shallow sea, in which the Ouray limestone was slowly accumulating, for this formation carries Mississippian fossils in its upper beds. After 300 or 400 feet of this limestone had been deposited, most of the land rose a little above sea level, apparently without folding in this vicinity, and the upper part of the Ouray limestone was subjected to erosion. In some places this erosion may have been marine, due to strong currents and wave action. Elsewhere the limestone emerged from the sea and its surface was slightly modified by subaerial erosion which developed deep solution crevices.

Pennsylvanian epoch.—The beds of the Molas formation represent the beginning of a long period of marine sedimentation which continued through all of Pennsylvanian time and into Permian time. The reddish color of the Molas beds may indicate an arid climate, for the iron-stained sediments were thoroughly oxidized before deposition. The deposits are of no great thickness and in places consist of mud and rounded fragments of the older beds. Upon them the sand, clay, and limestone of the Hermosa formation accumulated to a thickness of more than 2,000 feet. This formation is now admirably displayed in the Hermosa Cliffs, which parallel the Animas River in the Engineer Mountain quadrangle. This prominent scarp, shown on Plate 6, *B*, is an expression of the reaction of the Hermosa beds to stream erosion and glacial sapping.

Permian epoch.—Early in Permian time conditions changed, and the clastic sediments of the Rico formation were deposited in the shallowing seas. The sandstones of this formation are coarse and thick and are interbedded with grit and conglomerate which suggest near-shore or even continental origin.

This change from marine to continental sedimentation, begun during the deposition of the Rico formation, was completed in Permian time, as the Cutler formation is almost entirely a continental accumulation. Many of its beds consist of bright-red sandstone or shale. Conglomerate and grit are extremely common. The rare limestone beds are unfossiliferous. From a neighboring upland pebbles of quartzite, vein quartz, flint, granite, and numerous other igneous and metamorphic rocks were transported to the sites of Cutler sedimentation in the San Juan region. Disintegration of the exposed Cutler beds in recent time has liberated these resistant pebbles from their matrix, and they are now scattered broadcast over many surfaces where they may easily be mistaken for Quaternary gravel.

The Cutler is the youngest of the known Paleozoic formations in the San Juan region. In the southwestern part of the region Upper Triassic beds rest upon the Cutler without an obvious stratigraphic break. North of Ouray, however, there is a striking unconformity which indicates that during the transition from Paleozoic to Mesozoic time crustal movement flexed the Paleozoic strata and occasioned considerable erosion in a small part of the region.

MESOZOIC HISTORY

The Mesozoic era in the San Juan region was a time of prolonged accumulation of sedimentary rocks. Strata aggregating approximately 9,000 feet in thickness were laid down over most, if not all, of the region.

TRIASSIC TIME

The San Juan region at the beginning of the Mesozoic era may be pictured as an area of extremely slight relief, situated very close to sea level, but in the northeastern part of the Montrose quadrangle and the north half of the Uncompahgre quadrangle the uplift and crustal deformation that marked the end of Paleozoic time had formed an area of higher land. Here the Paleozoic strata were strongly arched and erosion was going forward aggressively.

In the later part of the Triassic period, and possibly extending into the Jurassic period, the Dolores formation was deposited over all the western half of the San Juan region. Conditions similar to those that had produced the red beds of the Cutler formation had returned. Thus there was built up a second red-bed formation characterized by mottled-gray shale, deep maroon sandstone, and irregularly recurring limestone conglomerate. The Dolores formation attained a maximum thickness of about 2,000 feet, but more commonly throughout the southwestern part of the San Juan region its thickness is several hundred feet less than that, and toward the east as well as the north and west it is commonly less than 500 feet thick.

The accumulation of the Dolores sediments was terminated by an episode of crustal deformation, far greater than any previous crumpling of the earth's crust which had occurred in this locality since the beginning of Cambrian sedimentation. Apparently all of the San Juan region east of a line approximating rather closely the east border of the Ignacio, Needle Mountains, Silverton, and Montrose quadrangles was greatly elevated and compressed into a series of strongly developed folds, complicated here and there by faults.

JURASSIC AND CRETACEOUS (?) TIME

The corrugated uplands of the eastern San Juan region, developed by this deformation, were immediately attacked by the rejuvenated streams of the disturbed localities and by the later part of the Jurassic period were reduced approximately to base-level. Throughout this time the recently accumulated sediments in the western half of the San Juan region had remained practically unaffected either by deformation or by erosion. Hence when sedimentation was renewed throughout the region by the accumulation of the La Plata sandstone, the new strata were there deposited in nearly perfect conformity to the old. East of the above-mentioned line, however, where crustal deformation had been succeeded by profound erosion, the La Plata sandstone overlapped the quondam land mass; consequently its beds transgress the upturned edges of all Paleozoic formations and over large areas rest upon the pre-Cambrian complex itself.

The conditions of La Plata sedimentation were somewhat peculiar. The formation consists in the San Juan region of two massive sandstones, separated by a small thickness of calcareous shale or limestone. The sandstones are of unusual purity, and the glistening white cliffs carved in them add greatly to the scenic beauty of the plateau country bordering upon the mountains. One such cliff is illustrated in Plate 6, *A*. It is possible that this sandstone is, in large part at least, a subaerial deposit, consisting of sand particles blown broadcast over a low-lying plain by the wind.

The 150 to 300 feet of the La Plata sandstone is succeeded conformably by deposits, from 400 to 900 feet in thickness, which have long been known as the "McElmo formation." These deposits display in general an alternation of sediments, shifting between fine-grained quartzose sand and marl or greenish mud, and in places thin beds of gypsum testify to the scarcity of moisture. Recent studies by geologists of the United States Geological Survey have shown that the "McElmo formation" in southwestern Colorado and southeastern Utah is separable into two formations—the Summerville formation, of Upper Jurassic age, and the Morrison formation, of Cretaceous(?) age.[1]

CRETACEOUS TIME

In the San Juan region the Dakota (?) sandstone, the lowest Upper Cretaceous formation, is between 100 and 200 feet in thickness. Thin beds of sandstone with numerous recurring conglomerate zones are separated by sandy shale, which in places carries thin seams of coal. In most localities the Dakota (?) includes one or two massive beds of very resistant sandstone, and these everywhere influence the topographic

[1] U. S. Geol. Survey Press Bull. 16318, July 29, 1927. The following statement is contributed by A. A. Baker, C. H. Dane, and J. B. Reeside, jr.:

Recent field work has shown that the names "McElmo formation" and "La Plata sandstone" have not been uniformly applied in the past. At its type locality in southwestern Colorado and in southeastern Utah the "McElmo formation" contains the Summerville formation, of Upper Jurassic age, and the Morrison formation, assigned with doubt to the Cretaceous. At some localities in the San Juan region it coincides with the Morrison formation and at others includes only part of the Morrison formation. The "La Plata sandstone" in the San Juan region normally includes at its base the Entrada sandstone, of Upper Jurassic age, a middle zone of limestone, of Morrison age, and an upper sandstone, of Morrison age. The Summerville formation is not present. At some localities in the mountains the middle zone is not recognizable, and at others neither middle nor upper zone can be distinguished and the formation consists only of the Entrada sandstone. In extreme western Colorado the name "La Plata" has been applied to the Navajo sandstone, the Carmel formation, and the Entrada sandstone, on the assumption that the three units were the same as those found normally in the San Juan region. This confusion in usage has made it expedient to drop both "McElmo" and "La Plata" for less equivocal names wherever possible, though in the present paper both are applied in accordance with past local usage.

details of the landscape. This sandstone is in many places the rim rock at the top of a canyon wall or at the margin of a mesa surface; especially adjacent to the southwest periphery of the range it is the cause of many a hogback.

With progressive deepening of the Cretaceous sea the strand line evidently moved to some locality remote from the San Juan region, and the sediments accumulating at this locality became progressively finer. Dark-gray mud was piled to a thickness of nearly 2,000 feet to form the clay shale known as Mancos shale. Thin sandstone lenses occur intermittently in the midst of the shale, and near the base there is commonly found a calcareous layer or two, rich in fossil remains of marine invertebrates.

About the middle of the Montana epoch the Cretaceous sea in the San Juan region was very materially decreased in depth. Coarser sediment was washed from the adjacent shores into the region and there accumulated to make the Mesaverde formation. This is a succession of alternating sandstone and shale with a few layers of marl or thin beds of limestone and a number of beds of coal, some of which is of excellent quality. The whole has a thickness ranging between 400 and 1,000 feet. In the lower portion is a massive, coarse cross-bedded sandstone which causes the most prominent scarp of the Mesa Verde and is the rim rock of many an upland flat in the peripheral zone of the San Juan region.

Again the Cretaceous sea was deepened and the shore line became more remote, so that during the final stages of the Montana epoch another thick shale formation, known as the Lewis shale, was deposited. This shale attains a total thickness of at least 2,000 feet and is in general somewhat finer grained and less resistant to erosion than the Mancos shale, which it somewhat resembles. Although the evidence is not so conclusive for believing that these later formations, like the early Dakota (?) sandstone, were deposited continuously throughout the San Juan province, it would yet seem most reasonable to make that assumption.

South of Durango and Pagosa Springs, in the midst of the San Juan Basin, which borders the San Juan Mountains on the south, there is a deposit of coal-bearing sandstone and shale which reaches a maximum thickness of at least 1,500 feet. This includes the Pictured Cliffs sandstone, the Fruitland formation, and the Kirtland shale of current usage. In all probability these strata were deposited in lagoons and swamps that existed after the local retreat of the Cretaceous sea, and it seems quite likely that the physiographic changes thus indicated were a response to the earlier of the crustal deformations that marked the transition from Mesozoic to Cenozoic time.

TERTIARY HISTORY

TRANSITION FROM CRETACEOUS TO TERTIARY

When the Cretaceous marine sedimentation ceased the San Juan region was an almost plane area approximately at sea level. The upper 6,000 or 8,000 feet of the earth's crust in this entire region was formed of the recently accumulated beds, ranging from the La Plata sandstone through the Lewis shale. In the eastern half and possibly in the central part of the region this terrane rested upon the peneplaned surface of the pre-Cambrian complex. In the western half of the region, however, the thick formations of Paleozoic and earliest Mesozoic age intervened between the La Plata sandstone and the ancient crystalline mass. Generally the Paleozoic strata were in structural conformity with the flat-lying Cretaceous beds. Only in the zone of transition between the east and west halves of the area were the older sedimentary rocks uptilted. Here the La Plata and younger beds overlap discordantly the upturned edges of the successive Paleozoic formations, beveled by erosion prior to La Plata time. From conditions such as these the modern San Juan Mountains were to be constructed during the Tertiary and Quaternary periods.

The first step in this constructive process was the regional uplift and domal deformation of the entire San Juan province. Gradually the epeirogenic uplift changed to a more localized and intensified orographic movement. A huge dome, 70 or 80 miles in length from east to west and 30 to 40 miles in width from north to south, was arched. The apex of this dome must have been not far from the northeast corner of the Needle Mountains quadrangle. This differential movement must have amounted to at least 10,000 feet, so that the summit of the dome would have been that much higher than the surrounding plain had not contemporaneous erosion partly neutralized the effects of deformation. In consequence of the movement the Paleozoic and Mesozoic strata, so far as now known, dip outward at angles approximating the slope of the flanks of the dome. Thus in the Ignacio quadrangle the regional dip is toward the south, in the Telluride and Rico quadrangles toward the west, in the Montrose quadrangle (as shown on pl. 7, *A*) toward the north.

This first warping of the San Juan dome was the expression in this locality of the widespread orographic movements which in the Rocky Mountain region represent the Laramide revolution. Obviously erosion would begin as soon as there was any appreciable difference in altitude between the center of the San Juan region and its periphery. Streams rising near the summit of the dome would radiate toward its margins. At their heads these streams would form canyons, whose depth would be determined by the amount of domal uplift. In their lower courses the same streams would tend to deposit the materials obtained from the canyons. It seems quite likely that a part at least of the formations known as Pictured Cliffs, Fruitland, Kirtland, McDermott, Animas, Puerco, Torrejon, etc., represent the products of this accumulation during the Laramide warping.

Early in this stage of crustal flexing and concomitant erosion there occurred the first of the repeated volcanic outbursts which characterize the Tertiary history of the San Juan region. The fragmental débris from these late Cretaceous or earliest Tertiary eruptions formed the Animas formation, consisting of agglomerate and tuff, chiefly of andesitic material. Remnants of the tuff have been found in the Animas Valley and elsewhere on the south slopes of the range in the Ignacio and Pagosa Springs quadrangles. The fossil plants which these beds contain have been assigned by Knowlton to the Eocene epoch, but that age designation for the formation has not been accepted by all geologists, and the Animas is still classified by the United States Geological Survey as Tertiary (?).

RIDGWAY GLACIAL EPOCH

Singularly enough, the next recorded event in the history of the San Juan Mountains was a glacial episode, but between the volcanic outbursts that furnished the débris of the Animas formation and this glaciation there was a long interval, during which erosion must have gnawed deeply into the newborn San Juan dome. The entire sedimentary veneer, 6,000 to 10,000 feet in thickness, was in places stripped from the surface of the pre-Cambrian complex at and near the center of the dome. Inevitably this process involved the carving and sculpturing of mountains, characterized by lofty peaks and deep-etched canyons. On the flanks of the dome, where swift-flowing streams encountered no more resistance than that afforded by the harder beds of the sandstone that has generally been called Dakota sandstone, an undulating plain was apparently produced. The surface of this lowland plain transgressed the many sedimentary formations from the Mesaverde at its outer margin to the Hermosa or even the Ignacio quartzite at its inner margin, where the plain was rising irregularly toward the higher mountains, within which large surfaces of pre-Cambrian granite, quartzite, and gneiss must have been exposed. Many of the peaks, however, were probably formed of the Paleozoic strata, such as the Hermosa and Cutler formations. In some localities extensive beds of volcanic tuff, produced by the late Cretaceous or earliest Tertiary volcanoes, the products of which are now disclosed in the Animas formation, had escaped removal. At the same time erosion had succeeded, in the interval subsequent to that volcanic outburst, in laying bare considerable masses of intrusive porphyry, which presumably filled the conduits through which the molten magma had approached the surface. How much time was involved by all this denudation can not now be estimated. It would seem, however, that the conditions thus sketched were achieved before the end of Eocene time.

Then came a change in climatic conditions of such import that glaciers of no mean size formed among these mountains. These ice masses presumably moved outward toward the peripheral lowlands and there formed great piedmont glaciers. Only a modicum of the extensive deposits of till which these piedmont glaciers must have made has escaped the vicissitudes of subsequent time and is now recognizable in the San Juan region. The most extensive deposits of this material, the Ridgway till, underlie the surface of Miller Mesa, on the north flanks of the mountains near Ridgway.[2] The type locality is shown on Plate 8. Here its composition indicates that two different bodies of ice invaded the area in succession. One deposited boulders derived from outcrops of many varieties of porphyry, several kinds of granite, some volcanic tuff, quartzite, sandstone, limestone, and conglomerate. Ice had moved from the central part of the mountains and plucked the sedimentary materials from the upturned strata at their north base. Overlying the till from this first glacial invasion is another body of glacial débris which must have been dropped by ice having very different sources, or at least by ice which had pursued a very different pathway to the Ridgway locality. This upper, so-called "pebble till" member of the Ridgway till is composed largely of finely pulverized shaly material, such as might result from the passage of vigorously eroding ice over large exposures of Mancos or Lewis shale.

On the south side of the range, in V Mountain,[3] near the center of the Summitville quadrangle, other deposits of early Tertiary till are known. Here the drift beneath the great mass of Tertiary volcanic débris is similar to that just described as the first of the two kinds of till in the Ridgway locality. The exposure is of special interest because it indicates that at this time glaciers must have been widespread in the ancient San Juan Mountains.

Still other exposures of tillite were examined during the summer of 1924 by the senior author, accompanied by Wallace R. Atwood, in the vicinity of Gunnison, Colo.[4] During the summer of 1925 Wallace R. At-

[2] Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 13–26, 1916.

[3] Atwood, W. W., Another locality of Eocene glaciation in southern Colorado: Jour. Geology, vol. 12, pp. 545–547, 1917.

[4] Atwood, W. W. and W. R., Ancient tillite near Gunnison, Colo. [abstract]: Geol. Soc. America Bull., vol. 36, p. 168, 1925.

wood continued the field studies in that locality, and the following description is based in part upon the observations which he made.

Just west of Gunnison and at several localities upstream as far as Parlins, a distance of about 10 miles, the ancient glacial formation is overlain by volcanic tuff or breccia. Both the tuff and the tillite are somewhat cemented and stand in bold cliffs or sharp pinnacles. They might attract attention first because of their hoodoolike forms, and a glance from the automobile road might easily suggest that the entire outcrop is a volcanic tuff.

The tillite contains boulders as much as 2 feet in diameter, an abundance of cobblestones, and a body of fine sand and silt which fills in the spaces between the larger stones. Subangular stones are common, and many specimens are distinctly striated. Boulders of granite, gneiss, schist, quartz, diorite, basalt, greenstone, slate, phyllite, quartzite, and sandstone are present. All of these except the sandstone came from pre-Cambrian formations. The sandstones may have come from the Cretaceous formations represented by a few outcrops in this vicinity.

At some of the outcrops of this tillite, as at those near Parlins, boulders of granite and gneiss 3 and even 4 feet in diameter are so disintegrated that the picks and shovels used in widening the roadway have cut through them rather than dislodged them.

The stones in this tillite indicate that the ice which deposited it must have come from or over an area of pre-Cambrian rock. There are several localities to the east, south, and west where the pre-Cambrian complex is the dominant formation. It is impossible as yet to say from which direction the ice came that invaded the Gunnison district.

The volcanic tuff overlying the tillite near Gunnison is presumably of middle Tertiary age, and the tillite is probably of the same age as that near Ridgway. It appears to have been deposited in somewhat dissected areas in the low lands bordering the early Tertiary mountains in this part of Colorado.

Wallace R. Atwood has also reported an occurrence of tillite at a locality about 1½ miles east of Cimarron, near the main automobile highway, visited by him in 1925. At this locality the till rests upon Mancos shale and appears to be overlain by a thick lava flow. It contains many boulders 2 to 3 feet in diameter and a few that reach 8 feet. These are composed of igneous rocks that were evidently derived from the San Juan Mountains, south of this locality. No specimens were found in the till that could have been derived from the lava which is in place and at higher horizons near this outcrop. There are numerous striated stones in this deposit and many others that are subangular and polished. The material is unquestionably of glacial origin, and it may possibly be another exposure of the early Tertiary tillite first discovered in the Ridgway region.

TELLURIDE CONGLOMERATE EPOCH

The glaciation of the early Tertiary San Juan Mountains seems to have been an incident in the midst of a long interval of erosion. Assisted by the ice the streams in these ancestral mountains succeeded after a time in reducing them to comparatively low altitudes. The western part of the region was reduced to a surface of slight relief, to which the name Telluride peneplain has been applied. The higher summits of the area now occupied by the Needle Mountains and much of the San Juan region farther east remained as rugged uplands overlooking this peneplain. Rapid erosion in this rugged, mountainous area produced a vast quantity of stream detritus, which was deposited upon the surface of the adjacent lowland as great piedmont alluvial fans. Slight down-warping of portions of the peneplain in the area now occupied by the western summits of the San Juan Mountains and the neighboring Mount Wilson group may have developed sharply defined basins of alluviation. The deposits laid down in these basins are of the bolson type, such as are to-day accumulating in many intermontane lowlands of the Southwest, and form the Telluride conglomerate.

In the Mount Wilson group this formation attains a thickness of 2,000 feet and includes a few beds of sandstone and shale. There it rests upon the eroded surface of the Mancos shale. About 30 miles to the east, near the Needle Mountains, the Telluride conglomerate is less than 100 feet in thickness and rests directly upon pre-Cambrian quartzite. In places on the north slopes of the mountains this formation overlies the Ridgway till, from which it has derived a few striated stones.

The pebbles of this conglomerate indicate that their sources were in a region having extensive exposures of pre-Cambrian igneous and metamorphic rocks and Paleozoic sedimentary rocks. Only a small amount of volcanic débris and intrusive porphyry was accessible to the streams conveying the detritus to the alluvial fans.

Doubtless the accumulation of such a continental formation as the Telluride must have involved an extremely long period of time, during which the mountains were progressively lowered and the base-leveled lowland gradually extended. Possibly the cessation of Telluride alluviation resulted from the completion of the heroic task of wearing away the mountains.

We may picture the San Juan region at the end of the Telluride epoch as having a maximum relief of only 1,000 or 2,000 feet between the highest land near the center of the San Juan dome, where degradation would still be in progress, and the flat lowland built by aggradation on the flanks of the dome. One generation of early Tertiary San Juan Mountains had suffered the fate that awaits all mountains. The cycle of erosion had nearly run its course. A region once rugged and mountainous had been reduced to rounded hills and low ridges, standing at only slight altitudes above an undulating plain.

LAKE FORK AND SAN JUAN VOLCANIC EPOCHS

The long interval of gradation that produced the Telluride conglomerate was followed by a short episode of violent volcanic activity. From one or more vents near the center of the Uncompahgre quadrangle extensive lava flows and a considerable mass of volcanic débris were ejected. The eruptive rocks thus formed have been named the Lake Fork breccia. Shortly thereafter other volcanic vents became active at localities not now definitely known. From them a tremendous quantity of detritus was spread broadcast over the whole northwest quarter of the San Juan province, making up the formation that has generally been called the San Juan tuff, the vast bulk of which was transported only a short distance from its source.

In the Montrose and Telluride quadrangles the San Juan tuff attains a thickness of 2,000 feet. The peculiarities of its composition and its occurrence in many places overlying Mancos shale make it characteristically a cliff former. The pinnacles and minarets carved from many of its bold and rugged cliffs are among the most interesting of the many scenic features of the San Juan region. The photograph reproduced in Plate 7, *B*, is typical.

At most localities the San Juan tuff rests upon the Telluride conglomerate. The plane of separation between the two is almost everywhere sharply demarked. It may therefore be inferred that the San Juan epoch, which was preceded by the eruptions of the Lake Fork epoch, continued for a time sufficiently long to permit the transportation and deposition of a vast quantity of volcanic débris. Gradually the material available for transportation by running water was exhausted, and soon thereafter the restless streams, no longer fully loaded, began anew their task of downward cutting. In places erosion had already made considerable headway; elsewhere deposition was still the rule.

SILVERTON VOLCANIC EPOCH

Erosion during the interval that followed the accumulation of the San Juan tuff left great cliffs overlooking deep valleys at several localities in the Silverton, Montrose, and Uncompahgre quadrangles. At a few places the streams cut channels even below the level of the Telluride peneplain. But before they had made much headway in the task of removing the great mass of San Juan and Lake Fork débris volcanic outbursts were renewed in the eruptions that constructed the well-defined Silverton volcanic series. Great quantities of lava were poured out from numerous vents to fill the hollows in the surface of the land and spread in great sheets over the San Juan tuff. The eruptions were for the most part confined to the neighborhood of the Silverton, San Cristobal, and Uncompahgre quadrangles. Some of the many lava flows welled quietly out from long fissures, but part of the Silverton series was the result of explosive outbursts, and in places volcanic cones were built.

The series itself consists of half a dozen formations representing successive eruptive stages, separated by short intervals of quiescence during which erosion held sway. Certain fossil leaves and shells in some of the tuffs and interstratified calcareous beds in the midst of the series indicate an Oligocene or early Miocene age.

POTOSI VOLCANIC EPOCH

As the volcanic energy of the Silverton epoch abated, the ever-ready agents of erosion once more began to dominate. The Silverton volcanic plateau was extensively eroded, and much detritus was transported to distances far beyond the limits of the San Juan region. Much the greater part of the Silverton series was removed from the region now occupied by the headwaters of the Rio Grande. Elsewhere, as for example west of Uncompahgre Peak, very little erosion was accomplished during this post-Silverton interval. Then came another long epoch of extremely violent volcanic activity. The numerous formations that have been recognized as a product of this outburst are grouped together into the Potosi volcanic series. The whole series is extremely complex and embraces many varieties of rocks, from water-laid pyroclastic deposits to vast lava flows. The variety of magmas represented was very great but is, of course, not of primary interest to the physiographer.

On the south side of the mountains in the region drained by the headwaters of the Piedra, the San Juan, the Chama, and the Conejos, volcanic materials were piled to a thickness of over 3,000 feet and form the Conejos formation. As displayed in Plate 9, *A*, the formation is very similar to the San Juan tuff. It is composed in the main of andesitic flows and agglomerate, but near the borders of this volcanic mass there are many beds of water-washed gravel and boulders with only minor amounts of volcanic ejecta as cementing material. The area covered by the Conejos beds is very great. This episode seems to have been a definite climax of volcanic eruption, with respect both to area involved and to amount of material belched forth.

In the southern part of the Conejos quadrangle and in much of the area adjacent on the south the pre-Cambrian complex had been stripped of its veneer of sedimentary rocks along the crest of an anticlinal axis extending far south into New Mexico. In the region now occupied by the headwaters of the Rio Brazos pre-Cambrian rocks formed a long line of low but rugged mountains, which presumably then as now was the divide between the Rio Grande and the San Juan drainage systems. Tremendous quantities of Conejos clastic and pyroclastic materials were carried into the valleys between these pre-Cambrian hills. Flows of andesite extended far southward and helped fill the lowlands between the pre-Cambrian heights. In the vicinity of the Brazos Canyon the Conejos formation in places attained a thickness of 2,500 feet, and many of the lower hills of quartzite and schist were buried.

Streams descending the flanks of the Conejos volcanoes washed débris derived from their easily eroded slopes to distances far beyond that reached by the flows of lava or the unwashed ejecta. Thus in the region now drained by the Tusas River the Conejos beds contain little eruptive material and consist of a great accumulation of fluviatile sand, gravel, and boulders. Necessarily the coarser fragments carried to the Rio Grande Basin by the streams rising in this volcanic area were deposited nearest to the mountains. The finer gravel and sand were washed scores of miles southward into the region adjoining Santa Fe and Espanola, where they form the lower part of the Santa Fe formation.

While these water-borne materials were accumulating in what is now the Rio Grande Basin, south and southeast of the San Juan Mountains, volcanic activity was continuing intermittently but with intense violence in all the eastern half of the mountain area. Lavas and tuffs of the Potosi series occur there in great profusion. Between successive outbursts of lava or explosive eruptions of whatever sort, there were numerous short intervals of comparative quiet, during which erosion modified the topography in places to such an extent that the successive formations of the Potosi series display numerous unconformities and overlaps. In spite of this interference offered by the streams to the constructive work of the volcanic forces, the net result of the Potosi epoch was a huge volcanic plateau, which in places was several thousand feet in height. Into this plateau numerous bodies, large and small, of intrusive rocks, generally porphyritic, were injected at different times. In places laccolithic masses raised the plateau surface by a few hundred feet. Elsewhere great fissures were filled to become dikes, some of which are in systems radiating from a volcanic pipe.

The exact extent of the Potosi volcanic plateau is not known. Undoubtedly in places, especially near its former margins, its materials have been entirely removed by erosion. It is certain, however, that practically all of the area included within the Ouray, Silverton, and Needle Mountains quadrangles and the entire San Juan country farther east was buried by this volcanic pile, which overlapped the surrounding region, especially on the south and west, for many miles. There is good reason for believing that the accumulation of this great mass of ejecta upon the surface was accompanied by a compensating depression of its buried floor. The surface beneath the Tertiary volcanic rocks in the San Juan Mountains is at the present time a great saucer tipped downward toward the east. If the entire thickness of the volcanic accumulation up to the end of Potosi time is estimated at 10,000 feet, it is not necessary to assume that the summit of the plateau was actually 10,000 feet above the surrounding lava-free territory. On the contrary, it seems likely that the prevolcanic surface gradually settled beneath its excessive overburden, so that in and near the Creede quadrangle, for example, that surface at the end of Potosi time was 5,000 feet or so below its relative altitude at the beginning of the volcanic accumulations. In spite of this compensation, however, the San Juan region at that time was a broad plateau, standing 3,000 or 4,000 feet and perhaps more above its surroundings.

FISHER VOLCANIC EPOCH

Subsequent to the outpouring of the youngest of the many lava flows which are referred to the Potosi epoch there seems to have been a somewhat longer interval of quiet than any which had occurred within the limits of Potosi time. Widespread erosion of the Potosi and older volcanic rocks was accomplished during this interval, as indicated by the relations of the next younger rocks to the Potosi series. Because of the apparent magnitude of this erosion interval, as well as because of differences in the nature of the volcanic magma, the lava and pyroclastic material which were next erupted in the San Juan region, consisting chiefly of quartz latite, have been placed in a separate unit, known as the Fisher quartz latite.

During the Fisher epoch considerable quantities of molten lava were poured out upon the earth's surface to fill the valleys that had been carved in the Potosi plateau and in places to overtop the divides. Large amounts of clastic material, ash, bombs, and volcanic ejecta of all sorts were erupted at many localities and are now interbedded with the lava. In many respects the Fisher epoch repeated the conditions of the Silverton and Potosi epochs, and during this time volcanic activity contributed in much the same way as before to the construction of the San Juan volcanic plateau.

In the main the Fisher rocks are confined to the central part of the San Juan region. They are especially prominent in and near the Creede quadrangle but have also been recognized in the neighboring portions of the San Cristobal and Summitville quadrangles.

INTERVAL BETWEEN FISHER AND HINSDALE VOLCANIC EPOCHS

The Fisher volcanic outbursts were followed in the San Juan region by a long interval free from any extensive volcanic activity. During this time erosion produced profound changes in the topography of the entire region. From the volcanic plateau, which had been progressively constructed by the long series of Tertiary volcanic eruptions, there was carved a great mountain range, the second or third generation of San Juan Mountains. The place occupied by those ancient mountains in the physiographic evolution of the San Juan region is indicated diagrammatically in Figure 4 and by sections on Plate 10. Their peaks and ridges were formed in the main by volcanic débris and the remnants of dissected lava flows. The higher summits were for a time approximately at the altitude of the former volcanic plateau surface. Probably many of the hills toward the southwest in the Engineer Mountain and Ignacio quadrangles were composed of sedimentary rocks, for in that portion of the region the veneer of volcanic rock must have been thin. The length of time involved in this transformation of the plateau into a maturely dissected mountain region must have been considerable. No data are available for determining accurately the time of its accomplishment. Inasmuch as the Potosi series is of Miocene age, it seems probable that this generation of mountains was developed during Pliocene time, but it will be safer to refer to them in a more general way as the late Tertiary San Juan Mountains.

It may have been at about this time that the great laccolithic intrusions which in the last analysis produced the Rico and La Plata Mountains, on the west and southwest flanks of the San Juan group, took place. That these laccoliths were formed in the later half of Tertiary time can scarcely be doubted, but no data are available for determining their time relation more accurately than that statement would imply. This igneous activity involved the formation of the Rico and La Plata domes and the intrusion of considerable masses of molten magma, which crystallized with a porphyritic texture to form the stocks and laccoliths within those smaller mountain groups. Each of these domes is an independent structural uplift of dimensions which, in comparison to those of the San Juan dome, are small. Each may therefore be thought of as a locally intense warping of the flanks of the great San Juan uplift. Presumably, the local movements were contemporaneous with certain of the broader flexures that resulted in the cumulative uplift of the entire San Juan region. The correlation of these minor local movements with the neighboring deformation is likely always to be a matter of speculation.

Our physiographic studies, however, lead to the conclusion that at the time of the late Tertiary San Juan Mountains erosion had similarly developed a rugged topography in both the Rico and the La Plata areas. While the volcanic plateau was undergoing dissection the La Plata and Rico domes were being carved into rugged mountains, which long ago disappeared entirely.

The continued effect of stream action during this long interval culminated in the almost complete destruction of the San Juan Mountains. Gradually the rugged boldness of mid maturity was softened to the gentler outlines of old age. Streams everywhere throughout the San Juan region reduced their courses approximately to base-level. Broad valley flats were gradually extended laterally until divides were degraded to lines of rounded hills. As might be expected, the more resistant portions of the volcanic plateau long remained as mountainous heights above the graded surface of the old-age topography. Even more significant was the fact that in the Needle Mountain region the surface of the pre-Cambrian complex, long buried beneath the Paleozoic and Mesozoic sedimentary rocks and for a time veneered, in addition, with volcanic débris, was now laid bare once more. This surface seems to have been 1,000 or 2,000 feet above the base-level of erosion and as a consequence was deeply trenched by the headwaters of the streams which traversed it. Sharp granite ridges and pinnacled quartzite peaks projected hundreds of feet above the valley flats, and here, because of the superior resistance of the rocks, destruction of the late Tertiary San Juan Mountains went on but slowly. Similar conditions prevailed in the vicinity of the Tusas Mountains, where pre-Cambrian hills had long defined the position of an anticlinal axis trending southward from the Los Pinos Canyon. The jagged crest of a long pre-Cambrian ridge there projected hundreds of feet above the adjacent valley flats, which had been much aggraded during Potosi time.

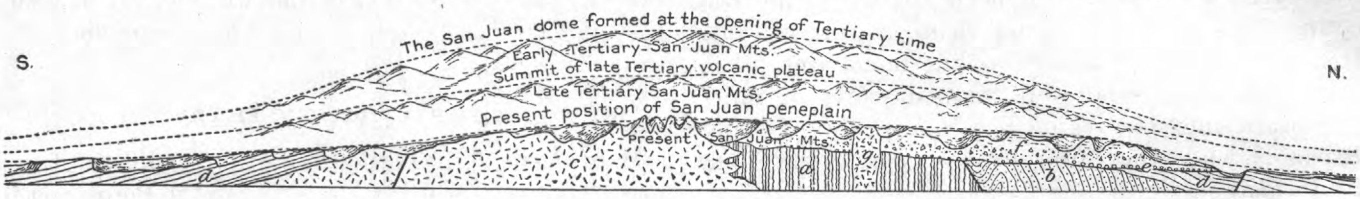


FIGURE 4.—Diagrammatic cross section showing the physiographic evolution of the San Juan region since the beginning of Tertiary time. *a*, Pre-Cambrian schist and gneiss; *b*, Algonkian quartzites; *c*, Pre-Cambrian granitic intrusion; *d*, Paleozoic and Mesozoic rocks; *e*, Ridgway till and Telluride conglomerate; *f*, middle and late Tertiary volcanics; *g*, Tertiary intrusives

Thus some time in the Pliocene epoch there was developed in the San Juan province a graded surface of low relief, which is now near the summit of the mountains. To this summit peneplain we have applied the name San Juan peneplain. This surface was the inevitable product of the long interval of comparatively uninterrupted erosion. For the most part it was about as level a plain as could be cut by running water. Above it, however, there stood many monadnocks which rose a few hundred feet, or even as much as 2,000 feet, above the general level. In places, as in the Needle Mountains and Cebolla quadrangles, these hills were the result of the superior resistance of the pre-Cambrian rocks which composed them. Others, like Uncompahgre Peak, remained as mountain heights solely by reason of their accidental remoteness from the major stream courses.

In time even these hills would have been reduced and the entire region transformed into a monotonous lowland plain occupying all of the San Juan Province and covering the present site of the La Plata, Rico, and San Juan Mountains, but time enough was not available.

The streams traversing the broad valleys leading outward from the groups of hills that formed the monadnocks mentioned above were sufficiently vigorous to transport gravel and small pebbles and scatter them along their courses. These gravel deposits have herein been given the local name Bayfield gravel. The pebbles were, of course, representative of the rocks in the respective drainage basins. As a result of their study definite assertions may be made concerning the relations of the San Juan peneplain to the underlying rock structure. Thus it is known that the wearing down of the late Tertiary San Juan Mountains to form the summit peneplain removed thousands of feet of volcanic beds and sedimentary strata. The general nature of the resulting relations is indicated on the diagram forming Figure 4 and the cross sections on Plate 10.

The gradual process of stream erosion, coupled with the spreading of fine gravel over portions of the graded surface of the San Juan peneplain, was terminated by the renewal of crustal warping. The great San Juan dome was once more affected by stresses that warped the surface in much the same manner as the earlier domal movements. Vertical uplift near the center of the dome raised that portion of the land 2,000 or 3,000 feet above the peripheral zone, and at the same time the entire southwestern part of the United States seems to have undergone an uplift amounting to several thousand feet. In the absence of definite information it seems best to consider that this deformation of the San Juan peneplain marks the transition between Tertiary and Quaternary time. It was apparently accompanied by still another volcanic episode, the last of great significance in San Juan history. To the lavas and eruptive débris of this epoch the name Hinsdale volcanic series has been applied by Cross.

HINSDALE VOLCANIC EPOCH (TERTIARY?)

Approximately at the end of the Peneplain erosion cycle considerable quantities of basalt and rhyolite were poured out upon the surface of the peneplain in the eastern half of the San Juan region. These lavas reach their maximum thickness in the Conejos quadrangle, adjacent to the San Luis Valley, at the far southeast corner of the region. Interbedded with the flows are some pyroclastic beds, which indicate the explosive violence of some of the eruptions. In places the Hinsdale volcanic series rests upon stream gravel which aggregates a thickness of several score of feet. This gravel, which is here named Los Pinos gravel, from exposures on Los Pinos Creek, Conejos County, and farther south in New Mexico, seems to be the equivalent of the Bayfield gravel, which has been recognized in many parts of the mountains and which is fully described in a later section of this report. Apparently the deformation of the San Juan peneplain, which was more or less contemporaneous with the Hinsdale eruptions, caused a rejuvenation of the streams that radiated from the center of the dome. Loaded by the products of rapid erosion in the recently elevated area at the heart of the San Juan region, these streams deposited great masses of débris as torrential fans on the lower slopes of the dome. It is upon certain of these fans that some members of the Hinsdale volcanic series rest.

SAN JUAN PENEPLAIN

As stated in the preceding section, erosion of the late Tertiary volcanic plateau which occupied much of the San Juan region produced an old-age surface to which the name San Juan peneplain is here applied, and the time when it was developed may be designated the Peneplain cycle of erosion. The development of this summit peneplain is really the first step in the physiographic history of the existing San Juan Mountains. It is therefore necessary to consider with some care the exact condition and nature of the peneplain. A special map (pl. 2) has been prepared to show the distribution of the peneplain remnants, the monadnocks that rose above it, the deposits of gravel and boulders upon its surface, the lava flows that rest upon it, and by contour lines the present attitude of the restored but deformed plain.

Existing remnants.—The existence of the San Juan peneplain was first ascertained by us on the southern slopes of the San Juan Mountains in the Ignacio quadrangle. Here there are a multitude of divides, mountain summits, and plateau surfaces which display a remarkable accordance in altitude. Their relations are indicated by the profiles drawn across the Ignacio quadrangle (fig. 5) and are emphasized on the peneplain map, Plate 2. The divide between the Florida and Animas Canyons, for example, is a gently undulating upland surface 1 to 2 miles in width, rising gradually from an altitude of 9,000 feet at the south to 12,000 feet 10 miles to the north, in the vicinity of the Needle Mountains. Neighboring divides on each side, which separate similar southward-trending valleys, have similar altitudes increasing regularly toward the center of the mountains. In the foothill zone numerous hogback ridges rise to altitudes of 8,000 to 9,000 feet, so arranged that a surface projected across their summits rises gently toward the mountains and coincides with the intercanyon uplands. Outlying mesas and plateaus, such as Bridge Timber Mountain and the Mesa Mountains, display remarkably smooth tops, which likewise slope gently away from the San Juan Mountains. These outliers carry the restored graded surface downward to an altitude of about 7,000 feet at the Colorado-New Mexico State line.

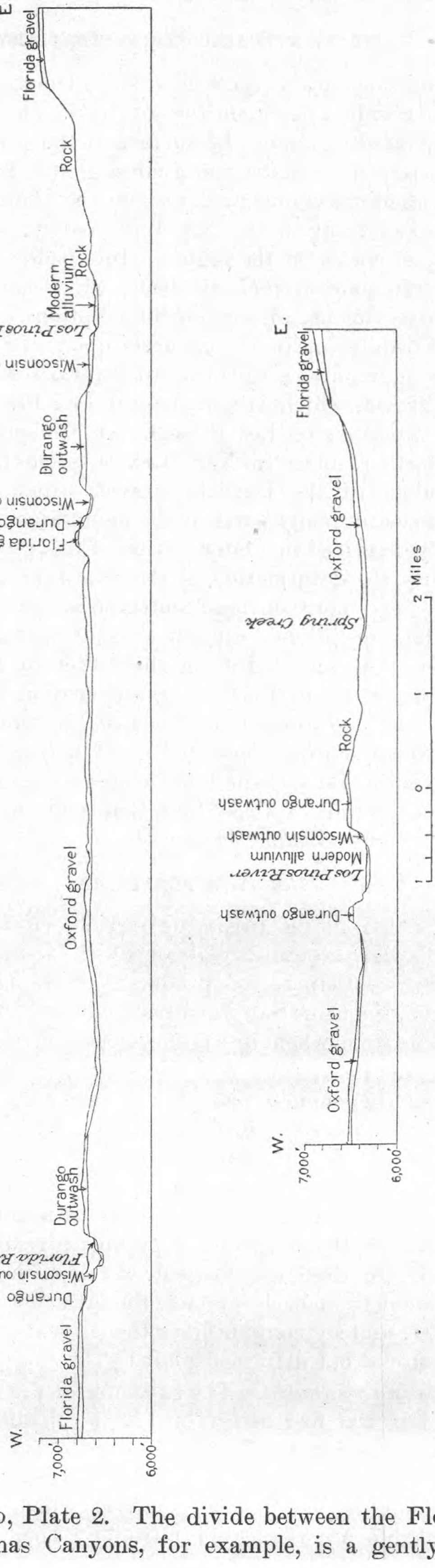


FIGURE 5.—Profiles across the Ignacio quadrangle, showing the relations between the several gravel-strewn surfaces at the southwest margin of the San Juan Mountains

The surface that is so easily reconstructed in imagination as the observer stands on any of these higher summits and surveys the panorama outstretched before him is neither smooth nor horizontal. Its gentle undulations are such as would appear upon any land surface that had been reduced by erosion approximately to base-level. Its notable inclination gives it a slope of considerably more than 100 feet to the mile, a fact which will be considered in greater detail in a subsequent paragraph. As thus restored on the south flanks of the mountains, this peneplain surface bevels the upturned edges of formations ranging in age from pre-Cambrian to early Tertiary. As indicated diagrammatically by the sections on Plate 10, the structural dome is truncated by it.

Upon many of the remnants of this once widespread surface is found to-day stream gravel which includes rocks quite foreign to the immediate locality. On Animas City Mountain, for example, an eminence composed of Mesozoic shale and sandstone, there are pebbles of quartzite and of granite which must have been derived from the Needle Mountains region. These pebbles could have been transported to their present locality only at a time before the intervening canyons and valleys had been carved. The field data, therefore, all combine to indicate that at one time the present summits of this part of the mountains were portions of an extensive lowland plain, worn as low as running water can readily wear the land, across which streams meandered from the central San Juan peaks.

Similar topographic conditions are present in other parts of the region. On all sides of the San Juan Mountains there are numerous upland surfaces of considerable extent which can be explained only on the basis that they are remnants of this ancient erosion surface. The extensive upland sloping westward from Storm Peak, between the East Dolores and West Dolores Rivers, is the largest remnant of this surface on the western flanks of the mountains. Trident Mesa, on the north side of the mountains, and the gently rounded upland known incongruously as Mesa Peak, in the northeast quarter of the Creede quadrangle, on the east slope, are but a few of countless peneplain remnants which might be listed. (See pl. 9, *B*.) Many more are indicated on Plate 2. In the heart of the mountains, in the Silverton, Needle Mountains, and San Cristobal quadrangles and the neighboring areas of extremely rugged peaks it is rare to find any extensive remnant of the peneplain which has escaped the vigorous erosion characteristic of this part of the region. However, as the peneplain surface is projected from the margin toward the center of the range it is found to coincide with many upland flats and high divides. Here the term "summit peneplain" is not so truly applicable. The surface coincides not with the crests of the highest peaks but with upland flats at slightly lower altitudes. Most of the majestic summits of the San Juan Mountains are reared aloft for a few hundred feet above the ancient plain. These were the monadnocks upon its surface. Among them Uncompahgre Peak was supreme, for its crest was more than 1,000 feet above the surrounding lowland. Pole Creek Mountain, San Luis Mountain, and the pinnacles of the Needle Mountains—in fact, nearly all the loftier peaks in the entire San Juan region—were hills only slightly less in height above the peneplain than Uncompahgre Peak itself. Doubtless these hills supplied the gravel deposited along the courses of the numerous streams where long-continued erosion had developed undulating lowlands.

In many parts of the San Juan Mountains the remnants of the San Juan peneplain bear, in addition to the scattered stream gravel noted in the preceding paragraph, a veneer of basalt which in places aggregates more than 200 feet in thickness. This basalt is the most conspicuous member of the Hinsdale volcanic series. Everywhere that it has been identified with certainty its topographic situation is such as to indicate that it was extruded upon the peneplain. Thus, in the Creede and Summitville quadrangles this basalt occurs only as a cap on the higher divides and uplands or as the summit formation in certain peaks. A characteristic exposure is that on Osier Mountain, in the southwest quarter of the Conejos quadrangle and therefore near the southeast corner of the area shown on Plate 2. There the San Juan peneplain is to-day an undulating upland at an altitude of 10,000 to 10,500 feet; Osier Park is a bit of the peneplain long protected by a veneer of Hinsdale basalt, most of which has lately been removed. Above this undulating table-land rises the flat-topped, mesalike Osier Mountain, with its summit 10,700 feet above the sea. The upper 150 feet of the mountain is a massive sheet of basalt which rests on beds of stream-washed gravel and boulders, aggregating about 200 feet in thickness.

Farther east, in the central and eastern portion of the Conejos quadrangle and elsewhere on the eastern front of the mountains at the margin of the San Luis Valley, the peneplain surface declines rather steeply toward the east. It carries an increasingly thick burden of gravel, boulders, and basaltic lavas. Most of the foothills south of the Alamosa River are inclined mesas and buttes, carved from these deposits on the peneplain surface. In this marginal zone the peneplain dips below the modern drainage lines and disappears beneath the gravel-strewn floor of the San Luis Valley.

Similar conditions exist on the eastern front of the Tusas Mountains, the extension of the San Juan Mountains southward in Rio Arriba County, N. Mex. In this region the peneplain surface seems never to have possessed the characteristics of old age. Rather it is so irregular and displays so great relief that the physiographer would describe it as an area of late mature topography. This character seems to be chiefly the result of the superior resistance to erosion offered by the pre-Cambrian terranes, which there were at the surface during the Peneplain cycle of erosion.

In the middle of the San Luis Valley, from latitude 37° 15′ southward past the Colorado-New Mexico boundary line, there is a group of mesas and rounded hills which rise boldly from the valley floor to heights of 500 to 1,500 feet. These are the San Luis Hills. (See pl. 11, *A*.) They are formed of a variety of lavas with some intrusive rocks and evidently were "islands" in the midst of the "sea" of stream-washed gravel which elsewhere veneers the floor of the valley. Their relations to the San Juan peneplain are described in detail in a subsequent section of this report. Here it may be stated that these hills were monadnocks on the ancient peneplain. Their mature or even youthful topography and their prominence above the general base-leveled surface result from the recency of the faulting which elevated them above their surroundings at so late a date in the Peneplain cycle of erosion that their degradation had little more than commenced when the cycle was terminated.

Present conditions.—Enough remnants of the San Juan peneplain have been observed and mapped to make possible a fairly accurate restoration of its surface. Peneplain remnants and deposits indicate its present altitude above sea level at a large number of points widely scattered throughout the San Juan area. From these altitudes as data the contour map forming Plate 2 has been drawn to represent the San Juan peneplain as it would now look if all the materials removed during subsequent cycles of erosion were restored to the valleys whence they came. A contour interval of 500 feet was chosen as appropriate. The contour lines are dotted where the peneplain surface is now buried beneath any of the deposits that have been laid down upon it. The traces of faults on which movement has occurred since the peneplain was formed are indicated by broken lines.

As thus restored the peneplain surface is nowhere smooth nor horizontal. Considerable portions of it in the central part of the San Juan region now stand more than 13,000 feet above the sea. In the foothills and near the margin of the range its present altitude is generally less than 9,000 feet. Viewed in the large the peneplain surface arches gently over the San Juan Mountains. The surface of this dome is, however, complicated by numerous minor undulations, so that certain points upon the peneplain stand more than 2,000 feet above other points only 4 or 5 miles away.

The departures of the peneplain surface from horizontality are the result of a combination of three factors. The lowland developed during the San Juan erosion cycle was not truly a peneplain. It possessed so many undulations, typical of an old-age surface, that the term plain could not have appropriately been given to it. Moreover, not all of the San Juan region had been reduced to the peneplain grade; many monadnocks of considerable height and area stood above the lowland. But most important is the fact that the surface since it was formed by erosion has been notably deformed during several episodes of crustal warping. In general, the major departures from horizontality which now characterize the contoured surface are evidently due to crustal movement, although many minor departures have resulted from the failure of the streams to complete their work of base-leveling. The residual monadnocks have been indicated on the map, but no attempt has been made to contour the form which they must have had when the San Juan erosion cycle was ended.

It is therefore appropriate to distinguish the minor elevations, resulting from incomplete gradation of the land, by designating them "residual hills." The terms "arch" and "sag" or "basin" have been applied to elevations and depressions, respectively, of the peneplain surface that are believed to have resulted chiefly from crustal warping.

The name San Juan dome may be applied to all that part of the peneplain which now stands more than 8,000 or 9,000 feet above sea level. This major dome extends from the vicinity of the Wilson, Rico, and La Plata Mountains, near the west margin of the mapped area, eastward to the west margin of the San Luis Valley and from the Gunnison Valley, at the north, to or beyond the south front of the San Juan Mountains, at the south. It therefore embraces the entire San Juan Mountain region, and these mountains are thus indicated as owing their present height above their surroundings to the crustal warping that formed this dome at the end of the San Juan erosion cycle and subsequently.

The San Juan dome is divided into two parts of about equal area by a large basin-shaped depression situated at the center of the area covered by Plate 2. This depression, the Hermit Basin, is bordered on the east by a fault with a throw of more than 2,500 feet. On the west and south the peneplain surface rises steeply from an altitude of less than 11,000 feet in the Hermit Basin to more than 13,000 feet at its rim. West of the basin the San Juan dome is modified by the presence of several groups of residual hills. Some of these occupy regions of strong rocks, such as the pre-Cambrian granite near Mount Eolus. The numerous monadnocks in the general vicinity of Uncompahgre Peak, Sunshine Peak, and Sneffels Peak are for the most part composed of volcanic rocks which may not have been any more resistant than the surrounding masses that were reduced to base-level. Very likely they owe their presence as residual elevations to their remoteness from the larger streams of the peneplain cycle.

On the western slope of the main San Juan dome there are three minor domes, each surmounted by monadnocks but each the result of local crustal movements. These bear the names of the small mountain groups that have been carved from them. At the south the west half of the San Juan dome slopes fairly regularly from the foot of the Eolus residual hills, at an altitude of about 13,000 feet to about 7,000 feet at the Colorado-New Mexico boundary line. Its present gradient therefore averages about 150 feet to the mile in that locality.

East of the Cannibal fault, which forms the east rim of the Hermit Basin, there is a long crescent-shaped fold to which the name Wheeler arch may be applied, inasmuch as the Wheeler National Monument is located near its crest. This arch curves eastward from the mountains north of Creede and extends between the Saguache sag on the north and the Del Norte sag on the south to the margin of the San Luis Valley. It is probable that this flexure of the San Juan peneplain is a part of a broad arch that traverses the area in the vicinity of Cochetopa Pass not covered by topographic maps and unites with a similar feature in the Sawatch Range near Marshall Pass. Southeast of the Hermit Basin there is a broad, low upwarp, standing 500 to 1,000 feet above its surroundings, which may be called the Piedra arch. The southwestward extension of the Del Norte sag is a shallow trough separating it from the broad, low arch in the vicinity of Summitville, which is in turn paralleled on the southeast by the Jasper arch. The east flank of this last-named flexure descends with a gradient of about 450 feet to the mile. Thus the San Juan peneplain is buried far beneath the floor of the San

Luis Valley, a short distance east of the mountain front.

It becomes immediately apparent that the peneplain thus restored antedates the formation of practically all the existing topographic features of the region. The modern topography in the mountains and adjacent plateaus is in the main the result of erosion below the peneplain level. From this ancient surface with its aged profiles the existing landscapes have been carved.

Date of peneplanation.—The peneplain is obviously younger than the youngest formations which it cuts and older than the oldest beds deposited upon it. The peneplain cuts across volcanic strata of both the Potosi and Fisher epochs, which are classified as Miocene. Peneplanation must therefore have occurred during late Pliocene time. The volcanic rocks of the Hinsdale epoch, which rest upon the peneplain surface, are therefore here considered to be either Pliocene or earliest Pleistocene and are tentatively classified as Pliocene (?).

Deformation.—The existing gradients of the peneplain, at most places considerably over 100 feet to the mile, could not have been those of the streams which developed this surface. Streams that fall more than a few feet to the mile are actively engaged in deepening their valleys. Such streams are cutting gorges or canyons in plateaus and mountains, not developing broad lowland plains. The gradient of an old-age river meandering across a lowland which it has itself developed is commonly only a few inches to the mile and never more than a few feet. It is necessary, therefore, to conclude that the San Juan peneplain has been notably deformed since its initial development. Deformation has arched the surface until it has assumed its present form—a broad, low, but very clearly defined dome bearing the minor flexures described in the preceding paragraphs. This, it would appear, is the cumulative effect of several successive episodes of crustal warping. The first of these may well be considered the event that marks the transition from Tertiary to Quaternary time.

At some time subsequent to the development of this broad lowland, before the streams had entirely completed their task of reducing the area to base-level, there occurred a pronounced uplift of the San Juan province, accompanied by the warping of the local peneplain. As a consequence the peneplain surface at the center of the range stood 3,000 feet or so higher than at its margin. This movement presumably disturbed very greatly the existing drainage systems. It might be expected that the rivers consequent upon the warped surface would radiate from the very center of the dome toward its periphery. Although the radial plan of the present San Juan drainage channels is noteworthy, it is not nearly so symmetrically perfect as might have been expected. The Animas River, for example, does not rise at the center of the dome but has its source close to the north front of the range and thence flows southward through its center. Apparently the ancestral stream, upon the peneplain before the domal warping, had extended itself by headward erosion far to the north, occupying the shallow valley indicated by the contour lines on the peneplain map. Warping of the peneplain was slow enough and of such a nature as to permit this stream at least to maintain its ancestral course. Thus it has always been the master stream among San Juan rivers.

The result of such pronounced warping as has just been sketched would be the rejuvenation of the decrepit rivers in the disturbed area. No longer could they pursue their peaceful pathways across a plain, but with new vigor consequent upon the increase in velocity they must now begin again the long task of down cutting. Velocities and therefore erosional efficiency would be greatest on the flanks of the dome where slopes were steepest. Here canyons would quickly be incised. Material thus obtained would load the rivers and be swept downstream. At the margin of the dome, where to-day are found the peripheral foothills and adjacent plateaus, stream velocities would decrease because of lessened slope. Here the rivers must perforce deposit the débris with which their channels were clogged. A widespreading alluvial fan would form beyond each canyon mouth, and thus the dome would be girdled by an apron of boulder and gravel deposits. The boulders and gravel were laid down upon the peneplain itself in the region adjacent to the dome, although they were actually a product of the destruction rather than the construction of that surface.

On the east side of the range, where the San Luis Valley lies now, the accumulation of stream-borne materials on the flanks of the domed peneplain was much greater than elsewhere. Either this portion of the peneplain had been warped downward to form a great basin extending eastward to the fault scarp along the west front of the Sangre de Cristo Range or else the ancestral Rio Grande was particularly inefficient in transporting the detritus carved from the San Juan dome. In any event the deposits on the peneplain accumulated to great thicknesses in the San Luis depression. Apparently while the central and western portions of the San Juan Range were being uplifted the eastern margin and the adjacent San Luis Valley were slowly sinking. Possibly this was in part or wholly a response to isostatic adjustment consequent upon the overloading of this particular place on its margin. Great quantities of river-borne débris were washed into the depression among the hills at the south margin of the San Luis Basin and filled the valleys on the eastern slopes of the Tusas Mountains along the side of the Rio Grande Valley in New Mexico.

While this process of sedimentation was continuing extensive flows of basaltic lavas of Hinsdale age flooded hundreds of square miles of country. For the most part the lava floods were poured out on the newly deposited beds of gravel and sand in the piedmont and valley regions. In part, however, the lavas spread over bare rock surfaces in the eastern half of the domed area. Their distribution is indicated on Plate 2.

The Hinsdale basalts[5] must have issued from many separate vents in different parts of the range, but the exact location of only a few of the vents is now known. One of the conduits through which the lavas ascended has been partly exposed on the southeast flank of Alpine Plateau, high on the wall of the gorge of the Lake Fork of the Gunnison River between the mouths of Fourth of July and Front Creeks. Escaping quietly from that orifice the basaltic lava flooded many square miles of the peneplain and reached nearly to the site of Cebolla, on the Gunnison River, near which a small remnant of the flow caps a hill at an altitude of 8,900 feet. The largest and thickest remnant of Hinsdale lava which flowed from that vent now forms the cap rock of Alpine Plateau. A similar cap on Cannibal Plateau, a few miles to the southeast, is probably another remnant of the same extensive sheet, although it may be formed of lava that issued from an independent orifice not now exposed to view.

Probably many of the thicker and larger bodies of basalt of the Hinsdale volcanic series indicated on Plate 2 conceal the pipelike conduits or short fissures through which the lava ascended, but most of the scattered patches of lava are presumably the dwindling remnants that have thus far escaped removal during the erosion of formerly widespread sheets now dissected into isolated fragments.

Some of the Hinsdale eruptions were evidently of the explosive type, as volcanic tuffs are in places found beneath the lava flows or interstratified with them. Rio Grande Pyramid (pl. 11, *B*) is described by Larsen, for example, as a Hinsdale volcano constructed to a height of about 1,000 feet above the floor on which it rests. Green Ridge, the most conspicuous elevation on the east margin of the San Juan Mountains, overlooking the San Luis Valley near Monte Vista, is a great mass of Hinsdale ejecta and lava which apparently represents a volcanic pile, somewhat modified by erosion but formerly built to a height of at least 2,000 feet above the peneplain surface. Los Mogotes, the twin hills rising above the inclined mesa north of the Conejos River, west of Antonito, similarly indicate the location of the vents through which the tuffs and lavas in the southeast corner of the San Juan region were ejected.

[5] We are indebted to Whitman Cross and E. S. Larsen for most of our information concerning these lavas.

Thus the eruption of the Hinsdale volcanic series seems to have been more or less contemporaneous with the warping of the peneplain at or near the end of the Tertiary or possibly the beginning of the Quaternary period and the resultant deposition of widespread alluvial fans about the periphery of the dome. A little later in the development of the region the very streams that had deposited the gravel fans began their dissection. The deformation of the peneplain had been but a local expression of regional uplift of almost continental dimensions. As the Colorado River, far to the southwest, succeeded in lowering its bed during the process of sculpturing the Grand Canyon in Arizona, the San Juan in consequence lowered its immediate stream channel. Rejuvenation worked upstream from the margins of the newly uplifted plateau until finally it influenced erosion within the San Juan province. Thus in time the rivers were able to lower their channels in the outlying peripheral zone adjacent to the San Juan dome. Thereafter the ancient gravel fans were left at progressively higher and higher levels above the stream beds. To-day these deposits cap the surface of outlying mesas and plateaus. To them we have applied the name Bridgetimber gravel, taken from the ridge southwest of Durango known as Bridge Timber Mountain, which is capped with this gravel.

The history of the Rio Grande, especially in the midst of the San Luis Valley, has been almost exactly the opposite of that recorded by the headwaters of the Colorado. Apparently without interruption from the first arching of the San Juan peneplain to the present time the Rio Grande has been constantly pouring deposits on the floor of the San Luis Valley north of the San Luis Hills. Here there is a great basin, 50 miles long from north to south and 35 miles wide from east to west, which throughout Quaternary time has been the site of steady alluviation. Each renewal of uplift of the San Juan dome seems to have been counterbalanced by renewed sinking of the San Luis depression. As recounted elsewhere in this report, this differential movement has tilted a huge block of the earth's crust, extending from the Sangre de Cristo fault on the east to the middle of the San Juan Mountains on the west. This block has apparently been hinged along a line close to the east front of the San Juan Mountains. Each upward movement of the half of the block west of this hinge line has been compensated by sinking of the half of the block east of the line. Thus the San Juan peneplain disappears beneath the gravel of the San Luis Valley and is to-day more than 1,000 feet below the valley floor in the middle and eastern half of the basin. Here the deposits corresponding to the Bridgetimber gravel are at levels far below the modern flood plains instead of high above them.

Chapter 4.—QUATERNARY HISTORY OF THE SAN JUAN REGION

If the deformation of the San Juan peneplain described in the preceding chapter has been correctly interpreted as marking the transition from Pliocene to Pleistocene time, the Bridgetimber gravel, the Hinsdale volcanic series, and the Los Pinos gravel, all of which were deposited during or immediately after that deformation, are similarly transitional in age. The history of their deposition, however, has been here tentatively described as the final episode of Tertiary time. Once the San Juan rivers had succeeded in trenching their channels in the peripheral zone bordering the San Juan dome, Quaternary time had fairly begun. The successive events in San Juan history subsequent to the deposition of the Bridgetimber gravel and the outpouring of the Hinsdale volcanic series are therefore to be sketched in this chapter in chronologic sequence.

The Quaternary history, as we now understand it, is exceedingly complex, but in its major outlines it is a comparatively simple story. Only a small part of the data on which our conclusions are based will be inserted in this somewhat generalized statement. For most of the facts the reader is referred to subsequent chapters, where the deposits of each successive stage are described in detail and the existing features are depicted in relation to the Quaternary history.

FLORIDA CYCLE OF EROSION

The rejuvenation that necessarily followed the deformation and uplift of the San Juan peneplain initiated a new cycle of erosion, which may be designated the Florida cycle, inasmuch as Florida Mesa, in the Ignacio quadrangle, is a result of the conditions which prevailed at that time.

A critical examination of any portion of the San Juan Mountains indicates that with few exceptions each of the larger valleys consists of an upper, outer trough with comparatively gentle slopes and an inner lower canyon with steep walls and truly youthful appearance. The Lake Fork of the Gunnison River, in the northwest quarter of the San Cristobal quadrangle, is an excellent illustration. (See fig. 6.) From the stream flat the valley walls rise almost precipitously for about 1,500 feet to a level where the gradient abruptly changes. Above the shoulder thus defined the slopes rise gradually about 2,000 feet higher. On the average the slant of the inner canyon wall is 1,000 feet in little more than a mile. Apparently the composite valley is the result of the carving of a youthful canyon deep into the floor of a mature valley.

The location of the shoulder that marks the rim of the inner canyon has been determined by the presence of rock of superior resistance in only a few places, but the break in valley slope is well-nigh universal and must be the result of a condition widespread throughout the San Juan province. The broad outer valleys above the inner canyons are the product of erosion during the Florida cycle.

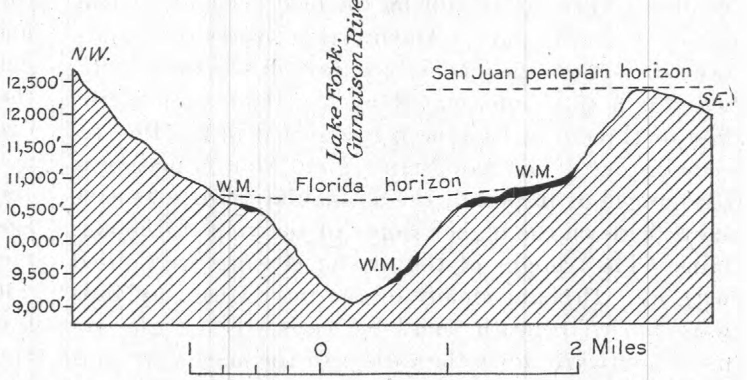


Figure 6.—Cross section of valley of Lake Fork of Gunnison River, from Grassy Mountain (at left) southeast to Continental Divide near Ruby Creek, San Cristobal quadrangle. The broad valley, developed during the Florida cycle of erosion, has its floor about 10,500 feet above sea level; below it is the steep-walled later canyon. W. M., Wisconsin moraine

The uplift that ended the Peneplain cycle of erosion had elevated the central portion of the San Juan region sufficiently to permit streams to cut downward about 2,000 or 2,500 feet below the peneplain before they reached the new base-level. At the north, west, and south margins of the mountain area differential uplift was considerably less, and here the new base-level was 600 to 1,000 feet below the former one. Toward this new base-level the larger streams lowered their channels in all parts of the range. As soon as the grade of each stream had been adjusted to the new conditions the widening of valleys by lateral planation commenced. In the regions of weaker rocks, in what is now the zone of peripheral lowland, erosion went on with comparative rapidity. Base-level was quickly approximated by the master streams, and broad valleys of late mature or even old aspect were carved. In the regions of more resistant rocks, which also were the localities in which the new base-level was at the greatest depth below the deformed peneplain, the transformation of youthful canyons into mature open valleys was a more difficult process. The valley profiles developed by the master streams in the center of the range were those of maturity; broadly U-shaped troughs characterized the landscape there. The smaller streams tributary to the larger rivers were, of course, less vigorous, and few of them had accomplished more than the notching of the surface by steep-sided gorges.

Portions of the floors of the postmature valleys in the regions of weaker rocks have since become the tops of mesas as a result of later uplift and further erosion. Deep canyons have since been carved beneath the broadly U-shaped troughs of the master streams in the regions of stronger rocks, and portions of the surface brought to grade during the Florida cycle are now recognizable as benches or shoulders high on the existing valley walls. The steep-sided gorges of the smaller streams can not now be distinguished from similar gorges carved during the next cycle of erosion.

Cerro glacial stage.—During this process of mountain dissection the normal course of stream erosion was for a time interrupted by a glacial episode, the first of three that have been recognized in the Pleistocene history of the San Juan region. The climate was so changed as to permit the accumulation of extensive snow fields on the higher slopes of the youthful mountains. The troughs of the master streams were filled with ice. Probably many of the interstream uplands were buried beneath small ice caps. Huge glaciers moved outward down the valleys of the master streams in all directions from the higher mountains and spread upon the adjacent lowland as great piedmont glaciers. Deposits made by these masses of ice have been recognized at many places in and near the mountains.

On the north slope of the range, for example, there are extensive bodies of glacial drift which indicate that the ice of this stage moved northward as far as Montrose and Cerro Summit. Because of the excellent exposures of glacial drift of this stage near Cerro Summit this ice epoch has been named the Cerro stage, and the deposits then formed have been named the Cerro till.[1]

The effects of the Cerro glaciation in sculpturing the mountain mass can not be recognized with certainty at any locality. Doubtless, however, the results were quite similar to those that follow alpine glaciation in any mountain range. Cirques were carved at the heads of most mountain valleys; interstream uplands were gouged and scraped by passing ice, so that after the disappearance of the Cerro glaciers a multitude of lakes were probably present in all parts of the mountain range. The valleys leading out toward the foothills were scraped smooth of projecting spurs and given even more of a U-shaped appearance and trough-like form than they had developed by stream erosion alone.

Great masses of morainic débris were dropped upon the surface of the lowlands adjacent to the mountains. Here there remain, even to the present day, many areas whose topography has been little changed from that developed by the deposition of the Cerro drift. The distribution of these deposits indicates that the Cerro ice was not confined to the valleys but overtopped divides and spread far across the lowland areas beyond the mountain fronts. The Cerro glaciation was the most extensive of the three Pleistocene glacial advances which have been recognized in the San Juan province.

Deposition of Florida gravel.—As the Cerro ice melted the San Juan streams began a new phase of their activity. The drainage had been greatly disturbed by glaciation. Huge masses of drift clogged many a mountain valley. Large amounts of glacial débris were available for removal by the streams. In the mountains there were many ice-scoured declivities over which the streams were flowing and which invited speedy erosion to a gentler grade. Conditions therefore combined to load every mountain torrent to its limit. The master streams that debouched from the mountain fronts upon the adjacent lowlands were, without exception, heavily loaded. In consequence broad alluvial fans composed of coarse débris were spread widely over the valley floors. A veneer of bouldery gravel, 10 to 50 feet in thickness, covered the floor of every valley beyond the foothill zone, and in certain of the broader troughs it extended far up the stream courses well within the mountain area.

In many places this stream gravel rested upon comparatively soft shale or thin-bedded sandstones. Since its deposition changes in the altitude of the San Juan region have permitted the streams to cut their modern channels far below the graded surface of that depositional stage. In consequence the gravel now caps extensive mesas rising above the modern lowland flats. One of the most conspicuous of these is Florida Mesa, southeast of Durango, near the center of the Ignacio quadrangle, and the gravel is therefore named the Florida gravel. Within the mountains there are many boulder-strewn terraces which may be correlated with table-lands beyond the foothills and represent the remnants of the same stream deposit.

End of the Florida cycle.—Deposition of the Florida gravel was terminated by a renewal of the domal uplift. Once more this portion of the earth's crust was warped. The same localities which had so many times been elevated above their surroundings were now uplifted again. The San Juan dome was made more pronounced. At the center of the range the uplift amounted to about 2,000 feet, but near the margin it was only a few hundred feet. As a result of this crustal

[1] Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, p. 14, 1915.

movement, streams which had been widening their valleys or depositing their load of gravel upon broad flood plains were quickened and rejuvenated. To the old task of down cutting and canyon carving the streams returned; the Florida cycle of erosion and deposition was ended.

CANYON CYCLE OF EROSION

The differential movement of the earth's crust which ended the Florida cycle of erosion upset the adjustment of streams to surface gradient everywhere within the San Juan region. Except along the eastern front of the mountains the crustal movement was an uplift of varying amounts, which necessarily resulted in the rejuvenation of all streams. In the central part of the region, where to-day are the highest mountains, the uplift caused the streams to commence the lowering of their immediate channels toward a new base-level several hundred feet below the graded surface developed during the Florida cycle. At the north, west, and south margins of the mountains the uplift was not so great, but even here its effect was to initiate a new phase of downward cutting and canyon development. On the east front of the mountains, however, in and near the San Luis Valley, the differential movement was of an opposite nature. The gently sloping torrential fans that had been deposited beyond the mountain front during the Florida cycle were warped downward. Apparently the whole floor of what is now the San Luis Valley was gently depressed. It appears that the movement was again a tilting of a huge block of the earth's crust. As before, the eastern margin of this block was defined by the nearly vertical fault plane that forms the west margin of the Sangre de Cristo Range, at the east side of the San Luis Valley. The tilted block was hinged along a line running north and south just within the San Juan Mountains, near the west margin of the Del Norte and Conejos quadrangles. Pivoted on this hinge, the portion of the earth's crust to the west of it was raised, while that to the east was depressed.

As a result of these crustal warpings and the consequent rejuvenation of streams, vigorous downward erosion was induced in all drainage basins throughout the San Juan region except in that portion which had been relatively depressed. Here the conditions for alluviation were not only continued but were rendered increasingly favorable. In the center of the mountains steep-walled canyons, hundreds or even thousands of feet in depth, were eroded, so that the name Canyon cycle of erosion may be used as appropriate. The canyons were incised beneath the floors of the valleys formed during the Florida cycle. On the north, west, and south margins of the range and the adjacent portions of the plateau country similar but somewhat shallower canyons and gorges were carved. The débris thus obtained in the upper reaches of all the streams tributary to the Colorado River was in the main carried far down the streams leading to the west beyond the San Juan region. The Rio Grande and its tributaries, however, were then, as now, flowing in a general easterly direction from the central part of the San Juan Mountains. The débris carved by these streams from the region of their headwaters was transported downstream to the recently depressed portion of the San Luis Valley and there spread over the valley floor. Thus while many remnants of the graded surfaces, veneered with deposits of the Florida erosion cycle, were left high above the new drainage lines in most parts of the San Juan region, on this eastern front the surfaces and gravel of that cycle were buried beneath a flood of stream-washed débris. The contrasted relations are indicated diagrammatically on Plate 10.

Durango glacial stage.—Sometime after the beginning of the Canyon cycle of erosion the climate of the San Juan region was sufficiently changed to cause another episode of refrigeration. Once more snow fields gathered in the higher mountains, and glacial ice formed at the heads of the larger valleys. The glaciers of this stage moved outward down the many valleys that radiated from the heart of the mountains. The glaciation has been named the Durango stage,[2] because the moraines and outwash deposits of the greatest glacier of this time, that in the Animas Valley, are well displayed near Durango. Apparently the ice filled every major valley within the mountains and crept downward and outward to reach its farthest limit approximately in the belt of foothills at their margin. Thus the terminus of the Animas Glacier was within the limits of the present city of Durango, 2 or 3 miles above the gateway in the line of hogbacks through which the Animas River passes from the mountains to the plains. The terminus of the Uncompahgre Glacier of this stage was 4 miles north of Ridgway, just beyond the mountain front on the north side of the San Juan region. The Rio Grande Glacier at this time was able to reach downstream only as far as the eastern margin of the San Cristobal quadrangle, 30 miles west of the east front of the mountains. Unlike the ice of the Cerro stage, the Durango glaciers seem to have been everywhere confined to the valleys. Nowhere did they spread beyond the foothills to form piedmont glaciers.

At the beginning of the Durango stage the streams coursing across the lowland surrounding the San Juan Mountains had generally developed broad valley flats. These flats were now veneered with gravel washed from the melting ice, and long valley trains stretched beyond the ice limits down each of the larger valleys.

[2] Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, p. 14, 1915.

That in the Animas Valley was more than 2 miles wide in the belt of peripheral lowland which the Animas crosses in the south half of the Ignacio quadrangle. Presumably, therefore, the streams had reached a temporary base-level and had begun lateral planation when interrupted by the Durango glaciation. Remnants of the graded surface at that level are, however, comparatively rare and have been observed only in the localities of weaker rocks beyond the mountain fronts. Their development seems to have been an incident of trivial importance in the physiographic history of the range.

Post-Durango and pre-Wisconsin interglacial stage.—As the Durango glaciers melted away the ice-freed streams resumed their task of mountain sculpturing. Glacial erosion had upset the balance between land slopes and stream velocities, so that a new episode of vigorous erosion ensued. Possibly also the disappearance of the Durango ice was nearly or quite contemporaneous with a renewal of domal uplift. In any event the streams cut rapidly downward below the floor which had been scraped smooth by ice during the Durango stage and below the surfaces which had been coated with fluvioglacial gravel from the same glaciers.

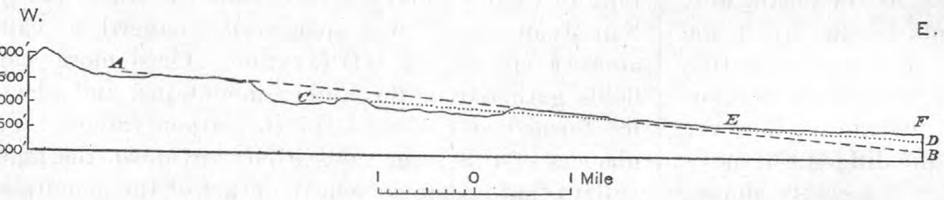


FIGURE 7.—Profile of east slope of San Juan Mountains at margin of San Luis Valley south of Del Norte. A–B, Broken lines connect remnants of gravel-covered terraces of Florida cycle of erosion; C–D, dotted lines connect terraces of post-Durango and pre-Wisconsin interglacial stage; E–F, surface of alluvium of San Luis Valley

The incision of stream channels ere long brought the streams in close proximity to the base-level toward which they were working, and in the regions where erosion was most rapid, because of less resistant rocks, wide valley flats were once more developed by lateral planation. In the heart of the range, where the rocks offered superior resistance to the activities of the streams, no opportunity seems to have been afforded during the interglacial stage which succeeded the Durango glacial stage for any very extensive amount of lateral planation. All the energy of the vigorous streams was there confined to the task of canyon deepening. It is therefore only in a few localities, and those generally beyond the mountain front, that remnants of this temporary base-level developed by the rivers of this interglacial time are preserved. In the main these remnants now appear as gravel-strewn rock terraces intermediate in height between the valley trains of the Durango and Wisconsin glaciers. Spring Creek Mesa, in the Uncompahgre Valley west of Montrose, is one of the largest surfaces now known to be covered by a post-Durango and pre-Wisconsin interglacial deposit. Similar but smaller terraces have been recognized in the valley of the Los Pinos River south of Bayfield, as well as in the Animas Valley south of Durango. At all these localities the graded surface developed at this time is 100 to 200 feet above the modern flood plains and 50 to 150 feet below the Durango outwash gravel.

Along the east front of the range there are a number of gently sloping gravel-strewn surfaces, intermediate in position between the modern flood plains and the surfaces developed during the Florida cycle of erosion, which dip eastward and disappear beneath the floor of the San Luis Valley. The relationship of these surfaces may best be comprehended from the accompanying diagram (fig. 7), which indicates that they represent a temporary halt in the differential tilting of this part of the earth's crust. While the mountains were being elevated the San Luis Valley was being depressed. Thus toward the west these post-Durango and pre-Wisconsin interglacial surfaces are cut far below the flats of the Florida cycle; but toward the east the two converge until they meet. Still farther east the post-Durango and pre-Wisconsin interglacial gravel covers the Florida gravel and is in turn similarly buried by modern stream deposits.

In the broad area of easily eroded shale and thin-bedded sandstone between the Animas and Los Pinos Rivers, south of the mountain front in the Ignacio quadrangle, considerable areas were reduced to the topography of old age at about this time. The gently undulating lowland surrounding the village of Oxford is strewn with scattered gravel and boulders left by the meandering streams that apparently deployed across this area during the time of temporary lateral planation. The names Oxford gravel and Oxford terraces are here applied to the deposits and graded surfaces of this substage in the dissection of the San Juan Mountains.

To-day all these surfaces with their scattering of Oxford gravel are scores or even hundreds of feet above the modern drainage lines, those on the east front of the range, of course, excepted. The development of widespread flats seems to have been merely a temporary phase in the steady progress of down cutting and canyon development, which is the chief incident of post-Durango and pre-Wisconsin interglacial time. Apparently, therefore, there must have been a renewal of mountain growth by crustal uplift which terminated this brief episode of stream alluviation on the wide stream flats of the Oxford substage. Again vigorous downward erosion characterized the work of all the streams in the San Juan region. Canyon deepening continued within the area of hard rocks, where lateral planation had not yet been begun. Gorge cutting was renewed wherever a wide valley had been developed. Thus at the end of this interglacial stage the streams were again vigorously deepening their valleys.

Wisconsin glacial stage.—Then came the last of the epochs of refrigeration which characterize Pleistocene time. Once more climatic conditions forced the San Juan region into the grip of a glacial stage. Alpine glaciers were formed in nearly all the valleys that had earlier been occupied by Durango ice. Most of the amphitheaters that had earlier been sculptured by that ice were once more the sites of vigorous glacial erosion. The general appearance of the region, crowded with glaciers at the climax of this stage, is indicated on Plate 3. In general the glaciers were not quite so large as those of the Durango stage. Certain valleys that had been occupied by Durango ice escaped glaciation during Wisconsin time. In nearly all the valleys that were glaciated during both these stages the later glaciers fall short 1 to 3 miles of reaching as far downstream as the earlier ones. Valley sculpturing was, of course, very materially affected by the Wisconsin glaciers, and much of the remarkable scenery of the San Juan region is a result of glaciation, which so ably reinforced the streams in their work of mountain carving.

Beyond the farthest reach of the great valley glaciers the streams, swollen by the floods escaping from the melting ice, spread tremendous quantities of glacial débris. Long valley trains stretched down each valley. These were for the most part narrow, rarely more than a mile in width. The stream flats that had been developed in the areas of softer rocks by that time were submerged beneath the gravel of these valley trains, which filled the stream channels to a height of 20 or 30 feet.

Post-Wisconsin erosion.—Although 10,000 or more years ago, it is but yesterday, as the geologist reckons time, that the San Juan Mountains were occupied by the ice of the Wisconsin stage. In the relatively short time which has elapsed since that ice melted away only the slightest of changes have taken place within the region. At many places glacial erosion or deposition, or both combined, left undrained depressions which were quickly filled with water. Many of these remain; the countless ponds and lakes, with turquoise water reflecting the emerald green of wooded slopes or the tawny brown of volcanic cliffs, constitute the last touch of beauty needed to make complete the magnificent scenery of the mountains. Other basins have been filled with sand and mud, from the flat surface of which the water has been drained by the cutting down of the outlets of the lakes, and are now fertile farm lands or mountain parks. Elsewhere streams have notched the higher portions of the floor across which the Wisconsin ice had moved. Gorges a score or even a few hundred feet in depth, like the famous Box Canyon at Ouray, have thus been formed. In many places glaciation resulted in the oversteepening of mountain walls and valley slopes, so that the rocks left in an unstable condition have at different times fallen in huge landslides. The importance of this phase of erosion is indicated by the extensive areas now covered by slide débris.

At many places at the present time streams are aggrading their channels or developing valley flats by lateral planation, but such places seem to be the exception, not the rule. They are found where glacial deposits or erosion had left the land surface in such a relation to the streams that the normal process of downward cutting is for a time rendered impossible. In the main the streams of the San Juan are to-day actively engaged in their age-long task of valley deepening.

SUMMARY

Thus, briefly sketched, the Quaternary history of the San Juan region indicates that during this latest of geologic periods the region has been subjected to almost constant crustal warping. Mountain growth by domal uplift seems to have been renewed so frequently as to appear practically continuous. The sculpturing of the mountains by the development of deep canyons is an obvious consequence of this crustal deformation. At times the streams have taken the lead in their contest with the forces of diastrophism and for a short interval have succeeded in developing widespread graded surfaces, but always the energies pent within the body of the earth have terminated the intervals of lateral planation and deposition and have forced the streams back to their work of valley deepening. In general there seem to have been two main cycles of erosion subsequent to that in which the San Juan peneplain was developed. The earlier of these, the Florida cycle, progressed in general to the stage of late maturity before the cycle was ended by crustal movement. The second cycle, the Canyon cycle, is still in the stage of youth.

Normal stream erosion during Quaternary time has been interrupted at least thrice by glaciation. The first of these glacial stages, the Cerro, occurred during the Florida cycle. The second and third, the Durango and Wisconsin, both took place during the Canyon cycle of erosion. All three were able assistants to the streams in their task of earth sculpturing, and each left deposits of considerable interest.

Chapter 5.—PHYSICAL FEATURES OF THE SAN JUAN REGION

The attempt has been made in chapter 2 to convey to the reader a general idea of the geography of the San Juan region. The main physiographic features of the region were there referred to, but detailed descriptions of the many physiographic units which constitute the San Juan province were not given. It is our intention here to consider the various physiographic types embraced within the San Juan region, classified according to their present form. In each class the most prominent or interesting examples will be described and an attempt will be made to explain the origin of each particular topographic feature by recounting the physiographic history inferred from its present structure and form.

BORDER MESAS AND PLATEAUS

The San Juan Mountains are bordered on the southwest, west, and northwest by plateaus that extend in a westerly direction for hundreds of miles. Close to the borders of the mountains these plateaus have been dissected by streams heading in the mountains. Where they have been carved into small fragments each detached portion constitutes a mesa; where the units between canyons are large they are called plateaus.

In general these mesas and plateaus are uplands with comparatively flat or gently undulating surfaces, bordered by precipitous cliffs descending abruptly to the floors of neighboring valleys. They are in every sense of the word table-lands. For the most part they are composed of sedimentary rocks, and many are capped with a "rim rock" of very resistant sandstone. Some, however, are composed of volcanic or other igneous rocks, and some of the surfaces bevel the upturned edges of inclined strata.

Uncompahgre Plateau.—The Uncompahgre Plateau is a vast upland surface that extends a distance of 75 miles to the northwest from the base of the San Juan Mountains and forms the divide between the Uncompahgre-Gunnison and San Miguel-Dolores River systems. The southeastern extremity of the plateau occupies the west-central part of the Montrose quadrangle and is known as Log Hill Mesa. (See pl. 16, *B*.)

The surface of the Uncompahgre Plateau is remarkably smooth. In general it slopes toward the northeast from its highest points on its southwest margin. In its surface have been carved numerous steep-sided narrow canyons which cross it from the southwest toward the northeast. These canyons are natural barriers to travel and are generally so youthful in form that there is little more than room for the stream bed on the floor between the parallel walls. At the south, in the southwest quarter of the Montrose quadrangle, the plateau is bounded by an abrupt escarpment trending east along the north margin of Pleasant Valley. This escarpment is close to 1,000 feet in height, and its upper portion is precipitous where the massive sandstone retains nearly vertical faces. Toward the east the plateau is bounded by a similarly abrupt though somewhat lower escarpment facing the Uncompahgre Valley. On its northeast margin, however, the plateau surface descends gradually to the level of the modern streams.

A few small elevations on different parts of the plateau rise above this smooth-tilted surface. The highest of these is Horsefly Peak, which stands 10,338 feet above sea level, or about 1,000 feet above the surface of the plateau in its vicinity. Horsefly Peak and other similar elevations are composed of shale which has been protected by a local cap of glacial drift of Cerro age.

Near its eastern margin the Uncompahgre Plateau surface is modified by McKenzie Butte, a prominent flat-topped hill that rises 500 feet above the plateau. This butte is due to the intrusion of a massive sill, which cuts across the gently inclined strata of the plateau and in places lifts the sedimentary beds high above their ordinary position.

Structurally the Uncompahgre Plateau is a great fault block, tilted gently toward the northeast. The escarpment that bounds it on its southern margin is a fault scarp that marks the presence of a nearly vertical fault plane along which the displacement amounted to more than 1,000 feet. The surface of the plateau is formed by very resistant Dakota(?) sandstone, of Upper Cretaceous age, from which the overlying shale has nearly everywhere been stripped. The slope of the plateau surface is the dip of the Dakota(?) sandstone, and the topographic feature is very evidently a direct response to the superior resistance to erosion offered by this formation. Wherever the overlying Mancos shale has escaped removal its preservation has been due to a cap of resistant boulder gravel, to glacial drift, or to the intrusion of igneous rock such as is found in McKenzie Butte.

It is apparent from the distribution of Cerro till in the Montrose quadrangle that the present surface of the Uncompahgre Plateau is entirely of post-Cerro age. At the time of the Cerro glaciation a greater or less thickness of Mancos shale must have extended over most of the area included in the plateau. Across the

Mancos shale surface the Cerro ice pushed to its farther limit somewhere in the vicinity of Montrose. After the melting of the ice and the regional uplift that permitted the extensive post-Cerro erosion of the entire San Juan region, nearly all of the glacial material and the shale that capped the Dakota(?) sandstone were stripped from the surface of that resistant formation. Only in such localities as Horsefly Peak, where the Cerro till was of considerable thickness, have the till and the subjacent shale been preserved.

The task of laying bare the Dakota (?) sandstone throughout this great area was not accomplished in any one stage of the physiographic history of the San Juan Mountains but has required a long period of time, stretching from the end of the Cerro glacial stage almost or quite to the present day. At the time that the boulders, pebbles, and sand here named the Florida gravel were strewn over the graded surfaces along the flood plains of the master streams in all this area, the task of uncovering the Dakota (?) sandstone was far from complete. On the north margin of the plateau, south of Montrose, graded surfaces of the Florida cycle form small mesas rising 50 to 200 feet above the plateau. These mesas are formed of remnants of Mancos shale capped by a resistant veneer of cobblestones and gravel. Similar but very much lower gravel-strewn flats in the same neighborhood are remnants of the valley train that resulted from fluvioglacial action in the Durango glacial stage. These flats, however, lie so little above the plateau surface that it is apparent that most of this gigantic task of laying bare the Dakota (?) floor must have been accomplished before the Durango glaciation. In large degree, therefore, the exhuming of the Dakota (?) sandstone and the consequent formation of the Uncompahgre Plateau occurred during the interval between the Cerro and Durango glacial stages. The many narrow canyons, such as Happy Canyon and the canyon of Spring Creek, whose trend is parallel to the strike of the Dakota (?) sandstone and which etch the surface of the plateau, are evidently of very recent origin. In all probability they have been carved chiefly during the stage of canyon cutting that appears to have been general throughout the San Juan region in post-Durango time.

Blue Mesa.—On each side of the canyon of the Gunnison River in and near the northern part of the Uncompahgre quadrangle there are many small mesas separated from one another by the youthful gorges of streams tributary to the Gunnison. Of those on the south side of the canyon, Blue Mesa is typical. It is a table-land having an area of about 10 square miles and bounded on the north by a steep cliff leading abruptly downward to a bench which directly overlooks the Black Canyon. On the west the mesa is separated from its neighbor, Fitzpatrick Mesa, by the steep-walled gorge of Blue Creek. Similarly, on the east the somewhat less canyonlike valley of Pine Creek separates Blue Mesa from Blue Creek Mesa. Toward the south, however, the surface of Blue Mesa descends rather gradually to the open swale traversed by the road between Madeira and Cimarron.

The sparsely timbered surface of Blue Mesa is not nearly so flat as might be inferred from its name. On the contrary, it is undulating, with numerous rounded hills separated by broad valleys. These valleys display the contour of old-age erosion forms and extend from the sources of the intermittent streams almost to the margin of the mesa. Farther downstream the valleys abruptly change in appearance; at the margin of the upland surface they are youthful ravines, tributary to the master canyons which almost surround the mesa. The striking contrast between the aged appearance of the upland surface and the youthful topographic forms of the surrounding canyons is everywhere noteworthy. The mesa surface appears to be a bit of old-age topography projecting islandlike from a sea of gorges and canyons.

The altitude of the summit of Blue Mesa ranges from 8,700 to 9,400 feet above sea level. No higher points overlook its surface except those found at some distance to the south, where the summits rise toward the higher peaks of the San Juan Mountains. The physiographic relation of the ancient erosion surface that forms the top of Blue Mesa immediately suggested the likelihood that it was a remnant of the San Juan peneplain, and, acting on this suggestion, we made diligent search early in the progress of our field work for stream gravel similar to that found elsewhere at correspondingly high altitudes. At several localities on Blue Mesa apparently waterworn cobblestones were found. However, one of the formations composing the mesa and exposed in many of its valleys is a volcanic agglomerate containing a variety of boulders and gravel. Unfortunately, these boulders weathering out of the loosely cemented agglomerate are seldom distinguishable from the modern stream gravel. Hence it would be unwise to assert that any of the pebbles on Blue Mesa should be interpreted as peneplain gravel. All the pebbles and boulders that were observed may represent the product of local weathering from the Tertiary volcanic rocks. On the other hand, certain gravel deposits found on the summit of Fitzpatrick Mesa, on Carpenter Ridge, and on Big Mesa are believed to be undoubted remnants of stream deposits made upon the San Juan peneplain. The altitude at which these areas of peneplain gravel were observed harmonizes closely with the altitude of Blue Mesa.

Although in places the surfaces of Blue Mesa and the similar neighboring uplands have been determined by the presence of resistant lava flows, they are at other places cut in pre-Cambrian rocks and elsewhere are determined by Mesozoic sandstones. The mesa surfaces, therefore, cut various formations and are only locally the result of flat-lying resistant beds. This fact, coupled with the presence of stream gravel, as noted, and the old-age stage of erosion on the uplands, makes quite certain their reference to the San Juan peneplain. Their highest portions have thus been indicated on Plate 2.

Blue Mesa and its neighbors are all in a zone of comparatively light rainfall. If the peneplain is restored in imagination by filling in the canyons and valleys that now separate its remnants, it is apparent that this portion of the ancient surface is comparatively low. At the north it rises gently toward the summit of the West Elk Mountains, and at the south it rises similarly toward the majestic peaks of the northern San Juan. Here, in the Gunnison trough, between these two ranges, is a sheltered nook prevented by surrounding highlands from receiving much precipitation. The abundant rainfall that descends upon the slopes of the mountains to the north and south is concentrated in the stream channels tributary to the Gunnison. In these channels the run-off is actively engaged in lowering the canyon floors, and the intervening uplands escape its destructive effects. Thus the mesas bordering the Gunnison have been isolated from one another, but they have retained, with slight alteration, the surface topography which they inherited from the peneplain stage.

Black Mesa.—Black Mesa occupies 25 or 30 square miles in and near the northwest corner of the Uncompahgre quadrangle and the northeast corner of the Montrose quadrangle, on the north side of the Black Canyon. Its topographic and physiographic relations are similar to those just described for Blue Mesa and are shown on Plate 2. The surface of Black Mesa, however, is somewhat more deeply trenched by the valleys of half a dozen streams that flow southwestward to the Gunnison. On the upland these streams are now in maturity in the erosion cycle, but they descend to join the main river through steep-walled gulches at extremely high gradients. Thus only the higher portion of the Black Mesa may be considered a remnant of the San Juan peneplain. The mature valleys of these smaller streams have been carved since that ancient cycle of erosion was ended by the rejuvenating uplift of the entire San Juan region.

Florida Mesa.—A large area of gently rolling upland between the Florida and Animas Rivers, near the center of the Ignacio quadrangle, is known as Florida Mesa. It is bordered on the east and south by steep escarpments which descend abruptly to the flood plain of the Florida River 100 to 400 feet below. On the west a similar cliff averaging 300 feet in height drops off to the floor of the Animas Valley. On the north Florida Mesa terminates against the foot of steeply inclined hogback ridges which form the foothills all along the southern margin of the San Juan Range.

The surface of the mesa slopes gently southward from an altitude of 7,200 feet at its north margin to only 6,300 feet at its southernmost extension near Bondad. The surface gradient is so regular and gentle that it forms an ideal grade for irrigation ditches, and most of the mesa is now under cultivation. This regularly undulating surface is very evidently the result of stream erosion in beds of comparatively soft shale and sandstone. Its preservation from destruction since the day when it marked the base-level of erosion to the present time, when it is an upland, high above base-level, is to be attributed to the veneer of cobblestones and boulders spread by heavily loaded streams upon it.

Narrow strips along the east and west sides of the mesa are in reality terraces 40 to 80 feet below the general surface. The gravel cap on these terraces is a part of the valley trains spread by streams issuing from glaciers of the Durango stage. The much larger central portion of the mesa is capped with gravel already described as a part of the formation to which we have given the name Florida gravel.

The Florida Mesa, therefore, is a remnant of a once widespread lowland, formed at or near base-level by erosion in the soft rocks that form the periphery of the San Juan Range. Upon this plain the débris of the stream beds was scattered far and wide. Later uplift terminated that erosion cycle and permitted the carving of the modern canyons, which have isolated the mesa surface and left it standing as a table-land hundreds of feet above the modern streams.

Mesa Mountains.—The northern portion of a maturely dissected plateau crossed by the south boundary of the Ignacio quadrangle between the Animas and Los Pinos Rivers and extending for scores of miles southward into New Mexico is known as the Mesa Mountains. As seen from the north, this plateau is a typical table-land with a flat top and steep sides descending approximately 1,000 feet to the lowland which intervenes between it and the southern foothills of the San Juan Mountains. As a matter of fact, the flatness of the plateau top is greatly exaggerated in any view from the distance. As soon as the explorer gains the summit of this plateau he finds it to be dissected by numerous southward-trending ravines and canyons. The actual upland is thereby rendered extremely irregular and dendritic, as indicated on Plate 2, which shows the remnants of the San Juan peneplain. The flatness of the intercanyon uplands, which from a distance gives the semblance of an extensive table-land, is not due to the presence of resistant strata, although in many places the rim of a canyon or the top of an escarpment is defended by massive sandstone. The composite plateau surface slopes gently southward from an altitude of 7,600 feet above sea level with a gradient averaging 150 feet to the mile. This slope is less than the dip of the sedimentary rocks composing the Mesa Mountains, and the plateau surface therefore bevels the edges of inclined beds. It is unquestionably an erosion surface formed by streams meandering across a lowland reduced nearly or quite to base-level. Nearly everywhere upon the plateau are boulders, cobblestones, and pebbles deposited by these same streams and described in chapter 7 as the Bridgetimber gravel.

The present isolated position of the Mesa Mountains is the result of erosion in the surrounding country since the deformation of the peneplain. Much of this work was accomplished during the erosion cycle that finally resulted in the formation of the boulder-capped mesas of the Florida cycle, for patches of Florida gravel have been observed on the lower slopes of the Mesa Mountains 600 to 800 feet below their summits.

Bridge Timber Mountain.—Bridge Timber Mountain is a long, narrow, flat-crested upland extending in a general north-south direction for a distance of about 10 miles along the west margin of the Ignacio quadrangle. Viewed from the east it is a conspicuous topographic feature, with its flat upper surface sloping gently southward from an altitude of 8,200 feet at its north end to 7,200 feet at its south end. Here also the gradient of the mesa surface is less than the dip of the formations that crop out along its steeply sloping sides. And here also the sprinkling of gravel upon its surface reinforces the argument which, even though based on topography alone, would have been conclusive. The surface of Bridge Timber Mountain is a small bit of the once widespread peneplain and inherits its smoothness from that former lowland level. Its steep sides and sculptured cliffs are the result of stream erosion since the peneplain cycle was ended by the rejuvenating uplift of the San Juan area.

Red Mesa.—Much of the area between the deeply scarred western slopes of Bridge Timber Mountain and the narrow flood plain of the La Plata River is occupied by Red Mesa. This is a low table-land which stands only a few score feet above the watercourses on either side. Its surface slopes gently from an altitude of 7,800 feet near Fort Lewis to 6,500 feet at its southern edge, 14 miles to the southwest. In every respect this mesa is the counterpart of Florida Mesa. Its gently undulating upper surface is a portion of the lowland plain developed toward the end of the Florida cycle of erosion. Its northwest margin is terraced by the valley train formed along the La Plata River during the Durango glacial stage. The steep cliffs that border it and the canyons that partly dissect it are the results of stream erosion since the boulder-strewn surface was uplifted at the end of the cycle of erosion which had brought it into existence.

Mesa Verde.—Far in the southwest corner of the San Juan region is a plateau of great extent, comparable in area to the Uncompahgre Plateau, which occupies the northwest corner of the region. This southwestern plateau is surrounded by abrupt escarpments which rise from 1,000 to 2,000 feet above the lowland that intervenes between it and the San Juan Mountains. (See pl. 5, *A*.) The upland is high enough to receive an annual rainfall adequate to support a covering of grass and a scattering of scrubby cedars and piñons; thus it has received the name Mesa Verde ("green table"). The apparent smoothness of the plateau surface, which appears so impressive from a distance, is, on closer examination, found to be apparent only. Mesa Verde is dissected by innumerable ravines and canyons, which greatly reduce the area of interstream uplands. It is a frayed and ragged mesa, carved so intricately and so deeply that it is a day's journey to travel 5 miles in a direction at right angles to the trend of the larger canyons. Mesa Verde trails invariably lead in a general north-south direction, following along a stream bed or clinging precariously to a narrow strip of upland between two canyons.

The Mesa Verde is but a portion of a widespread plateau which has been dissected by streams flowing southward and southwestward from the San Juan Mountains to the San Juan River and thence to the Colorado. If the canyons and the intervening lowlands were filled to the rim of the plateau fragments, the resulting surface would be an extremely regular one, sloping gently toward the southwest with a gradient of about 150 feet to the mile. Although in many places this surface would conform to the dip of resistant sandstone beds, throughout the large area it would bevel the upturned edges of sandstone and shales, which have in general a slightly steeper dip away from the mountain than the gradient of the plateau.

Scattered over the surface of the Mesa Verde are pebbles, beautifully worn and water polished, which must have come from the San Juan Mountains and doubtless traveled southwestward in stream courses long before the present valleys were developed. The Mesa Verde is unquestionably a remnant of the widespread San Juan peneplain. Its smooth top is an inheritance from the low-lying plain which once occupied most of the San Juan region. Its present appearance as a high table-land is a result of the uplift and dissection of that plain.

FOOTHILLS

Foothills form a conspicuous feature of the San Juan physiography on only the south and east flanks of the range. Elsewhere the mountains rise with comparative abruptness from the adjacent plateaus or lowlands.

Hogbacks of the Ignacio and Pagosa Springs quadrangles.—Between the La Plata and Piedra Valleys is a narrow belt of hogbacks that forms the southern margin of the San Juan Range. These hills are conspicuously developed in the neighborhood of the Florida River, near the center of the Ignacio quadrangle, where there are three sets of parallel ridges trending in a general east-west direction and rising with increasing altitude northward toward the high mountains. These ridges have knife-edge crests, which for short distances are as smooth and regular as a barn ridge but which are more commonly carved into a succession of jagged peaks. The inner and more northerly face of each ridge is commonly the steeper, and in many places the southern slope conforms to the dip of steeply inclined strata. The crest of each ridge is invariably formed by a bed of resistant sandstone, and the trend of the ridges is the same as the strike of the rocks. They are, therefore, typical hogbacks in the technical sense of that term as used by physiographers and have resulted from the erosion of steeply inclined strata of different resistance. The hard beds form the ridges and lines of hills; the soft beds occupy the intervening valleys and gulches.

West of the Animas Valley the dip is gentler and the hogbacks give place to cuestas such as Animas City Mountain and the ridge near Perins that terminates at Barnroof Point. East of the Florida River the sedimentary rocks are steeply inclined for many miles, and in consequence the hogbacks are well developed. The long ridge south of Nelson Sawmill, the elevation between Spring Gulch and the North Fork of Texas Creek, Grassy Mountain, and Wickenson Mountain are typical.

The higher summits of some of these hogbacks attain the altitude of the San Juan peneplain, and the long, smooth crests of certain ridges are doubtless an inheritance from that ancient cycle of erosion. Rarely is a peneplain remnant big enough to have retained the stream gravel which might have been deposited upon it, but in the hogback belt the slopes of the intervening gulches carry at many places a scattering of small pebbles which doubtless have gradually worked their way down the steep hillsides from their earlier resting place on the dwindling summits.

Foothills facing San Luis Valley.—The eastern front of the San Juan Mountains, facing the San Luis Valley, is unique among the San Juan physiographic features. Here the mountains rise with comparative gentleness from a flat, gravel-strewn floor. In and near the Del Norte quadrangle there is a wide belt of foothills which rise by easy stages to the high summits of the eastern San Juan Mountains. Many of these foothills are maturely dissected cuestas, formed by massive flows of resistant lava, which dip gently toward the east. Ordinarily these tilted lava sheets have been carved into irregular peaks and ridges, but in some places the typical cuesta form is retained for a considerable distance. Between the valleys of La Garita and Carnero Creeks, for example, the foothills have the form of sloping mesas which dip toward the San Luis Valley and disappear beneath the alluvium. South of the Rio Grande, in the vicinity of Limekiln and Raton Creeks, similar cuestas formed by inclined sheets of lava carry a veneer of stream gravel deposited upon their surfaces before the carving of the intervening valleys.

MOUNTAIN FRONTS

South front.—Beyond the foothills the mountain mass on the south side of the range rises somewhat gradually to the lofty central peaks. In the Ignacio quadrangle in particular, as shown in Plate 23, the San Juan peneplain dominates the sky line, and the view of the range from positions in the southern portion of the quadrangle is not so picturesque as that from other sides of the mountains, although in the far distance on a clear day the Needle Mountains may be seen from high points.

Farther east on the south side of the range, in the vicinity of Pagosa Springs, the higher mountain peaks, which here rise to altitudes between 12,000 and 13,000 feet above sea level, are nearer to the foothills. Here the slopes are more abrupt and the mountain views are more picturesque than in the Ignacio quadrangle. Gigantic peaks, such as Huerto and Piedra Peaks, Treasure Mountain, and Montezuma Peak, appear in their grandeur along the sky line. If one would advance into the range from this point and reach the Continental Divide or climb to the summit of Piedra Peak, a vast assemblage of rugged mountains would lie before him in a panorama.

East front.—On the east side, where the mountain range has been steadily depressed through the later physiographic stages, the mountain front is not bold. It rises gradually to those great heights which characterize the San Juan Range. The summit peneplain, with its softened contours, dominates the sky-line topography for the most part. From the floor of San Luis Valley, or from Monte Vista, one may catch glimpses of Bennett Mountain and Del Norte Peak, but it is necessary to pass some distance into the range or to climb to one of the summits in the Conejos quadrangle to get from this east side a correct conception of the rugged mountain topography which lies beyond.

North front.—The traveler approaching the range from the north, either in the Uncompahgre or the Montrose quadrangle, has rising before him one of the most magnificent of mountain panoramas found anywhere in North America. In the Uncompahgre quadrangle the great master summit, Uncompahgre Peak (14,306 feet), dominates the landscape. Near it are the

Matterhorn (13,589 feet), the Wetterhorn (14,017 feet), Coxcomb Peak (13,660 feet), Wildhorse Peak (13,268 feet) and many others of most picturesque form. In this region during early spring and late fall there is some resemblance to an Alpine scene, and throughout the winter the region must even more clearly resemble the mountains of Switzerland. During the summer the peaks have lost their snow, and yet with the brilliant colors that have resulted from weathering and disintegration of the volcanic rocks, the dark greens of the forested slopes, and the soft green grasses of the alpine pastures, this scene is one of striking beauty.

The one view of all the mountain fronts in the San Juan region which deserves special mention and which has been frequently photographed for its beauty is obtained at the northwest corner of the range. Such a view as that shown in Plate 11, *C*, may be had from many places in the valley of Dallas Creek west of Ridgway. From Dallas Divide on a clear day it is of striking beauty; from the south margin of the Uncompahgre Plateau this mountain front may be seen to good advantage. In it we recognize Hayden Peak (12,990 feet), Whipple Mountain (11,900 feet), Ruffner Mountain (12,300 feet), Mears Peak (13,488 feet), Campbell Peak (13,200 feet), Whitehouse Mountain (13,493 feet), and rising above all of them as a central and most majestic pyramid is Sneffels Peak (14,143 feet). This mountain front rises abruptly from the neighboring foothills. In it there may be seen from a distance several of the great amphitheatral basins which formerly contained ice. When examined in detail these basins are seen to contain many well-developed rock streams and rock slides; they also hold numerous little glacial lakes. The higher peaks are composed entirely of volcanic rocks, and in most of them the structure is horizontal, so that they have the form and contour of great pyramids. From the summit of Sneffels Peak the view over the range is one of the most impressive that can be seen anywhere in the San Juan region. The outlook to the east and south is over a sea of peaks, with deep, dark canyons separating them. The varied colors in the lava sheets and the more brilliant colors that have resulted from hydrothermal metamorphism add to the scenic beauty. Sneffels Peak itself is composed of a dark coarse-grained volcanic rock and is interpreted as a great volcanic plug.

The view from this lofty summit to the west and north overlooks the neighboring plateau country, where, in the blue haze of the semidesert region, there appear several small isolated groups of volcanic or laccolithic mountains.

West front.—In the west front of the San Juan Mountains are the outlying clusters of peaks such as the Mount Wilson group, and farther south the Rico and La Plata Mountains. In the northernmost of these three groups Wilson Peak rises to 14,026 feet above sea level and Mount Wilson to 14,250 feet. From a good outlook point on this mountain group one will see to the east a wonderful assemblage of rugged mountains and great amphitheatral catchment basins. To the west the outlook is over the plateau country, which stretches into Utah as far as the eye can reach. In the sky line of that view are the lower and smaller groups of volcanic mountains that characterize the Colorado Plateaus. The Rico Mountains do not appear very conspicuous as seen from the west. Their summits reach altitudes of a little over 12,000 feet, but they do not rise conspicuously above the bordering slopes of the plateau on the west.

The La Plata group, at the southwest corner of the San Juan Mountain region, appears from the lowlands in the vicinity of Mancos as a truly mountainous area. The peaks rise to altitudes of over 13,000 feet, and they are sufficiently isolated and bold to be picturesque. Hesperus Peak (13,225 feet), at the west margin of this group, is one of the more striking. Helmet Peak (11,976 feet) and Madden Peak (11,980 feet) also appear on the western front of the La Plata Mountains and may be seen from the bordering plateau country.

MOUNTAIN PEAKS

The summits of the higher peaks in the San Juan Range present a great variety of shapes and make each vista a scenic spectacle of notable grandeur. The hundreds of noble summits run the entire gamut of mountain forms but may in general be grouped into three broadly defined classes. Some are of the needle type—sharp fingers lifted high above their surroundings. Others are of the pyramid type—stolid, bulky masses with broad base and small summit area. Still others display smoothly rounded crests of the type to which the name " Old Baldy " is so frequently given in the Western States.

Needles of granitic rock.—The most conspicuous examples of the needlelike peaks are in the group of mountains near the center of the San Juan Range, which have long been known as the Needle Mountains. Here are a score of peaks approximating 14,000 feet in altitude, whose sharply pointed summits are reared for thousands of feet above the intervening valleys. Among them, Mount Eolus, Sunlight Peak, and Windom Mountain rival one another in their scenic splendor. (See pl. 12.) The remarkably sharp pinnacles and abrupt faces give a ruggedness to this group of peaks which is almost unequaled in this country. When viewed from such vantages as Overlook Point of Mountain View Crest, the lower slopes, where the granite or gneiss has been polished and smoothed by glacial action, glisten in the sunlight in striking contrast to the corroded dullness of the serrate summits, which were reared aloft above the ice fields during the glacial stages. The West Needle Mountains, culminating in Twilight Peak and including Potato Hill in the Engineer Mountain quadrangle, are only slightly less picturesque and are carved in the same granite massif, the central core of the western San Juan Range.

Somewhat similar needlelike pinnacles, carved from the granite complex by running water and sculptured or polished by ice, may be observed in the vicinity of the Flint Lakes, in the southwestern part of the San Cristobal quadrangle. Of these, Mount Oso is the chief and lifts its many-pointed crest high above the lesser peaks on either side.

For the most part the high peaks here described project well above the level of the restored San Juan peneplain. So intense has been the erosion of these areas that little remains to indicate the exact altitude of that ancient plain, but what suggestions are offered by the landscape all indicate that these lofty peaks were monadnocks, 500 to 1,000 feet in height above the surrounding plain. The stubbornness with which they resisted erosion in the peneplain cycle as well as throughout the long ages that have elapsed since then is a tribute to the superior hardness of the component granite and explains their modern beauty and picturesqueness.

Needlelike peaks of quartzite.—Just to the north of the Needle Mountains is a long file of splendid peaks known as the Grenadier Range. Their sharp-crested summits form a jagged sky line as seen from either side. Their steep slopes are worthy rivals to the bold contours of the Needle Mountains close at hand. Here again the scenic splendor is a result of the sculpturing of rocks endowed with superior resistance to erosion. In the Grenadier Range nearly all the peaks are of quartzite, which has retained as well as the granite the contrast between the glaciated and nonglaciated surfaces. In general, the upper 500 feet of each peak stood above the zone of ice action; these heights display creviced and etched walls in striking contrast to the smoothly polished slopes across which the ice gnawed its way.

Needlelike peaks of volcanic rock.—The bedded volcanic rocks that form most of the summits in the northern and eastern part of the San Juan region tend to form peaks of the pyramid rather than the needle type, but in some localities, where glacial and postglacial erosion has been especially intense, summits and ridges of remarkable sharpness have been formed.

In the southeast corner of the San Cristobal quadrangle and the adjacent corners of the Creede, Summitville, and Pagosa Springs quadrangles there is a splendid group of jagged peaks and sharply serrate ridges formed during the dissection of a volcanic plateau. Piedra Peak and South River Peak, which guard the pass across the Continental Divide from the head of the Piedra River to the head of the South River, are typical of this group. A little farther to the east Sawtooth Mountain and the peaks that surround Archuleta Lake form a cluster of rugged summits at the head of the San Juan River which well repay the traveler by their scenic splendor for the arduous labors necessary in traversing the precarious trails which lead to them. The varying resistance of the bedded volcanic rocks finds response in endless variety of mountain sculpture. Swift streams and thick glaciers have here carved pinnacled ridges and turrets of unusual beauty.

Along and near the bold northern front of the San Juan Mountains, where glacial and postglacial erosion has been at a maximum, the volcanic beds have in many places been sculptured into sharp pinnacles and needlelike peaks. Among these one of the most spectacular is Wetterhorn Peak, the sharp summit of which is reared more than 14,000 feet above the sea. In the southeast corner of the Ouray quadrangle the Potosi volcanic series includes many thick sheets of resistant lava which tend to form serrate mountain crests and sharply pinnacled ridges. Thus there is north of Wetterhorn a cluster of sharp peaks culminating in Coxcomb Peak, while to the east, in the southwest corner of the Uncompahgre quadrangle, one of the sharp summits is deservedly named Matterhorn Peak, because of its resemblance to the Alpine summit that bears that name.

The outlying group of mountains toward the northeast margin of the range, including San Luis Peak, is a complex of volcanic rocks which at many places are carved into sharply pointed crests. San Luis Peak itself, with its altitude of 14,149 feet, is a fit rival to the Matterhorn and points its splendid spire high above the sea of sharp crests that surround it.

Near Mount Wilson is Lizard Head (13,156 feet; pl. 13), in its upper 400 feet a sheer rock spire, absolutely insurmountable unless steps are artificially cut in the bare rock walls. It is a pinnacle and one of the most striking landmarks in the western portion of the range.

Finally, near the center of the mountains in and near the Silverton quadrangle, where ice action was especially severe on the higher mountain slopes, there are several sharp-pointed summits, such as Niagara Peak and Little Giant Mountain, which deserve mention. These, without exception, rose high above the ice fields which gnawed at the base of each peak, and did much toward giving to this rugged portion of the range its present appearance.

Sharp peaks of this type are found only in regions of mature dissection and great relief, where erosion has been and still is extremely rapid. The relations of the summits to the San Juan peneplain are therefore commonly obscured. The projection of the peneplain from surrounding regions indicates that these peaks were once monadnocks rising many hundreds of feet above the peneplain level. It is not to be inferred that they have retained even an approximation to the form which they possessed at the end of the peneplain cycle of erosion. Doubtless they are but sculptured fragments of the former monadnocks, but in a very real sense their scenic grandeur is, in part at least, an inheritance from their earlier state.

Needlelike summits of intrusive lava.—Many of the larger intrusive bodies of porphyritic rock which are very common in the western half of the San Juan Range have been carved into needlelike summits. Among these the Ophir Needles, which form the crest of a high ridge near the center of the Telluride quadrangle, are unusually spectacular. These pinnacles attain altitudes of somewhat less than 12,000 feet but are among the most rugged topographic features of the range. Certain of the highest summits are likewise pinnacled crests carved in intrusive rocks.

The peaks of the Mount Wilson group, at the far western margin of the region, display several sharp-pointed summits carved from a large stock of porphyry. The ascent of the jagged and precipitous slopes of Mount Wilson will give the adventure-seeking mountain climber all the thrills and dangers that he could desire. Wildhorse Peak, overlooking the Horsethief Trail, in the southeast corner of the Montrose quadrangle, is a similar pinnacle of intruded porphyry with a slender spire projected far above the lesser heights that surround it.

These pinnacles have had a physiographic history similar to that of the peaks composed of bedded volcanic rocks. They project above the San Juan peneplain and have recently been carved from the former monadnocks of that plain.

Pyramids of volcanic rock.—The highest summit of the entire San Juan Range, Uncompahgre Peak, 14,306 feet above sea level, is a pyramid of gigantic dimensions, sculptured from a dissected volcanic plateau. Its summit projected more than 1,000 feet above the ice fields that once polished its lower slopes. The mountain sides form a series of huge steps, because of the varying resistance to erosion offered by successive layers of the volcanic pile. The pyramidal outline gives these slopes a comparatively gentle gradient, so that the ascent of the mountain is surprisingly easy, considering its stupendous height. It is always possible to ride a horse within a few hundred feet of the top, and if the trail is cleared of fallen débris a good mount may carry the rider to the very summit itself.

Potosi Peak (pl. 14), in the northwest corner of the Silverton quadrangle, is another massive summit with pyramidal crest. On its slopes a fine display of bedded tuffs and lavas includes a large percentage of the several volcanic series of the range.

Whitehouse Mountain, near Ouray, is one of the most spectacular summits seen in approaching the San Juan Mountains from the north. It is a massive pyramid capped by lava sheets. As seen from the north, Abrams Mountain, a few miles south of Ouray, displays the typical pyramid form, but it is in reality merely the north end of a long ridge, the smooth crest of which is probably a close approximation to the former peneplain surface.

Most of the higher summits in the eastern part of the San Juan Mountains are peaks of quasi-pyramidal form, sculptured from the bedded volcanic rocks that compose most of this portion of the range. Among these Del Norte Peak, near the southeast corner of the Creede quadrangle, and Montezuma and Summit Peaks, a few miles north of the center of the Summitville quadrangle, are prominent.

Nearer the center of the range is the bold, massive mountain known as Bristol Head, towering 4,000 feet above the adjacent valley of the Rio Grande. The remarkable precipice which forms the southwest margin of this mountain is apparently a fault scarp from which huge masses of débris have fallen and slipped to the valley floor. The other faces of Bristol Head are ordinary stream-carved slopes.

Most of the pyramids of this type are at an altitude considerably above that of the San Juan peneplain in their vicinity. They presumably represent monadnocks that have been considerably altered by the vigorous erosion of more modern cycles, which has sculptured them into their present form.

Pyramidlike peaks of intrusive rocks.—Several of the larger intruded stocks and sills have been so sculptured by stream and ice erosion that portions of them now appear as massive pyramids, projecting high above their surroundings. Among these, Engineer Mountain and its neighbor, Hermosa Mountain, are two excellent examples. The steep slopes of each of these mountains have been the sources of numerous rock falls and landslides. Both of them must have remained as monadnocks several hundred feet above the surrounding peneplain at the end of the first cycle of erosion that has been recognized in the more recent history of the San Juan region.

Smoothly rounded crests of volcanic rock.—In certain parts of the range, notably toward the northeast, the summits are rounded crests rather than sharply pinnacled peaks. Most of the La Garita Mountains, such as Mesa Peak and Bowers Peak, belong in this class. The summits of these mountains were apparently very close to the general peneplain level and doubtless formed low-rounded hills at the end of the Peneplain cycle of erosion. Since then they have been uplifted to a lesser height than that attained by the peneplain surface farther west. As a consequence this group of mountains was occupied by very few glaciers during the Wisconsin stage of the Pleistocene epoch, and these were so small as to be of little effectiveness as agents of erosion. Hence the upland surfaces have been only slightly altered and still retain their earlier soft outlines.

HIGH TABLE-LANDS WITHIN THE RANGE

Within the San Juan Range there are a large number of high table-lands, some of which are of considerable extent. These are found in nearly all parts of the range and owe their form to a variety of causes. Some are dwindling remnants of the formerly extensive plains developed during the peneplain and Florida cycles of erosion. The preservation of these remnants may be due either to their remoteness from actively eroding streams or to the unusual resistance of the underlying rocks at the particular locality. Other upland surfaces are purely structural, the result of the presence of flat-lying strata such as massive lava sheets or firmly indurated sandstones, which offer superior resistance to erosion and from the surface of which the overlying softer beds have been stripped. In general, however, such structural table-lands have surfaces that closely approximated the position of either the peneplain or the Florida grade. Still other upland flats are chiefly the result of the planing action of large ice caps.

Trident Mesa is a high table-land on the north flank of the San Juan Mountains, bisected by the boundary line between the Montrose and Uncompahgre quadrangles. Its surface, 5 or 6 square miles in area, is about 11,000 feet above the sea and 2,000 to 3,000 feet above the adjacent canyon floors and lowlands. The mesa is a pile of volcanic rocks resting on Cretaceous shale and sandstone. The volcanic rocks are chiefly bedded agglomerate, and the surface of the mesa corresponds closely to the attitude of these beds. It is, however, an erosion surface, which presumably was formed near the base-level of erosion during the Peneplain cycle. Definite proof that the surface is a peneplain remnant, however, is lacking, as no gravel that could be identified with certainty as Bayfield gravel was found upon it.

A few miles farther east, near the center of the Uncompahgre quadrangle, is another high table-land known as the Alpine Plateau. Its gently undulating surface is the slightly modified top of extensive lava flows that were outpoured upon the San Juan peneplain at approximately the end of the Peneplain cycle of erosion. The streams that head upon it flow northward through valleys which at first are broad and shallow but which as they approach the margin of the plateau become deeper and steeper sided and in general would be classed as mature. Still farther downstream, below altitudes of 5,000 feet, the valleys again change, becoming youthful ravines and gorges. This change in topography may be in part due to changes in the resistance of the rocks but is more likely to be largely the result of rejuvenation, which has not yet had time to work far upstream.

A few miles farther southeast, across the canyon of the Lake Fork of the Gunnison River, is another similar table-land of even greater extent, known as the Cannibal Plateau. About 15 square miles of its surface is at an altitude of about 11,500 feet. Its top slopes gently outward from two rounded crests of 12,500 and 12,625 feet. These sloping surfaces have been determined in most part by the thick resistant lava sheets, and are modified by the work of numerous streams and one small glacier. The surface has also been broken by a long fault extending in a general northwesterly direction, which has given rise to the steep cliff overlooking Devils Lake.

Ten miles to the northeast, near the east margin of the Uncompahgre quadrangle, is another table-land known as Huntsman Mesa, the surface of which is between 9,700 and 10,100 feet above sea level. The topography of the mesa top is that of old age. Gently undulating crests separate broad, open, streamless valleys. The surrounding country is maturely dissected and broken by numerous steep-sided canyons. The mesa surface is therefore interpreted as a portion of the San Juan peneplain, veneered with Hinsdale lava, and preserved from destruction by its remoteness from the major stream channels.

In the San Cristobal quadrangle there are many remnants, large and small, of the once widespread upland plain. Most of these are surfaces determined by the position of flat-lying lavas, possessed of superior resistance to erosion. Upon none of them are there foreign pebbles that could be definitely recognized as deposits made by streams of the ancient Peneplain cycle. Most of the surfaces, however, are erosion surfaces, presenting an old appearance which is in striking contrast to the youthful aspect of the intervening areas. Possibly none of them is a perfect representative of the Peneplain or Florida graded surfaces, but probably all are close approximations to one or the other. The gently rounded summits, some of them several square miles in area, which approximate an altitude of 12,000 feet and follow the Continental Divide from the Lake Fork Canyon eastward toward San Luis Peak, are doubtless close to the peneplain level. The broad, flat summit of the upland north of Lost Lakes, which at one time stood as a mighty island buttress in the sea of Wisconsin ice, is likewise believed to be a remnant of the peneplain. Farther to the southward the surface of the Ruby Lake Plateau displays an old-age topography of true peneplain type.

The extensive flats of the Bristol Head Plateau are, in their intimate details, determined by unusually resistant lava sheets, to the surface of which they exactly conform. These are, in the main, intermediate in altitude between the Peneplain and Florida surfaces. They were probably formed, in a large degree, during the Florida cycle as a part of the dissection of the peneplain. Near the center of the quadrangle there are several long, narrow mesas separated by the deep canyons through which flow the tributaries to Spring Creek. These "finger mesas" carry nothing but local angular fragments, but they probably represent the approximate position of the Peneplain surface, which here was sagged to form the Hermit Basin, referred to on page 24 and shown on Plate 2.

Upland parks in north half of Creede quadrangle.—North of the Rio Grande, in the central portion of the Creede quadrangle, there are a number of upland benches at an altitude of about 11,000 feet. The area of some of these is 3 or 4 square miles, and they include the grasslands known as Wason Park and Blue Park. At the north these upland flats are bordered by mountains that rise in certain places to over 13,000 feet. Toward the south and southwest there are precipitous slopes which descend abruptly from the upland to the floor of the Rio Grande Valley, 3,000 feet beneath. Generally these high benches carry a veneer of rich soil which suggests a former lowland position, and at some localities there are boulders and gravel that must have been dropped along the courses of streams whose heads were in distant hills. The surface of these uplands is undulating, modified by the presence of low, rounded hills and broad, shallow valleys. In places the floor of a valley may correspond to the surface of a resistant lava flow, but their peculiar topography can not be explained on the basis of resistant beds alone.

The intermediate position of these upland areas, midway between the highest summits and the modern canyon floors, indicates that they are remnants of the early old-age or late-mature topography, which had been developed in this portion of the San Juan region by the end of the Florida cycle of erosion. Since the uplift of the graded surface of the Florida cycle the deep canyons and low valleys that cut this former topographic surface into innumerable fragments have been carved. The upland topography which remains has since been only slightly altered.

Glaciated uplands in Summitville quadrangle.—The Continental Divide and adjacent heights between Banded Peak and Conejos Peak, in the eastern part of the Summitville quadrangle, are parts of a somewhat maturely dissected plateau, the surface of which covers several square miles of upland between 11,300 and 12,400 feet above sea level. The higher peaks of this region, such as the two just named, rise a few hundred feet above the general upland level. The modern streams, such as the Navajo and Conejos Rivers and Elk Creek, flow in precipitous canyons on narrow floors 2,000 feet or more below the intervening upland. The upland surface has been intensely glaciated; polished and striated surfaces, deep carved grooves, roches moutonnées, and rock-basin lakes are common. Apparently this upland was covered by a comparatively thick ice cap from which glaciers moved radially down the several canyons that head in this part of the range. Ice sculpturing has, of course, greatly modified the preglacial topography of the upland, but its comparative flatness is clearly an inheritance from an early cycle of erosion. The agencies now at work, broadening, lengthening, and deepening the modern canyons, could not have developed the high undulating surface under existing conditions. It is believed, therefore, that this upland represents a portion of the San Juan peneplain, which at the advent of the last glacial episode had not yet been entirely destroyed.

Uplands in northwest corner of Del Norte quadrangle.—The uplands in and near the northwest corner of the Del Norte quadrangle, in the area drained by the Middle and North Forks of Carnero Creek, are of the mesa type. As suggested by the topographic map, they are broad, flat, gently undulating areas above which rise a few rounded summits such as Storm King. The topography is here largely controlled by the structure of the underlying rocks, as the flat mesas are capped by nearly horizontal lava sheets of superior resistance to erosion, and the higher summits are remnants of another set of overlying lava sheets. None of these flat areas carry gravel, and it is doubtful if their exact relations to the graded surfaces of past erosion cycles can be determined with certainty. It is probable, however, that the higher summits are close to the peneplain surface, whereas the extensive flats at 10,000 to 10,500 feet above sea level may represent the late mature topography of the Florida cycle.

Table-lands south of the Rio Grande on the eastern front.—Among the half dozen small upland flats that still remain in the eastern part of the range the most interesting is that known as Horseshoe Park. This is a remnant of a broad, late-mature valley now at an altitude of about 9,500 feet in the southwestern part of the Del Norte quadrangle. It is bordered on the east by the West Fork of San Francisco Creek, flowing in a canyon 500 to 1,000 feet in depth, which has apparently beheaded an earlier northwestward-flowing mature stream. On the west the park is cut off sharply by the abrupt descent into the steep-walled canyons of the tributaries to Pinos Creek. The park is undoubtedly the remnant of a valley that reached late maturity during the Florida cycle and has since been almost entirely destroyed by the carving of the modern canyons.

Uplands south of Needle Mountains.—The southern third of the Needle Mountains quadrangle and adjacent portions of the Ignacio quadrangle are occupied by undulating highlands separated and partly destroyed by numerous steep-walled canyons. These highlands, for the most part, slope gently southward, away from the mountains. Their northern points are at altitudes of about 12,000 feet above sea level, and above them the lofty summits of the Needle Mountains project 2,000 feet higher. The gradient of their surface, however, is such that if projected northward it would strike the slopes of the Needle Mountains only a few hundred feet below their highest crests. Certain of these mesas, such as East Silver, West Silver, and Endlich Mesas, display the effects of vigorous ice action. The granite of which they are composed is carved and etched into characteristic glacial features. Numerous tiny bodies of deep-blue water occupy the rock basins scoured by the ice as it rubbed across them. Others, such as Stag Mesa and Lime Mesa, were unaffected by glacial ice and display the normal stream-eroded topography of an old-age surface. These lofty uplands have a topography which is in striking contrast to the youthful lines of the intervening canyons. Their surfaces are only slightly modified from the forms typical of old age, which were developed here during the Peneplain cycle of erosion.

Table-lands near western margin of the range.—In the northern part of the Engineer Mountain quadrangle and the adjacent part of the Telluride quadrangle there are irregular uplands of considerable extent, which represent the San Juan peneplain in this portion of the range. Flattop has an irregularly rounded surface covering about 2 square miles at an altitude of about 12,000 feet. The preservation of this broad peneplain remnant in the midst of an area where dissection has been so complete that most of the summits are sharp peaks or serrate ridges is due to the protection afforded by a thick sill of resistant igneous rock which is exposed on the higher slopes of the hill. The topography of the surface, however, is that of old age, and it was doubtless produced during the Peneplain cycle of erosion.

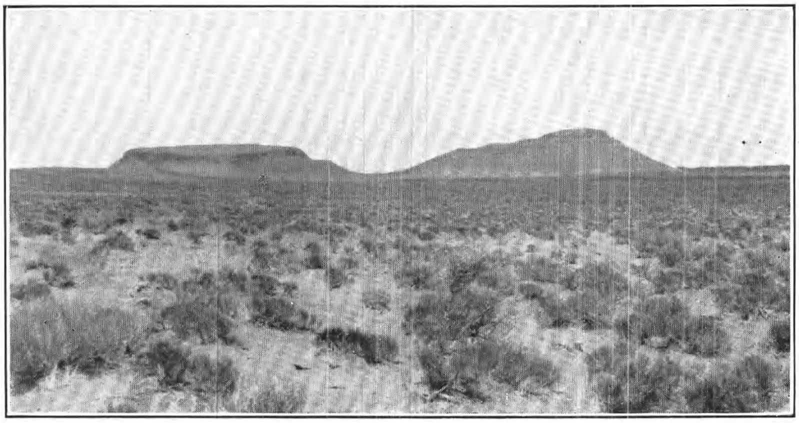
Uplands in Silverton quadrangle.—Even in the Silverton quadrangle, where erosion by ice and water has been unusually vigorous, there remain a few small uplands of slight relief. The most notable of these is known as American Flat, a broad, rolling grass-covered plain among the mountains near the northeast corner of the quadrangle. Above and about it the sharp peaks rise 1,000 feet or more, and below it great canyons are cut to depths of 3,000 or 4,000 feet. Glacial ice formed over the entire area and moved in several directions down the canyons that radiate from it; thus its preglacial topography has been considerably altered, but it still retains the marks of old age. It probably is a remnant of the San Juan peneplain.

Farther to the south, in the southeast corner of the Silverton quadrangle and the northeast corner of the Needle Mountains quadrangle, the Continental Divide takes the form of an irregular upland with gently undulating surface. The altitude is about 12,500 feet, and the high flat is bounded on all sides by precipitous descents of 2,000 or 3,000 feet to the floors of the neighboring canyons. Here again glacial action has sculptured the entire surface, but here as elsewhere the topography is such as to suggest that the upland has inherited its flat surface from the peneplain formed in the most ancient recognized erosion cycle.

CANYONS

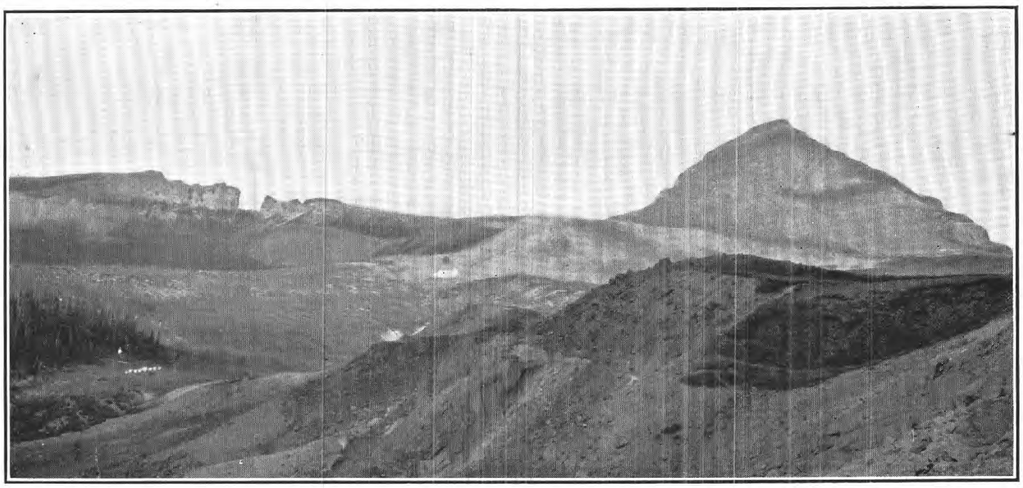
The glory of the lofty peaks that contributes so generously to the scenic beauty of the San Juan Mountains is rivaled only by the grandeur of the gigantic canyons that intervene between the peaks and radiate from the heart of the range. The mountaineer enjoying the vista from some vantage point high on an eerie crag is entranced by the glimpse of a mighty river so far beneath him that it appears merely as a silver thread winding in and out among the grassy lowland meadows, or is thrilled by the abysses that open at his feet, where this selfsame stream has carved a chasm deep into the heart of the mountain massif. Again, as he pursues his circuitous route along the bank of a swift rivulet, he is constantly awed by the towering cliffs and precipitous walls which rise almost vertically to dizzy heights from either bank of the foam-lashed stream and which with their pinnacles and palisades sculptured by wind and rain lend endless variety to the always glorious views. It is the canyons that contribute to the picturesqueness of the mountain scenery and make life in the mountains most joyous.

Animas Canyon.—The valley of the Animas River is the largest in the San Juan Range. The sources of this river are far to the north of Silverton, near the north margin of the mountains, whence the stream flows in a general southerly direction through the center of their western portion and finally escapes between the foothills only to find itself caught in another canyon through which it traverses the surrounding plateaus until it finally empties into the San Juan River at Farmington, N. Mex. Throughout this long course the stream traverses rocks of all ages and descriptions, from the intensely metamorphosed pre-Cambrian complex to the softest of Tertiary shale. In places the stream is lashed to foam where it cascades down the steep gradient of a glaciated gorge, but elsewhere it rambles slowly and quietly in a meandering course across lush meadows. In the heart of the range its waters are harnessed to provide energy for



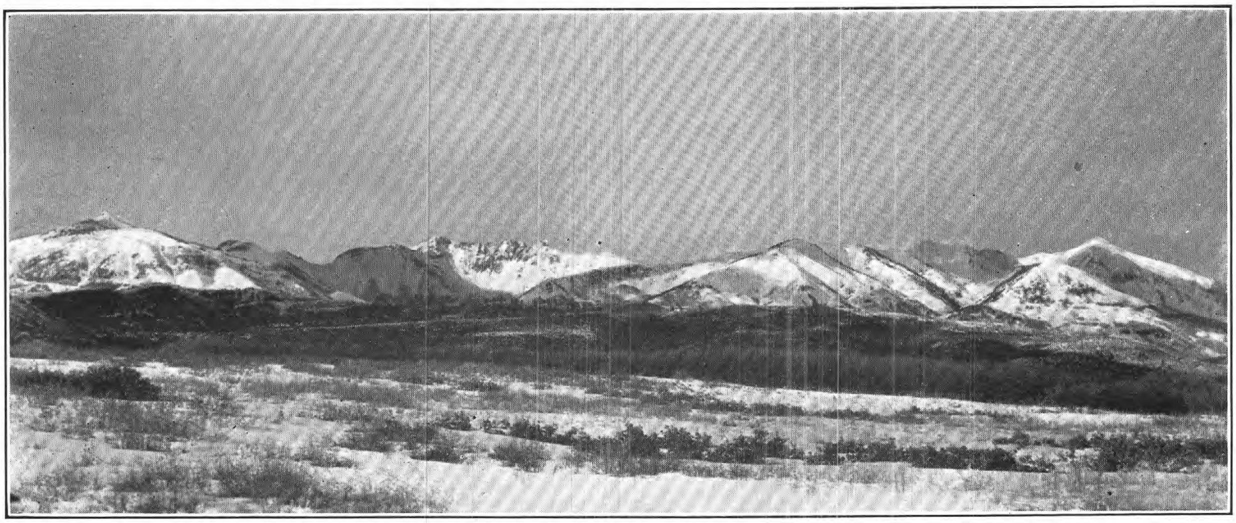
A. SAN LUIS HILLS

Table-land remnants in San Luis Valley, south of Alamosa. These and adjacent hills were once islands in a sea of lava.



B. RIO GRANDE PYRAMID AND STEWART PASS

The pyramid (13,380 feet) is a volcanic cone constructed upon the San Juan peneplain and left standing high above its surroundings when the adjacent valleys were excavated during the dissection of the deformed peneplain.

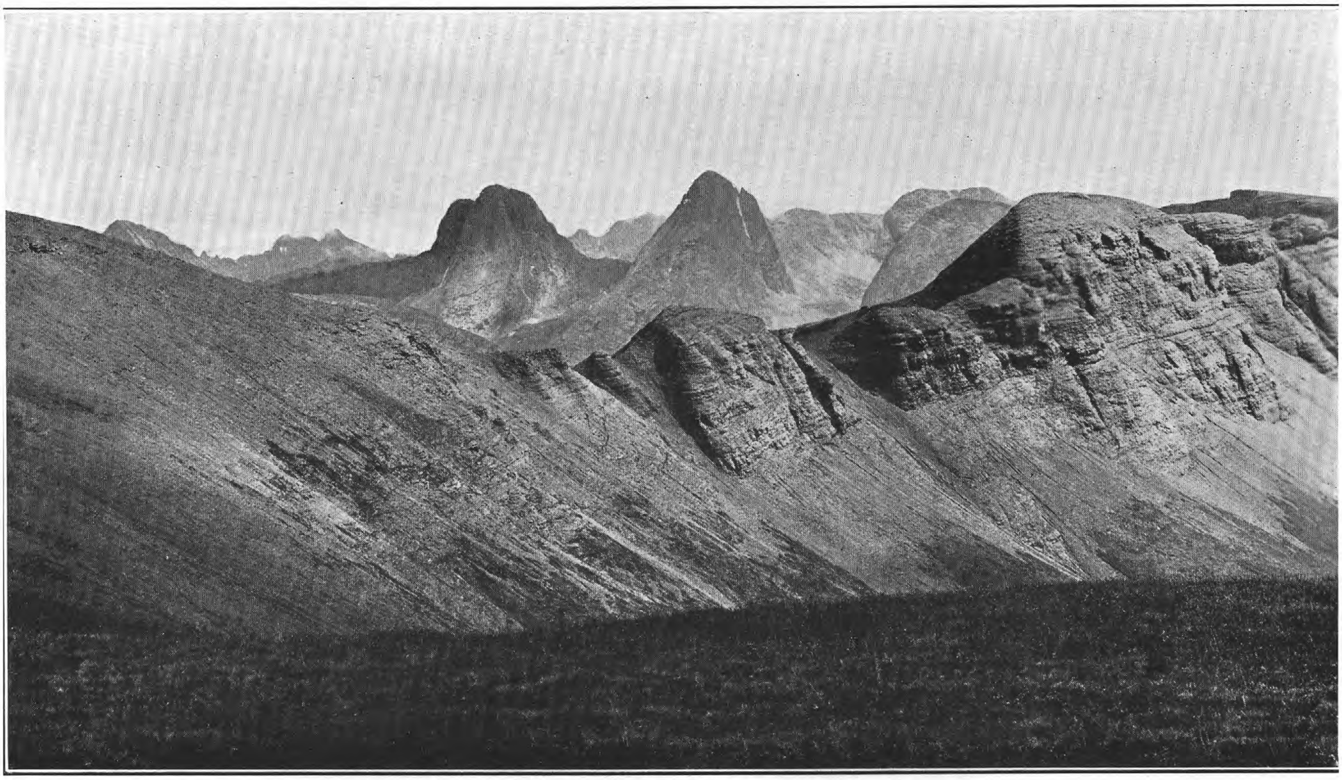


C. SAN JUAN MOUNTAIN FRONT

Northwestern front of San Juan Mountains, viewed from the bordering plateau at an altitude of about 8,000 feet. The summits rise to altitudes between 13,000 and 14,000 feet. Photograph by Enos Mills.

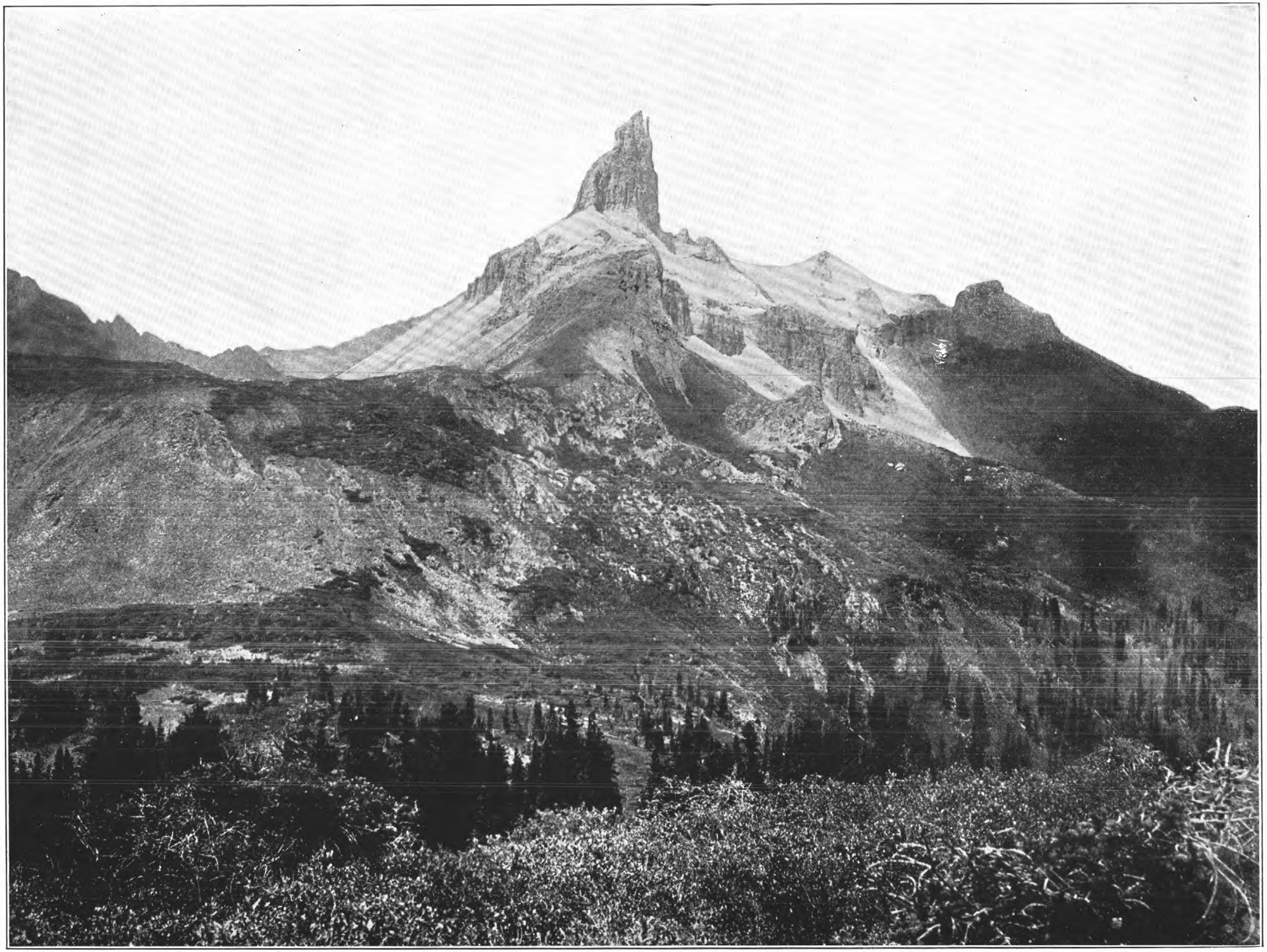
A. NEEDLE MOUNTAINS

A general view into the midst of the range, with a conspicuous cirque or amphitheatral basin in the middle ground. The bare rock surfaces on the slopes of most of the mountain peaks were smoothed and polished by the late Wisconsin ice. Photograph by Whitman Cross.



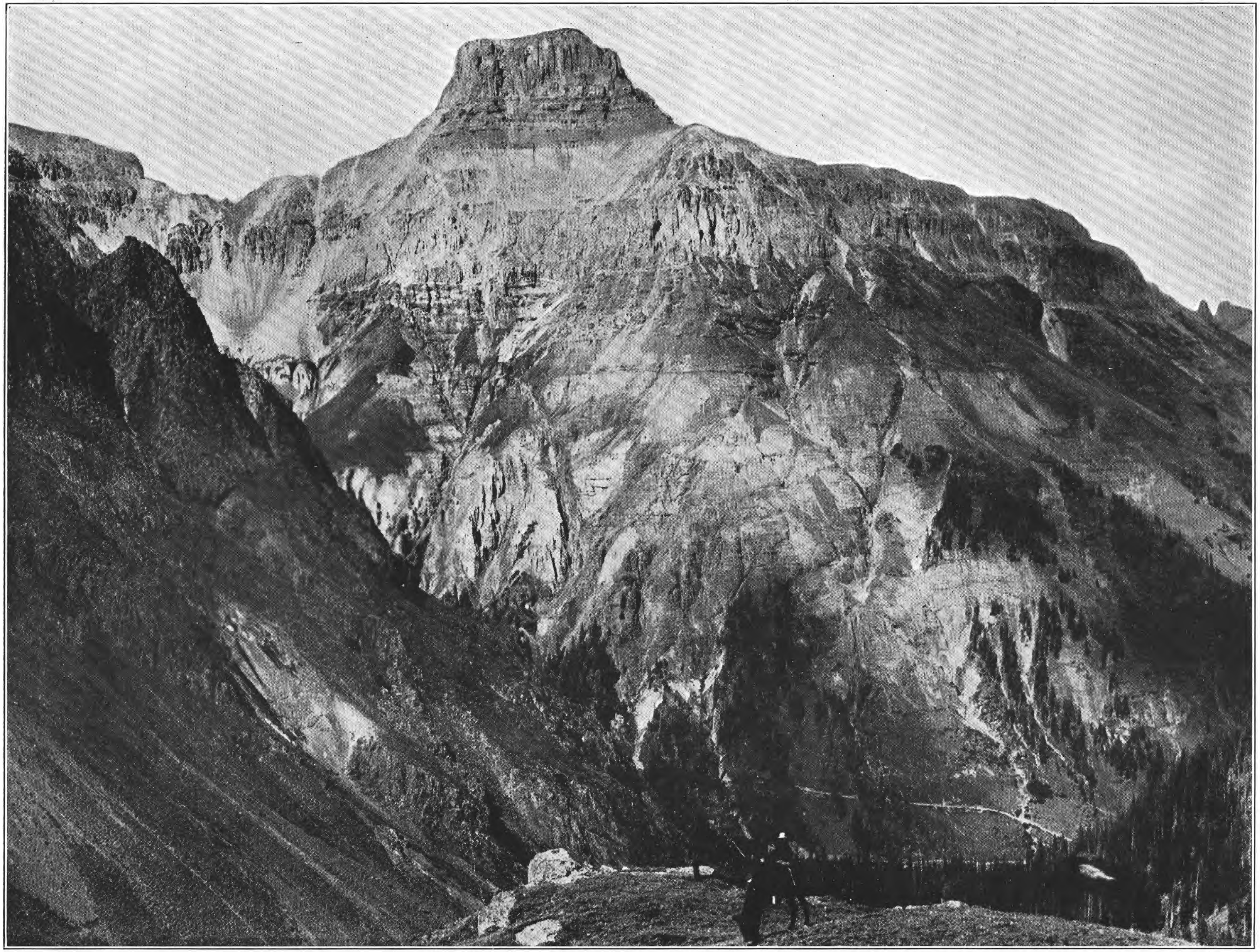
B. GRENADIER RANGE AND NEEDLE MOUNTAINS

The jagged peaks of the Grenadiers intervene in front of the cloud-draped pinnacles called the Needle Mountains, as viewed from the divide at the head of Whitehead Gulch. Photograph by Whitman Cross.



LIZARD HEAD

This is the most conspicuous isolated spire in the San Juan region. It rises nearly 500 feet, with almost vertical walls, from the summit of the mountain on which it stands. The tip of the spire is 13,156 feet above sea level. Photograph by Whitman Cross.

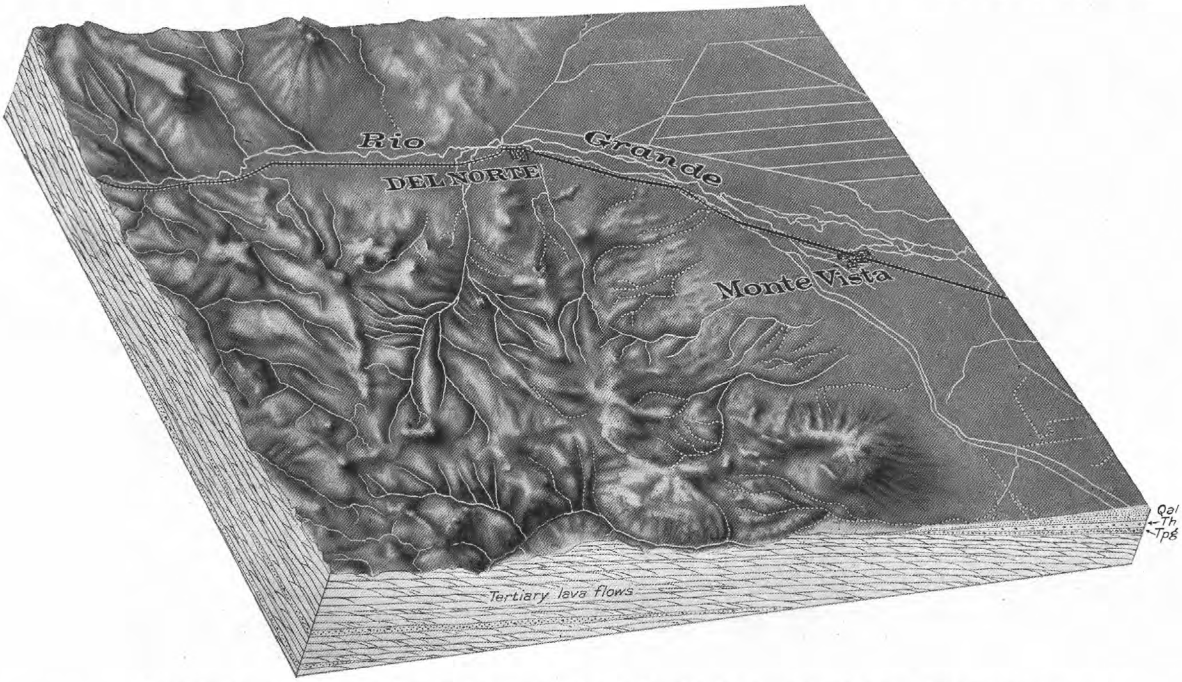


POTOSI PEAK

This view was taken from the south side of Stony Mountain. Canyon Creek is in the foreground. Potosi Peak is 13,763 feet above sea level and is one of the conspicuous features in the Silverton quadrangle. It is carved out of nearly horizontal beds of volcanic formations. [redacted]

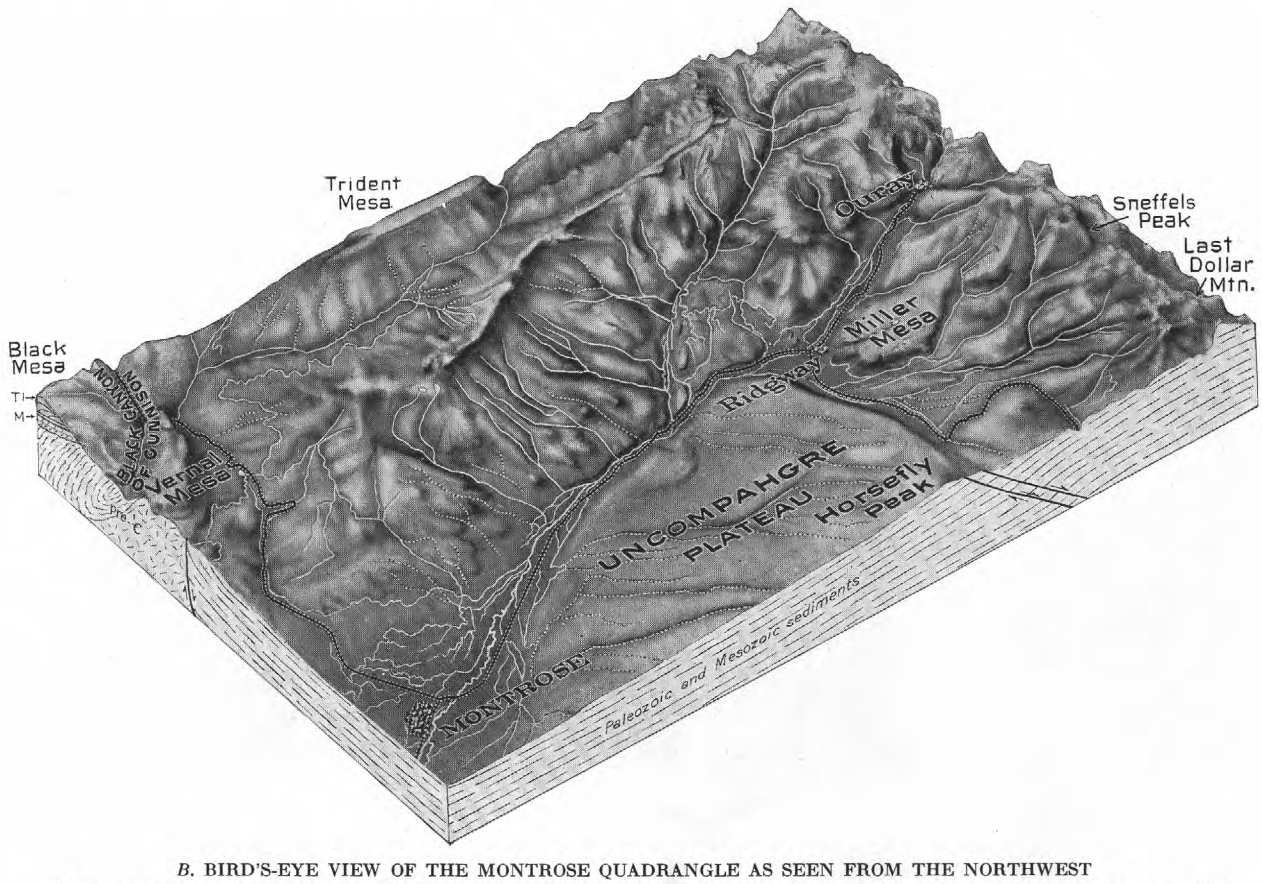
ANIMAS VALLEY ABOVE ANIMAS CITY

There is topographic unconformity between the maturely eroded upland and the youthful gulches cutting the lower slope. The steepness of that slope and the truncation of interstream spurs are largely due to glacial abrasion. The apparent old age of the stream is due to its meandering on an alluvial flat. This flat is underlain by silt deposited above the dam formed by the Wisconsin terminal moraine. As the outlet through the dam was deepened, many oxbows were cut off. Similar conditions are found in several other valleys. Photograph by Whitman Cross.



A. BIRD'S-EYE VIEW OF THE DEL NORTE QUADRANGLE AS SEEN FROM THE SOUTHWEST

The drawing shows the comparatively gentle slopes along the eastern front of the San Juan Mountains. The alluvium that fills the San Luis Valley (beneath the flat at the right) extends well up into the mountains along the course of the Rio Grande.



B. BIRD'S-EYE VIEW OF THE MONTROSE QUADRANGLE AS SEEN FROM THE NORTHWEST

The rugged mountains in the vicinity of Ouray rise boldly and abruptly above Miller Mesa, Uncompahgre Plateau, and the lowlands surrounding Montrose and Ridgway. Trident Mesa extends far to the north but is separated by comparatively low lands from the plateaus that crowd upon the walls of the Black Canyon of the Gunnison River.

the winning of precious metals from the mountain; beyond the foothills this same water again pays tribute to mankind in the irrigation of lowland farms. An adequate description of this valley would be a description of the entire western half of the range, and an adequate account of its history would tell the whole story of the mountains' past.

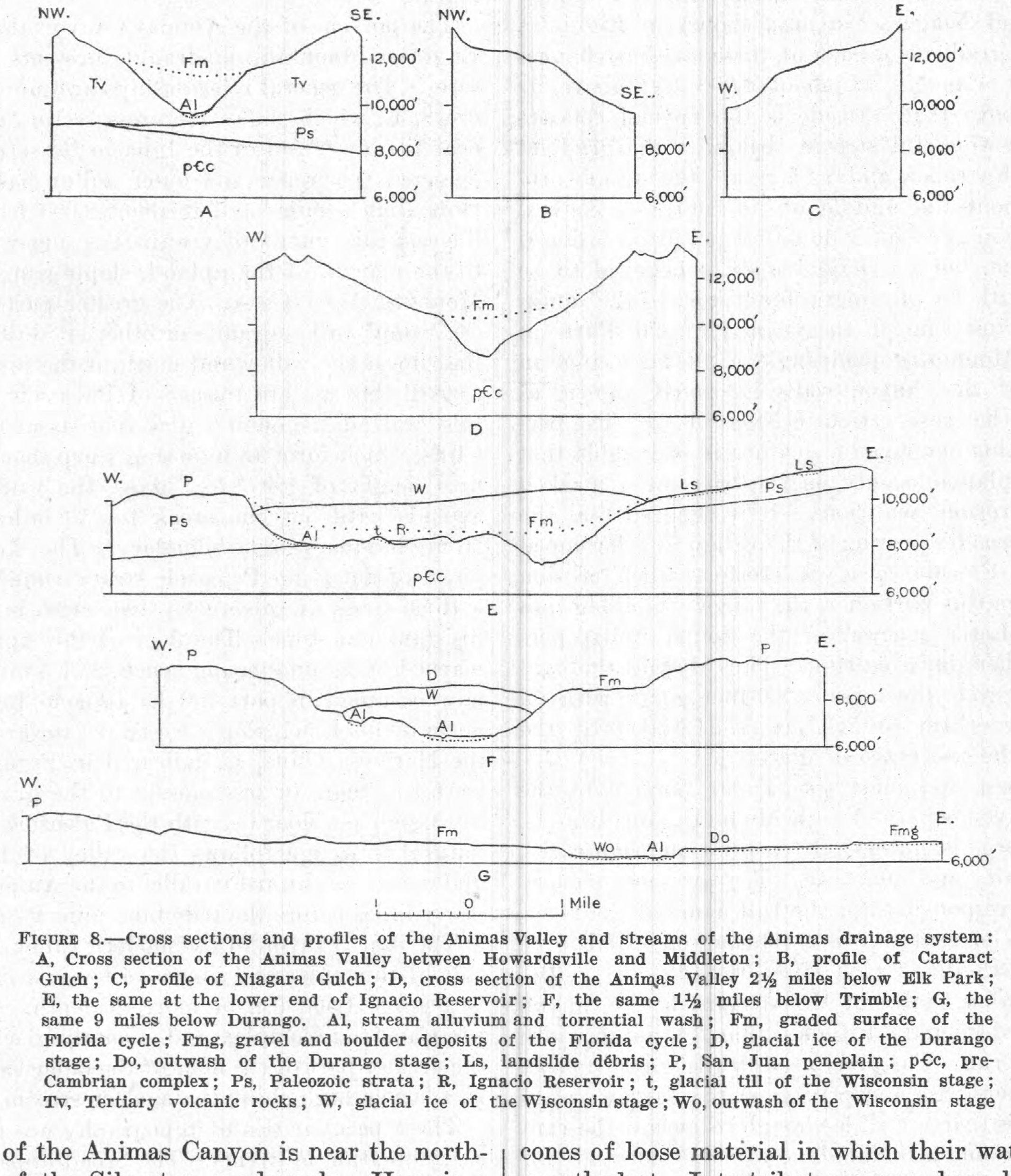


FIGURE 8.—Cross sections and profiles of the Animas Valley and streams of the Animas drainage system: A, Cross section of the Animas Valley between Howardsville and Middleton; B, profile of Cataract Gulch; C, profile of Niagara Gulch; D, cross section of the Animas Valley 2½ miles below Elk Park; E, the same at the lower end of Ignacio Reservoir; F, the same 1½ miles below Trimble; G, the same 9 miles below Durango. Al, stream alluvium and torrential wash; Fm, graded surface of the Florida cycle; Fmg, gravel and boulder deposits of the Florida cycle; D, glacial ice of the Durango stage; Do, outwash of the Durango stage; Ls, landslide débris; P, San Juan peneplain; p€c, pre-Cambrian complex; Ps, Paleozoic strata; R, Ignacio Reservoir; t, glacial till of the Wisconsin stage; Tv, Tertiary volcanic rocks; W, glacial ice of the Wisconsin stage; Wo, outwash of the Wisconsin stage

The head of the Animas Canyon is near the northeast corner of the Silverton quadrangle. Here is a barren and rocky mountainous district, where the ice has swept away all movable matter, smoothed and polished the rocks, and greatly deepened the old river courses. At Animas Forks, where several tributaries join to make the main river, the stream is already coursing along the floor of a canyon 2,000 feet and more in depth, a wonderful gorge with towering walls of bare rock. Along the stream channel from this point for a distance of 50 miles southward the marks of profound glaciation are everywhere present. Tributary streams enter the canyon as cataracts, tumbling over rock ledges high on the valley walls, and plunge in a series of cascades over the last 1,000 to 1,500 feet of their descent to join the main river. Some of these tributary streams have brought a large quantity of débris to their mouths, and there have built up steep cones of loose material in which their waters are frequently lost. Intertributary spurs have been beveled and truncated by the vigorous ice that must have formed a mass more than 2,000 feet thick throughout the upper portion of the valley.

In spite of the amount of glacial erosion, the contour of the canyon still displays at most localities the dual nature of the gorge as represented in the cross section between Howardsville and Middleton, shown in Figure 8, A. There is a pronounced shoulder on the canyon's wall midway between the modern stream channel and the higher summits on each side. The lofty slopes are much more gentle than the lower; there seems to be an outer and broader valley, in the floor of which an inner, steeper-walled gorge is carved. This inner gorge averages 2,000 feet in depth; the outer valley is ordinarily slightly deeper. The same topographic peculiarity is shown by the profiles of tributary streams, such as those that occupy Cataract and Niagara Gulches, shown in Figure 8, B, C. The gradient of each of these streams changes abruptly at a height of about 2,000 feet above its mouth. Above that altitude is the normal concave profile of a youthful stream; below it the gradient is very much steeper, and, as a result, the stream profile throughout the middle of its course is convex. This change in gradient is doubtless in part occasioned by glaciation, but its major cause is believed to be connected with the physiographic history of the range. Farther downstream, in the vicinity of Elk Park, in the Needle Mountains quadrangle, a similar change in the slope of the canyon walls is clearly shown, as depicted in the cross section in Figure 8, D. The persistence of this outer-valley feature is so notable that it seems explainable only on the basis of a marked change in erosion conditions. It is believed that the upper and broader portion of the valley was developed during the Florida cycle of erosion, when erosion progressed in this portion of the range well along into maturity. Later renewal of the domal uplift permitted further down cutting. Thus during the canyon-cutting cycle the inner 2,000-foot gorge with its extremely youthful profile has been eroded by the river with the assistance of glacial ice.

The deepest and most spectacular portion of the Animas Canyon is in the Needle Mountains quadrangle. Here the gorge is cut entirely in pre-Cambrian rocks, chiefly granite and quartzite. The awesome scenery is probably responsible for the full name of the river, of which its present title is a contraction—El Río de las Ánimas Perdidas (the river of lost souls). Between Snowdon Peak and Mount Garfield the canyon is 4,250 feet deep and a little less than 3 miles in width from rim to rim. The precipitous walls, scraped clean by the glaciers, rise abruptly from the narrow valley flat, which is scarcely wide enough to permit the railroad track to find a foothold, now on one side and now on the other side of the rushing torrent. Tributary streams have deposited great torrential fans at their mouths. On one such fan the little cluster of cabins known as Needleton has been built. In places the Animas glacier gouged long, narrow basins in the canyon floor. These were later filled with stream deposits and now provide pleasant camping places where tents may be erected in the shade of tall pine trees. Elk Park is a typical example of this topographic feature. Even in this extremely steep-walled portion of the canyon the change in gradient of the valley slopes, already referred to, is clearly indicated. There is a pronounced shoulder midway between the canyon floor and adjacent summit peaks at an altitude of 10,500 feet. Below this shoulder the valley walls are much steeper than above, giving clearly the effect of an inner youthful gorge eroded on the floor of an outer, more mature valley.

The portion of the Animas Canyon that lies in the Engineer Mountain quadrangle presents unusual features. The general relationships are indicated in Figure 8, E, which shows the cross section of the valley near the lower end of the Ignacio Reservoir. As thus depicted the upper and outer valley has a width of more than 5 miles and is about 2,000 feet deep. On the east this outer valley wall rises somewhat abruptly to the margin of the upland, sloping upward toward Mountain View Crest. The greater part of this eastern valley wall is granite or other crystalline rock, but the rim of the valley and much of the plateau surface toward the east are formed of Paleozoic strata. The west wall of the outer valley consists of the Hermosa Cliffs, which form an imposing scarp that rises steeply to a height of 1,500 feet above the valley floor and extends with but one break for 10 miles northward from the quadrangle boundary. The cliffs are composed of flat-lying Paleozoic strata comprising chiefly a thick mass of calcareous shale with a few beds of resistant limestone. The floor of this upper valley is marked by an undulating bench, 2 or 3 miles in width, now occupied in part by the Ignacio Reservoir. In general this bench slopes westward toward the foot of the Hermosa Cliffs, as indicated in Figure 8, E, and conforms more or less closely to the gradient of the pre-Cambrian floor beneath the Paleozoic strata. The natural drainage follows the valley of Elbert Creek and moves southward parallel to the Animas River for many miles before the tributary joins its main stream.

The inner canyon of the modern valley is at the east side of this older and upper valley just described. It is a gorge 1,500 feet or more in depth, carved in the pre-Cambrian complex and strongly glaciated. Thus the greater part of the floor of the older valley remains as a bench, high above the modern stream.

These peculiarities of topography are the result of a combination of events. The broad upper valley was doubtless in large part carved by the Animas River during the Florida cycle of erosion. At that time the base-level to which the streams were lowering their channels approximated very closely the plane of contact between the pre-Cambrian and Paleozoic rocks. In consequence a broad, shallow valley with a pre-Cambrian floor and gently sloping walls of sedimentary rocks was formed. After the rejuvenation of the Animas River at the end of the Florida cycle it would have been natural for the downward-cutting stream to incise its inner canyon along the west instead of the east side of this older valley, for there the valley floor was composed of comparatively weak formations. Presumably the interference of repeated glaciation is the cause of the unexpected situation of this inner gorge at the east side. It was from the east that the greater part of the ice entered this portion of the Animas Valley during each of the glacial episodes of Pleistocene time. Along the east margin of the great glacial tongue the ice would therefore have been much thicker and much more efficient as an eroding agent. On the retreat of the front of each glacier in the successive glacial stages the river would relocate itself along the channel partly carved for it by the ice. Thus the alternating episodes of glacial and stream erosion have formed this inner gorge and given it its modern appearance.

So also glaciation has had a large share in forming the remarkable escarpment along the west wall of the outer valley. This scarp is comparatively new, not yet deeply scarred by stream erosion. The tributaries that enter the valley from this side are typically hanging valleys. Undoubtedly the present form of the cliffs is chiefly the result of intense glacial erosion during the Wisconsin stage. The ice that entered this portion of the valley came in from Cascade Creek through the pass between Engineer Mountain and Potato Hill, between Potato Hill and the West Needle Mountains, down the main gorge of the Animas, and down the westward slopes from Mountain View Crest, in the Needle Mountains quadrangle. All these widespread masses of ice were perforce compressed into a tongue less than 5 miles in width. Much of the ice entered the neck of the funnel thus formed at such an angle that it must have exerted an enormous force against the west wall of the valley before it turned southward down the main avenues. This concentration of glacial forces against the west wall must have resulted in an unusual amount of erosion there. Scraping along the face of the Hermosa Cliffs, the ice plucked great blocks and slabs of brittle limestone from that face and gouged deeply into the softer and thicker beds of shaly strata, interlaminated with the limestone. The natural consequence of this relation between the valley wall and the glacial forces was the development of this remarkable scarp. At the same time great basins were gouged deep in the floor of the reservoir bench. These were originally the site of many lakes and ponds. Some, like Purgatory, were subsequently drained by swift-flowing, powerful streams. Others were filled with sediment and are now the sites of hay ranches. The lakes in still others, such as Columbine Lake, have been recently stocked with fish and afford the fishermen the best of sport. The construction of the Ignacio Dam permits the storage of a large amount of water and has enlarged and united lakes that originally occupied several separate basins. The water from this reservoir is conducted through a flume to the brink of the inner canyon and thence falls nearly 1,000 feet to the power plant at Tacoma.

Two miles south of the Engineer Mountain quadrangle line the reservoir bench descends gradually with the pre-Cambrian surface and disappears beneath stream level. At this point the Animas River escapes from the narrow gorge in which it had been confined from its very source and flows out upon the floor of a broad, flat-bottomed valley. For some 13 miles the stream meanders through fertile fields and past fruitful orchards, which cover the rich alluvium. (See pl. 15.) The flat is more than a mile wide and is bordered by fairly steep, rugged walls, which rise from 2,000 to 3,000 feet to the upland on each side of the valley. On the west wall, below the mouth of Hermosa Creek, there is a well-developed bench 600 or 800 feet above the stream. On the east wall at about twice that height there is a marked change in gradient of the slopes, as indicated in Figure 8, F. Here again the 2-cycle history of the Animas River is clearly indicated. The gentler upper slopes and wide bench are remnants of the late-mature valley formed here during the Florida cycle.

Near Animas the valley again narrows where the stream cuts through the moraine at the terminus of the Wisconsin glacier. For some time after the retreat of the front of that glacier the morainal ridge served to dam the valley, and much of the alluvium of the wide valley floor was collected in the lake that stretched upstream for many miles above this dam. Below the moraine the stream occupies a very narrow flood plain, which in turn is bordered by terraces, the remnants of outwashed valley trains of the Durango and Wisconsin glacial stages. Near Durango the valley consists of a comparatively narrow gateway between the hogback ridges, and a few miles farther south it broadens to a width of a dozen miles as it crosses the belt of lowland between the mountains and the neighboring plateaus. Here the cross profile of the valley is in general that suggested by Figure 8, G. The successive steps that rise on each side of the stream are the result of stream erosion and deposition on temporary base-levels, the highest of which dates back to the Florida cycle.

Near the south margin of the Ignacio quadrangle the Animas Valley narrows once again to form the gorge in which the stream is confined while traversing the plateau country, which stretches for hundreds of miles to the southwest. For a long distance in this gorge the stream flows across a narrow alluvial bottom. On each side of this flat there are gravel-capped rock terraces at various levels, the highest several hundred feet above the stream. Certain of these terraces are the remnants of glacial outwash; others represent normal stream erosion during temporary halts in the process of downward cutting. The highest bench level represents the graded surface of the Florida cycle. Above it the valley walls rise several hundred feet higher to the surface of the plateau. This upland is the southward extension of the summit of the Mesa Mountains and is a part of the San Juan peneplain.

The varied course of the Animas River thus outlined is undoubtedly an inheritance from its ancestral position upon the low-lying, gently undulating peneplain. This river rises near one side of a great mountain range and cuts through the heart of the mountains in a deep canyon carved in resistant crystalline rocks, whereas had its course been a few miles to the west it would have gone around the granite core of the range, and its valley would be in comparatively soft formations. Apparently the general direction of its flow was determined when the entire San Juan region presented few obstacles to its progress, and that course has been held despite the repeated episodes of domal uplift of the region. Thus its valley now presents every possible topographic type.

Uncompahgre Canyon.—The canyon of the Uncompahgre River bears much the same relation to the northern slope of the San Juan Mountains as the Animas Canyon does to the southern slope. The Uncompahgre River is, however, of much smaller dimensions, and its sources are only a few miles back from the mountain front, in the intensely glaciated wilderness of peaks and gorges where rise the several heads of the Animas River. Within a few miles the tributaries of the Uncompahgre have gathered themselves together into a considerable stream, which cascades swiftly along the steep floor of a magnificent canyon. North of Abrams Mountain this gorge is 3,000 feet deep and only 1½ miles in width from rim to rim. It is a canyon of singular beauty and grandeur. Its lower slopes, carved in pre-Cambrian quartzite, are exceptionally steep. From the glistening surface of the dark quartzite glacial ice has stripped all loose débris, so that bare rock precipices rise to dizzy heights on each side of the stream. The upper slopes of the canyon are more gentle and represent the broader valley of the Florida cycle. They are, for the most part, formed of bedded volcanic agglomerate and sheets of lava. These rocks disintegrate rapidly, and the slopes are sculptured into many pinnacles, spires, and turrets. A little farther north, near Ouray, the quartzite disappears beneath stream level, and the canyon broadens somewhat as it passes through the Paleozoic formations, which there underlie the volcanic pile. For a few miles below Ouray the valley retains its canyon form, and the narrow valley flat is hemmed in by high and steep cliffs almost to the mouth of Dexter Creek. Here, as elsewhere, the presence of the mature valley of the Florida cycle, high above the modern youthful canyon, is indicated by a pronounced change in the gradient of the valley walls at an altitude of about 9,000 feet.

Beyond Bachelor Switch the sides of the valley recede and leave a broad stretch of bottom land more than a mile in width, which continues downstream from Portland to Ridgway, a distance of 6 miles. Across this bottom land the stream meanders slowly, and much of its water is led away in irrigation ditches, to be distributed over the meadows and fields that crowd this lowland. On both sides of this flat the walls rise steeply to the uplands beyond. Their slopes are scraped clean and intertributary spurs have been truncated by glacial action. The general cross section is the typical **U** shape of a glaciated valley. (See pl. 16, *B*.)

Just beyond Ridgway the valley narrows abruptly to a sharp trench, where the stream cuts its way through the huge morainal dam that marks the terminus of the Wisconsin ice. Above this moraine, for some time after the retreat of the ice, there must have been a large shallow lake on the floor of which collected the alluvium that makes the fertile bottom lands.

Farther downstream the Uncompahgre River flows for some miles in a steep-walled, shallow canyon, floored with a narrow strip of alluvium and bordered by gravel-covered benches and mesas. The lowest of these terraces, only a few score feet above the stream channel, is capped with outwash from the Wisconsin glaciers. The next higher terraces, 300 feet or less above the stream, carry the similar materials of the Durango stage. The highest mesas, such as that immediately north of Chaffee Gulch, are 800 or 1,000 feet above the stream and carry Florida gravel.

Downstream from Eldredge the valley sides recede gradually. Within a few miles the valley has become broad, and the slopes rise to divides many miles distant on each side. The valley flat is also broader, the stream gradient is less, and the sluggish river meanders tortuously toward Montrose. The lower gravel-strewn terraces likewise become extremely broad. The fertile loam that covers them supports rich farms and splendid orchards. The water of the river, reinforced by the huge canal of the Gunnison irrigation project, is distributed over all these lower levels, and lands that once were desert are now dotted with beautiful farm homes.

Canyons of the Rio Grande and its tributaries.—The third of the five great rivers whose heads are within the rugged mountain mass of the Silverton quadrangle is the Rio Grande. This river flows in a general easterly direction through the east half of the range, in which it is by far the largest stream, until beyond the east front of the mountains it turns southward and drains San Luis Valley. The sources of this great stream are found in numerous steep-walled gulches in and near the southeast quarter of the Silverton quadrangle. The smoothly polished, glaciated surfaces of granite, quartzite, and other pre-Cambrian rocks form steep cliffs that rise abruptly as the walls of numerous U-shaped valleys from which projecting spurs and all débris have been cleaned by glaciation. In places small patches of moraine are preserved in sheltered nooks or remain as irregular loops across the valley floor. Only the higher peaks of this region of extremely rugged topography rose above the ice, which filled all the canyons and in places overtopped the lower divides.

A few miles east of its source the stream enters a region of volcanic agglomerate and lava sheets, which lap against the slopes of the ancient pre-Cambrian massif. The change in rocks does not, however, cause an immediate change in topography. Throughout the west half of the San Cristobal quadrangle the canyon of the Rio Grande and its tributaries, such as Ute Creek, Pole Creek, and Lost Trail Creek, are typically U-shaped glacial troughs, 3,000 to 4,000 feet in depth, separated by serrate divides studded with numerous sharp peaks. Even in this maturely dissected portion of the Rio Grande basin remnants of the topography developed during the Florida cycle of erosion are preserved in favored places. Between the mouths of Pole Creek and Ute Creek, for example, the Rio Grande Canyon shows a striking profile. The slopes above an altitude of 11,500 feet are comparatively gentle, but below that altitude the valley walls drop precipitously to the gently rounded floor of the canyon.

In the center of the San Cristobal quadrangle the Rio Grande Canyon is only about 2,000 feet deep, carved in bedded volcanic rocks and bordered on each side by a comparatively flat upland. Just above the mouth of Squaw Creek the canyon was partly blocked in postglacial time by a large landslide from its walls, and in consequence a long, flat strip of alluvium was deposited for a distance of about 6 miles above the dam. Presumably the water of the river was for a time ponded into a lake at this place, but later the dam was breeched, the lake drained, and the flat exposed to view. Within the last few years a reservoir has been constructed here to aid in conserving the waters of the Rio Grande for irrigation in San Luis Valley. The difficulties and dangers of this project, which involved the construction of a dam to close the gap between the landslide and the south wall of the valley, have been described elsewhere.[1] A short distance downstream the canyon walls converge and crowd the stream so closely that the canyon road climbs through the low saddle on the north wall of the valley and continues its course eastward along the floor of a near-by canyon, which a few miles farther downstream is tributary to the Rio Grande. This portion of the canyon, however, abruptly changes in the eastern third of the San Cristobal quadrangle, where the Rio Grande escapes from its narrow confines and flows across a flat more than a mile in width, bordered by comparatively gentle slopes that rise toward the plateaus on both sides. On the north a steeply inclined mesa intervenes between the Santa Maria rift valley and the precipitous façade of Bristol Head. The topographic features and physiographic history of the region surrounding Santa Maria Lake are detailed on page 157.

Near the east margin of the quadrangle, at the mouths of Middle Creek and its neighbors, the valley flat is bordered by low, undulating hills which are a part of the terminal moraine deposited at this extreme limit of the Wisconsin glacier. Here there is a peculiar flat-topped, outlying butte of volcanic rocks which rises in the midst of the valley floor and against the western face of which the Wisconsin glacier spent its last dwindling force in a vain attempt to overtop the obstacle.

At this point the Rio Grande is joined by three large tributaries from the south, whose canyons head in the vicinity of Piedra Peak. The canyon of Trout Creek is narrow and steep-walled, with little room for alluvium on its floor. The intertributary rock spurs, in places projecting into the canyon, retain glacially smoothed surfaces here and there. The rocks, however, weather rapidly, and many rugged, deeply etched surfaces appear on the canyon walls below the upper limit of glaciation. On the floor of the gorge are several small knolls of rock separated by ice-gouged depressions, and some of these show the expected signs of ice action.

Middle Creek occupies the next tributary valley toward the east. It heads in a large glacial cirque whose walls reach an altitude of more than 12,000 feet and from which great quantities of the easily eroded volcanic beds were removed by the ice. Not far below the cirque the floors and walls of the valley are completely mantled with glacial drift, which continues all the way to the Rio Grande. Most of this drift is in the form of more or less regular ridges, which tend to form loops across the valley.

The third and largest of the streams tributary to the Rio Grande at this place is the South River. It occupies a steep-walled canyon that heads beneath Piedra Peak. The floor of the canyon is generally covered by glacial débris, but since the retreat of the ice it has been largely modified by landslides and torrential wash. One of the larger slides has thrown a mass of débris more than 200 feet thick upon the canyon floor.

[1] Atwood, W. W., Relations of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, 1918.

Upstream from this landslide the stream was ponded for a time and a relatively wide valley flat was formed. The canyon walls above the landslide are formed in part of a volcanic agglomerate, which weathers very rapidly, so that it has retained very few signs of glaciation. Toward the mouth of the South River Canyon similar beds of volcanic débris are weathered into high pinnacles and isolated towers backed by abrupt cliffs that rise 300 and 400 feet above the stream bed.

Beyond the Wisconsin terminal moraine the Rio Grande swings far to the north in a graceful curve and flows for 10 miles through a broad valley, which, in its major features, is not unlike the valley immediately upstream from that moraine. Its floor is from 1 to 3 miles in width, and the walls, deep gullied and with numerous tributary gulches, rise gently to a height of about 4,000 feet above the stream bed. The presence of numerous intertributary spurs, projecting outward from these valley walls, is in striking contrast to the smoothness of the glaciated portion of the valley farther upstream. The bottom of the valley, too, is here occupied by numerous terraces, some of which are of large area and most of which are veneered with gravel washed outward from the ice that during the Pleistocene epoch occupied the upper part of the valley. The best-preserved terrace is that capped by outwash from the Wisconsin ice. It is easily traceable for more than 10 miles downstream from the Wisconsin terminal moraine. At the upstream beginning of this terrace its surface is 50 to 60 feet above the stream channel, but at the mouth of Willow Creek, 10 miles downstream, it is only 4 or 5 feet above the stream, and a short distance beyond it blends into the modern flood plain. The remnants of the Durango Valley train appear as terraces or benches on rock ledges above the Wisconsin terrace. They are of comparatively small area and have been more commonly preserved immediately downstream from a projecting spur of hard rock. Opposite tributary stream mouths the local torrential wash has generally built fans upon this bench so that it is slightly higher at such places than between the tributaries. The surfaces of all these terraces are not absolutely smooth, for the distributary channels of the old streams are well preserved upon them and give to them a relief of 10 or 15 feet.

In this portion of its course the Rio Grande is joined by two tributaries from the north, which rise on the southern slopes of San Luis Peak. The more westerly of the two is Sunnyside Creek, formed by the junction of Miners Creek and Rat Creek. Miners Creek heads in a large basin in the northeast corner of the San Cristobal quadrangle, where great masses of glacial ice accumulated during the Wisconsin stage. In consequence the upper portion of this valley contains thick moraine deposits, which continue down the canyon for some distance in the Creede quadrangle. The high canyon walls in the lower portion of this valley are locally concealed beneath a heavy mantle of talus. Many of the tributary rivulets have built large torrential fans at the mouths of their gorges. The head of the Rat Creek Valley is a spectacular amphitheater, deeply eroded and scraped clean of débris by the Wisconsin ice. Less than 5 miles below its head the valley is partly filled with the terminal moraine of the stubby glacier which formed in this amphitheater. Large landslide masses overlie this drift and extend far up the west side of the valley, which here is comparatively broad and shallow. Just below the terminal moraine Rat Creek drops abruptly into a deep, narrow gorge, which shows no signs of glaciation. Its closely spaced walls continue almost to the mouth of the stream.

The more easterly of the two tributaries of the Rio Grande above referred to is known as Willow Creek and is formed by the union of two branches just above the town of Creede. West Willow Creek rises in a strongly glaciated valley on the south slope of the Continental Divide, near the northwest corner of the Creede quadrangle. The basins at the head of the valley have been cleaned of all loose material, and their walls and floors have been smoothed by glacial erosion. On the east side of the valley the walls are steeper than on the west, more loose material has accumulated, and the gullying effects of tributary streams are much more distinct. Just below the Equity mine, for example, there are great accumulations of angular rock fragments on this side of the valley. Farther downstream landslides have been an important feature in determining the topography on the west side of the valley. Opposite Deerhorn Creek, a small tributary, the landslide topography merges into that of the terminal moraine, which is in part overlapped by slide débris. This moraine marks the farthest reach of the Wisconsin ice. Below it the stream drops rapidly into a deep, narrow gorge whose almost vertical walls and rugged, irregular contour are in striking contrast to the gentle outlines of the valley above the moraine. The narrow, steep-walled gorge confines the stream to its junction with East Willow Creek, just below which Willow Creek escapes into the broader valley in part occupied by the streets and houses of Creede.

East Willow Creek flows through a valley that is almost an exact replica of that just described. Above the Wisconsin terminal moraine the strongly glaciated valley is comparatively broad and shallow. Below that moraine it changes abruptly, and the stream cascades into a narrow gorge with walls rising almost vertically for several hundred feet. This change in character of the three valleys of Rat Creek, West Willow Creek, and East Willow Creek is only in small part the result of glaciation. The broad valleys above the terminal moraine have gentle slopes and display late mature topography, which has been only slightly modified by glacial erosion. The late mature aspect of this portion of these valleys is an inheritance from the Florida cycle of erosion, during which they were developed. The gorges downstream from the terminal moraine, typically youthful in their rugged narrowness, are the result of erosion during the canyon-cutting cycle, which followed the uplift of the older graded surface. Rejuvenation has progressed up each of these three streams only to the place where the character of the valley changes so abruptly.

The broad valley floor of this portion of the Rio Grande Canyon is abruptly terminated downstream near the center of the Creede quadrangle by the narrows known as Wagonwheel Gap. This is a picturesque notch cut in unusually resistant lavas. The walls rise almost vertically for 500 feet and leave scarcely room enough for the highway and the railroad beside the stream. From this point eastward for a distance of 10 or 11 miles the Rio Grande Canyon continues to be narrow. Narrow strips of alluvium and, in places, small terraces occupy the valley floor, but in spite of this the profile is sharply **V**-shaped. The rugged walls, deeply etched by weathering and carved by tributary streamlets, rise steeply to the upland level on each side of the canyon. Benches resulting from the presence of more than ordinarily resistant lava occur at various heights, and the rim of the upland plateau is itself formed of flat-lying lava sheets of superior resistance to erosion. Such tributary streams as Blue Creek flow at first across undulating surfaces in broad, late mature or old-age valleys. Midway of their courses they plunge abruptly into precipitous gorges, down which they cascade between nearly vertical walls until they join the main stream. These old upland valleys are interpreted as remnants of the former lowland developed during the Florida cycle.

Just below Wagonwheel Gap the Rio Grande is joined by Goose Creek, a large tributary coming in from the south. Its many heads nestle close against the Continental Divide in the vicinity of South River Peak, in the southwest corner of the Creede quadrangle. Numerous well-developed cirques contribute to the remarkably rugged scenery at the head of Goose Creek and its large tributary, Fisher Creek, and for many miles downstream from these basins the valley walls were smoothed and polished by ice. Just above the place where Roaring Fork joins Goose Creek the valley displays a postglacial gorge 60 feet in depth, carved below the floor overridden by the ice. The limit of the Wisconsin glacier is marked by a terminal moraine at the mouth of Leopard Creek, below which the valley walls are much more rugged and irregular than they are in the glaciated portion of the valley.

Near the mouth of the South Fork the Rio Grande Valley commences gradually to broaden, and from this point downstream the side slopes recede steadily until they curve outward to form the west slope of San Luis Valley, near the middle of the Del Norte quadrangle. (See pl. 16, *A*.) Stream terraces become a prominent feature in this valley. The modern flood plain ranges from a quarter of a mile to 3 miles in width, and in many places it is bordered by a low rock bench averaging half a mile in width, capped with fluvioglacial gravel of the Wisconsin glacial stage. In the eastern part of the Creede quadrangle this terrace is about 15 feet above the modern alluvial flat. Farther east, in the Del Norte quadrangle, it gradually declines in altitude, and near Del Norte its surface blends with that of the great alluvial fan of the Rio Grande, a portion of the compound alluvial fan that forms the west margin of San Luis Valley. Still farther downstream the surface of this fan coalesces with the modern flood plain. Another group of terraces at a somewhat higher level is believed to represent the remnants of the Durango Valley train. In this valley, near the east border of the quadrangle, it is 50 to 70 feet above the modern flood plain, but farther east it declines rapidly and blends with the Wisconsin terrace a short distance west of Del Norte.

The canyons occupied by the South Fork and its many tributaries are typical glacial troughs, displaying the normal **U**-shaped cross section of a valley once occupied by vigorously eroding ice. The South Fork Canyon itself is remarkably well cleaned of all loose material. Above the mouth of Beaver Creek many of the rock ledges, which give a steplike configuration to the canyon walls, at certain localities show smoothed surfaces due to glaciation. This canyon and its tributary, occupied by Pass Creek, afford a remarkably beautiful scenic route for the automobile road recently constructed over the Continental Divide. Two miles below the mouth of Beaver Creek the South Fork Canyon floor is half a mile in width and is heavily mantled with glacial débris, which forms there the terminal deposits of the many-pronged glacier.

Near Del Norte the Rio Grande emerges from its long confinement within the mountain range and moves sluggishly across the floor of the great San Luis Valley. The peculiar "drowned" appearance of the landscape near Del Norte is obviously a result of extensive deposition of gravel at this place. It is described more completely on page 165.

Canyon of the Lake Fork of the Gunnison River.—Another of the master streams of the San Juan Range which has its sources among the rugged mountains of the Silverton quadrangle is the Lake Fork of the Gunnison River. Its main head is in the American

Basin, a picturesque glacial amphitheater in the northeastern part of the quadrangle. Other tributaries rise in similar glacial cirques in that locality and unite to form a considerable river, which within a few miles of its sources is flowing in the bottom of a 3,000-foot canyon, with the walls rising sheer from both sides of the rushing torrent. Such canyons as that at Whitecross and those occupied by Cottonwood and Henson Creeks, in the northwest quarter of the San Cristobal quadrangle, are especially noteworthy for their beauty as well as for the perfection of their display of the results of mountain glaciation. Parts of these canyons are carved in great granite stocks or batholiths; other parts are composed of bedded volcanic flows and agglomerate. Regardless of the nature of the material, the walls are precipitous, and both sides and floors of the canyon are smoothed and cleared of all loose débris by glacial action. Tributary gulches are invariably hanging valleys whose height above the main stream is an index to the amount of glacial deepening in the main canyons. In places such streams as Cottonwood Creek have cut narrow gorges 15 to 25 feet in depth below the glaciated floor since the retreat of the Wisconsin ice. Beyond the abandoned mining camp known as Sherman the Lake Fork Canyon generally displays a valley flat approximating a quarter of a mile in width. The valley walls rise steeply 1,000 or 1,200 feet to the outer margin of a pronounced bench. From that position, midway between mountain peaks and valley flats, the valley walls rise gradually toward the divides on both sides. This high rock bench is a remnant of the late mature valley developed during the Florida cycle of erosion. Near Lake San Cristobal this upper and outer valley is remarkably well preserved and is in sharp contrast to the inner canyon formed during the canyon-cutting cycle, which is still in progress.

Henson Creek, Lake Fork's largest affluent, joins it just above Lake City. Its canyon is very similar to that of the larger stream. In the main it is well cleared of all débris by the ice that formed in the many cirques in the vicinity of Uncompahgre Peak, on the American Flat, in the southeast quarter of the Montrose quadrangle and the northeast quarter of the Silverton quadrangle. Despite the vigor of the glacial erosion, the 2-cycle origin of the valley is clearly shown.

At Lake City the valley floor is about a mile in width and is bordered by fairly steep slopes, which rise to the plateaus on both sides. Three miles farther downstream the valley bottom is occupied in part by the terminal moraine that marks the farthest advance of the Wisconsin ice. Beyond that place the valley walls are in strong contrast to those of the glaciated portion of the valley, for here the watercourses have deeply trenched the slopes, the intertributary spurs project far outward from the walls, and numerous irregularities due to unequal resistance to weathering are present nearly everywhere. From the terminal moraine to Madeira, a distance of 15 miles, the stream is either flowing on an extremely narrow valley flat or occupies a narrow but shallow rock gorge. Numerous rapids testify to the vigorous rate at which erosion is now progressing in this valley. Rock benches, a few feet above the narrow strips of modern alluvium or forming the rim of this miniature inner gorge, are capped with glacial gravel and are readily divisible into two sets. The lower of these, 20 to 50 feet above the stream bed, carries the remnants of the Wisconsin Valley train. The second set of terraces, 50 to 100 feet higher, is capped with outwash from the Durango ice.

The outer valley, formed during the Florida cycle, is 6 to 10 miles wide and 2,000 to 3,000 feet deep. The inner valley, carved during the canyon-cutting cycle, is less than 2 miles wide and averages about 800 feet in depth. At many places on the floor of the outer valley, as indicated in Plate 1, a veneer of gravel has remained.

Just below Spring Gulch, near the center of the Uncompahgre quadrangle, the unusual resistance of certain lava sheets has formed a conspicuous narrows, a veritable gateway scarcely wide enough to accommodate the water of the stream. The gateway is itself a product of the canyon-cutting cycle, and its walls rise sheer from the water's edge to a height of 600 feet. The flat tops of the ramparts were once the floor of the valley in the Florida cycle, but no pebbles recognizable as a part of the Florida gravel were found on it.

Downstream from Madeira the Lake Fork Canyon is of the typical plateau type—a narrow, winding chasm, incised beneath the surface of a flat upland. Its walls are about 1,000 feet high near Vanguard, but they decline to a height of only 200 feet near the point where the Lake Fork joins the Gunnison River. Lateral planation has not yet widened the valley floor, so that the canyon road which hugs the stream from Lake City to Madeira is forced to detour over the mesa surface as it continues toward Sapinero.

Canyons of the San Miguel River and its tributaries.—The last of the five great streams here to be considered that rise in the Silverton quadrangle is the San Miguel River. The heads of the main stream are in the Savage and Ingram Basins, compound cirques near the northwest corner of the quadrangle. The heads of numerous tributaries are in similar glacial basins in the Telluride quadrangle. Thence the stream flows in a general northwesterly direction across the neighboring plateau country to the Dolores River, which empties into the Colorado River.

The valley of Howard Fork, near the center of the Telluride quadrangle, is an excellent example of a

U-shaped, strongly glaciated canyon. Its north wall rises sheer to a height of about 4,000 feet above its floor. The intertributary spurs have been smoothed and truncated by the ice, and the débris has been swept far downstream. Swamp Canyon and the valley of Waterfall Creek, which join Howard Fork from the south, are typical hanging valleys with floors 200 to 300 feet above that of their main stream. The valley walls below the level of ice action are remarkably polished and in many places deeply grooved and striated. Above the limit of the ice the steep cliffs are weathered into pinnacles and turrets and at one point are crowned by the majestic spires known as Ophir Needles.

The San Miguel Valley also is strongly glaciated and typically U-shaped. The tributary streams above Telluride all cascade from hanging valleys. Above Pandora the amount of valley deepening below the ends of the tributary valleys is close to 1,500 feet. For a distance of about 5 miles downstream from Pandora the floor of the San Miguel Valley is a fertile alluvial flat a mile wide. Tributary streams have built low cones or broad fans of torrential material on the surface of this flat. The little town of San Miguel and the larger city of Telluride both take advantage of these fans, which serve admirably as town sites. On both sides of the flat the rock walls rise steeply to a height of 1,000 to 1,200 feet and then much more gently to the crests of the neighboring divides. Downstream the valley flat impinges against a great mass of glacial débris, which forms a morainic dam athwart the valley at Keystone. Obviously the flat above this barrier was once the floor of a long, shallow lake, which was gradually drained as the outflowing water incised its pathway through the dam. A few miles farther downstream the last of the glacial deposits made by the great compound San Miguel glacier occupies the lower valley slopes.

All that portion of the San Miguel Valley which is in the Telluride quadrangle shows the 2-cycle topography so generally displayed throughout the San Juan area. The broad outer valley of the Florida cycle is 8 to 15 miles wide and 1,000 to 2,000 feet deep. The inner canyon is scarcely 2 miles wide and is 1,000 to 1,500 feet deep. In many places but not everywhere the resistant flat-lying Dakota (?) sandstone forms the floor of the outer valley and the rim of the inner canyon.

Canyons of the San Juan River and its headwaters.—The San Juan River rises on the southern slopes of the San Juan Range, in the north half of the Summitville quadrangle. Its many heads are in a region of mature dissection but of comparatively low altitude, for the divides that surround its drainage basins in few places reach 12,000 feet above the sea. In consequence, ice action in this region is much less extensive than in the higher valleys of the streams heading in the Silverton quadrangle. Terminal moraines are found a few miles from the heads of the canyons, which beyond those moraines are clogged with débris and made rugged by numerous intertributary spurs. Above the mouth of the West Fork and below the small glacial basin near the head of the main San Juan Canyon the valley is some 6 miles wide and about 3,500 feet deep. Its rugged, deeply carved walls show clearly the change in gradient between the inner canyon, a mile wide and 1,000 feet deep, and the more gently sloping outer valley, in whose floor the inner gorge was incised.

At the mouth of the West Fork the San Juan Valley is choked by morainic débris, carried into it by this tributary from the north, but a few miles farther downstream the canyon opens out into a broad valley of the lowland type. A narrow flood plain is bordered by a low terrace, which carries the outwash of the Wisconsin ice. A higher bench is in many places preserved by its advantageous position and is covered with gravel, which represents the fluvioglacial deposit of the Durango stage. Still higher benches, some of them isolated as mesas 500 or 600 feet above the stream, are interpreted as remnants of the Florida graded surface. Above these, at distances of 3 or 4 miles from the main stream, Cerro till may be observed at several places in the Summitville quadrangle. The till caps the low divides between the San Juan and its neighbors and generally appears at levels 800 to 1,000 feet above the stream beds.

Farther downstream, in the southeast quarter of the Pagosa Springs quadrangle, the San Juan Canyon becomes a rock gorge 1,000 feet deep and 2 or 3 miles wide. The precipitous slopes are modified by rock benches, in many places gravel strewn, at varying heights above the stream. The rim rock that caps the canyon walls is generally a resistant sandstone. Above it the undulating surface of the plateau at many places carries pebbles of the type found elsewhere on the San Juan peneplain.

Dolores Canyons.—The Dolores River is the master stream on the west flank of the San Juan Mountains. It has two main heads of about equal length. The East Dolores River rises in the mountains near the south margin of the Telluride quadrangle and the adjacent portion of the Engineer Mountain quadrangle. Thence it flows in a general westerly direction and cuts directly through the heart of the outlying Rico Mountains. The West Dolores River has its sources high on the west slope of the Mount Wilson group, near the west margin of the Telluride quadrangle, and flows thence in a southwesterly direction to the place where it unites with the East Dolores River about 20 miles west of the San Juan Mountains. Thereafter its course is circuitous but bearing toward the northwest until it finally reaches the Colorado River a few miles west of the Colorado-Utah line.

The head of the East Dolores River is in a broad, high-level valley just west of Sliderock Ridge, in the Engineer Mountain quadrangle, and for several miles the stream flows with low gradient on the floor of a comparatively shallow depression, the gentle slopes of which attest late maturity or early old age. This is one of the few large streams in the San Juan region whose head has not been materially altered by glacial erosion but has retained a form resulting merely from stream action. Presumably this form of valley head represents that of most of the San Juan streams before the disturbing effects of the Durango and Wisconsin glacial episodes. The present form of the valley at its head is doubtless an inheritance from conditions that were widespread toward the end of the Florida cycle.

Farther downstream, in the southwest corner of the Telluride quadrangle, the East Dolores River flows with increasing velocity over an increasingly steep gradient and within a few miles is occupying the floor of a steep-walled canyon about 1,000 feet deep, incised in the floor of a broad outer valley, which is the downstream continuation of the gentle slopes at the valley head. For a few miles the Florida surface is represented by extensive benches high on both walls of the East Dolores Valley.

In the northeast quarter of the Rico quadrangle the East Dolores River cuts across the axis of the Rico Mountains, its steep-walled canyon, 3,000 to 4,000 feet deep, bisecting the mountain group into two approximately equal parts. Numerous tributaries from each side have brought large quantities of detritus, which obscures the solid rock on the lower slopes of this portion of the valley. Many landslide masses are present. No traces of the Florida cycle have been preserved. It is obvious that the course of the East Dolores River is antecedent to the final uplift of the Rico dome. That crustal movement must have been slow enough to permit the river to maintain the course inherited from the cycle of erosion when the San Juan peneplain was developed and to incise its canyon into the rising dome.

Beyond the Rico Mountains the East Dolores Canyon is of the typical plateau type. Deeply gullied walls rise abruptly from a narrow river flat for 1,200 to 1,500 feet to the upland surface. In the south half of the Rico quadrangle numerous tributaries have carved the plateau into a maze of sharp-crested ridges. In spite of the large amount of erosion along that portion of its course the East Dolores Valley has retained clear evidences of its 2-cycle history. The valley is a compound one, consisting of a mature upper valley, in the floor of which a youthful valley has been incised. The broad higher portion is very evidently the result of erosion during the cycle that terminated in the formation of the Florida surfaces. Regardless of resistant beds, the break in gradient is everywhere at approximately the same height, 600 to 800 feet above the modern valley flat.

The valley of the West Dolores River presents in a less striking way features similar to those of the East Dolores. The basins at its head are beautiful examples of glacial amphitheaters, with steep walls rising above a glacially scoured floor, dotted with rock-basin lakes such as the Navajo Lakes. Downstream to a point within a mile or two of Dunton glacial débris is commonly present along the lower slopes of the steep-sided valley. In places the river has carved an inner gorge 30 to 50 feet deep below the surface across which the ice had moved. Beyond the limits of glaciation the canyon walls are rugged and irregular, deeply sculptured by numerous tributaries. In only a few places are remnants of the graded surface produced in the Florida cycle preserved as sloping benches 1,000 feet or so above the valley floor.

Mancos Canyons.—The Mancos River is formed near Mancos, in the far southwest corner of the San Juan region, by the union of two streams of about equal dimensions, known as the East Mancos and West Mancos Rivers. Both rise on the west slope of the La Plata Mountains. Only the highest portions of their valleys immediately beneath the mountain summits have been glaciated. Here are great amphitheaters, deeply sculptured by ice but subsequently modified by weathering and stream erosion. Beyond these basins the streams quickly sink into narrow canyons about 500 feet deep. Near the western margin of the La Plata quadrangle the West Mancos Canyon is bordered by a comparatively smooth surface of the Florida cycle, heavily mantled with boulders, 400 to 500 feet above the modern valley flat.

Near the junction of the two main branches of the Mancos River the valleys have a width of many miles in the lowland between the mountains and the adjacent plateaus. Numerous gravel-strewn terraces and mesas rise steplike above the broad valley flat. The highest of these terraces are capped with Florida gravel; the lower ones carry fluvioglacial gravel. A few miles farther downstream the Mancos Valley narrows and becomes a steep-walled canyon between Mesa Verde and Menefee Mesa, whose gently undulating surfaces are about 2,000 feet above the stream course. Even in this narrow canyon the position of the abandoned valley of the Florida cycle is indicated by a pronounced shoulder on the valley slope midway between top and bottom.

La Plata Valley.—The La Plata River rises near the north margin of the La Plata Mountains, flows thence southward across this outlying range, and continues southward through the adjacent plateau country to the San Juan River. In its upper portion the stream occupies a typical mountain gorge which divides the La Plata Mountains into two halves. The rugged walls rise sheer from the stream bed to heights of 1,000 to 1,500 feet above the stream and thence slope more gently to the mountain summits, 2,000 feet higher. Clearly this is another late-mature valley of the Florida cycle, with a youthful canyon incised into its floor. Obviously the course of the La Plata River is antecedent to the last crustal movements that assisted in forming the La Plata dome and is inherited from the Peneplain cycle. At Parrott the stream escapes from the mountain gorge and commences its long journey across the plateaus. For a short distance its valley is wide, but at Hesperus it becomes a mere gateway through the hogback, which presses closely upon each side. Below the hogback the stream flows for a long distance on a narrow flood plain, bordered by fluvioglacial terraces, above which rise the low scarps of extensive mesas capped with Florida gravel. Here in the belt of lowlands that intervenes between the mountains and the plateaus the La Plata Valley has a width of nearly 20 miles. Just north of the Colorado-New Mexico line the valley sides converge and the stream traverses the region of plateaus in a youthful canyon.

Hermosa Canyon.—Of all the larger valleys in the San Juan region that least affected by glaciation is the valley of Hermosa Creek, a large tributary of the Animas River, which rises on the west slope of the San Juan Mountains, drains the greater part of the area between them and the outlying Rico and La Plata groups, and unites with the Animas in the northwest quarter of the Ignacio quadrangle. The valley of the tributary East Fork, at the center of the Engineer Mountain quadrangle, was occupied by a valley dependency from the Animas Glacier, which pushed westward across the low saddle at the head of this valley and reached its terminus at Hermosa Park. In consequence this tributary valley is broad, with U-shaped cross section and tributary spurs truncated in typical glacial fashion. The valley of the North Fork was slightly modified by ice during the Durango stage, but was not entered by the Wisconsin glaciers, so that its present form is more the result of stream erosion than of ice erosion.

In general the drainage basin of Hermosa Creek is a maturely dissected upland with no flat areas, either along the stream courses or on the divides between the sharply incised canyons. The valley of the main stream, especially south of Hermosa Park, displays a sharp V-shaped inner gorge, 800 to 1,000 feet deep, below the floor of a broader outer valley. The slopes that rise gradually from the brink of the inner canyon to the summits, several miles distant on each side, represent the Florida cycle of valley development.

In general the Hermosa Canyon, with its projecting intertributary spurs, rugged sides, and narrow, twisting floor, is in striking contrast to the glacially cleaned, smooth-walled valleys of similar streams that were affected by the vigorous glaciation of the Wisconsin stage.

Florida Canyon.—The Florida River has its sources on the uplands which rise toward the south crests of the Needle Mountains in the southern third of the Needle Mountains quadrangle. Thence it flows southward across nearly the whole length of the Ignacio quadrangle to its junction with the Animas River. In and near the mountains the Florida Canyon was strongly glaciated; in consequence the stream flows through a broadly U-shaped valley, well cleaned of débris by ice action. In places on the canyon floor deep basins, now filled with alluvium or the water of irrigation reservoirs, were gouged in less resistant materials by the ice. More commonly the canyon is narrow, and the rock walls rise sheer from the banks of the stream. Below Transfer Park the lower slopes and much of the valley bottom are buried beneath a considerable thickness of morainic materials, which extend to a point near the mouth of Miller Creek. Beyond there are scattered areas of older drift referred to the Durango stage. Still farther downstream there are numerous scattered remnants of valley trains, which now form two sets of disconnected terraces.

The Florida Canyon, especially in the northern part of the Ignacio quadrangle, consists of an upper, more open valley, with long, gentle slopes, clearly demarked from an inner, steeper-walled trough. The outer valley is, of course, a product of the Florida cycle of erosion, and the inner trough is of subsequent date.

The Florida River turns sharply toward the west near the center of the Ignacio quadrangle, and for half a dozen miles it occupies an asymmetric, interhogback valley. The north slope is comparatively gentle, rising with decreasing gradient from an altitude of about 7,500 feet to the peneplain remnants at or about 10,000 feet, which cap the divide between the Florida and Animas Valleys. The south side of the valley is much steeper, but here there is a pronounced rock bench, 500 to 700 feet above the stream, which represents the graded surface of the Florida cycle. Above this bench the valley walls rise very steeply to the serrate crest of the hogback ridge.

A few miles east of Durango the stream again changes its direction abruptly and escapes through the hogback into the lowland belt south of the foothills. There the stream flows on a narrow flood plain between rock terraces capped with fluvioglacial gravel, bordered by mesas strewn with Florida gravel or by gently undulating slopes that rise gradually toward the more distant plateau upland.

Vallecito Canyon.—Vallecito Creek flows southward near the east margin of the Needle Mountains quadrangle and joins the Los Pinos River in the northeast quarter of the Ignacio quadrangle. The canyons of this stream and its numerous tributaries within the Needle Mountains are carved in granite, quartzite, and slate of unusually great resistance, but in the work of erosion the streams have been ably reinforced by vigorous glaciers. These headed in the great amphitheaters beneath the Needle Mountains and the higher summits of the Grenadier Range, gathered together in the main valley, and there were welded into an erosive tool of unusual efficiency. In consequence the Vallecito Canyon was greatly deepened, projecting spurs were removed, and most of the loose débris was carried away. Glacially grooved and polished surfaces are present everywhere on its walls, which curve gracefully with steepening gradient from the stream channel to the crests, 4,000 to 5,000 feet above. Large torrential fans have been formed at the mouths of nearly all tributaries, and in many places along the stream channel there are considerable deposits of till. In places Vallecito Creek and its tributaries, such as Johnson Creek, have cut narrow postglacial gorges 50 to 75 feet in depth.

A short distance south of the Ignacio quadrangle boundary the pre-Cambrian complex descends below stream level; in consequence the valley walls recede and the valley loses its rugged, canyonlike appearance. For several miles the stream meanders across a large alluvial flat, from the sides of which the valley slopes rise steeply to a height of 4,000 feet or more above stream level. At the mouths of all small tributary streams there are torrential fans, composed of reworked glacial débris. Two miles south of the fish hatchery a recessional moraine curves across the valley floor. At the lower end of this flat, just above the terminal moraine that marks the farthest reach of the combined Vallecito-Pinos glacier, the Vallecito Valley opens into the valley of the Los Pinos River.

Los Pinos Canyon.—The sources of the Los Pinos River are in the peculiarly wild and strongly glaciated mountainous region in the southwest quarter of the San Cristobal quadrangle. Thence it flows in a southwesterly direction across the northwest corner of the Pagosa Springs quadrangle into the Ignacio quadrangle, in which it turns southward and continues in a fairly straight course toward its junction with the San Juan River, 15 miles south of the Colorado-New Mexico boundary line.

The canyons of the upper part of this river and its tributaries, such as Flint Fork and Lake Fork, are superb examples of the effects of vigorous glaciation in a region of high relief and resistant strata. Picturesque walls of granite or quartzite, polished and sculptured by the ice, rise sheer from the narrow canyon floor. Tributary gulches are typical hanging valleys, from which slender threads of water cascade into the main canyon.

At the point where the Los Pinos River enters the Ignacio quadrangle it flows between nearly vertical walls that rise about 2,000 feet above the valley flat, half a mile wide. After entering this quadrangle the river flows southward for 3 miles across this narrow alluvial plain and farther downstream is bordered by more gently sloping canyon walls. Then it turns abruptly toward the west and plunges through a narrow gorge choked by glacial drift. Huge granite and conglomerate boulders, as much as 25 feet in diameter, clog the stream course, and the river dashes and pounds around them in a most picturesque fashion.

This gorge is a little less than a mile in length, and beyond it the stream debouches upon a broad alluvial plain, bordered by steep walls that rise irregularly to the summits of Grassy Mountain and West Mountain, 2,000 to 3,500 feet above the stream channel. Here it is joined by Vallecito Creek, and together these waters flow southwestward through a typical asymmetric interhogback valley to the gateway near Columbus. A broadly curving terminal moraine, flanked by remnants of outwash terraces, occupies part of the valley floor.

Beyond the hogback gateway, near Columbus, the Los Pinos River emerges from the foothills and flows southward across the broad lowland in the south half of the Ignacio quadrangle. Here the valley flat is of considerable width and is bordered by rock benches that rise steplike on each side. These benches are capped with fluvioglacial and stream gravel, covered in places with a rich wind-blown loam that fits them well for farms.

After leaving the lowland of the Ignacio quadrangle, close to the Colorado-New Mexico boundary line, the Los Pinos River enters a rock gorge cut in the sandstone and shale that form the plateaus extending far to the south. At places this rock gorge is so narrow that there is scarcely room for the stream between its precipitous bluffs, and the canyon road must climb high along the sidehills in precarious situations where there is constant danger from rock slides. Elsewhere the valley widens slightly and a narrow belt of alluvium gives sufficient encouragement to induce a Mexican family to make a home upon it. At numerous levels on the canyon walls there are narrow ledges or benches due to the presence of harder sandstone strata. The plateau summit on each side of this gorge is a portion of the San Juan peneplain, but it is not certain which, if any, of the numerous intermediate benches represent the graded surface of the Florida cycle.

Weminuche Canyon.—Weminuche Creek rises south of the Continental Divide in the south half of the San

Cristobal quadrangle and flows thence southward to its junction with the Piedra River in the north half of the Pagosa Springs quadrangle. Near its head the valley is extremely rugged and somewhat irregular in form. Near the lower limit of the pre-Cambrian rocks it is partly blocked by huge knoblike masses that stand in the middle of the valley. Beyond these it is abruptly deepened, and after descending nearly 1,000 feet in less than 2 miles the stream flows smoothly southward on a broad alluvial bottom. Glacially smoothed slopes rise abruptly on each side, with the lower part obscured beneath a heavy mantle of glacial débris. Symmetrical fans of torrential detritus extend from tributary gulches far out on the alluvial bottom lands. A short distance south of the San Cristobal quadrangle a small recessional moraine crosses the valley as a belt of low, rounded hills about a quarter of a mile in width. Two miles farther south a broad terminal moraine occupies the bottom of the valley. For its entire length to this point the valley is notably broadened and deepened, and the valley slopes are remarkably cleaned as a result of the Wisconsin glaciation. Beyond the terminal moraine, however, the valley abruptly narrows, and it becomes a veritable canyon whose walls are much more rugged. Intertributary spurs project alternately from either side. The stream no longer enjoys the freedom of an alluvial flat but is constantly pinched between the confining walls. On the slopes at many localities there are remnants of a rock bench capped with glacial drift of the Durango stage. Huge blocks of Dakota (?) sandstone have slipped down over the underlying shale and litter the slopes of the gorge.

Just above its mouth the stream again cuts into the pre-Cambrian basement, and a narrow inner gorge is an expression of the superior resistance of these crystalline formations.

Huerto Canyon.—Huerto Creek is a similar tributary of the Piedra River and occupies a course roughly parallel to that of Weminuche Creek. The upper portion of its valley, north of the abrupt mountain escarpment near the south margin of the San Cristobal quadrangle, is a strongly glaciated, U-shaped canyon. In most places the walls are too steep to retain any loose material, and the bare rock surfaces show glacial polishing and smoothing. Near the lower end of this picturesque canyon the stream has cut a narrow, steep-walled gorge to a depth of 50 to 75 feet below the floor of the glacial trough.

Downstream from the mountain front the valley is wide and flat-bottomed, bordered by moraines and blocked near the south line of the San Cristobal quadrangle by thick accumulations of drift. These moraines continue across a low saddle on the west slope of the valley, through which in times long past Huerto Creek flowed to join Weminuche Creek. This ancient course, however, has been abandoned since the Durango glacial stage, and now the stream curves abruptly eastward and then flows in a narrow, rugged gorge to its union with the Piedra.

Piedra Canyon.—Piedra River rises in the far southeast corner of the San Cristobal quadrangle and thence traverses the entire length of the Pagosa Springs quadrangle until it unites with the San Juan close to the New Mexico boundary line. In its upper portion it flows in a strongly glaciated mountain gorge with steep walls and cliffs, somewhat smoothed by the Wisconsin ice. In places, as a mile north of the San Cristobal quadrangle boundary line, the canyon is extremely narrow and deep, with its foam-lashed stream dashing swiftly over a rock-strewn floor 2,500 feet below the canyon rims, which are little more than a mile apart.

At 3 or 4 miles beyond the quadrangle line the stream emerges from its mountain canyon and begins its long course across the plateau country. At first its valley is comparatively shallow, but within a short distance it becomes a canyon 800 to 1,000 feet deep, sharply incised beneath the surface of the bordering table-land. Below the mouth of Huerto Creek the Piedra Canyon is a narrow V-shaped gorge, the rim of which is formed of flat-lying Dakota (?) sandstone, with an extremely narrow floor cut into the pre-Cambrian complex. Apparently there has been little opportunity for the stream to widen its canyon by lateral planation since the cutting from the upland surface began.

Still farther downstream the pre-Cambrian formations disappear below stream level, and the remainder of the canyon is of the normal plateau type. Where weaker rocks form its walls it broadens to a width of several miles, as, for example, near the crossing of the Durango-Pagosa Springs automobile road. More commonly, however, the canyon walls are formed or capped by resistant sandstones, and under these conditions the valley is a steep-walled, V-shaped gorge.

Blanco Canyon.—The headwaters of the Rio Blanco are just west of the Continental Divide in the central portion of the Summitville quadrangle. For a distance of about 6 miles the stream flows through a very steep-sided gorge, in which the walls rise fully 3,000 feet above the bed of the stream. There is no trail through this portion, and it is almost impossible to get through afoot. In the next 5 miles the canyon walls recede to form a large, parklike basin. Here the floor is a rolling meadow which has been adapted for ranching, and there are several settlers and a public school in the basin. The Wisconsin glacier advanced to the lower end of this basin and left a mantle of glacial drift, which produces a rich soil suitable for pasture land.

Where tributary streams enter the parklike portion of this canyon they deploy, depositing vast quantities of detritus, and build up huge torrential fans. At places these fans blend with one another on the same side of the park and thus form a mantle of detrital material, which slopes gently to the margin of the bottom land in the central portion of the park.

A short distance below Blanco Basin the stream leaves the mountains and crosses an area of sedimentary rocks that rest in a nearly horizontal position. While winding through a somewhat sharply incised gorge, 500 to 1,000 feet deep, the stream is joined by Rito Blanco, and within a few miles it unites with the San Juan River.

Navajo Canyon.—The next large canyon southeast of the Rio Blanco on the west side of the Continental Divide is that of the Navajo River. This stream receives its headwaters from points near the very crest of the Continental Divide, where a number of glacial lakes, in an amphitheater formerly occupied by ice, contribute to the river. For a distance of 7 miles the canyon of the Navajo River is exceedingly picturesque, with steep sides and rugged walls. A trail runs near the stream, shifting now to one side and now to the other, following through the catchment area and over the crest into the headwaters of the Conejos drainage basin.

The middle portion of the Navajo Canyon, like the middle portion of the Rio Blanco Canyon, is a well-settled broad, parklike area, about 5 miles in length. This area is locally called Navajo Park. The ice that formed near the Continental Divide advanced southward through this canyon, spread out and covered the entire lowland of the park, and during the last stage of mountain glaciation reached its maximum position of advance at the south end, just above Peterson's ranch. On the lower slopes rising from the park there are thick morainic deposits with rolling topography. The central portion immediately bordering the stream is an alluvial flat. Torrential fans have been developed where the tributary streams enter the main canyon, and in the parklike area these fans have spread out until some of them are at least half a mile in width and more than that in length.

Beyond Navajo Park the Navajo River soon leaves the mountains, and turns westward around the south margin of Navajo Peak through an area of flat-lying sedimentary rocks. The stream is here in a canyon 500 to 1,000 feet deep. Small terraces along the stream mark the effects of outwash from great glaciers, and there is a narrow alluvial flat bordering the stream, which is for the most part appropriated by ranchmen and used as pastures.

Chama Canyon.—The upper portion of the Chama Canyon is near the southeast corner of the Summitville quadrangle. The stream receives its headwaters from numerous little lakes, due to glacial action, just south and west of the Continental Divide. These lakes are in the broad, flat-bottomed amphitheaters where the snow collected which formed the glaciers that occupied this canyon during the Pleistocene epoch. The upper basins are separated from the canyon by a very steep wall, the descent of which is extremely difficult. At the base of that wall the canyon bottom becomes less rugged; landslides and alluvial waste appear on each side. For a distance of fully 6 miles the canyon may be followed by a pack train without difficulty. In a part of this area there is a broad alluvial flat that furnishes good pasture land. Morainic materials mantle the lower slopes of the canyon at various places, and torrential fans are developed at the mouths of many of the tributary streams. At the southern margin of the quadrangle is the terminal moraine of the Wisconsin glacier. For a mile upstream from that point the canyon floor is blocked by morainic deposits with characteristic hummocky topography. Numerous little knobs and kettle holes, just such as may be found in the terminal and recessional moraines of the central plains of the United States, appear here in this moraine, left by the Chama Valley glacier.

South of the mapped area the Chama River enters New Mexico and flows for a distance through a somewhat broad valley, cut by the stream into the plateau country. Eventually, unlike the other streams from the south and west side of the Summitville quadrangle, it joins the Rio Grande.

Conejos Canyon.—Next to the Rio Grande Canyon that of the Conejos River is the most spectacular of the canyons on the east side of the range. The headwaters of the Conejos come from the central portion of the Summitville quadrangle. They are east of the Continental Divide, and this drainage in time reaches the Rio Grande. Near its head the Conejos is in a broad U-shaped canyon that can be followed on horseback; at a point about 7 miles below the head this canyon widens to about half a mile, and that greater width continues to a point near Platoro. This widened portion is known as Adams Park. It is an alluvial flat and serves as a pasture. Just below Platoro the valley bottom again broadens out into a parklike area floored with alluvium. Many of the tributary streams in this part of the Conejos Canyon have developed large torrential fans at their mouths, where their gradients decrease very notably within a short distance, and they are forced to deposit most of the material which they bring from their upper courses.

In crossing the Conejos quadrangle the canyon turns southward and then eastward. It is a steep-sided gorge, with walls rising nearly 3,000 feet above the alluvial bottom land. At some places morainic materials partly clog the valley, and at others there are great torrential fans built by tributary streams. Wisconsin ice advanced down this canyon to a point near the Elk Creek ranger station. In the earlier or Durango stage the ice filled the entire canyon in its middle portion and even rose high enough to deploy eastward on a plateaulike surface in the western part of the Conejos quadrangle, where to-day are numerous small lakes, such as Acascosa, Los Flores, and La Grallal. As the stream approaches the lowland valley to the east the alluvial flat becomes much broader, and the receding canyon walls lower and lower, until the stream begins its course across San Luis Valley, where it passes a little north of the town of Antonito and through the village of Conejos.

Alamosa Canyon.—The headwaters of Alamosa Creek are just north of those of the Conejos, on the east side of the Continental Divide in the Summitville quadrangle. They come from great catchment basins, which formerly contained ice and which to-day retain snow fields until late in the season. Glacial lakes, ponds, and marshes contribute to these waters throughout the summer. Soon the numerous small streams unite and flow in a very sharp gorge, which in general trends eastward into the Conejos quadrangle. The walls of this gorge rise from 2,000 to 3,000 feet above the stream. They are composed of thick sheets of lava and layers of fragmental material thrown out from the ancient volcanoes. Several little mining towns are located in the canyon bottom. Gilmore and Stunner are in the upper portion of the course; Jasper, a little farther downstream, is in the western part of the Conejos quadrangle. The valley bottom is sufficiently broad to permit the construction of a wagon road as far as Stunner. This canyon contained ice which advanced downstream as far as the lower end of the present Alamosa Reservoir. There the terminal moraine forms the margin of the great reservoir on the north and east. At places in the valley there are other remnants of glacial deposits, as shown on the maps in this report, and many of the tributary streams have emphasized their activities by depositing great torrential fans at their mouths. A few ranchmen have located in this valley. They use the bottom lands as fenced pastures and arrange to have their cattle graze in the national forests throughout the summer.

Downstream from the reservoir Alamosa Creek flows through a small gorge, which soon broadens out, and the stream finds itself entering the lowland area. Here it has developed a gigantic alluvial fan which extends 5 or 6 miles into San Luis Valley. Such large fans, built by the major streams as they enter the valley, offer most favorable opportunities for irrigation. Their slopes are usually just steep enough to carry the water from the apex of the fan to any portion where it is needed.

Saguache Canyon.—The many headwater streams of the Saguache River rise on the north slopes of the La Garita Mountains, in the northern part of the Creede quadrangle. Thence they flow in a general northeasterly direction, swinging finally toward the east. The main river leaves the mountains a short distance north of the north boundary of the Del Norte quadrangle and then swings southward, draining the north end of San Luis Valley. Several small glaciers occupied the basins at the extreme upper end of the Saguache headwaters, but none of these extended far down the valley. Hence the canyons formed by these streams are comparatively rugged and irregular. In general they are separated by table-lands and have extremely narrow valley floors. The highest of these intercanyon table-lands, such as Table Mountain, between the Middle and South Forks of the Saguache River, are remnants of the San Juan peneplain. Broad benches and intercanyon flats at levels 1,000 to 1,500 feet below these highest summits are believed to represent portions of the late mature valleys carved in this portion of the range during the Florida cycle of erosion. Beneath these surfaces the inner gorges of the Saguache River and its tributaries are sharply incised to depths of slightly less than 1,000 feet.

Downstream toward the mountain front the Saguache Valley widens considerably. For many miles above the town of Saguache it displays a broad alluvial flat several miles in width, bordered by low terraces which blend downstream into one another and into the modern flood plain. In general the topography has the same "drowned" appearance as that in the vicinity of Del Norte. The Saguache and the adjacent streams have built a great compound alluvial fan, portions of which extend far up the more open valley behind the mountain front.

Cebolla Canyon.—Cebolla Creek is a large tributary of the Gunnison River that rises among the San Luis Peaks and on the west slopes of Cannibal Plateau, near the southeast corner of the Uncompahgre quadrangle. Thence it flows northward, roughly parallel to Lake Fork, to its union with the Gunnison. In general its canyon is extremely irregular and shows more variation in form and dimensions than is customary among the streams of this region. For only short distances near the heads of such tributaries as Spring Creek and Mineral Creek were the canyons cleaned out by ice. Elsewhere the present topography is the result of stream erosion. In its upper third the Cebolla Canyon is a steep-sided, narrow gorge, whose walls rise abruptly to heights of 500 to 800 feet above a narrow valley flat. Above the rim of this inner gorge there are numerous broad, flat benches at varying heights above the stream. These are separated from one another by deeply sculptured slopes, which in places are fully as abrupt as those of the inner gorge. The surfaces of these benches invariably coincide with the surface of an unusually resistant lava sheet, and the intervening slopes are invariably cut in soft, crumbling tuff and agglomerate. Some of these benches are of unusual extent. The one on the south side of Cebolla Creek near the mouth of Mineral Creek, for example, is about a mile in width and extends for 2 miles parallel to Cebolla Creek, between the youthful canyons of the tributaries cut beneath its level. Its surface has the form of a shallow saucer, conforming perfectly to the original surface of the lava flow, from which all overlying material has been removed by streams and wind. Ordinarily more or less of the saucer, which occupies nine-tenths of the area of the bench, is occupied by a lake whose dimensions are variable, depending upon the volume of rainfall at different seasons of the year.

Other benches at other places along the valley are occasioned by the presence of this same lava sheet, and still others at varying altitudes conform to older or younger lavas. In all probability some of these benches correspond closely to the floor of the late mature valley which must have been carved here as elsewhere during the Florida cycle. None of them, however, carry gravel, and all are, at least in their details, the result of the differential hardness of underlying rock.

From Cathedral downstream the Cebolla Valley consists of several canyons alternating with broader portions where the valley sides are comparatively gentle. The canyons are due largely to structural conditions, for they occur where resistant rocks were crossed by the stream. But something more than geologic structure seems to be involved in the physiographic relations near Powderhorn. Here is the widest portion of the entire valley, with a flood plain half a mile in width. The adjacent slopes are late mature or old, in striking contrast to the youthful topography both upstream and down. Strangely enough, this more open portion of the valley occurs in a region of pre-Cambrian rock. It is true that here numerous faults have shattered the rock and may have made it less resistant, but it does not seem probable that this explanation is adequate. It appears as if a prevolcanic topography had been uncovered by the stream and its tributaries at this locality. The present topography is the result of stripping the volcanic cover from the surface of a region which, prior to the volcanic outbursts, had been carved into late mature form.

Black Canyon of the Gunnison River.—In many respects the Black Canyon of the Gunnison River is the most remarkable bit of scenery in the entire San Juan region. Certainly its peculiar physiographic features and unusual location merit the careful study which it has received and demand more than casual treatment here.

The canyon begins immediately downstream from the junction of the Lake Fork with the Gunnison, in the northwest corner of the Uncompahgre quadrangle. Upstream from that point the Gunnison River flows through a comparatively broad valley with an extremely irregular floor. In places the river meanders across a broad flood plain, but at several other places it is confined between the sheer walls of a narrow gorge, which rise 100 feet or more above the river. Just below Sapinero the river enters one of these gorges which at first appears to be in the same category as the narrows near Elkhorn or those a short distance below Cebolla. Here, however, the stream does not quickly escape, but, on the contrary, the canyon walls increase in height for a few miles until the river is flowing along the narrow bottom of a canyon whose walls rise sheer to heights of more than 1,000 feet above the stream. These walls increase rapidly in height downstream until, near the mouth of Cimarron Creek, the canyon is extremely rugged and picturesque, 2,000 feet or even more in depth. (See pl. 17, *C*.) Beyond the north boundary of the Montrose quadrangle the upland surface declines gradually downstream, the canyon walls decrease in height, and within a few miles the stream escapes from its long passage between the towering crags of the Black Canyon and continues its westward journey through a broad valley with gently sloping sides.

The railroad journey between Gunnison and Montrose permits the traveler to see to good advantage about half of this remarkable canyon, for the railroad track hugs the banks of the stream along its narrow floor as far as the mouth of Cimarron Creek. No adequate description of the scenery which may thus be observed can be penned. The photographs reproduced in Plate 17, *A* and *C*, give only a faint impression of the real grandeur of this rugged canyon. Beyond the mouth of Cimarron Creek there are no trails in the canyon, but the curious adventurer may again descend to its floor along the trail that leads to the intake of the Gunnison irrigation tunnel, a few miles north of the Montrose quadrangle. A true sense of the proportions of the canyon, however, is gained only from its rim. Unfortunately this can be approached in only a few places except by most laborious footwork. One of these places, however, gives the most remarkable outlook to be obtained anywhere in this part of Colorado. A recently constructed automobile road leads westward from Saguache along the north rim of the canyon, which drops sheer to dizzying depths. For a couple of miles the road is within a few feet of the canyon rim and provides outlook points that rival those of the Grand Canyon of the Yellowstone. (See pl. 17, *C*.)

The Black Canyon itself is cut in the pre-Cambrian complex, which consists chiefly of very dark micaceous schist impregnated by innumerable intrusions of a coarse-textured, generally dark granite. The weathered surfaces of these rocks, streaked and stained by organic acids, make the name Black Canyon appropriate, and except in the middle of the day the bottom of the canyon is constantly shrouded in gloomy twilight. Near and below the mouth of Cimarron Creek the stubby spurs that project from the canyon walls display a significant break in the slope. This change in gradient suggests that the lower 500 feet of the gorge with its steeper walls is due to a comparatively recent rejuvenation of the stream.

Above the rim of the canyon there is a broader, outer valley with comparatively gentle slopes. The canyon rim coincides with the surface of the pre-Cambrian complex. The flat bench formed by this surface rises gradually from Sapinero downstream to its highest point, not far from the intake of the Gunnison tunnel, where the altitude of the pre-Cambrian rocks is at a maximum. Beyond this point the bench declines with the decrease in altitude of the pre-Cambrian surface. Above this bench the outer valley has a width of 5 to 20 miles. Its gentle slopes are carved in Tertiary volcanic rock, chiefly agglomerate, which here overlies the pre-Cambrian terrane. At most localities—for example, in the northwest quarter of the Uncompahgre quadrangle—the gentle slopes of this outer valley lead to the foot of cliffs, 200 or 300 feet high, which rim the high mesas and plateaus capped with lava on each side of the Gunnison River. The depth of this outer valley from the plateau summits to the rim of the Black Canyon varies considerably from place to place but is generally less than 1,000 feet.

At most localities the south rim of the Black Canyon is about 200 feet higher than the north rim, because of the northward dip of the pre-Cambrian surface. The floor beneath the volcanic strata is in the form of a gently arched and gently plunging anticline, the axis of which is directed a few degrees east of north and passes through Vernal Mesa, in the northeast quarter of the Montrose quadrangle. This broadly arched floor terminates abruptly toward the south against a fault which runs for more than a score of miles approximately parallel to the general trend of the Black Canyon. The fault follows the cliff that forms the southwest wall of Vernal Mesa, passes close to the railroad station at Cimarron, traverses Fitzpatrick Mesa, and continues southeastward very near the old wagon road between the forks of Blue Creek and Madeira. Displacement on the fault plane was nearly vertical and amounted to several thousand feet, so that the comparatively soft sandstone and shale of Cretaceous age were brought into direct contact with the pre-Cambrian complex.

Erosion in these readily yielding sedimentary strata has progressed at much more rapid rate than was possible in the resistant pre-Cambrian crystalline rock. The Uncompahgre River, a stream much smaller than the Gunnison, has not only cut its channel to a depth more than 1,000 feet below the bottom of the Black Canyon but at Montrose has developed a wide, late-mature valley. Even so small a stream as Cedar Creek, which for part of its course runs parallel to the Gunnison at a distance of only a few miles, has been able to lower its channel several hundred feet below the bottom of the Black Canyon. This has made possible the success of the irrigation project which centers about the Gunnison tunnel. The intake of this tunnel is at the level of the canyon floor. The outlet, 6 miles distant, in the valley of Cedar Creek, is many feet lower. Thus a part of the water of the Gunnison is diverted and flows through this tunnel to the lower level of the adjacent valley, where it is distributed over hundreds of square miles of fertile farm lands.

The situation of the Black Canyon near the upper edge of the tilted fault block, where the Gunnison River flows for many miles within a few thousand yards of soft strata, is anomalous. The history of the Gunnison River necessary to explain its present peculiarities involves a combination of fortuitous circumstances that began far back in the Tertiary period and have continued almost to the present day.

Presumably the first and certainly the greatest movement on the Cimarron fault took place at or near the end of the Mesozoic era. This movement elevated the block extending northward from the fault plane so that the pre-Cambrian basement was lifted to the same height as the Cretaceous strata to the south. Subsequent erosion stripped the entire sedimentary cover from the pre-Cambrian rocks, cut downward an unknown distance into them, and developed an old-age topographic surface, the prevolcanic peneplain. Upon this surface during Tertiary time a great thickness of volcanic agglomerate, tuff, and flows accumulated. These deposits buried alike the resistant crystalline rocks and the soft sedimentary rocks on opposite sides of the fault.

With the dissipation of volcanic energy, stream erosion once more became the dominant force in the San Juan region. The huge volcanic pile was vigorously attacked by countless rivers and creeks. Near the end of Tertiary time the sculpturing of this region had produced a topography characteristic of late old age in the normal cycle of erosion. On the surface thus formed, the San Juan peneplain, the course of the Gunnison River was fixed. The ancestral stream was flowing practically everywhere upon and through volcanic materials. Its channel was strewn with gravel, some of which has been preserved on Fitzpatrick Mesa, Carpenter Ridge, and Black Mesa, at localities indicated on Plate 2.

Not long before the beginning of Pleistocene time the San Juan peneplain was generally uplifted and gently warped. The Gunnison, like the other streams in the San Juan region, was thus rejuvenated and began to incise its channel into the peneplain. In places, as near Vernal Mesa, the veneer of volcanic rock above the pre-Cambrian base was only a few score feet in thickness. Here the Gunnison channel was quickly cut down to the crystalline floor. At a distance of only 2 to 5 miles to the south there were, beneath the same volcanic veneer, the soft Cretaceous strata on the downthrown side of the Gunnison fault. There a valley thousands of feet deep could have been cut without encountering crystalline rocks. At only slightly greater distances to the north there were present beneath the same volcanic veneer similar soft rocks, which would likewise have afforded an easy road for the Gunnison River. The shallow gulch already cut beneath the peneplain surface, however, was sufficient to determine the future course of the Gunnison. Superimposed thus upon the pre-Cambrian ridge the stream was destined to maintain its course in this most unfavorable situation. In this way was fixed the position of the Black Canyon, in the hardest rocks to be found anywhere in this part of the State and within a few miles of the softest rocks. Down cutting along this superimposed pathway soon uncovered the pre-Cambrian complex from the vicinity of Curecanti downstream to a point far beyond the tunnel inlet. A valley of mature outline was rather quickly carved in the overlying volcanic materials, and the long, arduous task of cutting a gorge into the pre-Cambrian crystalline rocks was begun.

The next recorded episode in the history of the Black Canyon deals with the influence of glaciation upon the stream during the Cerro glacial stage. Deposits of till, referred to that stage, cap the summit of Vernal Mesa and lie along the margin of Bostwick Park. No glacial materials have been found on Black Mesa, directly across the canyon from Vernal Mesa. Apparently the Cerro ice approached the Black Canyon from the south, pushed across the low divide northeast of Cerro Summit, which then marked the southeast margin of Vernal Mesa, and moved down the gently sloping surface, in part now preserved as the mesa summit, reaching nearly or quite to the bottom of the broad valley, presumably with its inner shallow gorge which had developed by that time. If the ice had reached the Gunnison River itself and formed a barrier across the channel, alluviation would inevitably have occurred upstream. It is altogether possible, although it can not be stated with certainty, that the stream terraces now preserved high on the slopes of Black Mesa, Sapinero Mesa, Pine Creek Mesa, Carpenter Ridge, and elsewhere, which are capped with the earlier gravel, are a result of this hypothetical glacial dam. These terrace remnants are high on the valley walls above the rim of the inner gorge. If they are due to the glacial barrier they mark the depth attained in downward cutting at Cerro time. Whether or not this hypothesis concerning the earlier and higher gravel is correct, it seems certain from other considerations that the formation of the Black Canyon had scarcely begun at the time of the Cerro glaciation. The modern canyons of all the streams in the region south of the Black Canyon, including those tributary to the Gunnison, are of post-Cerro development. The walls of the Black Canyon adjacent to the Vernal Mesa show no signs of glaciation. The Cerro till is found on the mesa slope at the very brink of the gorge, but nowhere is there a glaciated surface within the gorge.

The melting of the Cerro ice was followed by the resumption of normal stream erosion. In the soft formations south of the Cimarron fault numerous streams, which eventually were tributaries to the Gunnison, reduced their channels to the base-level which at that time determined stream gradients and by lateral planation developed the graded surfaces of the Florida cycle. The coarser materials of the Cerro till were in part reworked by these streams, and a veneer of boulders and gravel thus chiefly derived was spread over many of these graded slopes. In the vicinity of the Black Canyon portions of this Florida gravel deposit now remain on the floor of Cedar Park, a broad valley at an altitude of about 7,200 feet, south of Cedar Creek station. Bostwick Park, a broad, gently sloping upland valley just north of the Montrose quadrangle, dates back to the same erosion cycle. The Gunnison River, however, was constantly occupied with the slow task of downward cutting. So great was the handicap imposed upon it by the resistant pre-Cambrian rocks that it never caught up with its own tributaries and was unable to begin the development of an alluvial flat by lateral planation. Upstream from the Black Canyon, where the Gunnison River was then working entirely in volcanic rocks, conditions were of course quite different, and there the Gunnison, like its neighbors, developed a broad, late-mature valley. A possible alternative explanation of the higher gravel referred to in a preceding paragraph is that it indicates the present situation of the floor of this valley formed during the Florida cycle.

The Florida cycle of erosion was abruptly terminated by a renewal of the regional uplift with the accompaniment of crustal warping. The great fault block of pre-Cambrian rock with its veneer of sedimentary and volcanic rocks was tilted upward along its southwest border. Vertical movement along the Cimarron fault plane was at this time at a maximum in the vicinity of Vernal Mesa, where it amounted to about 500 feet. The downward cutting of the Gunnison River in the Black Canyon kept pace with the upward tilting, which presumably was therefore accomplished by a long succession of small movements. The Gunnison, in spite of the fact that it is a superimposed river, is antecedent to the latest of the crustal disturbances that have modified this region.

The post-Cerro renewal of displacement on the Cimarron fault plane is indicated by many facts. The southwest margin of Vernal Mesa is a sheer cliff of such recency that its face is practically unscarred by the wear of streams. Nowhere upon it is there any sign of ice sculpturing. It seems beyond the bounds of possibility that the ice could have climbed this scarp without leaving a plain record of its ascent. To-day there is a complete gap between the Cerro till at the south of this cliff and the similar till that covers the mesa to the very brink of the scarp. These conditions are easily explained if at the time of the advance of the Cerro ice Vernal Mesa was relatively 500 feet lower than to-day. They are almost inexplicable in any other way.

That the latest crustal warping with its renewed uplift of the south margin of the great fault block was of postvolcanic date is indicated by the strong northward dip of the "rim rock" lava sheet, which caps most of the mesas on both sides of the Gunnison. The date of this movement is pushed forward still more by the fact that tilting north of the Cimarron fault has also deformed the peneplain which had been cut in the volcanic masses. The peneplain gravel on Fitzpatrick Mesa, within 2 miles of the fault scarp, is 9,200 feet above sea level. That on Black Mesa, 2 miles farther to the northeast, is between 9,000 and 9,100 feet; that on Carpenter Ridge, 10 miles to the east and 6 miles north of the Cimarron fault, is only 8,900 feet above sea level. Either the gravel was deposited by an eastward-flowing stream, an alternative which is out of the question, or else the valley flat of the westward-flowing stream, the ancestral Gunnison, along which it was laid down, has been gently warped since the end of the Peneplain cycle.

Furthermore, the present altitude of the restored surface upon which the higher gravel of the Gunnison rests indicates deformation such as that occasioned by the renewed displacement on the Cimarron fault at a time subsequent to the deposition of that gravel. The gravel in the main valley of the Gunnison near Curecanti is at an altitude of 8,600 feet. Upstream the successive remnants are at progressively lower altitudes, until at a distance of 5 miles above Curecanti the gravel is only 8,200 feet above sea level. Similarly, the correlative gravel capping the stream terraces in the valley of Curecanti Creek displays a slight downward slope upstream from the mouth of that valley. The present gradient of the terrace, restored by projecting a plane from one remnant to another, is about 50 feet to the mile in a direction at right angles to the Cimarron fault and declines up the valley toward the north; this again is in harmony with a post-Cerro date for the last displacement along this fault.

While the Gunnison River was incising the Black Canyon in the slowly rising surface of the pre-Cambrian block, the numerous tributary streams to the north and south were rapidly removing the softer rocks encountered there. Beneath the thin veneer of volcanic rocks, which could be removed with comparative ease, these tributaries found a great thickness of soft shale and thin-bedded sandstone. In consequence, broad valleys were developed there, and the land was cut away, so that to-day the surface only a few miles to the north and to the south of the canyon is lower than the bottom of the gorge itself. Veritably, the Black Canyon is cut along the top of a ridge.

These conditions necessitated a certain amount of stream adjustment. Doubtless in the future still more adjustment of the drainage to the underlying structure will take place. During the Florida cycle of erosion Bostwick Park was drained by a stream that rose in sec. 10, T. 48 N., R. 8 W., 3½ miles south of Lujane, near the north margin of the Montrose quadrangle. This river flowed in a general northerly direction, traversing Cedar Park and the entire length of Bostwick Park, to its junction with the Gunnison near the northwest end of the Black Canyon. For the last 2 or 3 miles this course was in a resistant pre-Cambrian complex; the remainder lay in comparatively soft sedimentary rocks. Downward cutting in the upper part of this tributary valley was almost prohibited by the slowness with which the stream could lower its mouth. At the same time Cedar Creek, a tributary of the Uncompahgre, was rapidly incising its valley in the soft shale to a depth even below the floor of the Black Canyon itself and by headward erosion was extending its gulch eastward across the path of the unfortunate stream in Bostwick Park. The resulting piracy decapitated the northward-flowing stream and separated Cedar Park from Bostwick Park.

Similar piracy resulted in the formation of the wind gaps that border Vernal Mesa on the east and Fitzpatrick Mesa on the west. The pirate in this case was Cimarron Creek and its tributaries. Probably the wind gap beside Fitzpatrick Mesa was formerly the lower course of Little Cimarron Creek. The main Cimarron was able to cut its channel downward near its mouth, where only a mile of pre-Cambrian rock intervened between the fault plane and the Gunnison River, at a rate which permitted it to keep pace with the Gunnison. Little Cimarron Creek was not only smaller and therefore less powerful but it had 3 miles of pre-Cambrian rocks to traverse. The handicap proved too great, and the water of Little Cimarron

Creek was diverted by the more favorably situated stream.

LAKES

The countless small bodies of water that are present in all parts of the San Juan region are not the least among the charming scenic features of these mountains. Most of them are small, averaging much less than a square mile in area, but a few are of considerable size. They occur in a great variety of topographic situations—on the surfaces of upland plateaus, on the floors of deep mountain canyons, and in undulating lowlands. They are likewise the result of various natural forces. The great majority are, of course, the result of glaciation, many others have come into existence because of landslides, and some are the consequence of crustal movement. A few have resulted from irregular deposition of alluvium on flood plains or at the mouths of tributary streams. Only a few of the more interesting lakes will be described here.

Lake San Cristobal.—One of the most accessible of the larger lakes in the San Juan region is that which occupies the valley of the Lake Fork of the Gunnison River, 3 miles south of Lake City, in the San Cristobal quadrangle. Lake San Cristobal is a beautiful body of water 2 miles long and somewhat less than a mile wide, from the shores of which the steep walls of the Lake Fork Canyon rise abruptly to great heights. (See pl. 17, *B.*) At the southern or upper end of the lake is a great reed-covered shallow expanse, where the Lake Fork has built a delta that will eventually extend until the lake becomes but a memory. At the north end of the lake the waves dash against the outer margin of the Slumgullion mud flow. Here, too, a delta, the sublacustrine continuation of a gracefully sloping torrential fan, is being built by the small stream descending Slumgullion Gulch. (See pl. 32, *A.*) The outlet of the lake at this end is close against the west wall of the valley. Here a small cascade, 40 feet in height, is formed where the outflowing water plunges into a tiny chasm which it has carved in the volcanic strata there exposed.

The lake is obviously due to the Slumgullion mud flow. This great mass of soft material, which in comparatively recent time swept down Slumgullion Gulch and poured lavalike into the Lake Fork Canyon, formed a dam completely across that canyon. The Lake Fork, stopped in its onward flow toward the Gunnison River, backed up against the dam until the water overtopped the natural spillway between the west wall of the valley and the mud flow. The level of this outlet determines the level of Lake San Cristobal. It is not now possible to prophesy which of the two contestants will win in their race to annihilate the lake—the receding falls at the head of the tiny chasm just referred to, or the spreading delta, gradually creeping northward from the upper end of the lake.

Santa Maria Lake.—In a long, narrow trough just west of Bristol Head, 4 miles northwest of Antelope Spring, near the eastern margin of the San Cristobal quadrangle, lies Santa Maria Lake. (See pl. 18. *A.*) The nearly parallel walls of the Santa Maria trough rise steeply from each side and give the depression the appearance of a rift valley. On the northeast the remarkable façade of Bristol Head rises over 3,000 feet above the lake level. To the southwest the wall of the valley is equally steep but rises only 800 feet above the average level of the lake. Northwest of the lake a thin mass of glacial drift, referred to the Durango glacial stage, rests upon the rock floor of the valley. Southeast of the lake vast quantities of débris have fallen from the cliff immediately below Bristol Head and have partly filled the depression. The landslide mass at this locality is fully 1 mile wide and 500 feet thick, extending for a distance of nearly 2 miles along the axis of the trough. It is to this landslide dam across the trough that the lake is due.

Normally Santa Maria Lake had no outlet. The run-off from only a small area entered the lake basin, and excess water seems to have seeped through the landslide barrier to issue at the surface as Antelope Spring. Within the last few years, however, an attempt has been made to use the Santa Maria depression as a storage reservoir to equalize the flow of the Rio Grande for the benefit of the irrigated farms in San Luis Valley. A concrete dam was built across the lowest sag in the rim of the basin a short distance northwest of the lake. The water of Clear Creek and several other small streams was led through an aqueduct into the basin. The consequent rise in the level of Santa Maria Lake made demands upon the landslide barrier forming its southeast rim which the loose débris of that barrier could not meet. The problem of preventing excessive seepage through the landslide mass has been very difficult to solve. It has been discussed elsewhere.[2]

Lost Lakes.—The Lost Lakes are two small bodies of water occupying rock basins on the surface of a high bench at the north side of the Rio Grande Canyon 3 miles west of the center of the San Cristobal quadrangle. The bench surrounding the lakes is occupied by many rock hills and ridges, the smooth surfaces of which display the effects of the ice that during the Wisconsin stage moved across this upland. The lakes are well stocked with trout and are a favorite resort of sportsmen from Creede and the cities of San Luis Valley. On the densely timbered slopes surrounding the lakes there is much wild game, so

[2] Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colorado: U. S. Geol. Survey Bull. 685, pp. 23–26, 1918.

that the spot is almost ideal for the fisherman or hunter. The lake basins are due to the irregular gouging characteristic of glacial erosion. The escarpment that borders them on the west and the cliff half a mile to the southeast appear to be largely the result of plucking by the ice, influenced in some degree by joint planes in the rock. Both these escarpments are approximately at right angles to the direction of ice movement.

Flint Lakes.—Similar small bodies of water occupying glacially eroded rock basins are common in the strongly glaciated area at the head of the Flint Fork of the Los Pinos River, in the southwest quarter of the San Cristobal quadrangle. This is a strongly glaciated area of unusually wild aspect. Many of the lakes which it includes are on the floors of glacial cirques. Others are at some distance down the glaciated canyons. Still others dot the surface of the irregular upland.

Emerald Lakes.—Two bodies of water, one large and one small, occupy the floor of the canyon of the Lake Fork of the Los Pinos River, midway of its length. Densely wooded slopes rise steeply from the shores of each lake to heights of 2,500 feet. These towering walls of dark-green spruce trees are reflected in the quiet water of the lakes and make their name singularly appropriate. The trail up the Los Pinos River and thence up the Lake Fork Canyon is long but not exceedingly difficult. The lakes, well stocked with fish and surrounded by forests abounding in game, afford ideal localities for a summer camp.

These lakes are the result of landslide barriers, which clog the canyon south of the lake. Huge masses of broken rock have slipped from the walls and are now piled in great disarray to a height of 300 feet or more upon the canyon floor.

Lake Como.—Among the many lakes on the floors of the glacial cirques in the Silverton quadrangle, Lake Como is one of the most beautiful. It occupies a glacially eroded rock basin at the head of Poughkeepsie Gulch, near the center of the north half of the quadrangle. It is bordered on three sides by steep walls of rock, and because of its great altitude and shaded position ice remains upon its surface even in midsummer near the shore, while farther out the quiet water, as blue as turquoise, reflects the mountain walls with their lingering patches of snow.

Trout Lake.—Trout Lake is situated a few miles south of the center of the Telluride quadrangle, on the floor of a broad mature valley. Its eastern and northern shores are skirted by the Rio Grande Southern Railroad, and its outlet has been artificially closed by the construction of a huge dam of log cribbing. The lake basin is surrounded by glacial drift; it is due to the irregular deposition of the moraine. The till rises 600 or 700 feet above the lake on the south and southeast sides but is not so high on the north and west sides, although on the north there is a poorly defined recessional moraine, which projects nearly across the valley floor.

Lake Eileen.—Lake Eileen is a small elongate body of water high on the west wall of the Vallecito Canyon, near the northeast corner of the Ignacio quadrangle. The lake is shallow and almost completely surrounded by a narrow strip of marsh land. At times its surface is almost concealed beneath water lilies, which grow in great profusion. On the west the bare rock walls of the canyon rise steeply more than 2,000 feet above the lake. On the other three sides there is an irregular moraine ridge, which rises abruptly from the lake. The depression partly filled by Lake Eileen lies between the lateral moraine and the rock walls of the canyon.

Crystal Lake.—Several small bodies of water in the San Juan region have gathered in irregular depressions on the surface of a landslide. Most of the landslide lakes in this mountain region result from the damming of a valley by fallen débris, but some, like Crystal Lake, Waterdog Lake, and Swanson Lake, are bodies of water in basins formed entirely of landslide materials. An area of fully 3 square miles east of Crystal Peak, 3 miles northwest of Lake City, in the southwest quarter of the Uncompahgre quadrangle, is mantled with a most confused mass of fallen débris. The irregular distribution of the heaps of angular material that have slipped down from the face of the peak has made many basins, in the largest of which the waters of Crystal Lake are gathered.

Devils Lake.—High on the surface of the Cannibal Plateau, in the southeast quarter of the Uncompahgre quadrangle, there is a lake known as Devils Lake. Its altitude of 11,968 feet might suggest that it is the result of glacial erosion or deposition, but examination reveals no indications whatever of the former presence of ice in this locality, nor do the few small landslides in the neighborhood explain the lake basin. Rock in place borders the lake on all sides. Toward the northeast there is a remarkably even cliff which rises wall-like 500 feet above the lake level and extends for 3 miles in a straight line trending northwest. On the other three sides the bare plateau surface rises gradually to much lesser heights. The cliff is apparently a fault scarp of recent date, and it is probable that the lake basin on the downthrown side of this fault is due entirely to crustal movement.

Russell Lakes.—In the northeast quarter of the Del Norte quadrangle there are several shallow bodies of water known as the Russell Lakes. In every respect these are in striking contrast to the lakes just described. They are on the surface of a semiarid lowland far beyond the mountain front. The larger ones are bordered on the east by narrow strips of sand dunes. The dunes and sand ridges rise 10 to 15 feet above the water level and support a scanty growth of desert vegetation. The level of the lakes fluctuates with the seasons. At one time there may be a beach 20 feet or more in width between the water and the sand dunes; at another time the waves may cut directly into the sides of the dunes. The lakes and adjacent marshy areas are at times the resting place of thousands of water fowl, which flock to them in great numbers in spite of the proximity of the well-traveled Gunbarrel Road. The location of the dunes upon the eastern shores of the lakes is doubtless the result of the prevailing westerly winds. The waves and currents of the shallow water bodies transport the sand, which when dry is picked from the beach by the wind. As there are no dunes west of the lakes, it seems more probable that the lakes have caused the dunes than that the dunes have caused the lakes. The basins may be due to wind erosion but are more probably the result of the irregular accumulation of sand and gravel upon the coalescing alluvial fans that extend out from the mountain front.

LOWLAND PARKS AND BASINS

At many places on the floors of the larger canyons in the San Juan Mountains there are broad alluvial flats, which, if small, and especially if they are treeless grasslands in the midst of the forests, are generally known as parks. If they are of considerable size and surrounded by high ridges they are more commonly called basins. Most of the lowland parks and basins are indirectly the result of glaciation. Many of them are the flat alluvial floors of temporary lakes that have been either filled or drained since the retreat of the ice. Still others are connected with landslides in a similar way.

Blanco Basin.—The broad alluvial flat, rimmed with high mountains, known as Blanco Basin, near the center of the Summitville quadrangle, is typical of a dozen similar lowland basins in the peripheral region around the San Juan Mountains. The basin occupies the floor of a strongly glaciated canyon, from which the ice has removed all loose débris while deepening and widening the stream-carved depression. At the lower end of the basin, just at the margin of the mountains, the ice deposited a great terminal moraine that formed a barrier across the valley. Upstream from this terminal moraine there was doubtless for some time a considerable lake. Into this lake the Rio Blanco and its main tributaries quickly swept great masses of alluvium. This was in part distributed broadcast over the lake floor and in part deposited as deltas at the mouth of the streams. At the same time the overflowing waters from the lake were cutting through the yielding glacial débris at the outlet. Thus by a combination of draining and filling the lake was doomed to disappear. Its abandoned floor, formed of the richest and most fertile material, is to-day ideal farm land. Thus Blanco Basin is a region of great productiveness; it is set like an oasis in the midst of a wilderness of slopes and peaks and canyons.

Other basins, identical in origin with Blanco Basin, include one in the Navajo Valley, another in the valley of the West Fork of the San Juan River, one near Weminuche Pass, the Vallecito Basin, the Animas Valley above Animas, the Uncompahgre Valley between Portland and Ridgway, and the Rio Grande Valley between the mouth of Trout Creek and Ingalls Gulch.

Hermosa Park.—The grassy lowland in the midst of the irregular hills at the junction of the East and North Forks of Hermosa Creek, known as Hermosa Park, is due to causes similar to those just mentioned. The park is floored with comparatively smooth-surfaced glacial drift deposited near the terminus of the valley dependency from the Animas Glacier which pushed westward across the divide at Old Tollgate and extended the full length of the East Fork Valley. Small areas in the park consist of alluvium which has filled the depressions on the moraine or has been deposited along the stream flat of the East Fork or North Fork.

Royal Park.—The broad alluvial flat on the floor of the valley of the South Fork of Carnero Creek, in the northeast corner of the Creede quadrangle, is known as Royal Park. Immediately downstream from it the South Fork cuts across an intrusive mass of diorite, which offers much more resistance to the forces of erosion than the tuffs and breccias of this part of the mountains. The delay in downward erosion occasioned by the intrusive rock has permitted the broadening of the valley upstream. Royal Park is therefore an expression of the differential resistance to erosion of the strata in its vicinity.

Bear Park.—The small grassy alluvial flat occupied by the decaying cabins of the abandoned mining camp at Beartown, near the northeast corner of the Needle Mountains quadrangle, is due to the blocking of Bear Creek by a small landslide precipitated into the canyon from its northwest wall. The lake once present above the landslide dam has long since been filled with alluvium from the swift-flowing mountain streams. Bear Park is the floor of this vanished lake.

Florida Parks.—In the Florida Canyon near its head, in the south half of the Needle Mountains quadrangle, there are two alluvial flats, each about a mile in length, known as Upper Park and Lower Park. Each was the site of a rock basin gouged in the canyon floor by the Florida glacier. The lakes which for a time occupied these basins have been filled with alluvium brought in by the tributary streams. More recently each park has been transformed into a reservoir by the construction of low earth and log dams across its lower end.

UNUSUAL FEATURES DUE TO WEATHERING

Radiating hogbacks north of Del Norte.—The 8,891-foot hill 7 miles north of Del Norte is the center of an area of intrusive rocks, which probably represent the throat and conduits of an ancient volcano. The hill is composed of much-altered diorite, and from it there radiate a score or more of dikes. The longer dikes are about 4 miles in length. Most of them stand above their surroundings as narrow, sharp-crested ridges, because of the superior resistance to weathering offered by the harder rocks of which they are composed.

Spheroidal weathering of Potosi latite.—One of the Potosi lava flows that crops out in the banks of Dry Creek and Raton Creek, near the middle of the south margin of the Del Norte quadrangle, displays spheroidal and columnar weathering in an unusually marked degree. The boulders resulting from spheroidal weathering closely simulate the products of glacial or stream action but are evidently the effects of weathering alone. In the production of the weathered columns and boulders the joints of the lava have played an important part.

Palisades of Bennett Creek.—The northeast face of the mountain that rises to a height of a little more than 11,200 feet between Poison Gulch and Bennett Creek, in the southwest corner of the Del Norte quadrangle, is capped by a massive lava sheet approximating 300 feet in thickness, in which vertical joints are closely spaced. The erosion of the Bennett Creek Canyon has developed from these joints the palisades that form the face of the rim rock at this place.

Cathedral Rock.—In the valley of Spring Creek just east of the southeast corner of the Uncompahgre quadrangle there is a striking example of fantastic weathering known as Cathedral Rock. It is carved in the light-brown tuffaceous material of that area. Near the base of the rock the horizontal bedding of the tuff is distinct, but above these beds huge columns and slender pinnacles rise with nearly vertical faces to heights of at least 200 feet. Towers and minarets rival one another in slenderness and height and together make a most picturesque display.

Wheeler National Monument.—About 20 miles east of Creede, at an altitude of 11,500 feet, on the south side of the San Luis Peaks, there is an area in which strikingly fantastic features abound. A tract of 300 acres in the midst of this area constitutes a national monument, named in honor of Gen. George M. Wheeler, one of the early explorers of the West. The rock at this locality is a moderately coarse volcanic tuff consisting of imperfectly stratified beds of fragmental débris which was blown into the air from volcanic vents and settled at this place. Individual particles in any bed may range from dust flakes to blocks 2 or 3 feet across. They have not been cemented together or firmly compacted, and the beds therefore crumble readily before the onslaught of rain and wind. For the most part the tuff is light gray or chalky white, although some of the larger fragments of lava have a distinctly pinkish hue.

As the rains have fallen upon this easily eroded material, the water has carried away much of the finer débris. Larger blocks have remained as capstones for sharp spires or pinnacles, which stand alone when the surrounding unprotected material has been washed away. Slight differences in texture or in amount of compacting result in the development of hoodoolike forms. Vertical joint cracks weaken the beds at more or less regular intervals, and hooded "ghosts" appear in ordered ranks, as shown in Plate 7, *B*, startlingly white against the green background of the forest.

As time passes the wind and the rain, assisted by changes in temperature and by frost action, will complete the disintegration of this rock material and carry it away. It is a pretty example of a landscape that is passing through a very interesting history. It is now at its prime and has developed a maximum of fantastic features. In the future the existing spires and pinnacles will crumble away, and ultimately this area will be reduced to one of the softened contour characteristic of old worn-down mountains. It was not so beautiful yesterday, and the beauty will be gone to-morrow.

Chimney Rock.—About 18 miles southwest of Pagosa Springs, just south of the main automobile highway from Pagosa Springs to Durango, there is a very conspicuous "chimney" that rises fully 1,000 feet above the roadway. This rock stands upon a remnant of Mancos shale and is itself composed of Mesaverde sandstone. The true "chimney" portion rises about 150 feet above the ridge. It is of light-yellow or buff color, with streaks of brown where particles of iron have been oxidized as ground waters have seeped into the fissures of this huge pillar. It is indeed a spectacular feature and probably insurmountable. Its walls are in places vertical and in some parts even overhanging.

The "chimney" is at the east end of a narrow mesa, and to the west there are other remnants of Mesaverde sandstone that rise as a comb of regular pinnaclelike forms. Beyond these knife-edge ridges the narrow mesa top is of unusual interest, because on it there are ruins of prehistoric homes that presumably date back to about the same period as the ancient ruins on the Mesa Verde. There are no true cliff dwellings about this ridge, but a few families evidently chose this somewhat high and isolated though tiny tableland for the site of a little village.

In a physiographic sense Chimney Rock represents a very late stage in the disintegration and decay of the flat-topped mesas common on the south and southwest sides of the San Juan Mountains. While sandstone of the Mesaverde formation remains as a preserving cap these mesas retain their flat tops, but when the sandstone gives way and is removed they soon lose their tablelike form. Here there remains but little of the former cap of sandstone; that which remains is reduced to pinnacles or "chimneys." The "chimneys" are all in the process of decay, and little by little, owing to changes in temperature, frost action, wind and rain work, they will disintegrate and crumble away or fall as blocks down the slope.

Features resulting from weathering of granitic rocks that form the core of the range are illustrated by Plate 19, *A*.

OUTLYING DOMES

Beyond the southwest front of the San Juan Mountains a number of isolated mountain groups rise high above the general plateau level in Colorado, Utah, Arizona, and New Mexico. From the western San Juan summits may be seen the La Plata, Rico, El Late, Carriso, Abajo, and La Sal Mountains and in the far distance the Henry Mountains, all of analogous origin and physiography. With many of these mountain groups physiographers are familiar by virtue of the matchless sketches of W. H. Holmes, presented in the reports of the Hayden Survey, and the classical descriptions of G. K. Gilbert and Whitman Cross. Two of these local mountain groups are so close to the San Juan Mountains that they must be considered in any comprehensive study of the San Juan area. These are the La Plata Mountains and the Rico Mountains. The others are situated at a considerable distance from the San Juan region and have been subjected to only cursory examination by us. They belong to the plateau province rather than to the mountain area.

Rico Mountains.—The Rico Mountains are separated from the western front of the San Juan by a maturely dissected region less than 10 miles in width. They occupy the northeast corner of the Rico quadrangle and the adjacent northwest portion of the Engineer Mountain quadrangle. They include a dozen peaks compactly grouped together within an oval area about 7 miles in diameter from east to west and 5 miles from north to south. This circle of high and rugged summits is divided by the deep canyon of the East Dolores River into two crescent-shaped halves. The higher summits are about 12,000 feet in altitude, and the sharply serrate divide on each side of the East Dolores Canyon within the mountain group nearly everywhere reaches at least 11,000 feet.

The Rico summits, rising well above timber line, are in general rounded heights rather than pinnacled peaks. In places, as on the slopes of Blackhawk Peak and Anchor Mountain, cliffs overlook the floors of glaciated amphitheaters sculptured on the mountain sides, but rarely is the topography so rugged as that of the San Juan Mountains, a few miles farther east. Tributary streams, a few of which are of great length, trench the walls of the East Dolores Canyon and separate the Rico summits by steep-walled gulches. The general appearance of the land forms in the Rico Mountains is illustrated in Plate 18, *B*. The outer slopes of the mountains descend steeply to the general level of the surrounding plateau, which toward the east is less than 9,000 feet above the sea, although between the Rico and San Juan Mountains the plateau summit rarely falls below 11,000 feet. In close proximity to the Rico Mountains this plateau is maturely dissected by the canyons of many streams.

In general the streams of the Rico Mountain region radiate from the center of the dome. The East Dolores River, however, is an exception to this rule; it rises at a considerable distance northeast of the mountains and flows directly through them, bisecting them as mentioned above.

The oval plan and domelike profile of the mountain group are in harmony with its geologic constitution.[3] The mountains were formed by the erosion of a huge dome, which resulted from the intrusion of great masses of molten lava that congealed into the numerous sills, sheets, dikes, and stocks of the region. These intrusions and the accompanying crustal disturbances lifted the strata to a height at least 4,000 feet above their position in the surrounding plateau, a position which they would likewise now have in the vicinity of Rico had they remained undisturbed. Streams immediately attacked this huge dome, stripped from it whatever cover of Tertiary rocks it may have had, and cut deep into the Cretaceous and older formations that now crop out in and near the mountains.

Data concerning the relation of the Rico Mountains to the San Juan peneplain are not as complete as might be desired. It is probable, however, that certain of the rounded summits in the Rico group represent low hills that once stood a few feet above the peneplain as scarcely perceptible monadnocks. Other upland surfaces close to the Rico Mountains are best explained on the assumption that they are remnants of the peneplain itself. (See pl. 2.) Thus it would appear that subsequent to the deformation of the Rico dome the entire uplifted area was reduced by stream erosion approximately to base-level. Late in Tertiary time the Rico region was therefore an undulating lowland, with scattered hills or knolls projecting slightly

[3] Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 7–165, 1900. Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

above its flat surface. On this plain the course of the East Dolores River was determined with little reference to the nature of the underlying rocks.

The general rejuvenation of the San Juan streams, resulting from the regional uplift that ended the Peneplain cycle of erosion, affected the drainage in the Rico locality in the same way as elsewhere. Apparently there was a slight renewal of the local domal uplift centering at Rico at this time. This movment, however, was so slight and so slow that the East Dolores River was able to maintain its ancestral course and lowered its channel with sufficient rapidity to keep pace with the uplift. As it cut downward the stream was later superimposed upon the strongly resistant Paleozoic formations and Tertiary intrusive rocks now exposed in its valley.

La Plata Mountains.—The La Plata Mountains form a compact group of high peaks in the La Plata quadrangle and the adjacent portion of the Ignacio quadrangle, 20 miles southwest of the San Juan mountain front. They have been adequately described by Cross and Spencer,[4] and only a summary is presented herewith.

Many of the summits of the La Plata Mountains rise more than 12,000 feet above sea level, and the highest, Hesperus Peak, reaches an altitude of 13,225 feet. All the principal summits lie within a circle 9 miles in diameter, the center of which is situated in the La Plata Valley near the mouth of Tirbircio Creek. The lesser summits and outlying ridges are within an oval area 12 to 15 miles in its longer diameter. As many of the peaks rise 1,000 feet or more above timber line and are carved from hard rocks, they have the characteristic rugged form, modified by talus slopes, common at this altitude throughout the western Cordillera. They are nearly all situated upon narrow divides on both sides of the La Plata River. In a few places surrounding the circle of inner peaks the slopes descending toward the plateaus are interrupted by lesser summits, due to large masses of igneous rock extending beyond the usual line of their prominent occurrence. Of these Helmet Peak and The Hogback are the main ones on the west. On the north, Sharkstooth is the only one of note; Bald Knob has a similar situation on the east, and on the south there are no outliers.

Appropriate to the domal form of the La Plata Mountains many of the minor streams have a general radiate arrangement. The La Plata River heads close to the north margin of the mountains and flows southward directly across their center, bisecting them into two approximately equal parts. The heads of this river and its many tributaries have vigorously eroded the mountain slopes looking inward toward the center of the group. At the same time tributaries to the Animas on the east, to the Mancos on the west, and to the East Dolores on the north are vigorously attacking and deeply gullying the outer slopes of the mountains.

During the glacial stages these streams were reinforced by numerous small glaciers that formed in the higher basins near the summits of the greater peaks. Here there are to-day many rugged amphitheaters and strong glaciated basins, which give to the La Plata Mountains a scenic beauty only less than that of the Needle Mountains, 35 miles to the northeast. Certain of the striking topographic features of the La Plata Mountains are shown in Plate 19, *B*.

The physiographic form and geologic constitution of the La Plata Mountains make clear the fact that this group is the result of the dissection of a dome caused by igneous intrusion and crustal deformation. Late in Tertiary time this locality was the site of the upward flow of huge masses of molten lava, which congealed into the laccoliths, sills, stocks, and dikes now well exposed in the walls of the La Plata Canyon.

With the uplift of the La Plata dome radial streams were developed, which were consequent upon the dip slope produced. These streams rapidly cut their way through the Tertiary cover that presumably was present at that time into the Cretaceous formations. They finally removed completely from the dome whatever Tertiary rocks may have been included in it and eroded from the central region practically all the Cretaceous strata. Thus the lower Mesozoic strata and the resistant intrusive rocks, which are now exposed, were uncovered. Erosion has been so extensive in this part of the San Juan region that data concerning the relation of the La Plata Mountains to the San Juan peneplain, so generally noted for other mountain groups toward the east, are not as complete as might be desired. Certain tentative conclusions, however, are justified. In the gravel on peneplain remnants far to the southwest there are pebbles of porphyry which must have come from the intrusive bodies of the La Plata Mountains. The uncovering of these intrusive bodies must, therefore, have been accomplished during the Peneplain cycle of erosion. Doubtless at the end of that cycle the La Plata Mountains stood as comparatively rugged monadnocks several hundred feet above the peneplain level. From these hills the radiating streams carried the gravel there obtained and spread it broadcast over the lowland to the south and west.

The pause in the downward cutting of the La Plata dome, occasioned by the close approach of its streams to the base-level of the Peneplain erosion cycle, permitted the La Plata River to gain the ascendancy over its neighboring rivals. By headward erosion it cut its channel backward almost through the circle of peaks

[4] Cross, Whitman, and Spencer, A. C., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

to their northern margin. This longer course favored the La Plata River throughout its subsequent history, and the dominant position then gained has been held to the present day.

The regional uplift that ended the Peneplain cycle of erosion rejuvenated the streams in the La Plata group as elsewhere throughout the region and accelerated their work of mountain dissection, so that they have gradually reduced their valleys to the present stage. This postpeneplain erosion was complicated by the development of the Florida graded surface, by glaciation, and by several stream adjustments, but the effect of all these events may better be discussed in other parts of this report.

Chapter 6.—PLEISTOCENE GLACIATION

The deposits resulting from and associated with the several episodes of Pleistocene glaciation are described in chapter 7, but in that chapter no attempt is made to describe the glaciers themselves or to direct attention to the effects of glaciation upon the topography of the region. These topics will, therefore, receive special treatment in the present chapter. Here the chronologic order of description is abandoned; instead of starting with the earliest and ending with the latest glaciers, the best-known ice masses, which are, of course, the most recent, will be described first; from these the description will continue to the less well-known and earlier glaciers of the Pleistocene epoch. Plate 3 has been prepared to accompany this chapter and should be referred to frequently by the reader.

WISCONSIN GLACIATION

EXTENT AND NATURE OF GLACIERS

The areas covered by ice during the last or Wisconsin glacial stage are indicated on Plate 3, which shows that a large part of the San Juan region was buried beneath the ice of that stage. Without exception, every major valley leading outward from the heart of the mountains was occupied by ice. Basins on the slopes of each of the higher mountain peaks served as sources for the glaciers. The restoration of those glaciers shown on Plate 3 presents a vivid picture of the conditions that must have prevailed at the climax of the Wisconsin stage and indicates the relatively small amount of ice-free land among the higher mountains at that time.

The ice that affected the San Juan region during the Wisconsin glacial stage was almost all in the form of alpine or valley glaciers. Each ice mass was confined to the valley in which it formed; none of the valley glaciers extended beyond the mountains for any appreciable distance across the surrounding lowlands. In fact, nearly all the glaciers terminated well within the zone of foothills surrounding the range.

At several localities in the mountains ice caps formed over the surface of uplands and buried the divides and peaks. Elsewhere small piedmont glaciers, such as the one on the north slopes of the Mount Wilson group, were formed by the coalescence of the ice from two or more valleys. But in the main the Wisconsin glaciation was distinctly of the valley type.

VALLEY GLACIERS OF THE WISCONSIN STAGE

Animas Glacier.—Among the many large glaciers that occupied the valleys radiating from the central massif of the San Juan Mountains, that which filled the Animas Valley was the largest. At its maximum extent the Animas Glacier had a length of more than 50 miles and an area of about 400 square miles. As shown on Plate 3, 75 catchment basins contributed to it. Approximately two-thirds of the area of the Silverton quadrangle was buried beneath this large glacier. Only the sharp rugged peaks of the mountains surrounding Silverton rose above the ice, and still less of bare rock projected above the great snow banks that must have existed on the ice and neighboring mountain spurs during the Wisconsin stage.

There were four main heads of the Animas Glacier. The easternmost gathered its ice from Eureka, Niagara, Minnie, and Maggie Gulches, each of which in turn received its glacial contribution from numerous catchment basins nestling against the higher slopes of the mountains on both sides of the upper Animas River. Another large ice stream, with its sources in the great cirques near Gladstone, moved southward down the valley of Cement Creek, receiving increments from each tributary gulch on its way, and finally coalesced with the ice from the upper Animas Valley near Silverton. Here also the Animas Glacier was swelled by the addition of much ice moving eastward down the valley of the South Fork of Mineral Creek. This glacial mass had originated in the remarkable cirques of the southeast quarter of the Telluride quadrangle and had been greatly swollen by the ice from Mineral Creek moving southward along the western margin of the Silverton quadrangle. Thus the main Animas Glacier was formed by the union of these several streams not far from the present site of Silverton.

Thence the ice moved in a general southerly direction. So great was its mass, however, that it could not be contained in the Animas Valley itself, but spread over the entire surface of the Molas Lake plateau, in the northwest corner of the Needle Mountains quadrangle. Here also the ice was increased in volume by contributions from the basins at the head of Lime Creek and on the southern and southeastern slopes of Grand Turk. The Continental Divide, in the northeast corner of the Needle Mountains quadrangle, at the head of Elk Creek, was largely buried beneath a small ice cap from which movement must have been outward in all directions. Part of this ice moving down Elk Creek was added to the Animas Glacier. The Grenadier Range and the Needle Mountains were nearly submerged beneath ice fields which filled to overflowing their many basins. Only the upper 500 feet or so of the higher peaks within these ranges stood above the ice and snow fields. Great amphitheaters were filled with ice to depths of 1,000 feet or more, and snow fields buried the divides at many points. Much of the ice thus formed in the central part of the Needle Mountains quadrangle moved westward and added to the volume of the Animas Glacier. Similar conditions were present in the West Needle Mountains and also the northeastward extension of these mountains to Snowdon Peak; these were in reality icesheds (to coin a term analogous to "watersheds"), as glacial masses moved from them in all directions, but all the ice from them was added to the Animas Glacier. Farther west a branch glacier originated in the great basins at the head of Cascade Creek and was swollen by contributions from the cirques on the east slopes of Graysill Mountain and from the one catchment basin on the north side of Engineer Mountain. The ice that had been moving in a southwesterly direction from the Molas Lake region buried the lower flanks of Potato Hill, so that only its uppermost 500 feet stood as a nunatak in the midst of the ice flood.

The divide at the head of the East Fork of Hermosa Creek was overtopped, and a long tongue of ice moved due west down that valley to its terminus near Hermosa Park. The main mass of Animas ice continued in its southward course and carved or scoured the surface of the broad bench between the Hermosa Cliffs and the Animas Canyon. The surface of the ice at many places reached within 500 feet of the crest of the cliffs, but nowhere else than at the head of the East Fork of Hermosa Creek was the barrier surmounted.

Other ice fields were formed on the uplands against the southern summits of Mountain View Crest, in the southwest quarter of the Needle Mountains quadrangle, and contributed to the moving floods of glacial ice in the Animas Valley. Stag Mesa and Lime Mesa were wedges that split these ice masses into narrow streamlike bodies and concentrated their flow in the valleys of Tank and Canyon Creeks. These additions from the east greatly thickened the Animas Glacier along its eastern margin, and doubtless assisted in the erosion of the deep and picturesque Animas Canyon at the east side of the Animas Valley.

After receiving contributions of ice from a multitude of catchment basins in the Silverton, Telluride, Engineer Mountain, and Needle Mountains quadrangles, the Animas Glacier moved southward into the Ignacio quadrangle, having a width of more than 4 miles and a maximum thickness of more than 3,000 feet. In the Ignacio quadrangle there were no additions to the glacier, but so great was the volume of ice derived from the basins nearer the center of the mountains that it buried the prominent rock bench high on the west wall of the Animas Valley. That portion of the glacier which was moving southward along the surface of this bench impinged directly against the northern slope of Animas City Mountain and a part of it was diverted to the southwest, forming a second small tongue of the Animas Glacier. It extended about 2 miles along the trough between Animas City Mountain and the spur projecting southeastward from Sliderock Mountain.

In the 12 miles from Baker Bridge to Animas the Animas River at the present time descends less than 200 feet. The lateral margin of the Animas Glacier, however, descended from an altitude of 8,700 feet at Baker Bridge to only 6,600 feet at its terminus at Animas. Thus the surface gradient of this portion of the glacier was about 175 feet to the mile.

Uncompahgre Glacier.—The Uncompahgre Glacier covered an area of about 100 square miles at its maximum extension and had a length of 22 miles. As shown on Plate 3, forty-seven catchment basins in the Silverton, Telluride, and Montrose quadrangles contributed to it. The most southerly of these basins are in the vicinity of Guston, in the northwest quarter of the Silverton quadrangle. The ice moving northward down Red Mountain Creek received glacial contributions from the basins at the heads of all the gulches tributary to that creek. Other extensive ice fields at the head of the Uncompahgre River in the vicinity of Lake Como combined with ice from the Mineral Point upland and was confluent to that in the valley of Red Mountain Creek. Still other bodies of ice from the catchment basins at the head of Canyon Creek, such as Imogene Basin, Pierson Basin, and the basin in which is situated the Yankee Boy mine, formed the Canyon Creek Glacier, which joined with the main mass of the Uncompahgre ice at the mouth of Canyon Creek. Additional ice fields accumulated in the amphitheaters east of Ouray and at the heads of Cascade and Bear Creeks. Together these swelled the dimensions of the Uncompahgre Glacier until it had a thickness of nearly 3,000 feet above the present site of Ouray. Thence the ice moved northwestward down the broad valley of the Uncompahgre River. Two other tributary glaciers added themselves to this mass of ice a short distance below Ouray, one from the west moving down Corbett Creek, and the other from the east moving down Dexter Creek. Beyond the last of these tributary glaciers the main tongue of the Uncompahgre ice extended 9 miles to its terminus near Dallas. In the 8 miles from Portland to Dallas the Uncompahgre River falls 350 feet. The margin of the Uncompahgre Glacier at Portland stood at an altitude of 8,800 feet; its terminus near Dallas at 7,000 feet. The Uncompahgre Glacier, therefore, had a surface gradient of about 225 feet to the mile.

Rio Grande Glacier.—The Rio Grande Glacier, on the eastern slope of the San Juan Mountains, was even larger than the Uncompahgre Glacier and ranked next in size to the Animas Glacier. Its length was more than 30 miles, and the area covered by it during its period of maximum size was more than 375 square miles. (See pl. 3.) The most westerly of the 56 catchment basins contributory to it were in the southeast corner of the Silverton quadrangle and the northeast corner of the Needle Mountains quadrangle. In those localities the Continental Divide was buried beneath thick masses of ice at many places; only the highest summits, such as Sheep Mountain, Canby Mountain, Greenhalgh Mountain, and Hunchback Mountain, reared their cragged peaks above the snow fields. Here there are few such deep-carved cirques as formed the basins at the heads of the Uncompahgre and Animas Glaciers, but from the mountain slopes and rounded summits the ice moved downward and concentrated along the axes of the larger valleys. Thus the trenches carved by West Fork, Bear Creek, Ute Creek, and other streams served to divert the glaciers into the valley of the Rio Grande. Other catchment basins in the western part of the San Cristobal quadrangle, such as those at the heads of Lost Trail and West Lost Trail Creeks and on the flanks of Rio Grande Pyramid, added their increments to the moving masses of ice. The glacier thus swollen topped the margins of the Rio Grande Valley and buried all but the higher divides.

Impinging against the western flank of the domeshaped mountain north of the Lost Lakes, near the center of San Cristobal quadrangle, the Rio Grande ice was split into two parts. One tongue moved north of this obstacle and crossed the divide near Heart Lake into the head of the valley of Clear Creek, down which it moved as far as Castle Rock Lake. The main body of the ice, far too great in volume to be contained in the Rio Grande Valley, carved its pathway over the plateau on which the Lost Lakes now lie, and, moving onward to the northeast, slipped downward into the narrow, deep, and steep-sided valleys of South Fork, Crooked Creek, House Canyon, and Road Canyon. Toward the north this mass of ice united with the Clear Creek tongue, and thus the domelike mountain north of the Lost Lakes was left as a large nunatak and is now a driftless area. The canyons leading eastward and northeastward from the Lost Lakes Plateau proved just sufficient to accommodate the glacial flood, which filled them almost but not quite to overflowing. In consequence the "finger mesas" between these canyons were left untouched by ice action.

At the same time other ice masses were accumulating in the valley leading northward from Weminuche Pass and in the basins bordering the valleys of Squaw and Little Squaw Creeks. These ice masses coalesced northward with the Rio Grande Glacier and somewhat expanded its volume. The divide through which the Creede-Silverton road now passes a short distance east of Long Park proved insufficient to check the northeastward motion of the ice, which overtopped it and moved into the canyon leading to the northeast. Thus certain of the higher points in the vicinity of Ingalls Gulch remained as the only summits above the surface of the ice. Below the mouth of Spring Creek the valley of the Rio Grande is broader and deeper. Here for the first time the depression was sufficiently great to contain the ice, and in the eastern third of the San Cristobal quadrangle the Rio Grande Glacier was confined to the stream valley. Notable lateral moraines were formed along both slopes of that valley between the Bristol Head and Ruby Lake plateaus.

Moving southeastward the ice was rapidly dwindling and losing momentum. Just before reaching its terminus, however, the Rio Grande Glacier received reinforcements from the south, where many catchment basins at the heads of Trout Creek, Middle Creek, and South River had contributed ice to form a glacier in each of these valleys. The northward-moving ice in these valleys united with the Rio Grande Glacier near the east boundary of the San Cristobal quadrangle, and the four confluent glaciers built a great terminal moraine which clogs the outlet of Lime Creek. Even thus reinforced the Rio Grande Glacier was unable to overtop the outlying mesa, which stands squarely athwart the Rio Grande Valley near Antelope Spring. The ice impinged against the southwestern slope of the mesa, but its maximum advance is marked by a prominent terminal moraine on the lower flanks of the hill. On the north and south the glacier pushed forward slightly beyond this obstacle, reaching Antelope Spring on the north and bulging forward into the valley of Lime Creek on the south.

Lake Fork Glacier.—The Lake Fork Glacier was similar in size to the Uncompahgre Glacier. It was composed of two branches of almost equal dimensions, one occupying the valley of Henson Creek and the other that of the Lake Fork of the Gunnison River. The catchment basins at the head of the Lake Fork are in the northeast corner of the Silverton quadrangle. Here the ice carved great cirques, such as American Basin. Thence it moved northward and eastward across the northwest quarter of the San Cristobal quadrangle. For many miles along this portion of the valley the master stream is now bordered by gulches and tributary valleys, each of which heads in a glacial cirque. Slopes are steeper here, and the dissection more mature than in the heart of the range near Silverton, so that the ice did not stand quite so high against the mountain summits. More than 1,000 feet of Sunshine Peak, for example, rose above the snow fields. Additional masses of ice from the basins near Whitecross added themselves to the Lake Fork Glacier, and the whole mass moved northeastward past the present site of Lake San Cristobal. Here a short, stubby dependency from the main glacier bulged eastward into Slumgullion Gulch and came to rest 600 feet below the divide between that gulch and the valley of Mill Creek. From the vicinity of Lake San Cristobal the main mass of the ice pushed northward, and after uniting with the ice from Henson Creek moved down the valley of the Lake Fork to its terminus opposite Sparling Gulch.

The Henson Creek wing of the Lake Fork Glacier drew its ice from a multitude of cirques and catchment basins in the southeast corner of the Montrose quadrangle, the northeast corner of the Silverton quadrangle, the southwest corner of the Uncompahgre quadrangle, and the northwest corner of the San Cristobal quadrangle. The high plateau above which Uncompahgre Peak lifts its pyramidal head was nearly everywhere covered by the ice field, but well-defined cirques are comparatively rare in the valley of Henson Creek. As the ice moved eastward it was confined to that valley in spite of the fact that the valley narrows beyond Henson to a width of only 1¼ miles. The narrowness of this valley, however, was largely compensated for by its depth, for at this point the ice was nearly 2,000 feet thick. The Henson Creek Glacier, uniting with the Lake Fork Glacier from the south, pushed the ice current far eastward, so that near Lake City ice reached 500 feet higher on the east wall of the Lake Fork Valley than on the west wall. The present site of Lake City, although only 3 miles from the terminus of this glacier, was buried beneath a mass of ice more than 1,500 feet thick.

San Miguel Glacier.—The San Miguel Glacier was likewise of large size by virtue of the fact that it consisted of many ice masses united to form a single compound glacier. It really originated in four great heads. The most northerly of these had its sources in the remarkable cirques near Telluride, such as Bridal Veil Basin, Ingram Basin, Savage Basin, and Marshall Basin. These cirques, though deeply carved by the ice, proved scarcely sufficient to contain the ice that gathered in them. Only the highest ridges and divides surrounding them were left above the reach of the glaciers. The ice from these basins concentrated in the valley of the San Miguel River and, moving westward over the site of Telluride, pushed on down the valley to gather reinforcements from the south. At Telluride the ice was more than 2,000 feet thick and had a width of nearly 2 miles.

Farther south, in the deep canyons at the head of Howard Fork, near Ophir, other ice fields were gathering. From them the ice pushed westward and near Ophir Station united with the ice from the head of the Lake Fork of the San Miguel River. The glacier in that valley had gathered in the many peaks east and south of Trout Lake. Thence it had moved northwestward until near the present site of Trout Lake it was split into two portions. One of these was forced southwestward across the divide at Lizard Head and added itself to the tiny glacier at the head of the East Dolores River. The other and larger portion moved northward down the valley of the Lake Fork, in which it was reinforced by ice from the Howard Fork on the one side and from a cirque on the northeastern face of Sunshine Mountain on the other. A little farther on it was joined by the Bilk Creek Glacier, the sources of which were on the eastern slopes of the Mount Wilson group. The triple glacier, thus coalesced into one, proved far too large for the valleys which were directing its motion, and its margins overflowed upon the mesa surfaces on both sides of the Lake Fork Canyon. This, however, so dissipated the force of the moving ice that shortly after its union with the San Miguel Glacier just below Keystone the composite glacier reached its terminus near the mouth of Deep Creek.

Vallecito-Pinos Glacier.—Another of the great valley glaciers that moved outward from the central part of the range was that which occupied the valleys of Vallecito Creek and the Los Pinos River. The glaciers in these two valleys were of about equal size and united with each other only 2 miles above their terminus, so that they are quite distinct throughout the greater part of their length, although they have a common terminal moraine.

The Vallecito Glacier drew its ice from the magnificent cirques and great catchment basins beneath the summits of the Needle Mountains and at the east end of the Grenadier Range. Only the highest peaks and summit ridges projected above the level of the ice, which in that locality covered nearly all the land surface. In the middle portion of the valley of Vallecito Creek the ice was at least 4,000 feet thick. A short distance to the east, in the southwest quarter of the San Cristobal quadrangle, the upland surrounding the Flint Lakes was buried beneath a small ice cap. Part of the ice moving outward from the center of this upland was contributory to the Vallecito Glacier. The general direction of movement of the ice was southward along the main valley of Vallecito Creek. At the northern boundary of the Ignacio quadrangle the glacier was about 5 miles wide and between 3,000 and 4,000 feet thick. In spite of these large dimensions, however, it came to rest a short distance beyond its confluence with the glacier occupying the valley of the Los Pinos River.

The Los Pinos Glacier drew its supply of ice from catchment basins and upland surfaces in the southwest quarter of the San Cristobal quadrangle. A large proportion was derived from the Flint Lakes ice cap, whence it moved down the valleys of the Flint Fork and Lake Fork. The rest was obtained from irregular basins on the south slope of the Continental Divide. At the place where this ice moved southward across the southern boundary of the San Cristobal quadrangle it had a width of 3½ miles and a maximum thickness of about 3,000 feet. Its surface gradient, however, was steep, so that it moved forward only about 11 miles. The ice of this combined Vallecito-Pinos Glacier therefore did not extend beyond the foothill zone but reached its terminus well within the mountains.

Cimarron Glacier.—The glacier occupying the valley of Cimarron Creek, on the northern slope of the range in the Montrose and Uncompahgre quadrangles, had a maximum length of about 20 miles. Its three heads occupied Cimarron Creek and the West and Middle Forks. Each drew its ice from half a dozen or more catchment basins on the northern slopes of the rugged peaks, such as Coxcomb, Wetterhorn, and Matterhorn, west of Uncompahgre Peak. Here the ice fields banked high on the slopes of the serrate summits, so that many of the lower divides between them were submerged beneath the glacial masses. Moving northward the ice was concentrated in the three valleys named and coalesced near Jackson. The long, narrow glacier in the West Fork Valley spilled over a gap in the west wall of that valley and sent a tonguelike dependency creeping westward down the valley of Owl Creek for about 2 miles. Northward from Jackson the combined glacier spread to a width of about 3 miles in the broader valley of Cimarron Creek. Here its thickness was only about 1,000 feet and the ice was able to move northward only about 8 miles before it reached its farthest terminus, near the mouth of Burdeck Creek.

Little Cimarron Glacier.—Paralleling the Cimarron Glacier on the east, near the west margin of the Uncompahgre quadrangle, there was a peculiarly slender ice mass in the valley of Little Cimarron Creek. The Little Cimarron Glacier originated in only four catchment basins at the head of its valley, and all but one of these were comparatively small. Near its head, beneath the shadow of Sheep Mountain, this glacier was less than 1½ miles wide and only 1,500 feet thick. Nevertheless, because of the steep gradient of the valley which it was following, the Little Cimarron Glacier moved northward nearly 12 miles from that place and finally reached its terminus 2 miles beyond Van Boxel's sawmill. Throughout the last 10 miles of its course the surface gradient of this glacier was nearly 300 feet to the mile.

Blue Creek Glacier.—The Little Cimarron Glacier was surpassed in slenderness by its neighbor in the valley of Blue Creek, a few miles to the east. The Blue Creek Glacier had a maximum length of 19 miles, although the total area covered by it and all its catchment basins is a little less than 30 square miles. Its largest cirque was that on the north slope of Uncompahgre Peak, where a great basin covering an area of about 2 square miles was carved. The ice in this basin overflowed across the divides to the north and east from the peak, which was left as a tremendous pyramid projecting 1,500 feet above the glistening fields of snow and ice. Other catchment basins a short distance to the north contributed to the glacier as it moved northward down the valley of Blue Creek. Still other cirques at the head of Fall Creek overflowed with ice, and a second glacier of comparatively small dimensions moved northward down that valley. At that time the stream in the upper part of the valley of Fall Creek had been tributary to Little Cimarron Creek by way of its East Fork; but as the ice moved northward it had sufficient volume to overtop the divide, and part of it spilled eastward into the deep but short valley which until that time had alone been occupied by Fall Creek. Thence this ice was tributary to that in the Blue Creek Valley. In spite of these reinforcements from the Fall Creek Glacier the Blue Creek ice had a width of only a scant mile immediately below the mouth of Fall Creek. Confined within the narrow, deep canyon of Blue Creek, the slender stream of ice moved forward 10 miles beyond that point. As it passed the mouth of the East Fork of Blue Creek a short, stubby dependency bulged eastward into the lower portion of that tributary valley. Beyond that point the width of the Blue Creek Glacier was nowhere more than three-quarters of a mile; its terminus was reached long before the canyon opened out into the rolling country between the Gunnison mesas and the mountains. In the last 10 miles of its course the surface gradient of this ice was about 200 feet to the mile.

Smaller valley glaciers.—Many lesser valleys between these larger streams on all sides of the range were occupied by glaciers of small dimensions. Such, for example, were the glaciers in the valleys of Weminuche and Huerto Creeks, Middle Fork, and the Piedra River in the southeast quarter of the San Cristobal quadrangle, all of which projected southward beyond the boundary of that quadrangle. In the same category should be mentioned the Florida Glacier, which rose on the south slope of the Needle Mountains and pushed southward down the valley of the Florida River, projecting 6 miles into the Ignacio quadrangle. Even smaller glaciers occupied the numerous tributary heads of Dallas Creek on the north slope of the range, in the southwest quarter of the Montrose quadrangle.

SMALL GLACIERS RADIATING FROM PEAKS

Rico Mountains.—The Rico Mountains are divided by the valley of the East Dolores River into two groups of peaks. The western group is within the Rico quadrangle, and the highest peaks in that group are Elliott Mountain and Anchor Mountain. Detailed geologic surveys have not been made by us in that group of mountains, but one brief reconnaissance trip yielded data which, coupled with the information obtained from earlier workers in the Rico quadrangle, form the basis for the following statements concerning the glaciation of the group. During the Wisconsin stage no glaciers of any size existed in these mountains, although doubtless extensive snow fields occupied the higher basins. On the southeast slope of Anchor Mountain a small cliff glacier was formed in the basin at the head of Burnett Creek. The glacier was wider than long and extended for little more than a quarter of a mile downward from its head. It is possible that a similar small cliff glacier was also present at the head of Johnny Bull Creek, on the northwest slope of Calico Peak, and that another small body of ice was formed in the basin at the head of Horse Creek, southeast of Johnny Bull Mountain. In both these places, however, ice movement was very feeble, and definite boundaries can not be set to the small glaciers which are believed to have existed. Neither of them was more than half a mile in length.

The eastern group of the Rico Mountains surrounds Blackhawk Peak, in the northwest quarter of the Engineer Mountain quadrangle. Six glaciers radiated from the center of this mountain group. The shortest was a little less than a mile in length, and the longest was nearly 5 miles. Each glacier had a single catchment basin, and from the ice fields at its head each moved outward down a steep, narrow valley. The largest basin was that on the northeast slope of Blackhawk Peak. Thence the ice moved northward into Silver Creek Valley and followed the curve of that valley eastward and southeastward into the Rico quadrangle. All told, only a few square miles was covered by ice in the Rico Mountains.

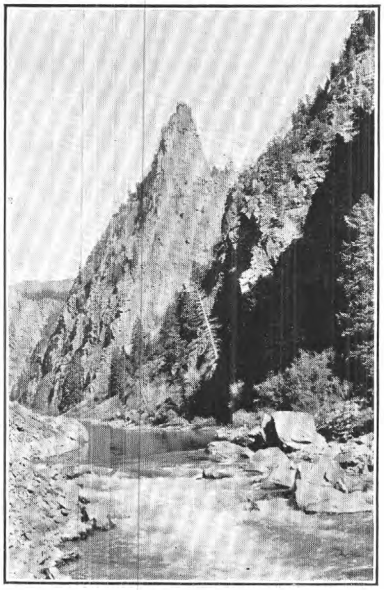
Mount Wilson group.—The half dozen peaks of which Mount Wilson is the chief, lying near the western border of the Telluride quadrangle, were centers from which a number of fair-sized glaciers moved. Magnificent cirques and well-developed catchment basins form the heads of all the valleys that trench the slopes of this group of mountains. Ice that formed in the basins on the north and west slopes of Wilson Peak moved northward and westward for a distance of 3½ miles. On the lower slope of this mountain a piedmont glacier of small size was developed by the coalescence of ice from these two basins. This spread out over the undulating plateau on both sides of the canyon of Big Bear Creek. The ice that formed on the east slope of Wilson Peak and in the basins between Lizard Head and Gladstone Peak was eventually tributary to the great San Miguel Glacier, already described. South of Gladstone Peak another smaller glacier formed at the head of Kilpacker Creek. Thence it moved down the shallow valley of that creek toward the East Dolores River, but it was not large enough to move far from its source, and its terminus is marked by moraines high above the canyon of the East Dolores. Still other glaciers formed on the west slope of Mount Wilson and moved westward for short distances to their termini just beyond the west margin of the Telluride quadrangle.

San Luis Peaks.—The San Luis Peaks form a compact group of mountains with their center near the point of intersection of the Uncompahgre, San Cristobal, and Creede quadrangles. In this mountain group there are many well-developed cirques and numerous catchment basins from which the ice descended the several valleys that radiate from the center of the group. Most of these glaciers were small. The two most westerly of them had lengths of only 2½ and 3 miles. Each was a long, narrow tongue of ice, which moved westward down the steep side slope of the valley of Cebolla Creek. The glacier in the valley of Rough Creek was nearly 4 miles in length and had an area of a little less than 4 square miles. Its head was in a catchment basin in the northeast corner of the San Cristobal quadrangle, on the northeast slope of the 13,420-foot mountain on the Hinsdale-Mineral County line. Thence it moved northward down Rough Creek and projected 2 miles into the Uncompahgre quadrangle. Its gradient throughout was very steep. The Mineral Creek Valley, in the northeast corner of the San Cristobal quadrangle, was occupied by a much larger mass of ice, which formed in the half dozen catchment basins surrounding the head of that valley. Thence the ice moved northward down the steep trough to its terminus in the southeast quarter of the Uncompahgre quadrangle.

Mesa Peak.—In spite of the high altitude of much of the northeast quarter of the Creede quadrangle only one small glacier formed in that area during the Wisconsin glacial stage. This was on the north slope of Mesa Peak, where a cirque was carved by the Wisconsin ice at the head of Bear Creek. From this cirque the ice moved northward about a mile.

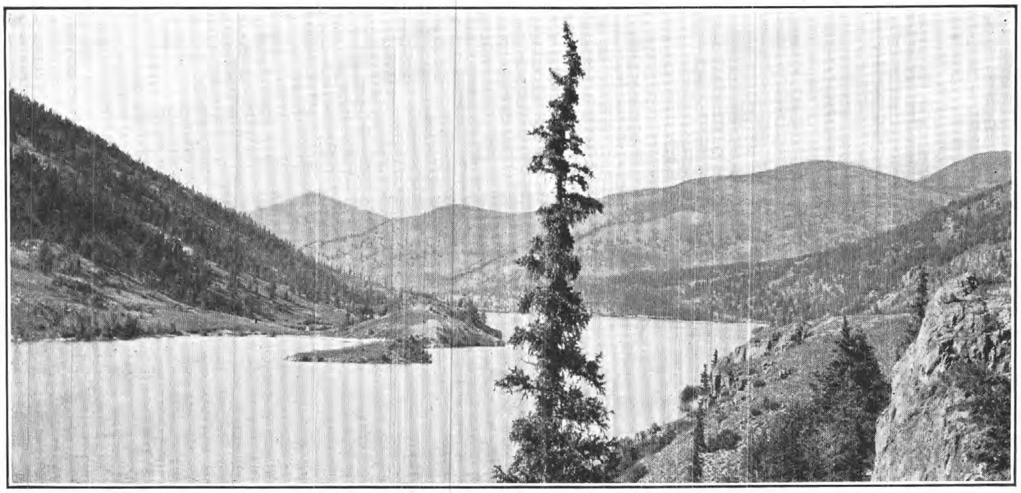
ICE CAPS

Flint Lakes region.—The upland surrounding the Flint Lakes, in the southwest quarter of the San Cristobal quadrangle, has in general an altitude of 12,000 feet or more. The presence of glacial striations, grooves, and other markings everywhere throughout



A. BLACK CANYON OF GUNNISON RIVER

View upstream to Curecanti Needle, a conspicuous feature resulting from differential weathering and erosion.

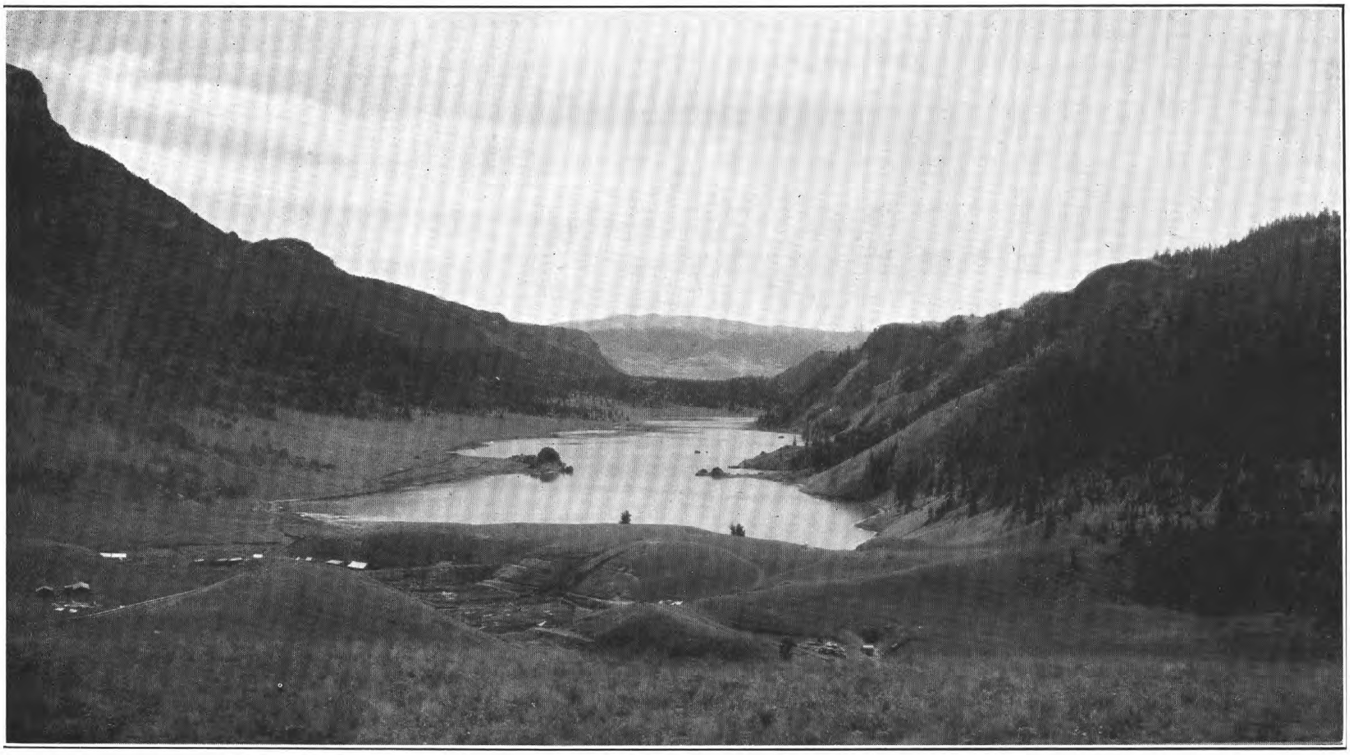


B. LAKE SAN CRISTOBAL

View from a point near the upper end of the lake. At the farther end, in the middle ground, is the lower portion of the Slumgullion mud flow, which ponded Lake Fork and thus produced this lake basin.

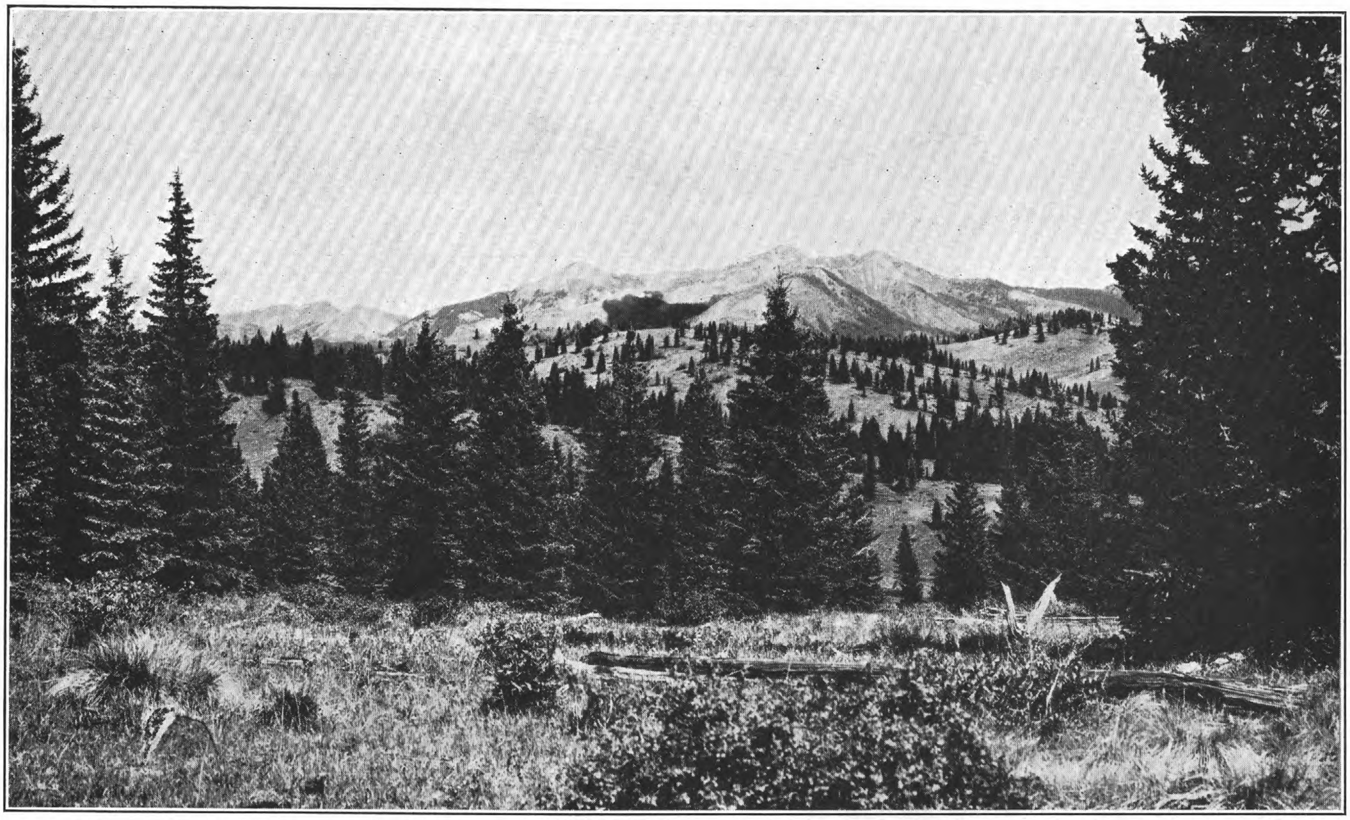
C. BLACK CANYON OF GUNNISON RIVER

View downstream from automobile road on the rim. Denver & Rio Grande Western Railroad on right bank, 1,000 feet below. Curecanti Needle in middle. This canyon has been cut in resistant crystalline rock since the Cerro stage of glaciation, hence its youthful character.



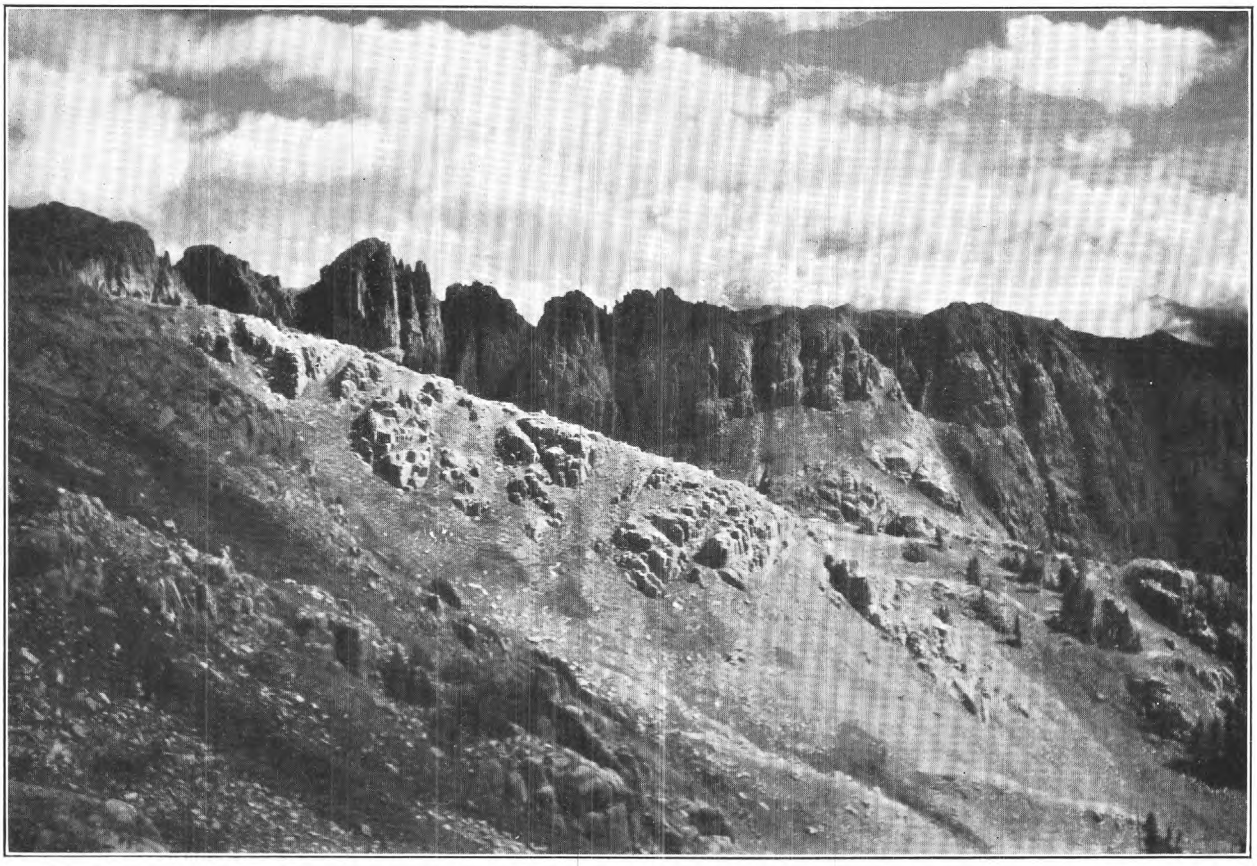
A. SANTA MARIA LAKE

The lake is held between morainic deposits, in the foreground, and a huge mass of landslide material at the farther end, which came down from Bristol Head. The lake serves as a reservoir for water used in irrigating parts of San Luis Valley. Photograph by Whitman Cross.



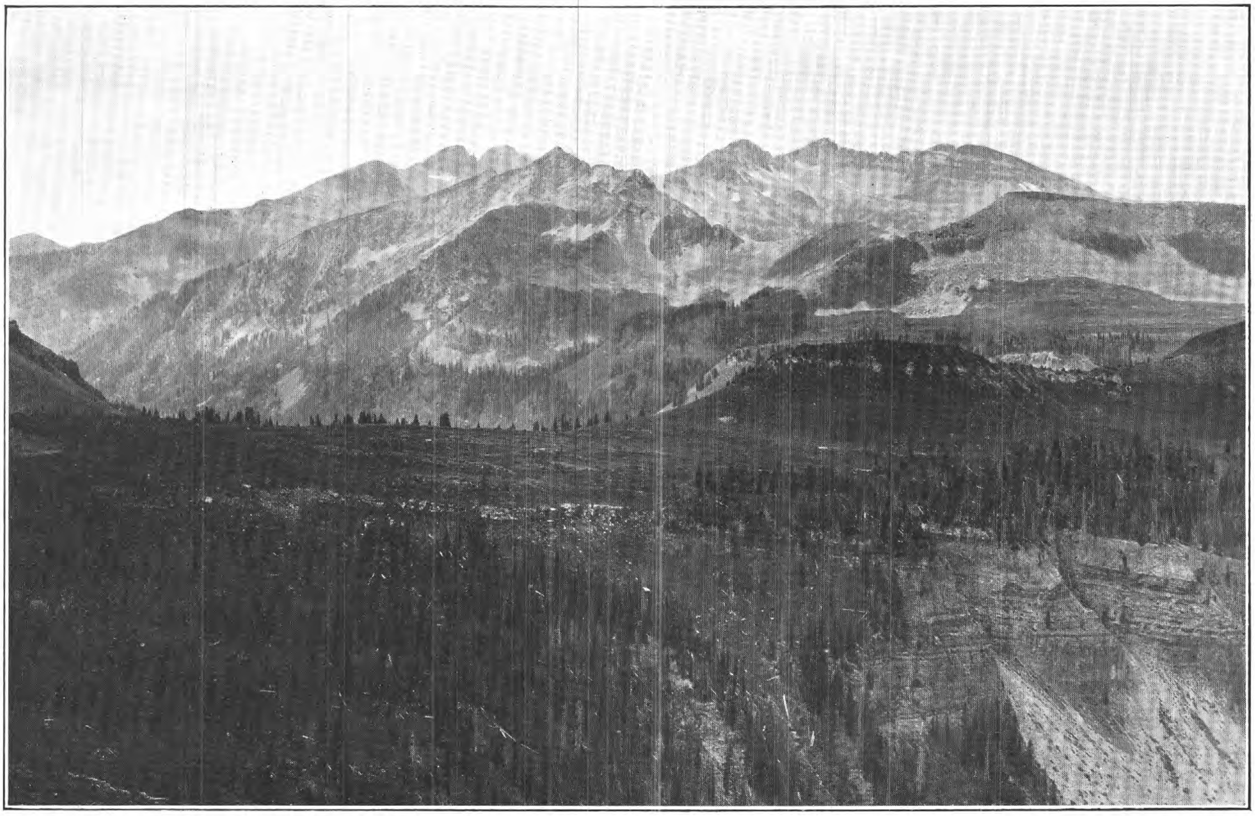
B. RICO MOUNTAINS

This secondary dome of mountains is west of the main San Juan Mountain area. Its superior elevation has led to a greater degree of dissection than has developed in the foreground of the view. Photograph by Whitman Cross.



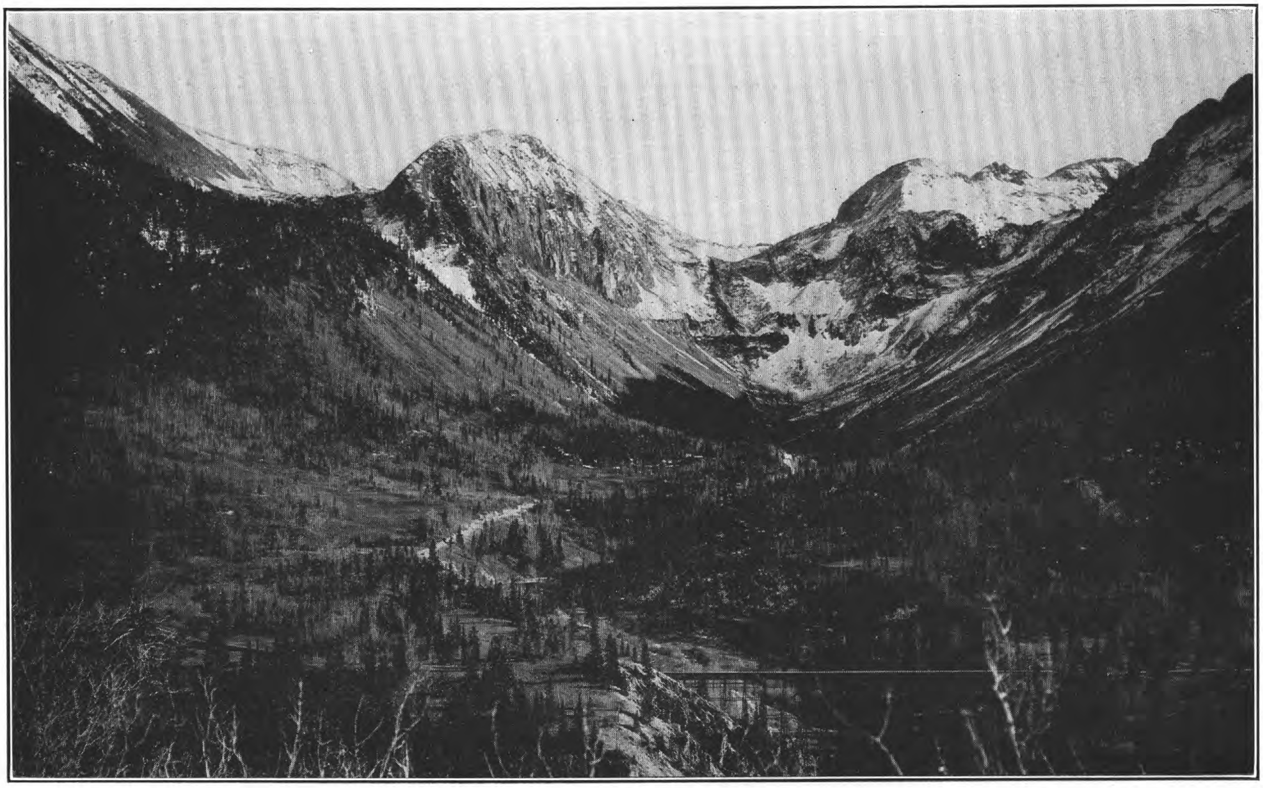
A. WEATHERED GRANITE

This view was taken at the east edge of Endlich Mesa, in the Needle Mountains quadrangle. It illustrates well the features that have resulted from the weathering of ancient granite rocks in the core of the range. Photograph by Whitman Cross.



B. WESTERN PEAKS OF THE LA PLATA MOUNTAINS

These mountain forms are due to the dissection of a secondary dome on the southwest flank of the broad San Juan uplift. Photograph by Whitman Cross.



A. GLACIAL BASINS AT HEAD OF ARRASTRE GULCH

Little Giant Basin at the left; Silver Lake Basin in the center. In the foreground there are glacial gravel deposits, which form the bench at the left of the stream courses. The gulch had a distinct U-shaped form when the ice melted away. Recent talus accumulations have sharpened somewhat the valley contour and made it more V shaped. Photograph by Whitman Cross.

B. GLACIAL EROSION IN NEEDLE MOUNTAINS

The smoothly rounded surfaces, near the head of Florida Canyon, are the result of abrasion by ice of the Wisconsin stage of glaciation. The ponds occupy hollows gouged out of the rock by the glacier. The jagged crests and weathered cliffs were above the limits of vigorous glaciation. Photograph by Whitman Cross.

this region indicates that it was occupied by an ice cap thick enough to bury all but the highest peaks and covering an area of many square miles. From the margins of this cap the ice moved readily outward and within a few miles of its source was confined to the valleys of such streams as Ute Creek, Flint Fork, Lake Fork, and Vallecito Creek. The thickness of this ice cap in places must have been as great as 1,000 feet, but its average thickness was probably only 300 or 400 feet.

Platoro region.—The ice cap centering in the high mountain country just south of the Platoro Plateau in the eastern part of the Summitville quadrangle, during the Wisconsin stage covered an area between 900 and 1,000 square miles in extent. At the maximum extension of the glaciers in this region there was continuous ice from north to south in nearly a straight line for about 48 miles and from east to west for 25 miles.

This great sheet of ice, mantled most of the time with a heavy covering of snow, varied greatly in thickness. On the high plateau it was probably from 500 to 1,000 feet thick; but it filled the great canyons in this portion of the range and in those places was at least 3,000 feet thick. Twelve major glaciers radiated from this huge cap of ice. They extended northward along the south fork of the Rio Grande, Pass Creek, Park Creek, Beaver Creek, and Pinos Creek. The ice that moved eastward became concentrated in the Alamosa and Conejos drainage systems. The chief tributaries of the Conejos from the west contained very considerable glaciers from this great collecting ground. To the south the ice followed the Chama, Navajo, and Blanco Canyons. Of these radiating glaciers the Conejos was the longest, reaching 36 miles from the Continental Divide to a point within a few miles of the margin of the range. The next longest was the Alamosa, which reached 23 miles down the canyon of Alamosa Creek. The Park Creek Glacier was 18 miles in length, the South Fork Glacier 16 miles, the Blanco 12 miles, and the Navajo 11 miles.

A few rugged mountain peaks rose as nunataks above this great ice cap. They were located near or on the Continental Divide in the Summitville quadrangle. Montezuma Peak and Summit Peak are in this group, but most of the mountain area that rose above the great snow fields is without any special name. In the region northwest of Platoro, in the vicinity of Prospect Mountain, Lookout Mountain, Cropsy Peak, and South Mountain, there was another group of nunataks.

The surface upon which the ice rested and over which it moved retains many indications of intense glaciation. Broad areas have been swept clean of all waste material. At many places there are beautifully polished, grooved, and striated rock surfaces. Into the rock floor at many places the ice gouged shallow basins, which now contain lakes. There are a few small moraines left within the area, but for the most part it is a barren waste.

The upland surface upon which the Platoro ice cap formed ranges in altitude from about 11,000 to 13,000 feet, and into it the canyons are incised from 2,000 to 3,000 feet.

This is the most easterly and southerly area of Pleistocene ice studied in the San Juan region. When added to the Flint Lake ice cap and the great areas of ice just north of the Needle Mountains, it permits the reproduction in imagination of an ice mantle in the San Juan region during the Wisconsin stage covering from northwest to southeast a distance of fully 140 miles. Above the ice surface there appeared but a few isolated, rugged peaks, and they undoubtedly were covered with snow much of the time when the ice occupied the upland surfaces and filled the great canyons of this range.

ALTITUDE OF CATCHMENT BASINS

The altitude of the basins in which the ice of the Wisconsin stage accumulated does not vary markedly from place to place within the San Juan Mountains. With few exceptions the floor of each large catchment basin is 12,000 feet or more above sea level, and the surrounding walls rise to altitudes of close to 13,000 feet as a minimum. On the southwest side of the range the critical altitude seems to be about 12,500 feet. Blackhawk Peak, in the eastern group of the Rico Mountains, has an altitude of 12,687 feet and was surrounded by ice fields that accumulated in basins whose floors were between 11,000 and 11,500 feet above sea level. Hermosa Mountain, 4 miles to the northeast of Blackhawk, has a summit altitude of 12,574 feet and is surrounded by an upland whose summits attain approximately 11,500 feet. No ice formed on the flanks of Hermosa Mountains during the Wisconsin stage. Similarly the western group of the Rico Mountains, with summit altitudes just over 12,500 feet, were occupied by only the smallest of cliff glaciers in two or three sheltered places.

Similar altitudes were necessary for the formation of ice fields on the northern slopes of the range. Here there are no peaks higher than 13,000 feet that were not surrounded by ice fields. On the other hand, certain valleys, such as that at the head of Elk Creek, in the southwest corner of the Uncompahgre quadrangle, contained no ice, although they rise on uplands whose altitude is as great as 12,800 feet. The lower limit of catchment basins on the north side of the range seems to be illustrated by the small basin in which the Powderhorn Lakes are almost concealed. This basin is on the northern margin of the Cannibal Plateau, in the southeast quarter of the Uncompahgre quadrangle.

The floor of the basin is at an altitude of 11,800 feet, and the highest point on the plateau at 12,600 feet.

About San Luis Peak, in the northwest corner of the Creede quadrangle, the catchment basins that gave rise to ice are to-day from 11,500 to a little over 12,000 feet above sea level. The basin at the head of the middle fork of the Saguache River has a floor altitude of 11,500 to 12,000 feet. The little basin just north of Mesa Peak, which contained a small body of ice, has an altitude of 12,000 feet; this was the northeastern most glacier of the Wisconsin stage in the San Juan region.

In the Conejos quadrangle there were few catchment areas that gave rise to true glaciers. The ice which invaded this quadrangle formed in the adjoining area to the west, in the great Platoro ice cap (p. 75). However, in the vicinity of Bennett Mountain, at the northwest corner of the quadrangle, a few catchment areas with floors fully 12,000 feet above sea level were the sources of small glaciers during the Wisconsin stage. They are the most easterly basins in the range in which ice formed during this last stage of the Pleistocene epoch.

ALTITUDE OF TERMINAL MORAINES

The altitude at which wastage resulting from melting of the ice equaled the amount of forward movement and thus caused the formation of terminal moraines varies markedly from place to place. In general the larger the glacier the lower the level to which it reached. The controlling feature seems to have been not climatic zones resulting from altitude but dimensions of the ice fields contributory to the individual glacier.

The terminal moraine of the Animas Glacier, the largest in the range, is only 6,600 feet above sea level. In sharp contrast to this low altitude the terminal moraine of one of the smallest of the San Juan glaciers is 12,350 feet above sea level. This is on the slope of the easternmost of the San Luis Peaks, in the northeast corner of the San Cristobal quadrangle. The ice moved only a short distance down the south flank of this peak and deposited the terminal moraine on the surface of the Willow Creek Plateau. Between these two altitudes there are terminal moraines at all heights.

The terminal moraine of the Rio Grande Glacier is 8,900 feet above sea level; that of the Lake Fork Glacier 8,700 feet. The Uncompahgre Glacier descended much lower and deposited its terminal moraine at a level of approximately 7,000 feet near Ridgway. The San Miguel Glacier reached downward to an altitude of 7,900 feet. The Vallecito-Pinos Glacier deposited its terminal moraine at 7,600 feet, and the Florida Glacier came to rest at 8,100 feet. The two small glaciers near the head of Cebolla Creek left their terminal deposits at 10,600 and 10,700 feet, and the still smaller glacier at the head of Ruby Creek, a little to the northwest of the center of the San Cristobal quadrangle, extended downward only to 11,000 feet. Appropriate to its larger dimensions the glacier in the valley of Cimarron Creek pushed downward to an altitude of only 7,700 feet, but the slender masses of ice in the valleys of Little Cimarron and Blue Creeks came to rest at 8,100 and 8,800 feet.

EFFECTS OF THE WISCONSIN GLACIATION

The results of glacial erosion are plainly discernible in all parts of the range that were affected by ice in the Wisconsin stage. These effects comprise a multitude of minor changes rather than any single modification of great significance. Notable cirques and deeply scoured basins are everywhere present in the regions of ice accumulation. Below these basins the valleys through which the ice moved now display a strongly U-shaped profile in striking contrast to the V-shaped profile of the normal stream-eroded valley in its youth.

The most remarkable of the many cirques and catchment basins of the range are found in the Silverton and Needle Mountains quadrangles, where glacial erosion was at its maximum. Nearly every peak in these two quadrangles is surrounded by glacial cirques of typical form. Their precipitous walls and half-concealed rock-basin lakes must be seen to be appreciated, although the photograph reproduced in Plate 20, *A*, gives some idea of their beauty and grandeur.

The depression between Greylock and Jagged Mountains, on the east side of Sunlight Peak, near the center of the Needle Mountains quadrangle, is one of the most spectacular basins in the San Juan Range. It is a gigantic amphitheater about 3 square miles in area, whose floor has been polished and smoothed by ice action and whose walls rise sheer to the jagged peaks that bound it. Several small ponds occupy rock basins in its floor. Opening outward toward the east, the basin grades into a broad U-shaped valley that leads to Vallecito Creek. Chicago Basin, just across the divide to the southwest, is a huge compound cirque which is divided into minor cirques by projecting spurs from the flanks of Mount Eolus, Jupiter Peak, and the other summits that overlook its polished floor. Here, as in most of the other cirques of the Needle Mountains, there are numerous rock-basin lakes and ponds. Throughout this region the ice stood high against the upper slopes of the mountains and at many places overtopped the divides. The contrast between the glacially smoothed, polished, and rounded lower slopes and the weathered, irregular, and jagged upper slopes is everywhere sharply marked. (See pl. 20, *B*.)

In a few localities the ice has vigorously eroded upland surfaces without the formation of typical cirques or basins. East Silver and West Silver Mesas, south of the center of the Needle Mountains quadrangle, are illustrations. They were both covered by ice that formed upon them and against the ridge that rises above their surface at the north. Ice action was vigorous and left many undrained depressions and roches moutonnées carved in the granite of the mesas.

As soon as the ice from the catchment basins became concentrated in definite channels it gained in erosive power and helped to develop a U-shaped valley. In some localities the amount of glacial erosion accomplished by the Wisconsin ice was very great. Cunningham Creek, for example, in the southeast quarter of the Silverton quadrangle, appears to have been deepened somewhat. Its rock walls have been scraped clean; intertributary spurs are beveled; its tributaries all occupy hanging valleys, from which they tumble in a series of cataracts to join the main stream.

In many valleys the contrast between the glacially eroded portion above a terminal moraine and the unglaciated stream-carved lower portion is noteworthy. The valley of the Florida River, in the northern part of the Ignacio quadrangle, and that of its neighbor, the Los Pinos River, are good examples.

Valley deepening by ice action varied in amount with the dimensions of the glacier. Consequently, the valleys of master streams were generally very much more deeply eroded than the valleys of their tributaries. Thus in many places the smaller tributaries have been left as hanging valleys. Innumerable examples might be cited, but two or three will suffice. Niagara Gulch, in the east-central portion of the Silverton quadrangle, is typical. The upper part of this valley is an open cirque of moderate gradient, but from the west margin of the upper basin the stream plunges in a series of cascades, descending 2,000 feet to the floor of the Animas Canyon in leaps of 100 feet or more at a time. In places the water passes behind projecting ledges and even under great natural bridges, where it has bored its way through the resistant rock and is rapidly increasing the dimensions of its channel. Cataract Gulch, near the center of the Silverton quadrangle, is almost a duplicate of the one just described. A similar but smaller hanging valley in the northwest corner of the San Cristobal quadrangle illustrates this topographic feature. Here, near Whitecross, is a clean-cut basin with a floor at an altitude above 12,000 feet, which has been swept clear of loose material by the ice and from which the water cascades to the main valley.

The effects of mountain glaciation upon the drainage system of the mountains are not nearly so vast as those of continental ice sheets moving over a relatively even surface. Mountain valleys control the direction of ice movement with almost absolute accuracy. Streams in the mountains are definitely fixed in deep-cut channels, from which they are seldom moved by glaciation. Nevertheless there are in the San Juan region a few examples of stream diversion as a result of Wisconsin glaciation. The East Fork of Little Cimarron Creek, in the southwest quarter of the Uncompahgre quadrangle, formerly headed against the flank of the 13,800-foot peak from which the ancestral East Fork followed the channel now occupied by Fall Creek above its falls. The Wisconsin glaciation, however, resulted in the breaking down of the low divide just above the falls of Fall Creek and the deposition of the morainal dam at the head of the present valley of the East Fork. With the withdrawal of the ice and the resumption of stream drainage Fall Creek assumed its modern proportion, and the East Fork was left beheaded by the diversion of its upper half to Blue Creek.

The most notable effects of glaciation upon drainage are the myriad lakes which dot the glaciated surface. (See pl. 21, *B*.) Many of these are rock-basin lakes, due to the unequal scour of eroding ice. Most of such lakes are in the cirques or other catchment basins in the area of high mountains. Practically all the lakes of the Silverton and Needle Mountains quadrangles, as well as those in the east half of the Telluride quadrangle and the southwest quarter of the San Cristobal quadrangle, come under this category. Other rock-basin lakes are on the surfaces of plateaus or benches across which the ice moved. The Lost Lakes, near the center of the San Cristobal quadrangle, and the many lakes between the Hermosa Cliffs and the Animas Canyon, in the southwest quarter of the Engineer Mountain quadrangle, are illustrations of this type. Still other lakes of glacial origin are due to unequal deposition of glacial drift. Trout Lake, in the Telluride quadrangle, is probably the best example, although there are many other such basins which have been completely silted by the accumulation of sediment in postglacial time.

FLUVIOGLACIAL STREAMS

The release of the ice-borne rock débris, or drift, during the advance and more especially during the retreat of the front of the Wisconsin glaciers resulted in loading the greatly swollen streams which led from the ice front down every valley whose head was glaciated. A great volume of silt-laden water, with pebbles, cobbles, and even large boulders rolling along the stream beds, swept outward from beneath the end of each tongue of ice. Conditions similar to those which now prevail in the Alaskan valleys, where glacial water fills the flood plains of the streams, existed in the San Juan region during the Wisconsin stage. The great volume of gravel that forms the valley trains leading downward from the terminal moraines in the San Juan valleys resulted from this fluvioglacial action. As shown on Plate 3, the glacial streams swept across flood plains much wider on the average than the modern flood plains. For example, the valley train along the Uncompahgre River had an average width of more than a mile, whereas the modern flood plain of that river averages much less than half a mile in width.

DURANGO GLACIATION

EXTENT AND NATURE OF GLACIERS

The vigorous erosive action of the Wisconsin ice in the heart of the San Juan Range has resulted in the complete obliteration of all data concerning the extent and nature of the Durango glaciers there. Only in those regions where the Durango ice extended beyond the farthest reach of the later Wisconsin glaciers are data available for a definite description of the Durango glaciers. Such conditions are found rather generally in the peripheral zone between the higher mountains and the neighboring foothills. Moreover, certain of the outlying hills and valleys were occupied by Durango ice but were not affected by ice during the Wisconsin stage. Here the Durango records are complete except where obliterated by stream erosion and weathering.

Although in general the Durango glaciers were larger and more extensive than the Wisconsin glaciers, none of them extended beyond the foothill zone surrounding the range or overrode the walls of the canyons far enough to spread out across the bordering lands. With the exception of small ice caps, which probably existed in certain regions during the Durango stage, even as they did later in the Wisconsin time, the Durango glaciers were all of the valley type.

Animas Valley.—Unquestionably the Animas Glacier of the Durango stage was the greatest of the valley glaciers that formed in the San Juan region at that time. Its gathering ground occupied hundreds of square miles in the Silverton and adjacent quadrangles, where the start was made toward the carving of the magnificent cirques that characterize the heads of the Animas tributaries there. Thence the ice moved southward along much the same pathway as was later followed by the similar glacier of the Wisconsin stage. Following the main canyon of the Animas the Durango ice was joined by glaciers that had formed farther west, in the heads of Lime Creek and Cascade Creek, and pushed through the gaps between Potato Hill, Engineer Mountain, and Grayrock Peak, to contribute to the great glacier in the Animas Valley.

So great were the dimensions of this glacier that it overtopped the divide at the head of the East Fork of Hermosa Creek and sent a long lobe westward down that valley. This lobe was probably of similar shape to that which later followed the same pathway during the Wisconsin stage. Apparently, however, it was a much thicker mass of ice and rose 400 or 500 feet higher on each wall of the East Fork Valley than the Wisconsin ice. Farther south the Animas Glacier was held in on its western margin by the Hermosa Cliffs, which rose a few hundred feet above its surface. Doubtless the vigorous erosion of this tremendous body of ice did much toward wearing back those cliffs and helped to strip the sedimentary rocks from the pre-Cambrian floor of the bench which they now overlook.

In the Ignacio quadrangle the Animas Glacier of the Durango stage was appreciably larger than its successor in Wisconsin time. Its lateral margins rested 500 feet or more above the marginal position of the later ice. A short lobe pushed up the lower end of the valley of Hermosa Creek for more than a mile farther than the Wisconsin ice. The terminal reached by this ice is a little over a mile beyond the moraine of the Wisconsin ice and just touches the northern limits of the city of Durango.

Florida Valley.—Similarly the Durango Glacier in the valley of the Florida River, the next large valley of the Animas, was somewhat more extensive than the Wisconsin ice in the same valley. The gathering grounds on the south slopes of the Needle Mountains were much the same in the two stages of glaciation, and the general route followed by the two glaciers was identical. The earlier ice mass, however, pushed southward nearly 2 miles farther than the later one. Thus the mouth of Miller Creek was blocked by ice, and the alluvial flat above the Durango lateral moraine across that valley doubtless dates from the time of maximum advance of the Durango ice.

Vallecito and Los Pinos Valleys.—In the valleys of Vallecito Creek and the Los Pinos River the Durango Glacier was similarly somewhat more extensive than the Wisconsin Glacier. On the west wall of the Vallecito Valley the Durango ice stood 700 feet above the line that marks the lateral margin of its successor in the Wisconsin stage. East Mountain, which projects southward between the two valleys and fills the angle formed by their union, was almost but not quite overridden by the Durango ice, which reached, at certain places, within 100 feet of its crest. The farthest reach of the Durango ice after the two wings of this great glacier had coalesced beyond East Mountain is marked by terminal deposits 2 miles farther downstream than the terminus of the Wisconsin ice.

Weminuche and Huerto Creeks.—At the time of the advance of the Durango ice Huerto Creek was tributary to Weminuche Creek through the low sag now partly filled with Wisconsin drift just south of the San Cristobal quadrangle; the ice of the two valleys coalesced at this point and moved down Weminuche Creek a distance of 3 miles below the lower limits of the Wisconsin drift. As elsewhere, the ice of Durango age in these two valleys stood much higher on the valley walls than the later ice. The entire surface of the undulating divide below 9,900 feet southward from the trail that connects the two valleys near the southern margin of the San Cristobal quadrangle was entirely submerged by the Durango ice.

Middle Fork and Piedra River.—In the valleys of the Piedra River and its Middle Fork the Durango ice was somewhat more extensive than the Wisconsin. The terminus of the Durango ice in the Middle Fork Valley was 1½ miles farther downstream than that of the Wisconsin glacier. In the Piedra Valley the earlier ice reached nearly a mile beyond the limit attained by the later.

Valleys of Summitville and Conejos quadrangles.—In the main valley of the San Juan River in the northwestern part of the Summitville quadrangle the moraines that represent the position of the Durango ice at its maximum extent flank the east margin of the valley for 4 miles downstream from the terminal moraine of the Wisconsin ice. These morainic masses rise 400 feet above the stream course. They are higher on the wall of the valley than the outwash or valley-train terraces of the Wisconsin stage, and from the southernmost of these morainic deposits of the Durango stage and extending far downstream—even to the vicinity of Pagosa Springs—there are terrace remnants of the Durango outwash.

Turkey Creek, a tributary to the San Juan from the west, also contains in its lower portion a few remnants of Durango moraines. It is certain that the Durango ice in that canyon was at least 2 miles longer than the Wisconsin ice. Very likely, however, the Turkey Creek ice advanced to the main canyon of the San Juan and joining the ice there moved down the San Juan Valley another mile or two. The valley of Rito Blanco contains a series of morainic deposits 2 miles below the Wisconsin moraines, which are interpreted as of Durango age.

The Blanco Glacier of the Durango stage left several morainic deposits 3 miles beyond the Wisconsin terminal moraine. They are to-day but irregular remnants of formerly more extensive moraines. The one on the east wall of the canyon just below Blanco Basin is, however, fully a mile wide and nearly 3 miles long.

In the Navajo Canyon no moraines have been differentiated as distinctly of Durango age. In this heavily forested, mountainous region it is extremely difficult to ascertain whether or not they are present or have been included in the moraines now mapped as of Wisconsin age. The map may be in error there, and yet it is quite possible that the ice of the Wisconsin stage advanced as far down the valley as the ice of the Durango stage. Under such conditions the earlier moraines are reworked and redeposited as moraines of the later stage. Downstream from the morainic deposits there is a series of high terraces which are interpreted without doubt as of Durango age. They are veneered with outwash from the earlier glacier, as below them in the valley are the outwash deposits of the Wisconsin stage.

In the Chama Valley the Wisconsin ice advanced to the very southern margin of the Summitville quadrangle. Beyond that line, in northern New Mexico, older morainic deposits were recognized and interpreted as of Durango age, but there was no base map available and that area is beyond the region covered by this study. The Chama Glacier of the Durango stage was about 2 miles longer than that of the Wisconsin stage.

In the Conejos quadrangle the valley glaciers of the Durango stage, in both the Conejos and the Alamosa Canyon, were longer by a mile or two than the glaciers of the Wisconsin stage, and the moraines of this earlier stage are higher on the valley slopes and a little farther downstream than the Wisconsin moraines.

A very notable and somewhat remarkable development of Durango moraines in the Conejos quadrangle appears on the upland surface between its two great canyons. These moraines are due to the welling over of the ice from the canyons and its deployment on this rolling upland surface. From the Conejos Canyon at a point near Trail Creek the ice moved eastward over the east wall of the canyon and spread out across a vast area as far east as the lower end of La Jara Reservoir. At the end of that reservoir, as well as farther south and southwest, the morainic deposits of this stage are plainly shown.

From the Alamosa Canyon the ice welled over the south wall near French Creek and spread onto the upland for a distance of about 2 miles. On this upland in the vicinity of Big Lake there are thick morainic deposits of this earlier stage, and the terminal position of the moraine is as clearly marked as the terminal moraines of the continental ice sheet in the interior of North America.

In the northwestern part of the Conejos quadrangle, as shown on Plate 1, there are a few areas of Durango drift; and some of the basins of this area, which were free from ice during the Wisconsin stage, contained ice during the Durango stage. They are at the eastern margin of the mountain glaciers in the San Juan region, and they indicate the lowest altitude at which ice accumulated.

Rio Grande.—Only near its eastern terminus in the Rio Grande Valley did the Durango glacier leave a record beyond the reach of the later ice. The tongues of ice which in Durango time moved down the canyon between the Finger Mesas, near the center of the San Cristobal quadrangle, united in the valley of Spring

Creek to push eastward across that broad valley until the glacier was stopped by the Bristol Head Plateau. Beyond Clear Creek, at the northwest margin of Santa Maria Lake, the Durango ice extended fully a mile farther east than the Wisconsin ice. Similarly, the terminus of the Durango ice in the valley of the Rio Grande at the mouth of Lime Creek is 2 miles beyond that of the Wisconsin ice. The conspicuous ridge southeast of Bristol Head on the floor of the Rio Grande Valley, which stalled the advance of the Wisconsin ice at that point, was overridden by the more extensive ice of the Durango glacier.

Lake Fork of Gunnison River.—In the vicinity of Lake City, near the south margin of the Uncompahgre quadrangle, the ice of the Durango stage stood several hundred feet higher on the walls of the Henson Creek and Lake Fork Valleys than the Wisconsin ice. In consequence the Durango ice pushed farther down the Lake Fork Valley and reached its terminus some distance beyond Sparling Gulch. Apparently this glacier had at least one more catchment basin than its successor in the same valleys, for ice formed below the east face of Crystal Peak during the Durango stage, whereas this basin held no ice in Wisconsin time. From this basin a small Durango glacier moved down Slaughterhouse Gulch to add its increment to the Lake Fork Glacier near the present site of Lake City.

Blue Creek.—The Blue Creek Valley, in the northern part of the Uncompahgre quadrangle, was occupied by an even longer though equally slender body of ice in Durango time than in Wisconsin time. The Durango ice pushed northward beyond the canyon into the more open country between the Gunnison Mesas and the San Juan Mountains proper and reached its farthest point only half a mile above the junction of Little Blue Creek with the larger Blue Creek. It is uncertain whether in Durango time the glacier in this valley coalesced with that in the upper valley of Fall Creek, as it did in Wisconsin time. In any event ice pushed much farther down the East Fork of Little Cimarron Creek and came to rest a little over 2 miles beyond the Wisconsin terminal moraine at the head of that valley.

The Durango glacier in this valley was the longest, in proportion to its width and area of gathering ground, of all the glaciers recorded in the San Juan region. This is doubtless due in part to the fact that it moved northward from the slopes of the highest mountain in the range. The névé fields at its head must have had a surface altitude well over 13,000 feet; the moraine at its terminus is 8,500 feet above sea level. The descent of 4,500 feet was accomplished in a distance of about 25 miles.

Little Cimarron Creek.—The Durango ice in the valley of Little Cimarron Creek extended 1½ miles farther north than the Wisconsin ice. It reached the open portion of the valley and spread out in a broad lobate form, reaching almost if not quite to the present site of Swanson Lake. Much of the record of glaciation in this locality has been obliterated by landslides so that it is not possible to delineate the Durango glacier with accuracy.

Cimarron Creek.—No data are available concerning the outlines of the Durango glaciers in the three heads of Cimarron Creek, but presumably they had much the same form as the Wisconsin glaciers in that region. Farther north, beyond the point where the three heads coalesced, the glacier was both broader and longer than the Wisconsin glacier. On the east wall of Cimarron Ridge the Durango ice stood 700 to 1,000 feet higher than the later Wisconsin ice. This gave the Durango ice sufficient momentum and forward impetus to carry it 3 miles farther downstream than the limit attained by the Wisconsin ice.

Uncompahgre Valley.—The gathering grounds of the Durango glacier in the valley of the Uncompahgre River were in the same high mountain region in the northern part of the Silverton quadrangle as those which later supplied the ice of the Wisconsin stage. Apparently, however, the volume of ice was much greater during the earlier glacial stage, and this fact, combined with the shallower depth of the Uncompahgre Valley at that time, caused the Durango ice to spill over the margin of the canyon north of Portland. Thus the lateral margin of the Durango ice encroached upon the surface of Miller Mesa 800 feet above the limit later attained by the Wisconsin ice. For the same reasons the Durango glacier pushed much farther north and overtopped the southeast margin of Log Hill Mesa as well as the flat-topped hills east of Dallas. The farthest reach of the Durango ice was a little more than 2 miles beyond that of the Wisconsin ice.

Heads of Dallas Creek.—The huge catchment basins on the north slopes of the Sawtooth Range, along the southern margin of the Montrose quadrangle, were filled with ice during Durango time in even greater volume than during the Wisconsin stage. The broad, stumpy glaciers that crept northward down the tributaries of Dallas Creek covered far more territory in Durango time than those of Wisconsin age. The glaciers moving northwestward from Whitehouse Mountain, for example, were nearly twice as large in the earlier as in the later stage. The two-headed glacier that occupied the valley of the East Fork of Dallas Creek pushed 2½ miles farther downstream in Durango time than the glacier in the Wisconsin stage.

Alder Creek.—The tiny glacier in the southwest corner of the Montrose quadrangle, which in the Wisconsin stage occupied one of the basins at the head of Alder Creek north of Last Dollar Mountain, was trivial in comparison with its predecessor. It is probable that in that earlier stage the western slopes of Hayden Peak and North Pole served as catchment basins, although no ice formed in them during Wisconsin time. Thence the ice pushed 4 miles down Alder Creek and covered an area several times as great as that occupied by the Wisconsin ice.

San Miguel River.—In the valley of the San Miguel River the ice of the Durango stage was very much more extensive than that of the succeeding Wisconsin stage. Northwest of Telluride the Durango ice from catchment basins on the south slopes of the Sawtooth Range covered intertributary spurs several hundred feet higher than those buried beneath the Wisconsin ice. Similarly the branch of the San Miguel Glacier that occupied the valley of Bilk Creek stood more than 300 feet higher on the west margin of that valley and in places overtopped the divide between it and the valley of Big Bear Creek. The terminus of the Durango glacier was probably much farther down the San Miguel Canyon than the point reached by the Wisconsin ice, but no records have been left to indicate its exact position. On the south rim of the San Miguel Canyon the Durango ice spread over the mesa north of Diamond Hill for at least 2 miles beyond the limit of the Wisconsin ice.

On the southern slope of Iron Mountain there is a broad basin at the head of Remine Creek, one of the tributaries of the San Miguel River. This basin was apparently not occupied by glacial ice during the Wisconsin stage but was the site of a considerable glacier during Durango time. This glacier apparently did not extend far enough down Remine Creek to coalesce with the glacier in the San Miguel Valley.

Mount Wilson group.—The glaciers that radiated from the central peaks of the Mount Wilson group, near the west margin of the Telluride quadrangle, during the Durango stage were all slightly larger than those that occupied the same region in Wisconsin time. To the north the Durango ice moved about a mile farther down the valleys of Big Bear Creek and Muddy Creek than the later ice. Similarly on the south the Durango glacier in the valley of Kilpacker Creek was at least a mile longer than the Wisconsin glacier in the same valley.

East Dolores River.—The East Dolores Glacier of Durango age stood several hundred feet higher on each wall of that valley and reached a mile farther downstream than the Wisconsin ice. The uplands at the head of the East Dolores in the northern part of the Engineer Mountain quadrangle rise only to altitudes of 11,500 to 12,000 feet and are bordered on the east by Sliderock Ridge, the summit altitude of which is only 12,428 feet. These altitudes were apparently not sufficient to permit the formation of ice during the Wisconsin stage. They were, however, great enough to cause ice to accumulate in the Durango stage, when the head of the East Dolores River was occupied by a small glacier that was augmented downstream by tributary glaciers from the Sheep Mountain and San Miguel Peak region.

Hermosa Mountain.—None of the streams that rise on the flanks of Hermosa Mountain were affected by ice during the Wisconsin glacial stage, but several of their valleys were filled with glaciers during the Durango stage. Thus a Durango glacier with its head on the northwest slope of Hermosa Mountain extended for a distance of 5 miles down Barlow Creek and reached almost to the mouth of that stream near Bennett's ranch. The North Fork of Hermosa Creek was likewise the site of a Durango glacier, which seems to have had at least three catchment basins. One of these was on the west slope of Graysill Mountain, another was on the southeast side of Hermosa Mountain, and the third was on the east slope of the easternmost peaks of the Rico Mountains south of Section Point. This compound glacier covered an area of about 20 square miles and had a maximum length of nearly 6 miles.

On the southern slope of Graysill Mountain west of Grayrock Peak there is an amphitheater which was apparently carved into its cirquelike form by Durango ice but was unoccupied during Wisconsin time. From this basin a small glacier moved southward about 3 miles and presumably was confluent with the East Fork lobe of the Animas Glacier, which invaded the Hermosa Park region from the east.

Rico Mountains.—Glacial records in the Rico Mountains are extremely meager, and they have not been studied by us in great detail. It is therefore impossible to describe accurately the Durango glaciers which occupied that region. In a general way it may be stated, however, that the Durango glaciers were very much more extensive than their successors during the Wisconsin stage. Numerous basins, especially in the West Rico Mountains, which had not sufficient altitude to catch ice during the Wisconsin stage served as catchment basins for the ice in the earlier stage.

La Plata Mountains.—The glaciers that formed in the La Plata Mountains during the Durango stage were in general somewhat more extensive than those of the Wisconsin stage, although in certain valleys, such as that at the head of the East Mancos River, no record of Durango ice was recognized by us. The glacier in the La Plata Valley was large enough to spread widely south of Parrott during Durango time; during the Wisconsin stage the glacier was a narrow tongue reaching less than a mile beyond Parrott. Again, the great basin southwest of Jackson Ridge and north of Helmet Peak was occupied by Durango ice, although it was not affected by glaciation during the Wisconsin stage.

ALTITUDE OF CATCHMENT BASINS

The altitude of some of the basins in which ice formed during the Durango stage was appreciably lower than that necessary for the formation of Wisconsin ice. Apparently every basin that served as a source of supply for the Wisconsin glaciers was also occupied during the earlier Durango stage by ice fields and névé. In addition other basins, such as those referred to in the preceding paragraph, in which no ice formed during the Wisconsin stage were occupied by ice fields during Durango time. In general, any basin with a floor higher than 11,000 feet above sea level and with rims rising 500 feet or more above the floor was a suitable gathering ground for Durango ice. In comparison with the Wisconsin basins, then, some of the Durango cirques were formed at altitudes about 500 feet lower than was necessary for the formation of glaciers during the later stage.

ALTITUDE OF TERMINAL MORAINES

A similar correspondence between the dimensions of a glacier and the altitude of its terminal moraine to that noted in connection with the Wisconsin ice is displayed by the Durango glaciers. In keeping with their generally larger dimensions the Durango glaciers ordinarily attained altitudes a few hundred feet lower than those of their Wisconsin successors in the same valleys. The largest of the Durango glaciers, that in the valley of the Animas River, terminated at 6,800 feet above sea level, whereas one of the smallest of the Durango glaciers, that in the valley of Remine Creek, seems to have descended only to 9,300 feet. Between these two limits Durango glaciers in different valleys reached many intermediate altitudes.

EFFECTS OF DURANGO GLACIATION

The topographic effects of the Durango glaciation are not nearly so pronounced as those of the more recent Wisconsin ice because of the length of time during which the topographic features carved by the Durango ice have been exposed to subsequent erosion. The cirques formed in Durango time were either greatly modified by the glaciers of Wisconsin time or else have been changed by subsequent stream erosion and rock weathering. In general it should be noted that the remarkable amphitheaters and basins of the strongly glaciated central portion of the range are not to be placed solely to the credit of Wisconsin ice. The first steps in their formation were taken in Durango time. It was the repeated ice action rather than the single episode of glaciation that has given them their remarkable form.

FLUVIOGLACIAL STREAMS

The fluvioglacial accompaniment of the Durango ice was practically identical with that which affected the streams during Wisconsin time. In the earlier as well as the later glacial stage large volumes of silt-laden water rushed for great distances down the valleys in whose upper portions ice was present. In general the width of the flood plains over which these streams from the Durango ice were flowing was closely similar to or slightly greater than the width of the later Wisconsin flood plains.

CERRO GLACIATION

Because of its remoteness and the great changes that have taken place since its occurrence the glaciation of the Cerro stage is not recorded completely. The fragmentary record now available for study falls far short of fulfilling our desires for information concerning that glaciation. Much of the description of the Cerro Glaciers must be based upon inferences, but those inferences are drawn from well-established facts.

The Cerro glaciation was by far the most extensive in the San Juan region. Large areas in the mountains must have been covered by ice sheets. Great piedmont glaciers formed at the base of the range and moved for many miles beyond the foothills. The Cerro ice was not restricted to mountain valleys like the later ice, but overtopped the divides and extended far beyond the mountain fronts.

On the north side of the range at least three-fourths of the Montrose quadrangle was buried beneath the ice of the Cerro stage. A great piedmont glacier moved from the front of the mountains northward for at least 17 miles, to some point north of Horsefly Peak, on the Uncompahgre Plateau. The topography of the region over which this glacier traveled must have been very unlike that of the present day, for only a few scattered remnants of its glaciated floor now remain as the higher hills and divides at the west margin of the Uncompahgre Valley. East of the present course of the Uncompahgre River ice of this same stage moved still farther northward, covering all the land in the vicinity of Cerro Summit and creeping to the very rim of the Black Canyon of the Gunnison River. On the east this glacier seems to have been held in by the steep rampart of Cimarron Ridge, but north of the Sawtooth Rocks, at the northern extremity of that ridge, the ice spread eastward and crossed Tongue Mesa into the valley of Cimarron Creek. The total area covered by this tremendous glacier north of the range must have closely approximated 500 square miles.

Farther east, in the Uncompahgre quadrangle, the record of Cerro glaciation has been almost entirely obliterated. It is known, however, that at least one large mass of ice moved northward from the vicinity of Uncompahgre Peak for at least 12 miles. In all probability the Cerro ice in that quadrangle was much more extensive than might be inferred from the present record of Cerro glaciation.

On the eastern front of the San Juan Range the records of Cerro glaciation are equally fragmentary. Such as they are, however, they indicate that during the early stage of glaciation much larger areas were covered by ice than during either of the later stages. Here, however, the Cerro ice was confined to the larger valleys in the mountains and did not extend at any point across the bordering lowland. In the valley of the Rio Grande the Cerro glacier pushed many miles downstream beyond the farthest limits of the Durango and Wisconsin ice. Just beyond the terminus of the Durango Glacier the Cerro ice was at least 1,000 feet thick and reached far up on the valley walls, so that its western margin stood along a line 2,000 feet above the modern valley bottom, which is far below the floor of the valley upon which the Cerro Glacier rested.

On the southern slopes of the San Juan Mountains there are excellent records of Cerro glaciation in the Summitville and Pagosa Springs quadrangles. A great ice sheet seems to have formed in the mountains at the head of the San Juan River; from it a huge piedmont glacier must have moved southwestward and covered all the lowland country on both sides of the San Juan and Blanco River Valleys. The area of this glacier beyond the mountain front must have been at least 60 square miles, and its terminus was at least 8 miles from the mountains. The contrast between this widespread glacier deploying over the undulating lowlands beyond the mountains and the narrow glaciers of the Durango and Wisconsin stages confined to single mountain valleys is especially striking.

A few miles farther west another large piedmont glacier extended far from the mountain front in Cerro time. Ice masses from the valleys of the Middle Fork of the Piedra River, Huerto Creek, the Piedra River, and several smaller streams appear to have united to form a single glacier. Its areal extent on the lowland in the Piedra Valley must have been at least 30 square miles, and its terminus was more than 6 miles from the mountain front.

The record of Cerro glaciation on the southwestern front of the mountains is very meager. It is possible that no large bodies of ice were present there, although it is more likely that the apparent absence of glaciation is only apparent, being due to gaps in the record. On the west slope of the La Plata Mountains a piedmont glacier must have moved westward in the valley of the Middle Mancos River to a point at least 4 miles west of Helmet Peak. Farther north, on the west slope of the San Juan Mountains southwest of the Mount Wilson group, a large valley glacier occupied the upper portion of the valley of the East Dolores River during Cerro time but did not extend far beyond the mountain front.

North of the Mount Wilson group there seems to have been another piedmont glacier of Cerro age, which crept northwestward from the mountains around Telluride. Its record is extremely obscure, but at a minimum it reached a point 6 miles from the mountain range, and covered an area of 25 to 30 square miles.

Chapter 7.—LATE TERTIARY (?) AND QUATERNARY FORMATIONS

Unconsolidated or partly indurated deposits of clay, sand, gravel, boulders, till, and other surficial materials mantle the solid rock at many localities in the San Juan region. Some of these deposits are of considerable thickness and great extent, entirely concealing the formations upon which they rest, so that they would be represented on any detailed geologic map. Others occupy only small areas or are of slight thickness, so that they easily escape notice and would not ordinarily be recorded in areal mapping. A mere handful of pebbles inconspicuously scattered over a hilltop may be of great significance in deciphering the later history of the mountains but scarcely deserve a place on the geologic map of customary scale. It has been the aim in the studies upon which this report is based to indicate on maps the location and nature of all materials that have been formed or deposited since the end of the Tertiary volcanic activity, if those materials are of significance in the geologic history of the region or if they effectually hide the character of the solid rock beneath them.

In discriminating between these surficial deposits, which constitute the late Tertiary and Quaternary formations of the region, it is necessary to combine information gained from a study of their topographic expression and relations with that derived from their lithology and composition. Physiography bears the same relation to Quaternary geology as paleontology bears to stratigraphy in general. By its aid formations of similar composition but unlike age may be distinguished.

The drawing of geologic boundaries for Quaternary formations such as those mapped in the San Juan region involves a large personal factor. Sharp contacts, like those marking the boundaries of a dike or separating a calcareous sedimentary rock from an arenaceous rock, are seldom found between surficial deposits of different origin or between a Quaternary formation and soil which has weathered in place. To indicate by a line on a map the contact between two kinds of alluvium which may be observed to blend perfectly into each other requires more of personal judgment than of accuracy in surveying methods. Many of the indicated geologic boundaries should therefore be considered approximate rather than exact. The wide latitude for differences of opinion concerning the limits of surficial deposits should be clearly recognized. The aim here has been to determine accurately the origin and relations of the various kinds of mantle rock and to be consistent throughout the region in the exercise of judgment in mapping their boundaries. In reading this chapter frequent reference should be made to Plate 1 (in pocket).

PLIOCENE OR EARLY PLEISTOCENE DEPOSITS

BAYFIELD GRAVEL

CHARACTER

Scattered over the surface at high levels within the mountain range or on the crests of the foothills are pebbles and boulders which, although comparatively inconspicuous, are of far-reaching significance in the interpretation of San Juan history. These pebbles are invariably rounded and smoothed by long-continued stream wear; in composition they are quite unlike the rocks upon which they rest. They display every evidence of transportation by running water for considerable distances over low gradients. From their occurrence on several hills a few miles north of Bayfield these deposits are here named the Bayfield gravel.

For the most part the Bayfield gravel consists of pebbles less than 5 inches in diameter; many are less than half an inch, and the majority are less than an inch. At some localities, however, these deposits include boulders 10 or 12 inches in diameter, and in at least one place there are boulders 2 to 3 feet long. The harder stones are beautifully polished and waterworn, but those composed of less resistant material are generally deeply weathered.

A great variety of rocks and minerals are represented. Quartzite of a bluish tint, milky-white quartz, dark-red jasper, chert, flint, greenstone, and basalt are the most common. Granite, both gray and pink, andesite, latite, gneiss, black schist, and other igneous or metamorphic rocks have also been identified.

DISTRIBUTION

These deposits are found high above the present drainage channels of the region. In altitude with respect to sea level they range from less than 8,000 feet to more than 13,000 feet, but they are always near the summit levels in the immediate locality where found. Rather commonly they rest upon the surfaces of flat-topped mesas or plateaus; elsewhere they occupy benches or shoulders, cols or divides, 2,000 or 3,000 feet above the major streams and a few hundred feet below the neighboring mountain summits. They are found near the center of the range as well as in the foothills on the south, west, and north.

Ignacio quadrangle.—Remnants of this formation are preserved at several localities within the Ignacio quadrangle on the southern slopes of the San Juan Mountains. It was here that they were first observed and their true significance recognized.[1] Pebbles and cobblestones of bluish quartzite and milky-white quartz, as much as 6 inches in diameter, rest on the highest part of Animas City Mountain, 3½ miles north of Durango, at altitudes up to 8,170 feet. This is the type locality for the formation, although the name Animas has previously been used for a geologic formation and so can not be applied to this gravel. Probably only the gravel above 8,000 or 8,100 feet is in place (where originally deposited); the other pebbles rolled down the dip slope from the mountain summit while the surface upon which they were originally deposited was undergoing dissection.

Pebbles of quartzite, jasper, quartz, and flint cap the divide between the Animas and Florida Rivers near the north margin of the quadrangle, at an altitude of 11,000 feet. Similar gravel occurs on the divide between Junction and Falls Creeks, 7 miles north-northwest of Durango, at altitudes between 9,600 and 9,900 feet. Quartzite, jasper, and quartz pebbles are present at numerous localities in the "hogback" region east of Durango, between the Animas and Los Pinos Rivers. They are scattered over numerous slopes, down which they have been carried by recent wash, but are probably in place on the highest points of several hills at the heads of Wallace Gulch and the South Fork of Texas Creek, at altitudes between 8,100 and 8,200 feet.

East of the Los Pinos River, between 3 and 5 miles north of Bayfield, are a number of flat-topped hills rising to altitudes of 7,550 to 7,800 feet. Several of these hills are capped with scattered pebbles, cobblestones, and boulders, which reach 10 inches in maximum diameter. Among these are pebbles of Vallecito conglomerate, fine-grained black schist, and banded quartzite, as well as the common constituents of the Bayfield gravel. Southeast of Bayfield a long, flat-topped mountain of the mesa type forms the divide between the drainage basins of the Los Pinos and Piedra Rivers and attains an altitude of about 8,500 feet. The greater part of its summit is east of the Ignacio quadrangle, in the Pagosa Springs quadrangle. Its surface is capped with a heavy mantle of gravel, in places more than 20 feet thick, and locally cemented by caliche into a fairly firm conglomerate. This is the only place on the south side of the range where the Bayfield gravel has been observed to form a deposit more than a foot in thickness. Elsewhere it consists of a mere scattering of pebbles.

Engineer Mountain quadrangle.—Much of the Engineer Mountain quadrangle is a dissected plateau that connects the western peaks of the San Juan Range with the lesser domes of the Rico and La Plata Mountains, bordering the main mountain system on the west. Bayfield gravel is preserved in at least two localities within the quadrangle. Pebbles and small boulders of quartzite, chert, granite, quartz, and gneiss, ranging from 2 to 10 inches in diameter, occur at an altitude of 10,200 feet on the summit overlooking the Hermosa Cliffs, 2 miles west of the Ignacio Reservoir dam. Similar waterworn gravel is reported by Iddings to occur on Graysill Mountain, in the north-central part of the quadrangle, at altitudes of 11,700 to 11,800 feet, where it rests on the broad, flat summit of the mountain mass at the base of one of the smaller knolls that rise 300 or 400 feet higher.

There are several other areas within this quadrangle which present fairly broad surfaces at the appropriate height for this formation and which have not been glaciated. Some of these tracts, such as the divide between the Dolores and Hermosa drainage systems, are mantled with pebbles resembling in composition and appearance the Bayfield gravel, but these pebbles may be largely or entirely of local origin, having weathered out of the Cutler formation, a conglomerate of Paleozoic age. It is only in localities so situated that all possibility of immediate derivation from the Cutler formation is excluded that the Bayfield gravel may be identified with certainty.

San Cristobal quadrangle.—The San Cristobal quadrangle is an area of extremely rugged topography at the very center of the San Juan Range. All except the western corners of the quadrangle is underlain by volcanic rocks. On the summit of the Continental Divide about 1½ miles east of Carson, in the northwest quarter of the quadrangle, at an altitude between 13,200 and 13,300 feet, there are at least 46 granite boulders, as much as 4 feet in diameter, some of which are beautifully rounded and polished and all of which are distinctly waterworn. These boulders are at least 20 miles from their source. They show no traces of glaciation and are apparently above the limits of ice action; indeed, it would be far more difficult to explain them as the result of transportation by ice than by running water. They rest upon lava and agglomerate of Potosi age.

In the southeast corner of the quadrangle is a gently sloping surface extending northward from the 12,880-foot hill (Green Mountain), which might be expected from its physiographic relations to carry Bayfield gravel. Resting on the Potosi volcanic rocks that form this small upland area there was noted a single pebble of fine-grained granite. It was about 3 inches in diameter and fairly well rounded, although not distinctly waterworn, and may represent this formation.

There are many other upland flats and benches in this and neighboring quadrangles which display the same physiographic relations as those shown by the surface upon which the Bayfield gravel rests. Many

[1] Atwood, W. W., Physiographic studies in the San Juan district of Colorado: Jour. Geology, vol. 19, pp. 449–453, 1911.

of these areas, however, have been repeatedly glaciated and must thereby have lost whatever gravel deposits they may have received in preglacial time. American Flat, in the northeast corner of the Silverton quadrangle and the southeast corner of the Montrose quadrangle, is typical of such surfaces swept clean of all glacial and preglacial detritus. Other areas have been searched carefully for remnants of the Bayfield gravel without success. It is, perhaps, more to be wondered at that there are any recognizable relics of this oldest of surficial deposits than that there are so few to be reported within the heart of the mountain range.

Uncompahgre quadrangle.—The greater part of the Uncompahgre quadrangle falls within the deeply dissected plateau that borders the San Juan Range on the north, but the southwest corner of the quadrangle includes several of the most rugged peaks of the range. At several localities there are divides, mesas, or plateaus attaining an altitude comparable with that of the surfaces beneath the Bayfield gravel elsewhere. Some of these gently undulating upland surfaces carry a scattering of gravel, many of the stones of which are well rounded and apparently waterworn but all of which may be of local origin so far as their lithology is concerned, for no pebbles of other than volcanic rock were observed. On the assumption that such localities received no wash from the pre-Cambrian rocks that crop out 20 to 40 miles away toward the north, west, and south, their surficial mantle might be tentatively interpreted as remnants of the Bayfield gravel. They have not, however, been indicated as such on the maps we have drawn, as we recognize the possibility that they may be entirely of local origin.

The Gunnison Canyon, which traverses the northern part of the quadrangle, is bordered on both sides by high mesas separated by the youthful valleys of tributary streams. Certain of these mesas carry deposits of boulders, cobbles, and pebbles closely resembling ancient stream gravel that has been deeply weathered. The materials, however, are all volcanic, largely basic effusive rocks and glass, and are of local origin. They have resulted from the disintegration of a volcanic agglomerate, the West Elk breccia, which may be seen at numerous outcrops in this locality.

Gravel of very different lithologic composition has been noted at four places in this vicinity. It consists of pebbles of quartzite, granite, quartz, chert, greenstone, basalt, and black schist—the typical components of the Bayfield gravel. For the most part the stones are less than 4 inches in diameter, but the deposits include cobbles and boulders as much as a foot in length. All are beautifully polished, rounded, and waterworn. Two of the localities where these deposits of Bayfield gravel have been observed are on the slopes of Carpenter Ridge near its crest, at an altitude of 8,800 feet. At each of these localities the gravel is probably overlain by a thin sheet of Hinsdale basalt. Another remnant of the Bayfield gravel is on Fitzpatrick Mesa near its north margin, at an altitude of 9,200 feet; and the fourth is on the north side of the Gunnison Canyon above the rim of Black Mesa, between 9,000 and 9,200 feet above sea level.

Summitville quadrangle.—Certain parts of the Continental Divide and adjacent upland surfaces in the southeast quarter of the Summitville quadrangle carry deposits of pebbles and boulders, in many places mingled with soil, which from their composition and distribution may be recognized as Bayfield gravel. Three localities are worthy of special notice. Two of these are on the Continental Divide between the head of Elk Creek on the east and the drainage basin of the Navajo River on the west, at altitudes of 12,100 to 12,300 feet. In this part of the quadrangle there are many broad upland surfaces between 11,500 and 12,500 feet above sea level, which because of their striking accordance in altitude and relative smoothness are evidently to be interpreted as remnants of the San Juan peneplain. Many of them have been glaciated, and the two gravel-strewn areas just mentioned were covered by ice during the Wisconsin glacial stage. The Bayfield gravel at these two localities, however, was protected from removal by a cap of basaltic lava, one of the Hinsdale flows.

The third exposure of Bayfield gravel in this corner of the Summitville quadrangle is on the flat divide between the Chama River and the upper reaches of the Los Pinos River. The gravel-strewn area is a large one and extends far eastward into the Conejos quadrangle. In the Summitville quadrangle the gravel is rarely over 100 feet in thickness, and at many localities the formation contains more soil than pebbles. Toward the east, in the Conejos quadrangle, it becomes thicker and coarser, so that 4 or 5 miles east of the Summitville-Conejos boundary line the deposit is over 200 feet thick. Here also the Bayfield gravel has been protected from erosion by a cap of resistant Hinsdale basalt.

Conejos quadrangle.—The large area of Bayfield gravel just referred to is one of many areas in the Conejos quadrangle that are occupied by gravel resting on the peneplain. Inasmuch, however, as the peneplain deposits have somewhat different physiographic relations and very much greater thickness in and near the Conejos quadrangle than in other parts of the San Juan Mountains, the greater part of them will be described in a subsequent section as the Los Pinos gravel.

At the locality just mentioned, at the head of Los Pinos Creek in the southwest quarter of the Conejos quadrangle, the two kinds of peneplain deposits—Bayfield gravel and Los Pinos gravel—blend into each other. Evidently the two were nearly or quite contemporaneous. Subsequent to their deposition the lava of the Hinsdale epoch was poured out upon the lowland plain. Where its surface was strewn with gravel the basalt covered the pebbles. In other localities, where the rocks were bare or covered only with soil, no gravel now intervenes between the basalt and the underlying terranes—for example, on the upland flats west of the Conejos Canyon, north of the tributary Elk Creek, near the west margin of this quadrangle.

ORIGIN

Summarizing these facts concerning the distribution and composition of the Bayfield gravel, we may state that these deposits are found on the surfaces of isolated mesas, on the smooth crests of major divides, or on high gentle slopes near the summits of mountain peaks and that they are composed of resistant materials, many of which may be entirely foreign to the locality where they are found. It is evident that the deposition of these pebbles must have antedated the formation of the present topography of the region; they could have been deposited only at a time before the existing valleys were excavated. Their size, composition, shape, and appearance all suggest that they are for the most part the products of a long period of erosion and were transported by streams with low gradient winding over a surface of low relief. Their accumulation must have taken place when what are now isolated hills were portions of a gently rolling, undulating surface about as near sea level as running water could reduce the region. To such a surface the term " peneplain " may be correctly applied.

Standing upon any remnant of Bayfield gravel, the observer can not fail to be impressed by the remarkable accordance in altitude between the adjacent mesas, plateaus, divides, and summits. (See pl. 21, *A*.) If the peneplain surface is projected across the modern valleys and lowlands, it coincides at many points with the crests of existing land masses whose tops are relics of the ancient topography. Eagerly the physiographer makes note of a dozen localities where other vestiges of the old stream gravel may well be sought. Generally he is doomed to disappointment in his search, for at most places the peneplain surface was a surface of erosion, not of deposition, and in only a few places have the surface deposits been preserved where they were first laid down. But sufficient areas of gravel have been discovered to corroborate unequivocally the conclusion reached from topographic and structural relations that subsequent to the Fisher volcanic epoch the San Juan Mountains were reduced by stream erosion to a region of slight relief.

Projection toward the heart of the mountains of the peneplain upon which rests the Bayfield gravel shows clearly that it does not coincide with the summits of the higher peaks. At many localities there were hills a few hundred feet or even as much as 1,000 feet high which projected as monadnocks above the surrounding lowland. These were doubtless the sources from which streams obtained the Bayfield gravel, and from them the products of mature decomposition and long-continued disintegration were washed outward toward the mouths of the master rivers of that time. It was near certain of these monadnocks that the large boulders were left on what is now the Continental Divide near Carson, for the rivers on the peneplain could not transport them far across the ancient lowland. At many places along the valley floors gravel banks or pebbly bars were deposited by the meandering streams. These would contain a fairly complete assortment of the most resistant materials cropping out within each drainage basin. A modicum of these stream deposits have been so favorably situated as to escape entire destruction during the succeeding cycles of erosion, and they constitute the formation now under consideration. In some localities the gravel has been protected by the cap of Hinsdale basalt which flowed out upon it after its deposition.

The reconstruction of the peneplain as it may be observed anywhere in the San Juan country does not give a strictly accurate picture of the region during the Bayfield epoch, for the surface thus mentally visualized is not even approximately horizontal but is that of a great dome, the center of which is 4,000 or 5,000 feet higher than the periphery. Near Carson, in the midst of the sea of peaks surrounding Uncompahgre Peak, the gravel is at an altitude of 13,200 feet, whereas on Carpenter Ridge, 40 miles to the north, it is only 8,800 feet above sea level. At the north margin of the Ignacio quadrangle the peneplain surface now has an altitude of more than 11,500 feet, but a dozen miles south of that point it has descended to less than 8,500 feet, from which it slopes gently to 7,000 feet at the southern margin of the quadrangle. Obviously, streams with gradients of 100 or 150 feet to the mile will not be spreading a veneer of small pebbles along their courses but will rather be excavating canyons and gorges. It is evident, therefore, that the surface upon which the Bayfield gravel was deposited has been notably deformed since it was laid down.

AGE

The Bayfield gravel was deposited before the earliest known Pleistocene glaciation of the region. Drift of the Cerro glacial stage rests upon the slopes of valleys excavated beneath the peneplain. On the other hand, the peneplain on which the gravel rests was not developed until after the Miocene Fisher volcanic outbursts had ceased. The age of this formation may therefore be Pliocene or very early Pleistocene.

Even if the Cerro glaciation is correlated with the Kansan glacial stage, the second episode of glaciation in the Mississippi Valley—and that is not an improbable correlation—the assertion can not be definitely made that the Bayfield gravel is pre-Pleistocene, though it is certainly pre-Cerro. It seems reasonable that Pleistocene time may date back to include an appreciable interval preceding the Cerro stage. Pre-Cerro erosion of the San Juan peneplain was quantitatively somewhat greater than post-Cerro erosion of the San Juan Mountains, but this difference may be due to differences in relations between base-level and mountain summits or to differences in climate and can not be used as a measure of the actual duration of either erosion cycle.

On the other hand, in compliance with the principle that "diastrophism is the ultimate basis of correlation," an appropriate milestone to mark the beginning of Quaternary time would seem to be the deforming movements that cut short the Peneplain erosion cycle and stopped the spread of the Bayfield gravel over the lowlands that had been produced during that cycle. On that basis this gravel is an upper Pliocene formation, a conclusion that seems to be in harmony with all available facts.

CORRELATION

It is obvious that the crustal stability indicated by the development of the San Juan peneplain, with its scattered deposits of Bayfield gravel, is a condition that would not have been confined to the immediate San Juan region. Such stability of the earth's crust must have been very widespread. It is therefore to be presumed that similar surfaces with old-age features and possibly with comparable deposits of gravel would have been developed in other parts of the Rocky Mountain province at this time. Indeed, it is quite probable that similar conditions produced similar results in other parts of North America outside of the Rocky Mountains. It is therefore desirable to attempt a tentative correlation of the Bayfield gravel with similar deposits in other regions. This correlation is fraught with many dangers. Most of the conclusions must at present be quite tentative. Data for making adequate comparisons are so few that the tendency, because of lack of knowledge, to jump at conclusions that appear reasonable must be strongly curbed. Rarely has it been found possible to date with any degree of accuracy the peneplains and peneplain deposits that have been recognized by many geologists in all parts of North America. It will, however, be of much value to review the literature of this subject, with the hope of assembling facts from which a reasonably adequate picture may be formed of the appearance of other physiographic provinces at the time that the San Juan peneplain was completed.

In making this comparison it will be necessary to consider not merely the formations and deposits that may possibly be correlative with the Bayfield gravel but in addition the formerly graded surfaces that may have been contemporaneous with the San Juan peneplain on which this gravel rests. The following paragraphs dealing with the correlation of the Bayfield gravel will therefore include a discussion of the correlation of the San Juan peneplain with similar physiographic features beyond the boundaries of the San Juan province.

Colorado Front Range.—The numerous broad, flat uplands among the rugged peaks of the Colorado Front Range have been interpreted by many observers as remnants of a former lowland plain.

> After one or more cycles of erosion of whose details little is known, the granite ranges became an imperfect plain, above which unreduced areas remained as scattered monadnocks from 500 to 2,500 feet in height. This peneplain, if such an imperfectly reduced area may be designated by that term, must have extended throughout the region of the Colorado Front Range, for remnants of it are still perceived at many points throughout the range.[2]

Recently Lee [3] has described the peneplain remnants in the Rocky Mountain National Park and elsewhere in the Front Range as belonging to two separate surfaces developed during successive cycles of erosion. The higher and older peneplain remnants are referred to the Flattop peneplain; the lower, younger, and more widespread remnants of a graded surface are described as the product of the Rocky Mountain cycle. Lee's results have been corroborated by a detailed study of the physiography of portions of the Front Range made in 1924 by Little.[4] A reconnaissance through the Front Range and thence by way of the Arkansas Valley to the San Juan region, made by Atwood [5] in 1924, served to correlate definitely the Rocky Mountain peneplain of the Front Range with the San Juan peneplain.

Resting on remnants of the Rocky Mountain peneplain in the general vicinity of Pikes Peak there are a number of scattered deposits of gravel beds lithologically comparable to the Bayfield gravel of the San Juan region. These were apparently first noted by the late George H. Stone, a conversation with whom in 1910, when he was a resident in Colorado Springs, revealed the fact that he had interpreted the gravel beds as the deposits of rivers which in old age were still at work reducing the monadnocks on the Rocky Mountain peneplain surface. Enough gravel had

[2] Davis, W. M., The Colorado Front Range: Assoc. Am. Geographers Annals, vol. 1, p. 40, 1911.

[3] Lee, W. T., Peneplains of the Front Range and Rocky Mountain National Park, Colorado: U. S. Geol. Survey Bull. 730, pp. 1–17, 1922.

[4] Little, H. P., Erosional cycles in the Front Range of Colorado and their correlation: Geol. Soc. America Bull., vol. 36, pp. 495–512, 1925.

[5] Atwood, W. W., paper presented before the Geological Society of America at Washington in 1924.

been noted to lead Professor Stone to hope that the courses of these ancestral rivers might thereby be determined. Apparently the gravel deposits on the uplands in the Front Range are at least in part equivalent in origin and physiographic relations to the Bayfield gravel of the San Juan region.

The Rocky Mountain peneplain has generally been referred to the late Tertiary. Lee,[6] for example, makes the following statement:

> There are some reasons for believing that this orographic disturbance [the deformation of the Rocky Mountain peneplain] marks the beginning of the Quaternary period. The surface gravel of the plain, which seems to have been spread out by streams in the later part of the Rocky Mountain cycle, contains fossil bones said to indicate Pliocene or Pleistocene time. If this dating of the last great uplift of the Rocky Mountains at the beginning of the Quaternary is correct, the canyon cycle of erosion is coextensive with Quaternary time.

Attempting to decipher the relations between the physiographic surfaces in the Front Range and the history of the adjacent portion of the Great Plains, Mather[7] similarly reached the conclusion that the dissection of the Flattop peneplain to form the Rocky Mountain peneplain was more or less contemporaneous with the construction of the High Plains, the materials of which were in large degree derived from erosion in the mountains during the Rocky Mountain cycle. Thus there was developed, near the end of Pliocene time, a graded surface which was the result of degradation in the Front Range and of aggradation in the Great Plains. These conclusions would indicate that the Rocky Mountain peneplain was formed during Pliocene time and was deformed approximately at the end of that epoch.

The studies made in 1924 by Mather also revealed the fact that the Rocky Mountain peneplain, as described by Lee, is equivalent to the Sherman peneplain in the Laramie Mountains, the extension of the Front Range northward in Wyoming. This peneplain was described in 1909 by Blackwelder,[8] who concluded that it was of late Tertiary age.

Wind River Mountains.—The well-developed and prominently displayed peneplain near the summit of the Wind River Mountains and adjacent ranges in western Wyoming has likewise been described by many geologists. Like the San Juan peneplain, that on the Wind River Mountains is surmounted by monadnocks rising a few hundred to 2,000 or 3,000 feet above its general level.[9]

Blackwelder pointed out that the Summit peneplain on the Wind River Mountains must have been developed between middle Miocene and earliest Quaternary time; and at the time of his writing he was inclined to regard the peneplain as of Pliocene age. Other geologists who have described similar features have assigned other dates to that peneplain. Baker[10] refers it to the middle of the Miocene epoch; Westgate and Branson[11] have likewise referred the peneplain in rather general terms to middle Tertiary time.

BRIDGETIMBER GRAVEL

CHARACTER

If the peneplain bearing the Bayfield gravel is projected southward or westward from the mountains, across the peripheral belt of lowlands, it coincides topographically with the surface of such plateaus as the Mesa Mountains, at the southern margin of the Ignacio quadrangle, or the Mesa Verde (pl. 5, *A*), in the southwest corner of the San Juan area. It might be supposed that these peneplain remnants, far removed from the monadnocks of the central massif, would be sprinkled with smaller pebbles and finer gravel than those nearer the headwaters of streams upon the peneplain. On the contrary, the gravel which they carry includes large boulders, many of which are 3 feet in diameter and a few of which attain a length of 5 or even 6 feet. With the larger masses there are also abundant pebbles and finer materials, but no till; the deposit is water-laid. From the excellent exposures of these materials on the summit of Bridge Timber Mountain, at the west margin of the south half of the Ignacio quadrangle, they are named the Bridgetimber gravel.

These bouldery beds include pebbles and cobblestones similar in composition and appearance to the Bayfield gravel and in addition contain rounded boulders and subangular fragments from most of the igneous, sedimentary, and metamorphic rocks that crop out in the San Juan region. The more resistant materials, such as quartzite and jasper, are smoothly polished and waterworn; the less resistant, such as latite and granite, are deeply decayed and much weathered. All have been transported considerable distances by running water.

At certain localities the Bridgetimber gravel comprises a deposit 10 to 20 feet thick, but more commonly it is only 5 or 6 feet thick. Few exposures sufficiently perfect to reveal stratification were discovered.

The two formations described as Bayfield gravel and Bridgetimber gravel both rest upon the same pene-

[6] Lee, W. T., op. cit., p. 17.

[7] Mather, K. F., Physiographic surfaces in the northern part of the Colorado Front Range and their equivalents on the Great Plains: Geol. Soc. America Bull., vol. 36, pp. 134–135, 1925.

[8] Blackwelder, Eliot, Cenozoic history of the Laramie region of Wyoming: Jour. Geology, vol. 17, pp. 429–444, 1909.

[9] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 97–117, 193–217, 307–340, 1915.

[10] Baker, C. L., Notes on the Cenozoic history of central Wyoming: Geol. Soc. America Bull., vol. 23, pp. 73–74, 1912.

[11] Westgate, L. G., and Branson, E. B., The later Cenozoic history of the Wind River Mountains, Wyoming: Jour. Geology, vol. 21, pp. 142–159, 1913.

planed surface. At one locality, near Bayfield, in the Ignacio quadrangle, they seem to intergrade into each other, but elsewhere they are clearly distinguished by the marked difference in the size of their components. In addition, there are no monadnocks rising above the peneplain in the vicinity of the deposits of Bridgetimber gravel, as there invariably are within a few miles of the remnants of Bayfield gravel.

DISTRIBUTION

Ignacio quadrangle.—A typical locality of the Bridgetimber gravel is on the summit of the Mesa Mountains, near the southern margin of the Ignacio quadrangle, between the Animas and Los Pinos Rivers. Boulders and gravel are widespread on the sloping plateau summit from the northern rim, which ranges in altitude from 7,400 to 7,600 feet, to and beyond the quadrangle line at 7,000 and 7,200 feet. The larger stones consist of banded quartzite from the Algonkian Uncompahgre formation, which crops out in the upper courses of the Animas, Florida, and Los Pinos Rivers; deeply weathered granite, among which may be recognized the Eolus granite of the Needle Mountains; diorite, also much weathered, derived from the intrusive rocks of the La Plata Mountains; and grit such as is characteristic of the lower part of the Dakota (?) sandstone. The smaller pebbles include in addition quartz, chert, flint, and jasper; hornblende schist from the Archean (?) of the Animas Valley; greenstone from Irving Peak and its vicinity, near the headwaters of Vallecito Creek and the Los Pinos River; and an occasional pebble of rhyolite or other silicic volcanic rock.

As thus noted, the great majority of these stones, boulders 3 or 4 feet in diameter as well as pebbles of small size, must have been transported more than 25 miles from the nearest outcrops that represent their source. These outcrops are all within the higher mountain groups near the central part of the San Juan Range, where the altitudes range from 9,000 to 14,500 feet above the sea.

Among these far-traveled stones, those composed of diorite and hornblende schist have not been observed in the fluvioglacial gravel along the Florida and Los Pinos Rivers but are present, though not nearly so weathered, in the terraces on the Animas. The conspicuous Vallecito conglomerate, boulders of which are very abundant along the Los Pinos River, does not appear among the Bridgetimber boulders on the Mesa Mountains except at the east end, within a few miles of that river.

Similar débris caps the plateau of identical topographic expression east of the Los Pinos River, the northern part of which falls within the Ignacio quadrangle 3 miles east of La Boca. As stated above (p. 89), Bridge Timber Mountain, west of the Animas, is likewise veneered with boulders and gravel in beds which in places are nearly or quite 20 feet thick. At this locality, however, the materials are somewhat different from the assemblage on the Mesa Mountains. The Vallecito conglomerate is, of course, missing, and the most frequently observed rocks are diorite and monzonite, many of which are porphyritic, and white, pink, or mottled sandstones from the La Plata Mountains.

Largo quadrangle.—A reconnaissance down the Los Pinos River to the San Juan, made in 1910, revealed the fact that the Bridgetimber gravel caps the plateau on both sides of the Los Pinos River as far as the rim of the San Juan Valley. These plateau surfaces are in reality merely the southward extensions of the Mesa Mountains. At 50 miles from the San Juan foothills the larger boulders of this formation have diameters as great as 3 feet. Doubtless this boulder gravel extends great distances southward on the plateaus of New Mexico, and presumably the constituents decrease in size with increase in distance from their source.

La Plata quadrangle.—The scattered boulders found by Cross and Spencer [12] on the upland surface north of the Ute coal mine, in the La Plata quadrangle, are probably a part of this formation, although it is possible that they should be referred to the Bayfield gravel.

The flat tops of the Rampart Hills and the surfaces of neighboring uplands near the source of the West Mancos River in the northwestern part of the quadrangle carry a scattered deposit of boulders, probably from the Bridgetimber gravel, at altitudes between 9,300 and 9,800 feet. These boulders are nearer to their sources in the mountains than any other portions of this formation that have been recognized in the San Juan region. Their composition indicates that they were derived from the intrusive and deformed sedimentary rocks of the La Plata dome.

Similar scattered boulders were noted at altitudes between 8,400 and 8,600 feet on the summit of Menefee Mountain, in the far southwest corner of this quadrangle and extending into the area shown on the topographic map of Mesa Verde National Park at a point 2½ miles southeast of Mancos. The east spur of this bifurcated mountain has apparently lost whatever mantle of Bridgetimber gravel it once may have had, but at several places on the west spur, in the S. ½ sec. 35, T. 35 N., R. 13 W., there are a few patches of what must once have been a much more widespread deposit. Among the boulders there is a great variety of sandstone, some of which is slightly quartzitic; two or three kinds of fine-grained basic igneous rock, presumably derived from some of the

[12] Cross, Whitman, and Spencer, A. C., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 5, 1899.

sills or dikes of the La Plata Mountains; the easily recognized diorite, diorite porphyry, and monzonite porphyry of the larger intrusive masses of the same region; and an occasional cobblestone of vein quartz. The larger stones have a diameter of about 2 feet; the majority are between 6 and 10 inches in diameter. The dioritic rocks are especially weathered, but all have apparently been exposed to the decaying influence of the atmosphere for a long time since they were dropped by the rivers whose currents had induced their rounded or subangular outlines.

Mesa Verde National Park.—Scattered over the surfaces of the much dissected Mesa Verde are many pebbles and cobbles, beautifully worn and polished, which must have come from the San Juan Mountains and traveled southwestward in stream courses on the ancient upland surface before the present valleys were developed.[13] These doubtless represent the Bridgetimber gravel of that area, although to-day they are so inconspicuous that they may easily escape observation.

At the north end of Big Mesa, which is between Whites Canyon and the Mancos River, near the east margin of the Mesa Verde, there is a considerable deposit of pebbles, cobblestones, and small boulders. These are for the most part beautifully polished specimens of the very hardest materials available for transportation by the streams flowing from the mountains to the bordering plateau surfaces. Many varieties of quartz and jasper form the smaller pebbles, and they are believed to represent the débris spread along stream channels during the later stages of the formation of the San Juan peneplain. Scattered about on this same mesa surface and associated with the peneplain gravel are cobblestones and small boulders, which are interpreted as remnants of the boulder deposits washed out from the mountains soon after the peneplain was uplifted and the streams rejuvenated.

Soda Canyon quadrangle.—In the west-central portion of the Soda Canyon quadrangle, and on the surface of the mesa just west of the point at which Soda Canyon meets the main canyon of the Mancos River, there is a large area mantled with Bridgetimber gravel. Jesse L. Nusbaum, superintendent of the Mesa Verde National Park, discovered this deposit and has reported that it covers at least 300 acres. The individual stones reach 18 inches in diameter and are mingled with gravel. Among the stones are specimens of granite, schist, banded slate, quartz, and greenstone. Such rocks are characteristic of the gravel and boulders on the San Juan peneplain to the south and southwest of the range. Their source was within the central portion of the San Juan Mountain area, where the pre-Cambrian rocks appear at the surface and yield fragments to the streams. This discovery is a most welcome addition to the chain of evidence supporting the argument for the peneplain in the San Juan region and the extension of that peneplain far out over the bordering plateaus.

Uncompahgre quadrangle.—Only one deposit that could possibly represent the Bridgetimber gravel has been observed on the north side of the San Juan Mountains, and it is thus identified with some doubt as to the correctness of the interpretation. On the surface of Big Mesa, in the northeast corner of the Uncompahgre quadrangle, are many small pebbles of quartz, quartzite, granite, greenstone, and black schist, and a few boulders of quartzite or quartzite conglomerate, some of which are 4 feet in length. Many of the pebbles and boulders are well rounded, but most of them are subangular in outline. They rest upon Tertiary volcanic rocks, which are in turn underlain by pre-Cambrian rocks, and they are evidently products of transportation from a considerable distance. Big Mesa has an altitude of 8,500 to 8,700 feet and is the highest land in that vicinity. In composition and relations to their environment these pebbles and boulders resemble so closely those of the Bridgetimber gravel on the south side of the range that it is possible that all belong to the same formation.

Del Norte quadrangle.—On the northeast side of the Rio Grande, opposite Sevenmile Plaza, near the center of the Del Norte quadrangle, there is a deposit of gravel which may be tentatively correlated with the Bridgetimber gravel in other parts of the range. The gravel at this locality forms a mesa about a third of a mile long from east to west and nearly as broad from north to south. The downstream end of this mesa, toward the southeast, is only 10 or 15 feet above the present stream channel of the Rio Grande and almost merges into the flood-plain alluvium. Its surface, however, rises rapidly upstream, so that at the northwest the mesa is between 125 and 150 feet above the river. The mesa is composed entirely of sand, gravel, and boulders, all stream laid. In many places the stratification is excellent, and at some exposures cross-bedding was observed. A rough division into zones of gravel, of coarse boulders, and of sand is conspicuous.

The larger boulders of this deposit are mostly not over a foot in major diameter, but a few stones 2 feet or more in diameter were seen. All are well rounded by stream wear. They consist of a great variety of volcanic rocks; careful search revealed but one granite pebble and no quartzite. Boulders of quartzite and granite are abundant in the modern stream deposit at the foot of the escarpments bounding the mesa. The lithology and topography of the mesa suggest that it is a remnant of a deposit made when the headwaters of the Rio Grande were not engaged as they are now in the vigorous dissection of

[13] Atwood, W. W., A geographic study of the Mesa Verde: Assoc. Am. Geographers Annals, vol. 1, pp. 95–100, 1912.

the pre-Cambrian terranes in the San Cristobal and Silverton quadrangles. The deposit is, therefore, a very ancient one. It can scarcely be correlated with the somewhat similar remnants of the Florida gravel a few miles farther south, because of its excessively tilted surface and its greater distance from the mountain front. All the data available concerning it are in harmony with the conclusion that this is a remnant of the Bridgetimber gravel, which formerly must have been widespread along the east front of the range.

Southeastern margin of the San Juan region.—All along the eastern front of the San Juan Mountains in the Conejos quadrangle and to the south in Rio Arriba County, N. Mex., and extending far to the east, there are thick deposits of boulders, gravel, sand, and clay which are evidently the local equivalent of the Bridgetimber gravel. These deposits, however, are overlain by one or more sheets of basalt and in places are interstratified with similar basaltic flows or with beds of volcanic tuff. Cross and Larsen [14] have applied the name Los Pinos to the gravel. It seems appropriate for us to use this name as the designation of the peneplain deposits in the area referred to. The Los Pinos gravel therefore receives separate treatment in subsequent pages of this report.

ORIGIN

As indicated by the details of composition and distribution stated above, the Bridgetimber gravel rests upon remnants of the same graded surface occupied by the Bayfield gravel but at greater distances from the monadnocks at the heart of the range. Obviously the streams that deposited small pebbles near their sources could not at the same time transport large boulders to distant places. The two deposits, in spite of their similar physiographic relations, demand unlike conditions, especially as regards stream velocity and gradient.

It is believed [15] that at the end of the cycle of erosion during which the San Juan peneplain was developed and subsequent to the deposition of the Bayfield gravel along the stream courses on that peneplain there was a general crustal elevation of the San Juan region. Uplift was considerably greater in the area now occupied by mountains than it was in the surrounding area. As a result a number of domes—the San Juan dome, La Plata dome, Rico dome, and others—were elevated 1,000 to 3,000 feet above the general flat-lying land mass. The headwaters of the streams in the uplifted areas were so rejuvenated that they carried, together with sand and gravel, many large boulders to the base of the range and spread that material in alluvial fans over the neighboring surfaces. The streams that now cross the plateaus south and west of the San Juan Mountains were also rejuvenated in their lower courses as a result of the regional uplift. As rejuvenation worked upstream and canyons were cut among the broad plateaus, the growth of the great alluvial fans ceased, and their dissection began. The Bridgetimber gravel is therefore a deposit which marks the beginning of the new cycle of erosion among the headwaters of the master streams and is the result of a temporary period of alluviation in the zone around the margin of the San Juan dome.

AGE AND CORRELATION

As thus interpreted, the Bridgetimber gravel may be a little more recent than the Bayfield gravel of the mountain area. Both are preglacial, and both may be as old as Pliocene. If, however, the regional uplift and local doming that deformed the peneplain is considered as marking the transition from Tertiary to Quaternary time, the Bridgetimber gravel must be considered the earliest Pleistocene formation that has been recognized in the San Juan Mountains, for its deposition immediately followed that diastrophic disturbance.

At many places throughout the Cordilleran region of North and South America there are deposits of boulders bearing somewhat the same relations to their environment as those described above as characteristic of the Bridgetimber gravel. In the absence of fossils or other specific evidence concerning their age, it is extremely hazardous to attempt anything like definite correlations between these varied deposits.

LOS PINOS GRAVEL

CHARACTER

In and near the Conejos quadrangle, at the southeast margin of the San Juan region, the San Juan peneplain, elsewhere covered in part by the Bayfield and Bridgetimber gravels, is buried beneath a deposit of gravel, sand, tuff, boulders, and lava flows, which in places aggregate more than 500 feet in thickness. This change in the deposits on the peneplain is clearly demarked at the eastern margin of the Summitville quadrangle and in the western part of the Conejos quadrangle. At some localities in each of these two quadrangles dark flows of Hinsdale basalt rest directly upon the remnants of the peneplain, the surface on which these lavas were extruded before the carving of such canyons as that of the Conejos River and its tributary Elk Creek. At other localities a sheet of gravel and boulders of varying thickness intervenes between the peneplaned surface and the Hinsdale basalt. Obviously the gravel was spread by running waters upon the peneplaned lowland before the outpouring of the

[14] Cross, Whitman, and Larsen, E. S., A brief review of the geology of the San Juan region of southwestern Colorado (in preparation).

[15] Atwood, W. W., Physiographic studies in the San Juan district of Colorado: Jour. Geology, vol. 19, pp. 449–453, 1911.

basalt. Close to the Summitville-Conejos boundary line this deposit of gravel is comparatively thin, approximating 100 feet in thickness, and it has there been considered an integral part of the Bayfield gravel (p. 86). Farther east the gravel beds become very much thicker, and the name Los Pinos applied to them by Cross and Larsen, from their exposures in the canyon of Los Pinos Creek near the town of San Miguel, in the extreme northern part of New Mexico, will be used to designate them. This place is 10 or 12 miles southwest of Antonito, Colo.

The Los Pinos gravel is an extremely variable formation of stream-laid boulders, gravel, and sand, which in some localities contains intercalated beds of light-gray silicic tuff. The pebbles and cobblestones contained in it include a great variety of rocks derived from the erosion of the pre-Hinsdale volcanic rocks of the San Juan region. In localities so situated that the streams depositing the Los Pinos gravel had access to pre-Cambrian granite, schist, and quartzite there is a variable proportion of stones derived from these terranes. Everywhere the deposit is evidently water-laid. Gravel beds separated by thinner strata of fine sand and locally even by layers of clay are conspicuous features. Cross-bedding is sufficiently common to suggest that the deposit partakes of the nature of torrential wash. In every respect it appears to be the result of the same sort of geologic processes as those that deposited the bouldery Bridgetimber gravel, except for the beds of volcanic ejecta and the lava flows commonly found near or at its top.

The Los Pinos gravel appears to have been generally covered by one or more sheets of Hinsdale basalt ranging from 50 to 100 feet in thickness. These flows are in places separated from each other by thin beds of volcanic tuff, loosely cemented and sufficiently stratified to make clear the fact that the fine products of volcanic eruption were transported some distance by running water before they came to rest.

The Los Pinos gravel ranges in thickness from a few feet to more than 500 feet. In general the deposit is thicker toward the east, where it disappears beneath the floor of San Luis Valley, than toward the west, where the frayed remnants occupy the interstream uplands.

DISTRIBUTION

Conejos quadrangle.—The Los Pinos gravel is conspicuous throughout the middle of the Conejos quadrangle from Alamosa Creek southward. Excellent and readily accessible exposures are found in the steep bluff bordering the south side of the valley flat of the Conejos River 3 miles upstream from Mogote and overlooking the State automobile highway. About 500 feet of gravel, sand, tuff, and boulders are here exposed. The beds dip very gently eastward and are overlain by typical Hinsdale basalt, perfectly conformable to the gravel beds. Similar strata form the steep escarpment on the north side of the river and continue northward from Los Mogotes. Toward the east both gravel and basalt descend until they disappear beneath the alluvium of San Luis Valley. Westward they rise until the floor beneath the gravel becomes the intervalley upland.

Between La Jara and Alamosa Creeks there are many excellent exposures of the Los Pinos gravel and the Hinsdale volcanic series. The large flat gravel mesa 2 miles northwest of Center is one of the northern outposts of Los Pinos gravel from which the basalt capping has been entirely removed. Its similarity in composition, topography, and physiographic relations to the smaller mesa near Sevenmile Plaza, in the Del Norte quadrangle, described as a part of the Bridgetimber gravel, is noteworthy.

The floor on which the Los Pinos gravel rests is fairly smooth, with only the minor undulations of any well-graded erosion surface. It slopes eastward with a gradient averaging between 200 and 300 feet to the mile. This is much steeper than the gradient of the eastward-flowing streams. La Jara Creek, for example, flows eastward through a canyon which in T. 34 N., R. 6 E., is cut almost 1,000 feet below a somewhat dissected plateau carrying scattered patches of Los Pinos gravel, remnants only a few feet thick of a once much thicker and more widespread formation. Toward the east the patches of Los Pinos gravel increase in size and finally become a continuous sheet, descending to form the canyon walls. In the southwest quarter of T. 34 N., R. 7 E., the gravel is less than 200 feet thick and is capped by basalt flows. In sec. 28 of this township the easterly dip of the gravel carries its base below the floor of the canyon, and its increase in thickness permits it to form the entire canyon walls, 500 feet high. Here there are scattered lenticular masses of basalt recurring at different horizons among the gravel beds. Farther downstream, toward the northeast, the gravel and basalt descend to lower and lower altitudes, the canyon becomes shallower, and finally near the mouth of La Jara Canyon the gravel disappears below the modern alluvium.

South of the Conejos Canyon the patches of Los Pinos gravel are a conspicuous feature on the surface of the plateau on both sides of Toltec Gorge. Osier Mountain is a mesalike eminence rising steeply to a height of 500 feet above the undulating surface of the plateau between the Conejos and Los Pinos Canyons. It is composed of Los Pinos gravel overlain by a protective cap of Hinsdale basalt.

Throughout the Conejos quadrangle it is very common for the Los Pinos gravel to rest upon an eroded

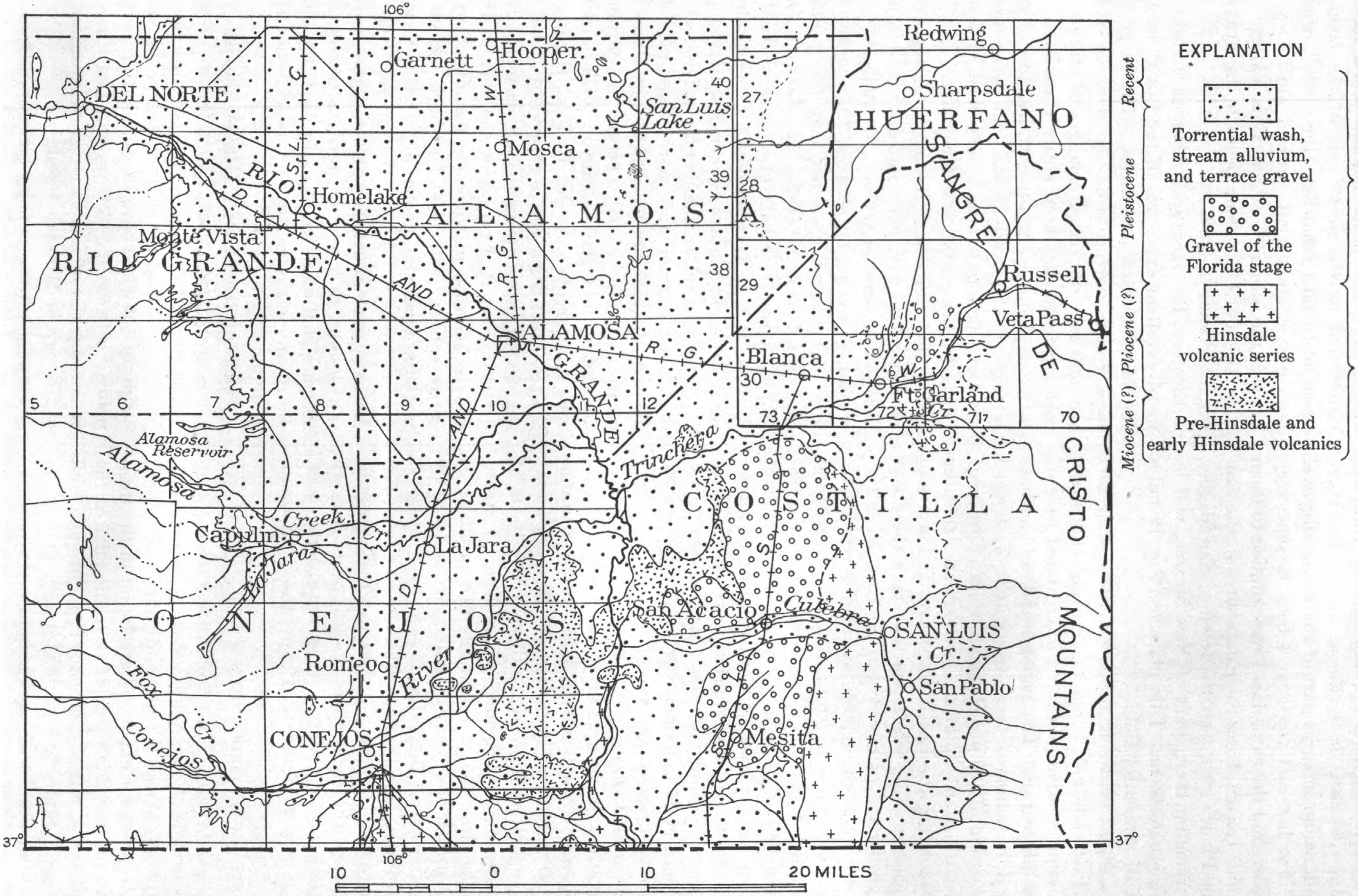


FIGURE 9.—Map of San Luis Valley, Colorado, showing areal geology

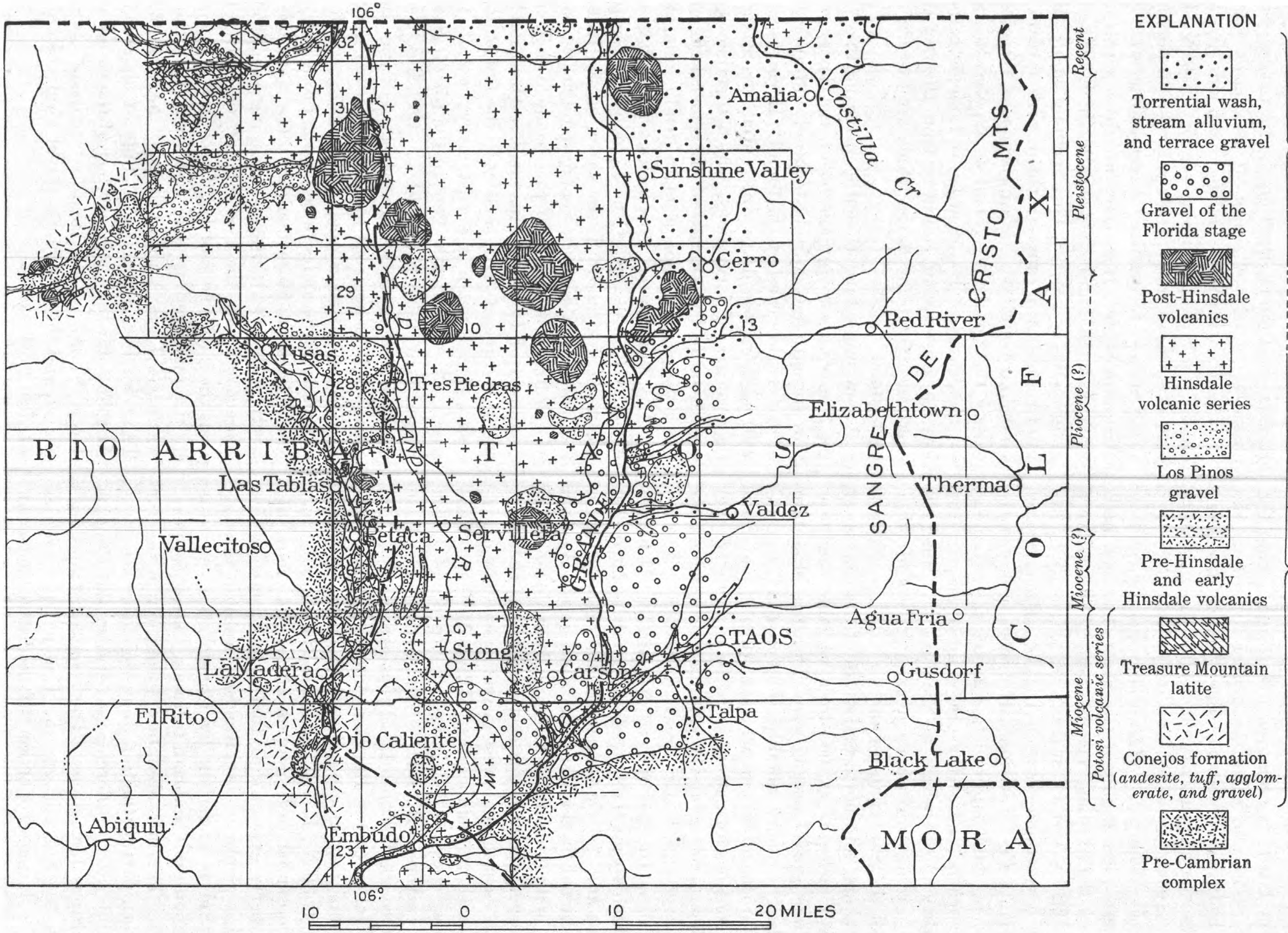


FIGURE 10.—Map of San Luis Valley, New Mexico, showing areal geology

surface of Treasure Mountain latite which seems to have been exposed on the peneplain over considerable areas. In some localities, however, as between Big Horn Creek and Massey Gulch, in and near T. 32 N., R. 7 E., the latite was removed by erosion during the peneplain cycle, and there the gravel rests upon the andesitic breccias and flows of the Conejos formation, which elsewhere generally underlie the Treasure Mountain lavas.

Rio Arriba County, N. Mex.—The region adjoining the Conejos quadrangle on the south has not been mapped in detail, but reconnaissance studies were made in 1922 by Mather in this area primarily to determine the relations between the Los Pinos gravel and the Santa Fe formation. His work was greatly facilitated by data supplied to him by E. S. Larsen, who had spent a part of the preceding summer in the same locality and to whom we are especially indebted for much valuable information about this and other portions of the San Juan region.

The uplands, both north and south of the canyon of Los Pinos Creek, are capped by a variable thickness of Los Pinos gravel resting upon Treasure Mountain latite, which is here notably thinner than it commonly is to the north and which in turn is underlain by the Conejos formation. The Los Pinos gravel thins to disappearance in the vicinity of the tributaries Beaver Creek and Toltec Creek, in R. 6 E. Toward the east it is thicker and is overlain by Hinsdale basalt, which forms the cap of the small isolated Big Horn Peak and the wide eastward-sloping mesas traversed or skirted by the Denver & Rio Grande Western Railroad as it climbs from Antonito toward the rim of Toltec Gorge. The regular eastward dip of the Hinsdale basalt carries the lowest gravel beds below drainage level a short distance east of San Miguel. Thus the narrow, steep-walled gorge of Los Pinos Creek where it traverses R. 8 E. is cut through Hinsdale basalt 200 to 400 feet into Los Pinos gravel.

In the valley of the Rio San Antonio, 2 miles upstream from the mouth of the tributary Nutritus Creek, in T. 30 N., R. 7 E., the Los Pinos gravel may be again observed resting upon latite, but this is the most southerly exposure of that type of lava which was noted. South of the Rio San Antonio the Los Pinos gravel is underlain by Conejos beds or rests directly upon pre-Cambrian terranes. The disappearance of the Treasure Mountain formation in the far southeastern part of the San Juan region makes it extremely difficult to differentiate between the Conejos and Los Pinos formations. The typical Conejos formation in the Summitville and Conejos quadrangles contains a large proportion of andesitic material, which there characterizes most of its beds. It is an extremely variable volcanic agglomerate with intervening flows of andesite. In places in the Summitville quadrangle a considerable thickness of the Conejos formation consists of stream-laid gravel and boulders with little or no débris derived directly from volcanic outbursts. Toward the southeast, in and near Rio Arriba County, the Conejos formation changes in character, chiefly by reason of its smaller proportion of volcanic materials. On the north side of the valley of the Rio San Antonio in sec. 5, T. 30 N., R. 7 E., lava flows are confined to the upper 40 or 50 feet of the Conejos formation, directly beneath Treasure Mountain latite. Here there are thick sheets of somewhat brecciated andesite beneath which 400 to 500 feet of gravel is exposed. This includes many layers of light-colored tuff interstratified with stream gravel, sand, and boulders. In appearance it resembles very closely the Los Pinos gravel as exposed in the Conejos quadrangle. Its identity as Conejos rather than Los Pinos is evident, however, from the fact that it is overlain by andesite flows, which are in turn overlain by latite.

A few miles farther south, in the northern part of the Tusas Creek drainage basin, the Treasure Mountain formation is entirely lacking, and andesite flows or breccias are rarely to be found. In consequence it is well-nigh impossible to differentiate from each other the two gravel formations, which together aggregate over 1,000 feet in thickness. In general the gravel of the Conejos formation is more firmly indurated than the Los Pinos beds. Near Tusas post office, in T. 28 N., R. 8 E., the top of the Conejos beds is probably about 500 feet above Tusas Creek on the east wall of the valley, and only the remaining 400 feet to the top of the higher summits of the divide is believed to be composed of Los Pinos materials. Here as elsewhere the beds dip eastward; in R. 9 E. the Los Pinos gravel disappears beneath the customary cap of Hinsdale basalt, which forms the floor of the Rio Grande Valley in and near T. 28 N., R. 10 E. (See figs. 9 and 10.)

At several localities southeast of Tusas there are gravel beds at horizons physiographically appropriate for the top of the Conejos formation, which contain unusually large andesite boulders, 2 to 5 feet in diameter. These andesite boulder zones were used tentatively in the reconnaissance mapping as indicating the contact between the two similar deposits. On this basis the lowest beds of Los Pinos gravel are traversed by the road leading due west from Tres Piedras toward the Tusas Valley, close to the west margin of T. 28 N., R. 9 E., at an altitude of about 8,700 feet. At that point the lower 500 feet of the east wall of the Tusas Valley would then be composed of Conejos gravel, and the Los Pinos gravel would be only 300 to 400 feet in thickness.

Still farther south, in the vicinity of Las Tablas and Petaca, there are extensive exposures of typical Conejos andesite on the east slope of the Tusas Valley.

The exposures in the tributary Canyon del Agua are excellent and easily accessible by the well-traveled road leading from Tres Piedras to Las Tablas. Here the base of the Los Pinos gravel must be above the uppermost beds containing andesite, for the andesitic flows and breccias appear to be identical with those of the Conejos formation at the type localities 40 miles to the north. Thus differentiated, the Conejos formation is between 500 and 600 feet in thickness, and the Los Pinos gravel ranges from 300 to 500 feet. The gravel beds are capped with basalt and near Las Tablas form the foundation beneath a post-Hinsdale volcanic cone.

In the Tusas Valley the Conejos formation rests upon an extremely uneven surface; rugged hills of pre-Cambrian rock were partly or completely buried by the stream-borne detritus and volcanic ejecta. West of the Tusas the pre-Cambrian terrane becomes a mountain range culminating in such eminences as Kiawa Mountain and Tusas Mountain, the summits of which are at altitudes of about 9,500 and 10,000 feet, respectively. These pre-Cambrian hills apparently formed the southwest margin of the basin in which the Conejos materials were deposited. The large proportion of granite, quartzite, and metamorphic igneous rocks composing the Conejos boulders suggests that the pre-Cambrian massif was undergoing vigorous erosion while the gravel was accumulating in the adjacent trough.

This ancient and partly buried range of pre-Cambrian hills is to-day the divide between the Brazos drainage basin west of the Tusas Valley, and the eastward-flowing streams in the vicinity of Tusas. The pre-Cambrian massif culminates as a gently undulating upland, above which many maturely dissected hills rise 400 to 500 feet and below which the modern canyons have been eroded to depths of 1,000 feet or more. This upland is evidently an ancient erosion surface formed by postmature streams. It is undoubtedly the southeastward extension of the San Juan peneplain, recognized generally throughout the San Juan area. Its topography may be thought of as picturing rather faithfully the appearance of the pre-Cambrian area in and near the Needle Mountains as it would look to-day had it not been glaciated. Kiawa and Tusas Mountains and the many neighboring summits are monadnocks above the graded surface, closely comparable in dimensions to monadnocks formed of similar resistant materials in other parts of the San Juan region. To-day this ancient graded surface slopes regularly and gently from an altitude of about 10,500 feet in T. 31 N., R. 6 E., to only 8,750 feet in T. 27 N., R. 8 E., 25 miles to the southeast. Projected eastward the peneplain coincides with the base of the Los Pinos gravel east of the Tusas River.

In places the Los Pinos gravel overlaps the Conejos formation and rests upon the pre-Cambrian terranes. Thus near Hopewell there are small patches of Los Pinos gravel at an altitude of 9,700 feet, resting in the saddle through which the road from the Tusas Valley leads to the abandoned mining camp. The general relations of the peneplain surface to the gravel deposits are indicated in Figure 11.

Rio Brazos Canyon area.—An area in the northwestern part of Rio Arriba County has been mapped in detail because of its unusual geologic and topographic features. Much of the area east of the Rio Brazos and its tributary Gavilan Creek is occupied by Los Pinos gravel. On the south rim of the canyon, near the center of the mapped area, Los Pinos gravel rests upon Conejos andesite flows, but near the Jenson cabin and elsewhere on the south rim of the tributary Canyon Manga the andesite flow is lacking and the Los Pinos gravel lies upon very similar Conejos gravel. The Conejos formed the floor beneath the Los Pinos deposits wherever the andesite flows were completely removed by erosion during the Peneplain cycle. Apparently these flows were much thinner in the eastern third of the Brazos area than elsewhere; indeed, it is possible that the upper andesite flows never extended as far as the eastern boundary of this area. Where the andesite is absent it is extremely difficult to identify the plane separating the underlying Conejos gravel from the overlying and very similar Los Pinos gravel. Both formations contain a great many stones derived from the pre-Cambrian of the immediate vicinity. Neither is very firmly indurated, and in consequence the hillsides are generally covered with loose pebbles and cobblestones.

The floor beneath the Conejos gravel is exceedingly irregular. (See fig. 12.) The débris of this formation seems to have been washed into a group of rugged

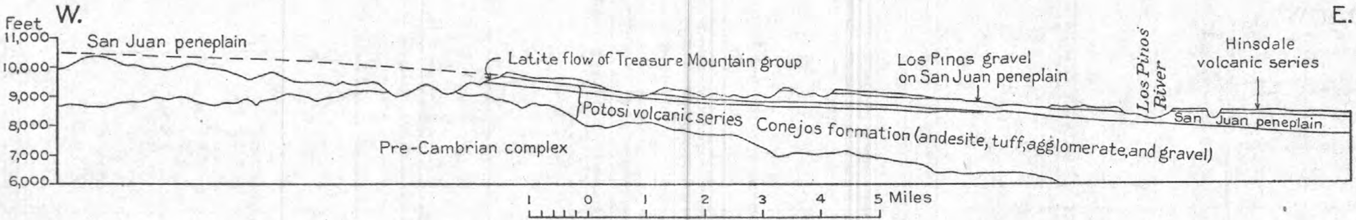


FIGURE 11.—Section from east to west approximately 1 mile south of Conejos quadrangle. At the left are dissected remnants of the San Juan peneplain, which descends steeply toward the east and is there buried beneath Los Pinos gravel and Hinsdale basalt

pre-Cambrian hills, where it filled the valleys and buried the lesser summits. In consequence the thickness, including intercalated lava flows and measured from the lowest gravel beds near the bottom of the Brazos Canyon to the top of Brazos Peak, in the far northwestern corner, amounts to 2,200 feet. Hills of pre-Cambrian gneiss and quartzite, 1,200 to 1,500 feet in height, were completely buried under Conejos débris and have since been partly exposed by Recent erosion. Toward the southeast the Conejos formation seems to have been somewhat thinner, so that it failed to bury completely the pre-Cambrian hills in that part of the area, or if it did bury them, they were partly exhumed during the peneplain erosion cycle, so that before the deposition of the Los Pinos gravel there were many hills of quartzite and gneiss rising 300 to 1,000 feet above the graded surface. These hills seem to have been surrounded and in part buried by Los Pinos gravel, which overlaps the Conejos formation and extends far up the slopes of such hills of gneiss as hill 10,828 and its neighbors, in the southeast corner of the area. Finally the Hinsdale basalt poured out upon the gravel surface. Remnants of it are found at altitudes as great as 10,750 feet near the east margin of the area. The maximum thickness of the Los Pinos gravel from the top of the andesite flows near the Brazos Canyon rim to the adjacent remnants of Hinsdale basalt is 650 feet.

The great mass of sand and gravel is evidently a fluviatile and possibly in part lacustrine deposit composed of sediments derived chiefly from the erosion of the San Juan and Sangre de Cristo Mountains at the north. These materials were deposited in a basin bordered by the pre-Cambrian upland north of El Rito. Near the margin of this basin were hills of crystalline rock, such as the hill west of Ojo Caliente and its neighbor southeast of La Madera. They were buried by the débris of the Santa Fe beds and have since been partly uncovered by post-Los Pinos erosion. The filling of this basin seems to have been terminated by the outpouring of Hinsdale basalt, which probably at one time covered nearly or quite all of the sand and gravel. The field studies of Mather in 1922, however, have led to the conclusion that only a small part, approximately the upper third, of the Santa Fe formation is really of Los Pinos age. The rest is believed to be principally the southeastward extension of the Conejos formation.

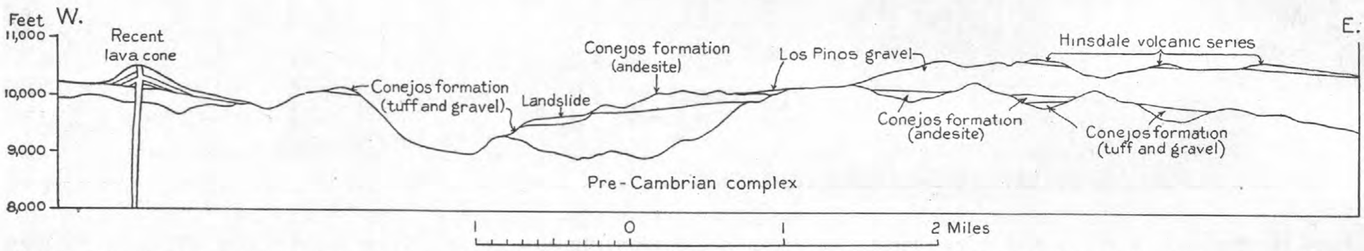


FIGURE 12.—Section from east to west across the Rio Brazos, Rio Arriba County, N. Mex., showing the relations of Conejos gravel and Los Pinos gravel to the floors on which they lie

Abiquiu region.—Much of the area surrounding Abiquiu is occupied by gravel and sand, some of which is of Los Pinos age and the rest of which may easily be confused with Los Pinos deposits, because certain of the mesas which it composes are capped with Hinsdale basalt. Among these, Black Mesa, Cerro de los Minos, and the long tonguelike uplands sloping outward from the Valle Mountains, far toward the southwest, are noteworthy.

These sand and gravel deposits in the general vicinity of Abiquiu form a large part of the widespread formation to which the name Santa Fe has been applied since the classic explorations of the Hayden Survey. The relation of the Santa Fe formation to the volcanic and postvolcanic history of the San Juan region is a problem of major importance.

Typical Conejos andesite is interbedded with Santa Fe gravel at many localities. From 12 to 15 miles north of Ojo Caliente the lower slopes on the west side of the valley of the Tusas River are composed of rhyolite flows, overlain by typical Conejos andesite flows and breccia aggregating nearly 300 feet in thickness. These blend southward into an agglomerate containing very little igneous material. Ten miles farther south there are other localities where andesitic breccia is interstratified with sand and gravel of the Santa Fe beds. One of the most noteworthy of these is 2 miles north of Ojo Caliente, on the west side of the river. The andesite here is clearly interstratified with Santa Fe gravel and occurs to a height of 350 feet above the river bed. Other exposures of the same andesitic breccia, interbedded with Santa Fe gravel, were noted on the north side of the tributary joining the Caliente River 3 miles southwest of Ojo Caliente. The most southerly exposure of andesitic material that was observed is 2 miles north of Caseta and 4 miles east of Cerro de los Minos. Here, as elsewhere, the andesitic breccia is interbedded with Santa Fe gravel.

Clearly all that portion of the Santa Fe formation up to the highest beds that contain andesite breccia should be correlated with the Conejos formation of the

San Juan area. In all probability beds even higher in the Santa Fe should also be thus correlated. Moreover, the southward extensions of the gravel beds, which nearer the San Juan Mountains merge into the andesite flows and breccias, are of Conejos age even though they are beyond the limits attained by the volcanic ejecta. On this basis the Los Pinos equivalent in the Santa Fe formation is not over 300 or 400 feet thick in the general vicinity of Abiquiu. Over much of the area it has been removed by post-Los Pinos erosion, which has cut deep into the underlying Conejos and Santa Fe beds. Remnants of the Los Pinos gravel underlying Hinsdale basalt are exposed in the escarpment that rims Black Mesa and Cerro de los Minos. Probably all the sand and gravel near La Madera, Ojo Caliente, and El Rito is of Conejos age.

San Luis Valley.—East of the 106th meridian the Los Pinos gravel is widespread beneath the floor of San Luis Valley, where it is generally capped by Hinsdale basalt. South of the San Luis Hills, in the New Mexico portion of the valley, this basalt is at the surface over wide areas. The gravel crops out between the mountain front and the Denver & Rio Grande Western Railroad in a long, narrow strip of territory extending north from Barranca past Taos Junction and Servilleta to Tres Piedras. To the east it disappears beneath the basalt but is again exposed in the canyon of the Rio Grande. At Dunn's bridge this canyon is about 300 feet deep but fails to reach the base of the basalt flows, which are there piled one upon another to a great thickness. Ten miles farther south, where the canyon is crossed by the road connecting Taos Junction and Taos, the Rio Grande has cut its way through the entire thickness of the basalt and has eroded its gorge deep into the underlying Los Pinos gravel. Throughout this portion of the canyon of the Rio Grande the steep walls of the gorge are so completely mantled with landslide débris that exposures of rock in place are extremely rare. Great ledges of basalt have slipped down over the surface of the yielding gravel and closely simulate outcropping ledges, scores or even hundreds of feet below the base of the lowest basalt flow.

In secs. 32 and 33, T. 24 N., R. 11 E., at a point approximately 4 miles due east of Barranca, there is an unusually good exposure of the strata beneath the Hinsdale basalt on the east side of the Rio Grande Canyon and the north side of the canyon of a tributary stream that joins the Rio Grande from the east. This tributary flows along the contact between the pre-Cambrian massif of the Sangre de Cristo Range, which here projects in an outlying group of hills far to the west of Picuris Peak. Between it and the Rio Grande there is a high mesa partly isolated from the plateau, the southwest side of which is comparatively free from the landslide débris that so generally obscures the slopes beneath the rim rock of the gorge. As observed from the State highway (see pl. 22, *A*), which here follows the left bank of the Rio Grande, this mesa is composed of Santa Fe gravel capped by Hinsdale basalt. All but the upper 40 or 50 feet of the gravel dips fairly steeply toward the north or northwest. The topmost beds are practically horizontal, as is the overlying basalt cap. The contact between the two parts of the gravel is a typical angular unconformity. The lower beds, about 300 feet of which is exposed, were tilted and eroded before the topmost beds were deposited. Possibly this unconformity marks the contact between the Conejos and Los Pinos equivalents in the Santa Fe formation. If so, the Los Pinos gravel is only 40 or 50 feet thick at this place; the basalt flows aggregate between 150 and 200 feet.

There are no exposures of Los Pinos gravel in the central portion of San Luis Valley in the neighborhood of the San Luis Hills, but the relations of the gravel to these hills may be inferred from the relation of the Hinsdale basalt to them. As determined by Larsen,[16] the San Luis Hills are remnants of a maturely dissected plateau composed of Los Pinos volcanic rocks whose relations to the volcanic series of the San Juan Mountains are not definitely known. During the outpouring of the Hinsdale lavas basalt flowed across the lowlands, surrounded the San Luis Hills, and partly filled the depressions between them. Thus for a time these hills were islands in the midst of a sea of lava. Inasmuch as there is invariably a considerable thickness of Los Pinos gravel beneath the Hinsdale basalt wherever it has been pierced by stream erosion or in well drillings in or near San Luis Valley, it is concluded that the San Luis Hills are surrounded by gravel washed into that part of the valley during the Los Pinos epoch of alluviation before the outpouring of basalt. In other words, these hills were monadnocks on the peneplain and bear the same relations to the gravel deposits as the monadnocks of pre-Cambrian rock in the vicinity of Tusas. (See pl. 10, sections G, H, and I.) These monadnocks of comparatively nonresistant volcanic materials were carved from tilted and uplifted fault blocks. They remained at considerable heights above the peneplain because the crustal movements which raised the fault blocks occurred very late in the Peneplain erosion cycle. The time intervening between this localized faulting and the regional deformation that ended that cycle was insufficient to permit the removal of these hills. The streams were able merely to develop a mature topography of somewhat isolated mesas in this area of elevated fault blocks.

North of the San Luis Hills the Los Pinos gravel as well as the Hinsdale basalt is quite generally buried

[16] Larsen, E. S., personal communication.

beneath a considerable thickness of post-Hinsdale sediments. Siebenthal[17] records that in the southwestern part of the north half of San Luis Valley there are a number of wells that pass through the overlying clay, sand, and gravel and penetrate a sheet of lava below which gravel and pumice beds are found. This lava is doubtless the Hinsdale basalt, and the immediately underlying gravel is Los Pinos. Near La Jara the upper beds of this gravel are between 250 and 300 feet below the surface. They are capped by a lava flow 30 to 50 feet thick. In and north of Alamosa several wells nearly or quite 1,000 feet in depth fail to reach the basalt that separates the Los Pinos gravel from the overlying post-Hinsdale sediments. The deepest well in the valley of which an accurate record is available is the so-called "oil well" 4 miles east of Mosca. It is 1,283 feet deep and likewise fails to reach the Hinsdale basalt.

Sand and gravel beds, confidently believed to be the eastward extension of the Los Pinos gravel, appear at the surface near the east margin of San Luis Valley in the vicinity of Fort Garland and in San Pedro Mesa, 25 miles farther south.[18] East and southeast of Fort Garland there are several prominent mesas isolated by Trinchera Creek and its tributaries from one another and from the Culebra Range, which borders this portion of San Luis Valley on the east. These mesas are bounded by bold escarpments on the west, where they rise 250 to 500 feet above the floor of the valley. The mesas south of the railroad are partly capped with lava flows which dip 6°–8° E. and are presumably of Hinsdale age. Their west margins are approximately in line with the west front of the Sangre de Cristo Range. Apparently a major fault plane with upthrow on the east runs approximately through Fort Garland in a direction a little west of north. Movement along this fault plane has in comparatively recent time lifted the Los Pinos gravel above drainage level and caused its exposure in these mesas.

ORIGIN

The Los Pinos gravel is clearly the equivalent of the bouldery Bridgetimber gravel and owes its composition, distribution, and geologic relations to the same forces. The formation is in the main the result of stream deposition immediately after the deformation that ended the Peneplain erosion cycle. As elsewhere in the San Juan region, so here in the southeast quarter this deformation quickened the action of the ancient streams in their upper courses, near the top of the dome, and caused the accumulation of a great apron of torrential wash around its periphery. The only differences between the Los Pinos gravel and the Bridgetimber gravel are those due to volcanic activity contemporaneous with the deposition of this great mass of alluvial débris. As a result beds of tuff and local beds of lava are interstratified with the stream-laid sand and gravel. Late in the epoch of alluviation there were several successive extrusions of basalt. The last of these seems to have been the most widespread. Literally thousands of square miles of gravel-strewn lowlands were covered by a tremendous composite lava flow. Its remnants cap the Los Pinos gravel throughout nearly all the area in which they have been recognized. Other portions of the same flow extended beyond the gravel beds to rest upon the solid rock of other parts of the peneplaned surface.

There is one noteworthy difference between the physiographic relations of the Los Pinos gravel and those of the Bridgetimber gravel. The Bridgetimber gravel seems everywhere to have been deposited upon a comparatively smooth lowland. In the area of accumulation of the Los Pinos gravel, on the contrary, there were many hills and mesas rising a few hundred feet above the adjacent plain. These were surrounded and some of them completely buried by the gravel and the subsequent lava flows. Some of these monadnocks on the lowland plain were composed of extremely resistant quartzite, gneiss, and schist. Their persistence as hills in a region of otherwise old topography was due to their superior resistance to the forces of erosion. Among these, the peaks and rounded summits of pre-Cambrian rock in the Brazos Canyon area and elsewhere in the vicinity of Tusas, the granite and quartzite hills whose tops project above the lava in the vicinity of Tres Piedras, and the western outposts of the Sangre de Cristo Range west of Picuris Peak are noteworthy. Others among the monadnocks of Hinsdale time were rounded hills or tablelike mesas of volcanic rock, the resistance of which was not notably greater than that of somewhat similar volcanic rocks that elsewhere had been reduced to base-level. These monadnocks were the result of the mature dissection of plateaus that had been elevated by crustal movements occurring so late in the Peneplain erosion cycle that the streams in their vicinity had only been able to carve a mature or late mature topography before the cycle ended. Among these are the San Luis Hills, in an area where the diastrophism that terminated the Peneplain cycle changed a region of mature topography undergoing probably vigorous erosion into an area of sedimentation. The uplands of the erosion cycle became islands in the alluvial basin; subsequently they were surrounded by the lava flows of late Hinsdale time.

[17] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, pp. 43, 44, 1910.

[18] Cf. Endlich, F. M., Geological report on the southeastern district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, pp. 136–137, 1877.

AGE

If our conclusion as to the similarity of origin of the bouldery Bridgetimber gravel and the Los Pinos gravel is correct, the two are essentially contemporaneous. The reasoning which led to the conclusion that the Bridgetimber gravel is of latest Pliocene or earliest Pleistocene age applies with equal force to the Los Pinos gravel.

PLEISTOCENE DEPOSITS

CERRO TILL

DISCOVERY

Glacial drift of the type which we now call Cerro till seems to have been first recognized in the early eighties by Hills,[19] who stated that "for several miles west of Tongue Mesa [in the northeast quarter of the Montrose quadrangle] the country is covered with coarse boulder drift." At that time it was assumed that all the glacial deposits of the San Juan Mountains were the result of the same episode of glaciation. Thus Hills concluded that "the entire western slope of the mountains, except probably the higher peaks, was covered with an unbroken sheet of ice," and that "as the ice sheet retreated it became divided and finally separated into distinct glaciers corresponding to the principal valleys." It should also be noted that by no means all the surficial materials interpreted by Hills as glacial drift were deposited by ice. For example, the "continuous deposit of drift" in the Rio Grande Valley above Wagonwheel Gap is largely fluvioglacial gravel, and the "huge terminal moraine" between Santa Maria Lake and Antelope Spring is a mass of landslide débris.

Morainal deposits of the Cerro glacial stage were first described as the work of pre-Wisconsin glaciers by Howe and Cross[20] in 1906 as a result of field investigations in the Uncompahgre Valley, on the north side of the San Juan Range. Drift of the same age within the Ouray quadrangle was recorded by the same authors[21] in their description of that quadrangle as "earlier moraines," for at that time the occurrence of only two glacial stages in the Pleistocene history of the San Juan Mountains had been recognized.

In the summer of 1911 Cerro till was first observed by us in the valleys of Weminuche and Huerto Creeks and the Piedra River, on the southeastern slopes of the range, and of the Rio Grande, on the eastern slopes. Later in the same season the "earlier moraines" in and near the Ouray quadrangle, on the northern slopes, were examined. It was now evident that there were two glacial stages subsequent to that which produced the Cerro till, and in a preliminary statement[22] of the results thus far obtained by our glacial studies in the San Juan region this earliest stage was referred to as the "San Juan glacial epoch."

The name Cerro was first used in 1915[23] and was selected from Cerro Summit, near the north margin of the Montrose quadrangle, on which there are thick glacial deposits of this early Pleistocene stage.

DISTRIBUTION

The Cerro till occurs at many isolated localities around and near the margin of the San Juan Mountains and has been identified on all sides of the range. The patches of drift of this glacial stage are found on interstream divides or high on the slopes of the major valleys. Very few of the scattered remnants are opposite the mouths of the modern canyons; nearly all are beyond the mountain spurs, at localities that could not be reached by valley glaciers descending the mountain canyons of to-day. The materials of the drift, although they conform in a general way to the composition of the adjacent parts of the mountain range, differ markedly from those of the drift of later ice ages found in close proximity to the modern canyons. Rocks that once capped the mountain summits but are now almost entirely missing are represented in great abundance in the Cerro till. Boulders of other formations, such as those of pre-Cambrian or earlier Paleozoic age, which in certain regions have been uncovered only in the lower parts of the deeper canyons, are almost entirely absent from the Cerro drift, deposited by ice that must have moved over those portions of the range before these canyons had been deeply incised. The great antiquity of these deposits is also attested by the deeply weathered boulders and the extent of stream erosion, which has nearly obliterated all signs of morainic topography in them. Their glacial origin is made certain by the size of the boulders, the heterogeneous mixture of all sizes of rock fragments, and the striated and polished surfaces of many of the stones preserved under favorable conditions in some part of nearly every mass of the ancient till.

Montrose quadrangle.—The type locality of the Cerro till is Cerro Summit, in the northeast quarter of the Montrose quadrangle, near which much of the country is mantled with the drift of this, the oldest known Pleistocene ice in the western mountains. Excellent exposures may be observed from the Denver & Rio Grande Western Railroad at the summit and for

[19] Hills, R. C., Extinct glaciers of the San Juan Mountains, Colo.: Am. Jour. Sci., 3d ser., vol. 27, pp. 391–396, 1884; Colorado Sci. Soc. Proc., vol. 1, pp. 39–46, 1883.

[20] Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 17, pp. 251–274, 1906.

[21] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), 1907.

[22] Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colorado: Jour. Geology, vol. 20, pp. 385–409, 1912.

[23] Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 13–26, 1915.

some distance west of it. The drift is a heterogeneous mixture of various materials ranging in size from the finest rock flour to boulders 25 feet in length—a typical glacial till. The larger boulders and blocks are commonly composed of Potosi latite, a rock which characterizes the Cerro till throughout the quadrangle. Other pebbles and boulders consist of andesite, basalt, tuff, porphyry, and sandstone. Pebbles or cobbles of granite, quartzite, and greenstone are extremely rare but may be found at some exposures. All of these are small and well rounded; they were derived from the Telluride conglomerate rather than from the pre-Cambrian formations now exposed in the upper reaches of the Uncompahgre River. Many of the fragments of volcanic rocks, especially the larger ones, are angular, but there is also much well-rounded and subangular material. Most of the stones, especially those of coarser texture, are deeply weathered. Some boulders more than a foot in diameter are so thoroughly decomposed that they may be crushed in the fingers to sand. Others that have been recently uncovered by surficial slumping or stream erosion display well-preserved glacial markings, flat facets, and striae. Striated boulders are, of course, very rare but may be found by careful search at good exposures. Typical moraine topography with low, rounded knobs and shallow kettles may be seen in certain small areas, but not all the material mapped as moraine is actually in place as deposited from the ice. The till rests upon soft shales of Mesaverde and Mancos age, and the giving way of these shales has caused many small landslides. Much of the morainic material consequently lies lower on the slopes than when it was originally dropped from the Cerro Glacier. At most places this creeping of the material can scarcely be called landslide, and it has seemed advisable to indicate all that does not show distinct landslide topography as moraine in place. The Cerro till with its heavy boulders and abundant gravel is more resistant to erosion than the underlying shale, in spite of its unconsolidated condition, so that in many places it has preserved the original surface upon which it was deposited. At other spots the larger streams, such as Cedar Creek and its major tributaries, have cut deep trenches through the drift and far down into the Cretaceous shale.

Similar deposits of Cerro till cap the summit of Vernal Mesa, extending within a mile of the northern boundary of the quadrangle, and form a line of irregular hills on the west side of Bostwick Park, a few miles farther northwest. The till on Vernal Mesa is of unusual interest because of its relation to the Black Canyon of the Gunnison River and to the fault scarp that forms the southern margin of the upland. The mesa surface is a portion of the upper and outer valley of the Gunnison River, and the morainic débris descends the gentle slope practically to the canyon rim. It is evident, therefore, that the Gunnison Valley was well defined before the Cerro glacial stage. The 600-foot cliff that rises sheer above the Cerro deposits of the Cedar Creek Valley marks the fault contact between pre-Cambrian gneiss and Cretaceous shale. It bears no sign of glaciation; indeed, it could probably not be climbed by ice from the south unless the ice was considerably over 1,000 feet thick and was moving forward vigorously. We were therefore very much surprised to find the deposit of glacial drift above the escarpment, resting on the volcanic rocks that cap the pre-Cambrian rock of the mesa. The possibility of a northern or northwestern source for the ancient glaciers of this vicinity may be dismissed, for no glacial deposit could be found on Black Mesa or the other mesas north of the Gunnison Canyon. It is therefore extremely likely that displacement amounting to 500 or 600 feet has taken place along this fault plane since Cerro time and that the drift of Vernal Mesa has thus been elevated above that in the valley of Cedar Creek. Such displacement is indicated on the structure contour map of the San Juan peneplain forming Plate 2.

Southeast of Cerro Summit portions of Tongue Mesa and the divide between Squaw and Cimarron Creeks have retained patches of old glacial drift. There has been considerable landsliding in these localities, and large areas of shale have been laid bare by the removal of the mantle of till. Boulders from the drift are present on many shale slopes in the valleys between the deposits of till indicated on the map. These are the only areas of Cerro drift in the Cimarron Valley, either in this quadrangle or in the Uncompahgre quadrangle; apparently the Cerro ice in the Uncompahgre Valley spread eastward across the divide north of Cimarron Ridge.

From Cedar Creek south to Cow Creek the east side of the Uncompahgre Valley is heavily mantled with Cerro drift in each intertributary area. The patches of till terminate eastward at the foot of the steep slopes of Cimarron Ridge, from which many landslides have descended over the upper portion of the glacial débris. Toward the Uncompahgre River the frayed and ragged margin of the erosion remnants descends to altitudes about 1,000 feet above the modern stream channel. The patches of drift in this locality which lie within the Ouray quadrangle were mapped by Cross and Howe[24] as "earlier moraines" and have been briefly described in our paper of 1912. Throughout this general area large boulders or blocks of Potosi latite such as those in the type deposit at Cerro Summit are absent, although certain of the volcanic rocks are thought to have come from the Silverton or Potosi volcanic series. The drift materials have been derived

[24] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), 1907.

chiefly from the San Juan tuff, the coarse volcanic agglomerate composing Cimarron Ridge. In all other respects these deposits are identical with those at Cerro Summit, into which they appear to blend in the vicinity of Dry Cedar Creek. At one locality on Burro Creek a good section of the moraine shows that it is composed of rounded, subangular, and angular boulders of various sizes embedded in fine boulder clay. No quartzite and only a few granite cobbles are present there. Near the headwaters of Billy Creek there are many undrained depressions, some of them containing ponds, in this drift. Farther north the Cerro till is at least 90 feet thick and displays a similar morainic topography. A vertical section shows a weathered zone about 10 feet in thickness which has been oxidized to a brown color, while the lower portion of the deposit is gray. A few of the boulders there are striated.

On the west side of the Uncompahgre River the most conspicuous remnant of the Cerro drift is that which caps Horsefly Peak (pl. 22, *B*) and the neighboring hills on the crest of the watershed between the Uncompahgre and Dolores Basins, near the west margin of the quadrangle. To the description of these deposits given by Howe and Cross [25] there is little to add. Lithologically they are identical with the correlated drift of Cerro Summit. Most of the boulders are deeply weathered, but by turning over a large number of them, so that the lower faces not yet exposed to the atmosphere could be examined, three or four were found to be striated and grooved by ice action. Several small areas with their original morainic topography practically undisturbed were seen. The Mancos shale, on which the drift rests, has given way at many places, however, and contiguous areas that have been mapped as landslide contain a considerable volume of drift mingled with the shale débris.

Several hundred square miles of the surface of the Uncompahgre Plateau and of Log Hill Mesa, which is really the southeastern extremity of the plateau, consists of Dakota (?) sandstone swept clean of all overlying shale or drift. Boulders of volcanic rock resting on the sandstone here and there testify to the former extent of Cerro till over the eastern part of the plateau. The most northerly remnant of drift that could be mapped as such and which we have seen is a mile southwest of the Government Spring and 4 miles north of Horsefly Peak. It forms a hill 40 or 50 feet high and contains many large blocks of weathered Potosi latite, some of which are over 15 feet in length. Howe and Cross [26] report another hillock of similar drift 6 miles farther north.

At 5½ miles south of Horsefly Peak a prominent hill known as West Baldy rises about 800 feet above the Howard Flats. Mancos shale forms the base of the hill, but the upper 500 feet of it is composed of or heavily mantled with Cerro till. The largest stones in this drift are at least 12 feet in diameter. Most of the larger boulders consist of latite; the others are composed of volcanic glass, diabase, basalt, rhyolite, diorite, andesite, and rarely of sedimentary rocks. Mingled with these are many small, well-rounded, and waterworn pebbles of granite, quartz, quartzite, chert, schist, jasper, and porphyry, which doubtless came from the Telluride conglomerate. A few faintly striated stones were found, but the more notable feature is the absence of smooth surfaces on the boulders in this accumulation. Many of the larger ones are fractured, and almost all are more or less exfoliated.

Similar deposits occur on South Baldy and other hills to the south and southeast of West Baldy, as well as on several hills rising above the level of Hastings Mesa, in the southwest corner of the quadrangle. Large decayed blocks of latite may also be seen here and there on the surface of Miller Mesa in the vicinity of Lake Otonawanda, although no other remnants of the drift from which they have probably come have remained there.

Uncompahgre quadrangle.—The great extent of the Cerro moraines in the Montrose quadrangle is in striking contrast to the scarcity of such deposits in the Uncompahgre quadrangle, where only one area of this ancient till has been identified with certainty. The intervalley upland between the canyons of Little Cimarron and Blue Creeks, 10 miles north of Uncompahgre Peak, is a postmature surface with broad, shallow valleys and gently undulating topography. The master streams in the canyons on each side are 700 or 800 feet below its average altitude. As indicated on Plate 1, an area of several square miles of this surface is mantled with bouldery material which shows by its topography, composition, and striated stones that it is glacial till. Most of the boulders are deeply weathered, and the whole deposit displays every evidence of great antiquity. Drift of subsequent stages is confined to the slopes and floors of the modern valleys; ice could not have reached this locality since the present canyon system was even approximately developed without overriding the divides and uplands, none of which show any sign of glaciation. The preservation of this ancient moraine is the result of a peculiar chain of fortuitous incidents which include two occurrences of stream piracy.

Immediately before the Cerro glaciation a late-mature topography had been developed in this locality by streams heading in the vicinity of Uncompahgre Peak and flowing northward. One of these followed the course of Fall Creek to the falls east of Sheep Mountain, continued northward in the valley now occupied by the upper 2 or 3 miles of the upper East Fork of

[25] Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 17, pp. 261–262, 1906.

[26] Howe, Ernest, and Cross, Whitman, op. cit., p. 262.

Little Cimarron Creek, passed through the col now traversed by the north-south trail from the upper meadows of Fall Creek, crossed the area now occupied by Cerro till, and followed the general course of the lower East Fork of Little Cimarron Creek to the present cite of Van Boxel's sawmill. (See fig. 13, A.) This was also the general route of the Cerro ice as it moved northward from the high mountains. During the Canyon cycle of erosion, subsequent to the Cerro stage, the upper East Fork of Little Cimarron Creek diverted the headwaters of the preglacial stream toward the west and cut its channel so deep that the ice of the Durango glacial stage was deflected in that direction. (See fig. 13, B.) Still later Fall Creek, probably assisted by the Wisconsin ice, diverted the greater part of these stolen waters toward the east. Consequently the Wisconsin ice turned into the valley of Blue Creek, and once more the patch of Cerro drift was preserved from destruction. (See fig. 13, C.) Since Cerro time this small area has been little eroded, although the surrounding areas have all been deeply dissected by streams and glaciers.

East of the Lake Fork of the Gunnison River, between Fourth of July and Devil Creeks, there are two small patches of surficial débris which may be remnants of a Cerro moraine. The materials of this deposit resemble drift, although a glacial origin could not be demonstrated. Boulders and blocks of a variety of volcanic rocks are embedded in a fine sandy matrix, but no boulders with glacial markings could be found. The surface is gently undulating and does not exhibit erosion topography. It may be either a softened moraine or a modified landslide. The position and physiographic relations of the deposit are those to be expected for the Cerro drift, and there is apparently no adequate source for a landslide in that position. The two patches have both been mapped as landslide, however, because the data are not considered sufficient to prove glaciation of the Lake Fork during Cerro time.

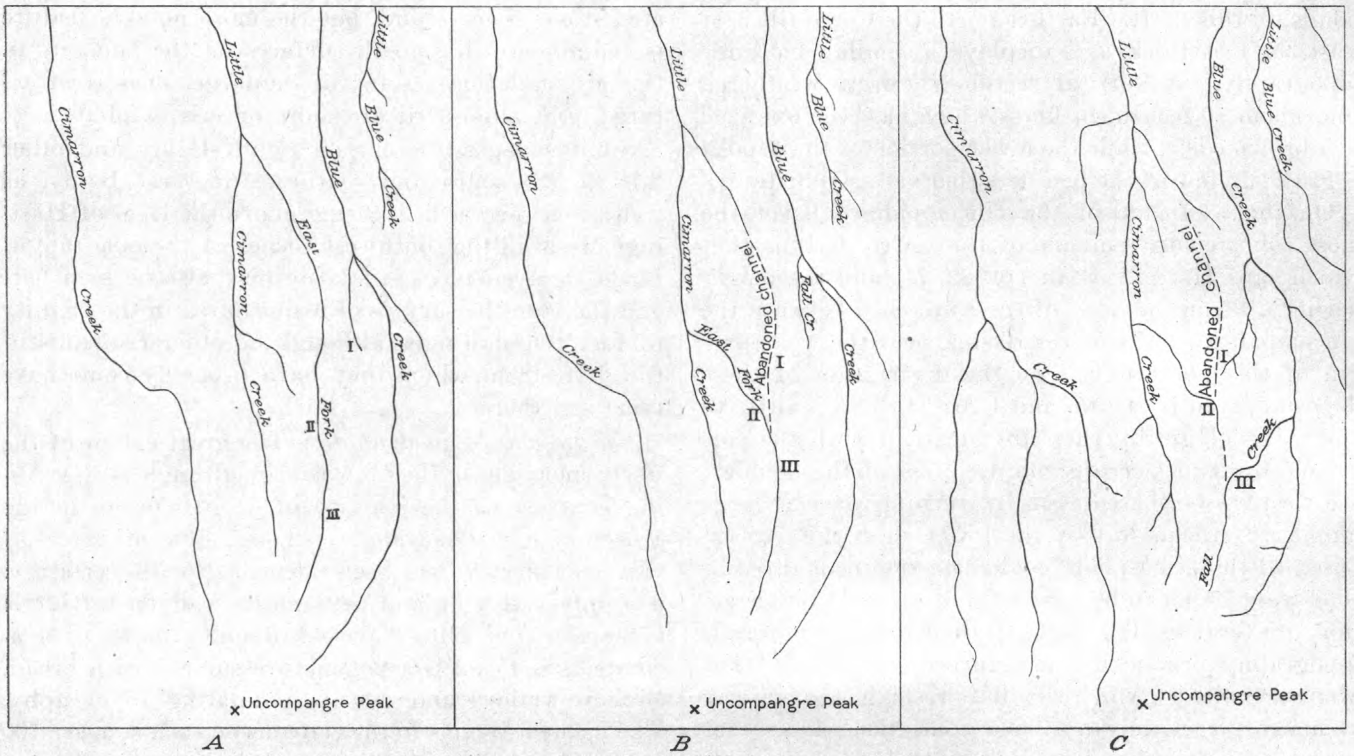


Figure 13.—Maps of area north of Uncompahgre Peak. A, showing arrangement of streams before Cerro glaciation. Drainage changes were caused by glaciers of Durango and Wisconsin stages at I, II, III. B, showing drainage change during the post-Cerro and pre-Durango interglacial stage. Dotted line shows abandoned route. C, showing main streams at present time. During or after the Wisconsin stage the East Fork of Cimarron Creek was beheaded at III by Fall Creek

San Cristobal quadrangle.—Near the east margin of the San Cristobal quadrangle small patches of glacial drift have been found halfway up the slopes that climb steeply from the Rio Grande to the plateau surface which culminates in Bristol Head. As indicated in Figure 14, the morainic masses lie between 1,000 and 2,000 feet above the flood plain of the Rio Grande and rest upon shoulders or benches that mark a distinct topographic break between an older outer valley and a more youthful inner canyon. They appear to have been dropped from ice that occupied the older valley at a time preceding the cutting of the present canyon. The composition of the boulders in the drift indicates that the sources of the ice must have been in the areas of pre-Cambrian rocks near the headwaters of the Rio Grande, in the central part of the mountains. The relation of these isolated remnants of a till sheet to the moraines of the later glacial stages makes clear the correlation with the Cerro drift on the northern slopes of the range.

Creede quadrangle.—Down the valley from the locality in the San Cristobal quadrangle just described remnants of this very high and very ancient drift are found as scattered boulders along the eastern and northern slopes of the Rio Grande Valley as far as the hills just west of Creede. These morainic masses have all been reworked since the Cerro stage of glaciation, but boulders of pre-Cambrian rock from the heart of the range are not uncommon on the intertributary spurs.

In the northeastern part of this quadrangle is a very small area of glacial drift on the margin of Groundhog Park to which the attention of Mather was directed by J. Fred Hunter. The " park " is a remnant of a post-mature valley, cut off from its surroundings on three sides by deep youthful canyons. Its gently undulating surface is now 2,000 feet above the general base-level of the region and is mantled at the single locality near its northeast extremity with morainic débris. None of the neighboring canyons have been occupied by ice, and the only other evidence of glaciation in that vicinity is the dissected moraine of a small glacier that formed beneath Mesa Peak after the modern canyons were carved. The conditions are closely similar to those between Little Cimarron and Blue Creeks, north of Uncompahgre Peak, in the Uncompahgre quadrangle. The drift must be referred to the Cerro stage.

A small patch of glacial drift showing somewhat similar relations is reported by Mr. P. E. James to be present on the slopes at the head of Little Aspen Creek, 1½ miles south of Del Norte Peak, in the southeast corner of the quadrangle. This drift is about 2,000 feet above the floor of the neighboring valley of Pinos Creek. It is far above the reach of any Wisconsin ice in this neighborhood and is likewise so situated that the possibility of its deposition by Durango ice is excluded. Its great antiquity is further attested by the much modified morainic topography which it shows and by the deeply weathered condition of its boulders. There can be little doubt that it is a remnant of the Cerro till, which may formerly have been widespread in this part of the range.

Del Norte quadrangle.—Glacial deposits within the Del Norte quadrangle are extremely rare, but moraines of each of the three Pleistocene glacial stages have been identified with a fair degree of certainty along the western margin of the quadrangle. Those of the Cerro stage are in the northwest quarter of the quadrangle, on the upland east of Poso Creek. Thick deposits of bouldery débris fill the saddle between the drainage basin of Poso Creek and the head of an unnamed tributary of Carnero Creek. Similar débris rests on the upper slopes of the valley of Poso Creek and extends at about the same altitude into the valley of the South Fork of Carnero Creek. The lower slopes below the thick drift are veneered with wash from the easily eroded deposits at the higher levels. The higher deposits have a topography suggestive of an ancient and much modified moraine, for the low, rounded hills irregularly scattered over the surface are separated by shallow depressions and undrained hollows. Good sections of débris are not exposed, but boulders 4 or 5 feet long are lying on the surface. These include a variety of volcanic rocks, and all are deeply decomposed. The physiographic situation is exactly such as would be expected for drift of the same age as that at Cerro Summit.

Summitville quadrangle.—Numerous isolated patches of Cerro till in the southern and southeastern

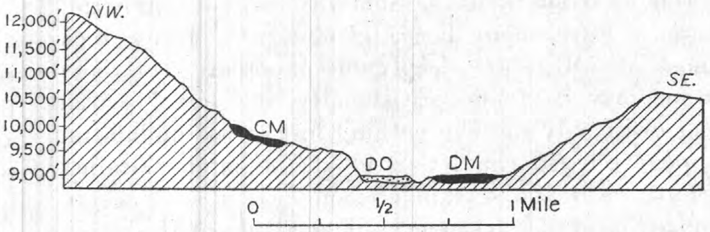


FIGURE 14.—Section across the Rio Grande Valley near east margin of San Cristobal quadrangle. Cerro till (CM) rests on a bench 500 feet above the Durango terminal moraine (DM) and the adjacent valley train (DO), which are on the valley flat near the river

parts of the Summitville quadrangle have escaped destruction. These, with few exceptions, occupy the summits or crests of the higher hills or divides adjacent to the valleys of the San Juan River, the Rio Blanco, and the tributaries of these streams. The occurrence on Blue Mountain, in secs. 8 and 9, T. 34 N., R. 1 E., is typical. There the ancient drift is found more than 1,000 feet above the Rio Blanco, about 5 miles downstream from the mountain gateway into Blanco Basin. Several smaller remnants are present in similar topographic surroundings farther downstream, as indicated on Plate 1. The deposits near the northeast corner of T. 35 N., R. 1 W., display a similar relationship to the San Juan River. At all these localities recent erosion has caused more or less of the drift to slump down the slopes and has scattered boulders over the hillsides below their original positions. Some of the material mapped as Cerro till probably occupies at present a position much lower than that in which it was left by the Cerro ice.

Two areas of Cerro till are present in sec. 13, T. 32 N., R. 2 E., near the middle of the southern boundary line of the quadrangle, one on each side of the upper reaches of the Little Chama River. They occupy the lower slopes of a postmature valley, the floor of which is nearly 1,000 feet above the flood plain of the Navajo River, a short distance to the northwest. As indicated on Plate 1, this aged, high-level valley is now occupied by the head of Little Chama River, which at this point has cut little if any below the grade established at the time this broad valley was sculptured. Its topographic relations to the valley of the Navajo River, immediately north and northwest of it, clearly indicate that piracy has taken place here. At the time of Cerro glaciation, the Navajo River drained southward and was tributary to the Chama. Ice formed in the heads of its tributary valleys and moved southward some distance beyond the Colorado-New Mexico line. Later one of the heads of the San Juan, working along the valley now occupied by the Navajo River in the vicinity of Chromo, beheaded the former Little Chama River and diverted the captured waters westward into the present channel of the Navajo. Thus the areas of Cerro till have been left undisturbed in a region where post-Cerro erosion has been comparatively slight.

The Cerro drift in the Summitville quadrangle contains a great many large boulders of volcanic rock, most of which are deeply decomposed. A striated stone may be found occasionally by careful search, but ordinarily there is nothing left of the undulating topography so characteristic of the later moraines. Slope wash and stream erosion have long since removed most of the topographic evidence of the glacial origin of these timeworn materials. Arthur Iddings reported orally to the authors that the Cerro drift in the Rio Blanco Valley may be differentiated from that of the later glacial stages by the absence of boulders of light-gray porphyry, which are common in the more recent drift. Evidently the Cerro ice did not cut down to the porphyritic laccoliths now exposed in Blanco Basin.

Pagosa Springs quadrangle.—At the time of our investigation the only base map available for physiographic studies in the Pagosa Springs quadrangle, immediately south of the San Cristobal quadrangle, was the reconnaissance map prepared about 1873 by the Hayden Survey. Although this map proved entirely unsuited for detailed records, it has served very acceptably as a base for exploratory work, which revealed the presence of large bodies of Cerro till in the northern part of the area. Since our field studies were completed, the topographers of the United States Geological Survey have mapped this quadrangle, and the map has been published on the scale of 1 : 125,000. To this new map our field data have been transferred in the office. (See pl. 1.)

Morainic deposits on the west side of Huerto Creek extend from a point 2 miles south of the San Cristobal quadrangle to a point within a mile of its junction with the Piedra River and are, in part, fully 1,000 feet above the Huerto stream channel. They mantle the slope toward the stream in great landslide masses, which appear to have come down in very recent time. In this deposit there are boulders as much as 9 feet in diameter, and striated material is not uncommon. Similar glacial débris covers about 2 square miles of the upland surface between Huerto Creek and the Middle Fork of the Piedra River, the next tributary to the east, and a third smaller patch of Cerro till caps the divide east of the Middle Fork. These materials all appear to have come from the headwaters of the Piedra River, toward the northeast, and all lie well beyond the limits of the later ice advances. It is inferred from their relations, from the absence of the marks of glaciation in the Huerto Canyon, and from the distribution of other materials, interpreted as of the same age that the ice which left these moraines advanced over a surface that corresponded to the altitude of the intervalley uplands and that the 1,000-foot canyon of Huerto Creek has been excavated since the melting of that ice.

Another large remnant of the Cerro drift occurs on a ridge 1,000 feet above the Piedra River, on the south side of the valley. Many of the boulders in this deposit range from 5 to 10 feet in diameter, and a few are 25 feet. As the dissection of the country has progressed since the Cerro glacial stage, some of these boulders have rolled down the valley slopes.

Ignacio quadrangle.—No deposits of Cerro till have been found within the limits of the Ignacio quadrangle, but certain accumulations of boulders at two localities can be explained without difficulty only by postulating that they are relics of very ancient moraines from which all the finer particles have been removed.

On the divide between the Los Pinos River and Spring Creek, 2½ miles southeast of Ignacio, there are scores of large boulders of Vallecito conglomerate, as much as 10 feet in diameter. Typical ones are shown in Plate 22, *C*. They rest upon Tertiary shale, are not part of any recognizable glacial or fluviatile deposit, and appear to have been let down to their present position during the dissection of the terrane upon which they rested. No distinct marks of glaciation were found on these stones; indeed, all of them are unusually weathered for boulders of quartzitic composition. They are at least 25 miles from their source and at an altitude nearly as great as that of the nearer outcrops of the formation from which they were derived.

Still farther from the mountains, on the rolling upland surface 3 miles west of La Boca, are similar boulders of the same rock, many of which are 5 feet in diameter. Neither glacial markings nor waterworn surfaces are present, as these boulders, too, are deeply weathered. Many of the stones have been broken by changes in temperature and by frost work; in some the pebbles have weathered from the quartzite matrix.

The boulder deposits capping the neighboring mesas or veneering the river terraces contain boulders as large as 3 feet in diameter, but these are exceptional; most of the river-borne stones are less than a foot in length. Although it would be unwise to assert that boulders 7 to 10 feet in diameter could not be washed over low gradients for distances of 25 or 30 miles, such a contingency is certainly very unlikely. On the other hand, if the Cerro glaciers attained dimensions on the south side of the San Juan Range analogous to those known to have been reached by the ice of this stage in the Uncompahgre Valley, these large erratics are in situations exactly suitable for terminal and lateral moraines from the Los Pinos-Vallecito Glacier of the Cerro stage.

Telluride quadrangle.—The glacial deposits of the Telluride quadrangle, on the west side of the San Juan Range, have been described by Hole.[27] Many small areas of morainic débris were grouped together under "the common name of earlier drift," although it is "certain that all of the deposits" so classed "are not of the same age," as "the evidence afforded by deposits in the Telluride quadrangle is not sufficient to warrant the conclusion that three distinct glacial epochs are to be recognized."[28] The extension of our glacial studies southward from the Montrose quadrangle, in which the criteria for the recognition of the three Pleistocene glacial stages are so well displayed, has made possible the identification of Cerro till from the "earlier drift" deposits of the Telluride region.

The frayed remnant of a glacial moraine, precariously perched upon the summit of Diamond Hill, in the northwest corner of the quadrangle, is typical Cerro till. Its physiographic environment is the counterpart of that displayed by the patches of drift on Hastings Mesa, 12 miles to the north. A slightly larger body of drift, 2 miles southwest of Diamond Hill, on the plateau above the bend in Big Bear Creek, was probably deposited during the same glacial stage. In both of these deposits the boulders, which attain 8 feet in diameter, are deeply weathered. In spite of the extensive decay which has altered all but well-protected surfaces, glacial markings were observed by Mather on two or three of the stones in the drift on Diamond Hill. Many varieties of volcanic rocks, among which Potosi latite is especially common, are mingled with quartzite and granite boulders from the Telluride conglomerate in this ancient drift.

In the far southwest corner of the quadrangle there are several bodies of glacial drift which rest upon the gentle slopes of the postmature, outer valley of the East Dolores River above the rim of the modern, youthful canyon. Glacial moraines of two later stages are found within this inner canyon, and these older masses are therefore referred to the Cerro stage. They contain boulders of the porphyry intrusive which forms the Mount Wilson massif, boulders from the Telluride conglomerate, and blocks of the underlying Dakota (?) sandstone. The boulders are as much as 8 or 10 feet in diameter.

[27] Hole, A. D., Glaciation in the Telluride quadrangle, Colorado: Jour. Geology, vol. 20, pp. 502–529, 606–639, 710–737, 1912.

[28] Idem, p. 733.

AGE

The great antiquity of the Cerro till is suggested by the weathering and erosion which have greatly modified it and is demonstrated by its composition but is adequately appreciated only by an examination of its physiographic relations.

Weathering of the Cerro erratics.—Reference has been made in the preceding paragraphs to the deeply weathered surfaces of the boulders contained in it. Striae or other glacial markings are extremely rare and may ordinarily be found only after prolonged search. Some boulders several inches in diameter are so completed rotted that they may be crushed in the fingers. On comparing them with the drift boulders of the two younger glacial stages the Cerro erratics appear several times as old.

It is, however, easy to overestimate the age of the Cerro till on the basis of relative weathering alone. Its boulders are nearly all composed of volcanic rocks—glassy lavas, bombs, and dense or porphyritic intrusives. These are much less resistant to weathering agents than the quartzites or other metamorphic rocks of pre-Cambrian age and are somewhat less resistant than the sedimentary rocks or the local granite and syenite. In most of the deposits of drift from the later glaciers these more resistant materials form a considerable proportion of the larger stones and hence lend an aspect of freshness and recency, in striking contrast to the weather-beaten appearance of the Cerro boulders.

Erosion of the Cerro moraines.—The Cerro moraines have been so successfully attacked by the agents of erosion that in few localities have they preserved a semblance of their original morainal topography. The smaller areas, mapped as Cerro till, are without exception formless masses of glacial drift which have long since lost the surface expression typical of the débris recently liberated from melting ice. Most of the larger areas have been so profoundly modified that undrained depressions and rounded knobs are absent. Their surfaces are carved into the erosion lines of a stream-worn topography or display the chaotic contours of landslide masses. One is reminded of the topographic expression of the Illinoian drift in Ohio or the Kansan drift in Iowa.

Composition of the Cerro till.—The profound changes that have been effected in the topography of the San Juan country in post-Cerro time are indicated by the composition of the Cerro till in the deposits on the northern and northwestern flanks of the range. These are in turn an index to the lapse of time since the Cerro glacial stage.

In the Montrose quadrangle the Cerro drift is readily differentiated from that of the two later glacial stages by the great number of large boulders of Potosi latite which it contains, in marked contrast to the paucity of boulders from that formation in the more recent moraines. This series of lava flows probably once covered the neighboring mountains but has since been removed from all except a few of the higher summits. Evidently extensive masses of Potosi rocks must have been so situated with respect to the ice as to afford unusually favorable opportunities for the plucking of large blocks from them. Furthermore, erosion during the post-Cerro and pre-Durango interglacial stage, subsequent to the Cerro glaciation, must have so modified the San Juan Mountains as to remove the Potosi rocks from the zone of active sapping by the time of the Durango glacial stage.

Just what physiographic changes were involved in this obviously great erosion are not known. Hole [29] infers from it "the removal by erosion in the high mountain tracts of not less than 1,000 feet of igneous rock." This inference in turn leads to the conclusion that the total relief of the mountains was at least as great in Cerro time as to-day. Since Cerro time, according to this view, the mountain summits and the floors of the major valleys have alike been degraded about 1,000 feet. We wish, however to present an alternative suggestion which we believe to be more in consonance with certain facts that will presently be reported, although it can not be demonstrated from the known data. It seems quite likely, as further explained in the section of this report devoted to the description of the Cerro glaciers, that the ice of the Cerro stage was not confined to valleys but formed a great ice cap over the crest of the range and spread in large piedmont masses across the adjacent lowland. No analogy may be drawn between the zone of maximum erosion beneath such an ice cap and the zone of excessive plucking by ice confined to definite valleys and originating in alpine cirques. We picture the San Juan region just before the Cerro stage as a slightly rather than maturely dissected plateau, with domelike profile and with its summit at approximately the same position relative to the rock formations as the crests of the higher peaks to-day. The mountain valleys then were broad and shallow. Many cubic miles of Potosi volcanic rocks, which have since been removed from between the peaks and serrate divides, were present to supply débris to the ice cap that was forming on the intervalley uplands, which have since been carved to needle points and knife-edges. Under this view the relief in the mountains in Cerro time was much less than at the present time.

[29] Hole, A. D., op. cit., pp. 734–736.

Still more significant, and with a direct bearing upon the problem of the last paragraph, are the conclusions that necessarily follow from the comparative scarcity of quartzite and granitic boulders in the Cerro till of these same localities in and near the Uncompahgre Valley. The rare fragments of plutonic or metamorphic rocks present in those deposits seem to have been derived from the Telluride conglomerate, which immediately underlies the Tertiary volcanic rocks of the range. The abundant quartzite boulders of the two more recent glacial deposits are in the main derived from Uncompahgre quartzite (pre-Cambrian) of the Uncompahgre Canyon south of Ouray, and the absence of boulders from this formation in the drift of the Cerro stage indicates that the formation was not exposed in this part of the range at the time of the Cerro glaciation. At the present time quartzite of the Uncompahgre formation forms the canyon walls up to a height of 2,000 feet above the stream, in the Silverton quadrangle. The canyons in that area must have been deepened at least that amount since the glaciation that left the drift of Horsefly Peak and beneath Cimarron Ridge.

Similarly, the absence of boulders of porphyry from the drift of the Rio Blanco Valley may be used as an index of the amount of post-Cerro erosion in that part of the San Juan region. A large porphyritic laccolith or other intrusive body has been trenched to a depth of at least 2,000 feet in Blanco Basin, but at the time of Cerro glaciation not even its upper surface had been bared.

Physiographic relations of the Cerro moraines.—The great age of the Cerro till, suggested by the foregoing considerations, becomes vividly impressed by an examination of the relations of the remnants of that till to the present physiography of the region. (See pl. 2.) Characteristic profiles (figs. 14 and 15) are presented to aid the reader in grasping the significance of the positions in which the Cerro drift is now found. These convey an idea of the amount of erosion that has occurred in the foothill region and indicate the time relation of the Cerro glaciation to the erosion cycles in the San Juan Mountains.

The position of the Cerro glacial deposits, on and near the divides between the present drainage channels and in front of the modern mountain spurs, is in sharp contrast to that of the bodies of drift from the later glaciers, which are restricted to the present valleys. Hundreds of square miles of surface, between the mountains and the remnants of Cerro till, have been entirely cleared of this glacial débris, and deep canyons now intervene between the mountain front and the isolated hills capped with Cerro glacial boulders. Profound modifications in drainage and topographic expression have occurred since the melting of the Cerro ice. In general, the valley floors in the peripheral zone surrounding the higher summits of the range have been lowered 500 to 1,000 feet below the stratigraphic horizon which they occupied during the Cerro stage.

The Cerro deposits that cap Horsefly Peak and West Baldy are now separated from the mountain front by Dallas and Leopard Creeks, which have lowered their channels 500 to 1,000 feet below the surface upon which the ice of this stage rested. (See fig. 15.) South Baldy and other summits to the west that are capped with Cerro drift are similarly dissevered from one another and from the main mountain front by erosion depressions, 3 to 6 miles wide and 600 to 1,100 feet deep. Farther north the few scattered remnants and boulders of Cerro till resting on the surface of the Uncompahgre Plateau indicate that this surface is in the main of post-Cerro origin. Its sculpturing involved the complete removal of the Mancos shale, except where it was preserved by reason of remoteness from stream channels and an extraordinarily thick mantle of Cerro drift, and the incision of canyons into the Dakota(?) and subjacent formations. Many of these canyons, such as Happy Canyon and those of Horsefly and Spring Creeks, are 200 to 500 feet in depth.

East of the Uncompahgre River the surface upon which the Cerro till rests has been deeply dissected by the numerous tributaries of that river. Cow Creek has lowered its valley about 700 feet at a point due east of Ridgway. Burro Creek, a comparatively small tributary stream, has carved a valley 700 feet deep and a mile wide in the shale and sandstone beneath the Cerro till. Cedar Creek has beheaded the northward-flowing stream that formerly traversed the length of Bostwick Park and has developed its westward-flowing drainage system since Cerro time.

On the west side of the San Juan Range, in the southwest corner of the Telluride quadrangle, the East Dolores River has excavated a canyon more than 1,000 feet deep below the floor across which the Cerro ice moved. On the southern side of the range, in the Piedra Valley, drift of this glacial stage, which came from the mountains at the heads of the Middle Fork and the main Piedra River, is now separated from those mountains by the 1,000-foot canyon of Huerto Creek, which must be entirely of post-Cerro age. Southeast of the San Juan River in the Summitville quadrangle, the tattered remnants of Cerro drift display similar topographic relations to their surroundings; the Rio Blanco has lowered its channel 700 to 900 feet below the base of the adjacent bodies of Cerro till, and many square miles of deeply and maturely dissected country intervene between the drift areas and the mountain front.

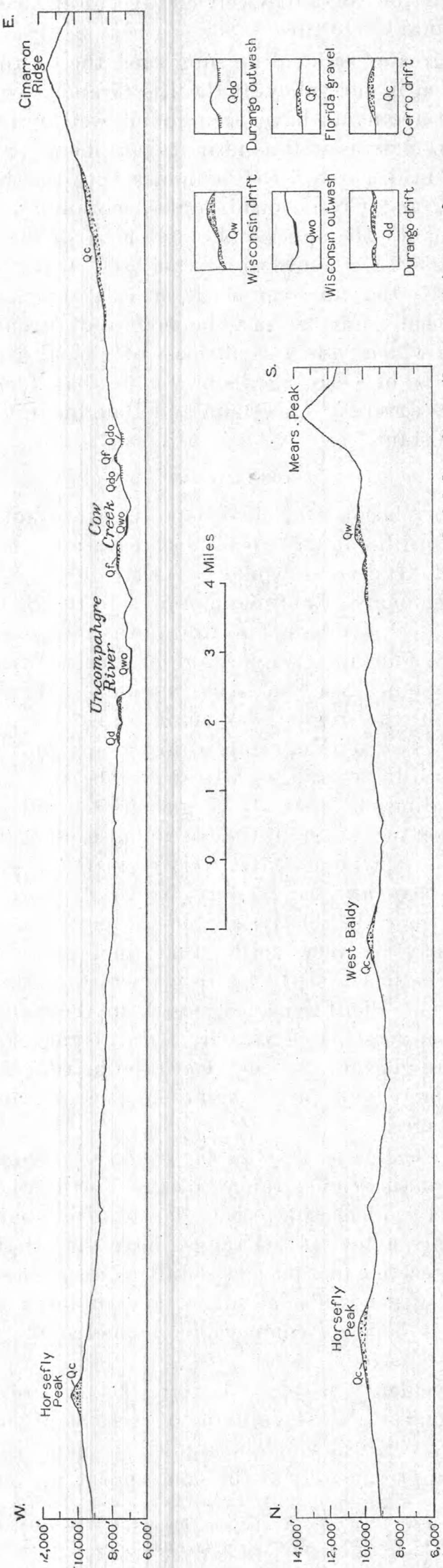


FIGURE 15.—Sections through Horsefly Peak, Montrose quadrangle, showing the relation of the glacial deposits to the present topography

The Little Chama River has been beheaded, and the canyon of the Navajo River, 800 feet deep, has been eroded since Cerro time.

Even greater valley deepening since the Cerro stage is recorded in the valley of the Rio Grande, for there the drift remnants have been found well within the mountain mass as well as near its periphery. East of Bristol Head, close to the boundary between the San Cristobal and Creede quadrangles, morainic accumulations mantle the upper and outer slopes of the valley 1,500 to 2,500 feet above the stream bed. (See fig. 14.) Apparently the inner canyon is entirely of post-Cerro development. Farther east the surface of Groundhog Park, on which rests a small mass of glacial drift believed to be of Cerro age, is now more than 1,000 feet above the waters of La Garita and Baughman Creeks, 2 miles distant.

CORRELATION

The correlation of glacial deposits in distant parts of the Cordilleran province must necessarily be only tentative. Indeed it would be unsafe to assert that all the remnants of antique moraines in the San Juan region which have been described in the foregoing paragraphs belong to a single stage of glacial expansion and recession. Nor can it be supposed that each ice advance in this region was accompanied by proportionately great developments of glaciers in each of the other Cordilleran ranges. It should be remembered that the dimensions of alpine glaciers depend just as much upon mountain altitude as upon secular climatic conditions. Undoubtedly very great diastrophic changes have affected western North America since Pliocene time; the relative altitude of mountain ranges to-day may be very unlike that during the Cerro stage. The fact that the Cerro glaciers were the most extensive of Pleistocene ice masses in the San Juan Mountains does not necessarily indicate that contemporaneous glaciers in other Cordilleran ranges were likewise more widespread than their successors in later glacial stages.

Early Pleistocene drift in the western mountains.—In each of the higher ranges of the North American Cordillera evidence of recent glaciation is abundant, but in only a few of the ranges have glacial studies been prosecuted in sufficient detail to distinguish the effects of distinct glacial stages, and in few of these have drift deposits comparable in age to the Cerro till been reported.

Blackwelder [30] has described the deposits of three glacial stages in the mountains of western Wyoming. The oldest drift, to which he applied the name Buffalo, must be approximately of the same age as the Cerro.

> The deposits * * * now exist only in the form of remnants on flat-topped divides or isolated hills, or on spurs along valley slopes. * * * The grouping of these remnants suggests that they are part of originally more extensive bodies which have since been cut to pieces by the growth of canyons. The canyons have been excavated, not only through the drift sheet itself, but 200 to 1,000 feet in the underlying rock.[31]

Like the ice of the Cerro stage in the San Juan Mountains, the Buffalo ice in the Teton and Wind River Ranges covered a much larger area than the glaciers of the two later stages. It is reported to have spread far out upon plateau surfaces at least 25 miles from the mountains.

While studying the records of ancient glaciation in the Big Horn Mountains, Salisbury, Bastin, and Blackwelder [32] discovered some very old morainic deposits which they determined to be of pre-Wisconsin age. From their description it would appear that possibly some of that material should be correlated with the Cerro till of the San Juan region. They did not distinguish three separate stages of Pleistocene glaciation, and therefore the possibility remains that their earlier or pre-Wisconsin drift is of Durango age.

In central Montana just east of Glacier National Park Alden [33] has recognized pre-Wisconsin glacial drift that would seem from his description to be of about the same age as the Cerro till of the San Juan region. Confidence in this correlation is based in large part on the similar topographic relations of these drift deposits, due to the extensive and deep erosion which has taken place since they were laid down in their respective regions. It appears that in both localities these drift deposits preceded the development of the modern valleys and canyons, and younger Pleistocene glacial deposits are found in close association with those modern valleys. In describing the location of these high-level drift deposits Alden states:

> The presence of glaciated pebbles in the deposit capping Milk River Ridge * * * and their presence also in the type exposure of the "Kennedy gravels" certainly point to such a correlation. If the valleys between these high-level tracts have been excavated to depths of 900 to 1,600 feet, and the headward extensions of these valleys into the mountains have been correspondingly deepened since the deposition of this drift, we must refer a considerable part of the sculpturing of the mountains to Pleistocene time, for the contours marking the levels of the tops of this drift extend far up toward the heads of the mountain valleys, in most cases nearly or quite to the cliffs below the upper cirques.

Atwood [34] reported in 1916 a very old Pleistocene morainic deposit in the vicinity of Butte, Mont. From the studies carried on at that time it was clear

[30] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 27–117, 193–217, 307–340, 1915.

[31] Idem, pp. 328–329.

[32] U. S. Geol. Survey Geol. Atlas, Cloud Peak-Fort McKinney folio (No. 142), pp. 9–12, 1906.

[33] Alden, W. C., Geol. Soc. America Bull., vol. 23, pp. 687–708, 1912; vol. 35, pp. 405–408, 1924.

[34] Atwood, W. W., Physiographic conditions at Butte, Mont.: Econ. Geology, vol. 11, pp. 697–732, 1916.

that those deposits were of pre-Wisconsin age. He is now inclined to correlate them with the Cerro till of the San Juan region. From their topographic position they appear to have been deposited before the modern stream valleys and canyons of the neighboring ranges had been developed.

It is believed that many other localities in the western mountains of the United States and of Canada will yield evidence of this very early Pleistocene drift.

Early Pleistocene drift in Mississippi Valley.—The correlation of the deposits from the continental ice sheets of the Mississippi Valley with those made by glaciers or ice caps in distant mountain ranges is extremely hazardous. The conditions controlling weathering and erosion may be as widely dissimilar as the composition of the till in the two regions. To evaluate unerringly the many varying factors is scarcely possible in the present stage of knowledge. In the absence of exposures showing superposition of deposits of the two types any correlation must be considered distinctly tentative.

Leverett [35] has suggested the correlation of the Cerro drift with that of the Kansan stage. Alden's studies in Montana, Wyoming, and farther east lead him to favor correlation with either the Kansan or the Nebraskan stage.[36] In our opinion these suggestions are altogether reasonable, although we are not at present ready to bar the consideration that the Cerro till may have been formed contemporaneously with the Illinoian. The Cerro till is certainly older than the Iowan of northeastern Iowa. It is quite possible that certain deposits in the San Juan region, here referred to the Cerro stage, are as ancient as the Nebraskan till of the Mississippi Valley, but we believe that most of these ancient moraines in the San Juan region are comparable to either the Illinoian or the Kansan till east of the mountains.

Early Pleistocene drift in the Alps.—The extensive studies of the glacial deposits in the Alps carried on by Penck and Bruckner [37] have resulted in the description of four distinct stages of ice action with three accompanying interglacial stages. A comparison of those European deposits with the till of the Mississippi Valley has led Leverett [38] to correlate the European Günz with the American Nebraskan, the Mindel with the Kansan, the Riss with the Illinoian, and the Würm with the Wisconsin.

Either the Günz, with its accompanying outwash known as the older Deckenschotter, or the Mindel must be the counterpart in Europe of the Cerro drift in the San Juan region. The Durango drift in the San Juan region is doubtless the time equivalent of the Riss, but we believe it to be entirely possible that both the Riss and the Durango are more nearly equivalent in time to the Iowan than to the Illinoian stage.

[35] Leverett, Frank, Glacial formations in the United States: Geol. Soc. America Bull., vol. 28, pp. 143–144, 1917.

[36] Alden, W. C., personal communication, 1926.

[37] Penck, Albrecht, and Bruckner, Ed., Die Alpen in Eiszeitalter, 1909.

[38] Leverett, Frank, Comparison of North American and European glacial deposits: Zeitschr. Gletscherkunde, vol. 4, pp. 241–316, 1910; see also vol. 5, pp. 315–316, 1911.

FLORIDA GRAVEL

CHARACTER

On all sides of the San Juan Mountains, in the foothills and in each of the larger valleys radiating from the mountain core, there are more or less extensive deposits of boulders and gravel to which the name Florida gravel is applied from the fact that it caps Florida Mesa. In most places these deposits cap the surfaces of mesas or table-lands intermediate in altitude between the higher summits of the locality and the present valley floors. Elsewhere they occur on terraces extending far into the heart of the range and far out between the plateaus traversed by the master streams. Ordinarily these mesas and terraces rise gradually upstream with gradients somewhat steeper than those of the adjacent stream beds. Consequently they are higher above the streams in and near the mountains than they are beyond the foothills, where they descend toward but, with the exception of those on the east front, never reach the modern flood plains. Everywhere except on the margin of San Luis Valley they maintain their position approximately halfway between the highest and the lowest altitudes in their immediate vicinity.

The materials of the Florida gravel range from coarse sand or grit to large cobbles and boulders. The great bulk of the deposit consists of pebbles and cobblestones with a major diameter between 3 and 6 inches. Boulders a foot or two in length are not uncommon, and occasionally a 3-foot boulder may be observed. At many places the surface of these gravel beds is covered with a mantle of light yellowish-brown loam that was spread broadcast by the wind and settled down into the interstices between the stones.

Most of the stones, large and small, are conspicuously rounded and waterworn. (See pl. 22, *D*.) In all respects they are identical with those now being transported by the many rivers and creeks of the range. In many exposures the stones appear in rudely stratified deposits, and in a few localities the gravel is well bedded. Ordinarily it forms a thin veneer only 10 or 20 feet in thickness, but it has a known maximum thickness of slightly more than 50 feet. The surface upon which the gravel rests is even, truncating the gently dipping strata of the peripheral zone and rarely determined by the outcrops of resistant beds. It is evidently the product of stream erosion approximately at grade.

Lithologically the Florida gravel varies much from place to place in different parts of the range, but within a single drainage basin it displays a fairly homogeneous composition. In general, its components embrace a variety of rocks quite similar to those which now crop out within the local drainage basin. For example, in all the valleys that lead from the La Plata Mountains the Florida gravel is characterized by abundant boulders from the diorite and monzonite porphyries of the La Plata laccoliths and sills. In the drainage basin of the Los Pinos River the gravel includes many fragments of Vallecito conglomerate, derived from the southeastern part of the Needle Mountains quadrangle, while farther east and north it is composed almost entirely of volcanic materials.

DISTRIBUTION

Ignacio quadrangle.—The Florida gravel is well displayed at many points in the Ignacio quadrangle, on the south side of the San Juan Range. It was there first observed by us and its true significance appreciated. For these and other reasons Florida Mesa, between the Animas and Florida Rivers, is chosen as the type locality for this formation. As shown in the perspective diagram (pl. 23), this gently rolling intervalley area is bounded on the east, west, and south by abrupt escarpments averaging 300 feet in height and is limited on the north by foothills that rise 600 feet above the mesa to the peneplain level. On the west this escarpment is broken by a number of terraced steps that descend to the Animas channel. The uppermost of these terraces is 40 to 80 feet below the mesa summit and is mantled with the outwash gravel of the Durango stage, the second of the three Pleistocene glacial stages recognized in the region. Similarly, on the east the outwash deposits of the same glacial stage in the Florida Valley form a bench on the valley side 20 to 30 feet below the mesa surface. Gravel mantles the entire surface of the mesa and is well exposed in a number of cuts along the Denver & Rio Grande Western Railroad southwest of Florida. (See pl. 22, *D.*) They include boulders of quartz, quartzite, granite, diorite, greenstone, sandstone, and grit, all of which crop out in the upper courses of the Florida and the Animas. The gravel veneer ranges in thickness from 10 to 50 feet and rests upon the eroded surface of late Cretaceous and early Tertiary shale and sandstone. The mesa top slopes southward, away from the mountains, at a grade which permits the spreading of irrigating waters, and a large part of the surface, covered with an excellent soil of wind-blown loam, is under cultivation.

East of Ignacio are two large and several small gravel-capped mesas rising abruptly 100 to 150 feet above the channels of the Los Pinos River and its tributaries Ute and Spring Creeks. These carry an assortment of pebbles and boulders comprising most if not all of the many varieties of igneous and sedimentary rocks that crop out in the drainage basin of the Los Pinos and Vallecito Creek. They are the isolated remnants of a former gravel-strewn floor of the bolson type, which has been dissected by the modern streams. Farther east and northeast other remnants of the same graded surface are preserved as long sloping terraces rising gradually toward the east and terminating abruptly against the sides of the hills that lie along the eastern boundary of the quadrangle. At their upper ends these terraces are between 7,300 and 7,500 feet above sea level and about 1,000 feet below the peneplain gravel capping the hilltops. They carry only local materials, chiefly rounded sandstone fragments, intermingled with quartzite pebbles that presumably have been let down from the dissected peneplain surface.

Other gravel-strewn mesas and terraces in the drainage basin of Lightner Creek, west and northwest of Durango, represent the Florida horizon at that locality. These have a much steeper gradient, 200 to 400 feet to the mile, befitting their situation far from the master streams. Most of the boulders in the formation there consist of porphyritic rocks from the La Plata intrusive rocks; these are mixed with the hard sandstones from the foothill zone of upturned sedimentary strata. The gravel is at present 500 to 800 feet above the flood plain of Lightner Creek.

La Plata, Red Mesa, and Soda Canyon quadrangles.—The extensive deposits of Florida gravel within the La Plata quadrangle have been mapped and described by Cross and Spencer[39] under the name "higher terrace gravels." These extend far down the La Plata River beyond ancient Fort Lewis, and cap Red Mesa, a replica of Florida Mesa, described above. The physiographic relations of the formation are well displayed by the gravel-strewn, tablelike divide between Cherry Creek and the East Mancos River in the western part of the La Plata quadrangle. The Florida gravel is there about 800 feet below the peneplain remnants, such as Menefee Mountain, and 600 feet above the adjacent valley floors.

Montrose quadrangle.—The most extensive bodies of Florida gravel on the north side of the San Juan Mountains are found within the Montrose quadrangle and in the broad valley of the Uncompahgre River leading away to the northwest from Montrose. The few exposures of this formation in the southeast quarter of the quadrangle were mapped and described by Cross and Howe[40] as "earlier terrace gravels."

[39] Cross, Whitman, and Spencer, A. C., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

[40] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 133), 1907.

The southwestern extension of the Horsefly Peak ridge and the flat-topped shale hill a mile to the south, in T. 45 N., R. 10 W., are capped with a veneer of stream-washed boulders and pebbles. The materials are the same as those in the Cerro till on Horsefly Peak, but the maximum size is much smaller; the boulders are stream worn, and a rough assortment as by running water may be observed. The more northerly of these two deposits bears a relation to the Cerro moraine similar to that of fluvioglacial outwash, but the location—toward the mountains from the moraine—is not that which would be expected for an outwash deposit. Apparently the gravel was deposited by running water some time after the ice of the Cerro stage had begun to retreat and not at the time of maximum advance of the ice front.

drift and were therefore the result of stream activity during the interglacial interval which succeeded the withdrawal of the Cerro ice.

Farther north, in the vicinity of Montrose, the numerous well-developed terraces, covered with alluvial wash deposited before the Uncompahgre had attained the low level of its modern flood plain, fall naturally into four groups at successively higher levels above the river channel. The highest of these is of Florida age. Remnants of that graded surface are sufficiently numerous on both sides of the Uncompahgre Valley in this vicinity to warrant their correlation on the basis of accordant altitude, and the Florida plain may be projected with no break of more than 3 miles from one remnant to another throughout the length of the valley from the glacial moraines near Dallas to the quadrangle line north of Montrose. Reference to this, the earliest epoch of alluviation that has been recognized near Montrose, is made doubly sure, however, by the fact that quartzite boulders are very abundant in the gravel of more recent age. The Florida gravel rests on benchlike terraces midway between the highest and lowest altitudes of the locality, as well as on the summits of isolated buttes and mesas. The materials of this formation seem to have been transported by running water, which in some places was reworking the drift left by the Cerro ice and elsewhere was carving its pathway deeper into the volcanic and sedimentary rocks of the range. The boulders are largely of volcanic rocks, for at the time of the Cerro glaciation and the Florida alluviation that portion of the San Juan Range embraced within the Uncompahgre drainage basin was dissected below the Tertiary volcanic rocks in only a few localities. Well-rounded boulders as much as 4 feet in diameter are common as far north as the latitude of Montrose. Good exposures may be observed along the South Canal of the Gunnison irrigation project, 1 to 3 miles south of Cedar Creek.

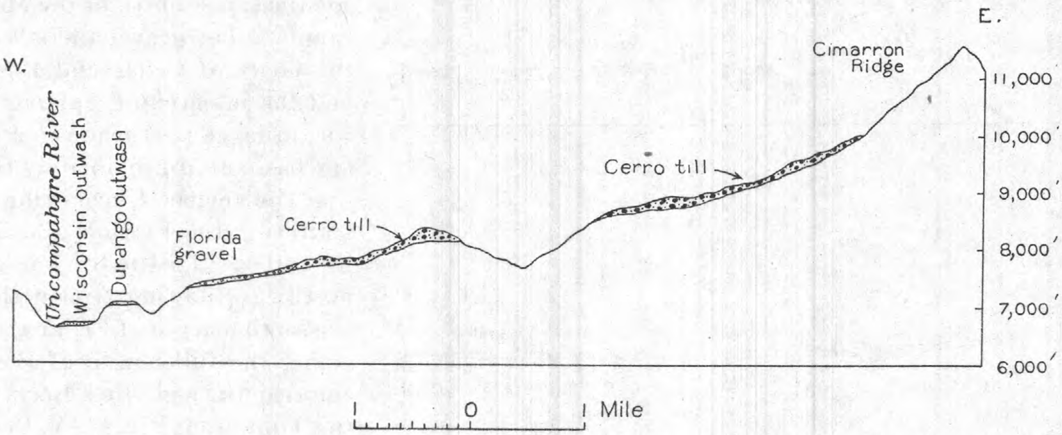


FIGURE 16.—Profile showing relation of the Florida gravel to the Cerro till on the east side of the Uncompahgre Vallley in the Montrose quadrangle

East of the Uncompahgre River near the center of the quadrangle there are several deposits of Florida gravel on both sides of Cow Creek. Some of these, like that between Alkali and Cow Creeks in sec. 26, T. 46 N., R. 8 W., or that north of Chaffee Gulch in section 4 of the same township, cap isolated mesas, the flat inclined tops of which are surrounded by steep slopes that fall abruptly toward the stream channels, 500 to 800 feet below the gravel veneer. Others rest upon the downstream portions of the intervalley spurs that project westward from the gaunt crest of Cimarron Ridge between the steep-sided ravines carved by such streams as Burro and Deer Creeks. Their location is indicated on Figure 16. In the main, these intervalley spurs are mantled with Cerro glacial drift, but there are fairly extensive surfaces, sloping rather gently toward the Uncompahgre, so smooth that they may be safely interpreted as graded surfaces of erosion, a conclusion which is greatly strengthened by the fact that the boulders strewn over them are water worn and assorted as to size. Here, likewise, it is apparent that these surfaces of the Florida erosion cycle were cut in and below the deposits of Cerro

In many places the veneer of boulders is 20 to 50 feet thick and has served as a protecting cap for the soft Cretaceous shale on which it rests. Excellent illustrations are found on the lower slopes of the Uncompahgre Plateau, on the southwest side of the Uncompahgre River, due south of Montrose. The topographic relations there are suggested by Figure 17. The gravel-capped hills consist of easily eroded shale, which has elsewhere been entirely stripped from the inclined surface of the very resistant Dakota (?) sandstone, the cap rock of the plateau. These remnants of the Florida surface are all situated within 4 miles of the Uncompahgre River. Apparently they represent the approximate position of the southwest margin of the valley floor upon which the alluviation of the Florida cycle of erosion took place. Farther southwest the shale rose above the surface of aggradation during Florida time, as suggested in Figure 17, B, and hence received no protective mantle of boulders. Subsequent erosion has removed these unprotected masses of shale that were more remote from the master stream but has not yet succeeded in obliterating all records of the episode of boulder deposition. One of the most conspicuous of these boulder-capped hills is Table Mountain, just north of the Montrose quadrangle on the northeast side of the Uncompahgre River. (See pl. 24, *B*.) Its flat summit carries a thick mantle of gravel and boulders deposited during this early period of alluviation.

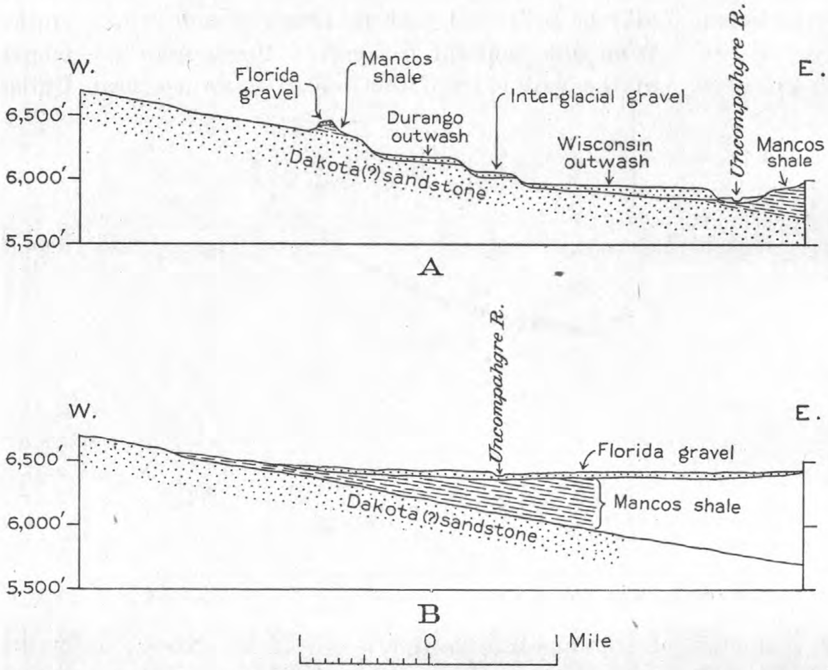


FIGURE 17.—Profile and structure section southwest of Montrose, Colo. A, The present relation of a mesa capped by Florida gravel to the Cretaceous shale and sandstone of this locality; B, the same section as it must have appeared during the deposition of the Florida gravel

There are extensive deposits of Florida gravel in the vicinity of Cedar Creek, 9 miles east of Montrose. Between altitudes of 7,100 and 7,300 feet on the south side of the railroad there is a roughly triangular basin known locally as Cedar Park. Its gently undulating floor is covered with alluvium of Florida age. On the east and west the park is hemmed in by hills of Cerro drift and Mancos shale; on the north it terminates abruptly at the brink of the youthful valley of Cedar Creek, which flows westward, 350 feet below the park level. North of Cedar Creek are several gently sloping intervalley uplands and benches, which would be continuous with Cedar Park were it not for the ravines and canyons of Cedar Creek and its tributaries, cut beneath the ancient surface of aggradation which they represent. These lead in turn to Bostwick Park, another silt-floored basin high above the modern drainage lines, just north of the Montrose quadrangle. The gravel and silt deposit upon the floors of Cedar and Bostwick Parks and the intervening uplands and benches was in large part made in a single drainage basin at approximately the same time that the ancient Uncompahgre River was scattering the Florida gravel throughout its valley. This basin was drained by a northward-flowing stream that rose near the south margin of Cedar Park and, traversing the full length of Bostwick Park, emptied through Red Rock Canyon into the Gunnison River. Valley cutting in the resistant pre-Cambrian complex in Red Rock Canyon proved so difficult that the stream was unable to handle all the material brought to it by slope wash and by tributary streams working in the easily eroded Cerro till and Cretaceous shale in the parks. Post-Cerro faulting (see p. 102) may also have interfered with the northward transportation of débris. Hence the basin floor became mantled with alluvium to a depth of 50 to 100 feet. Subsequent piracy (see p. 61) committed by Cedar Creek bisected the former drainage line and permitted the partial dissection of the surface of alluviation.

Uncompahgre quadrangle.—The Lake Fork of the Gunnison River traverses the mid length of the Uncompahgre quadrangle. Next to the Uncompahgre River it is the largest northward-flowing stream on the north side of the San Juan Range. Distinct and conspicuous benches, 1,000 feet above the Lake Fork channel and 2,000 feet below the adjacent plateau summits, are numerous on both sides of the stream between Lake City and the mouth of Trout Creek. These benches truncate the lava flows and are not due to the structure of the rocks. They decline downstream at an appropriate angle for an ancient stream bed and are mantled with a wash of boulders and cobbles of volcanic rocks. They are remnants of the abandoned floor of an ancient valley, not so wide as that occupied by the Uncompahgre River in Florida time and hence neither so extensive nor so flat as the contemporary surface in the Montrose quadrangle.

Near the northwest corner of the Uncompahgre quadrangle there is a broad mountain valley on the west side of Fitzpatrick Mesa, the floor of which is covered with alluvium but which is not now occupied by a stream. The topographic situation and expression of this wind gap, from which a stream has been diverted by Stumpy Creek, are suitable for a valley of the Florida cycle of erosion. The alluvium upon its floor is therefore tentatively interpreted as a Florida deposit.

Reference should also be made in this connection to certain deposits of boulders and gravel concerning whose origin no positive conclusions have been reached. Numerous boulders are scattered over the divides west of Blue Creek and east of Little Blue Creek adjacent to the Cimarron fault line. On the divide between Little Cimarron and Blue Creeks these boulders appear to rest upon a terrace or bench a few feet above and north of the main east-west road, now a part of the Rainbow Automobile Trail. They reach 2 feet in diameter but more commonly are 1 foot or less. Most of these boulders are of volcanic rock, but there are also many of quartzite and some of granite. Boulders of all these materials are known to occur in the San Juan and West Elk volcanic agglomerates, which crop out on the slopes of the mesas to the south and north. The quartzite boulders, however, are far more abundant among these scattered boulders than in the agglomerates and tuffs. This may be due to a concentration of the more resistant rocks during the disintegration of the agglomerate. Again, the location of the boulders near the Cimarron fault may help to explain their origin. The La Plata sandstone is quartzitic at many localities, and it might be especially metamorphosed near the fault plane. Formerly it must almost certainly have been present somewhere near these localities and may have supplied the quartzite. It is evident, then, that these boulders are by no means surely of stream origin. If they are, however, their presence requires some special explanation. The higher surfaces adjacent to these saddles do not carry boulders, and therefore they can not be interpreted as wash from the San Juan peneplain. They are not of glacial origin, except possibly as outwash, and are slightly higher than one would expect to find Florida materials. It is possible that these boulder-strewn saddles represent a former course of the Gunnison River or one of its larger tributaries, but that is hardly likely. It is more probable that they were derived from the tuffs or other local formations, have not been carried far, and are of little significance in deciphering the more recent geologic history of the region.

Creede quadrangle.—Deposits identifiable as Florida gravel are of small amount and slight extent in the Creede quadrangle. This area in the heart of the eastern San Juan Mountains is one of vigorous erosion. Nearly all parts of it have been maturely dissected, so that remnants of the graded surface on which the Florida gravel now rests are neither numerous nor of great extent. The most noteworthy are situated north of the Rio Grande Canyon and south of the La Garita Mountains. Blue Park, one of the Florida remnants in that area, is a wide upland valley with gentle slopes between 10,300 and 10,800 feet above sea level, 1,500 to 2,000 feet above the bed of the adjacent Rio Grande and 500 to 1,000 feet below the neighboring mountain summits. This upland surface is underlain by a resistant lava flow, to which is to be largely ascribed the preservation of so wide an area of flat land at so great a height above the modern base-level. Its surface, however, is an erosion surface of mature type, sculptured by running water at a time when it closely approximated the base-level of erosion. The floor of the park is occupied by a very thick mantle of soil and rock waste. In places there are considerable accumulations of pebbles and boulders, all of which may be of local origin, as no materials derived from the pre-Cambrian area at the western margin of the Rio Grande drainage basin were observed. For this reason no Florida gravel has been represented at this locality on the maps. It is, however, quite probable that much of the accumulation of soil and local rock fragments took place during the final stages of the Florida erosion cycle.

Similar statements apply to Wason Park and the wide table-land south of the Wheeler National Monument. These upland surfaces are at altitudes of 11,000 to 11,800 feet and are clearly the northwestern extension of the same graded surface as that of which Blue Park is a part. Especially in the area drained by the headwaters of the West Fork of Bellows Creek these uplands are mantled with soil and rock waste that might well be considered the equivalent of the Florida gravel at this place.

Groundhog Park, in the northeast quarter of the quadrangle, is another upland surface with postmature erosion topography, high above the modern drainage lines and considerably below the adjacent summits. It likewise owes its preservation to resistant lava flows, which form cliffs around its rim, but the lava of its floor is a very different formation from that beneath Blue and Wason Parks. The soil and rock waste thickly accumulated on the floor of this park may likewise be interpreted as the local equivalent of the Florida gravel.

Del Norte quadrangle.—Extensive deposits of boulders and gravel on the eastern slopes of the San Juan Mountains, in the foothill zone bordering San Luis Valley, are believed to represent the Florida gravel, although correlation with the type deposit can not be made with certainty. These deposits are especially well developed in the south-central part of the Del Norte quadrangle west of Monte Vista. (See pl. 16, *A*.) The mountain front in that locality is bordered by low, gently sloping mesas covered with a veneer of washed gravel. As viewed from the valley these appear to be maturely dissected torrential fans of great size built out from the main stream channels, but when they are closely examined it is at once evident that this is not a true conception of them. Each mesa remnant consists of volcanic rocks—flows and tuffs—which dip toward the east. In places the surface of a mesa may coincide with the surface of a lava flow, but more commonly the mesa surface bevels the edges of the inclined volcanic flows, having a more gentle eastward dip. This is especially noteworthy when the summit level of the entire group of mesas is mentally reconstructed by projecting the graded surface from one mesa to another across the intervening lowland. Upon these remnants of a former more extensive and continuous plain there is found a deposit of waterworn gravel and cobbles composed of a variety of volcanic rocks, which ranges in thickness from a few inches to 20 feet. The mesas are therefore erosional features whose surface has been covered with gravel, doubtless deposited late in the cycle of erosion during which they were brought to grade.

In the area under consideration two sets of these gravel-veneered mesas may be observed at different heights above the modern stream beds. It is the higher of the two with which we are now concerned. Downstream the two mesa levels converge rapidly and decline somewhat abruptly until in places they merge into the modern alluvium. The Florida surface is in certain localities terminated on the east by an abrupt slope, the product of erosion during the dissection of the mesa, but elsewhere it continues downward unbroken to altitudes of 8,700 feet or less and there disappears beneath the more recent deposits of the lower mesa level or beneath the compound alluvial fan on the margin of San Luis Valley.

Upstream toward the west the Florida surface rises much more steeply than the channels of such streams as Rock Creek or Raton Creek; in secs. 29 and 32, T. 38 N., R. 7 E., for example, the Florida gravel is less than 100 feet above the bed of Rock Creek, whereas 3½ miles farther west it is more than 400 feet above the same stream. Gravel mantles the Florida surface nearly everywhere below an altitude of about 8,500 feet and occurs in places up to 9,000 feet. Farther west the reconstructed surface upon which the Florida gravel rests impinges against the middle slopes of hills and mountains that rise 1,000 to 2,500 feet higher. Penetrating farther into the mountains along the west margin of this quadrangle, the Florida surface is represented by Horseshoe Park and other broad intermontane basins high above the present drainage lines. Thus by easy stages the physiographic correlation may be made with surfaces of postmature erosion, which have elsewhere been linked with the typical Florida gravel of the south side of the range.

Conejos quadrangle.—The Florida gravel in the Conejos quadrangle is very similar to that in the Del Norte quadrangle, just described. Low, gently sloping mesas, veneered with a mantle of washed gravel and stream-borne boulders, border the mountain front from Rock Creek, at the north margin of the quadrangle, to La Jara Creek, near its center. The more conspicuous of these mesas are indicated on Plate 1. Each is a tilted table-land of volcanic rock partly concealed by a deposit of Florida gravel. Here, as in the Del Norte quadrangle, to the north, the surfaces of the mesas commonly bevel the edges of inclined volcanic beds that dip more steeply toward the east than the inclination of the mesa surface.

On both sides of Gato Creek the Florida remnants decline eastward until they disappear beneath the torrential wash of San Luis Valley. To the west they rise with steeper gradient than that of the streams, so that 2 or 3 miles west of the valley alluvium they are 200 to 400 feet above the adjacent creeks.

South of Alamosa Creek the Florida gravel overlies Hinsdale basalt or rests directly upon Los Pinos gravel. Much of the material of the Florida gravel there has been derived from the underlying Los Pinos gravel and has not been carried far. The surface is, however, one of noteworthy smoothness, sloping eastward with a gradient of about 200 feet to the mile. Steeper erosion surfaces carved in the Hinsdale basalt and Los Pinos gravel bound the Florida remnants on all sides.

Several long, narrow, fingerlike areas of Florida gravel occupy the flat upland between La Jara Creek, Rajadero Canyon, and the numerous tributary gulches of this broken area. Here, as in the region a few miles to the north, the Florida gravel rests upon Hinsdale basalt or Los Pinos gravel. At many places there is doubtless little more than a local smoothing of the Los Pinos gravel, the pebbles of which were transported but short distances by streams flowing and working approximately at grade. These surfaces all descend much more rapidly toward the east than the gradients of the adjacent streams. Thus they are brought from altitudes of nearly 9,000 feet near the west margin of R. 7 E., where they are found at heights of 500 feet or more above the stream beds, down to about 8,000 feet near the east margin of the same range, where they disappear beneath the modern alluvium. In the southeast quarter of the Conejos quadrangle the Florida gravel caps low terraces on the south side of the Conejos River. Near Antonito these terraces merge into the modern alluvium of San Luis Valley. Toward the west they rise somewhat more rapidly than the stream flat of the Conejos River, so that 12 miles west of Antonito the Florida gravel is on benches about 100 feet above the stream channel.

Summitville and Pagosa Springs quadrangles.—Numerous deposits of Florida gravel have been recognized in the drainage basin of the San Juan River near the west margin of the Summitville quadrangle and in the Pagosa Springs quadrangle, adjoining it on the west. The areas of gravel and boulders are of small extent but are of special interest because their relation to glacial deposits is so clearly shown. The Florida gravel mantles terraces and flat divides at altitudes intermediate between that of the Cerro glacial draft and of the Durango till. Farther down the valley the boulder-strewn mesas are 100 to 200 feet above the outwash from the Durango glaciers. In some localities the Florida gravel caps the higher hills, which are generally flat-topped though commonly so reduced by stream erosion that summit areas are very small. Nearly everywhere the boulders have rolled and slumped down the slopes to such an extent that the exact limit or thickness of the boulder cap can not be accurately determined.

Rio Arriba County, N. Mex.—In the valley of the Rio San Antonio and its tributary Nutritus Creek, in Rio Arriba County, N. Mex., there is a widely developed system of gravel-strewn terraces about one-third the way up from the modern flood plains to the adjacent mountain summits. The slope of these terraces is steeper than the river gradients. The Florida gravel that caps them is only 100 to 150 feet above the Rio San Antonio in the vicinity of San Antonio ranger station, in the northwest corner of T. 30 N., R. 8 E., but a few miles up Nutritus Creek, near the center of the same township, the equivalent stream terrace is 300 feet or more above the stream bed. The conditions are therefore identical with those in the quadrangles farther north where detailed mapping was done, and the correlation of these deposits with the Florida gravel seems justified.

The valley of the Tusas River, south of Tusas, is occupied in part by a very prominent terrace, remnants of which appear both above and below the narrows in the northeast quarter of T. 27 N., R. 8 E., where the stream is hemmed in on both sides by steep walls of pre-Cambrian rock. Above the narrows, in the open portion of the valley west of Tres Piedras, this terrace is found on each side of the modern flood plain at a height of 100 to 300 feet. The Cow Creek ranger station is on its surface. At this locality the terrace appears to be stream built, rather than the result of a temporary cessation of valley deepening, for no rock appears on the streamward face beneath the sand and gravel of which at least its upper surface is composed. The appearance, however, is probably deceptive; this terrace, like the others on which the Florida gravel was strewn, is believed to represent the base-level of a former erosion cycle, to which the stream degraded its valley in the soft yielding sand and gravel of the Conejos formation, which here abuts against the pre-Cambrian massif of the Tusas Mountains.

Farther south, downstream from the narrows of the Tusas, in the vicinity of Petaca and La Madera, there are numerous remnants of the same terrace. That it is the result chiefly of stream degradation rather than aggradation is here clearly shown; the graded surface coincides with a rock bench, formed in part of Tertiary volcanic rocks and in part of pre-Cambrian gneiss, across which the road from Petaca leads southward toward La Madera.

San Luis Valley.—Gravel deposits believed to be equivalent to the Florida gravel are widespread on the east side of San Luis Valley at the foot of the Sangre de Cristo Mountains. In the drainage basins of Ute Creek and Sangre de Cristo Creek, east and northeast of Fort Garland, there are numerous mesalike remnants of two graded surfaces at different levels. The lower surface stands about 35 to 40 feet above the present drainage level; the upper surface is about 250 feet higher. Both surfaces rise gently toward Blanca Peak, and on the lower slopes of that peak there are two series of flat-topped spurs, sloping mesas, and gently inclined benches, which may be correlated with the mesas nearer the automobile highway leading downward from La Veta Pass. Both sets of mesas are gravel strewn. They are composed of Los Pinos gravel and Hinsdale basalt, but the mesa surfaces are in general inclined southward or southwestward, whereas the gravel beds and lava flows pitch to the east. The flat surfaces of these table-lands are therefore due to erosion, and they may truly be called graded surfaces, although their present inclination from the mountains toward the valley is considerably steeper than the gradient of the streams at the time they were formed. The gravel strewn over the top of the higher terrace is doubtless the equivalent in the Sangre de Cristo Range of the Florida gravel of the San Juan Mountains. Apparently there has been renewed elevation of the Sangre de Cristo Range, accompanied by tilting of these boulder-capped mesas in a manner very similar to that which must have occurred in the San Juan Mountains.

Undoubtedly Florida gravel was distributed continuously throughout San Luis Valley north of the San Luis Hills. Like the earlier Los Pinos gravel, it is to-day concealed beneath the more recent fill in this basin. Presumably the Florida gravel has been penetrated by the drill in practically all the deeper water wells of the valley. There is, however, no way of distinguishing between the various parts of the post-Los Pinos deposit, which, at least, in the central part of the valley, was probably accumulating steadily throughout Quaternary time.

From the San Luis Hills southward nearly to Taos Junction the floor of the San Luis Valley is composed of Hinsdale basalt devoid of a gravel cap. In all probability this portion of the valley stood too high to receive a veneer of Florida gravel. It apparently has not been the site of alluviation since Los Pinos time. In the vicinity of Dunn's Bridge and near Taos Junction, however, the basalt floor is strewn with pebbles and cobbles brought by streams from distant mountains. These gravel deposits are 20 to 100 feet thick and cover scores of square miles on both sides of the steep-walled canyon of the Rio Grande. Eastward from this canyon the deposits become much thicker, and the flat surface of the gravel beds rises gently toward the Sangre de Cristo Range. Between the Rio Grande and the mountains, from Cuesta southward to the Ranchos de Taos, nearly every interstream area is occupied by a prominent flat-topped gravel mesa, inclined gently toward the west. These mesas are isolated from one another by the valleys of the streams flowing westward toward the Rio Grande, with flood plains 200 to 400 feet below the mesa summits. The physiographic relations are clearly displayed on both sides of the valley of the Rio Hondo, north and south of the town of Arroyo Hondo, as well as in the vicinity of San Cristobal Creek, a few miles to the north.

ORIGIN

The statements made above concerning the character and distribution of the Florida gravel include the salient facts upon which any conclusion as to the origin of this deposit must be based. Conditions of stream erosion and deposition similar to those that spread the Bridgetimber gravel must have once more been operative. The diastrophism that permitted streams to cut below the peneplain upon which the Bayfield gravel and the Bridgetimber gravel had been spread initiated a long cycle of erosion in the San Juan area. A new base-level of erosion was established, intermediate between that to which the streams had been working in the peneplain cycle and the base-level indicated by the channels of the master streams to-day. Toward this base-level the streams radiating from the central portion of each of the great domes began to carve their way.

The larger rivers were measurably successful in this new task of erosion. Considerable areas in the peripheral region about each mountain massif, especially where these areas were underlain by weak strata, were reduced to flat plains or undulating lowlands. Nearer the headwaters of the master streams and in the regions of more resistant rocks less progress was made; a mature topography of broadly U-shaped valleys was characteristic there, for lateral planation had accomplished little before the erosion cycle was brought to an end. In the immediate vicinity of the monadnocks that towered above the San Juan peneplain only youthful canyons and ravines were carved; not everywhere did even the larger rivers succeed in lowering their channels to the new grade.

Then marked climatic changes resulted in the Cerro glaciation, and the streams were heavily loaded with débris washed from the melting ice. Much of this load must have been dropped in the areas of old-age topography, beyond the foothill zone, where stream gradients were necessarily low. With the retreat of the ice, large amounts of easily eroded material were left available for attack by the vigorous streams in the area of mature or youthful topography, within the mountains proper. Glaciation had likewise disturbed the adjustment of many portions of the drainage to the grades that had previously been established by running water alone; energetic attrition at many places contributed largely to the excessive burden imposed upon the run-off in the outlying areas of low gradient. Hence, during and for some time after Cerro glaciation extensive alluviation went on about the margins of the mountains and in places even within the mountain masses themselves. Broad, low piedmont alluvial fans stretched from the foothills wherever a master stream debouched upon the plain and covered a large part of the area that had earlier been reduced to base-level by those same streams. Within the mountains postmature valleys, broad-floored and with low gradient, were the sites of boulder and gravel accumulation.

This episode of extensive piedmont alluviation was terminated by a renewal of diastrophic activity, which resulted in an uplift of the whole San Juan province and an accentuation of the arching in the mountain domes. The rejuvenated streams began to incise their channels, and even in the peripheral lowlands aggradation gave place to degradation. A third cycle of erosion had commenced; the former alluvial plains became plateaus and mesas above the new base-level. Gravel-floored valley flats were left as terraces and benches on valley walls above the new stream beds.

On the east side of the mountains, however, conditions were quite different from those that prevailed elsewhere. The uplift of the San Juan dome was in reality not a vertical movement but was accomplished by the tilting of a large block of the earth's crust. This tilted block was bounded on the east of the great meridional fault along the east side of the San Luis Valley. As the block tilted, it raised the entire San Juan mass and the surrounding lowland on the northwest, west, and south to an appreciably higher altitude, but toward the east the tilting depressed San Luis Valley to a relatively lower position. It is possible that excessive loading of that portion of the earth's crust combined with rapid erosion of the eastern San Juan Mountains imposed an isostatic factor that influenced diastrophism there. In any event, much of the Florida surface in the San Luis area was depressed and has been subsequently buried beneath deposits of the succeeding erosion cycles. Only a narrow strip of the graded surface along the foothills in the Del Norte and Conejos quadrangles has remained above the level of the gravel and silt floods and now forms the inclined mesas with their thin veneer of boulders and cobbles described above.

AGE

The Florida gravel is clearly of Pleistocene age. It was deposited immediately after the Cerro glacial stage and long before the Durango glaciation. This fact is at once apparent from the relative distribution and topographic situation of the deposits as detailed above.

The amount of erosion accomplished during the cycle that began with the first deformation of the San Juan peneplain and ended with the first deformation of the Florida graded surface was relatively much greater than that accomplished in all subsequent time. Probably it would have required three times as much time for the streams and glaciers of the San Juan Mountains to develop the topography that characterized the Florida surface as to carve the modern canyons below that surface. If, therefore, the deformation of the San Juan peneplain is taken as the milestone marking the beginning of Pleistocene time, the conclusion seems valid that the Florida gravel dates back to a time about one-third the way through the Pleistocene. This may be one reason for referring the Cerro glaciation, which did not long precede the deposition of the Florida gravel, to the Illinoian rather than to the Kansan glacial stage. On the other hand, this would also lead to the inference that if the Cerro glaciation is in reality Kansan or Nebraskan the deformation of the San Juan peneplain occurred earlier, perhaps in middle Pliocene time rather than at the beginning of the Pleistocene.

EARLIER TERRACE GRAVEL OF THE GUNNISON RIVER

CHARACTER

In the northern part of the Uncompahgre quadrangle, close to the Gunnison River, there are several deposits of terrace gravel which have been grouped together. It is impossible to correlate this gravel certainly with any other fluviatile gravel in the San Juan region, and no tentative correlation is attempted, because it is believed that the deposit is sufficiently individual to warrant separate treatment. It is typically exposed in proximity to the Rainbow Automobile Trail, which renders it readily accessible, and this is also the locality at which the deposit was first observed by us. It is in sec. 4, T. 48 N., R. 4 W., half a mile east of Pine Creek and half a mile south of the Gunnison River, about 2 miles southwest of Sapinero. The gravel occurs on a small terrace between 8,050 and 8,150 feet above sea level and nearly 1,000 feet above the bottom of the Gunnison Canyon. The deposit consists of beautifully waterworn pebbles and cobbles, most of which are between 3 and 8 inches in greater diameter. The largest are 20 to 22 inches in length, but these are not common. They include a variety of minerals and rocks—white and pink quartzite, milky quartz, jasper, chert, gray and pink granite of both coarse and fine texture, pink pegmatite, gray and black limestone, basalt, and schist. Boulders and blocks of latite from the "rim rock" of the Pine Creek Mesa, the northern escarpment of which rises abruptly above the gravel-strewn terrace, mantle the hillside and are intermingled with the gravel. Pebbles from it have been washed or have fallen down the slopes below the terrace level and may be found as far as the brink of the inner canyon carved by the Gunnison River in the pre-Cambrian complex. Only a few square feet of the terrace still retains its original smooth surface, and it is impossible to ascertain the original thickness of the gravel.

Other deposits of similar gravel, displaying the same assemblage of diverse rocks with the same waterworn appearance, have been found and mapped at a number of localities. Directly north of the type locality, on the southeast slope of Sapinero Mesa, this gravel occurs at an altitude of 7,950 feet, 150 feet lower than on the south side of the canyon. Two remnants of similar terraces are crossed by the Sapinero-Lake City wagon road west of Fourmile Gulch, at an altitude of 7,950 to 8,150 feet. Much farther upstream in the Gunnison Valley similar gravel was observed in sec. 24, T. 49 N., R. 3 W., at an altitude of 8,075 feet, and in the northwest corner of sec. 20, T. 49 N., R. 2 W., about 50 feet higher.

Downstream from the type locality the successive remnants of this earlier gravel likewise occur at successively higher altitudes—in the southern part of sec. 34, T. 49 N., R. 5 W., at 8,300 feet; in sec. 28 of the same township at 8,400 feet; and at two localities in sec. 29 at 8,500 and 8,600 feet. The most westerly deposit of this gravel that we observed is likewise the highest. It is on the southeast slope of Black Mesa near Curecanti, in the southwest corner of sec. 31, T. 49 N., R. 5 W., at an altitude of 8,650 feet. The remnant of a terrace there is surrounded by landslide débris from the cliffs above and from the terrace itself, all but a small part of it having slumped downward toward the canyon rim. The pebbles and boulders compose a deposit of considerable thickness, probably 40 or 50 feet.

ORIGIN

The earlier gravel of the Gunnison River is evidently of fluviatile origin and is presumably a relic of a stream-bed deposit made by the river during an earlier cycle of erosion. It can not be asserted that all the deposits described above were formed during a single episode of deposition; they may be far from contemporaneous. Yet the inference, drawn from the close similarity of altitude and the regularity of the gradient which they represent (see fig. 18), is that such was the case. If so, it is obvious that the surface upon which they were originally laid down has been materially warped since they were left in their present position.

A number of hypotheses to explain these deposits were carefully considered in the field. The most plausible is the one which harmonizes best with the general history of the Black Canyon of the Gunnison as recounted on page 60. It may not be considered the final statement of origin but is presented here merely as the best suggestion which it is now possible to make.

The Gunnison River is a superimposed stream, the course of which was inherited from the Peneplain cycle of erosion. Early in Pleistocene time it had carved for itself a broad mature valley in the volcanic rocks along its course and had begun to uncover the pre-Cambrian complex of its present canyon. Erosion in the crystalline rocks of this complex was obviously very difficult, and the stream was checked in its downward cutting where it was forced to traverse such rocks. For some distance upstream from that part of its course the volcanic rocks were easily eroded and the gentle gradient of an elderly stream was developed. But in the headwaters of the Gunnison and its tributaries the gradients remained high, and erosion was rapid. Hence the portion of the master stream between Iola and Curecanti became so heavily loaded that in this part of its bed the gravel described above was deposited. At about this time also the diastrophic movements that ended the Florida cycle of erosion began to warp the valley of the Gunnison River. An elevation of the Black Canyon region, as explained elsewhere, went on so slowly that the river was able to keep its westward course athwart the rising land mass without notable ponding. This, however, may have been an important contributory cause of deposition. As the stream succeeded in incising its course into the pre-Cambrian rocks, it lowered its channel at all points upstream, and the earlier gravel of the Gunnison was abandoned on benches and terraces at ever-increasing heights above the descending stream channel. Finally, this long-continued slow warping of the earth's crust probably resulted in an upward slope of the terrace downstream from Sapinero toward Curecanti, such as seems to be indicated by the terrace remnants.

AGE

The earlier terrace gravel of the Gunnison River was deposited before the Black Canyon of the Gunnison was formed and after the Gunnison had begun the dissection of the San Juan peneplain. It is therefore considered to be of early Pleistocene age and of approximately the same age as the Florida gravel, if the foregoing hypothesis as to its origin is true, but as this origin is different from that of the Florida gravel it is designated by a different name.

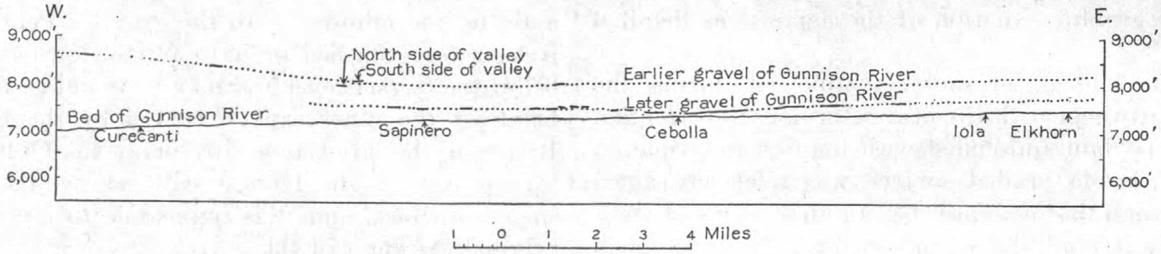


FIGURE 18.—Longitudinal profile of the Gunnison River between Elkhorn and Curecanti. Heavy black lines show location and altitude of earlier and later gravels of the Gunnison River. Dotted lines show restored profiles of valley floors on which the gravel was strewn during the earlier history of the Gunnison River

DURANGO TILL

DISCOVERY

The effects of comparatively recent glaciation in the San Juan Mountains have been noted by many observers and are so apparent that they can not escape the attention of any careful observer, whether trained in glaciology or not. Most of these effects, however, are the results of glaciation during the Wisconsin stage. Certain gravel deposits suggestive of glaciation in more remote Pleistocene time were noted in the folios descriptive of the Telluride, La Plata, Silverton, Needle Mountains, and Rico quadrangles. Satisfactory evidence of an earlier stage of glaciation was found in the progress of field work in the Ouray quadrangle;[41] it should be noted, however, that

[41] Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 17, pp. 260–261, 1906. Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153). p. 7, 1907.

the "earlier moraines" described there are now known to be a part of the Cerro glacial deposits. More recently, in the Engineer Mountain quadrangle, the deposits of two distinct glacial stages were recognized and mapped;[42] the "earlier glacial drift" of that quadrangle is here identified as Durango till. Similarly, in the Telluride quadrangle, many morainic deposits older than the Wisconsin have been noted;[43] the greater part of these are now referred to the Durango stage.

When, in 1910, we began our field studies in the outlying portion of the mountains in the Ignacio quadrangle, we had the benefit of manuscript maps and field notes by Allen D. Hole, covering the glaciated portion of the Animas Valley. Here were clearly indicated glacial deposits of two distinct stages, and for the first time the drift which we now term the type deposit of Durango till was described. Our extension of the glacial studies into the neighboring valleys toward the east and west made it clear that the distinction was by no means a local one. For a time the term "older drift" was used,[44] but the following summer, when the field studies were extended to the east and north, it became evident that there were three instead of two Pleistocene glacial stages recognizable in the region. In the first statement of this fact the field name "Bighorn moraine" was applied to the deposits now under consideration, which were correlated with similar glacial deposits in the Big Horn Mountains of Wyoming.[45] The present name, Durango till, was first used in 1915,[46] the local name being considered preferable to the correlation affirmed by the use of the Wyoming name.

DISTRIBUTION

Type locality.—The type locality of the Durango till is in the Animas Valley, in the Durango quadrangle, 1½ to 3 miles northeast of Durango. At this place there is a conspicuous terrace, which extends along the east side of the Animas Valley from Spring Creek almost continuously to Horse Gulch. (See pls. 1 and 25, *A*.) The terrace consists of rock; its surface bevels the edges of the sedimentary strata, which there dip in a general southerly direction. Its top is 250 to 300 feet above the adjacent bed of the Animas River. The northern and northeastern part of this terrace is occupied by the Durango till, a portion of the terminal moraine of the Animas Glacier which had moved southward down the valley at the Durango stage of glaciation. The southern part of the terrace is mantled with outwash gravel deposited as a valley train by the water flowing from the ice that left this terminal moraine.

The valley floor, 250 to 300 feet below this terrace, is occupied by the terminal moraine and outwash gravel of another valley glacier, which reached as far south as Animas, pushing almost to the foot of the escarpment below the terrace. It is evident that the two moraines were deposited at different times; during the interval between their deposition the Animas River cut a fairly broad trench 250 feet below the flat on which it had been flowing at the time of the earlier of these two stages of glaciation.

The Durango till forms a deposit of varying thickness and of typical morainic aspect. The surface is very irregular, with many knobs and hummocks and a few shallow, undrained depressions. Apparently there has been only slight modification of the moraine by wind and water since its deposition. The composition is that of ordinary glacial drift—boulders, large and small, embedded in a clay and silt matrix. The stones include practically every variety of rock that crops out in the Animas drainage basin. The more common boulders are red sandstone and grit, quartzite, coarse and fine granite of varying color and mineral composition, black hornblende-rich schist, and greenstone.

One might expect the boulders of this glacial moraine to be more deeply and generally weathered than those in the moraine on the valley flat at Animas, but the differences are so slight that it was deemed unsafe to rely upon the degree of weathering as a criterion to be used in identifying Durango till at other localities. Nor is the variety of boulders or the composition of the till different in the two deposits. The conspicuous difference is physiographic and is clearly brought out by a consideration of the amount of erosion which must have taken place in the interval between the deposition of the two bodies of till.

Animas Valley.—In addition to the remnant of the Durango terminal moraine in the Animas Valley, described above as forming the type deposit of this formation, there are several other areas of Durango till in that valley. One of these is apparently another fragment of the terminal moraine in a most precarious situation, west of Animas, on a narrow shale divide between Junction Creek and the Animas River. Only a few square rods of the deposit is really in place; most of it has been undercut by erosion and is slowly slumping and sliding down the slopes of the ridge toward the valley floor on each side. Originally this mass of till occupied a position analogous to that of the type deposit—some distance beyond the ter-

[42] Hole A. D., Glacial geology of the Engineer Mountain quadrangle: U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), pp. 8–9, 1910.

[43] Hole, A. D., Glaciation in the Telluride quadrangle, Colorado: Jour. Geology, vol. 20, pp. 502–529, 605–639, 710–737, 1912.

[44] Atwood, W. W., Physiographic studies in the San Juan district of Colorado: Jour. Geology, vol. 19, p. 449, 1911.

[45] Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colorado: Jour. Geology, vol. 20, pp. 392–409, 1912.

[46] Atwood, W. W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, p. 14, pl. 1, 1915.

minal moraine of the Wisconsin stage and high above the outwash gravel from that stage. Together, the two areas of terminal moraine define the limits of the Durango ice in this valley.

Several remnants of a lateral moraine are perched on the west wall of the valley opposite Trimble and Hermosa. They occupy the higher gentle slopes of intertributary spurs a few hundred feet above the limits reached by the Wisconsin ice. Other masses of Durango till were left in the lower portion of the Valley of Hermosa Creek by a tongue-shaped lobe of the Animas Glacier, which moved up the tributary valley about 2 miles. The drift here is on a rock bench on both sides of the creek, which has incised a steep-sided gorge 200 or 300 feet deep below the older valley floor on which the Durango ice rested.

Hermosa Valley.—Several bodies of Durango till have been observed in the valleys occupied by the headwaters of Hermosa Creek within the Engineer Mountain quadrangle. These were first described by Hole.[47] The till in the valleys of the North Fork and its tributaries is of local origin, containing only boulders of sedimentary and volcanic rocks that crop out in and at the heads of the immediate streams. No cirques of the Wisconsin type occur at the heads of these streams; sufficient time has elapsed since they were ice filled for weathering and erosion to obliterate the features that elsewhere characterize the glacial basins formed during the Wisconsin stage. Since the deposition of the drift the North Fork has lowered its channel 75 to 100 feet in rock. The evidence is conclusive that during the Durango glacial stage the streams heading against the west and south slopes of Graysill Mountain, the south slope of Hermosa Mountain, and the east slopes of the Rico Mountains were occupied by ice, but that these same basins were ice free during the succeeding Wisconsin glacial stage.

As reported by Hole, there are scattered erratic boulders on the south slope of the East Fork of Hermosa Creek, 200 to 500 feet above the limits of the Wisconsin moraine, and in a similar situation on the west side of the valley of Hermosa Creek just below Hermosa Park. Among these boulders are stones of monzonite derived from the head of Cascade Creek. Apparently the East Fork was invaded during Durango as well as Wisconsin time (see pl. 3) by a tongue-shaped lobe from the larger body of ice in the valleys of Cascade Creek and the Animas River, and here as elsewhere the earlier of the two glaciers was somewhat more extensive than the later.

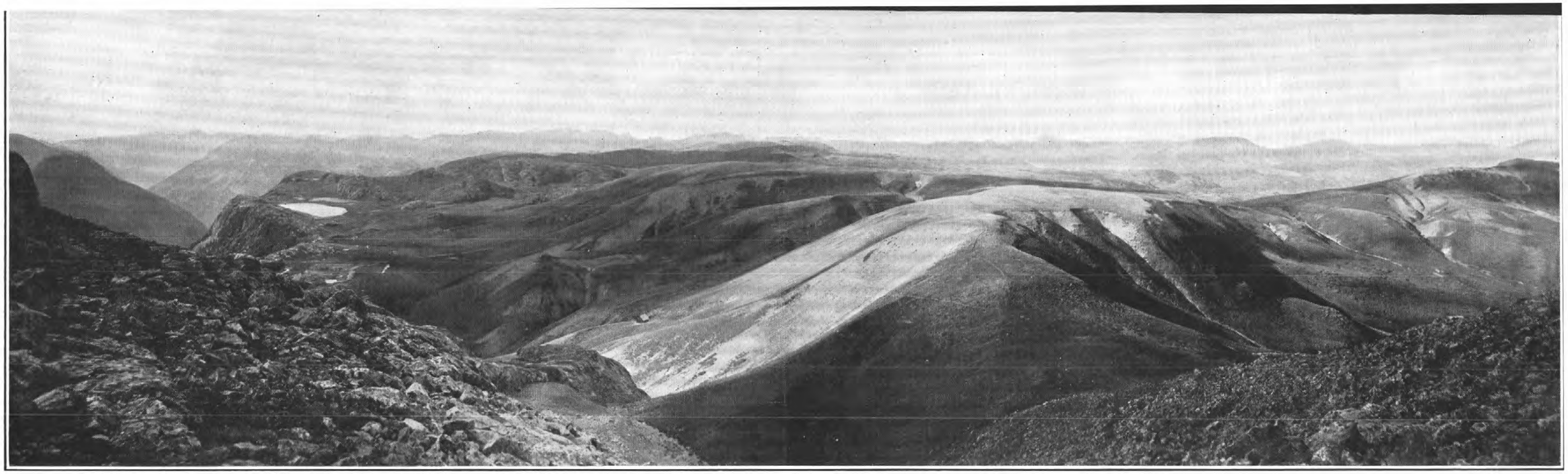
Florida Valley.—The terminal moraine of the Durango ice in the valley of the Florida River is 1½ miles downstream from that of the Wisconsin glacier. Both are in the northwestern part of T. 36 N., R. 7 W., in the Ignacio quadrangle. The Durango till is chiefly on the east side of the valley; the west wall is too steep to permit the lodgment of much loose material. Exposures along the wagon road, newly graded in 1910, showed that this drift contains many granite boulders as much as 2 feet in diameter so completely disintegrated that the shovel has cut them in two. The age of the terminal moraine is likewise shown by the fact that it may be connected with rock terraces veneered with fluvioglacial gravel which at its upstream end is nearly 200 feet above the present stream bed.

A conspicuous lateral moraine lies athwart the valley of Miller Creek, a tributary which joins the Florida River a mile above the terminal moraine. The drift and ice dam caused the tributary stream to deposit considerable silt along its lower course, and there is now a fertile meadow, some of which is under cultivation, between 8,700 and 9,800 feet above sea level. Alluviation here ceased so long ago that these silts have been extensively dissected, and there is now no semblance of lake-bottom marshes such as are found where lateral moraines of the Wisconsin stage have similar topographic relations.

Los Pinos-Vallecito Valley.—About 2 miles downstream from the junction of Vallecito Creek and the Los Pinos River, in the northeast corner of the Ignacio quadrangle, there is a pronounced morainic belt which stands somewhat above the Los Pinos Valley floor and is interpreted as the terminal of the Durango ice. The moraine displays something of the short ridge and hummock topography that characterizes deposits made by ice on lowland. In general it has a much older appearance than the unaltered terminal ridges of the Wisconsin moraine. It is composed of typical boulder till with a great abundance of large granite boulders, some of which are more than 20 feet in length. Many of the granite masses were plucked from the extensive outcrops of Eolus granite in the Needle Mountains, at the head of the Vallecito drainage basin. Boulders of the conspicuous Vallecito conglomerate from the same general area are also characteristic of the drift and stream wash in these valleys.

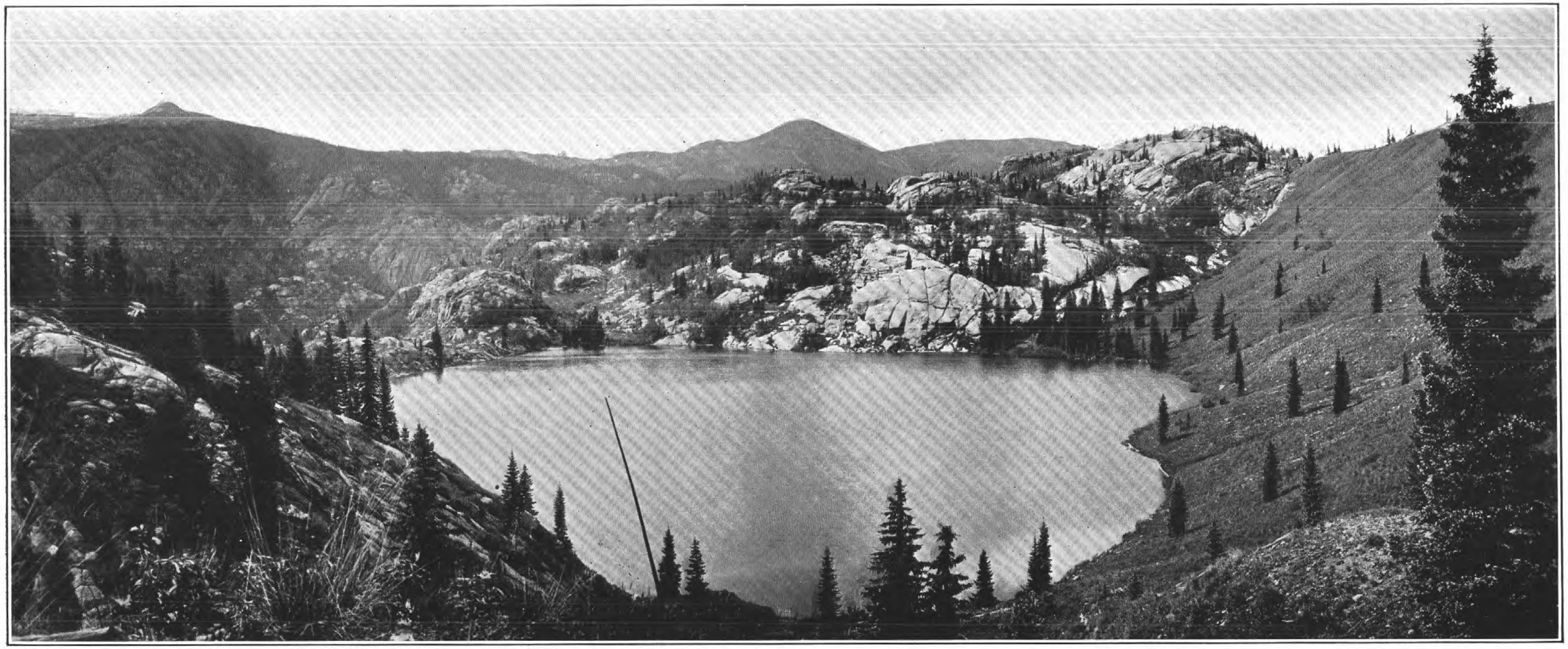
Well-defined lateral moraines may be traced several miles upstream from the terminal. Graham Park, 1,200 feet above the Vallecito bottom land on the west side of the valley, is an alluvial filling behind one of these moraines. The southern portion of East Mountain, between Vallecito Creek and the Los Pinos River, carries a lateral moraine on each side, one parallel to each valley, and at the tip a medial moraine that marks the union of the ice in the two valleys. The Durango till extends at this point to an altitude of about 9,100 feet, more than 500 feet higher than the upper limit of the Wisconsin drift.

[47] Hole, A. D., Glacial geology of the Engineer Mountain quadrangle: U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), p. 9, 1910.



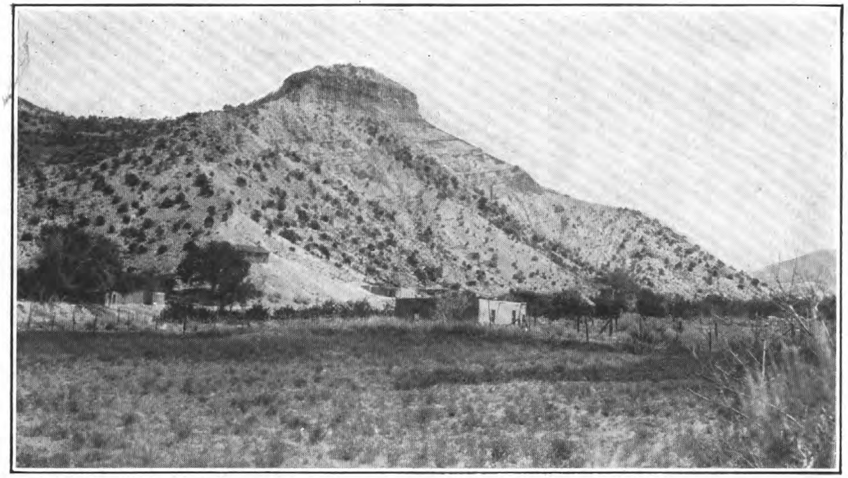
A. SAN JUAN MOUNTAINS NEAR HEAD OF ELK CREEK

The gently rounded upland in the central portion of this area is the Continental Divide and represents the horizon of the San Juan peneplain. The peaks and ridges in the distance are monadnocks above the peneplain. Photograph by Whitman Cross.



B. A HIGH MOUNTAIN LAKE IN THE SAN CRISTOBAL QUADRANGLE

This lake without a name is about 1 mile north of the pass where the trail crosses from the Los Pinos River into the valley of Weminuche Creek. The granite area on the far side of the lake has been severely glaciated, all loose material has been removed, and the rock surfaces are polished and striated. At the right the slope is composed of San Juan tuff, much disintegrated. In the distance there are bedded volcanic formations resting upon the granite. Photograph by Whitman Cross.

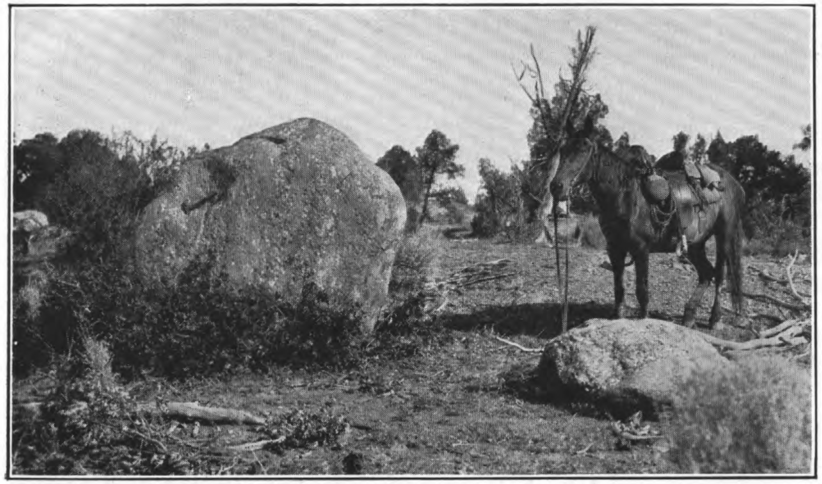


A. EAST WALL OF RIO GRANDE CANYON NORTHWEST OF PICURIS PEAK, N. MEX.

Near the summit a bed of Hinsdale lava rests unconformably on horizontal beds of gravel, which in turn lie unconformably on the eroded surface of tilted gravel beds, composing the greater part of the hill.

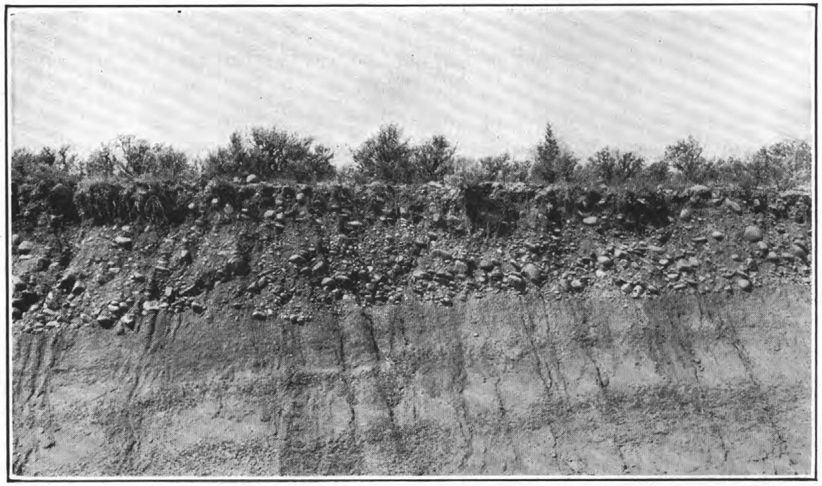
B. CERRO TILL AT HORSEFLY PEAK, MONTROSE QUADRANGLE

Horsefly Peak is an isolated hill of Mancos shale rising steeply above Uncompahgre Plateau. It is capped by Cerro glacial till in which are large blocks of latite. The flanks of the hill have been greatly modified by landslides in which the till has slumped down over the shale.



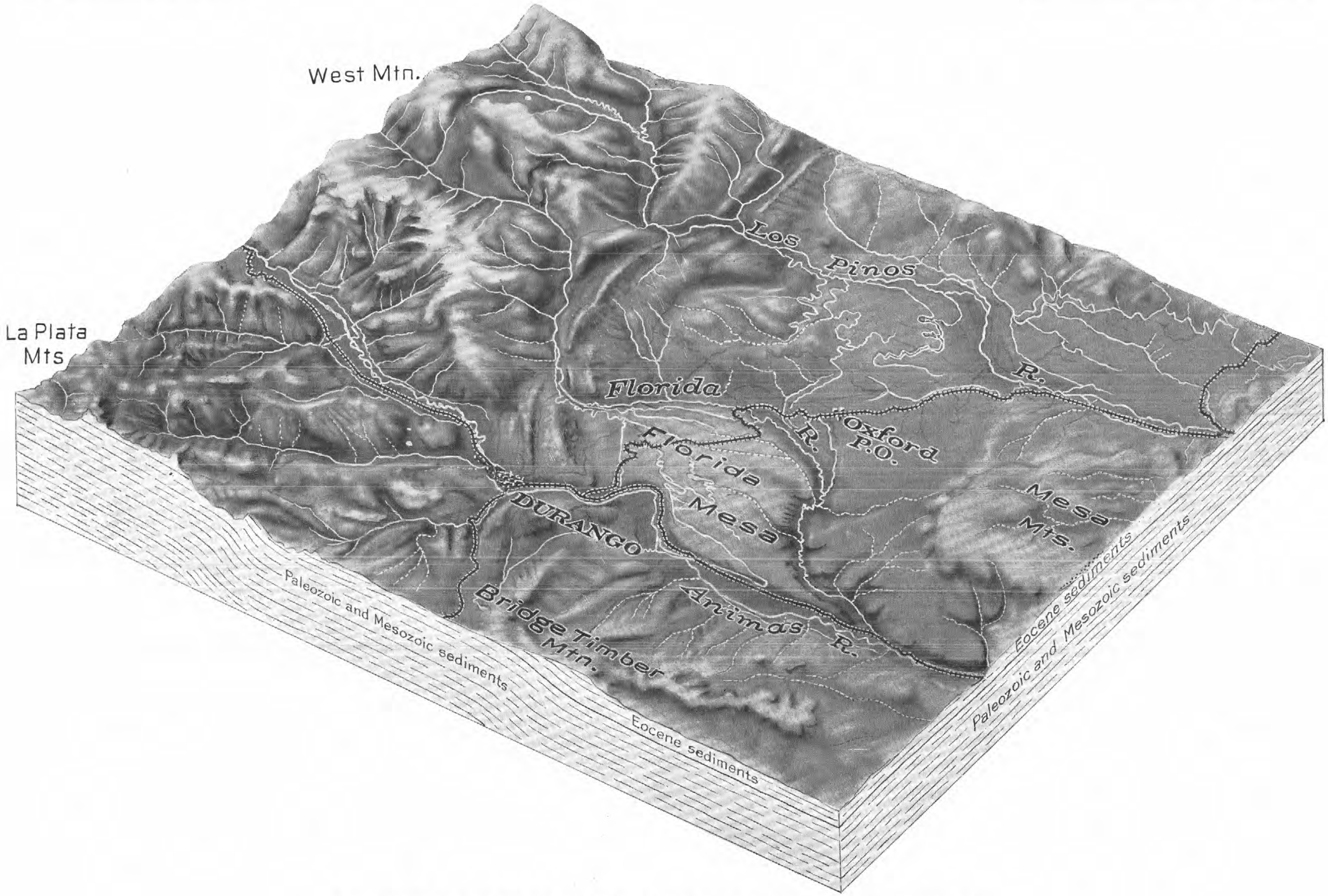
C. BOULDERS OF VALLECITO CONGLOMERATE

These huge stones are southeast of Ignacio, at least 25 miles from their source. The larger ones are at least 12 feet long. They are not in the present stream courses and were probably brought to this position by an ancient glacier.

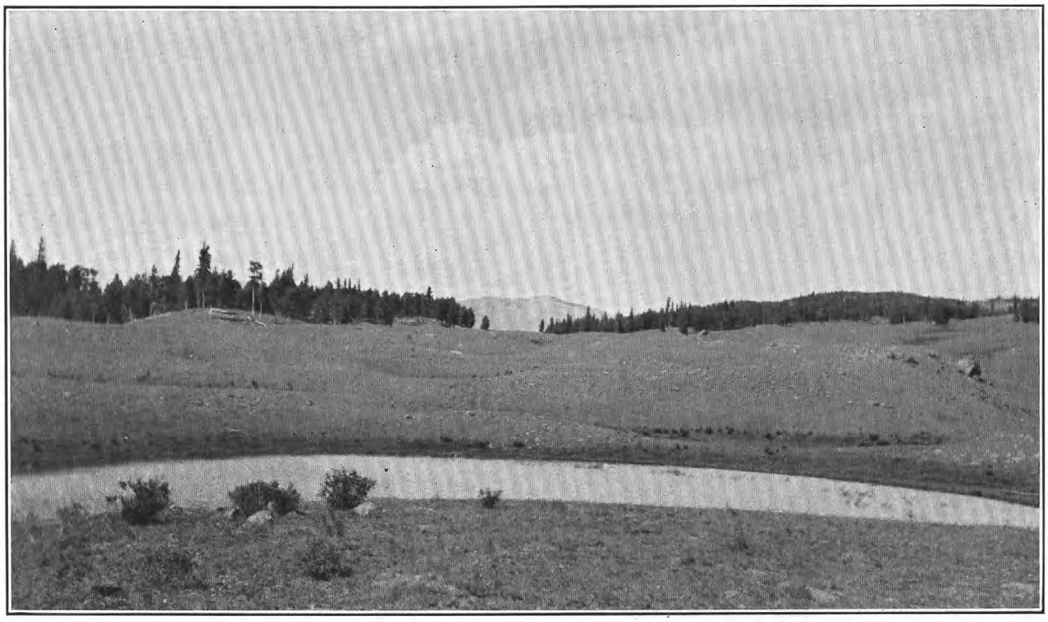


D. FLORIDA GRAVEL

View near east margin of Florida Mesa, where the mantle of loose gravel and boulders is more than 20 feet thick.

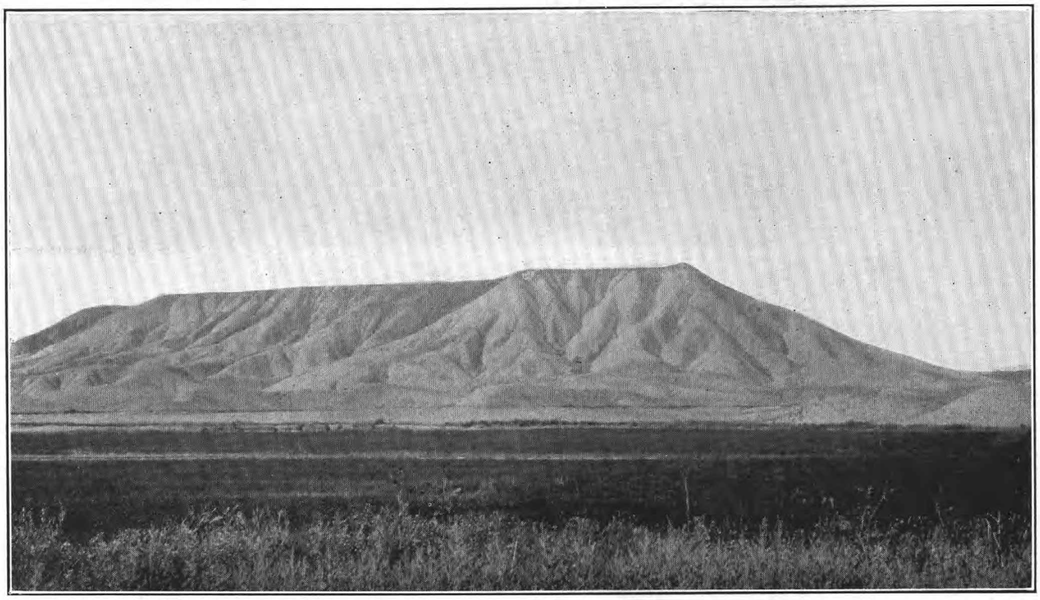


BIRD'S-EYE VIEW OF THE IGNACIO QUADRANGLE AS SEEN FROM THE SOUTHWEST



A. MORAINE NEAR HEADWATERS OF LA JARA CREEK

This hummocky moraine was formed at the margin of a small lobe of ice that welled over the south wall of Alamosa Canyon.



B. TABLE MOUNTAIN, NORTHEAST OF MONTROSE

The flat summit of this shale hill is protected by a thick bed of gravel and boulders deposited by streams during the Florida stage.

Weminuche and Huerto Valleys.—Lateral and terminal moraines of the Durango stage are fairly well preserved in the valleys of Weminuche and Huerto Creeks, in the south-central part of the San Cristobal quadrangle, and some distance farther south in the Pagosa Springs quadrangle. (See pl. 1.) At the time of the advance of the Durango ice Huerto Creek was tributary to the Weminuche through the low sag, now partly filled with Wisconsin drift, just south of the San Cristobal quadrangle, and the ice in the two valleys, coalescing at this point, moved down Weminuche Creek a distance of 3 miles below the lower limit of Wisconsin ice in that valley. Remnants of the Durango terminal moraine are there found on rock benches 75 feet above the present stream. In this older drift there are boulders of the granite of the Los Pinos River as much as 30 feet in diameter.

The Durango lateral and medial moraines extend only a short distance northward into the San Cristobal quadrangle. West of Weminuche Creek the upper limit of ice action is marked by thick morainic deposits high on the valley wall, about 300 feet above the Wisconsin till. A miniature park at an altitude of 9,200 feet a mile north of the quadrangle line is the result of alluviation behind the lateral moraine. The divide between Weminuche and Huerto Creeks is mantled with drift, in large part of a medial moraine resulting from the coalescence of the ice in the two valleys. Again on the east wall of the Huerto Valley is another lateral moraine, the upper limit of which is concealed beneath landslide débris from higher slopes.

Valley of the Middle Fork of the Piedra.—The slopes of the valley traversed by the Middle Fork of the Piedra River are mantled with Durango till from a point about a mile north of the south edge of the San Cristobal quadrangle for a distance of about 3 miles to the south. The moraines of the Durango stage are high above those of the Wisconsin ice, and beyond the Wisconsin terminal they rest on rock benches well above the level of Wisconsin outwash.

Piedra Valley.—Similar conditions are present in the valley of the Piedra River in the Pagosa Springs quadrangle. Lateral moraines of the Durango stage on both sides of the valley may be traced downstream to a dissected terminal moraine resting on a rock bench, considerably above the modern stream channel. Outwash gravel, beyond the terminal, caps a series of rock terraces about 100 feet above the valley train from the Wisconsin ice.

Turkey Valley.—Arthur Iddings, who was assisting in the field work, reports the presence of small areas of considerably weathered glacial drift in the valley of Turkey Creek, in the northwest corner of the Summitville quadrangle, between 1½ and 4 miles above its mouth. These deposits are at varying distances above the valley bottom and are in sharp contrast to the unweathered drift of the Wisconsin stage farther upstream on the valley floor. The remnants of Durango till are not sufficient to define accurately the limit of Durango ice, but here as elsewhere it would appear that the Durango glacier was larger than that of the latest glacial stage.

Mr. Iddings also suggests the probability that the Durango ice spilled over the divide into Snowball Creek and sent a small branch down the valley of that stream for a mile or two. The time available for his examinations in that area was not sufficient to settle the questions raised by the presence of apparently glaciated stones of volcanic origin which he found a mile below the head of that small creek.

San Juan Valley.—Irregular masses of Durango till may be observed on the eastern slope of the San Juan Valley in T. 36 N., R. 1 W., in the northwestern part of the Summitville quadrangle. These rest on a well-defined rock terrace, 150 feet above the Wisconsin valley train, and extend about 4 miles downstream beyond the Wisconsin terminal moraine. Beyond the Durango drift is outwash gravel at a similarly high level above the modern stream. The Durango moraines display undrained depressions at several localities and have received less wind-blown material than the Cerro drift in the immediate vicinity, from which the Durango till may be readily distinguished by its topographic situation within the valley of the San Juan proper.

Valley of Rito Blanco.—Three remnants of Durango till in the valley of Rito Blanco were mapped by Mr. Iddings. They occur in secs. 9 and 10, T. 35 N., R. 1 E., and indicate that the Durango ice in this small valley formed a glacier at least 5 miles long, whereas the Wisconsin glacier in the same basin was less than half as great. The Durango till at this locality is especially characterized by an abundance of very large boulders, some of which are 40 to 50 feet in diameter. They consist of the porphyritic intrusive rocks and volcanic tuffs that form the mountains at the head of the stream.

Blanco Valley.—The Durango ice in the valley of the Rio Blanco pushed nearly 4 miles beyond the point which later marked the terminus of the Wisconsin glacier and crept out beyond the mountain front, although confined strictly to the single valley. Numerous remnants of the moraines deposited by it are present on both sides of the stream in T. 34 N., R. 1 E. They rest on Mancos shale, and as a consequence some of the till has slipped down into the inner valley of the Rio Blanco, carved to a depth of 200 to 300 feet below the floor across which the Durango ice had moved. Lithologically the Durango till is apparently identical with that of Wisconsin age, but both are sharply differentiated from the older Cerro drift by the fact that they contain an abundance of boulders of light-gray porphyry, which is absent from the near-by Cerro deposits.

Navajo Valley.—No deposits of Durango till were mapped in the valley of the Navajo River, although our conviction that this valley was occupied by Durango ice is recorded by our identification of the higher terraces in the vicinity of Chromo as remnants of the Durango valley train. It is possible that the Durango ice did not push so far southward in this valley as the later Wisconsin ice, which would thus have obliterated the record left by the earlier glacier. It is more likely, however, that here, as elsewhere, the Durango glacier was the more extensive of the two, so that one would expect to find remnants of the Durango terminal moraine on the slopes, a few hundred feet above the modern valley flat in the vicinity of Peterson's ranch. These slopes, however, are heavily mantled with landslide débris. It is probable that landslides and running water have concealed, greatly modified, or entirely removed the Durango till in this valley.

Chama Valley.—Similarly there are no deposits of Durango till indicated on the maps of the territory drained by the Chama River. It happens that in this valley the Wisconsin terminal moraine extends exactly to the southern margin of the Summitville quadrangle. Durango moraines are probably present in the Chama Valley a short distance farther south. No detailed topographic map of that region was available at the time of our field work there, and the study of the Quaternary deposits was not carried south into New Mexico at this place.

Los Pinos Valley.—Another of the several streams named Los Pinos in the San Juan region rises in the southeast quarter of the Summitville quadrangle, traverses the southwest quarter of the Conejos quadrangle, and continues eastward south of the New Mexico line. Several small areas of Durango till were mapped by Atwood in T. 32 N., R. 5 E., just within the Conejos quadrangle. These are half a mile to 3 miles downstream from the terminal moraine left by the Wisconsin ice. They are found on the walls of the Los Pinos Valley or on neighboring uplands 200 feet or more above the modern flood plain. Here, as elsewhere, the Durango ice was slightly more extensive than the Wisconsin ice, and a notable amount of valley deepening has taken place since the deposition of the Durango drift.

Conejos Valley.—Drift deposited by the Durango ice in the drainage basin of the Conejos River still covers large areas of upland east of the Conejos Canyon, in spite of the vigorous erosion to which this region has been subjected in comparatively recent time. The most noteworthy body of drift at this locality forms the conspicuous group of low hills and ridges extending westward and southward from the south end of the La Jara Reservoir. (See pl. 24, *A*.) An unusually distinct frontal moraine lies like a huge crescent, curving eastward through the southern part of secs. 23 and 24, T. 35 N., R. 5 E., swinging southward from sec. 19, T. 35 N., R. 6 E., into the NE. 1/4 sec. 30 in the same township, forming the shore of the La Jara Reservoir for half a mile, and continuing southward in secs. 29 and 32. It is this frontal moraine that blocked the former channel of La Jara Creek and forced it to cut a narrow gorge, partly in the eastern margin of the moraine, where the present outlet of the reservoir is placed.[48] Several square miles of the upland north of Jarosa Creek, south and west of this frontal moraine, are occupied by ground moraine deposited by the same glacier. In places the topography is notably irregular with numerous rounded knobs separated by shallow undrained depressions, some of which are the sites of marshes or ponds, such as Chicago Bog.

The numerous tributaries of Jarosa Creek have, however, deeply trenched this drift, and, as indicated on Plate 1, they have in some localities carved their channels deep into the underlying rock. Similar masses of ground moraine cover the upland south of Jarosa Creek in and near the northeast quarter of T. 34 N., R. 5 E. Twin Lakes, Beaver Lake, La Grallal Lake, and Dry Lake all occupy depressions on the surface of this moraine. It has been deeply dissected by a number of the small streams of the region. Jarosa Creek has cut a valley, averaging half a mile in width and exceeding 150 feet in depth, in the volcanic rocks beneath these two large masses of ground moraine. Other similar patches of till deposited by the same ice are present farther west in the general vicinity of Acascosa and Empedrada Lakes, but these have not been indicated on the map. The materials of all these moraines are almost exclusively of volcanic origin. They appear to have been obtained by the glacier at no great distance to the west. Apparently a large body of ice overtopped the Conejos Canyon wall, now 1,600 feet high, and bulged far out to the east across the upland now mantled by these moraines.

Similar bodies of glacial drift are present close to the rim of the Conejos Canyon on the upland overlooking the Horton ranch and the Elk Creek ranger station. At this locality, too, the Durango ice overflowed the Conejos Canyon and spread out for nearly a mile beyond its narrow confines. Hidden Lake is a tiny body of water almost concealed in one of the depressions of the lateral moraine thus formed.

Presumably the terminus of the Durango ice in the Conejos Canyon must have been situated a short dis-

[48] Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, pp. 36–37, 1918.

tance downstream from the terminal moraine left by the later and somewhat smaller glacier that occupied that canyon during the Wisconsin stage. This part of the canyon is, however, narrow and steep walled. Erosion has here been very vigorous, and it would be surprising if such easily removed materials as glacial drift had remained to the present day. Near the northeast corner of sec. 27, T. 33 N., R. 6 E., there is, however, a small mass of glacial drift perched on a rock terrace 40 feet above the swift-flowing Conejos River, which may be the last remnant of the Durango terminal moraine. It is so nearly surrounded by torrential wash from the rapidly wasting cliffs that rise abruptly on the north side of the canyon at this point that its relation to the moraines and outwash deposits of the Wisconsin stage can not be determined with certainty. Although indicated on our maps as Durango drift, it may be only an outlying body of Wisconsin till.

Alamosa Valley.—The frontal moraine of the Durango glacier in the Alamosa Valley is one of the best preserved of all the marginal deposits left by ice of this age in the San Juan region. It is situated on the margin of the plateau overlooking the Alamosa Reservoir from the north and east, at a height of 200 to 500 feet above the floor of the Alamosa Canyon. A long, narrow deposit of glacial drift, distributed in the form of a hummocky ridge, extends southeastward from the SW. 1/4 sec. 10, T. 36 N., R. 6 E., for 1 1/2 miles close to the canyon rim and then curves southward at right angles to the Alamosa Valley in the SE. 1/4 sec. 14 of the same township. Another remnant of the same frontal moraine is present on the south wall of the canyon directly across the valley at a similar height above the reservoir. Since the terminal moraine was deposited across the valley half a mile below the present site of the reservoir dam, the river has not only breached the moraine but has cut a passageway in the underlying rock to a depth of 250 feet.

The relations of the Durango terminal moraine to the similar moraine deposited by the Wisconsin ice are clearly shown in this vicinity. The Durango moraine was not only farther down the valley and at a greater distance from the stream but also at a much greater height above the present drainage channel, perched on a rock bench scores of feet above the flat mantled with Wisconsin till. There is no appreciable difference in the composition of the two bodies of till, nor does the Durango drift appear notably more weathered or modified by stream action, but the great difference in age is indicated by the large amount of canyon deepening that must have been accomplished by Alamosa Creek in the interval between the two glacial episodes.

A few miles farther west there is a large area of ground moraine mantling the upland in the vicinity of Big Lake. Glacial drift extends southward from the Alamosa Valley through a broad col into the head of the La Jara Valley. At the southern limit of the drift, near the center of sec. 25, T. 36 N., R. 5 E., the ground moraine is bordered by a rather inconspicuous frontal moraine, composed of several irregular ridges arranged somewhat as a loop across the valley. Beyond, to the south, there is an outwash plain which blends into the wide alluvial flat north of La Jara Reservoir. The surface of this body of Durango drift is irregular, with many knolls and knobs rising prominently above the intervening depressions. Many of the depressions are occupied by small bodies of water, of which Big Lake is the largest. The whole deposit is evidently the débris left by a short lobe from the main Durango glacier in the Alamosa Valley, which bulged southward across the divide into the head of La Jara Valley.

Valley of Rock Creek.—The two forks that unite to form Rock Creek near the north margin of the Conejos quadrangle rise on the eastern slopes of the ridge culminating in Bennett, Sheep, and Silver Mountains. Although there are large basins at the blunt heads of these two valleys, neither is notably cirquelike, nor is either cleaned of loose débris, as are the heads of valleys that were occupied by ice during the Wisconsin stage. It is probable that both these valleys were occupied by ice in Durango time, but the glaciers were neither vigorous nor large. Two small patches of glacial till near the head of the North Fork of Rock Creek probably mark with a fair degree of accuracy the terminus of the Durango ice in that valley. The North Fork has sunk its valley 150 feet below the floor on which the Durango terminal moraine was deposited, and the original morainic topography of the drift at this point has long since been completely obliterated.

Raton Valley.—Two of the forks of Raton Creek, in the southwestern part of the Del Norte quadrangle, rise in large amphitheaterlike basins on the northeast slopes of Pintado Mountain. Each of these basins appears to have been occupied by ice during the Durango stage. They are not the typical cirques that result from glaciation of the Wisconsin stage, nor are they normal stream-eroded valley heads. Both appear to be old cirques that were never so intensely glaciated as the basins in which ice accumulated during Wisconsin time and that have been considerably modified by stream erosion and torrential accumulations subsequent to weak glaciation.

Moraines extend down the valleys in the vicinity of Raton Park to an altitude of 9,300 feet. These moraines are very stony and contain many subangular boulders of volcanic rock, some of which are 15 to 20 feet in diameter. The boulders are much weathered, and no glacial striae were observed. In many places typical moraine topography has been retained, with scattered basins occupied by small ponds. Outwash boulders and gravel, now much weathered, mantle the slopes extending beyond the moraine in the southerly fork of Raton Creek. The evidence all points strongly toward the Durango age of these glacial deposits.

Valley of Middle Fork of San Francisco Creek.—The Middle Fork of San Francisco Creek rises on the northeastern slope of Bennett Mountain, near the north margin of the Conejos quadrangle, and flows northward in the southwestern part of the Del Norte quadrangle. Wisconsin moraines extend northward from a point near the valley head to a point about a quarter of a mile north of the Del Norte quadrangle boundary, where the drift forms conspicuous ridges that curve together downstream. Beyond the lowermost of these prominent moraines is another pair of ridges of a more discontinuous, broken character, which are separated from the upstream moraines by a small but typical area of outwash gravel and boulders. There is no evidence to prove whether this lowermost deposit of till is of Wisconsin or Durango age. It is indicated on Plate 1 as Durango till, because of the slight similarity of conditions here to those at Durango and Ridgway, where there has been notable stream erosion between the two epochs.

Valley of Rio Grande.—The valley of the Rio Grande contains several deposits of Durango till in the general vicinity of Bristol Head. The largest of these is in the Creede quadrangle close to its western margin. Eastward from the great mass of Wisconsin till that clogs the lower reaches of Middle Creek and South River where they flow across the Rio Grande flat to join the master stream, there are morainal deposits banked against the valley side on the outside of the great northward bend in the Rio Grande near Antelope Spring. The morainal hills form a barrier across the lower part of the valley of Lime Creek, swinging crescentlike from north to south throughout a distance of more than 3 miles. The drift in the northern two-thirds of this lateral moraine contains large numbers of boulders of quartzite, schist, gneiss, and granite, which must have been derived from the pre-Cambrian rocks of the Continental Divide at the head of the Rio Grande; the southern third of the moraine contains few such boulders but is composed almost exclusively of volcanic rocks brought from the headwaters of South River, only a few miles away. The topography of the Durango till at this locality has been greatly modified by erosion, and the moraine is sharply demarked from the more recent and fresher deposit of Wisconsin age, which borders it on the west.

A frayed remnant of the Durango terminal moraine occupies a sheltered reentrant facing the Rio Grande about 3 miles downstream from the Wisconsin terminal, in sec. 28, T. 41 N., R. 1 W. It rests on a rock bench 100 feet or more above outwash gravel of Wisconsin age and is partly buried by débris from the cliffs that rise above it toward the east.

Within the San Cristobal quadrangle there is a conspicuous flat-topped hill which rises abruptly to a height of more than 300 feet above the valley floor, southeast of Bristol Head, exactly in the middle of the broad, flat valley. The Wisconsin ice was stopped from further advance at this point by its inability to climb the barrier presented by this hill, but upon the summit there are drift boulders dropped there when the more extensive Durango ice pushed onward toward its terminal, 3 miles downstream.

Another remnant of a lateral moraine resting near the summit of the ridge that forms the southwest wall of the Santa Maria trough is referred to the Durango stage because it seems to be well beyond the limit of the Wisconsin ice in that vicinity. The greater extent of the Durango glacier in comparison with that of the Wisconsin stage is again attested by the presence of Durango till, partly filling the northwest end of the Santa Maria trough near the junction of Boulder Creek with Clear Creek. The Durango ice, moving down the canyons east of the Lost Lakes, entirely filled the valley of Clear Creek and pushed a short lobe into the Santa Maria trough. The moraine deposited at the end of this lobe has been deeply trenched by Boulder Creek and is separated from the younger Wisconsin drift by alluvial and outwash deposits. It contains many boulders brought from the pre-Cambrian complex, 20 miles to the west.

Valley of Miners Creek.—Miners Creek heads west of San Luis Peak, near the northwest corner of the San Cristobal quadrangle. Ice accumulated in the basin within this quadrangle and pushed downstream a considerable distance into the Creede quadrangle. The terminal moraine of the Wisconsin stage is at an altitude of 9,000 feet, 1½ miles northwest of Sunnyside. Below this point the canyon walls are steep and rugged, deeply carved by stream erosion and weathering. This lower portion was therefore glaciated only in a pre-Wisconsin stage. Morainic drift near Sunnyside is believed to be the result of Durango glaciation.

Groundhog Valley.—The tributaries of the north fork of Groundhog Creek have their sources in high basins near the east end of the La Garita Mountains, in the northeast corner of the Creede quadrangle. The three valley heads on the southeast side of the divide, between Mesa Peak and Bowers Peak, are cirquelike but lack the rugged character, steep walls, and deeply eroded floor that may ordinarily be observed in cirques carved by ice of the Wisconsin stage—such, for example, as that at the head of Bear Creek, on the north side of Mesa Peak. The remoteness of the episode of ice sculpturing in those basins is further attested by the fact that the second amphitheater to the northeast from Mesa Peak has lost a portion of its bounding wall by the vigorous erosion of Bear Creek; it may be called a beheaded cirque. Apparently these basins were not occupied by ice during the Wisconsin stage but were glaciated during Durango time.

Certain of the streams flowing from these basins traverse a mass of glacial débris 1½ to 3 miles upstream from the forks of Groundhog Creek. The drift has been deeply trenched, and at many points the streams have carved their channels far into the underlying volcanic rocks, although in most places their courses are choked with torrential wash. The boulders of the drift are very much weathered, though this is not very significant because of the nature of the volcanic rocks of which they are composed. The general aspect of the moraines is old, and this fact, coupled with the appearance of the basins where the ice that deposited them must have formed, leads to their interpretation as of Durango age.

Valley of Cave Creek.—The stream that rises on the southeast side of Boot Mountain, in the northeast corner of the Creede quadrangle, and flows thence into the Del Norte quadrangle is known as Cave Creek. The basin at its head is broad and has comparatively gentle slopes, much modified since glaciation by weathering and erosion. Two morainic ridges converge downstream a mile or two below its head. Their softened outline, the amount of erosion that has affected them, and the quantities of talus and débris that have slumped down upon them all suggest considerable antiquity. Apparently the head of this valley was occupied during the Durango stage by a glacier about 2 miles long and has been ice-free ever since.

Saguache Valley.—Several small bodies of Durango till in the drainage basin of the Saguache River, on the north side of the La Garita Mountains, indicate that the Durango ice in that region was of considerably greater extent than the Wisconsin glaciers. Between Halfmoon Pass and Table Mountain, in the north-central part of the Creede quadrangle, glacial drift occurs at half a dozen localities. It is composed largely of fragments of volcanic rock plucked from the mountains at the head of the South Fork of the Saguache River. The boulders are deeply decayed, and little semblance to morainic topography remains. The patches of drift indicated on Plate 1 are separated from one another by erosion channels that have dissected the ancient moraines and are now carved deep into the underlying volcanic rocks.

Valley of Lake Fork of Gunnison River.—Four bodies of Durango till have been mapped in the valley of the Lake Fork of the Gunnison in the immediate vicinity of Lake City, in the southern part of the Uncompahgre quadrangle. The most noteworthy of these are the small patches of morainic débris on either side of Sparling Gulch, well beyond the conspicuous moraine that marks the terminus of the Wisconsin glacier. The older drift is deeply weathered and has suffered extensive erosion since it was dropped from the ice that brought it to its present situation. The moraine in Slaughterhouse Gulch is likewise at some distance beyond the limit of Wisconsin ice as determined by the remnants of lateral moraines parallel to the Lake Fork. The larger mass of moraine, east of Lake City, is partly buried beneath landslide from the cliffs above and has itself suffered considerable modification by slumping; the line that separates the Durango and Wisconsin moraines on Plate 1 is therefore only an approximation.

The Durango drift near Lake City contains a great abundance of granite boulders, which must have come from the head of the Lake Fork, in the San Cristobal quadrangle. Many of the stones are striated, but morainal topography has long since been obliterated.

Blue Valley.—The glacial deposits on both sides of Blue Creek 1 mile upstream from the mouth of Little Blue Creek, in the northwestern part of the Uncompahgre quadrangle, are composed of Durango till. Blue Creek has incised a canyon more than 100 feet below the floor upon which that drift was deposited. Upstream from the moraine and only a few feet above the creek are outwash deposits from the more recent Wisconsin glacier.

Little Cimarron Valley.—The terminal moraine of the glacier that during the Durango stage occupied the valley of Little Cimarron Creek, near the west margin of the Uncompahgre quadrangle, rests on shale slopes on both sides of the stream about 5 miles above its junction with Cimarron Creek. The moraines have retained their knob and kettle topography, and typical sections of till containing boulders as much as 8 feet in length are exposed by small landslides around the margins. On the west a long, low ridge curves downward and outward upon the valley slope to a level 300 feet above the stream. On the east slope the moraine is of irregular shape but occupies a similar position above the valley floor. The terminus of the Wisconsin ice was about 2 miles upstream from this point.

Little Cimarron Creek is credited with two East Forks. Of these the more southerly one was glaciated during the Durango stage. At that time the portion of Fall Creek above the falls had not been diverted to Blue Creek but formed the head of this East Fork. (See fig. 13, *B*.) Ice forming in the basin at the head of what is now Fall Creek moved northward and may have been confluent with the ice in the Little Cimarron Valley. A remnant of a moraine, which may have been either the terminal or a recessional moraine, occurs on both sides of this East Fork 2 miles downstream from the Wisconsin terminal, which now fills the valley at the head of the fork. This moraine is composed of Durango till.

Cimarron Valley.—Extensive deposits of Durango drift have been mapped in the valley of Cimarron Creek in the northeast quarter of the Montrose quadrangle. The west side of the valley, from Veo Creek southward, is for many miles mantled with till deposited by ice that pushed 3 miles downstream beyond the point reached by the later Wisconsin ice. The Durango drift rises several hundred feet higher on the slopes of Cimarron Ridge than the later deposits of the Wisconsin stage. At one place near the north end of Cimarron Ridge a conspicuous lateral moraine was thrown across a tributary valley. The lake thus formed has been largely filled by post-Durango alluviation.

A small portion of the Durango terminal moraine in this valley has been preserved as a prominent ridge trending northwestward on the east side of the stream, a short distance north of the Cimarron mud flow in secs. 5, 7, and 8, T. 47 N., R. 6 W. Much of the drift, both in this moraine and elsewhere on the sides of the Cimarron Valley, has been more or less disturbed by landslides. Nearly everywhere it rests upon Cretaceous shale, which readily yields when saturated and causes numerous slumps where slopes are steep.

Uncompahgre Valley.—Morainal deposits of Durango till are preserved on the hills near Dallas, in the Uncompahgre Valley near the center of the Montrose quadrangle. Toward the west the extreme southeast corner of Log Hill Mesa is capped by a deposit of glacial drift. The drift boulders, some of which are striated, reach 3 feet in diameter and comprise quartzite, sandstone, shale, tuff, and a variety of volcanic rocks. This assemblage of stones is not unlike that in the Wisconsin terminal moraine on the valley floor near Ridgway, but it differs markedly, especially in the presence of many quartzite boulders, from that in the Cerro till in the same valley.

On the hills east of Dallas, just across the valley, are other remnants of the Durango moraines. Erosion has obliterated almost all semblance of morainal topography, but glaciated stones are easily found. Both of these masses of drift rest on a rock floor about 500 feet above the present channel of the Uncompahgre, and within this 500-foot canyon there are portions of the valley train washed down the valley from the Wisconsin ice. (See fig. 16.)

Dallas Valley.—Several of the many heads of Dallas Creek rise on the imposing north front of the Sawtooth Mountains, at the south margin of the Montrose quadrangle. Each of these streams displays moraines of both Wisconsin and Durango age, and not far distant are deposits of Cerro till. The Durango till is situated in the immediate valleys of the several streams; it does not cap interstream divides, like the Cerro till. (See fig. 19.) At the same time its considerable age is indicated by the fact that the streams have lowered their courses scores or even hundreds of feet, as on the West Fork, below the level upon which the drift was deposited. In every valley the Durango terminal moraines are situated farther downstream from those of Wisconsin age and are clearly demarked from them.

Alder Valley.—Similar conditions may be observed on Alder Creek, in the far northwest corner of the same quadrangle. Glacial débris mantles the shale slopes near the road leading south from Hastings Mesa. Huge boulders of volcanic rock from the higher basins have disintegrated until some are mere heaps of broken rock. Morainic topography is still retained, however, and the till character of the débris is quite evident. The Wisconsin terminal is 1½ miles farther upstream and 800 feet higher than the base of this deposit of Durango till.

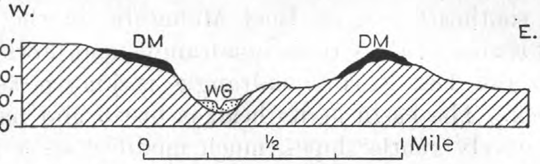


FIGURE 19.—Cross section of Uncompahgre Valley near Dallas, showing relations of Durango till (DM) on the upper slopes to the inner and later valley on the bottom of which is outwash of the Wisconsin stage (WG)

San Miguel Valley.—The deposits of Durango till in the San Miguel Valley and elsewhere in the Telluride quadrangle have been mapped and described by Hole[49] under the name "Drift of earlier epoch." Only brief reference to them need be made here. The divide between Eder and Mill Creeks, 2½ miles northwest of Telluride, is capped with Durango till, the lower limit of which is much obscured by local landslides. This moraine, as well as that on the similar divide west of Eder Creek, was apparently deposited by ice from the large basins beneath Dallas and Gilpin Peaks, which spread over all this lower land during Durango time.

The basin of Remine Creek seems to have escaped glaciation during the Wisconsin stage but was occupied by ice during Durango time. Two small remnants of the terminal moraine from that ice are indicated on Plate 1. A portion of the lateral moraine of the Durango glacier in the valley of Deep Creek is crossed by the mesa road from Telluride. Other masses of Durango till rest on the surface of the Diamond Hill upland close to the brink of the San Miguel Canyon. None have been found within the canyon, which presumably has been greatly deepened by stream erosion in post-Durango time.

[49] Hole, A. D., Glaciation in the Telluride quadrangle, Colorado: Jour. Geology, vol. 20, pp. 511–512, 710–737, 1912.

Just beyond the terminal moraine of the composite glacier which in Wisconsin time moved northward from the Mount Wilson group down valleys tributary to Big Bear Creek are several isolated areas of older glacial drift. These, likewise, are referred to the Durango glacial stage.

East Dolores Valley.—Similar conditions exist in the southwest corner of the Telluride quadrangle. Barlow Creek and the head of the East Dolores River, in the Engineer Mountain quadrangle, did not suffer glaciation during the Wisconsin stage, but both were occupied by Durango ice. Only scanty remnants of the Durango till have escaped erosion, which has greatly deepened these valleys since Durango time. Kilpacker Creek and other tributaries of the East Dolores flow through valleys in which glacial drift of both Wisconsin and Durango age may be recognized. The Durango moraines are downstream from the Wisconsin terminals or are in the form of lateral moraines at higher altitudes than those reached by the Wisconsin ice.

La Plata Mountains.—Three small bodies of Durango drift were mapped by Atwood in the La Plata quadrangle. The largest of these is situated on a bench 200 to 500 feet above the valley of the West Mancos River, near the mouth of Echo Creek, at an altitude of about 10,000 feet. The drift at that locality is clearly distinct from the deposits left by the Wisconsin glaciers, which form a lateral moraine on the inner slopes of the West Mancos Valley. The Durango ice seems to have formed in Owen Basin and neighboring cirques on the west side of the La Plata Mountains, and it may have occupied the head of Echo Creek Valley between Jackson Ridge and Helmet Peak. That valley was not glaciated during the Wisconsin stage, and its blunt head encircled by fairly steep, high walls suggests ice action during the earlier episode of glaciation. No remnant of a Durango terminal moraine in the West Mancos Valley has been found. The outer slopes of that valley beyond the point reached by the Wisconsin ice are generally covered with landslide débris, and it is possible, though scarcely probable, that the Durango terminal has there been destroyed. In any event, one of two conclusions seems necessary. Either the ice of the Durango stage in the head of the West Mancos Valley was more widespread than the Wisconsin ice in the same valley, or the head of Echo Creek was occupied by Durango ice but not by Wisconsin ice.

Two small areas of Durango moraine have been preserved in the valley of the La Plata River near Parrott, where the stream leaves the mountains. On the east side of the valley this morainal material is at an altitude of about 9,000 feet, some 300 feet higher than the Wisconsin moraine on the river flat below. Water-transported boulders from the moraine or from the Durango ice are strewn over the hillside for some distance southward from the remnant of moraine. West of Parrott the Durango deposits have been almost entirely obliterated by landslides on the lower slopes of Parrott Peak, but a small strip of undisturbed moraine has been mapped at the same altitude as that of the drift across the valley. Probably each of these remnants is a part of a lateral moraine, and consequently they do not indicate the terminus of the Durango ice. It is clear that the Durango ice was of somewhat greater extent than the later Wisconsin ice in this valley.

AGE

The chronologic position of the Durango stage in the Pleistocene epoch is indicated by the relations of the Durango deposits to the Cerro till and Florida gravel on the one hand and to the Wisconsin glacial drift on the other. The Durango till is clearly intermediate in age between the drifts of the other two glacial stages that have been recognized in the San Juan region.

The physiographic relations of the rock floor upon which rest the observed remnants of Durango till and outwash to that upon which the Florida gravel was spread indicate a considerable interval of valley deepening between the two epochs in all localities where the deposits are now in proximity. Not only did the master streams lower their channels 100 to 200 feet below the Florida gravel horizon in the marginal zone about the mountains, but after reaching the lower level they accomplished considerable lateral planation before they were interrupted by glaciation. Valley flats a mile or two wide were not uncommon in the vicinity of the Durango terminal moraines and for many miles downstream beyond the foothills.

Even more significant is the fact that in certain valleys there are marked differences in the composition of the boulders in the Cerro and Durango tills. During the time which intervened between the deposition of the Cerro till in the Uncompahgre Valley, with its paucity of quartzite boulders, and the Durango glaciation in that same valley, the Uncompahgre Canyon south of Ouray must have been carved deeply enough into the quartzite of the Uncompahgre formation to expose that formation so generously that the Durango ice could pluck an abundance of boulders from it. Similarly, in the Blanco Valley, on the south side of the range, the stripping of the cover of volcanic rocks from the surface of the monzonite porphyry laccolith must have been largely accomplished in the post-Cerro and pre-Durango interglacial interval, for boulders of the monzonite are absent from the older till but numerous in the later drift.

On the other hand, the post-Durango and pre-Wisconsin interglacial interval may also be estimated by the amount of valley deepening and erosion that occurred between those two episodes of glaciation. The Animas River lowered its valley 250 feet near Durango; the Uncompahgre River deepened its valley by more than 400 feet near Ridgway. These are perhaps the maximum figures, in keeping with the large volume of these two streams. But on the average even such streams as the Florida River and Weminuche Creek lowered their channels 75 to 100 feet in the foothill zone. How much canyon deepening was effected in the heart of the range can only be conjectured.

In general, it would appear that the length of the post-Cerro and pre-Durango interglacial interval must have been several times as great as the length of time between the Durango and Wisconsin glaciations. The Durango stage must then be referred to the later part of the Pleistocene epoch.

CORRELATION

Pleistocene drift in western mountains.—In many of the higher ranges of the North American Cordillera glacial drift of two distinct stages has been identified and described. The Durango till may safely be correlated with the earlier glacial deposits of most of these ranges on the basis of similarities in topographic situation and amount of postglacial erosion.

The earlier glacial drift of the Big Horn Mountains of Wyoming [50] is closely similar to the Durango till as regards the amount of weathering to which it has been exposed and the extent of denudation of the region since its deposition. The glaciers that dropped it were likewise slightly more extensive than those which produced the latest drift of that area.

The older drift of the Sawatch Range [51] and the Front Range [52] seems to be closely comparable to the Durango till. The "moraines of the earlier epoch" in the Uinta and Wasatch Mountains [53] bear an identical relation to the present topography and more recent drift deposits. The till of the Bull Lake stage in western Wyoming as defined by Blackwelder [54] may likewise be tentatively correlated with that of the Durango stage, a correlation already suggested by Blackwelder.[55]

In December, 1916, Atwood [56] reported positive evidence of a pre-Wisconsin stage of ice work in the region southwest of Butte, Mont. There is a very massive deposit of till which retains a faint morainic topography in the broad valley directly south from Silverbow. Boulders as large as 25 feet in diameter are abundant. The hills are arranged as an irregular ridge, which, when followed southward, is found to be related to the amphitheatral area at the head of Basin Creek, as a great lateral moraine. The ice which formed that moraine must have covered the entire area from the Highlands, or Red Mountain, northward to Butte and may even have covered the area where the city now stands. He reported several other deposits of pre-Wisconsin age in that vicinity and would now venture the correlation of these very old massive morainic deposits in the vicinity of Butte with the Durango stage in the San Juan region. The moraines of the Wisconsin stage are very well developed and readily recognized in the Butte region.

Pleistocene drift in Mississippi Valley.—Reference has already been made to the hazardous nature of an attempt to correlate the earlier drifts in a remote range of the American Cordillera with the glacial deposits of the Mississippi Valley. At best, any such correlation must be considered extremely tentative. It is, however, of advantage to make some sort of comparison between the various glacial deposits in the areas mentioned.

Leverett [57] has suggested the correlation of the Durango drift with the Illinoian stage, commenting on the similarity of preservation of the two deposits. Such a correlation is a very reasonable one, although probably its correctness can never be satisfactorily proved or disproved. In our opinion it is equally reasonable to suggest that the Durango till is of approximately the same age as the Iowan drift of northeastern Iowa. The physiographic evidence which leads to the conclusion that the post-Cerro and pre-Durango interglacial interval was very much longer than the post-Durango and pre-Wisconsin interval has already been noted. The proportional lengths of time are roughly similar to those which have been ordinarily accepted as demarking the Kansan and Iowan and the Iowan and Wisconsin intervals respectively. Certainly the Durango till is older than the earliest Wisconsin drift, and with equal certainty it is much younger than the Kansan. To us it seems likely that the Durango is the San Juan equivalent of the Iowan drift.

DURANGO OUTWASH

The downstream side of the terminal moraine composed of Durango till at the type locality near Durango blends into the head of a valley train, remnants of which have been traced for 30 miles down the Animas Valley. Similarly, in many other valleys in

[50] Salisbury, R. D., and Blackwelder, Eliot, Glaciation in the Big Horn Mountains: Jour. Geology, vol. 11, pp. 216–223, 1903.

[51] Capps, S. R., and Leffingwell, E. DeK., Pleistocene geology of the Sawatch Range near Leadville, Colo.: Jour. Geology, vol. 12, p. 701, 1904. Westgate, L. G., The Twin Lakes glaciated area, Colorado: Jour. Geology, vol. 13, p. 291, 1905. Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colorado: U. S. Geol. Survey Bull. 386, p. 36, 1909.

[52] Ball, S. H., General geology of the Georgetown quadrangle, Colorado: U. S. Geol. Survey Prof. Paper 63, pp. 84–85, 1908.

[53] Atwood, W. W., Glaciation of the Uinta and Wasatch Mountains: U. S. Geol. Survey Prof. Paper 61, pp. 12, 68, 92, 1909.

[54] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, p. 327, 1915.

[55] Idem, p. 333.

[56] Atwood, W. W., The physiographic conditions at Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, p. 717, 1916.

[57] Leverett, Frank, Glacial formations in the western United States [abstract]: Geol. Soc. America Bull., vol. 28, p. 143, 1917.

which Durango till has been recognized outwash gravel of the same age extends far down the courses of the streams radiating from the range. These deposits are mapped as Durango outwash.

This outwash consists of boulders, pebbles, sand, and finer materials deposited by the streams that issued from the melting glaciers of the Durango stage. The materials are the same as those in the Durango till of each valley and are therefore representative of the rocks that crop out in each drainage basin. The Durango outwash, for example, in the Los Pinos Valley is characterized by an abundance of boulders of the conspicuous Vallecito conglomerate; that in the Animas Valley includes many stones derived from the pre-Cambrian schist of the West Needle Mountains. The surface of these river-borne materials is generally mantled by a deposit of wind-blown loam, which in many localities has transformed what would otherwise be a barren stony waste into fertile farm land.

The boulders range in size from a maximum of 5 feet near the head of the valley train through a maximum of 3 feet a few miles downstream to a maximum of less than 2 feet at a distance of 15 or 20 miles from the Durango terminal moraines. Most of the stones, however, are less than a foot in greater diameter. Most of them are well rounded, but a few angular or faceted stones are present.

The surface of the Durango outwash is not everywhere smooth, but in many localities displays the irregularities of ancient stream channels formed by the river floods that washed the débris downstream. In consequence the surface has a relief of 10 or 12 feet, in the form of low swells or ridges roughly parallel to the longer axis of the valley. Where well exposed, the pebbles and boulders are generally rudely stratified, or where the material is finer the bedding may be quite perfect.

This material forms a veneer 10 to 40 feet thick on the surface of rock terraces at varying heights above the modern stream channels. Except on the east side of the mountains the surface declines downstream at much the same rate as the stream gradient, so that except in a few places the Durango outwash maintains a fairly constant height above the modern flood plain. Where the strata are notably inclined the terraces bevel the upturned edges of the beds. Elsewhere the gravel may be underlain by either soft shale or hard rock with equal frequency.

These terraces have suffered much erosion and are rarely continuous for more than a mile or two. They are commonly best preserved immediately downstream from a projecting spur of resistant rock, which has protected them from complete removal by undercutting of the modern stream. Ordinarily they are bounded on the streamward side by steep escarpments in which the rock foundation for each terrace may be seen. They are conspicuous features of nearly every large valley in the outskirts of the mountains and in the peripheral plateau country. The identification of the gravel as glacial outwash rather than as a simple stream deposit is dependent upon the tracing of the terrace system upstream until it blends into the Durango moraine.

Animas Valley.—Terraces capped with Durango outwash are well displayed in the Animas Valley from the margin of the Durango moraine near Durango down to its mouth and thence down the San Juan Valley at least as far as Shiprock, N. Mex. Near Durango, as shown in Plate 25, *A*, the terrace is 200 to 250 feet above the river, and a few miles farther downstream it is 40 to 80 feet below the Florida gravel, which caps the greater part of Florida Mesa. Near Lodo and Posta the valley floor of which the terraces are remnants had a width of 3½ miles.

Florida Valley.—Remnants of the valley train of Durango age are scarce along the Florida River within the first few miles downstream from the terminus of the Durango ice, but beyond the gateway through the hogback ridges the terrace becomes fairly continuous. It is about 100 feet above the stream and 40 to 50 feet below the Florida gravel level. The width of the ancient valley flat of which the terraces are remnants was little more than a mile except near Oxford, where it attained a width of 2 miles in the easily eroded shale of that locality.

Los Pinos Valley.—Immediately downstream from the terminal of the Durango ice in the Los Pinos and Vallecito Valleys the outwash gravel is only 75 feet above the modern flood plain, but a few miles farther south it caps a terrace 125 to 150 feet above the stream. This is the next to the highest of the four terraces that form so conspicuous a feature of the Los Pinos Valley between Bayfield and La Boca. Near Bayfield the outwash gravel originally covered a valley flat 2½ miles wide.

San Juan Valley.—Outwash gravel of Durango age is well displayed along the San Juan River near Pagosa Springs, where it caps the next to the highest terrace 250 feet above the river. In places the gravel is nearly 100 feet thick, representing the thickest accumulation of valley-train material that has been observed in the San Juan Mountains. The Durango terrace is about 100 feet below the Florida gravel.

Blanco Valley.—Outwash from the Durango ice was apparently of very slight extent in the valley of the Rio Blanco. A single remnant of this material forms a narrow terrace, 125 to 150 feet above the river bed, on the east side of the valley in sec. 29, T. 34 N., R. 1 E. At the time of the Durango glaciation the valley train was confined within limits so narrow that it has since been almost entirely destroyed.

Navajo Valley.—Although no glacial drift that could be considered as belonging to the Durango stage has been observed in the upper reaches of the Navajo River, there is a set of terraces which by analogy with other valleys has been indicated on the map as representing the valley train of Durango time. As elsewhere, these are rock terraces strewn with gravel believed to be glacial outwash. They are found on both sides of the Navajo at many localities in the southern part of the Summitville quadrangle. These terrace remnants are 150 to 175 feet above the Wisconsin outwash, which is only a few feet above the modern alluvium.

Conejos Valley.—In the valley of the Conejos River in the southeast quarter of the Conejos quadrangle there are three clearly defined systems of river terraces. The middle one of the three is the most extensive. Its westernmost remnant, near the mouth of Fox Creek, is 100 to 125 feet above the flood plain of the Conejos River and 50 to 60 feet above the lower terrace, which farther upstream abuts against the Wisconsin terminal moraine and is therefore the Wisconsin valley train. Although the Durango terminal moraine can not be identified with certainty, it is probably correct to interpret this higher terrace as representing the Durango outwash in this valley. Downstream toward the east it approaches nearer and nearer the modern flood plain, and in the vicinity of Mogote the two coincide.

Alamosa Valley.—Somewhat similar relations are exhibited by the Durango outwash in the valley of Alamosa Creek, near the center of the Conejos quadrangle. The westernmost remnant of the upper terrace system, near Jacobs Hill, is 60 to 70 feet above the stream bed. It is there a gravel-strewn rock bench. Toward the east its height above the modern flood plain steadily decreases, and the outwash gravel blends into the modern alluvium 1½ miles above Capulin.

Apparently there has been an appreciable warping of the earth's crust along the eastern front of the San Juan Mountains in and near the Conejos quadrangle since the retreat of the Durango ice. In consequence the Durango terrace has to-day a steeper pitch than it possessed originally; and the eastern fringe of the outwash deposit is buried beneath the modern alluvium of San Luis Valley.

Rio Grande Valley.—In the valley of the Rio Grande between the west margin of the Creede quadrangle and Wagonwheel Gap there are three sets of terraces, the highest of which may be traced upstream to the Durango moraines. It may also be observed in the valley of Willow Creek as far north as Creede. This terrace, capped with Durango outwash, is a rock bench 80 to 100 feet above the river between the moraines and the gap, but it declines downstream and blends into the modern alluvium in the eastern part of the Creede quadrangle and the western part of the Del Norte quadrangle. Projected farther east, this plane of alluviation would be some distance below the floor of San Luis Valley.

Valley of Mineral Creek.—Near the confluence of Mineral and Cebolla Creeks, in the southeast corner of the Uncompahgre quadrangle, there are three broad remnants of a gravel deposit capping rock benches about 50 feet above the present flood plain. The gravel consists of stream-worn cobbles identical with the outwash deposits of neighboring streams. Although no Durango till has been identified in these valleys, it is tentatively referred to the Durango stage because of its topographic situation on the rock bench.

Valley of Lake Fork of Gunnison River.—Beginning a few miles below Lake City and continuing down the Lake Fork as far as Madeira Siding, there are two sets of prominent terraces within the inner gorge. The higher of the two is 70 to 100 feet above the stream bed and is the typical boulder-mantled rock bench of the Durango stage. It is 250 to 300 feet below the benches covered with Florida gravel.

Uncompahgre Valley.—Remnants of Durango outwash gravel are present in many places in the valleys of the Uncompahgre River and its tributaries in the Montrose quadrangle. Those areas embraced within the Ouray quadrangle are described as "earlier alluvium" in the Ouray folio. Near Montrose, where four different terraces are conspicuously developed, the next to the highest terrace is mantled with Durango outwash.

Near the Durango till in the vicinity of Dallas the outwash gravel is about 400 feet above the modern alluvium, but the surface of the valley train declines downstream at a slightly greater rate than the stream bed, so that near Montrose it is only a little more than 200 feet above the river. Similarly near Cow Creek the Durango terrace is 300 feet below the Florida terrace, but at a distance of 10 miles downstream the two gravel-covered terraces converge to about half that vertical distance.

NONGLACIAL ALLUVIUM OF THE DURANGO STAGE

CHARACTER

The disturbing effect of Durango glaciation gave rise to alluviation beyond the margin of the ice in certain localities under conditions such that outwash materials form an extremely minor part of the deposits. Glaciation was the ultimate but not the proximate cause of these deposits, a few of which were laid down under such favorable conditions that portions of them still remain.

An alpine glacier occupying a main valley is ordinarily a barrier across the mouth of a tributary nonglaciated valley. The barrier may be perpetuated by the lateral moraines, which last long after the ice has melted away, or the barrier may be ice only and as ephemeral as the glacial climate. In either case ponding of the tributary stream will probably result in the accumulation of alluvium in the form of lake beds, the materials of which are brought mainly from the basin of the nonglaciated stream and only in small amount are contributed by the ice mass. These deposits will ordinarily be subjected to vigorous erosion as soon as the ice has retreated or the lateral moraine has been cut through, but not all evidence of this form of alluviation has been erased from the San Juan region.

Similarly, a tributary whose stream valley is unoccupied by ice may be dammed by the building of a valley train. The valley train will commonly hold up the drainage from the tributary channel sufficiently to impose upon it conditions of alluviation which would not normally have occurred at that point in its history. Alluvial deposits thus formed are later attacked by the stream and eroded either completely or into terraces, the summit of which corresponds closely to the surface of the valley train opposite the mouth of the tributary. Illustrations of gravel-capped terraces which probably originated in this way are not wanting in the San Juan region.

DISTRIBUTION

Ignacio quadrangle.—The great glacier of the Durango stage in the Animas Valley must inevitably have acted as a dam across the tributary Hermosa Valley. Presumably a lake was formed at the margin of the ice lobe that pushed a short distance up this tributary. Into this lake there would have been abundant drainage, not only from the precipitation within the Hermosa drainage basin but from the melting ice that entered the valley from the east in the middle of the Engineer Mountain quadrangle and pushed as far westward as Hermosa Park, as well as from the ice front across the lower end of the valley near Hermosa. Most of the sediment that was thus brought into the basin has long since been removed, but the record of this lacustrine deposition has been preserved at several localities between the northern boundary of the quadrangle and the moraines near the mouth of the stream. Gravel-strewn benches slope rapidly upward from the brink of the inner gorge, which is of post-Durango age, and are crossed by the Hermosa trail between 2 and 3 miles upstream from the Animas Valley road. The highest gravel of these benches is at an altitude of 7,900 feet, which probably represents the level at which the ponded waters escaped along the contact between the ice margin and the wall of the Animas Valley. Farther upstream on Hermosa Creek, near the mouth of Dutch Creek, are similar though smaller and more gently sloping terraces carrying débris, part of which is foreign to that locality. These likewise are between 7,600 and 7,800 feet above sea level and may represent sediments deposited near the upper end of the lake. No other evidences of the presence of this ephemeral glacial lake have been observed.

Junction Creek is another large stream which was free from ice but which debouched into the Animas River close to the terminus of the Durango glacier. Gravel-capped terraces on both sides of its inner gorge are too low to represent the Florida gravel horizon at that locality and are believed to be the result of the ponding of the lower reaches of the stream by ice and outwash gravel in the Animas Valley. The water-worn boulders and cobbles strewn over the surface of these terraces are of local materials that crop out within the drainage basin of the creek.

Lightner Creek was similarly affected by the construction of the valley train in the Animas Valley. Small benches on the spurs of the hogback that parallels the stream on the south just above its mouth carry the Durango outwash level far to the west, beyond the reach of the ice-fed torrents of the main valley. A similar level is again recognizable near the mouth of Deep Creek, where boulders and gravel borne by streams from the La Plata Mountains, at the head of Lightner Creek, rest upon a conspicuous rock shelf 150 feet above the stream bed.

Near the northeast corner of the quadrangle, on the western slope of the Vallecito Creek Valley, a prominent lateral moraine of Durango age crosses the mouth of a small tributary gulch. Graham Park is the silt-covered floor of a vanished lake which has been drained in comparatively recent time but which formerly occupied the basin between the lateral moraine and the walls of the gulch.

Montrose quadrangle.—Identical conditions to those just sketched are found on the margin of the Durango moraine in the Cimarron Valley in sec. 35, T. 47 N., R. 7 W. A conspicuous lateral moraine formed a long, narrow basin high on the slope of Cimarron Ridge, in which a flat floor has been built up by accumulation of silt.

POST-DURANGO AND PRE-WISCONSIN INTERGLACIAL DEPOSITS, INCLUDING OXFORD GRAVEL

Under the general term post-Durango and pre-Wisconsin interglacial deposits we have grouped together three different kinds of Quaternary formations that are indicated more or less conclusively to have been accumulated during this interglacial interval: (1) In several of the larger valleys in which outwash gravel of Durango and Wisconsin age is clearly recognizable there are terraces intermediate in height between the remnants of the two sets of valley trains. The stream gravel that caps these intermediate levels must date from this interglacial time. (2) In outlying portions of the San Juan province there are certain large areas of old-age topography between or distant from the larger streams and so extensively covered with silt that solid rock nowhere appears. Their topographic situation is such as to show clearly that the deposits were made since Durango time, and their relations to the Wisconsin outwash suggest that much of the deposition had been completed before the Wisconsin glaciation. To this silt and gravel the name Oxford may be applied (see p. 30) because of its wide development in the vicinity of the town of that name, in the Ignacio quadrangle. (3) In still other regions, distantly removed from glacial or fluvioglacial deposition, gravel is strewn over low mesas and divides with such topographic relations that the deposits may be tentatively referred to the last interglacial interval by analogy with topographic forms that are so close to the effects of glaciation as to afford a fairly accurate basis for chronologic assignment.

Because these varied deposits, resulting from the activity of diverse agencies, were formed at approximately the same time they are here assembled under one heading.

Ignacio quadrangle.—On the west side of the Los Pinos River 3 miles south of Bayfield there is a broad remnant of a terrace intermediate in altitude between the higher Durango outwash terrace that borders it on the northwest and the lower Wisconsin outwash terrace that borders it on the south. Like both of these terraces it is a rock bench veneered with a deposit of stream gravel and boulders. Its surface is about 50 feet above the Wisconsin outwash and 40 feet below the Durango gravel. It must therefore represent a local and temporary base-level in the dissection of the valley during the post-Durango and pre-Wisconsin interglacial interval.

A large area in the south-central portion of the Ignacio quadrangle, in the general vicinity of Oxford post office, is so extensively silt-covered that outcrops of solid rock are rarely found. The region is one of old-age topography, bounded on the north by the hogbacks of the foothill zone and on the south by the steep escarpment of the Mesa Mountains, which overlook the undulating plain. On the east and west are the terraced valleys of the Los Pinos and the Florida Rivers. As shown in Figure 5, the gravel-strewn surfaces of the Florida gravel and Durango outwash levels are distinctly above the undulating plain, which must have been carved to its present level subsequent to the spreading of those gravel deposits along the stream channels. The similar terrace representing the Wisconsin outwash deposits is generally somewhat below the adjacent portion of the silt-covered area, and the single remnant of an intermediate terrace, referred to in the preceding paragraph, is at approximately the same level as the average height of that area. It would appear, therefore, that this old-age topography was largely the result of erosion in the interval between the Durango and Wisconsin glacial episodes; that the land capped with Durango outwash was protected by its bouldery covering from rapid degradation and remained at a higher level in spite of its closer proximity to the master streams; and that after the stage of approximate base-leveling in this area of soft shales and crumbling sandstone the master streams lowered their flood plains to the level now represented by the remnants of Wisconsin valley trains.

Throughout the greater part of this interstream area the rocks are deeply buried beneath a mantle of silt, which appears as a structureless yellow-brown adobe clay or loam. Probably most of it is wind blown. Here and there boulders of foreign materials and stream gravel from the higher mountains may be observed. Presumably most of these have been let down during the degradation of this area below the Florida gravel and Durango outwash surfaces.

The post-Durango and pre-Wisconsin interglacial silts of this area are now undergoing rather vigorous dissection and presumably have been subjected to erosion ever since the Wisconsin glacial stage. Arroyos 10 to 50 feet deep mark the courses of the intermittent streams and give excellent exposures of the surface materials. It is rare for these cuttings to penetrate the silt and expose the solid rock beneath.

Similar deposits of interglacial silt have been mapped in the vicinity of Pine Ridge, near the west margin of the quadrangle; on the floor of the Bocea Basin, north of the Florida Mesa; along the courses of Spring Creek and its tributaries east of the Los Pinos River; and elsewhere in the lowlands of the south half of the quadrangle.

Montrose quadrangle.—Beginning near Colona and extending downstream beyond Montrose four sets of gravel-strewn terraces occur in the valley of the Uncompahgre River. The highest of these has already been described as representative of the Florida cycle of erosion, the second when traced upstream merges into the terminal moraine of the Durango stage, and the fourth may likewise be connected with the glacial drift of the Wisconsin stage. The third terrace level, therefore, must have been the flood plain of the Uncompahgre River during the post-Durango and pre-Wisconsin interglacial interval; its mantle of gravel and boulders is a stream deposit made during that time.

Of the numerous remnants of this temporary base-level which have been examined the largest is the surface of Spring Creek Mesa, a fertile table-land just west of Montrose, which, irrigated with water from the Uncompahgre or from the Gunnison through the Gunnison tunnel and the South Canal, is one of the most productive orchard lands of the western slope. Its surface is 50 feet above the Wisconsin outwash and 40 feet below the Durango gravel train.

Del Norte quadrangle.—Two sets of sloping gravel-strewn mesas border San Luis Valley west of Monte Vista. The higher set is believed to represent the Florida stage of alluviation on that side of the range. The lower set of mesas in some places blends into the compound alluvial fan of the San Luis Basin, but elsewhere it is bounded on the east by cliffs 20 to 40 feet high, which descend abruptly from the mesa level to the valley floor. Westward the mesa surfaces rise more rapidly than the stream gradients, so that at their mountainward margins they are 150 to 200 feet above the adjacent stream beds. (See fig. 7.) By analogy with conditions elsewhere in the range these lower mesas are referred tentatively to the post-Durango and pre-Wisconsin interglacial interval.

The sloping mesas with their veneer of stream gravel are indicative of upward tilting of the mountains and downward tilting of San Luis Valley during Quaternary time. Doubtless mountain growth and valley depression were more or less continuous, but in this portion of the Del Norte quadrangle there were evidently two main stages, which we are correlating with the Florida and the post-Durango and pre-Wisconsin episodes of base-leveling in other parts of the range. As the mountains were dissected and made lighter by erosion, San Luis Valley was built up and made heavier by deposition. Tilting recorded by these sloping mesas appears to be an excellent example of isostatic adjustment.

Conejos quadrangle.—The lower of the two sets of tilted mesas recognized in the Del Norte quadrangle, along the eastern front of the mountains, continues southward into the Conejos quadrangle. Rather extensive remnants of this ancient graded surface are present immediately south of Rock Creek, near the north margin of the quadrangle. Other smaller areas, similarly gravel-strewn and displaying the same relations to their surroundings, occur at several places within a short distance of Gato Creek. Here it is possible to trace this graded surface several miles westward, well within the mountains northwest of Chiquito Peak, where small areas of gravel-strewn upland occur at altitudes as great as 8,700 feet above sea level, 300 feet above the adjacent bed of Gato Creek.

The general relations of these sloping mesas in the Conejos quadrangle are identical with those described in the preceding section with reference to the adjacent Del Norte area.

WISCONSIN TILL

GENERAL CHARACTER

Glacial drift deposited during the latest stage of glaciation in the San Juan Mountains is present in nearly every valley in the heart of the range and forms one of the most widespread and conspicuous of Quaternary formations. An attempt has been made to indicate on the maps all deposits of Wisconsin till now at the surface and thick enough to obscure the underlying rock. Outside of these areas and within the area which was covered with ice during the Wisconsin stage, many small patches of drift and scattered boulders may be observed. By noting the distribution of all glacial débris and the detailed topography of the canyon walls it is possible to delineate with a fair degree of accuracy the limits of glaciers at the time of their maximum advance. In this way was prepared Plate 3, a restoration of the Wisconsin glaciers to their former maximum dimensions; Wisconsin till may be found anywhere within the area represented on that map as ice-covered, even though its presence may not be indicated on the areal-geology map, Plate 1.

The materials composing the Wisconsin till are of the familiar kinds typical of glacial drift wherever found—boulders, large and small, angular or rounded, striated and faceted or unmarked by ice, embedded in a matrix of clay, sand, or rock flour—the whole seldom displaying any stratification but appearing as a structureless mass of heterogeneous materials. In general, the glaciers of Wisconsin age in the San Juan Mountains were confined each to its own individual mountain valley; hence the composition of the stones in the drift is an epitome of the formations cropping out in the particular valley or drainage basin upstream from the place of lodgment. Ordinarily the larger stones are between 5 and 10 feet in length, but not uncommonly individual boulders or blocks with one dimension as great as 25 feet may be seen. Glacial striae and ice-smoothed surfaces are extremely common on the loose stones in the drift, as well as upon the solid rock within the glaciated area.

As will be noted below in greater detail, the Wisconsin till is found in the mountain valleys in such topographic situations as to indicate that there has been little or no deepening of the valleys since the retreat of the ice. The few exceptions to this rule are recounted in the descriptions of the individual deposits. The original morainic topography, characterized by irregular hills and numerous undrained depressions, is still conspicuous. In general, the till is scattered unevenly as ground moraine upon the valley floors and gentler slopes, but terminal moraines are strongly developed in many valleys. The terminal moraines consist in places of a single crescentic ridge but more commonly of a belt of morainic hills that crosses the valley and ranges from a few rods to a mile in width. At either side of the canyon this moraine may blend or connect with a lateral moraine deposited at the side of the valley or on the lower slopes, as the ice melted away. Recessional moraines are rare in the San Juan Mountains, but a few have been noted. They are, of course, similar in most respects to the terminal moraines, having been deposited under like conditions at the front of the glacier during its withdrawal. Lateral moraines form prominent ridges, high on the valley slopes and generally extending in a direction parallel to the axis of the valley. The position of such moraines represents the minimum altitude of the ice that occupied the main canyon, for the material composing them was probably let down somewhat during the melting of the ice before it became lodged on the slope. In composition and structure the lateral moraines resemble the terminal and recessional moraines, but they do not contain pockets of stratified material such as are common in the frontal moraines. The stones in the lateral moraines are commonly more angular than those that were carried near the base of the glacier.

DISTRIBUTION

Animas Valley.—The terminal moraine of the Wisconsin ice in the Animas Valley forms a double line of hills curving across the valley flat at Animas.[58] The short ridges and mounds rise 50 or 60 feet above the alluvial flat on the north and the outwash terrace on the south. (See pls. 1 and 25, *B*.) The river has cut a narrow channel through the moraine at the west side of the valley. In keeping with the variety of rocks exposed in the gathering grounds of the Animas Glacier, which covered hundreds of square miles in the Engineer Mountain, Needle Mountains, Silverton, and Telluride quadrangles, the variety of materials in the till is very great. Several kinds of granite, various schistose rocks, quartzite, grit, and sandstone are conspicuous. Apparently the volcanic rocks were less able to withstand the vicissitudes of a 40-mile journey in the ice than the metamorphic and plutonic rocks of the pre-Cambrian complex.

Just north of Animas City Mountain a valley nearly half a mile wide extends from the Animas Valley westward and southward to the Junction Creek Valley. A lobe of the Animas Glacier extended toward the southwest down this valley for a distance of 1½ miles. At its terminus a deposit of morainic material in the form of small hills was made on the valley floor, and a ridge of morainic débris having the appearance of a "push moraine" was left extending for about 200 feet up the southwest wall of the valley.

Farther north an irregular lateral moraine was left lying on the rock bench west of Trimble. Short lateral-moraine ridges were thrown across the mouths of tributary gulches on both sides of the valley—one west of Baker Bridge and the other south of Coon Creek. The basins thus formed by the morainic barriers have been largely silted up with postglacial alluvium. The one at the west is at an altitude of 8,700 feet; that at the east and a little farther downstream is 300 feet lower; the valley floor between the two is 6,700 feet above the sea.

In the Engineer Mountain quadrangle, as described by Hole,[59] a long lobe from the Animas Glacier pushed across the low divide west of Cascade Creek into the head of the East Fork of Hermosa Creek. (See pl. 3.) Its terminus is represented by heavy but irregular masses of Wisconsin till in and near Hermosa Park, 6 miles west of the divide. Here, too, is the only recessional moraine that may be credited to the Animas Glacier. At the Old Tollgate, near the head of the East Fork of Hermosa Creek, there is a U-shaped moraine consisting of a succession of low hills and short ridges, which represents the margin of this lobe at a late stage in the withdrawal of the ice. Many other areas of Wisconsin till may be observed within the large area covered by the Animas Glacier with its many tributary ice bodies; most of the conspicuous masses of drift have been indicated on Plate 1. Some are in the form of distinct lateral ridges, such as the two moraines high above the Animas Canyon and extending parallel to it on both sides of Canyon Creek in the southeast corner of the Engineer Mountain quadrangle. Others occupy sheltered nooks at the margin of the Animas Valley floor in the break at the foot of the steep slopes of the valley sides; this is a common situation for the drift in the Silverton quadrangle. Again, the till may be disposed in the form of lateral or recessional moraines deposited by the small glaciers that lingered in the tributary valleys after the main valley had been cleared of ice. In this category belong the prominent morainic ridges on the slopes of Canyon Creek in the southwest corner of the Needle Mountains quadrangle and the elongated hills of drift near Lime Creek in the southeast corner of the Telluride quadrangle.

In the main, however, the amount of drift that now remains in the area formerly covered by the Animas Glacier is surprisingly small, in view of the tremendous amount of rock sculpturing which was accomplished by the Animas ice in the hundreds of catchment basins whence it came.

Florida Valley.—Glacial drift deposited by the Wisconsin Glacier in the Florida Valley is comparatively abundant on both sides of the valley from the mouth of Miller Creek, 6 miles south of the northern boundary of the Ignacio quadrangle, upstream nearly to Transfer Park, and on the west side of the valley lateral moraines continue to a point 2 miles north of the south boundary of the Needle Mountains quadrangle. There is no pronounced terminal moraine near the mouth of Miller Creek, but upstream from that place the drift is very thick on both slopes of the valley. It occurs

[58] Stone, G. H., The Las Animas Glacier: Jour. Geology, vol. 1, pp. 471–475, 1893. Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 17, pp. 255–256, 1906.

[59] Hole, A. D., Glacial geology of the Engineer Mountain quadrangle: U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), pp. 8–9, 1910.

in short ridges and hillocks parallel in a general way to the trend of the valley and mantles the slopes almost continuously to the upper limit of the ice action. Near Blodgett Creek the upper limit of the drift is about 900 feet above the Florida River, and at the north boundary of the Ignacio quadrangle it is about 1,200 feet above the stream. Only small bodies of till remain or were ever deposited in the region of vigorous glacial erosion nearer the headwaters of the tributary streams on the south slopes of the Needle Mountains.

The composition of the drift of the Florida Valley is less diversified than that in the Animas Valley. In the comparatively small area of ice accumulation from which the Florida Glacier was fed (pl. 3) there are only a few varieties of rock. The boulders of the drift are, therefore, chiefly coarse-grained Eolus granite, Ignacio quartzite, and sedimentary rocks.

Los Pinos and Vallecito Valleys.—The terminal moraine that marks the southern limit of the confluent glaciers from the Los Pinos and Vallecito Canyons is found in the valley of the Los Pinos just below the junction of the two streams, in the northeastern part of the Ignacio quadrangle. The Wisconsin till forms a series of hills, 30 or 40 feet above the modern alluvium, arranged in a crescentic belt across the valley floor. Through them the Los Pinos has cut a narrow channel.

Upstream from the terminal deposits the lower slopes of each of the two valleys are for some distance continuously mantled with glacial drift. The drift is especially heavy on the southern slopes of East Mountain and extends for a short distance across the valley flat in a southwesterly direction in the form of a medial moraine. A mile and a half south of the fish hatchery on Vallecito Creek a recessional moraine crosses the valley. From the west wall two crescentic ridges composed of hills and knobs, 15 to 30 feet high, extend nearly halfway across the bottomlands. On the east side of the valley two shorter ridges jut out from the drift-mantled slopes in a position complementary to the longer ones.

West of the fish hatchery, high on the valley slope, the drift for a short distance forms a well-defined lateral moraine curving westward into the mouth of a tributary valley. Beyond this lateral moraine is a basin partly filled by the water of Lake Eileen, nestling within the concave side of this curve. For some distance toward the north the ice-scoured hillsides are devoid of any notable veneer of till, but above the mouth of Johnson Creek, in the Needle Mountains quadrangle, the valley of Vallecito Creek is more broadly U-shaped, and Wisconsin till occurs at the margin of the stream flat and fills the angle between valley slopes and floor.

The Wisconsin till of the Vallecito and lower Los Pinos Valleys is characterized by an abundance of boulders of Vallecito conglomerate—the "calico rock" of the down-valley residents, so named because of its pebbles of vivid red jasper, black magnetite, and limpid quartz set in a matrix of milk-white quartz. Associated with it are several varieties of granite, masses of Ignacio quartzite, and an assortment of sedimentary rocks. Huge boulders, 20 to 25 feet long, of granite are not uncommon in the drift, and downstream from Kirkpatricks they clog the channel of the Los Pinos River in a most picturesque fashion.

East of the Ignacio quadrangle, in the northwest corner of the Pagosa Springs quadrangle, Wisconsin till is thickly piled on the east slope of the Los Pinos Valley. The ridge northeast of Kirkpatrick's ranch is heavily veneered with glacial drift. Some of the small valleys tributary to the Los Pinos south of this ranch seem to have been nearly filled by morainal material. Farther upstream, at the mouth of the Lake Fork, there is a great deal of coarse morainal material extending from the river several hundred feet up the east slope. Some of the blocks in this mass are very large, and it is probable that a considerable amount of landslide débris is mingled with the glacial material here. On the other hand, the many foreign boulders of greenstone and quartzite from the head of the Lake Fork associated with the local granite fragments indicate the importance of glacial ice among the agencies that have produced this Quaternary deposit.[60] Farther north, in the broader portion of the Los Pinos Canyon, above the mouth of the Flint Fork, in the San Cristobal quadrangle, there are notable accumulations of drift on both sides of the narrow valley flat. The valley of a small tributary entering from the east 1½ miles above the Flint Fork is clogged with glacial drift. For about 2 miles opposite Cache Lake the floor and sides of the Los Pinos Valley are devoid of any large body of till; beyond, however, there is a nearly continuous veneer of till and slide débris which continues through Weminuche Pass to the brink of the Rio Grande Canyon. The very large boulders of granite of the Los Pinos River in the moraine adjacent to the trail between 10,100 and 10,400 feet, just above the cliff overlooking the Rio Grande, indicate that ice from the head of the Los Pinos River crossed the pass to the Rio Grande, for no corresponding rock is known in the drainage basin of the latter stream.

Piedra Valley.—The three large streams that flow southward out of the San Cristobal quadrangle east of the Los Pinos River enter the Piedra River, one of the largest tributaries of the San Juan, a short distance south of the quadrangle line. The terminal moraines of the Wisconsin ice that occupied these valleys are all within the Pagosa Springs quadrangle, of which

[60] Cross, Whitman, manuscript notes.

a detailed topographic map was not available at the time of our field studies, but are well within the foothill zone, as indicated on Plate 1.

The drift that marks the terminus of the latest ice in the Weminuche Valley forms a morainic belt about 1 mile wide extending to a point about 2½ miles south of the San Cristobal quadrangle. The moraine rests on the modern valley floor and has not yet been entirely cut through by the creek. Its surface shows the characteristic knob and kettle topography, with rounded hills from 10 to 40 feet high and numerous ponds and lakelets, the largest of which is about 100 yards long. On both sides the terminal moraine blends into lateral moraines that extend almost continuously for nearly 7 miles upstream. The eastern lateral moraine curves far to the east through the low sag between the valleys of Weminuche and Huerto Creeks, immediately south of the quadrangle line. This sag is about 200 feet above the valley floor of Weminuche Creek but only 50 feet above that of Huerto Creek. It marks a former course of the drainage in this locality when Huerto Creek was tributary to Weminuche Creek. Before the Wisconsin glacial stage the modern drainage courses had been established, and at that time the side of the Weminuche Glacier bulged eastward through this sag until the front of the lobe thus formed united with the ice in the Huerto Valley. Upon the retreat of the ice front morainic débris was dropped over the floor of the sag, and boulders of the characteristic granite of the Los Pinos River—a rock which does not crop out in the Huerto drainage basin—were scattered over the low divide into the western margin of the Huerto Valley. A little more than a mile upstream from the terminal moraine of Weminuche Valley, a low recessional moraine forms a broad loop across the valley flat. Its crest is relatively even and is only 20 feet above the stream; apparently it was graded by stream or wave action before the terminal-moraine barrier was breached. A mile farther upstream and half a mile north of the quadrangle line there is another looplike deposit of morainic material. This last recessional moraine is of small extent and reaches only part way from the middle of the valley floor toward the sides. It consists of low, rounded hills that stand only a few feet above the broad alluvial plain across which the stream meanders. At the south margin of the San Cristobal quadrangle the lateral moraines on both sides of Weminuche Creek attain an altitude of 8,800 feet. From this point northward the morainic belt climbs at a rate of about 150 feet to the mile.

The terminal moraine in the Huerto Valley is also a belt, more than a mile wide, which crosses the valley floor and extends some distance up the valley slopes. It is bisected by the southern boundary of the San Cristobal quadrangle. At the west it blends into the lateral deposits from the Weminuche Glacier, which fill the low sag (see p. 78) in the interstream divide. Irregular recessional loops are present at two places north of the terminal. Lateral moraines are well developed on the valley slopes, especially near the trail that leads from Huerto Creek to Palisade Lake. Nearly everywhere the Wisconsin till has a strong morainal topography, and upon the surface numerous large boulders are scattered.[61]

The Wisconsin till in the valley of the Middle Fork of Piedra River displays similar features. It is disposed in the form of a prominent terminal moraine that loops across the valley and blends into lateral moraines. These are parallel to the valley and extend upstream to the lower end of the canyon carved by the headwaters of this stream in the volcanic rocks of the higher mountains. The lower margin of the drift is nearly a mile south of the San Cristobal quadrangle.

All the mapped deposits of Wisconsin drift in the main Piedra Valley are in the Pagosa Springs quadrangle. Well-defined terminal and lateral moraines occupy the floor and lower slopes of the broad portion of the valley, which has been eroded in the less resistant sedimentary rocks exposed downstream from the volcanic terrane. The terminal moraine has been only narrowly breached by the river and fills the modern stream channel for a distance of about a mile.

Turkey Creek Valley.—One of the largest tributaries near the head of the San Juan River in the northwestern part of the Summitville quadrangle is Turkey Creek. Its valley, beginning at a point 3½ miles above its lower end and extending for a distance of 6 miles upstream, is occupied by irregular masses of Wisconsin till. There is no definite arrangement into terminal and lateral moraines, but much of the lower and broader part of the valley is mantled with drift.

Valley of West Fork of San Juan River.—The Wisconsin till in the valley of the West Fork of the San Juan River is disposed in the form of well-marked terminal, recessional, and lateral moraines. The terminal moraine covers the bottom of the valley at the junction of the West Fork with the main San Juan, which was blocked by the ice from the north. The drift there is more than 200 feet thick and displays a strongly undulating topography of low knolls and shallow depressions. The two streams have succeeded only in cutting narrow channels through the drift. Lateral moraines extend 500 or 600 feet up the slopes of the valley above the alluvial plain across which the West Fork finds a sinuous course. These moraines continue with slight interruptions upstream to the mouth of Wolf Creek on the east and the entrance of the gorge occupied by Borns Lake on the west. Recessional deposits form a loop across the valley flat a

[61] Endlich, F. M., Ancient glaciers in southern Colorado: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, pp. 217–219, 1877.

short distance south of the Himes ranch, and irregular morainic hills protrude above the alluvium immediately north of the recessional moraine.

San Juan Valley.—The main head of the San Juan River was occupied by a comparatively small glacier. Upstream from the mouth of the West Fork the river flows in a deep, narrow canyon between rugged walls of volcanic rock. At 5 miles above the forks a much broader portion of the valley begins. This is the glaciated portion of the river channel, and thick moraines may be observed on the south side of the valley flat, from which they extend several hundred feet up the more gentle slopes. The ice pushed only a short distance into the canyon below this broad valley, and small masses of Wisconsin till mark its terminus there.

Sand Creek Valley.—Glacial drift of Wisconsin age forms long terminal and lateral ridges partly clogging the valley of Sand Creek, a tributary of the San Juan, in secs. 14 and 23, T. 36 N., R. 1 E. These moraines extend to a distance of only 4½ miles downstream from the two large glacial basins on the west side of the ridge trending northward from Nipple Mountain.

Blanco Valley.—Blanco Basin, in the center of the Summitville quadrangle, is nearly surrounded by Wisconsin till arranged in lateral and terminal moraines. The Rio Blanco has carved a narrow channel through the terminal-moraine barrier, and little modification of its topography has been accomplished. The moraines are especially notable for large boulders, a few of which approach 70 feet in their greatest dimensions. Among the stones in the till the most conspicuous are those composed of light-gray porphyry from the intrusive rocks of this valley.

Navajo Valley.—Thick masses of glacial drift form a conspicuous terminal moraine in the valley of the Navajo River a short distance north of Peterson's ranch and extend several miles northward on both sides of the valley as lateral moraines. On the west, where the slopes rise steeply toward the ridge that trends north from Navajo Peak, the upper limits of the drift are considerably obscured by extensive landslide masses, and in many places the drift has slipped appreciably downhill over the soft, yielding shale upon which it rests. The Navajo River has cut a passageway with a narrow valley flat through the terminal deposits. These deposits originally formed a dam across the valley, behind which the water accumulated as a lake, in which considerable alluvium was deposited. This accounts for the flat floor of the basin extending 2½ miles south from Bond House.

Chama Valley.—Glacial drift of the Wisconsin stage is widespread in the valley of the Chama River, from the south boundary of the Summitville quadrangle northward for several miles. The terminal moraine completely clogged the valley, and for a distance of 1½ miles the river is still engaged in cutting a channel through its thick materials. Considerable masses of ground moraine extend up the valley of the tributary Archuleta Creek and veneer the upland bench between it and the master stream. On the east side of the Chama Valley a few miles upstream from the terminal moraine there is a notable lateral moraine 600 to 800 feet above the modern valley flat. Its eastern and higher margin is partly obscured by postglacial landslide débris.

Los Pinos Valley.—Los Pinos Creek,[62] which rises in the southeast corner of the Summitville quadrangle, flows thence southeastward across the southwest corner of the Conejos quadrangle, where Wisconsin till is widespread in its valley. Neff Mountain probably stood as a nunatak in the midst of the glacial ice. Its lower slopes are mantled with Wisconsin drift, which partly clogs the lower part of the valley of Los Pinos Creek on the north and east.

The terminal moraine forms a loop across the valley of Los Pinos Creek close to the place at which it receives the waters of Cumbres Creek. A lobe from the main Los Pinos Glacier must have moved northward up the valleys of the North Fork and Grouse Creek, for a great mass of Wisconsin till extends up these valleys and fills the divide between the head of Grouse Creek and the adjacent portion of the valley of La Manga Creek.

Conejos Valley.—Wisconsin till is present at numerous localities in the valley of the Conejos River and its many tributaries in the western part of the Conejos quadrangle and the eastern half of the Summitville quadrangle. The terminal moraine is a group of low, rounded hills separated from one another by stratified gravel that is in part the result of glacial outwash during the recession of the ice. These hills are scattered over the valley flat near the mouth of Sheep Creek, in sec. 22, T. 33 N., R. 6 E. Upstream from them the Conejos Valley is appreciably wider and more U-shaped in cross section than immediately downstream from the terminal.

Considerable masses of drift mantle the south slope of the Conejos Valley on both sides of La Manga Creek, a few miles farther upstream. Other masses of ground moraine border the valley flat of the Conejos River in the vicinity of the Horton ranch and beyond that place for several miles upstream.

North of Nigger Mountain, on the plateaulike upland east of the Conejos Canyon, there are large areas of drift deposited by ice that must have brimmed the Conejos Canyon and moved far to the east across the upland. Only the westernmost of these deposits are believed to have been dropped by the Wisconsin ice. Much of the drift has been so deeply trenched by the numerous tributaries of Jarosa Creek that it is con-

[62] Not to be confused with the Los Pinos River, in the Ignacio quadrangle, farther west.

sidered to be of Durango rather than of Wisconsin age. There is, however, no clear distinction between the two types of drift at this place, and the boundary line indicated on Plate 1 is not to be considered more than an approximation to the truth. In any event there is no doubt but that the drift surrounding Los Flores Lake and the small masses of till between the lake and the rim of the Conejos Canyon are of Wisconsin age.

A thick mass of Wisconsin till, partaking somewhat of the nature of a medial moraine, occupies the floor of the Conejos Canyon immediately upstream from the junction of the South Fork and the Conejos. The valleys of both these main heads of the Conejos River are notably free from glacial débris from this point westward and northwestward nearly to their sources. Just east of Blue Lake, in the Summitville quadrangle, however, there are several areas of moraine in the head of the South Fork. Similar bodies of thin drift are scattered over the upland or have been preserved in tributary valleys in the vicinity of Platoro and Adams Park, on the upper reaches of the main Conejos River.

Alamosa Valley.—The Wisconsin ice in the valley of Alamosa Creek left a very prominent terminal moraine in the form of a loop inclosing the lower end of the basin now occupied by the Alamosa Reservoir. The relations of this moraine to the reservoir are shown in Figure 20. The moraine completely filled the preglacial channel of Alamosa Creek at this place, and as the glacier retreated the water issuing from the melting ice found a new course at the south edge of the valley and there cut a narrow gorge in rock. This gorge, which is due to the disarrangement of drainage caused by the glacier and the moraine it left, is the site of the reservoir dam thrown across the stream channel from the firm rock walls on both sides.[63]

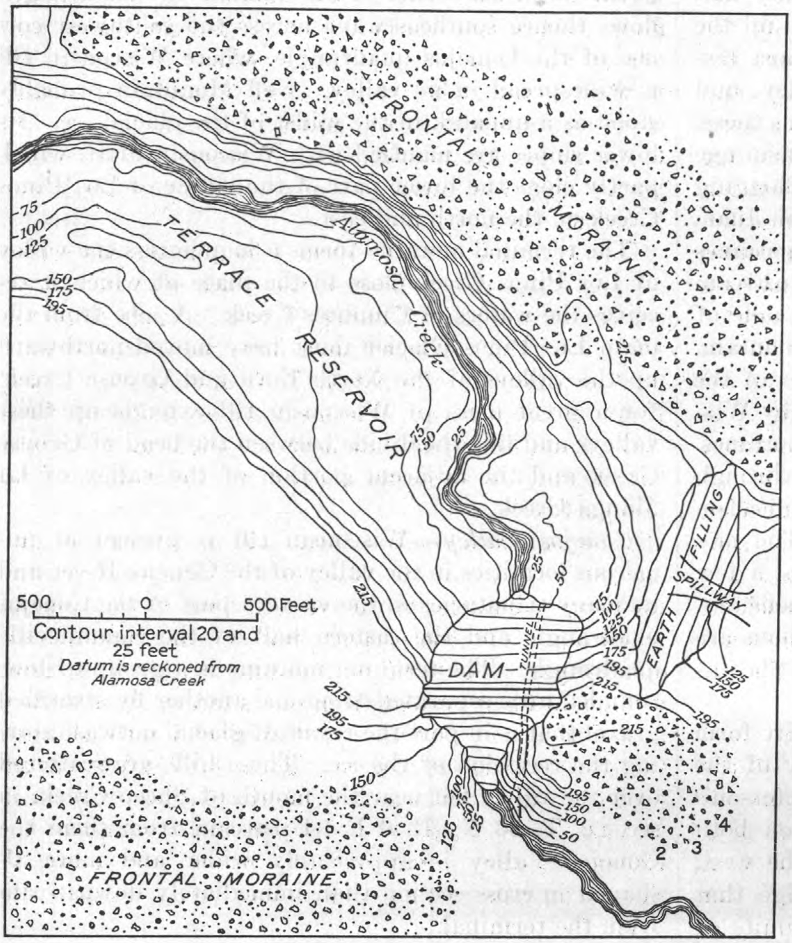


FIGURE 20.—Sketch map of the lower end of the Alamosa Reservoir

The portion of the Wisconsin terminal moraine on the north side of the river is bordered on the north and east by an approximately parallel and similarly curving ridge of glacial drift believed to represent a part of the terminal moraine of the Durango ice. Between the two ridges is a deep, narrow valley traversed by the wagon road descending from the upland toward the dam. The outer drift ridge is perched on a rock bench high above a cliff that drops sheer to the lower level on which is the inner moraine. Apparently there has been an appreciable amount of valley deepening at this point since the deposition of the outer moraine and before the inner loop was deposited. The relations are somewhat similar to those in the Animas and other valleys where the distinctions between the drift of the two stages are made more vivid by the presence of outwash terraces.

Six miles upstream from the Wisconsin terminal moraine there is a large mass of glacial drift on the slopes south of Alamosa Creek in the vicinity of the Silver Lakes. These lakes occupy basins on the surface of the ground moraine, which here has an unusually irregular topography.

Far to the west, in the northeast quarter of the Summitville quadrangle, there are numerous bodies of Wisconsin drift of sufficient size to be represented on the maps. Most of these occupy somewhat protected troughs of tributary streams or are immediately downstream from prominent rock knobs or ridges. The more notable of these are in the vicinity of Stunner and along the Wightman Fork near Summitville.

Valley of Middle Fork of San Francisco Creek.—The Middle Fork of San Francisco Creek has its sources on the eastern slopes of Bennett Mountain, in the northwest corner of the Conejos quadrangle. Thence it flows northward into the southwest quarter of the Del Norte quadrangle. At its head there are two small glacial

[63] Atwood, W. W., Relations of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colorado: U. S. Geol. Survey Bull. 685, pp. 33–39, 1918.

cirques, the floors of which are mantled with Wisconsin drift. Glacial débris extends down the valley leading from these basins to a point about a quarter of a mile north of the Conejos quadrangle. At that point the till forms conspicuous morainic ridges, which curve together downstream. The moraines are unusually stony, and the boulders consist exclusively of volcanic rocks. At the east side of the moraines there is a large landslide which has disturbed and partly covered them. The San Francisco Lakes fill depressions on the surface of the drift in and near the glacial cirques on the slopes of Bennett Mountain.

Pinos Valley.—Pinos Creek rises in the northeast corner of the Summitville quadrangle, traverses the southeast corner of the Creede quadrangle, and continues through the Del Norte quadrangle to its junction with the Rio Grande near Del Norte. Glacial drift of Wisconsin type mantles the lower part of the ridge between Pinos Creek and its tributary, Castle Rock Creek, at the point where Pinos Creek crosses the Creede-Del Norte quadrangle boundary. Another mass of drift is situated a short distance downstream on the east side of Pinos Creek, between it and Burro Creek. These bodies of drift are apparently the remains of the terminal moraine dropped by a long, narrow glacier that stretched northeastward down the valley of Pinos Creek from gathering grounds in the Summitville quadrangle on the north slopes of North and Old Baldy Mountains.

Valleys of South Fork and Beaver Creek.—The South Fork of the Rio Grande, which rises in the northern part of the Summitville quadrangle and crosses through the southern part of the Creede quadrangle, occupies one of the most notable canyons in the Rio Grande Basin. It is much frequented to-day, for a State automobile highway follows it from the Rio Grande to Wolf Creek Pass and thence down the south side of the mountains to Pagosa Springs.

This great canyon, about 22 miles in length, contained a large glacier during the Wisconsin stage. Its terminal moraine rests on the valley floor about 2 miles upstream from the valley of the Rio Grande and extends at least 2 miles upstream from the farthest position of the ice front. Above the terminal moraine a few scattered areas of till remain in the canyon in sheltered places where the stream has not yet been able to remove the loose débris.

The valleys occupied by the east fork of the South Fork and by Beaver Creek contained ice tributary to the glacier that advanced through the canyon of the South Fork. Extensive moraines were left at several places in each of these valleys. The reservoir in the valley of Beaver Creek extends upstream from a recessional moraine, and the slopes of the valley to the west of the reservoir and in part on the east side are mantled with thick moranic deposits.

Goose Creek Valley.—The amount of Wisconsin till in the valley of Goose Creek, in the Creede quadrangle, is astonishingly small in view of the amount of rock sculpturing accomplished by the Wisconsin ice in that valley and in the tributary valley of Fisher Creek. The terminal moraine of the double-headed glacier is situated in the valley of the larger stream a little over 2 miles south of the Hot Springs Hotel, near Wagonwheel Gap. Toward the east it forms a spur jutting out from the tip of the divide between Goose and Leopard Creeks. On the west it forms a group of low hills nestling against the foot of the valley slope. A scanty deposit of till may also be observed a short distance below the mouth of the Roaring Fork, but elsewhere the valley is remarkably clean.

Valleys on slope of Fisher Mountain.—Three small glaciers, each less than 4 miles long, formed in short valleys on the northern slopes of Fisher Mountain, west of Goose Creek. These left irregular but comparatively thick deposits of Wisconsin till in the lower parts of the glaciated valleys. The moraine in the Roaring Fork is the most conspicuous of the three.

Valley of Rio Grande.—The composite glacier that occupied the valleys of the headwaters of the Rio Grande and its many tributaries was one of the largest in the San Juan Mountains. It left abundant and widespread deposits of Wisconsin till in and near the San Cristobal quadrangle. The terminal moraine rests on the broad, flat valley floor south and southeast of Bristol Head. The subdued morainal topography of low, rounded hills and shallow basins (pl. 26, *A*) is in striking contrast to the alluvial plain upstream and the outwash terraces downstream from the heavy mass of till, the thickness of which is probably 200 to 300 feet. Near the middle of the Rio Grande Valley and in that portion of the moraine near Antelope Spring the material is almost entirely that left by the main Rio Grande Glacier and contains great quantities of boulders of pre-Cambrian rocks—quartzite, schist, gneiss, and granite—which must have been obtained near the headwaters of the Rio Grande, 15 to 25 miles away. The débris in the southern part of the terminal moraine was largely transported by tributary glaciers that occupied the valleys of Trout Creek, Middle Creek, South River, and Ivy Creek; these glaciers moved exclusively over volcanic rocks, chiefly lava flows and agglomerates. The valleys of these tributary streams contain considerable bodies of drift, presumably deposited in the main during the recession of the ice. In Middle Creek especially the Wisconsin till is widespread over the valley floor and is disposed in more or less regular ridges that tend to form loops across the valley and suggest recessional moraines.

Lateral moraine ridges high on the slopes of the Ruby Lake Plateau, south of the Rio Grande, indicate that the upper limit of the ice in the main valley was

800 to 1,000 feet above the valley floor. A small recessional deposit on the alluvial flat between Workman and Woodfern Creeks marks a brief pause in the retreat of the main body of ice. Farther northwest the valley of Spring Creek and the irregular lowlands for some distance northward are mantled with thick masses of Wisconsin till forming numerous low hills and knobs interspersed with basinlike depressions. The drift here contains many boulders brought from the pre-Cambrian complex far to the west. These moraines and the ice from which the débris was dropped formed a dam across the southward-trending valleys now occupied by Clear Creek and Deep Creek, so that extensive lacustrine deposits were accumulated there.

Irregular areas of Wisconsin till are found at intervals on the floors of House Canyon, Road Canyon, and the canyons traversed by Crooked Creek and the South Fork of Clear Creek, through which the ice moved in carrying the débris to the Spring Creek region. A miniature recessional moraine in Road Canyon was utilized in the construction of the dam to transform the alluvial flat above the moraine into a "fish lake."[64] The Hermit Lakes occupy the larger depressions in the ground moraine deposited in the canyon occupied by them. The long, narrow flat-topped divides between these glaciated canyons do not carry drift, nor do they display any evidence whatsoever of glaciation. Farther west, however, they unite to form a plateau on the surface of which the Lost Lakes are hidden, and here great masses of Wisconsin till occur. The squat hill that rises to an altitude of 12,300 feet immediately north of the Lost Lakes was a nunatak in the midst of the ice fields, breasting the floods of ice that descended from the many cirques along the Continental Divide at the head of the Rio Grande. In the lee of this hill, near the head of Grouse Creek and extending into the upper part of the valley of Clear Creek, the ground moraine is especially thick and extensive. A lobe of ice pushed down Clear Creek for only a short distance; its terminus is marked by the morainal loops at the northeast side of Castle Rock Lake. Several morainic ridges, in many places not much more than a scattering of large boulders arranged roughly in crescentic form, mark the recessional stages of the glacier in the Clear Creek Valley upstream from the lake. In all this region the drift was derived mainly from the local volcanic rocks, but it contains also scattered boulders of pre-Cambrian gneiss, granite, and quartzite from the Needle Mountains massif. The amount of these foreign boulders is exceedingly small when compared with their great abundance in and near the canyon traversed by the Rio Grande.

[64] Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, p. 22, 1918.

On the south side of the Rio Grande there are considerable bodies of Wisconsin till on the floor and lower slopes of the more open canyons. In the vicinity of Weminuche Pass and near the head of Ute Creek the disposition of this till is such as to suggest lateral and frontal moraines deposited during a late stage in the withdrawal of the ice.

Miners Creek Valley.—Miners Creek heads in the mountains in the northeast corner of the San Cristobal quadrangle and flows southeastward into the Creede quadrangle. The upper portion of its canyon contains thick morainic deposits irregularly mantling the floor and lower slopes. The terminus of the ice in this valley is marked by small masses of till at an altitude of 9,000 feet. Long after the ice had melted from the deeper canyon it lingered in the higher basins. On the Bristol Head Plateau, at the head of Shallow Creek, for example, there was apparently a cliff glacier 2 miles wide and only a little more than a mile long beneath the eastward-facing scarp, which rises to 12,500 feet above sea level. This glacier left an extremely irregular deposit, as indicated on Plate 1, with innumerable knobs and hills between many small ponds and marshes in undrained depressions.

Rat Creek Valley.—Rat Creek rises in an ice-scoured amphitheater in the northwest corner of the Creede quadrangle and flows southward to Sunnyside. The Wisconsin terminal moraine, at an altitude of 10,900 feet, is a thick mass of glacial débris in the bottom of the valley. Farther upstream the till on the valley floor is arranged in longitudinal ridges running north and south, parallel to the stream, but not properly located for lateral moraines.

Willow Creek Valley.—Each of the two forks of Willow Creek has the valley form typical of most of the streams that join the Rio Grande from the north within the Creede quadrangle. The upper part of the valley is broad and mature; the lower part is a narrow, rugged gorge, through which the stream descends in rapids and cataracts from the high level of the mature valley to the low level of the Rio Grande. In East Willow and West Willow Creeks terminal moraines of the Wisconsin stage occupy the valley floor at the lower margin of the mature portion and at the head of the youthful gorge. That in the West Willow Creek Valley descends to an altitude of 10,300 feet; that in the East Willow Creek Valley to 9,600 feet.

La Garita Mountains.—The plateaus and rounded "peaks" that form the divide between the Saguache and Rio Grande drainage in the north-central part of the Creede quadrangle are known as the La Garita Mountains. In spite of their great altitude, only small glaciers formed on their slopes during the Wisconsin stage. The most easterly of these was in the head of the Bear Creek Valley, on the north side of Mesa Peak.

Spring Creek Valley.—The head of Spring Creek is immediately south of San Luis Peak, in the northwest corner of the Creede quadrangle; thence it flows northwestward to Cebolla Creek, which it joins at Cathedral, in the southeast corner of the Uncompahgre quadrangle. The Wisconsin terminal moraine is 6 miles above its mouth, in the unmapped area east of the Uncompahgre quadrangle. It is a thick deposit choking the valley and crowding the stream into a narrow channel.

Mineral Creek Valley.—The next stream to the west, Mineral Creek, rises in the northeastern part of the San Cristobal quadrangle. Scanty deposits of Wisconsin till may be observed in its valley in that quadrangle. The terminal moraine is small and inconspicuous. It is at an altitude of 9,500 feet in the Uncompahgre quadrangle, 3 miles above the junction of this stream with Cebolla Creek.

Rough Creek Valley.—The terminal moraine in the valley of Rough Creek, parallel to Mineral Creek on the west, is much larger. Its lower end is 2 miles above the mouth of the stream, at an altitude of 9,900 feet. For 3 miles upstream thick deposits of drift choke the valley and mantle the slopes to a height of 600 feet above the stream bed. Much of the material in the drift is subangular rather than rounded; the total length of the glacier was only 5 miles.

Valley of Lake Fork of Gunnison River.—The terminal moraine of the great composite Lake Fork Glacier lies a short distance downstream from Lake City. As represented on Plate 1, Wisconsin till is present on both sides of the river, but the greater mass of débris forms a bench east of the narrow stream flat with an irregular rolling surface 150 to 200 feet above the stream bed. The boulders in this huge deposit of till are chiefly volcanic but include some granitic rocks from the pre-Cambrian areas near the head of the Lake Fork.

Many scattered areas of Wisconsin till have been mapped in the valleys of Henson Creek, the Lake Fork, and their tributaries above this terminal moraine. Most of these occupy sheltered places on the floors of tributary gulches or rest in the angles between the floors and sides of the larger valleys. Lateral moraines on the higher and more gentle slopes east of Lake San Cristobal mark the upper limit of ice action there. They are 2,300 feet above the valley floor. The road up Wager Gulch to Carson traverses a large mass of till for a distance of about 2 miles. This deposit is in a protected position on the slopes of the outer valley of the Lake Fork, well above the brink of the inner gorge.

Blue Creek Valley.—The source of Blue Creek is at the foot of Uncompahgre Peak; thence it flows northward to the Gunnison River at Curecanti. For several miles downstream from the mouth of the East Fork the valley floor is nearly continuously covered with Wisconsin till. At and near the crossing of the Alpine Trail the moraine is unusually thick and displays a strikingly hummocky topography. It fills the bottom of the valley so completely that the stream has but a narrow notch to follow. No terminal moraine is present in this valley, but the most northerly deposit of Wisconsin till descends to an altitude of 8,900 feet 5 miles above the mouth of Little Blue Creek.

The East Fork of Blue Creek was not itself glaciated, but it was entered by a tongue of ice from the glacier in the larger valley. This pushed a mile up the East Fork and left a thick deposit of drift, which near the crossing of the Uncompahgre sheep drive displays a typical morainal topography. Farther upstream, toward the west, Blue Creek is joined by Fall Creek. As related elsewhere, piracy has occurred here, and Blue Creek has benefited by the drainage change. The diversion of the headwaters of Fall Creek from the Little Cimarron Creek drainage basin was either accomplished shortly before the Wisconsin stage or was an effect of the ice action. In either event the ice in Fall Creek merged with that in the Blue Creek Valley. Morainal deposits above the falls indicate that the smaller stream of ice pushed northward past the site of the falls and left Wisconsin till clogging the former channel of the creek. As shown in Plate 1, this drift body now forms the divide at the head of the upper of the two East Forks of Little Cimarron Creek.

Little Cimarron Valley.—Moraines of Wisconsin age begin about 2 miles upstream from the terminus of the Durango ice in the valley of Little Cimarron Creek. They rest on the modern valley floor and consist of a number of irregular ridges that curve inward to a position almost at right angles to the trend of the valley. Several small lakes occupy depressions in the moraine. The margins of the deposit of till are buried beneath landslides from the slopes above.

Cimarron Valley.—Wisconsin till is unusually extensive in the valley of Cimarron Creek in the eastern part of the Montrose quadrangle. Beginning near the mouth of Burdeck Creek, 8 miles south of the village of Cimarron, and continuing upstream to the vicinity of the Jackson ranger station, all the lower slopes and bottom of the valley are mantled with morainic débris. Numerous ponds dot the surface of the drift and nestle between the irregular knolls and hillocks. Similar irregular masses of Wisconsin till cover the lower slopes drained by the West Fork and Middle Fork for some distance upstream from the larger creek. Just north of Chimney Peak the moraines of the West Fork Valley fill the low sag in the divide and extend westward into the upper part of the Owl Creek Valley for 1½ miles. As described by Cross and Howe,[65] a distributary from the glacier in West Fork must have

[65] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 7, 1907.

pushed over that divide into the Cow Creek drainage basin.

Cow Creek Valley.—The only morainic area that has been mapped in the valley of Cow Creek is that which represents the terminal deposit of the Wisconsin ice. It is an irregular body of drift with typical morainal topography, massed against the upstream side of Ramshorn Ridge.

Uncompahgre Valley.—The deposits of Wisconsin till in the valley of the Uncompahgre River have been previously described[66] under the name "Later moraines and glacial drift," and the description need not be repeated here. The terminal moraine, in the vicinity of Ridgway (pl. 1), is the largest that has been observed in the San Juan region; it is over 400 feet thick and 2 miles long, crossing the valley northeast of Ridgway.

Dallas Valley.—Each of the many heads of Dallas Creek, which rise on the northern slopes of the San Juan Mountains near the south margin of the Montrose quadrangle, has been occupied by Wisconsin ice. The moraines are generally conspicuous and sharply defined. All rest on the modern valley floors and have been little more than trenched by postglacial erosion.

Telluride quadrangle.—The Wisconsin till in the Telluride quadrangle has been described in detail by Hole,[67] and it is unnecessary to repeat the descriptions here. The minor differences that exist in interpretation of the surficial deposits may be readily grasped by a comparison of Hole's map of this area with ours. Such differences are of no practical importance in deciphering the history of the region.

Rico Mountains.—Half a dozen small glaciers radiated from the group of peaks in the western part of the Engineer Mountain quadrangle, which are in reality the eastern outposts of the Rico Mountains. Well-marked terminal moraines are generally present in each of the valleys which they occupied.

La Plata Mountains.—Masses of stony till are present on the floor of the basins at the heads of many of the streams within the La Plata Mountains, and several moraines of Wisconsin age were mapped in the peripheral portions of that mountain group by Atwood in 1920.

The terminal moraine of the La Plata Glacier is near the ancient mining town of Parrott, near the point where the La Plata River leaves the mountains to flow southward across the plateau to the San Juan. A considerable mass of irregularly disposed drift clogs the valley floor so that the river now flows in a narrow trough along the east side of the valley. A large torrential fan, on which the cabins of Parrott were constructed, has been built upon the surface of the moraine by the small stream that plunges down the southeast end of the ridge culminating in Parrott Peak. Three-quarters of a mile farther downstream, at an altitude of 8,600 feet, the farther margin of the terminal moraine is bordered by the outwashed gravel of a valley train, the surface of which is about 30 feet above the modern flood plain of the La Plata River.

Inconspicuous but typically formed lateral moraines occupy the slopes of the valley of the East Mancos River at altitudes of 9,000 to 10,500 feet west and northwest of Madden Peak. These curve toward each other and descend rapidly in elevation downstream, but no terminal moraine crosses this valley. No Wisconsin till was found in the valley of the Middle Mancos River, and this stream seems not to have been disturbed by ice during that stage. The twin forks that form the head of the West Mancos River were each affected by Wisconsin ice, and several disconnected areas of moraines are present near the point at which the two forks unite. The terminal deposits extend down to an altitude of 8,600 feet and are found close to the banks of the river. A medial moraine veneers the tip of the ridge separating the valleys of the two forks, and lateral moraines on the outer slopes of each valley extend a little more than a mile upstream from their junction.

AGE

The extreme recency of the Wisconsin till is shown in many ways. Its boulders are fresh and unaltered, retaining many polished surfaces and striae. Post-Wisconsin weathering and stream erosion have been very slight, as shown not only by the glaciated rock surfaces so numerous in the upper courses of the streams but also by the character of the glacial débris itself. Most of the streams are still engaged in the task of cutting channels through the drift and clearing it away from their courses, and downstream from the terminal moraines the outwash terraces are not more than a score or two of feet above the modern stream bed. In some places picturesque gorges of considerable depth have been cut below the floor exposed upon the withdrawal of the Wisconsin ice. Henson Creek, for example, has a postglacial gorge 50 to 60 feet deep in places. The Rio Grande above Lost Trail Creek flows through a canyon cut nearly 100 feet into resistant rock since the ice withdrew from that portion of the valley. But these are local conditions, made possible by the unevenness of the glacial floor and forced upon the streams in the task of developing a smooth gradient; they do not indicate widespread lowering of stream channels but quite the reverse. They serve only to emphasize the paucity of postglacial stream erosion. Most conspicuous of all, as noted by many observers in the western mountains,

[66] Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 17, pp. 251–274, 1906. Cross, Whitman, and Howe, Ernest, op. cit., p. 7.

[67] Hole, A. D., Glaciation in the Telluride quadrangle, Colorado: Jour. Geology, vol. 20, pp. 502–529, 605–639, 710–737, 1912.

is the slight modification which these later glacial deposits have undergone. Typical knob and kettle topography is present in the drift deposits at many places, and small lakes occupy many of the undrained depressions.

Obviously, the various deposits of Wisconsin till are by no means of exactly the same age. The recession and final melting of the Wisconsin glaciers required many thousands of years and covered an interval of time far longer than that which has elapsed since the last of these glaciers disappeared. During the retreat there must have been many oscillations of climate, some of which caused slight readvances of the ice.[68] Such oscillations frequently gave rise to recessional moraines, a few of which have been described and some of which might be considered to be post-Wisconsin in age. The data all point to the presence of numerous small glaciers in the higher basins, such as those in the Silverton quadrangle, long after the main canyons were free from ice. The stony till on the floor of such basins in the higher parts of the mountain range is of very recent origin. Although at the present time there are neither ice nor névé fields in the San Juan Mountains there are many snow fields which persist through nearly, or quite, the entire season. In fact, a great bank of crevassed and characteristically green ice was seen by Cross[69] in 1895 in the large glacial cirque at the head of Dallas Creek, west of Sneffels Peak.

All these deposits of till, in spite of their extreme recency, are the natural concomitants of waning glaciation. They are the successive parts of the results ensuing from a single episode of secular refrigeration. It has therefore seemed wisest to make no distinctions between the oldest and the youngest but to group all together as Wisconsin in age.

CORRELATION

It is only natural, in view of the extreme recency of this latest till, to correlate it with the products of Wisconsin glaciation elsewhere in the North American Cordillera, in the Mississippi Valley, and in other continents. It is obviously the equivalent of the latest Pleistocene glacial deposits that have been observed in every group of high mountains in the West. Nor can there be any doubt concerning the substantial correlation of this drift with that of the Wisconsin stage in the Mississippi Valley and the Würm stage in the Alps.

WISCONSIN OUTWASH

In nearly every large valley leading out from the central portion of the San Juan region low terraces, generally 20 feet or so above the modern alluvium, may be observed. These terraces are commonly composed of gravel, but in some places they are rock benches veneered with a thin layer of stream deposits. The materials are generally rather small cobbles and pebbles, but here and there boulders a foot or more in diameter are included. Most of them are well rounded and waterworn.

When traced upstream these low terraces almost invariably blend into the downstream side of the Wisconsin terminal moraine. The gravel of which the terraces are composed is therefore believed to be largely fluvioglacial material washed from the melting ice and deposited as a valley train extending far down the course of the silt-laden streams.

The width of the Wisconsin Valley trains was much less than that of the earlier Durango outwash; seldom is a width of more than a mile indicated for the Wisconsin gravel. As a consequence, it is probable that the Wisconsin outwash deposits are generally much thicker than the Durango gravel trains. The earlier outwash materials average less than a score of feet in thickness and rarely attain as much as 50 feet. The Wisconsin outwash terrace, however, is ordinarily 20 to 30 feet above the modern alluvium, and in some valleys it is 50 to 60 feet high. Nevertheless, it is extremely rare for solid rock to be exposed in the post-Wisconsin cuttings beneath the terraces.

Wisconsin outwash gravel is well displayed in the Animas Valley, and part of the deposits there are represented on Plate 1. The city of Durango is built upon the outwash a short distance downstream from the terminal moraine, and thence downstream far beyond the limits of the Ignacio quadrangle this terrace is covered with fertile wind-blown loam nearly everywhere under cultivation. In the Los Pinos Valley the outwash gravel is exposed near the Indian agency at Ignacio and elsewhere along the stream channel. At Ignacio the mission churches and certain of the Indian school buildings are on the Wisconsin terrace. Wherever observed in both these valleys it maintains a fairly constant height above the stream.

The San Juan River near Pagosa Springs has cut well below the base of the Wisconsin outwash gravel at several localities. The terrace remnants of the Wisconsin Valley train stand 60 to 80 feet above the present stream bed, whereas the gravel aggregates only 40 or 50 feet in thickness. Several sharp contacts between the overlying gravel and the Mancos shale on which it rests may be seen between the town of Pagosa Springs and the mouth of Turkey Creek.

Wisconsin outwash materials cap the lower terrace in the Conejos Valley, of which there are several remnants near the middle of the Conejos quadrangle. Close to the Wisconsin terminal moraine the top of the valley train is now about 40 feet above the bed of the Conejos River. At several localities in the south-

[68] Cf. Hopkins, T. C., Glacial erosion in the San Juan Mountains, Colorado: Wyoming Hist. and Geol. Soc. Proc., vol. 11, pp. 2, 11, 1911.

[69] Howe, Ernest, and Cross, Whitman, Glacial phenomena of the San Juan Mountains, Colorado: Geol. Soc. America Bull., vol. 19, p. 254, 1906.

east quarter of T. 33 N., R. 8 E., the river has cut 20 feet into the rock beneath the outwash gravel. Upstream from the terminal there are several terraces of fluvioglacial materials that were apparently deposited during the recession of the ice, when considerable débris was washed into the depressions between the higher hills of the terminal moraine. Downstream toward the east the Wisconsin terrace has a steeper gradient than the modern stream and in consequence it is found at lower and lower heights above the flood plain. In sec. 34, T. 33 N., R. 7 E., the two terraces coincide. Farther east the Wisconsin outwash is buried beneath the modern alluvium.

Somewhat similar relations between the Wisconsin outwash and the recent stream alluvium recur in the valley of Alamosa Creek, a few miles to the north. In the portion of this valley between Jacobs Hill and Chiquita Peak the remnants of the Wisconsin Valley train are now 15 to 20 feet above the valley flat. Two miles downstream, in sec. 29, T. 36 N., R. 7 E., the Wisconsin terrace descends to the level of the modern alluvium. Farther east the fluvioglacial gravel of this stage is concealed by postglacial wash.

In the valley of the Rio Grande, the next largest stream to the north on the east front of the mountains, the Wisconsin outwash terrace is the best preserved of the numerous terraces in the western part of the Creede quadrangle. At the margin of the terminal moraine near Antelope Spring the river is 50 to 20 feet below this terrace, but 10 miles downstream it is only 5 or 6 feet below the bench. For a considerable distance beyond this point no remnants of the Wisconsin terrace are present, and it may be that the outwash is there the same as or beneath the modern alluvium. Below Wagonwheel Gap the Wisconsin terrace is well preserved as a long, narrow bench on each side of the narrow modern flood plain from 5 to 20 feet above the stream bed. At South Fork the terrace is half a mile wide, and between South Fork and Granger it is a prominent feature on both sides of the valley. From Granger eastward its surface declines regularly with a steeper gradient than that of the modern alluvium. In the Del Norte quadrangle 5 miles west of Del Norte the outwash terrace is more than a mile wide but is only 5 or 6 feet above the river bed. Near Pinos Creek the terrace blends into the modern alluvium, and farther east the fluvioglacial materials are beneath the bed of the Rio Grande.

The Wisconsin outwash terrace is well displayed along the Uncompahgre River from the very edge of the terminal moraine at Ridgway to a point some distance north of Montrose. This gravel is the "later terrace gravels" of the Ouray folio. At Dallas the terrace stands 60 feet above the stream, but the two converge downstream until near Montrose the outwash gravel is less than 20 feet above the modern alluvium. Montrose is built upon a remnant of the valley train, which merges farther east into stream alluvium and torrential wash brought down upon it by the tributary streams from that direction. Directly across the river from the railway station, in the broad depression between the brick works hill and Spring Creek Mesa, is another remnant of the outwash deposits, which there blend entirely into the modern stream alluvium. Four miles downstream the terrace beneath the city of Montrose likewise descends to the flood-plain level.

TERRACE GRAVEL NOT DIRECTLY CONNECTED WITH GLACIATION

Along certain of the rivers and creeks of the San Juan region there are low terraces which bear the same relation to the modern stream channels as the Wisconsin outwash terraces but which are in valleys so situated that they can not be, or can not be proved to be, the result of fluvioglacial processes. Some of these bear the same relation to the Wisconsin valley trains as that borne by the "nonglacial alluvium of the Durango stage" to the Durango outwash gravel. Others are clearly the result of interference with stream erosion by rocks of superior resistance situated downstream from the terrace remnants. Still others may be remnants of former flood plains abandoned because of crustal movements, stream piracy, changes in stream load, or some other event. Generally these terraces are rock benches capped by a thin veneer of stream gravel; they range in height above the stream from 5 to 50 feet.

For descriptive purposes these deposits may be grouped under the above caption, although they are not by any means contemporaneous nor the result of a single type of geologic process. Nevertheless, it seems quite certain that all the deposits which have been included in this category are of Pleistocene age. A comparison of the position of the Wisconsin outwash terraces with respect to the modern stream channels indicates that even the lowest of these nonglacial stream terraces must have been the site of stream deposition at least as long ago as the Wisconsin stage. On the other hand, the most ancient of them can not date back much beyond the time when the Durango outwash gravel was strewn over flood plains now represented by terraces as high above the neighboring streams as the highest of these deposits.

LATER TERRACE GRAVEL OF THE GUNNISON RIVER

On both sides of the Gunnison River in the northern part of the Uncompahgre quadrangle, between Sapinero and Elkhorn, there are many gravel-strewn rock terraces 100 to 300 feet above the stream bed. The unconsolidated materials that veneer the surface of these terraces have been mapped as later terrace gravel of the Gunnison River. They are very similar in composition, size, and shape to the deposits described on page 119 as earlier terrace gravel of the Gunnison River but are clearly distinct from them because of their situation at much lower levels with respect to the stream channel. Definite correlation of this gravel with other deposits in the San Juan region has not been possible and it is therefore treated as a separate formation.

Near Iola a gravel-strewn terrace on the north side of the Gunnison River is a conspicuous feature of the landscape. Its streamward margin is an abrupt escarpment averaging 50 feet in height, which rises from the alluvial flat of the modern flood plain to the gently sloping surface of the terrace. This surface rises gradually toward the north, where it is covered by torrential wash from the valley slopes. Similarly, near Cebolla there are several remnants of this same gravel-strewn surface, which here are 100 to 200 feet above the stream channel. Still farther west, in the vicinity of Sapinero, there are other remnants of the same bench 300 to 400 feet above the stream. Not only is this discontinuous terrace higher above the river bed near the entrance to the Black Canyon than it is farther upstream but it is also higher above sea level at each locality downstream toward Sapinero.

At all these localities the gravel is merely a thin coating 5 to 20 feet in thickness deposited upon the graded rock surface. A few individual stones are as much as 2 feet in diameter, but most of the pebbles are between 1 inch and 3 inches in their greatest dimension. No exposures displaying stratification were noted, but there is no doubt of their fluviatile origin.

Apparently this gravel was deposited by the Gunnison River upon its flood plain at a time when the river had attained a temporary base-level and was broadening its valley by lateral planation. In all probability the development of that ancient flood plain was closely associated with the carving of the Black Canyon of the Gunnison, a few miles farther downstream. The same conditions that controlled the deposition of the earlier terrace gravel, as described in a preceding section, doubtless were repeated at a later stage in the erosion of this region, and thus in a very real sense the later gravel of the Gunnison duplicates the earlier. The intermittent warping of the earth's crust, which in the final analysis is the underlying cause of the present Black Canyon, was also the cause of the existing upward slope of the terrace remnants, veneered with the later gravel, downstream from Elkhorn to Sapinero.

No direct connection has been found between the later gravel of the Gunnison and deposits from the ice of any of the glacial stages in the San Juan region. It is therefore impossible to state definitely the age of this gravel. It seems quite likely, however, that the gravel was formed during post-Durango and pre-Wisconsin interglacial time, when streams in many other parts of the range were at work broadening their flood plains.

LATE PLEISTOCENE AND RECENT DEPOSITS

LANDSLIDES

CLASSIFICATION

At innumerable localities in different parts of the San Juan Mountains the topographic, lithologic, or structural conditions have been particularly favorable for the development of landslides in great variety of form and composition. No observer of natural phenomena in this mountain group can fail to be impressed by the magnitude of the work accomplished by this process of degradation. Few mountain valleys may be traversed for any distance without an opportunity of seeing large masses of earth or rock débris which have slipped or fallen down the mountain sides. Special studies of the landslides in the Rico Mountains [70] and in the western part of the San Juan region [71] have already been made. Detailed descriptions of the larger or more noteworthy slides in that part of the region may be found in the folios descriptive of the quadrangles included in it.

In our mapping we have attempted to discriminate between three different kinds of slides or rock falls. The distinctions between them may be understood by a reference to the following table showing the classification of San Juan landslides proposed by Howe [72] as an adaptation of the earlier classification of Heim [73] to the local conditions in southwestern Colorado.

Classification of the San Juan landslides

Kind of slide	Examples
Movements of detritus	
Soil (or earth) creeps	C. H. C. Hill, Rico.
Earth slides or soil slips	Cimarron landslide.
Mud flows	Slumgullion, San Cristobal quadrangle.
Talus slumps	Rock stream of American Basin.
Movements of solid rock	
Rock slides; large masses of rock rotating backward on axes parallel to trend of slope down which movement takes place.	Most San Juan landslides; noteworthy examples at the end of Hayden Mountain, Ouray, and in Red Mountain and Ironton Park districts, Silverton.

[70] Cross, Whitman, Geology of the Rico Mountains, Colorado: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 129–151, 1900.

[71] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: U. S. Geol. Survey Prof. Paper 67, 1909.

[72] Howe, Ernest, op. cit., p. 55.

[73] Heim, Albert, Ueber Bergsturze, Zurich, 1882.

Kind of slide	Examples
Rock falls; rocks shattered; if of sufficient magnitude shattered rock may move with great velocity outward from base of cliffs as a flow of newly made detritus.	Rock streams.
Movements of both detritus and solid rock	
Rock falls or slides on detritus, resulting in the movement of both.	Rock slides of Canyon Creek, Ouray, on glacial gravel.
Miscellaneous	
Slides from artificial cuts	Many examples of minor importance.
Sinking of ground over mines or caverns.	A few examples.

The first three kinds of movement of detritus listed by Howe have been mapped and will be described as "Mud flows and earth slides." Talus slumps, if of conspicuous character, and rock falls are grouped together as "Rock streams." Other movements of solid rock, or of solid rock and detritus, are called "Landslides" and will be described and their origin discussed in this section. We are thus using the term in a restricted sense to include only a part of the phenomena that might be comprised within its broader limits.

GENERAL FEATURES

The topography of landslide masses is commonly so irregular and broken as to suggest vividly the nature of the disturbances to which the present disposition of the material is to be ascribed. Short ridges and elongated hillocks alternate with crescentic marshlands or oval ponds. In general the longer axis of ridge or depression is roughly parallel to cliffs from which the landslide came or to the trend of the slope on which the débris rests. In most slides the knolls and ridges are asymmetric; the slopes facing the mountain side from which the débris has come are ordinarily gentler than those facing outward, in the direction in which movement has taken place. The ponds and little lakes that occupy depressions among these ridges or between the broken rock and the cliffs from which it has fallen are commonly stagnant; drainage is irregular and disturbed.

The shape of landslide masses ordinarily suggests a viscous body arrested in the act of flowing downhill. Above the slide the scar on the mountain side which marks the places from which the material slumped or fell is commonly visible. Below, the entire mass bulges outward in more or less perfect conformity to the topography of the land over which it has moved. Or, again, a slide may have come with so great velocity from one wall of a canyon that it has crossed the stream and mounted several hundred feet up the farther slope. The suggestion that there has been movement like that of a stiff liquid or plastic substance is often impressed with startling clearness upon the observer stationed at a point sufficiently remote to permit him to view the entire mass in relation to its surroundings.

The materials comprising a landslide consist of rock masses and soil. Individual rocks may range in size from small fragments to huge blocks weighing hundreds of tons. Wherever the exposures permit observation, as along stream channels or artificial cuts, the chaotic nature of the fallen material is readily apparent. Individual blocks of stratified rock or lava have been thrown in all directions and now lie in all attitudes. In some of the larger and less shattered blocks of originally bedded materials the dip of the strata is downward toward the mountain side, as if the block had fallen backward as it slipped down. This tendency to rotate backward about axes parallel to the trend of the slope down which the blocks are moving is common but by no means universal. A pitch of the block in the opposite direction is not so frequently observed, because if the top plunges forward the chances are that the whole mass will be shattered into fragments.

Invariably the materials are all of local origin. Their variety is customarily no greater than the variety of rocks in the cliff or hillside from which the slide came. Likewise, the blocks are sharply angular fragments, broken but not worn. Some slides, however, may embrace a great variety of boulders or rounded stones. This is common if the slide has involved the movement of a stream deposit or body of glacial drift as well as that of the underlying solid rock. Or it may result from the fact that among the formations cropping out on the particular hillside is a volcanic tuff or agglomerate from which the boulders came.

Obviously, no one description would fit all the slides that have been observed in the San Juan Mountains, for these occur under diverse conditions and have taken place at many different times. Nor is it practicable to describe all the slides that have been considered of sufficient importance to find a place on the maps showing surficial deposits. Many of the landslides have already been described in detail in the geologic folios descriptive of certain quadrangles in the region, and others are discussed in the publications above referred to. Representative slides and others of peculiar interest will be briefly treated in the following pages.

LANDSLIDES INVOLVING SEDIMENTARY ROCKS ONLY

Florida Valley.—The landslides on the east side of the Florida Valley in the northeastern part of the Ignacio quadrangle are typical of those formed entirely in sedimentary rocks. The basin of the stream tributary to the Florida River from the east at Transfer Park is choked by landslide débris above the deposits of Wisconsin till. Angular blocks and fragments of sedimentary rock disposed in many small ridges and hillocks extend back to the base of the more abrupt cliffs above the 10,500-foot contour line. Some of the ridges are crescentic in shape and are roughly parallel to the cliffs above, from which the material composing them was derived. Behind the ridges there are many marshes and bogs.

The sedimentary rocks involved in this slide are chiefly of Carboniferous age. Resting on the comparatively thin formations of Cambrian, Devonian, and Mississippian age is the thick mass of Pennsylvanian strata, which includes the Molas, Hermosa, and Rico formations, named in ascending order. The Molas formation and the lower beds of the Hermosa are chiefly shale with a few beds of sandstone or limestone. The middle and upper portion of the Hermosa formation is made up for the most part of a succession of thick beds of limestone. These limestone beds form the cliffs above the landslide débris and have contributed largely to the blocks in the fallen chaotic mass. Evidently the shale beneath these massive limestone beds was incompetent to bear the superincumbent load at this locality, where rapid stream erosion developed an oversteepened slope.

Two miles to the south, in the NW. ¼ sec. 32, T. 37 N., R. 7 W., there is a smaller landslide at an altitude of about 9,000 feet. It is likewise composed almost entirely of sedimentary fragments from the scarred cliff which rises above it, but in this instance the fall also involved some movement of the glacial drift, which here formed a rather thick mantle on the hillside. The topography of the disturbed area is in sharp contrast to that of the undisturbed moraines on each side. This slide is evidently of very recent occurrence, as the cliff above it is little weathered, and in 1910 the débris of the slide was covered by a young growth of timber, in striking contrast to the older timber around it.

The trail that climbs from Transfer Park up the west side of the Florida Valley toward the surface of Lime Mesa traverses another extensive area of landslide material as it passes from the Ignacio quadrangle into the Needle Mountains quadrangle. This slide, like the larger one on the east side of the valley, has resulted from the fall of ledges of Hermosa limestone when the underlying shaly strata gave way. The débris rests in part against the outer side of a lateral moraine, parts of which were much disturbed by the slide.

East Mountain.—Similar geologic and topographic conditions prevail in the large area mantled with slide débris on the east side of Vallecito Creek opposite the fish hatchery in the northeast corner of the Ignacio quadrangle. Fully 2 square miles of hillside is here covered with a chaotic mass of sedimentary materials, conspicuous among which are large numbers of blocks and ledges of Hermosa limestone which have slipped for hundreds of feet down the slope.

Canyon Creek.—Strata of the Hermosa formation are likewise the only ones involved in the slipping that has taken place on both sides of Canyon Creek, which drains the high inclined mesas bordering the southern slopes of the Needle Mountains in the southwest corner of the Needle Mountains quadrangle. The slides in this area have been described by Howe[74] as follows:

> Probably more than 4 square miles of territory are covered by landslide débris occurring in three areas. In two of them that border Canyon Creek directly there is clear topographic evidence as to the origin of the fallen material. In these two localities the débris lies on moderately steep slopes, above which in a few places are unhealed scars, but in most cases steeper and more even slopes are the only indication of rock in place. In the upper part of the southern and larger area many blocks of sandstone and limestone may still be distinguished, often separated from one another by deep, open fractures or crevasses indicating that movement has taken place in recent times. Lower down the slopes the surface is more rounded and gentler in relief, with numerous ponds and springs, and is covered by a heavy growth of timber indicating greater antiquity.
>
> The smaller area north of Canyon Creek has a very characteristic topography of unmistakable landslide origin. Marshes and small pools are abundant, the fallen blocks are separated from one another by trenches, and narrow ridges descend, one below another, like steps for 600 feet. The rocks in place dip about 6° SW., while the direction of the landslide movement has been both to the northwest and to the southeast, at right angles to the direction of the dip.
>
> The third area is of slightly different character. It lies about the headwaters of a northern fork of Canyon Creek and borders Tank Creek, a more northerly tributary of the Animas, on the northwest side of a broad, flat ridge that forms the divide between these northern forks and Canyon Creek proper. Five or six small streams drain this region and, just beyond its lower limits, join to form the north fork of Canyon Creek. The topography is that characteristic of landslides considerably softened by age. The relief is gentle, springs are numerous, and undrained pools, bogs, and hollows indicate the locations of old trenches between fallen blocks. As a rule the area bears evidence of considerable age, but in a few places fairly fresh scars may be noted, especially near the head.
>
> The puzzling feature of this landslide locality is the fact that there appears to be no point from which the material can have fallen; there is no high land or ridge in the vicinity, and the moderate slope upon which the material rests, a little over 1,000 feet in a mile and a half, is noteworthy. It is believed that in this region, previous to the occurrence of the landslides, high, narrow ridges existed, and the slipping of material from their sides into the drains or ravines between them not only lowered the ridges but filled the drains and resulted in the present irregular topography of low relief. The upper limits of these slides are shown with fair clearness and may be traced about the ends of the ridges from one drain to another. The lower or outer edges are more difficult to make out, partly because the accumulations are less thick, and also because in a great many cases loose rock and soil has slipped down over glacial gravels or moraine, causing a mingling of the two sorts of material.

[74] Howe, Ernest, op. cit., p. 28.

Cascade Creek.—Two small but interesting landslides in the drainage area of Cascade Creek, near the northeast corner of the Engineer Mountain quadrangle, come in this general category and have been thus described by Cross:[75]

In the east branch of Cascade Creek, traversed by the trail to Silverton, near the northern boundary of the quadrangle, there is a landslide mass of La Plata sandstone of somewhat unusual relations. It lies in the lower part of the valley, and the slide took place down a dip slope of not more than 10°. Probably this slip was caused by the saturation of the shale layers on which the upper massive La Plata sandstone rests.

About 2 miles north of Engineer Mountain, between the forks of another eastern branch of Cascade Creek, a portion of a prominent point of the red Cutler beds has become detached and has slipped in large sections down the slope, the separate masses lying at different distances from the point of detachment. The rear masses are separated at the surface from rock in place by crevices, without great dislocation. The front part has been broken off. Further sliding is undoubtedly in progress at this locality.

termixed with pulverized and fragmental material from the Morrison and Summerville formations. Apparently cliff recession in the shale of the latter formations was normally more rapid than the retreat of the resistant rim-rock sandstone. The sandstone, undermined, broke off in large masses and crashed down the steep slope to rest near the foot of the cliff.

LANDSLIDES INVOLVING BOTH SEDIMENTARY AND BEDDED VOLCANIC ROCKS

Trident Mesa.—The northern slopes of Trident Mesa, half in the Montrose quadrangle and half in the Uncompahgre quadrangle, afford unusually favorable conditions for widespread development of landslides. The mesa is composed largely of San Juan tuff and agglomerate. Near its northern extremity this pyroclastic material is underlain by Mancos shale, which forms the lower few hundred feet of the valley sides. The shale is thin bedded, soft, clayey, and friable.

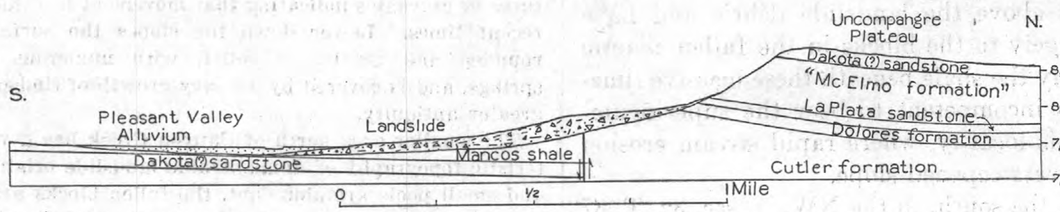


FIGURE 21.—Structure section of a landslide on the south margin of the Uncompahgre Plateau, Montrose quadrangle, Colorado

Pleasant Valley.—Another group of slides that involve the movement of solely sedimentary rocks may be observed at many localities on the lower slopes of the escarpment that bounds the Uncompahgre Plateau on the south and southwest. The north side of Pleasant Valley, west of Ridgway, in the southwest quarter of the Montrose quadrangle, is formed by this fault scarp, and similar conditions recur at intervals for many miles to the west, extending far out across the unmapped plateau country west of the Montrose quadrangle.

As indicated in Figure 21, the surface of the plateau is composed of Dakota (?) sandstone, a massive quartzose sandstone aggregating nearly 200 feet in thickness. This is underlain by the Morrison and Summerville formations, 700 to 800 feet thick, consisting of friable sandy shale with a few beds of argillaceous sandstone and impure limestone. The plateau surface is essentially a dip slope, and the beds dip gently into the hillside all along the escarpment. Downward movement of landslide débris has therefore not been effected by slipping along bedding planes. On the other hand, there is a set of joint planes parallel to the fault, which may have facilitated landslide action.

The landslide débris is composed in great part of blocks of Dakota (?) sandstone, large and small, in-

When wet it is especially slippery and presents little resistance to crushing stresses.

All the slopes below the base of the tuff are modified more or less by slumping. A true outcrop of the Mancos shale in place is very seldom found. The cliffs of tuff, formed almost entirely by the recession contingent upon the slides, are notably abrupt and tower precariously above the irregular slopes below. These slopes present every evidence of the disturbances to which their present topography is due. Apparently the huge masses of San Juan tuff, in places fresh, unweathered, and angular but elsewhere crumbling into a mere heap of boulders and volcanic bombs, have descended at many different times. The present condition of the material is the result of a succession of falls, which presumably continued until a condition of fairly stable equilibrium had been attained. Movement of the entire mass is now an almost imperceptible creep with an occasional, more spectacular slump, as the lower slopes of this shale hillside are reduced by stream erosion.

Swanson Lake.—Identically the same stratigraphic and topographic conditions present themselves in the region surrounding Swanson Lake between Little Cimarron and Blue Creeks (fig. 22) in the northwest quarter of the Uncompahgre quadrangle. Immediately south of Swanson Lake, which occupies an undrained depression behind one of the ridges of fallen débris, huge pinnacles of tuff have slid outward and down-

[75] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), p. 9, 1910.

ward with a minimum of tilting and are now hundreds of feet from their original position but with vertical faces and horizontal bedding planes still intact. Elsewhere the tuff has crumbled and broken, much of the matrix has been pulverized or decayed, and great heaps of the tuff boulders with a few fragments of the tuff itself modify the surface.

Within the limits of the Durango glaciation drift boulders are added to the slide material from the cliffs above. The presence of the glacial boulders obviously makes it difficult to distinguish slide from glacial débris, as striated boulders may occur in the landslides, and angular fragments of tuff may be present in the glacial drift. Topographic expression, especially the relation between the trend of the ridges and the direction of the cliffs bordering the valley, was mainly relied upon in making the distinctions required for the mapping of the region.

ate and San Juan tuff. The sandstones have suffered the same fate as the volcanic rocks, which elsewhere rest directly upon the incompetent shale and have contributed to the materials of the slide, in which angular blocks of sandstone are mingled with boulders and fragments from the Telluride and San Juan formations.

Cow Creek.—The lower slopes of the east side of the Cow Creek Valley upstream from the mouth of Red Creek, in the southeastern part of the Montrose quadrangle, are heavily mantled with slide débris. Most of it is of sedimentary origin, derived from the Cutler formation, which crops out here, but the overlying San Juan tuff has contributed a considerable percentage of the chaotic material. The Cutler strata in the landslide area dip at a fairly high angle down the mountain side, the strike of the beds being roughly parallel to the trend of the valley sides at many points.

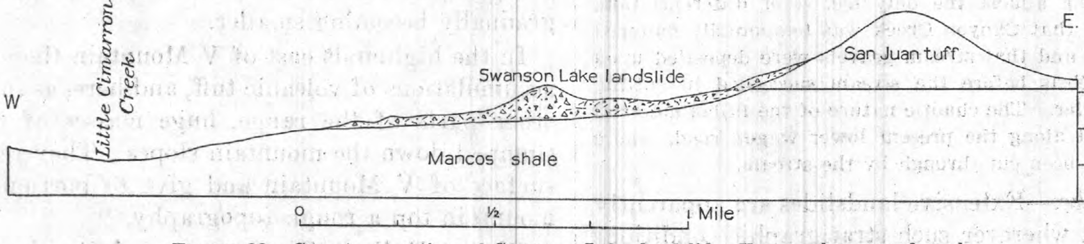


FIGURE 22.—Structure section of Swanson Lake landslide, Uncompahgre quadrangle

Tongue Mesa.—Tongue Mesa is the northward extension of Cimarron Ridge in the northeast quarter of the Montrose quadrangle. It consists largely of Cretaceous shale and sandstone, among which the Mancos shale is the thickest formation, but is capped with San Juan tuff and agglomerate. The instability of a shale foundation beneath massive volcanic beds is further demonstrated by the numerous slides that modify the slopes and even the summit of the mesa. Many of the slides involve the movement of glacial materials from the Cerro till, which was at one time generally deposited over the area north of the Sawtooth Rocks.

The effect of the numerous falls of volcanic rocks upon the sculptured cliffs from which the sliding has started is well illustrated by the names applied to these northern outposts of Cimarron Ridge. Castle Rock, Washboard Rock, Sawtooth Rocks, and Storm King all rise abruptly above the upper margin of landslide débris. The relations of the fallen débris to the bedrock topography are represented in Figure 22.

Lou Creek.—Most of the small streams that join to form Lou Creek, a tributary to Cow Creek not far southeast of the center of the Montrose quadrangle, rise in the midst of landslide materials on the western slopes of Cimarron Ridge. Throughout much of this area the Mesaverde sandstones intervene between the Mancos shale and the overlying Telluride conglomer-

Consequently much of the slipping has occurred along the bedding planes between those strata.

This landslide is therefore a good illustration of a true "Felsschlipf," as that term was defined by Heim, who restricted it to slides where stratified rocks dip in the direction of the slope of the hill of which they form a part.

Amphitheater.—According to Cross and Howe,[76]

> The Amphitheater, directly east of Ouray [pl. 26, *B*], is filled to a depth of several hundred feet with landslide débris that fell from the cliffs of the San Juan formation, in which the cirque has been eroded, and, although the deposits are covered for the most part with vegetation, Portland Creek and its side streams have carved deep trenches, in whose sides, which are at many places more than 200 feet high, the chaotic nature of the accumulation is well displayed.

Late Paleozoic and early Mesozoic sedimentary strata form the foot of the cliffs around the Amphitheater and appear on both sides of the slide. They have likewise supplied a modicum of material for the great heap of débris. But it is doubtful if the presence of these sedimentary rocks beneath the San Juan tuff was of any mechanical importance in facilitating the downfall of the slide material. Excessive steepening of the cliffs by bergschrund quarrying during the Wisconsin glacial stage was presumably quite suffi-

[76] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 8, 1907.

cient to cause the landslide, regardless of the presence of sedimentary rocks beneath the volcanic pile.

Hayden Mountain.—Howe [77] describes the Hayden Mountain slide as follows:

Southwest of the town of Ouray and on the southeast side of Canyon Creek at the end of Hayden Mountain landslide débris covers an area of about 1 square mile. The upper part of Hayden Mountain consists of San Juan tuff, resting upon a thin band of Telluride conglomerate, which in turn lies on the sandstones and grits of the Hermosa formation. All of these rocks are represented in the fallen material, which has the characteristic block and trench surface, lacking regular drainage, and at the base of which are numerous springs. At the end of the Hayden Mountain ridge the block and trench structure is unusually well developed, and the mingling of the blocks of different formations is not common, indicating that the slipping has been moderate although involving a considerable area. An abundance of glacial gravels occurs in Canyon Creek, which have been in part covered by the landslide débris. The relation of the two kinds of land waste is often obscure, the subangular form and striation of the boulders in the marginal material affording almost the only means of differentiation. It is also shown that Canyon Creek was temporarily dammed by the landslide and that stream gravels were deposited upon the landslide débris before the stream succeeded in cutting through the barrier. The chaotic nature of the fallen material is well exhibited along the present lower wagon road, where the old dam has been cut through by the stream.

Palisade Lake.—Extensive landslides are apparently to be expected wherever such stratigraphic conditions as those responsible for the Swanson Lake and Trident Mesa landslides are present. On the south side of the range such relations—clay shale on the lower slopes of the valleys overlain by agglomerate and breccia—occur in the region between Weminuche Creek and the Middle Fork of the Piedra River. Of the numerous slides in that area only two are represented on the accompanying maps; these are in the southern part of the San Cristobal quadrangle. One is on the west wall of the valley of Huerto Creek, and the other surrounds Palisade Lake and mantles the divide between that lake and the Middle Fork.

Directly above the Mancos shale at these localities there is a variably thick mass of unconsolidated or poorly cemented boulders and gravel. These materials are overlain by volcanic tuff and breccia, with a few thin sheets of lava, which together comprise the Conejos formation of the Potosi volcanic series. All these materials have contributed to the slide débris, which now mantles the slopes underlain by the shale.

V Mountain.—About 20 miles southeast of Pagosa Springs, in the south-central portion of the Summitville quadrangle, there is a remarkable development of landslides on the slopes and over the surface of a broad mesalike area known as V Mountain. The summit of this mountain rises to an altitude of 10,700 feet above the sea, or about 2,500 feet above the general level of the country to the west and south. At its eastern border there is a high area that rises about 2,500 feet above the surface of this V-shaped mountain.

Most of V Mountain is composed of Mancos shale, but it is capped at places with Mesaverde sandstone. This geologic relation produces almost ideal conditions for the development of landslides on a large scale. The soft shale, which becomes a remarkable lubricant when it is wet, gives way under the heavy load of the massive layers of sandstone, and one huge mass after another slips down the hillside.

V Mountain is bordered on the north, west, and south with extensive areas that are mantled with landslides. The topography of the younger landslide areas is exceedingly rough and at places hummocky. The slides nearer the rim of the mountain display all the characteristics of young landslide blocks. The older slides, farther out from the mountain, have been subdued by erosion. The process of giving way is still going on, and the surface of this mesalike mountain is gradually becoming smaller.

In the highlands east of V Mountain there are vast accumulations of volcanic tuff, and here, as in so many other parts of the range, huge masses of tuff have slumped down the mountain slopes. They rest on the surface of V Mountain and give to portions of this mountain top a rough topography.

Chama Valley.—The presence of Conejos agglomerate resting upon Cretaceous shale in the southeast corner of the Summitville quadrangle has occasioned many landslides in the Chama Valley. At some places the valley slopes seem to have been oversteepened during the Wisconsin glacial stage by ice erosion. Thus in the vicinity of the Chama Gun and Rod Club landslide débris is mingled with glacial débris at many localities. Elsewhere, above the upper limit of glacial action, ordinary stream erosion has sufficiently steepened the valley sides to destroy equilibrium and has permitted the volcanic materials to slip down the slope over the yielding shale. On the east side of the Chama River the many lakes and ponds high on the valley side are for the most part in the midst of landslide débris.

Silver Mountain.—One of the largest areas of landslide débris observed in the San Juan Mountains is in the central part of the Telluride quadrangle northwest of Silver Mountain. It has been adequately described by the geologists who worked earlier in that region.[78] The geologic conditions in this area on the west front of the range are the same as those in the large landslide areas on the north and south sides. Mancos shale, exposed well above the master streams, is overlain by Telluride conglomerate and San Juan tuff, with Tertiary lava flows forming the higher

[77] Howe, Ernest, op. cit., p. 30.

[78] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 11, 1899. Howe, Ernest, Landslides in the San Juan Mountains, Colo.: U. S. Geol. Survey Prof. Paper 67, pp. 17–19, 1909.

mountain summits. Here, as elsewhere, the outcrop of the Mancos shale is concealed beneath a variably thick mantle of débris from the higher formations.

The general topographic expression of this landslide mass suggests that it is older than many of the similar slides described above. Such streams as Turkey Creek, Vance Creek, and Prospect Creek have well-established drainage systems and have accomplished much toward the restoration of normal drainage conditions subsequent to the complete destruction of drainage lines that must have accompanied the rock falls. Few undrained depressions, occupied by marshes or ponds, remain. Nearly everywhere throughout the slide area the harsh irregularities of the more recent slides have been subdued and modified toward more normal erosion features.

The relation of the Silver Mountain slide débris to the drift deposits of the Wisconsin glacial stage is in keeping with this suggestion of greater age. (See fig. 23.) Till dropped from the ice of the small glaciers that formed in Turkey and Alta Basins and in the cirque at the head of Prospect Creek rests on top of the slide débris on both sides of Bald Mountain. Without doubt the greater part of the volcanic masses that have contributed to the slide material must have fallen from the face of the cliffs before these small glaciers sculptured the basins in which they formed. Again, the lateral moraine of the larger glacier that moved down the valley of the Lake Fork of the San Miguel River appears in places to have been deposited on top of the outer margin of the slide. Elsewhere the reverse is true, and it is evident that slide débris has moved down onto glacial gravel. Apparently the original fall of the large masses of volcanic agglomerate and lava antedated the Wisconsin glaciation, but since the deposition of the Wisconsin till, and, indeed, continuing down to the present day, minor movements of the disintegrating fragments of these earlier falls have caused downward slumping on a comparatively small scale. The whole mass of slide débris may be considered to be in unstable equilibrium and subject to minor and relatively quiet movement toward lower positions on the surface of the slippery shale.

The experience recorded by Cross [79] as having occurred during the sinking of the shaft at the Currency mine, located on the slide near its southern extremity, is suggestive of what is probably going on generally throughout the mass:

Tunnels running nearly parallel to the general slope of the country in the vicinity exhibit a crushing of the timbers, especially on the upper or mountain side. The Currency shaft could not be kept vertical, the bottom moving down the slope and with a twist indicating some undulation in the shale surface upon which the sliding mass rests. A short distance from the Currency shaft a prospect tunnel in broken-up San Juan material was run into an older tunnel whose timbers were all crushed together, the entrance to this old working having been obliterated by recent sliding.

Yellow Mountain.—The landslide on Yellow Mountain is described by Howe [80] as follows:

Another landslide, covering an area of about 3 square miles, took place on the southwest face of Yellow Mountain, just east of Trout Lake. It is believed that the lake owes its origin to a dam of slide material at its lower end, now almost completely eroded away. This landslide, whose general characteristics are essentially the same as those of the Silver Mountain slip, presents to-day abundant evidence of its origin. As in the case of the Silver Mountain slide, the bedded volcanics rested on Mancos shale, which gave way under their superincumbent load, permitting a large block of the volcanics to slip about 1,000 feet vertically below their former position.

A noteworthy feature of this landslide is that a very large part, if not all, of the fallen material slipped at one time, and the present accumulation is not the result of component slips; the mass was naturally much fractured but was not broken up into many small blocks.

There appear to be two fairly distinct parts of this landslide area. The upper part is made up entirely of the Potosi volcanic series, and in all the distinct outcrops the lamination dips toward the east or the northeast at various angles, in many places exceeding 30°. The apex of this somewhat pyramidal rhyolite mass is very near the crest of the main ridge from which the slide has occurred and which is made up of tufflike flow breccias at the very base of the Potosi volcanic series. * * * Fracture planes, marking lines of dislocation, traverse the mass in several directions. Below the line of rhyolite is a broken, wooded country with numerous knobs or huge blocks of San Juan tuff and other formations and occasionally one of rhyolite. The structure in these exposures is very vari-

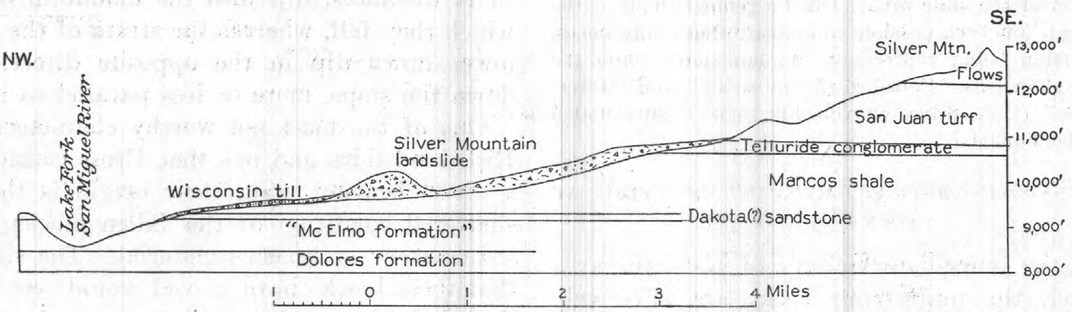


FIGURE 23.—Structure section of Silver Mountain landslide from summit of Silver Mountain to Lake Fork of San Miguel River, south of Turkey Creek

[79] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 11, 1899.

[80] Howe, Ernest, op. cit., pp. 19–20.

able, in no two being quite alike, and the conclusion is that they are not outcrops of rock in normal relation to the rhyolite above.

The second part of the landslide extends from the rhyolite down to Trout Lake. Its topography is very irregular. There are numerous hillocks and short ridges covered by aspens, with sink holes on the upper side of many of them, and the drainage winds intricately around among them. Large blocks of Telluride conglomerate are numerous, and surfaces of considerable extent show only débris of the formation, but still lower may be found areas equally characterized by the San Juan tuff. Some of the larger knolls have ledgelike outcrops, showing that either the San Juan or the Telluride is present in mass. * * * The breaking up or fracturing of the fallen material, either at the time of the fall or subsequent to it, appears to have been of varying intensity, depending on the character of the different formations involved and their relative positions with respect to one another. Thus the uppermost rhyolite, when compared with the underlying tuffs and Telluride conglomerate, suffered relatively little, although much fractured. The tuffs and conglomerates appear to have been very completely fractured, while the Mancos shale underlying them now has no recognizable structure and in fact forms a very small part of the slide area. On the geologic map of the Telluride folio it has been possible to indicate these differences, the lower portion being represented as landslide, while the upper part is shown as "Potosi rhyolitic series" and "Intermediate series" (i. e., Silverton volcanic series), surrounded by landslide boundaries.

LANDSLIDES INVOLVING BOTH SEDIMENTARY AND INTRUSIVE ROCKS

Rico.—In the immediate vicinity of Rico, the area within which the underlying rocks are effectively masked by a thick covering of detritus, most of which is of landslide character, probably exceeds that in which solid rock in place is exposed. According to Cross, "Much prospecting has been done in the Rico Mountains, and in many places the failure to recognize the purely superficial nature of the ground in which exploration was being carried on has resulted in the useless expenditure of time and money." A study of the landslides is therefore of prime economic importance. They have been described in detail by Cross[81] and Howe,[82] from whose reports the following statements are summarized or quoted.

Five large areas of slide débris are of special interest in this region. These are found in Horse Gulch on each side of Horse Creek, on the western face of Telescope Mountain, locally known as C. H. C. Hill, covering the entire southeastern extension of Expectation Mountain, on the east side of the East Dolores River north of Spruce Gulch, and on the southwest slope of Landslip Mountain. (See pl. 27.) In every slide the formations involved are the sandstone, shale, and limestone constituting the Hermosa, Rico, and Cutler formations, with monzonite and monzonite porphyry of the many sills and stocks that are intruded into these late Paleozoic sedimentary rocks.

Throughout the greater part of these five areas the topographic features are typical of fallen landslide material and consist of the usual blocks, trenches, and irregular mounds and heaps of débris of varying composition. In certain localities, as on the ridge between Burnett and Sulphur Creeks, there is illustrated an advanced stage in the history of landslide areas, when the ordinary agencies of degradation have nearly completed their work of effacing the scars caused by the successive slips, leaving little evidence in the smooth slopes of the confusion existing beneath.

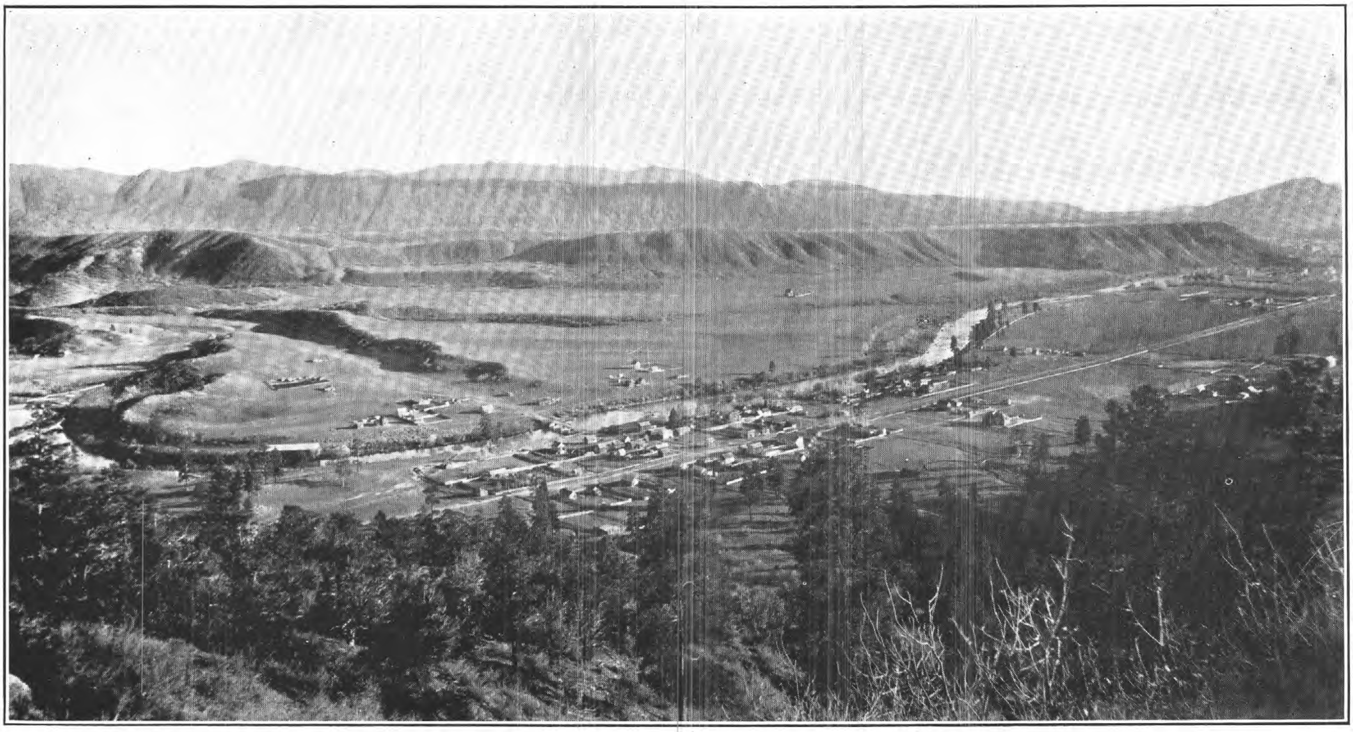
A feature characteristic of the Horse Gulch slide and of other landslide areas in this region is the attitude of the fallen blocks of massive sandstone or intrusive porphyry. The blocks at the head of the slide near the upper cliff, which appear to have fallen in relatively recent time and have moved comparatively short distances, dip into the mountain or cliff from which they fell, whereas the strata of the older blocks lower down dip in the opposite direction—that is, down the slope, more or less parallel to its direction.

One of the most noteworthy characteristics of the Rico landslides and one that Cross considers to have a direct bearing upon their origin is the extremely shattered condition of the fallen blocks, whether of sedimentary or igneous material. The short distance that these blocks have moved would seem to indicate that their shattered condition can not be attributed to their fall alone but must have existed before the landslide movement began, while the rocks were still in place. This is certainly so in the slides on Darling Ridge and the ridge between Sulphur and Burnett Creeks.

With the exception of a few minor outlying areas, all the landslides have occurred near the center of the Rico dome. The character of this domelike uplift, now thoroughly dissected, is clearly shown in the attitude of the sedimentary beds near Rico, where the dips range from 10° to 25°. In practically all the slides the fracturing and subsequent movement of the landslide blocks have been at sharp angles to, or across, the stratification planes of the sedimentary rocks rather than parallel to these planes—in other words, nearly all the slides have occurred near the center of the dissected dome and not on its flanks, the only noteworthy exception being the Landslip Mountain area.

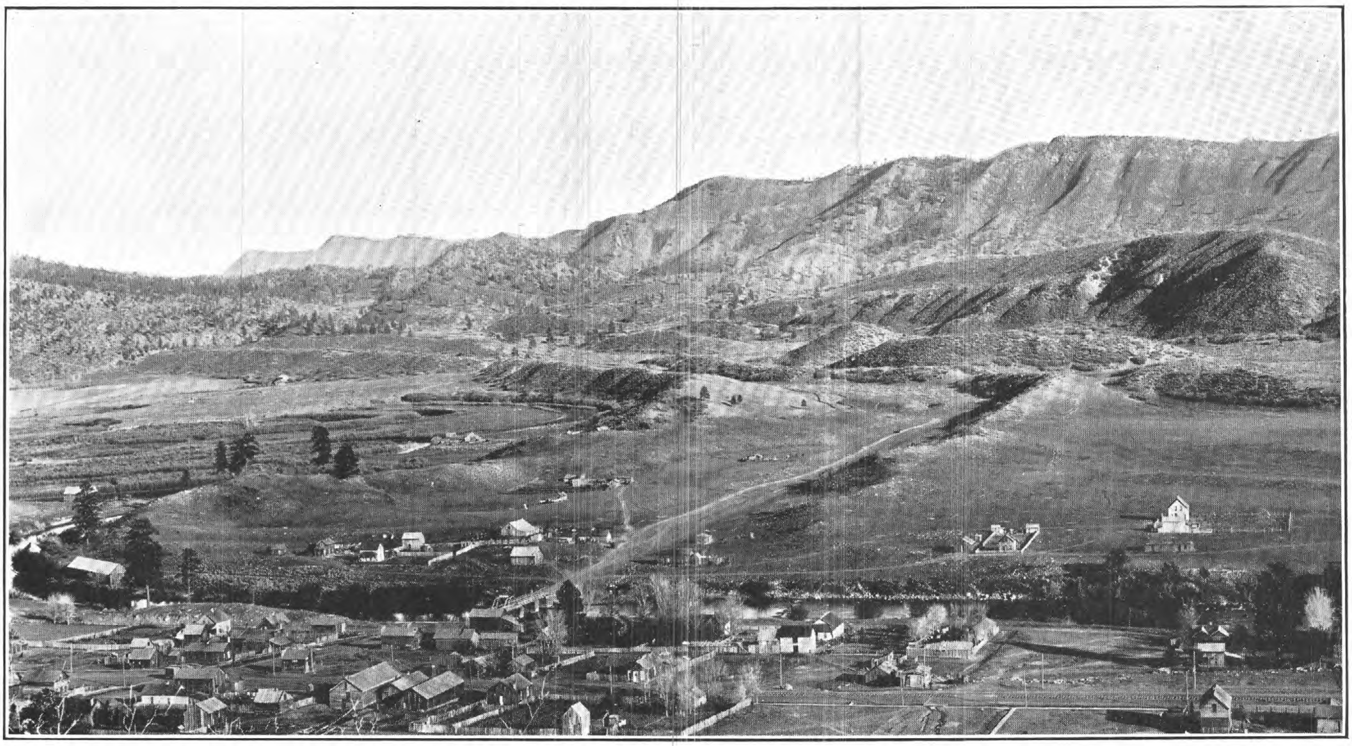
Dexter Creek.—In the general vicinity of Ouray there are a number of laccolithic or sill-like intrusions of quartz monzonite porphyry. Certain of these masses rest upon Mancos shale or other Cretaceous beds, as they are intruded into the very base of the bedded volcanic series. Where exposed along hillsides, these igneous bodies are very much more resistant

[81] Cross, Whitman, Geology of the Rico Mountains: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 129–151, 1900.
[82] Howe, Ernest, op. cit., pp. 21–25.



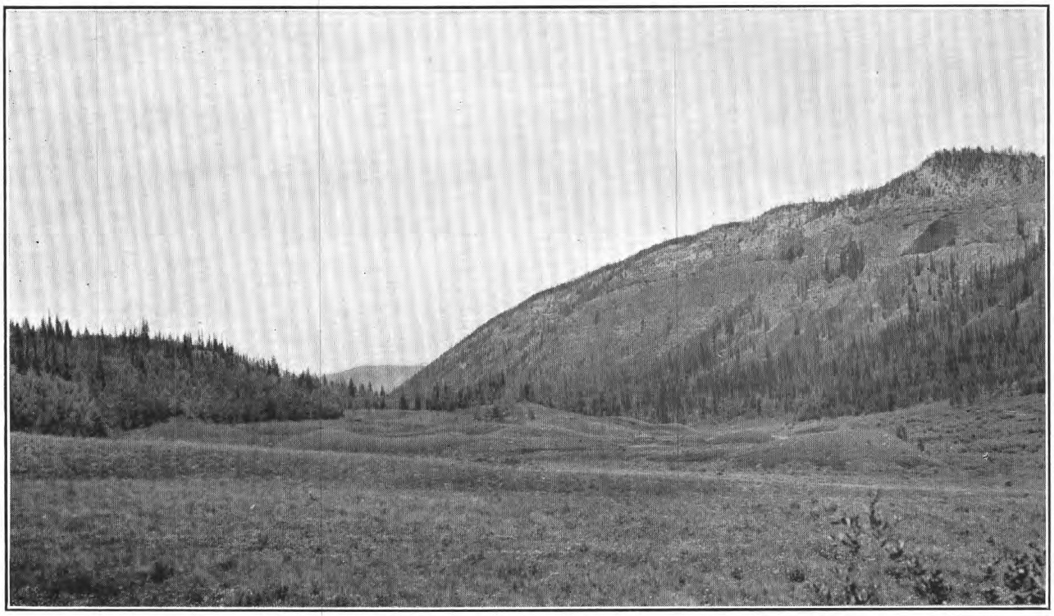
A. VALLEY OF ANIMAS RIVER NEAR ANIMAS CITY

View southeast over Animas City; Durango at right. Low ridges in left middle ground are terminal moraine of Wisconsin stage of Animas glacier; outwash terrace extends thence downstream to right. Above the bluff back of this are partly eroded terminal moraine and outwash terrace of Durango stage of glaciation. The valley between the high terrace and the low terrace was eroded to a depth of about 250 feet between the Durango and Wisconsin stages of glaciation. Photograph by Whitman Cross.



B. MORAINES IN THE ANIMAS VALLEY NEAR ANIMAS CITY

The low ridges crossing the bottom land are the terminal moraine of the Wisconsin stage of the Animas glacier. Downstream, to the right, is the outwash terrace. On the brushy ridge between this and the mountain in the right background is the terminal moraine of the Durango stage. Photograph by Whitman Cross.



A. TERMINAL MORAINE IN RIO GRANDE VALLEY

The low bouldery knolls in the middle ground are part of the terminal moraine formed at the east side of the canyon of Red Mountain Creek (or South River) by ice of the Wisconsin stage.

B. GLACIAL CIRQUE ABOVE OURAY

This small cirque was occupied by ice during the glacial epoch. The floor of the amphitheater is now mantled in part with glacial drift and in part with landslide débris.

LANDSLIP MOUNTAIN, RICO QUADRANGLE

This view was taken on the south face of the mountain as seen from the west. It shows clearly the topographic forms due to landslides. Photograph by Whitman Cross.

LANDSLIDES ON RED MOUNTAIN, SILVERTON QUADRANGLE

Showing topography developed by landslides. Some of the material may have been moved by a Pleistocene glacier, but most of it is local. Disintegration of the mountain mass has caused slumping at intervals, so that the mountain face has retreated. Photograph by Whitman Cross.

A. RECENT LANDSLIDE IN VALLEY OF WEST LOST TRAIL CREEK

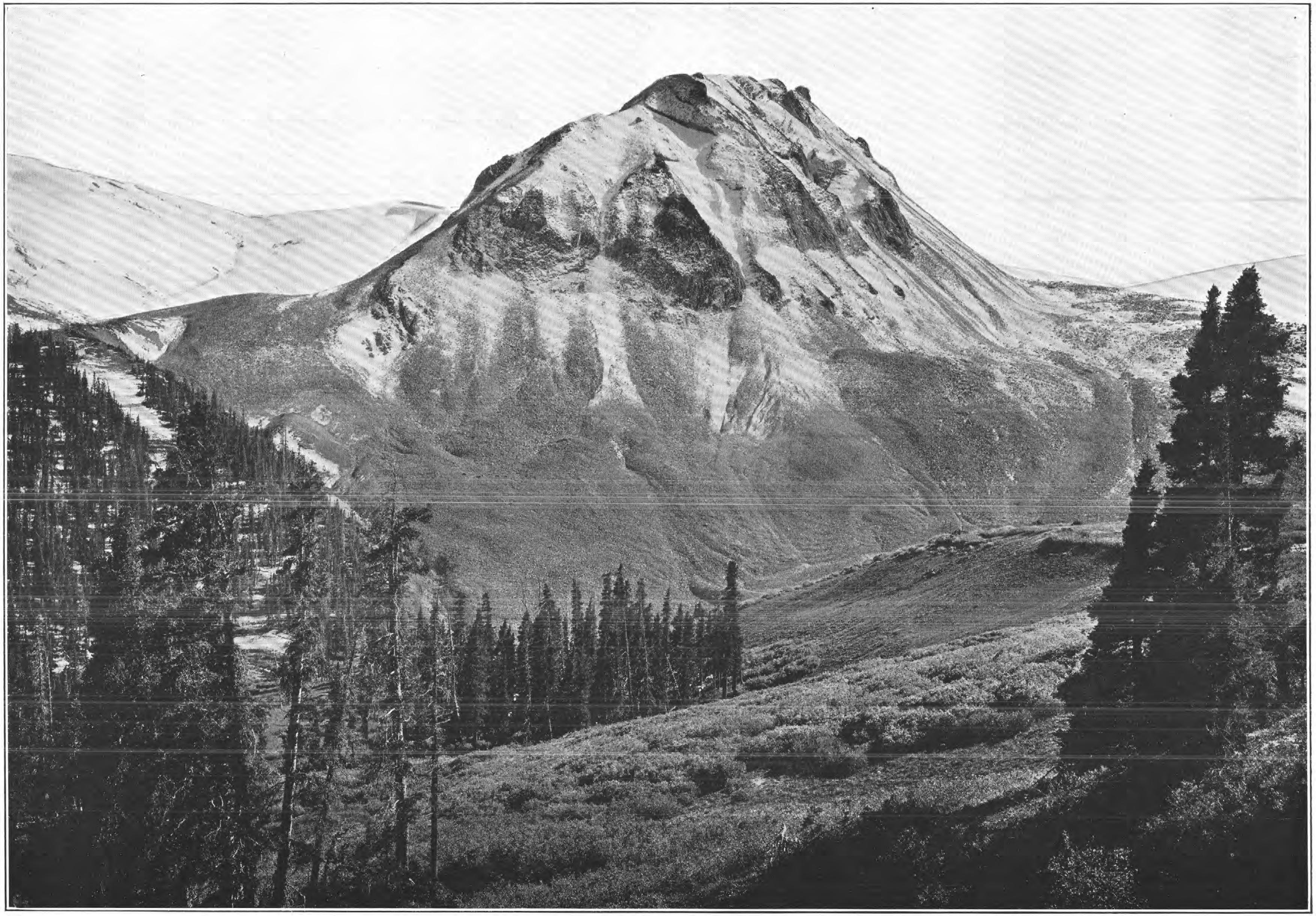
In the foreground is a fresh landslide, such as are numerous in the high basin region of the mountains. The fragments are angular, and the ridges roughly parallel the slope from which the débris slid. Such characteristics aid in distinguishing landslide débris from morainic deposits. Photograph by Whitman Cross.

B. ROCK STREAM IN HORSESHOE BASIN, SILVERTON QUADRANGLE

Horseshoe Basin is high above the tree line, where changes in temperature and frost action produce vast quantities of angular débris. Talus cones accumulate at the base of steep slopes, and in places, as here shown, the angular detritus moves slowly down the canyon as a great rock stream. Photograph by Whitman Cross.

ROCK STREAM IN SILVER BASIN

One of the most remarkable rock streams of the San Juan region, about 2 miles south of Sneffels, Silverton quadrangle. The margin of the huge mass of angular débris is abrupt. On its surface are concentric ridges resulting from the "fragmental flow" which has characterized the movement of the whole. Photograph by Whitman Cross.



TALUS SLOPES NEAR THE HEAD OF NORTH FORK OF HENSON CREEK, SILVERTON QUADRANGLE

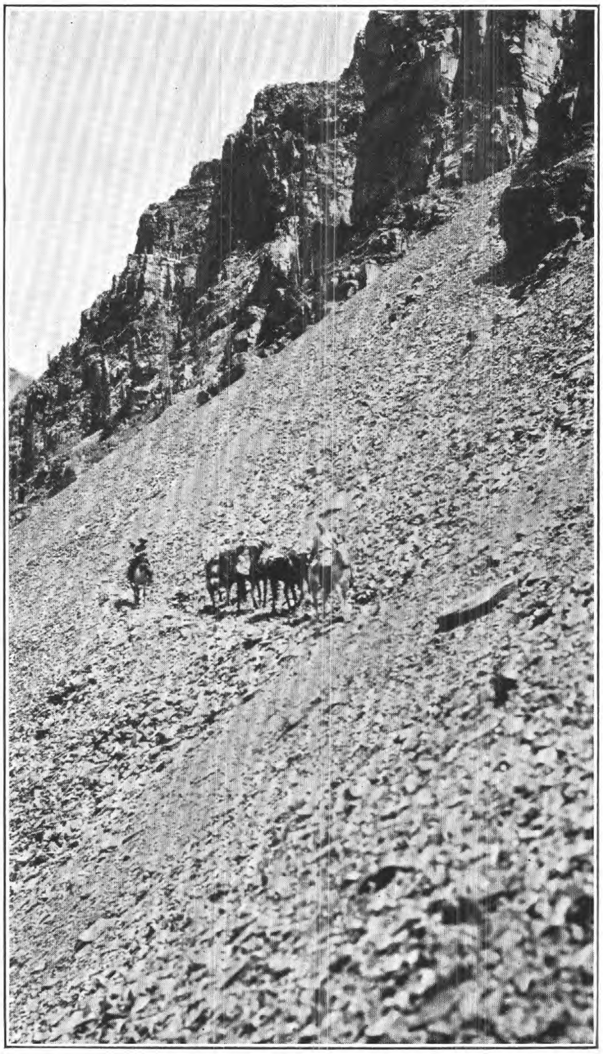
Great quantities of rock waste have accumulated upon the flanks of this mountain. As indicated by the flow lines in the middle distance, the angular débris has, in places, crept downward. Photograph by Whitman Cross

A. SLUMGULLION MUD FLOW, SAN CRISTOBAL QUADRANGLE

View eastward across Lake Fork Valley, showing great mud flow heading below edge of volcanic plateau on sky line 3 miles distant and 2,700 feet above San Cristobal Lake, in foreground. The flow dammed Lake Fork and impounded the lake. Delta at lower right formed by stream cutting the small gorge at south margin of the flow. Surface of flow very uneven. Overturned trees and recent scars in places indicate very recent movement. Photograph by Whitman Cross.

B. TORRENTIAL FANS IN ANIMAS VALLEY, SILVERTON QUADRANGLE

The two cone-shaped piles of débris that mantle the lower slopes of this valley wall have accumulated since the disappearance of the last glaciers from this valley. The apex of each of the two coalesced fans is at the lower end of a V-shaped gulch from which most of the fan débris has been removed by mountain torrents. Photograph by Whitman Cross.

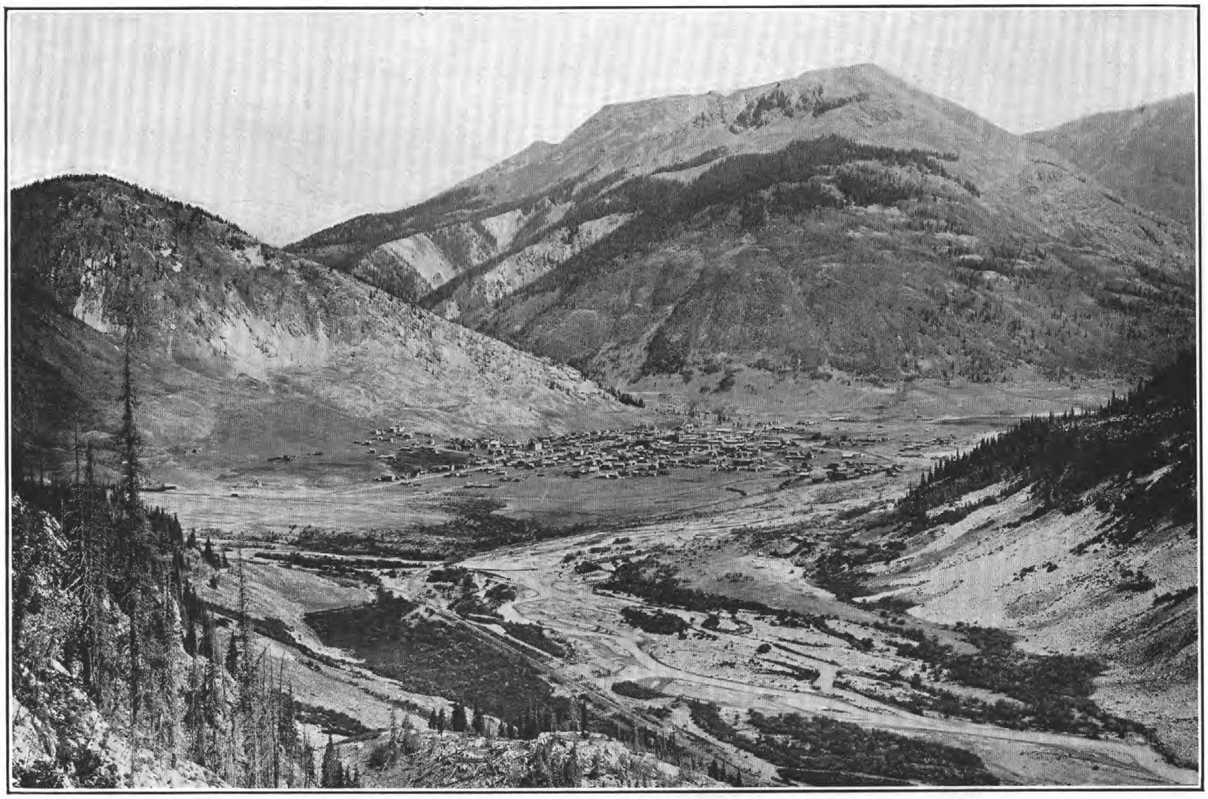


A. TALUS SLOPE, SAN JUAN MOUNTAINS

Steep slope on an accumulation of rock fragments fallen from cliffs above. Steepness of talus is determined by angle of rest of such sliding and rolling material.

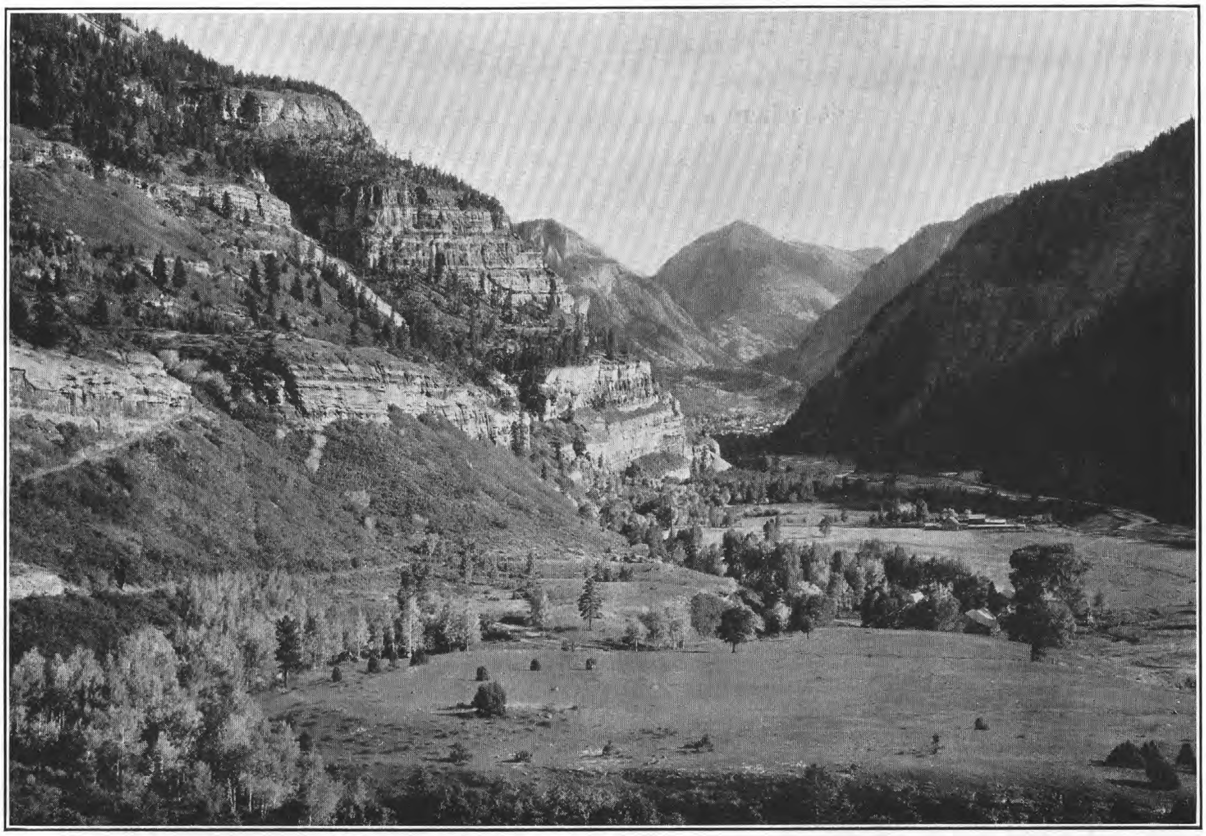
B. MATERIALS OF A TORRENTIAL FAN

Angular and subangular blocks and boulders as much as several feet in diameter are mixed with sand and clay, generally unsorted and unstratified, and in places might be mistaken for glacial till.



A. VALLEY OF ANIMAS RIVER AT SILVERTON

Silverton is in the center of one of the more active mining districts of the San Juan Mountains. Photograph by Whitman Cross.



B. UNCOMPAHGRE VALLEY

In the foreground are ranch lands such as extend far into the mountains. In the background is Ouray, at the entrance to the canyons through which roads and trails lead to mining camps.

to erosion than the underlying shale. Steep slopes are therefore favored, and many landslides have resulted from the incompetence of the shale to stand up under the load of overlying igneous rock.

Two such landslide areas have been mapped on the southern slope of the Dexter Creek Valley. Near the Bachelor mine the hillside has an extremely rough surface, is largely without soil, and is composed of great blocks of porphyry, usually much shattered. The downward movement has evidently been very slight and was accompanied by much shattering and straining of the porphyry, but only a small part of the rock was precipitated into the creek below.

Corbett Creek.—Similar structural conditions have caused the slides west of the Uncompahgre River on both sides of Corbett Creek, a few miles northwest of Ouray. A thick sill of massive porphyry or a thin laccolith rests upon Mancos shale and crops out along a valley side which has been greatly steepened by glacial erosion. As a consequence slipping has been both frequent and extensive.

Blackhawk Peak.—There are several small slides on the higher slopes of the eastern group of the Rico Mountains, of which Blackhawk Peak, in the western part of the Engineer Mountain quadrangle, is the most prominent. In most of these, according to Cross, the material that has fallen represents a ledge of intrusive porphyry inadequately supported by soft sedimentary rock of the Cutler formation.

Flattop.—A landslide of unusual character is present on the west slope of Flattop, near the northwest corner of the Engineer Mountain quadrangle, where a mass of soft Mancos shale with a small sill of intrusive porphyry has been dislocated. The débris has slipped in an irregular streamlike body down a steep gulch into the valley of Barlow Creek.

Hesperus Peak.—Several large masses of slide débris rest on the northwest slopes and in the adjacent valleys of the La Plata Mountains. One of the most conspicuous of these is between the two forks of the West Mancos River on the north slope of Hesperus Peak. According to Cross and Spencer, the sliding has taken place upon the Mancos shale. The materials that now lie in an irregular mixture upon the shale comprise the igneous rock of the intrusive body in the ridge above the Dakota (?) sandstone and fragments from the underlying Morrison and Summerville formations. This anomaly is explained by the great fault that crosses the landslide area. The eastern part of the area is characterized by almost complete lack of drainage, little ponds being formed by crescent-shaped dams. Here large blocks are of rare occurrence. To the west of this there is an area where the whole surface is covered by huge blocks of Dakota (?) sandstone in confused relation.

Sharkstooth Ridge.—The broad spur of the La Plata Mountains extending from Sharkstooth northwestward between the head of the West Mancos River and Bear Creek is modified by landslide débris which at three localities extends from points near its crest far down the slopes. The ridge is composed largely of Mancos shale defended by a backbone of flat-lying intruded porphyry, a remnant of a laccolith or thick sill. Numerous fragments of this intrusive rock have slipped downward upon the inclined surface of the soft, yielding shale.

The largest of these three areas of landslide débris, indicated on Plate 1, is also the oldest. Its topography is not nearly so irregular as that of the other two. Fairly long streams have established drainage channels across its surface. In general it has the same subdued appearance as the Silver Mountain landslide.

LANDSLIDES INVOLVING SEDIMENTARY STRATA AND SURFICIAL DETRITUS

Numerous landslides on the slopes of Horsefly Peak and the adjacent ridges and hills in the Montrose quadrangle are likewise due to the presence of Mancos shale near the foot of steep slopes. In these places, however, the resistant "rim rock" that causes the development of oversteepened cliffs antecedent to the rock falls is unconsolidated gravel and boulder clay, the till of the Cerro glacial stage. At several localities, such as Horsefly Peak, West Baldy, and South Baldy, the presence of uncommonly thick masses of Cerro till protected the underlying Mancos shale from erosion during the post-Cerro cycle. The stripping of the unprotected shale in intervening and surrounding areas left these bodies of Cerro till perched high on the summits and upper slopes of prominent ridges and hills. Oversteepening of the slopes has resulted in the slipping of the shale and till at many places.

The topography resulting from these movements is generally quite distinct from the softened morainal topography which in places has remained. The slides are characterized by numerous ridges, roughly parallel to one another and to the trend of the slope on which they occur. Between and above these ridges are ponds and marshes, some of which are represented on the topographic map. Instead of a knob and kettle topography like that of the undisturbed moraines, the topography of the slides is characterized by ridges and trenches.

Similar slumps of gravel and boulder caps may be observed east of the Uncompahgre River near the margins of the frayed remnants of Cerro till and Florida gravel, between the river and Cimarron Creek. Near the head of Beaton Creek, on the hillside south of Squaw Creek, and elsewhere these slumps attain dimensions great enough to warrant their representation on the maps.

LANDSLIDES INVOLVING BEDDED VOLCANIC ROCKS ONLY

Sheep Mountain.—The features of the landslide area on the southern slope of Sheep Mountain, in the southeast quarter of the Silverton quadrangle, are typical of numerous slides in the volcanic portion of the San Juan region.

Massive flows of latite of the Silverton and Potosi volcanic series rest at this point on the San Juan tuff, which is here not well consolidated. The massive flows above this weak foundation are jointed to an unusual degree, and simple conditions of instability appear to be the chief cause of the landslide action. The present topography is clearly the result of the slipping of many small blocks, and this process appears to be still in progress, for blocks may be observed on the point of splitting off from the still unhealed scar on the south face of Sheep Mountain.

The topography in the upper part of the area resembles closely that of a large kettle moraine, and the presence of considerable true morainal material adjoining the landslide area to the northwest caused not a little difficulty in the differentiation of these two formations. The landslide material may be distinguished by the sharp, angular character of its débris, which is strongly contrasted to the rounded or subangular appearance of the drift. The absence of latite of the Potosi volcanic series in the drift and the abundance of this material in the landslide débris is another distinguishing feature.[83]

Ironton Park.—Howe [84] gives the following description of the landslide in Ironton Park:

The landslide area of Ironton Park, in the northeastern part of the Silverton quadrangle, extends from Hendrick Gulch on the north to Gray Copper Gulch on the south, a distance of more than 2 miles, while from the level of Ironton Park upward for fully 2,000 feet the hillside surface is characterized by typical landslide topography. Material of landslide origin also covers a considerable portion of the hillsides west of Ironton Park, but its topographic expression is less pronounced.

From favorable points of view the hillside south of Hendrick Gulch presents one of the most typical landslide-covered slopes that has been observed in the San Juan region. Although mantled by a heavy growth of young aspen, the characteristic block and trench or ridge structure of the surface is well shown. One feature perhaps better exhibited here than anywhere else is the crowding together of the individual blocks near the lower part of the slope, causing a steeper inclination of the general surface of the slide area in its lower portion than exists nearer the crest of the ridge. The profile of the lower part of the ridge is roughly convex, while that of the upper portion is concave. * * *

The fallen material consists in part of San Juan tuff and of the massive flows and breccias of the Silverton volcanic series of andesites and latites; and on account of their similarity to one another or the extremely decomposed condition of certain parts of the Silverton volcanic series it becomes very difficult to tell how far blocks have slipped and from what points they were derived. Because of their unshattered and massive condition it is believed that individual blocks have moved comparatively short distances. The absence of a well-defined scar back of the landslide material seems to show that no very general movement has taken place and that the landslide débris, notwithstanding its characteristic topography, is of a decidedly superficial nature. This locality presents one of the best examples of a considerable area covered by the moderate slipping of many blocks, large and small.

Henson Creek.—In the extreme southeast corner of the Montrose quadrangle, south of the North Fork of Henson Creek, is a large landslide area that extends eastward into the Uncompahgre quadrangle. The ridge south of the stream consists of volcanic rocks, chiefly lava flows, of the Silverton series. These rocks have been greatly shattered, and nearly the whole slope for 2 or 3 miles is made up of landslide débris. Near the crest are some blocks several hundred feet in diameter, but on the lower slopes the detritus is much broken and in part covered by vegetation.

San Cristobal quadrangle.—Most of the slides that have been mapped in the San Cristobal quadrangle involve the movement of volcanic rocks only. As a rule the slipping has apparently been due to the undermining of fairly massive lava flows that were resting upon poorly consolidated tuff or agglomerate. The region is one of profound glacial erosion, with numerous steep-sided valleys whose walls have been sculptured by ice. At many localities along these oversteepened slopes the underlying pyroclastic formations were unable to bear their load of more massive flows and sheets. Landslides have therefore been of frequent occurrence, and their results may be observed in nearly every valley. A few of them will be described in detail.

Weminuche Pass.—Landslide materials completely cover the end of the great spur from the west between two large branches of the Los Pinos River a short distance south of Weminuche Pass. The débris was derived from the rugged cliff of Potosi latite and andesite that towers above the upper edge of the slide. All parts of the jumbled mass of broken rock display the peculiar topographic forms of landslide areas. The fallen débris dammed the Los Pinos River and caused the deposition of bedded gravel in the valley just below Weminuche Pass.[85]

Ragans Lake.—The basin of Ragans Lake, in House Canyon, near the center of the San Cristobal quadrangle, was the result of a large landslide that effectively dammed the canyon a short distance below its upper extremity. (See fig. 24.) The narrow divide to the south between House Canyon and Road Canyon is capped with a massive volcanic flow, which rests upon a soft volcanic tuff. Part of this divide slipped into the valley toward the north, leaving the broad gap in the otherwise smooth crest of the divide between

[83] Howe, Ernest, op. cit., p. 27.
[84] Idem, pp. 25–26.
[85] Cross, Whitman, manuscript notes.

these two canyons, and formed a broad dam across the canyon into which it fell. The massive lava was completely shattered as it fell, and many angular blocks are among the heaps of débris that fill the valley for nearly a mile east of the lake. Irregular mounds and ridges of débris trend east, parallel with the axis of the valley. All the débris appears to be of local origin.

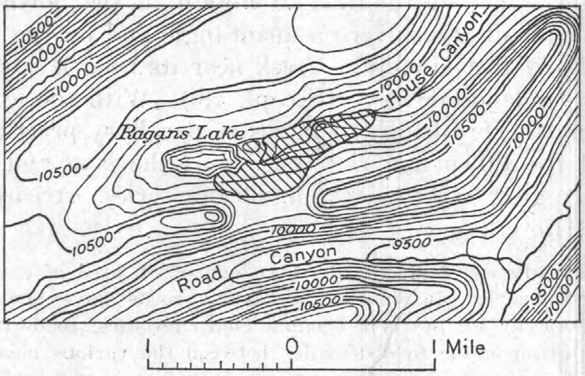


FIGURE 24.—Map of Ragans Lake landslide, San Cristobal quadrangle

Castle Rock.—Castle Rock, a prominent topographic feature near the head of Clear Creek, is a landslide block displaying rather unusual characteristics. It is composed of columnar lava resting upon an agglomerate that weathers rapidly and crumbles easily. The rock has moved outward over this unstable base about 130 feet as it slipped 30 or 40 feet downward. In moving some portions were broken and so disturbed that the structure lines stand at various angles in the loosened blocks.

Bristol Head.—Santa Maria Lake occupies a part of the floor of a narrow steep-sided rift valley near the east margin of the San Cristobal quadrangle. Toward the northeast the valley wall rises sheer to the summit of Bristol Head more than 3,000 feet above the lake. Vast quantities of volcanic débris have fallen from the cliff immediately below and toward the southeast from Bristol Head and have partly filled the troughlike depression. The landslide mass at this locality is fully a mile wide and 500 feet thick, extending for nearly 2 miles along the axis of the trough. It forms the south boundary of the lake and of the Santa Maria Reservoir,[86] constructed by the building of a dam across the northwest end of the rift valley. On the east and southeast the landslide débris is partly buried beneath more recent accumulations of torrential wash and stream alluvium. The cliff from which the slide material broke away is composed of interbedded lava and volcanic tuff.

Union Reservoir.—The valley of the Rio Grande throughout the central portion of the San Cristobal quadrangle is a steep-walled canyon cut about 1,000 feet deep into a series of volcanic tuffs, breccias, and flows capped by a single remarkably thick lava flow. At a point south of Long Park, on the north wall of this canyon, the underlying tuff proved incapable of supporting its overburden of bedded volcanic rocks. The landslide that resulted precipitated a huge mass of débris into the canyon, where it covered about a third of a square mile and temporarily blocked the course of the stream. While the river was carving a pathway for itself through the slide material the floor of the valley upstream from the slide was transformed by alluviation into a fertile meadow 7 miles in length.

The constriction in the stream valley at the lower end of this meadow was selected as the site for a dam, which was built from the rock wall on the south to the heap of débris forming the slide on the north. The water thus ponded submerges about two-thirds of the meadow and forms the Farmers' Union Reservoir.[87]

Blue Mesa.—The large landslide area on the northern slope of Blue Mesa, in the northwestern part of the Uncompahgre quadrangle, is typical of a score of slides that have occurred in close proximity to the Gunnison River between Iola and Delta. Blue Mesa is near the east end of the Black Canyon, and in this region the Tertiary volcanic rocks rest directly upon the pre-Cambrian complex exposed in the walls of the canyon. The general geologic conditions are indicated in Figure 25.

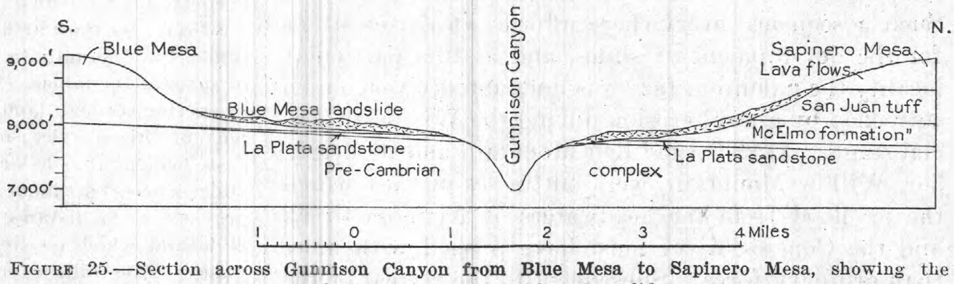


FIGURE 25.—Section across Gunnison Canyon from Blue Mesa to Sapinero Mesa, showing the relations of the Blue Mesa landslide

The bedded volcanic rocks consist of a loosely cemented agglomerate, the West Elk breccia, overlain by fairly massive lava flows of the Potosi series. Wherever the slopes are steep the agglomerate fails to support its overburden, and landslides on a large or small scale are the result. The Blue Mesa slide is one of the largest and covers more than 2 square miles.

Lake City.—A similar sequence of crumbling tuff or disintegrating agglomerate overlain by massive flows has resulted in many another landslide in the Uncom-

[86] Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colorado: U. S. Geol. Survey Bull. 685, pp. 23–26, 1919.

[87] Idem, pp. 18–20.

pahgre quadrangle. One of these temporarily blocked the course of the Lake Fork of the Gunnison River just below Lake City. The silt-covered flat that forms the site of the town is in part, at least, the result of alluviation caused by the dam of slide débris, through which the stream subsequently excavated a narrow channel.

Crystal Lake.—About 2½ miles northwest of Lake City is a large landslide mass covering more than 2 square miles surrounding Crystal Lake. Heaps of angular material, broken and fallen from the east face of Crystal Peak, lie in a most confused mass. Here also the presence of volcanic tuff beneath massive lava flows appears to have given ideal conditions for the breaking down of the mountain mass by gravity.

Red Mountain.—One of the numerous "Red Mountains" in the San Juan region is in the northwest quarter of the Conejos quadrangle, on the divide between the Alamosa and Conejos drainage systems. Its summit rises sheer for 400 feet above a large area of landslide débris that covers more than 2 square miles of upland immediately northwest of the mountain crest. The landslide topography has been considerably modified by stream erosion, although the slide is clearly of post-Wisconsin age. Road Camp Gulch is occupied by one of several streams that have developed youthful drainage channels upon the surface of the slide. There are, however, many knobs and irregular knolls separated by undrained depressions. At only a few localities, such as that near the southern extremity of the slide, do these features show notable parallelism with the cliff from which the débris has fallen. Red Mountain is composed of agglomerate and breccia overlain by massive lava flows. Such a sequence everywhere affords ideal conditions for the development of slides, and at this particular locality the mountain face was undoubtedly very much steepened by glacial erosion during the Wisconsin glacial stage. At that time Red Mountain and its neighbor, Willow Mountain, were buttresses against which the ice flood from the headwaters of Alamosa Creek and the Conejos River must have pushed with more than ordinary force. Subsequent to the retreat of the ice, possibly while snow fields still lingered on these higher summits, the water-soaked agglomerate and breccia yielded beneath the weight of the overlying rock, and the large landslide was the inevitable result.

Elk Creek, McIntyre Peak, and Neff Mountain.—Three small landslides at Elk Creek, McIntyre Peak, and Neff Mountain and other masses of fallen débris in the western part of the Conejos quadrangle are due to geologic conditions identical with those described in the preceding paragraph. Each is found on a slope that was oversteepened by glacial erosion during the Wisconsin stage. In each there are large masses of volcanic breccia and lava that have slumped downhill and now lie in a confused and irregular mass upon an incompetent foundation of volcanic agglomerate.

LANDSLIDES INVOLVING BEDDED AND INTRUSIVE VOLCANIC ROCKS ONLY

Red Mountain.—About 6 square miles on the northwest slopes of the Red Mountain in the northwest quarter of the Silverton quadrangle and on the west side of Red Mountain Creek near its head is covered by landslide débris. (See pl. 28.) With the exception of a few bodies of intrusive porphyry practically all the fallen material consists of the lava and tuff belonging to the Silverton volcanic series. According to Howe,[88]

The district is at the northern end of an area of extreme decomposition, in which the various rocks have now lost practically all of their original characteristics, rendering it quite impossible to distinguish between the various members of the Silverton volcanic series. It is not improbable that this decomposition of the rocks has been an important factor in the occurrence of the landslides, having sensibly reduced the cohesion and strength of the rocks involved.

Few landslide areas present greater topographic evidence of their origin than does the Red Mountain district. * * * The most interesting portion is that near the center of the area, north of the town of Red Mountain and surrounding the well-known Paymaster, Yankee Girl, and Guston mines. The material covering the area which lies between Red Mountain Creek and Gray Copper Gulch has come entirely from the western slopes of the three summits of Red Mountain and consists of decomposed and altered andesite and breccia of the Silverton volcanic series with not a little intrusive porphyry such as occurs at the summit of Red Mountain No. 3. In the southern part of the area the topography is more hummock than ridgelike, and at first sight the peculiar chaotic mingling of these mounds and hillocks suggests that the whole surface is covered by landslide débris. The amount of this material is, however, less than at first appears, for some of the mounds or hillocks are actually in place, as is shown by the deep workings of some of the mines. * * * Two instances of rock in place projecting through landslide material occur in the northeastern part of this district southwest of Corkscrew Gulch. * * * It is evident that a large part of the hillside consists of landslide débris, but about midway on the slope is a point which projects some distance above the general level of the landslide and which on close examination is found to be rock in place. This hill is encompassed by landslide material and stands out with its simple outline in striking contrast to the peculiar topography surrounding it. This, with the less conspicuous outcrops farther south in the vicinity of the mines, strongly indicates that in the time immediately preceding the landslide epoch the topography must have been more rugged than it is to-day; that the valley of Red Mountain Creek must have been steep and narrow, with many spurs and sharp ridges between the tributary ravines; and that the present gentler slopes were formed both by the downfall of the higher points and by the filling in of the lower portions of the valley by landslides. A few spurs or ridges, which for some reason escaped destruction, remain, but otherwise obliteration of the details of the old topography was almost complete.

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[88] Howe, Ernest, op. cit., pp. 26–27.

The lithologic character of the fallen material also indicates a complex origin—that is, certain blocks of intrusive porphyry have clearly come from near the summit of Red Mountain No. 3, as has also much of the extremely altered rock of the Silverton volcanic series—but adjacent to such masses are blocks of comparatively fresh andesite that are believed to have been derived from some of the projecting ridges referred to, farther from the seat of decomposition. The shattered condition of most of this fallen material is the only means of distinguishing certainly the landslide hillocks from those of the projecting rock in place, which is not shattered but considerably decomposed.

The most important points to be noted in connection with this Red Mountain district are the extremely superficial character of the landslide action, notwithstanding the wide area covered by the fallen débris, the fact that the present topography is due to innumerable small slips, and the fact that the slipping appears to have been dependent upon two factors—the decomposed and unconsolidated nature of the rocks and the probably bold topography which existed previous to the falling. In this connection, however, it should be pointed out that at a good many other localities in this region precisely similar causal conditions now exist, and yet no landsliding has taken place—a fact which also held true in the Rico district.

Los Mogotes.—The upland north of the Conejos River, which slopes in all directions from Los Mogotes, the two volcanic cones in sec. 26, T. 33 N., R. 7 E., in the southeast quarter of the Conejos quadrangle, is composed of Los Pinos gravel with several sheets of basalt interstratified among the upper beds and is capped with a thick sheet of basalt. On the south this upland is bounded by a steep slope that drops precipitously for nearly 1,000 feet to the floor of the Conejos Canyon. Near Broils Bridge the lower part of this precipice is concealed by a landslide mass of unusual interest. The fallen débris occupies an area about a mile in length from east to west and less than a quarter of a mile in width and fills the angle between the escarpment and the valley flat. Apparently a huge ledge of basalt has slipped bodily downward as the gravel and sand on which it rested yielded beneath its weight. At first glance the observer from a distance is likely to infer that this ledge is the outcrop of a basalt sheet intercalated near the base of the Los Pinos gravel, but careful examination shows that it is a section of the higher sheets which has here slipped down without notable shattering or tilting.

Brazos Canyon.—Similar stratigraphic conditions—lava sheets interbedded with gravel and sands—have produced a landslide of very dissimilar appearance that is one of the notable features of the Brazos Canyon, approximately at the center of the area shown on the Rio Brazos Canyon map. The gravel and lava sheets at this locality are a part of the Conejos rather than the Los Pinos formation, but their composition and topographic expression are much the same. The slide on the north side of the canyon at the locality just noted is a huge fan-shaped mass of very much broken and extremely confused débris covering a part of the canyon wall from an altitude of about 10,000 feet almost to the stream bed, more than 1,500 feet below. Its surface is marked by many ledges and hollows, some of which have a rough alinement, giving a suggestion of loops that are convex downward and outward not unlike those on the surface of rock streams. The materials involved are entirely the bedded sand, gravel, and lava sheets of the Conejos formation. The oversteepening that presumably was an important factor in causing the slide was due to the rapid deepening of the Brazos Canyon by stream erosion. Both upstream and downstream from the landslide the canyon walls are in large part composed of pre-Cambrian quartzite, schist, and gneiss, which are eminently adapted for holding up steep cliffs, but just at this locality the irregular floor beneath the Conejos formation is much lower than elsewhere, and the gravel is found in place almost at the bottom of the canyon. These unconsolidated beds could not stand with a sheer face 1,500 feet in height, and the landslide was the natural result.

Similar conditions have caused the smaller but similar landslide on the south side of the canyon at this same locality. Here the pre-Cambrian rocks are higher than at the north, and in consequence the slide is for the most part perched high on the canyon wall above the pre-Cambrian complex and beneath the rim rock formed by the andesite flow from which much of the coarser débris of the slide has evidently fallen.

LANDSLIDES INVOLVING PRE-CAMBRIAN ROCKS ONLY

Elk Creek.—On the broad floor of Elk Creek, in the north-central part of the Needle Mountains quadrangle, a great heap of rock débris three-quarters of a mile in length extends nearly from one side of the valley to the other at a point about 3 miles east of Elk Park. The surface of the slide material is hummocky and crevassed, and a steep slope nearly 75 feet high bounds it on all sides. Similar loosened and disturbed detritus covers the lower 1,000 feet of the south valley wall.

The rocks of this area are a part of the Uncompahgre formation, a pre-Cambrian metamorphic series of quartzite and slate. At this particular locality these rocks are much jointed and faulted. Well-developed planes of cleavage lying at high angles have facilitated the slipping of enormous masses of rock from the cliff face to the valley below.[89]

Emerald Lakes.—The basin containing the Emerald Lakes, in the southwest corner of the San Cristobal quadrangle, was caused by a landslide that blocked the canyon of the Lake Fork of the Los Pinos River at that locality. The slide débris is a jumble of huge granite blocks and evidently came from the granite

[89] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), p. 7, 1905.

slope on the east side of the valley. It contains no quartzite, the rock that forms the cliffs towering above it on the west, nor does it include rocks from the Uncompahgre formation and Irving greenstone, which occur in the Lake Fork Canyon above the Emerald Lakes. A smaller slide of granite occurs somewhat below the larger one, and the two are now separated by wash material, most of which has come from the east side of the larger landslide.[90]

In all probability these slides in the Lake Fork Canyon are an effect of glacial erosion. Ice action was very vigorous in this narrow trough, leading away from one of the few broad uplands in the San Juan Mountains that seem to have been occupied during Wisconsin time by an ice cap. Not only was the canyon deepened but its walls were greatly steepened, so that the equilibrium of even so staunch a cliff maker as the massive granite of the pre-Cambrian terrane was destroyed. Joint planes and other fractured zones doubtless contributed to the instability of the rock wall.

FACTORS CONTROLLING LANDSLIDES IN THE SAN JUAN REGION

It is apparent from the foregoing descriptions of the landslides that have been observed in the San Juan Mountains that the greater number of them occurred at localities where hard, massive beds resting upon soft, yielding beds were exposed in fairly steep slopes. As pointed out by Howe,[91] none of the soft or incompetent formations have figured so prominently in landslide action as the Mancos formation, a soft, friable clay shale aggregating about 1,200 feet in thickness. Wherever it is exposed beneath comparatively resistant rock slides are commonly found, even though the slopes down which the slides have moved may be fairly gentle. Among the massive strata that have participated in such landslides, the bedded volcanic rocks are the most common. The entire zone in which tuffs and lava sheets rest upon Mancos shale on both the northern and southern slopes of the mountain range is characterized by numerous and extensive slides. Intrusive sills or laccoliths suffer the same fate when exposed to similar conditions, as, indeed, do other sedimentary beds and even surficial accumulations of gravel and boulders.

Second in volume of materials moved are the landslides in which relatively soft or partly consolidated tuff or volcanic agglomerate has failed to support an overburden of massive lava. This condition, it will be noted, is the most common, though by no means universal, at localities where slides have involved volcanic rocks only. The San Juan tuff has served as the incompetent foundation in many of the slides that have been described.

Probably the third class in quantitative importance is the group in which shale of some other sedimentary formation than the Mancos has given way and permitted the overlying strata to fall. In this class the shaly or sandy beds near the base of the Hermosa formation and the shale of the Morrison and Summerville formations are especially noteworthy.

Howe[92] says:

> Other conditions of physical weakness that have played important parts in the occurrence of landslides in regions of both volcanic and sedimentary rocks are those of an extensive primary jointing and secondary shattering. Of the jointing the best examples are to be found in the trachyte sheets of Engineer Mountain. In the Rico landslide district the shattered condition of the rocks is particularly noteworthy, as was pointed out by Cross in his discussion of the landslide phenomena of that district. Cross considers that this shattering has been the most important internal cause of the Rico landslides and emphasizes the fact that the shattering is independent of the lithological character and structural attitude of the formations involved, and that there is nothing in either of these conditions especially favorable to landslides. In fact, as was pointed out in the description of the landslides, the attitude of the beds is that of structural strength rather than weakness at points where slips have occurred. Similar conditions are believed to have existed, though in a less marked degree, in the Red Mountain district. In this area volcanic rocks alone have been involved in the landslides, and the influence of hard and soft layers may be practically eliminated from the discussion of the causal conditions of these landslides. It is, however, a region of pronounced fracturing, as shown in the numerous fissure veins, and is near a center of marked decomposition in which all the rocks of the Silverton volcanic series have been involved. In this area the rocks can hardly be described as shattered, but they are traversed by an extremely intricate system of joints, a condition clearly shown when one attempts to trim a small hand specimen, a light blow being sufficient to cause a small block to break into innumerable angular fragments bounded by joint planes intersecting at all angles. Although decomposition of the rocks has doubtless played a part in the Red Mountain landslides, this internal cause of landslide action can not be regarded as important.

Larger structural relations have played an almost negligible part in the San Juan landslides. Only two of the larger slides seem to have taken place by movement along bedding planes in the direction of dip. These two are the Elk Creek and Cow Creek landslides, in both of which the disturbed strata dip in the direction of the valley, suggesting that the attitude of the beds is probably the main cause of the surficial movement.

In certain of the localities mentioned above prominent fault systems have doubtless had something to do with landslide action, either directly by affording convenient planes of cleavage or of slipping, or indirectly by their influence upon the topography or stratigraphic

[90] Cross, Whitman, manuscript notes.

[91] Howe, Ernest, op. cit., pp. 44–49.

[92] Howe, Ernest, op. cit., p. 45.

succession, but these can have been of significance in only a few places. As pointed out by Cross in his discussion of the cause of landslides in the Rico district, some of the regions of most intense faulting are almost free from slide phenomena, and many of the most pronounced and extensive landslides are remote from faults of any consequence.

One of the most influential of the conditions governing the landslide phenomena of the San Juan region is, of course, the topography of the locality where the slide occurs. Like most of the other ranges of the North American Cordillera, the San Juan Mountains are characterized by bold and rugged slopes. Rapid erosion by swift streams with high gradients has been ably assisted by glaciation in the task of oversteepening valley slopes and mountain fronts. This condition of oversteepness must have existed generally throughout the San Juan Mountains, both in the area affected by recent glaciation and in the area that was beyond the reach of the Wisconsin ice. It is conceivable that the steep cliffs that made possible the rock falls at certain localities were developed by ice action during one of the earlier glacial episodes, but on the whole it is probable that normal stream erosion and atmospheric weathering have played a far larger part in forming topographic features conducive to landslides than glaciation in spite of its repeated occurrence.

Many sheer cliffs or steep slopes were carved in rocks possessing sufficient stability to resist the forces that elsewhere under similar topographic conditions have caused enormous masses of stone to fall from insecure positions to the valley below. The influence of topography upon landslides is necessarily of very great importance, but it is only one of several contributory causes. At many localities it is far outweighed by the other factors concerned.

Among the other causes contributory or conducive to landslide action, which are referred to by Howe [93] as "external causes," are two of probably great importance. These are the saturation of the ground by meteoric waters and the influence of earthquake shocks.

Precipitation upon the higher slopes of the San Juan Mountains is very heavy. During the summer the almost daily rains combine with the constant flow of water from the melting snow fields to keep the hillsides and uplands continually saturated. The porous or shattered condition of the volcanic rocks at many localities has favored the seepage of large quantities of moisture into the underlying shale. Not only does the large amount of ground water add to the weight of overburden upon the shale but at the same time it renders the shale less capable of supporting its overburden. Gliding planes are lubricated, and rocks otherwise quite rigid become of semifluid consistency. Especially in the landslides within the central portion or on the higher slopes of the range the influence of ground water has doubtless been very marked.

Earthquake shocks, whether the result of volcanic activity or, as is more probable, the external manifestation of internal adjustments to strains concomitant upon renewed mountain growth or continued erosion, have doubtless been the final cause that set in motion certain of the landslide masses. Minor earthquake shocks have been felt from time to time in the San Juan region, and a few have been sufficiently noteworthy to be recorded in the literature of the subject. It is, however, unlikely that such shocks have really been an important factor among the causes of landslides in this region. With rare exceptions earthquake vibrations have merely jarred loose and started into motion earth or rock masses that would sooner or later have slipped from their places without the added impetus of the earthquake shock, because of continued operation of the other and more essential conditions contributory to landslide development.

AGE OF THE SAN JUAN LANDSLIDES

Attention has been directed in certain of the foregoing descriptions to evidence indicative of the considerable antiquity of landslide development and in certain other descriptions to the appearance of extreme recency of the movement of débris. The first of the many falls of rock to form the great landslide mass of the Silver Mountain area must have preceded the Wisconsin glaciation of that area, and hence that slide, at least, must date in part from Pleistocene time. On the other hand, much of the movement of material in that same landslide must be postglacial, and in certain places movement is still continuing at the present time. The many slides that have been mapped in mountain valleys that have been scraped clean and sculptured by glaciers of the Wisconsin stage are obviously of Recent age. Certain slides, such as the small area in sec. 32, T. 37 N., R. 7 W., in the Florida Valley, are so recent as to be marked by a growth of young timber, in sharp contrast to the older forest growth of the surrounding lands.

The study and comparison of the hundreds of landslides that have been observed in the San Juan region makes it apparent that there was no one epoch of landslide activity to which they may all be referred. The landslide processes have been continually in operation during Pleistocene and Recent time. Most of the slides that may now be observed have occurred since the Wisconsin glaciation and are therefore of Recent age. Many of them probably took place immediately after the withdrawal of the ice, but even these are far from contemporaneous.

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[93] Howe, Ernest, op. cit., p. 46.

ROCK STREAMS

Enormous masses of rock débris are present in many of the glacial cirques or rest on the higher slopes of certain mountain peaks and ridges in the San Juan Mountains. (See pl. 29, *A*.) Although partaking of the nature of landslides, they must be considered in a separate category, because of the unusual features which they display. The material of which they are composed closely resembles ordinary talus. Sharply angular and little-weathered blocks of volcanic or granitic rocks, ranging in size from blocks 15 feet or more in length down to fine sand particles, are mixed together in a haphazard manner just as in the accumulations of talus at the foot of a steep slope. But, as shown in Plate 29, *B*, these heaps of débris display a form quite unlike that of the steeply and evenly sloping piles of detritus at the base of cliffs. When seen from some high vantage point they appear like small glaciers, stretching outward and downward from the foot of the cliff. Or if they have a billowy surface, as many of them do, they may closely simulate a short, broad tongue of viscous lava flowing from a volcanic vent across the floor of a crater. To such masses the appropriate name rock streams has been applied by Howe,[94] who has made a careful and critical study of many of them.

About 100 rock streams are present in the San Juan region, nearly all of them in that portion of the mountains covered by Howe's field studies. The few that have been observed in other parts of the range present no other noteworthy features. We have therefore little to add to Howe's excellent treatise upon this subject.

DISTRIBUTION

Silverton quadrangle.—More than 30 rock streams have been mapped in the Silverton quadrangle. Most of these have been described by Cross and Howe in the Silverton folio, and in greater detail by Howe in the professional paper above cited. The rock stream in Pierson Basin, in the northwest corner of the quadrangle, may be taken as typical of this Quaternary formation. It consists of broken rock fragments distributed in a tongue-shaped mass, occupying the greater part of the floor of a glacial cirque. It is more than three-quarters of a mile long and averages about one-third of a mile in width. The surface is characterized by innumerable rounded mounds or hummocks sharply separated from one another. Near its margin these mounds are roughly arranged in irregular lines, approximately parallel to the end and sides of the stream. The material composing this stream was derived from the impressive cliff at the south end of the basin. The lateral ridges of the cirque seem to have contributed nothing to the pile of detritus.

In the neighboring cirque toward the west, known as Silver Basin, there are three smaller rock streams, the largest of which is reminiscent of a ropy lava flow. The character of this rock stream in the head of the Silver Basin is shown in Plate 30.

Another of the interesting rock streams in the Silverton quadrangle is that in Imogene Basin, near the Camp Bird mine. It is noteworthy because of its smooth surface and sharp boundaries. It is also on a more steeply sloping surface than those just described, and this doubtless explains the unusually great length in proportion to its width.

All the rock streams in the Silverton quadrangle (pl. 31) are situated either in glacial cirques or on slopes that have been oversteepened by the glaciers of the Wisconsin glacial stage. All of them involve detritus of volcanic rocks of either intrusive or extrusive origin.

Telluride quadrangle.—There are about a dozen small rock streams in the Telluride quadrangle. Most of these are in the glacial basins of the San Juan Mountains proper, but some are found in similar geographic relations beneath the higher peaks and ridges of the Mount Wilson group near the west margin of the quadrangle. In all important respects these rock streams are identical with those of the Silverton quadrangle.

Montrose quadrangle.—Several characteristic rock streams are present on the northern slopes of the San Juan Mountains in the southernmost portion of the Montrose quadrangle. Those in the basin northeast of Sneffels Peak and on the west slopes of Wetterhorn Peak are typical. All the rock streams in this quadrangle are on recently glaciated slopes and involve the fracturing of Tertiary volcanic materials.

Engineer Mountain quadrangle.—About a score of rock streams have been mapped in the north half of the Engineer Mountain quadrangle. Some of these are in the Rico Mountains, near the west margin of the quadrangle, and others are in the outlying basins of the San Juan Mountains in the northeastern part of the area. The rock stream on the slopes of Engineer Mountain is especially noteworthy because of its large dimensions. It and other streams in its vicinity have been described by Cross in the Engineer Mountain folio and by Howe in the professional paper previously cited. Engineer Mountain is composed of an intrusive sill of quartz trachyte resting upon a base of Carboniferous sandstone and shale. The material of the rock stream is derived almost entirely from the strongly jointed volcanic rock. The detritus on the slopes of the mountain is confined almost exclusively to the northern and western slopes. It is significant that the sill of igneous rock is inclined several degrees toward

[94] Howe, Ernest, op. cit., pp. 31–40, 49–54, 1909.

the northwest. Thus the structural conditions have assisted greatly in producing the débris of which the rock streams are composed.

Intrusive trachyte of the same sort composes Sliderock Range and Graysill Mountain. Numerous small rock streams composed of fragments from this sill are present on all slopes of these two ridges. Some of these smaller rock streams are on slopes that have not been sculptured by the Wisconsin ice. In such places the development of the steep cliff overlooking a gentler slope, which seems essential to the formation of a rock stream, is the result of marked differences in resistance to erosion displayed by the intrusive rock and the Carboniferous sedimentary rocks that underlie the sill.

A number of small rock streams surround Hermosa Mountain, and here also the materials involved are fragments derived from the breaking down of intrusive volcanic rocks. The slopes of Hermosa Mountain were not affected by glaciation during the Wisconsin glacial stage but were presumably steepened by ice action during the Durango stage.

Needle Mountains quadrangle.—The Needle Mountains quadrangle is an area of extremely rugged mountains with numerous glacial cirques, the precipitous rims of which rise abruptly from the basin floors. The topographic conditions in general are similar to those in the Silverton quadrangle, to the north, but rock streams are extremely rare in these basins. Three small rock streams have been mapped in basins on the slopes of Snowdon Peak and one near Aztec Mountain, but no other accumulations of rock débris of sufficient dimensions to be indicated on the map are present here. The detritus in the basins near Snowdon Peak is derived from the fracturing and weathering of pre-Cambrian quartzite and slate; that near Aztec Mountain is the result of the disintegration of granite. In respect to composition, therefore, the rock streams of the Needle Mountains are in striking contrast to those found elsewhere in the range.

San Cristobal quadrangle.—The comparative scarcity of rock streams in areas devoid of intrusive rocks is emphasized by the distribution of rock streams in the San Cristobal quadrangle. North of the Rio Grande in the northwest quarter of the quadrangle the strongly glaciated mountains are composed of volcanic masses identical with those in the adjacent Silverton quadrangle. Here a number of small rock streams have been mapped. The mountains south of the Rio Grande in the southwest quarter of the quadrangle are equally rugged and present even more strikingly sculptured rock basins, but these mountains are composed of pre-Cambrian granitic and metamorphic rocks, and only one rock stream, and that a very tiny one, has been observed there.

Farther east, where intrusive rocks again make up the massif of the San Juan Mountains, rock streams of small dimensions are present here and there. On the slopes of Piedra Peak, for example, there are three such masses of detritus.

ORIGIN

Rock streams are believed to be landslides of a special character. In them the falling rock mass has been completely broken into débris, which has acquired a momentum sufficient to transform it into a rapidly flowing body. Thus the rock fragments have descended in streamlike form far beyond the normal limit of a landslide. Rock streams are unique among landslides because of the materials of which they are composed and the conditions of rock disintegration which have permitted the rapid fragmentation of tremendous rock masses, rather than because of differences in the causal forces involved in the slide. Nearly all the rock streams of the San Juan area are composed of detritus derived from intrusive rocks or lava sheets. These rocks are extensively jointed and have been carved into steep cliffs or projecting spurs by glacial erosion, so that from time to time huge masses have fallen and, breaking into relatively small fragments, have formed a mass of débris which has moved as a stream far down the slope.

AGE

With few exceptions the rock streams of the San Juan Mountains are very obviously of postglacial age. Most of them are found in glacial cirques that have been vacated by the ice at a comparatively recent geologic date. The few exceptions to this rule are composed of fragmented débris so slightly decomposed by weathering that there can be no doubt of its similar recent date.

MUD FLOWS

Still another type of landslide has been observed in the San Juan Mountains which is sufficiently distinct from the ordinary fallen débris to merit special description. To this type of landslide the name mud flow has been frequently applied. The name is significant because it implies what seem to be the facts—that the motion has been a flowing rather than a sliding of surficial débris, and that the material was in a finely disintegrated state and saturated with moisture at the time of movement.

Slumgullion mud flow.—The remarkable mud flow that forms the dam across the Lake Fork of the Gunnison River at the north end of Lake San Cristobal, in the San Cristobal quadrangle, was observed and described by Endlich.[95] It was also described by Howe,[96] on the basis of data supplied by Cross. The essential features of this flow are clearly brought out by

[95] Endlich, F. M., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 203, 1876.

[96] Howe, Ernest, op. cit., pp. 40–41.

Plate 32, *A*, reproduced from a photograph by Cross. As shown on Plate 1, the flow starts at the base of a cliff at an altitude of about 11,500 feet on the south face of a ridge that forms the divide between the Lake Fork and Mill Creek, near the southern boundary of the Uncompahgre quadrangle. The ridge is formed of volcanic rocks in nearly horizontal position. These consist of alternating beds of tuff and flows of rhyolite and latite, which at this place have been extensively decomposed by solfataric agencies. Apparently, this alteration had been especially thorough beneath several massive latite flows that form the upper 200 to 300 feet of the ridge referred to, and at the extreme head of a small side tributary of Slumgullion Gulch. These overlying rocks were also extensively decomposed. At a certain time, perhaps during some abnormally wet season, this incoherent decomposed material became so extensively saturated with water as to be unable to bear the load of rock and gave way; the overlying materials broke into fragments, and the whole mass of mud and rock fragments rushed as a flow southwestward down the lateral gulch to the main Slumgullion Gulch and due west down that to the Lake Fork, 6 miles from the place of starting. On reaching the Lake Fork, whose course is here at right angles to Slumgullion Gulch, the flow turned north and ended about three-quarters of a mile beyond. The volume was sufficient to dam the Lake Fork and to cause the formation of Lake San Cristobal, which extends for nearly 2 miles up the Lake Fork Valley. The end of the flow is at an altitude of about 8,900 feet, 2,600 feet below its head.

The forest growth on the surface of the mass of débris shows that the flow occurred many years ago. On the upper part of the flow the trees are in many places overturned or tilted at various angles, testifying to recent movement; on the lower part such disturbance is rare.

Cimarron mud flow.—On the west side and near the north end of Trident Mesa, at the east margin of the Montrose quadrangle, there is a mud flow somewhat smaller than the great Slumgullion flow. Here a large mass of disintegrated volcanic débris moved into the valley of Cimarron Creek and turned downstream. The total length of this mud flow is about 2 miles, and at places it is fully half a mile in width. It descends from an altitude of 9,000 feet to 7,500 feet. The slope is steeper than that in the Slumgullion mud flow, and the resulting topography in this huge mass of confused material is exceedingly hummocky. The angularity of the material and the topography resemble those of ordinary landslides, but the streamlike form of the deposit marks it as of special nature and closely akin to the Slumgullion mud flow.

The Cimarron flow or slide is of special interest because the date of its occurrence is definitely fixed as between the 18th and 25th of July, 1886. A few days later it was visited by Cross,[97] whose detailed description of the phenomena as they appeared at that time, before any serious modification of the form of the fallen material could have taken place, was reprinted by Howe.[98] Both Cross and Howe emphasize the efficiency of the moisture in the water-soaked rock and soil as an aid to gravity in initiating and maintaining movement of the surficial material.

TALUS

Great accumulations of broken rock débris cover the solid rock on many hillsides and mountain slopes in the San Juan region. In places these accumulations are so extensive as effectually to hide the nature of the underlying rock, but only a few such masses of débris are indicated upon our maps. The topographic conditions, rock formations, and climatic environment of the San Juan Mountains make this region especially fitted for the formation of extensive talus slopes. In the heart of the range, where stream valleys rival glacial cirques in their precipitous walls, these talus slopes form a conspicuous feature in every view. The material has obviously been derived from the weathering and disintegration of the rock in place. Loose fragments dropping or sliding down the slopes have come to rest in the angle between the wall and the floor of every valley. Gradually this accumulation has gone on until the mass has come to have a surface inclined at the angle of rest for the particles involved. (See pl. 33, *A*.) The efficiency with which changes in temperature, freezing and thawing, and the other agents of rock disintegration are operating in the San Juan Mountains may be noted at many places. Above timber line the traveler is frequently startled by the noise of crashing blocks as fragments from the higher cliffs fall pell-mell downward to contribute to the talus heaps that mantle the lower slopes.

Illustrations of talus accumulations might be cited from almost every part of every quadrangle in the San Juan region, but attention will here be directed to only a few. In the Silverton quadrangle, on the north side of Maggie Gulch below the falls, there are long slopes of rock débris which reach from the stream bed to the vertical jagged wall of rock nearly 1,000 feet above. Similarly in the Telluride quadrangle the upper part of the valley of Deep Creek is partly filled by the great accumulations of talus at the base of cliffs on both sides of the stream. Many of the slopes in the Mount Wilson group, near the western margin of the same quadrangle, are likewise thickly mantled with talus.

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[97] Cross, Whitman, The Cimarron landslide, July, 1886: Colorado Sci. Soc. Proc., 1886, pp. 116–126.

[98] Howe, Ernest, op. cit., pp. 13–15.

Beds of volcanic tuff overlain by or interstratified with lava flows contribute large amounts of rock débris, and where exposed on the faces of steep cliffs such formations are nearly always more or less concealed by a talus accumulation. In the northeastern part of the San Cristobal quadrangle, for example, the plateau north of Bristol Head is bordered on the east by a steep cliff, at the foot of which there are unusually great masses of débris. This cliff was oversteepened by glaciation during the Wisconsin glacial stage. Since the withdrawal of the ice talus from the cliff has accumulated as a veneer upon the upper portion of the glacial moraine at the foot of the cliff; the line between the glacial débris and the talus is sharply drawn. The San Luis Peaks, a few miles farther to the northeast, consist of a complex of volcanic rocks of such nature that a large quantity of talus forms rapidly. The many steep slopes of the cirques within that group of peaks and many of the peaks themselves are completely mantled with the loose blocks.

TORRENTIAL WASH

Wherever the gradient of mountain streams is abruptly lessened the decrease in velocity results in a tendency toward deposition of load. In times of flood when snow is rapidly melting or immediately after a torrential midsummer downpour the mountain streams are heavily laden with débris, so that wherever the velocity is checked deposition takes place. The deposition of material tends to make a broad, low cone or fan-shaped heap of débris. Such deposits of torrential wash are found in all parts of the range. (See pl. 32, *B*.)

The débris composing these deposits is heterogeneous and practically unsorted. Some of these accumulations display a slight suggestion of stratification, in that the fragments of tabular shape rest nearly or quite horizontally, but most of such deposits are devoid of structure. Individual components range in size from large boulders, 10 feet or more in length, down to the finest of mud particles. (See pl. 33, *B*.)

Common situations for such deposits of torrential wash are at the junctions of small tributaries with larger streams. Where valley sides have been steepened by glaciation the small brooks and rills cascading down those slopes bear much débris to their mouths, and hence the floors of gulches and ravines are ordinarily buried more or less completely beneath torrential wash.

On the floors of larger streams the fan-shaped deposits of torrential material made by the tributaries generally blend into the stream alluvium, so that it is impossible to map accurately the contact line. The attempt has been made, however, to indicate on the maps the masses of alluvial material of distinctly torrential character, as contrasted with those deposited on valley flats by meandering streams.

Torrential fans are well displayed along the foot of the Hermosa Cliffs, in the Engineer Mountain and Durango quadrangles. Here the streams are so closely spaced that the torrential deposit of one coalesces with that of its neighbors on both sides to make a strip of débris many miles in width, filling the angle between the cliffs and the floor of the Animas Valley. Again, the fans along the margins of the broad flat of Uncompahgre Creek between Ouray and Ridgway are noteworthy because of their symmetry and characteristic outline.

Occasionally a torrential fan at the mouth of a tributary stream has served as a dam to block the flow of the main stream, and thus has resulted in the formation of extensive alluvial flats along the floor of the main stream. In certain localities these alluvial flats, and indeed the surface of the fan itself, have proved favorable locations for farms. Elsewhere ranch homes are situated on the surface of gently sloping fans, which afford sufficient level ground above the danger of flood water in the midst of the rugged mountain scenery. Kirpatrick's home, near the mouth of East Creek, in the northeastern corner of the Ignacio quadrangle, is an excellent illustration of such a location. Many of the ranch houses in the valley of the Animas River north of Durango have similar situations. Even such considerable towns as Ouray and Telluride have been built upon the surfaces of the larger deposits of torrential wash.

COMPOUND ALLUVIAL FANS OF SAN LUIS VALLEY

The eastern front of the San Juan Mountains bordering San Luis Valley is buried beneath the gravel and sand of an extensive system of compound alluvial fans. In the Rio Grande Valley near Del Norte the topography is peculiarly interesting. Many steep-sided rock hills rise abruptly 250 to 500 feet above the surface of the valley. They are the summits of hills and ridges whose lower slopes have been submerged beneath a deposit of sand and gravel. This detritus was in large measure derived from the headwaters of the Rio Grande, but some of it was accumulated as a result of wash from tributary streams, such as Old Womans Creek, and from the slopes of the hills themselves.

The general topographic effect is that of a coast line which has been recently submerged, giving rise to the drowned-valley type of topography. The hills rising above the valley fill are analogous to the islands of such a coast. The long reentrant angles of torrential wash extending up the valleys of torrential streams are comparable to the estuaries and bays of the drowned coast.

Similar topographic conditions are displayed in the vicinity of Saguache, a short distance north of the northern boundary of the Del Norte quadrangle. Here again the topography is that of an area drowned by alluviation, and only the crests of the hills rise above the alluvial flat.

All along the western margin of San Luis Valley from Saguache south into New Mexico the gravel of the compound alluvial fans slopes gracefully upward against the mountain front. The summit of each cone or fan is found far up some mountain valley, and the lateral flanks blend perfectly into those of the neighboring fans to north and south. The character of the rocks has combined with the peculiar climatic conditions to develop in an unusual way this type of recent formation.

The locations at the mouths of mountain valleys and the forms of these torrential fans are favorable for the distribution over their surfaces of water for irrigation. The main canal is brought out of the mountains at the apex of the fan, and from that point the various distributary canals and ditches are developed on more or less of a radial plan. The water thus flows easily to any portion of the fan.

MODERN ALLUVIUM

Recent deposits of gravel, sand, mud, and vegetable mold cover the flood plains of the larger streams throughout the San Juan region and occur in lesser amounts on the floors of basins. These deposits are indicated on the accompanying maps as alluvium. They are for the most part composed of fine material, generally veneered with a fertile soil, supporting a verdant cover of grass and flowering plants. The surface of such materials is ordinarily nearly or quite horizontal. Some of these deposits have been made by meandering streams; others are the result of the accumulation of débris in lakes, ponds, or marshes.

Deposits of stream alluvium are especially noteworthy on the floors of the larger valleys in the zone surrounding the range. Here the alluvium is generally closely associated with glacial drift. The many square miles of stream alluvium in the valleys of the Animas River and Vallecito Creek, on the south side of the range, in the northern part of the Ignacio quadrangle, is doubtless due in large degree to dams formed by the terminal moraines of the Wisconsin ice. Much of the material composing these flood plains was of glacial origin and was liberated from the ice during the time of recession. It is possible that the terminal moraines from which the ice was retreating were so complete barriers that they caused lakes to develop temporarily between them and the ice fronts.

Similarly extensive deposits of stream alluvium immediately upstream from terminal moraines are found in the Uncompahgre Valley, on the north side of the range between Ridgway and Ouray (pl. 34, *B*), and in the Rio Grande Valley near the east margin of the San Cristobal quadrangle, as well as in many other valleys at other points around the mountains. (See pl. 1.)

In the midst of the higher mountains glacial erosion has in many places resulted in the formation of shallow basins, which doubtless were the sites of lakes or ponds immediately after the disappearance of the ice. As a result the floors of these basins are now flat areas of fertile soil. Among them are Ironton Park, in the northern part of the Silverton quadrangle, and the broad flat on which the city of Silverton is built. (See pl. 34, *A*.) Purgatory and other depressions floored with alluvium near the east margin of the Engineer Mountain quadrangle fall in the same category. Similarly in the Needle Mountains quadrangle there are a number of such areas of alluvium—for example, the two parks on the upper course of the Florida River.

Within the area covered by the ice of the Wisconsin stage irregular deposition of glacial drift has resulted in the formation of many small, shallow basins, which since the withdrawal of the ice have been filled with alluvial materials. Most of these are too insignificant to map, but a few are worthy of note. The alluvial flat surrounding Lake Eileen, on the west slope of the valley of Vallecito Creek, in the northeast corner of the Ignacio quadrangle, is the result of alluviation between the valley wall and a lateral moraine of the Wisconsin ice. The half dozen irregularly shaped areas of alluvium in Hermosa Park and on the floor of the valley of the East Fork of Hermosa Creek, in the central part of the Engineer Mountain quadrangle, are chiefly the result of the silting of basins formed by irregular deposition of drift in that valley. Farther north, along the course of the unnamed tributary of the East Dolores River followed by the Rio Grande Southern Railroad track as it climbs to the divide at Lizard Head station, there are other masses of alluvium filling basins that seem to have originated in the same way. One more illustration from the many that might be cited will suffice. The small area of alluvium surrounded by glacial drift on the bench east of Weminuche Creek above the falls, in the south-central part of the San Cristobal quadrangle, is typical of this class.

Many other silt-filled basins in the San Juan Mountains have been formed as a result of landslide action. Small areas of alluvium clogging the trenches and troughs on the surface of landslide masses or in the characteristic trench between the landslide débris and the cliff from which it has slipped are, of course, very abundant. Elsewhere landslides have acted as dams across valleys and have thus ponded for a time the water that had hitherto been coursing down the channel. The long, narrow alluvial flat now partly occupied by the Farmers' Reservoir, in the Rio Grande Valley near the center of the San Cristobal quadrangle, is the result of a landslide dam which blocked the stream at the point where the reservoir dam was later constructed. The broad area of alluvium just south of Weminuche Pass, at the head of the Los Pinos River in the same quadrangle, is the result of the blocking of that stream by a large slide immediately south of the alluvial area. The alluvial flat that forms the site of Lake City, bordering the Lake Fork of the Gunnison River near the south margin of the Uncompahgre quadrangle, is the result of silting of a basin presumably once occupied by a small lake formed by the blocking of the streams by landslides a short distance north of the present town. In the northern part of the Needle Mountains quadrangle there are two rather large areas of alluvium which have resulted from similar blocking of streams by slides. One forms the beautiful park in the upper portion of the valley of Elk Creek. The other is the broad meadow traversed by Bear Creek and occupied by the half dozen decaying log cabins known as Beartown.

CHAPTER 8.—UTILIZATION OF THE SAN JUAN REGION BY MAN

The body of this report gives a description and an explanation of the physical features of the San Juan region. When the field work was assigned to us in 1908, there was no intention of having the investigation go further than a thorough scientific and technical study of the physiography of the region. However, during the period of field studies there has been a remarkable development in the scientific study of geography in this country, and into that study has come a deeper appreciation of the significance of the environmental factors in influencing human activities. In the utilization of the land and other natural resources of the country man has been very largely directed, and often definitely limited, by the physical features, the climate, the soil, and the drainage conditions in the area where he has chosen to settle.

In many ways the San Juan Mountain region illustrates most strikingly the marked influences of geographic conditions upon routes of travel, upon the location of settlements, upon human occupations, and upon the ultimate utilization of the natural resources of the region. We have thought, therefore, that it would be appropriate to outline in this closing chapter the more human aspects of our geographic study of the San Juan region.

Early period of prospecting.—This region first attracted the attention of white men through its mineral resources. Early in the seventies of the nineteenth century a number of hardy pioneer prospectors visited this bold, rugged mountain country. Reports of mineral wealth had reached them through meetings with the Indians who frequented this range on their hunting expeditions and spent their summers in the beautiful mountain canyons where fish and berries were abundant and where the grass for their livestock was luxuriant.

The prospectors worked their way through the valley bottoms, occasionally testing the stream gravel for placer gold, and, as in most of the great mining regions of the world, some rich placer deposits were found and worked. But the search for the true mineral veins and lodes led these hardy prospectors higher and higher into the mountains. They scrambled along precipitous ledges, even to the summits of many of the loftier peaks. They examined with great care the walls of the deep canyons, and at numerous places where surface conditions looked promising they sank test holes or drove prospecting tunnels.

Establishment of mining centers.—With the discovery of rich veins of gold, silver, and the ores of lead and zinc, more and more people came into the region to try their fortunes at mining. There sprang up in the eighties a number of mining towns. Near the north base of the mountains, on an alluvial fan built out by a tributary stream into the main valley of the Uncompahgre River, the town of Ouray was located. In the valley of the San Miguel River, on the western slope, Telluride was built. Rico is in the heart of a secondary dome on the west flank of the mountain range known as the Rico Mountains. Durango, which now serves as a smelting center, is built on the terraces of the Animas River near the south margin of the range. (See pls. 26, *B*, and 34.) Silverton, also on the Animas, is in the central portion of the San Juan region. Creede is on a little tributary of the Rio Grande and is the chief mining center of the eastern slope of the mountains. Lake City is on the Lake Fork of the Gunnison, near the north margin of the mountain area.

With the exception of Durango, each of these cities is located as far upstream in the canyons as transportation conditions were favorable and suitable town sites were available. When the days of railroad construction came, in the early nineties, these mining towns were found to be so located that spurs from the main lines of railroad could be built to each one of them. They became termini of the railroad transportation facilities. From Silverton additional spurs have been extended farther into the heart of the range, but Ouray, Telluride, Lake City, and Creede still mark that notable break in transportation which takes place when the end of the railroad is reached and goods and passengers must be transferred to the backs of horses or mules, to wagons, or, with modern development, to motor trucks. These towns illustrate very notably the tendency for centers of population to develop at breaks in transportation facilities.

Each of the cities in the San Juan region has served as a social and commercial center for a large part of the mountain area. To these centers have come produce and manufactured goods from other sections of the country. All the supplies necessary for the conduct of the mining business have been received at these cities and distributed to the mines. The products of the mines, usually in the form of concentrates, have been brought to these cities and there loaded for shipment to smelters or refineries.

Many a lesser mining center has been built still higher in the mountains, far beyond the reach of the railroads, at a point where some particular mine has been developed; or, more often, where there was a small group of mines. This is illustrated by Summitville and Platoro, in the eastern part of the mountain area, and by Animas Forks and Ironton, in the central part.

As is common in the history of many mining regions, some of the lesser towns, which were formerly prosperous, have ceased to be producing centers and, for a time, at least, are quiet. To-day such deserted mining camps are scenes of desolation. There may be a lone watchman taking care of a few of the more valuable properties, but for the most part the streets and the tramways, the shops and the town hall, once scenes of great activity, are absolutely quiet. The traveler may pass to-day through one of these former centers of activity, where hope and confidence stimulated thousands to carry on an intensive search for mineral wealth in the mountains and even to make large investments, and yet see no one. Perchance, however, someone dwelling in the lower portions of the range or in some freshly established mining camp may be heard tearing down the old houses to procure building material or firewood for his new home.

Second stage in settlement.—After the great influx of prospectors and miners there came into the mountain region a group of settlers who were attracted by the broad, fertile lowlands in the valley bottoms. These were the ranchmen who saw in the pasture lands of the mountains the possibilities of producing hay and grain for livestock and many of the vegetables needed for home consumption. They could carry on dairy farming in the rich grasslands of the valley bottoms and produce milk, butter, and cheese for their local needs; and they could sell their surplus dairy products in the mining towns. Little by little these rich alluvial plains were taken up as homesteads. Cattle, horses, and sheep were driven into the mountain forests or high above the forests on the grasslands of the alpine pastures during the summer. When fall came the stock was brought into the lowland pastures for the winter. Ranch life has become characteristic of many portions of the San Juan region. Nearly every available acre of river bottom has now been put under cultivation. The narrow terraces of the Lake Fork of the Gunnison serve as hay fields, and some have been planted with alfalfa. In the broad lowland of the valley of the Uncompahgre hay and grain are produced, and in the valley of Dallas Creek there is a rich area of ranch land. As a response to the development of agricultural and grazing life in the valley of the Uncompahgre, a number of smaller towns have been built up. Ridgway is near the junction of Dallas Creek and the Uncompahgre River and has little or no interest in the mineral resources of the region, for its people are interested in ranch life. Farther downstream are Eldredge and Colona, Uncompahgre and Montrose. With decreasing altitude down the valley of the Uncompahgre the climate becomes suitable for fruit raising. In the vicinity of Colona and Uncompahgre and especially at Montrose there are large and successful orchards. During certain seasons the shipment of fresh fruit has been delayed by imperfect transportation facilities, and the local fruit growers have established a canning factory.

In the broad lowland of the valley of the Uncompahgre River there may now be seen each summer hundreds of acres planted to sugar beets.

At the southwest margin of the mountains, in the vicinity of Mancos, there is a broad, rolling lowland which is devoted to ranch life. Here a combination of agriculture and stock raising has made possible a very prosperous community.

Near the south margin of the mountains and extending southward for many miles into New Mexico the modern flood plain and the stream terraces of the Animas Valley have been appropriated for general agriculture or for fruit raising. The valley bottoms and the terraces offer very attractive sites for ranchmen. The cattle, horses, and sheep are sent far into the mountains for summer pastures, but they return to the home ranch for winter feeding. Many ranchers take their sheep into the plateau country for the winter.

The description could continue around the range, mentioning each one of the valleys with about the same comments. In the valleys of the Florida River, Vallecito Creek, and the San Juan River, which flow southward from the mountain area, there are very excellent ranch lands. In the eastern part of the range the valley of the Rio Grande is the chief drainage line, and in that valley is a broad alluvial bottom and several terraces that are suitable for cultivation. For a distance of fully 40 miles upstream into the range from Del Norte the valley of the Rio Grande is a continuous succession of ranches. Virtually every available acre has been appropriated for pasture or for raising hay or alfalfa or peas or grain. In many places vegetable farming is carried on for more than home consumption, and the surplus is sent to the neighboring cities.

In the valleys of the Rio Grande and its South Fork a notable industry has been developed through the cultivation of head lettuce. Acres and acres are now devoted to the production of this one crop. New sawmills have been established for making crates suitable for shipping this product to distant markets. The industry is being carried on with most modern methods. Huge motor trucks are used to carry the empty crates to the fields and to return with the loaded crates to the railroad station at South Fork. There is a combination of soil, moisture, and temperature conditions in this portion of the range that makes possible an unusually crisp and fresh growth of the head lettuce.

Other valleys of the east slope, such as those of Alamosa Creek and the Conejos River, have been appropriated by ranchmen. The valley bottoms are fenced off into pastures or hay fields or grain fields, and attractive homes have been constructed.

This second stage in the settlement and development of the San Juan region has produced a permanent population. These people have built attractive homes, churches, and schoolhouses and have entered upon a community life with every indication of prosperity.

Irrigation reservoirs.—The heavy precipitation in the San Juan Mountains provides a surplus of water, which is much needed in the lower parts of the larger valleys and in the bordering plateau regions. This has led to the establishment of a number of large reservoirs in the mountain area, each in a canyon just upstream from a constricted portion where a dam has been built. The Alamosa and La Jara Reservoirs, in the southeastern part of the range, are placed to hold the surplus waters in the drainage systems of Alamosa and La Jara Creeks, respectively. The Farmers' Union Reservoir, in the valley of the Rio Grande, ponds the water for a distance of about 7 miles and is a truly beautiful lake. The surplus water held in this reservoir during the period of heavy run-off is released chiefly in San Luis Valley during the later part of the growing season. Santa Maria Lake, which has been described on page 157, now serves as an irrigation reservoir, and the waters retained there during the flood period of the streams in that vicinity are turned into the Rio Grande and withdrawn by irrigation canals and ditches in San Luis Valley when the crops there need additional water.

The Ignacio Reservoir, formed by a dam on Elbert Creek, is on the upland just west of the Animas River, above the little town of Tacoma. The water is carried to the rim of the canyon of the Animas and, in descending into the gorge, passes through a power plant where it turns the great wheels and generates electricity. The water on leaving the power plant enters the Animas River and is then available for irrigation farther downstream.

In addition to these artificial reservoirs, the many glacial lakes and those due to landslides in the mountain area serve as natural reservoirs, most of which are drawn upon by the ranchmen for irrigation.

A special paper on the reservoirs of the San Juan region was prepared by Atwood[1] in 1918.

Climate.—This mountain region, which extends from 37° to 38° 30′ north latitude, is in the midst of the belt of westerly winds. As it is on the western margin of the southern division of the Rocky Mountains it has a rainfall more evenly distributed throughout the year than in the country farther to the east.

During the winter the precipitation comes largely with the winds from the west, which are carrying moisture from the Pacific Ocean. As the winds rise in crossing the mountain area, their moisture content becomes more and more condensed and during the winter falls in the form of snow, which in some localities, as at Silverton, reaches a depth of nearly 200 inches, or a little over 16 feet.

In the summer the rainfall derived from the western winds is augmented by moisture brought by winds from the Gulf of Mexico. This influx of warm, moist winds from the Gulf is due largely to the low-pressure conditions over the hot interior plateaus and the relatively high pressure over the Gulf. The resulting slow movement of air northward from the Gulf, frequently augmented by cyclones moving eastward across the United States, results in warm, moist southerly winds in the San Juan region, and as these winds strike the mountains they are cooled and forced to give up a portion of their moisture content.

In the foothill belt the annual rainfall commonly ranges from 10 to 15 inches. On the lower mountain slopes it is from 15 to 20 inches, but in the higher mountain area it is over 20 inches. The snowfall has been recorded at certain of the settlements in the mountain area. At Rico the mean annual snowfall is 148 inches and at Silverton 196 inches. In the lower valleys bordering the range the mean summer temperature is from 60° to 65°. On the lower slopes of the mountains it is from 55° to 60°, and in the high mountains it is commonly below 55°. In these high mountains the temperature during the summer often falls to the freezing point, and the smaller pools of water may be found frozen over almost any morning. Snow may fall at any time, and it is almost certain to fall a few times during each month of the summer.

The mountain air is extremely fresh and bracing. During the day the bright sun has that healthful and invigorating influence common to the high mountain atmosphere. In the cool of the evening the air has a freshness that is often reflected in the stories told about the camp fire. As the night advances the rapid radiation of heat from the high mountains reduces the temperature so greatly that an abundance of warm woolen bedding is necessary for comfort, even during the warmest months of the summer. Many a camper unfamiliar with the conditions of radiation here has crawled out of his bed a little before sunrise commenting vigorously upon the temperature as he shivered in his efforts to build a fire. The summer nights in these high mountains are much colder than those in central Alaska, and a camping outfit that

[1] Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, 1918.

would be suitable for that far northern country during the summer is not adequate for the higher altitudes of the San Juan Mountains.

In the valley bottoms and in the lower land bordering the range the frostless growing season is 100 to 125 days. Nearer the mountains and on their lower slopes the growing season ranges from 75 to 100 days, and in the higher mountains it is less than 75 days. At lower and lower altitudes, such as are found in traveling northward within the valley of the Uncompahgre, the growing season increases gradually to 150 days, and even more.

Of prime significance to those engaged in fruit raising and agriculture is the date of the last spring frost. The observations available on this date show that in the high mountains, or even in San Luis Valley, it may come after June 1, which means at any time during the year. On the intermediate slopes of the mountains there is a belt where the last killing frost may be expected somewhere between May 20 and June 1. A little farther out and lower the last frost is expected between May 10 and May 20, and farther and farther from the range it is earlier and earlier.

Influence of climatic conditions upon mining.—Those who came into the mountain region in search of mineral wealth gave little heed to climatic conditions. Such men will go almost anywhere if there is a fair chance of discovering a body of rich ore. To be sure, the heavy snowfall of winter and the severe cold at high altitudes affected their building plans and the provisioning of mining camps for the winter season. Recent winter avalanches have imprisoned for weeks the inhabitants of certain of the mining towns in the central part of the mountain area. The heavy rainfall of the region had provided luxuriant forests, which these prospectors drew upon most freely for building material and for mine timbers. The mountain streams, with their many waterfalls and rapids, provided an abundance of pure, clear water which could be used in the stamp mills and concentrating plants or for generating electric power. The mining industry of the San Juan Mountains is greatly indebted to the favorable climatic conditions, which have made possible an abundance of electric power. Electricity is being carried over the mountains to the several mining centers and then taken into the mines to illuminate the tunnels and shafts.

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National forests.—Most of the San Juan region has been set aside as parts of several national forests. In the vicinity of the Gunnison River and in the valley of the Uncompahgre River there are good grassland areas. In San Luis Valley there is another broad area, originally grassland, most of which has been appropriated for ranches or farms. Ascending the range from the bordering lowland one passes through a belt of yellow pine or a belt with yellow pine and Douglas fir mixed. Above this belt is a zone of Engelmann spruce. Above the spruce belt there are many alpine gardens and some broad, barren areas. Numerous grassy parks in the mountains afford summer pasturage.

Regulations concerning national forests are subject to modification from time to time, and information concerning them should be obtained from the Forest Service when wanted.

Transportation.—The railroads in the San Juan region are shown on Plates 1 and 2.

Wagon roads were constructed very early by those interested in mining enterprises and later by ranchmen. More recently, through county and State cooperation, excellent automobile highways have been completed, and others are under construction. The range can now be crossed at several places by automobile with comfort and ease.

Those who would abandon railroad trains and automobiles may find a still greater treat by following the trails through the high mountain areas. One of the most notable scenic trails in America follows the Continental Divide from a point near Cumbres, in the southeastern part of the mountain area, northwestward to a point near Silverton, and from that point many other excellent trails are available, so that the entire mountain area may be viewed from the sky line. No region offers any more magnificent mountain scenery, more attractive camping places, or better fishing than these routes far from the common highways in the San Juan region.

The topographic maps of the United States Geological Survey, if carefully interpreted, will help one in laying out routes through the mountains. The service of the forest rangers should be sought by those unacquainted with the higher trails, or unaccustomed to the responsibility of leading parties through such rugged mountains. Such travel should not be undertaken by any who are not experienced in the care of stock in high mountain regions.

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