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GEOMORPHOLOGY OF THE SAN JUAN MOUNTAINS

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INTRODUCTION

The San Juan Mountains are essentially the result of erosion of a domally uplifted part of the earth's outer shell, covering nearly 10,000 square miles and extending about 90 miles east-west and about 70 miles north-south. Erosion has been accomplished predominantly by running water and alpine galciers. Uplift ot the dome has been intermittent and locally was complicated by faulting and by the development of broad sags on its summit and flanks. There have been repeated episodes of extensive volcanic activity. Climatic conditions suitable for the generation and vigorous activity of numerous, large, valley glaciers have recurred at irregular intervals of relatively short duration. Consequently, the geomorphic history of this rugged mountain range is exeedingly but probably not extraordinarily complex.

This summary account deals primarily with the west-central part of the mountain system, in the area traversed along a general south-north route from Durango to Ouray. It is based in large part upon the field studies made between 1910 and 1924 by Wallace W. Atwood and Kirtley F. Mather (1932) and their associates.

PRE-CENEZOIC HISTORY

Precambrian Events

Precambrian rocks compose the central massif of the San Juan Mountains. They are exposed in the Needle Mountains and adjacent peaks, in the canyon of Animas River, and elsewhere in the range. The complex of gneisses, schists, granites, quartzites, slates, recrystallized conglomerates, and other highly metamorphosed sediments indicates that the Precambrian history of this region is divisible into three long intervals of time, each of which was terminated by episodes of profound crustal movement.

Beginning at least as early as the last of those three orogenic episodes, a considerable part of the San Juan region, centering in the Needle Mountains, has consistently and repeatedly reacted to diastrophic forces as a positive element of the earth's crust. Domal uplifts instigated erosion which progressed toward base level with greater or lesser success. Eventually each erosion cycle was terminated by another domal uplift; this sequence of events has recurred again and again. The details of this history are lacking for the earlier sequences, especially for those that occurred in Precambrian time, but the records are increasingly clear toward the present time.

It would appear, moreover, that the diastrophism affecting this region during the Precambrian eras was essentially different from that occurring in Paleozoic and later eras. The Precambrian rocks have been subjected to intense horizontal stresses, whereas the sedimentary and volcanic rocks that rest upon the basement complex have been subjected predominantly to differential vertical movements.

Paleozoic Events

During the transition from Precambrian to Cambrian time, the San Juan region was a land mass undergoing erosion. Before the end of the Cambrian period a surface of slight relief had been developed. The lower undulations of this surface were submerged beneath marine waters during at least the episode of sedimentation responsible for the Ignacio quartzite in what was probably late Cambrian time. But not until late Devonian time did the first recorded, widespread epicontinental seas cover the entire San Juan region. Thereafter, during the Mississippian and Pennsylvanian periods, the region was the site of discontinuous but prolonged accumulation of marine sediments. Among the several Paleozoic formations recognized by those concerned with the bedrock geology of the region, the most conspicuous is the Pennsylvanian Hermosa group, more than 2,000 feet thick, displayed in the Hermosa cliffs on the west side of the Animas River Valley in the southeast quarter of the Engineer Mountain quadrangle.

Early in Permian time conditions changed. The marine limestones were overlain by shallow-water clastic sediments and these in turn by nonmarine conglomerate, sandstone, and shale. Somewhere in the region, possibly in the locality occupied today by the Needle Mountains, there was a pronounced domal uplift from which vigorously eroding streams derived pebbles for the Cutler formation the greater part of which is of Permian age. The pebbles in the Cutler beds include vein quartz, granite, quartzite, and other igneous and metamorphic rocks that must have come from the Precambrian basement complex. Disintegration of those beds in recent time has liberated these resistant pebbles from their matrix and many of them are now scattered broadcast over surfaces where they may easily be mistaken for Quaternary gravel.

The transition from Paleozoic to Mesozoic time was marked by crustal movements that flexed the Paleozoic strata and occasioned considerable erosion in some parts of the region, but in the Durango-Silverton area there is no obvious stratigraphic break between the Cutler formation and the overlying Triassic beds.

Mesozoic Events

In many significant ways, the history of the Mesozoic era in the San Juan region repeats that of the Paleozoic era. Marine and nonmarine sediments accumulated to thicknesses of several thousand feet. These sediments included the various resistant sandstones, such as the Dakota and beds in the Mesaverde group, which later formed hogback ridges to defend the summits of mesas in the region peripheral to the higher mountains.

Toward the end of Cretaceous time, the San Juan region was a plain with only slight undulations, approximately at sea level. Beneath this plain were the flat-lying, recently accumulated beds, 6,000-8,000 feet thick, ranging from the Entrada and Morrison through the Lewis. In the eastern half and possibly in the central part of the region, these strata rested upon rocks of the Precambrian complex. In the western half of the region, however, the thick formations of Paleozoic and earliest Mesozoic age intervened between the Entrada sandstone and the Precambrian rocks. These were the spatial conditions prior to the construction of the modern San Juan Mountains during the Tertiary and Quaternary periods.

The first step in this constructive process was the regional domal uplift of the entire San Juan province. A great elongate oval dome was gradually arched upward, so that its summit, located apparently in the northeast quarter of the Needle Mountains quadrangle, was eventually at least 10,000 feet higher than the surrounding plain. As a result of this diastrophism the Paleozoic and Mesozoic strata dipped outward at angles approximating the slope of the flanks of the dome.

Erosion, of course, began as soon as there was any appreciable difference in altitude between the center of the dome and its periphery. Streams radiating from the center cut deep canyons in their upper reaches and deposited gravel, sand, and silt in their lower courses. These deposits, spreading widely over the peripheral lowland, contributed much material to such formations as those now designated the Pictured Cliffs, Fruitland, Kirtland, and McDermott.

Early in this long episode of crustal flexing and concomitant erosion there occurred the first of the many volcanic eruptions which characterize the Tertiary history of the San Juan Mountains. The fragmental debris from these late Cretaceous and/or Paleocene eruptions formed the Animas formation, remnants of which are found on the south slopes of the range in the Ignacio and Pagosa Springs quadrangles.

TERTIARY HISTORY

Paleocene (?) Glaciation

By the time the San Juan dome had been arched several thousand feet upward, stream erosion had stripped the thick veneer of sedimentary rocks from the Precambrian basement in many places near and at the apex of the dome, and there presumably had cut deep canyons in the crystalline complex. Bodies of intrusive porphyries, also exposed in canyons or on mountainsides, possibly crystallized from the magma that fed the volcanoes responsible for the igneous debris in the Animas formation.

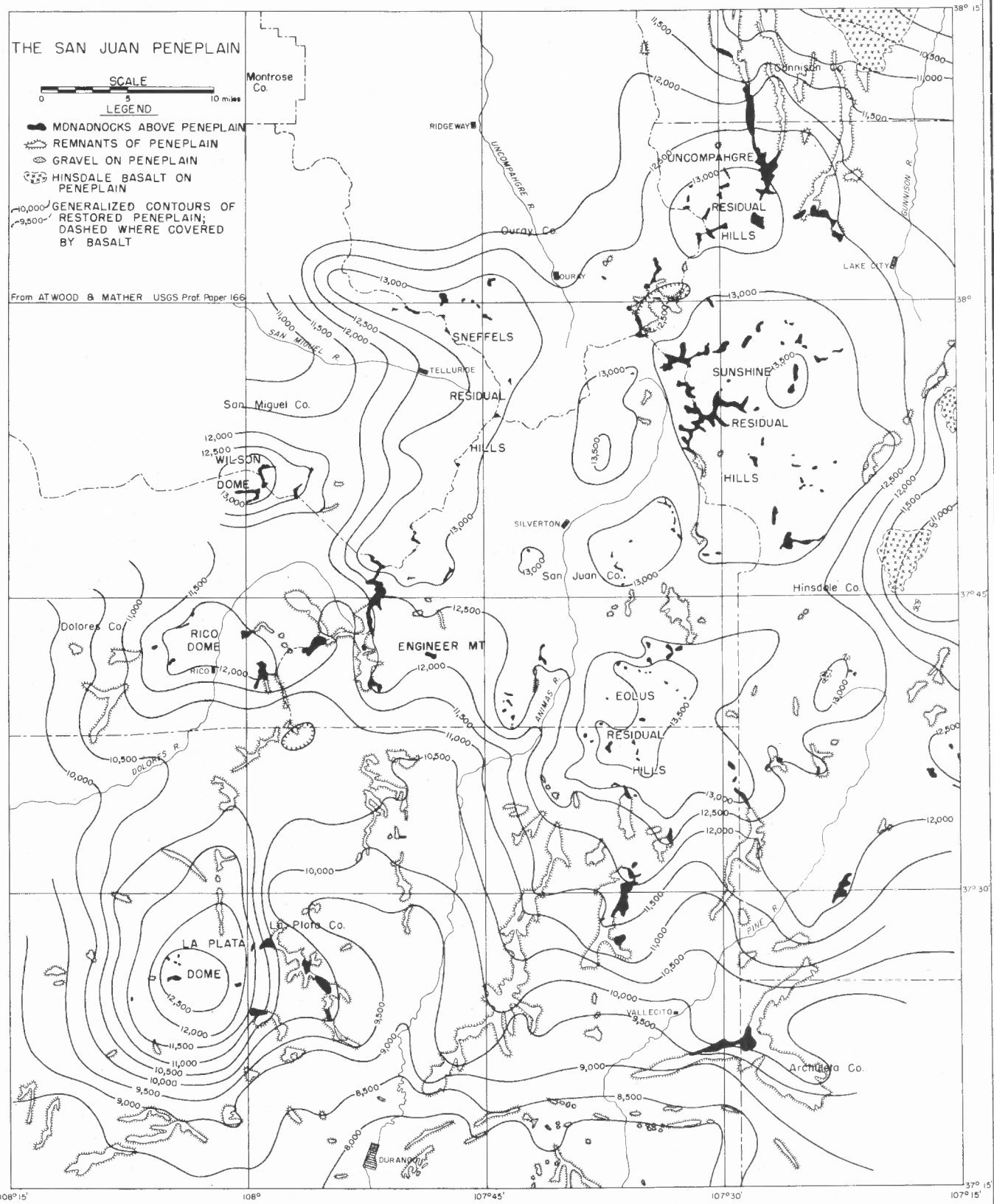
Under these conditions, glaciers formed in the now-vanished mountains and spread outward as large piedmont glaciers over the adjacent lowland. Remnants of the till deposited by those glaciers occur at several places in the northern part of the San Juan region. The type locality is in Miller Mesa near Ridgway; hence the name Ridgway till. Here the till rests on Mancos shale and is overlain by the Telluride conglomerate and San Juan tuff.

The identification of the Ridgway formation as a glacial till has recently been challenged by Van Houten (1957, p. 383-338), who stated that it "is as reasonably a mudflow and stream deposit as it is a tillite". The exposures on the slopes of Miller Mesa should be re-examined in the light of modern knowledge of mudflows associated with volcanic activity. I have not seen those exposures since 1914, but unless my recollection is badly mistaken there can be no reasonable doubt of the glacial origin of that material.

There is no available evidence to assign a precise geologic age to the Ridgway till. It is younger than Mancos and older than the Telluride, so is probably Paleocene, possibly Eocene, in age.

Telluride Conglomerate Epoch

Before the end of Eocene time, stream erosion, assisted by the Ridgway glaciation, had well-nigh completed the task of wearing away the generation of San Juan Mountains carved from the dome uplifted in late Cretaceous-early Tertiary time. The apron of stream deposits surrounding the dwindling mountains crept inward



Drafted by: F.E. FROST

FIG. 1

toward the last residual hills. Remnants of the thinning edges of those lowland deposits, known as the Telluride conglomerate, are now found resting unconformably on rocks of all ages from Precambrian to Cretaceous. One generation of San Juan Mountains had been reduced to rounded hills and low ridges, standing at only slight altitudes above an undulating plain.

Tertiary Volcanism

Beginning in early Miocene time and continuing throughout the Pliocene, the San Juan region was the locus of intense volcanic activity on what must have been a most spectacular scale. Volcanic mountains and plateaus were constructed of pyroclastic ejecta and lava flows, with numerous intrusions of porphyritic rocks. Only the part of the region southwest from the Needle Mountains failed to receive a thick covering of this volcanic material. Most notable in the Durango-Silverton-Ouray area is the San Juan tuff, which was piled to a thickness of at least 2,000 feet, and is exposed in the amphitheatre and high ridge east of Ouray, and the somewhat younger Silverton volcanic series of flows and tuffs that form the ridge between Cement and Mineral Creeks, northwest of Silverton.

Peneplain Cycle of Erosion

The task of the rivers and their tributaries in reducing the volcanic mountains and plateaus to base level did not require, however, the removal of all volcanic material erupted on the erosion surface developed during the Telluride epoch. In many places the surface beneath the volcanic veneer sagged downward even as the eruptions were taking place. Thus the base of the volcanic rocks slopes steeply downward more than 2,500 feet in less than 5 miles near Silverton (Larsen and Cross, 1956, pl. 4).

Be that as it may, by late Pliocene time, the entire San Juan region had once more been worn down to a surface of moderate relief, large parts of which displayed the topography of a peneplain (fig. 1). This, the San Juan peneplain, was an undulating surface cutting across all the bedrock formations from the Precambrian through the Fisher quartz latite. Above the peneplain stood many monadnocks, several hundred feet high, such as the "Eolus residual hills" in the Needle Mountain area. Across the peneplain flowed senile rivers in broad valleys with their lateral slopes rising gently to rounded interfluves, two or three hundred feet above the valley floor.

As shown on Figure 1, the San Juan peneplain is not truly a summit peneplain. Moreover it has been notably deformed, not simply uplifted, since it was developed by stream erosion. Observable remnants slope upward on the crest of the divide between the Animas and Florida Rivers from an altitude of 8,500 feet, 5 miles northeast from Durango, to an altitude of nearly 13,000 feet on the south margin of the Needle Mountains, 16 miles farther toward the northeast. Other remnants are at altitudes between 12,500 and 13,000 feet on the north side of the Needles, between White Dome and Whitehead Peak. Projecting the surface inward toward the 14,000+ foot peaks, such as Mt. Eolus, Pigeon, and Sunlight, it has an altitude of approximately 13,500 feet. Thus, throughout the San Juan Mountains the highest summits in many localities were residual hills 500 feet or more above the peneplain.

At many places on remnants of the peneplain, stream gravels are strewn upon that ancient surface. These include well-rounded pebbles of quartzite, granite, and metamorphic rocks quite foreign to the locality where found. On the highest part of Animas City Mountain, 4 miles north of Durango, for example, there are pebbles of granite and other rocks that must have been derived from the Needle Mountains region. These could have been transported to that place only before the intervening valleys and canyons had been excavated. Similarly, there are scattered pebbles, obviously transported by streams from a considerable distance, on the peneplain remnant at an altitude of 11,000 feet on the divide due east from Rockwood.

In the eastern and north-central parts of the San Juan region, many remnants of the peneplain bear, in addition to the scattered stream gravel, 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. The evidence is conclusive that it was extruded upon the peneplain. This latest renewal of extensive volcanic activity occurred either immediately before or during the crustal movements that once more arched the San Juan dome upward and initiated the Florida cycle of erosion.

QUATERNARY HISTORY

Florida Cycle of Erosion

This renewal of crustal movement may be taken as the milestone to mark the transition from Tertiary to Quaternary time. The uplift of the central part of the San Juan region was sufficient to permit the rejuvenated streams to erode downward about 2,000-2,500 feet below the peneplain before they reached a new base level. At the north, west, and south margins of the mountain area differential uplift was less and here the new base level was 600-1,000 feet below the former one. The interval of time dur-

ing which the work of the master streams in the San Juan area was influenced by their relations to this new base level is designated as the Florida cycle of erosion, inasmuch as the broad flat surface of Florida Mesa was a result of the conditions prevailing then.

In the peripheral lowland, with its less resistant rocks, broad valleys of late mature or 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 San Juan peneplain, the transformation of youthful canyons into mature open valleys was a more difficult process. Broadly U-shaped valleys characterized the landscape there. As a result of erosion during the Florida cycle, followed by the vigorous downcutting that took place in subsequent time, the larger valleys within the area of rugged mountains almost everywhere display an upper, outer trough with comparatively gentle slopes and an inner, lower canyon with steep walls and truly youthful appearance. Some of the surfaces brought to grade during the Florida cycle are now recognizable as benches or shoulders high on the existing valley walls.

Cerro Glacial Stage

During this process of mountain dissection, the normal course of stream erosion was interrupted by a glacial episode, the first of the three Pleistocene glaciations that have been identified in the region. Glaciers not only filled the major valleys, but spread out as extensive piedmont glaciers on parts of the adjacent lowland. Remnants of the till deposited by these glaciers have been left on interfluves and valley slopes, high above the existing stream beds, northwest and north of Ouray. For example, South Baldy, 9 miles northwest of Ouray, is covered with this comparatively old till.

Deposition of Florida Gravel

As the Cerro ice melted away, the master streams that debouched from the mountain fronts upon adjacent lowlands were heavily loaded with coarse debris. A veneer of bouldery gravel, 10-50 feet thick, was spread over the floor of every valley beyond the foothill zone, and in some of the broader troughs extended far up the stream courses to well within the mounatin area. One of the most extensive remnants of this gravel deposit now caps Florida Mesa and has defended the weak shales and thin sandstones of that locality from later erosion.

Canyon Cycle of Erosion

Deposition of the Florida gravel was terminated by another episode of crustal flexing. At the center of the range the uplift amounted to about 2,000 feet, but near the margin was only a few hundred feet. Thus the San Juan dome was made somewhat more pronounced. The new cycle of erosion initiated by this crustal movement is responsible for the steep-walled canyons, hundreds and even thousands of feet deep, incised beneath floors of the valleys formed during the Florida cycle.

Durango Glacial Stage

Sometime after the beginning of the Canyon cycle of erosion, the San Juan Mountains were again occupied by alpine glaciers. The Animas Glacier of this stage had its terminus within the limits of the present city of Durango. Remnants of the terminal moraine may be seen on a terrace which extends along the east side of the Animas Valley from Spring Gulch almost continuously to Horse Gulch. The surface of the terraces bevels the edges of the southerly-dipping sedimentary rocks, and is 250-300 feet above the adjacent river bed. The northern and northeastern part of this terrace is occupied by the Durango till and its southern part is mantled with outwash gravel. This latter deposit is the beginning of a valley train, of which other extensive remnants may be seen on the rock terrace that extends far southward along the east side of the Animas Valley as a part of Florida Mesa but at a distinctly lower altitude than the other and much larger part of the mesa.

Likewise, in the Uncompahgre Valley and elsewhere in the region, the Durango till and outwash are on rock benches or terraces, scores or hundreds of feet above the stream beds and the valley floors upon which the deposits of the later Wisconsin glaciers are found. The distinction between the Durango glacial and glacio-fluvial deposits and those of the later Wisconsin ice, is based on their physiographic relations rather than upon the possible differences in the amount of weathering of the materials. Time enough must have elapsed between these two glacial episodes to permit the deepening of the valleys by downward erosion in bed rock to depths indicated by the present elevation of these rock benches or terraces above the adjacent valley floors.

Durango-Later-Wisconsin Interglacial Interval

The downward erosion just mentioned probably implies a further but slight upward flexing of the San Juan dome. This increased the gradient of the streams in the radiating valleys at just about the same time that the Durango ice melted away. The new base level had been established in many of the valleys and new valley flats were being developed when for the third time during the Pleistocene the region was again occupied by alpine glaciers.

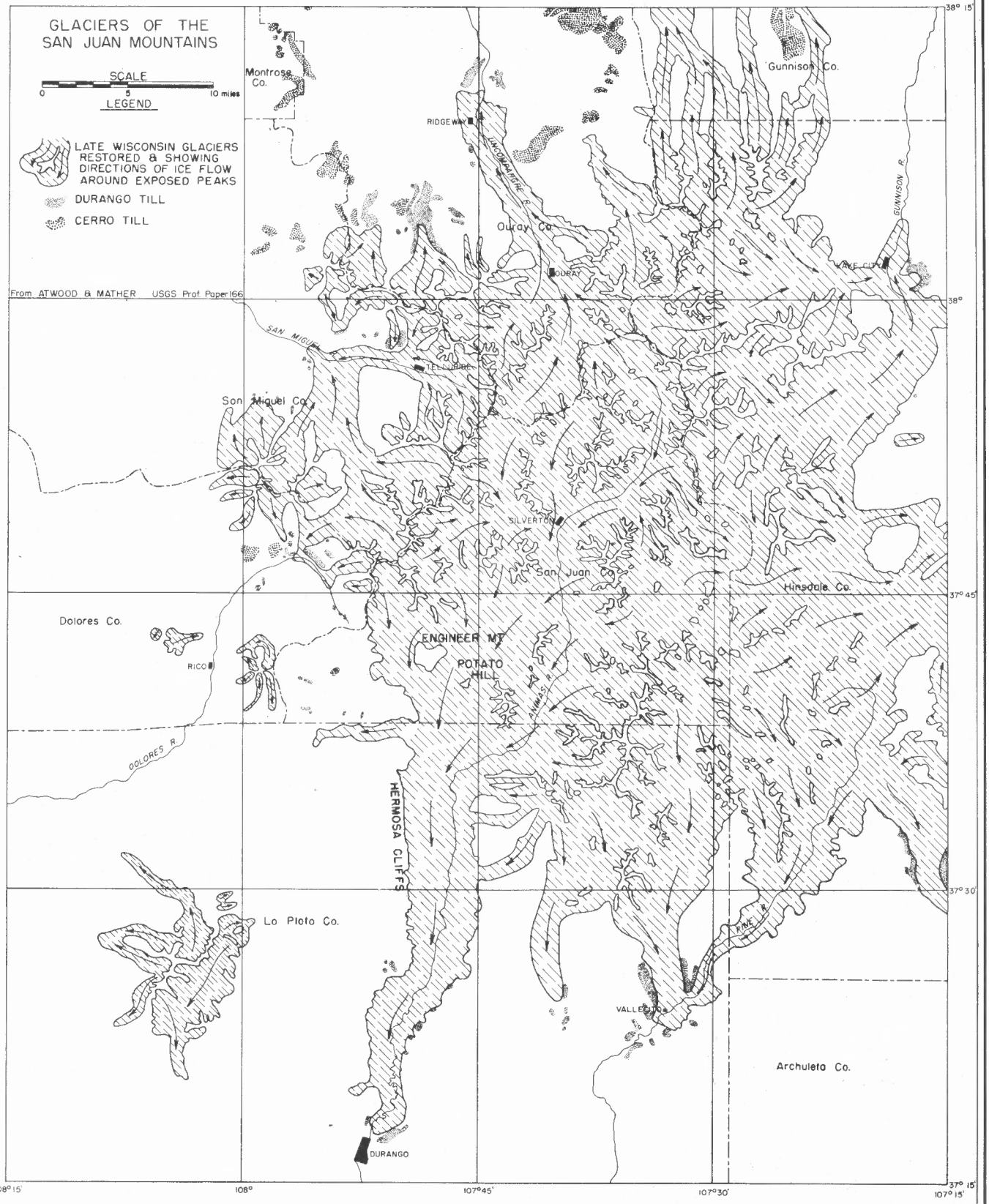

GLACIERS OF THE
SAN JUAN MOUNTAINS
SCALE
0 5 10 miles
LEGEND
LATE WISCONSIN GLACIERS RESTORED & SHOWING DIRECTIONS OF ICE FLOW AROUND EXPOSED PEAKS
DURANGO TILL
CERRO TILL
From ATWOOD & MATHER USGS Prof. Paper166
Montrose Co.
Gunnison Co.
RIDGEWAY
LINCOLN FORK R.
Ouray Co.
OURAY
GUNNISON R.
LAKE CITY
SAN MIGUEL R.
TELLURIDE
San Miguel Co.
SILVERTON
San Juan
Hinsdale Co.
Dolores Co.
ENGINEER MT.
POTATO HILL
RICO
ANIMAS R.
DOLORES R.
HERMOSA CLIFFS
La Plata Co.
LAKE R.
VALLECITO
Archuleta Co.
DURANGO
38° 15'
38°
37° 45'
37° 30'
37° 15'
108° 15'
108°
107° 45'
107° 30'
107° 15'
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FIG. 2

Later-Wisconsin Glacial Stage

During this last episode of widespread glaciation every major valley in the San Juan Mountains was occupied by glaical ice. The magnificent system of these spectacular glaciers is shown on Figure 2. With few exceptions these glaciers deposited conspicuous frontal moraines which mark their termini at the time of their maximum extent. In some places there are remnants of lateral moraines, high on the valley walls, but recessional moraines are somewhat surprisingly rare.

The terminal moraine of the Animas Glacier of this stage forms a double line of low, rounded hills curving across the valley flat at Animas City, a few miles north of Durango. The valley train of outwash gravel is now a discontinuous series of low terraces extending far southward down the Animas Valley and standing 20-40 feet above the modern flood plain. The city of Durango is built in large part upon one of these terraces.

Post-glacial Time

The melting away of the last glaciers was followed by vigorous stream erosion in all of the higher parts of the region. Post-glacial ravines, such as the Box Canyon near Ouray and steep-sided post-glacial notches through the giant glacial steps in the Animas Valley, have been excavated by swift streams where topographic conditions were favorable. Elsewhere the streams meander across flats where glacial erosion and deposition had left considerable fill, upstream from terminal moraines. Landslides, rock streams, and other types of mass movement of superficial debris are especially numerous. But in the main, the topography of the San Juan Mountains is today much as it was a few thousand years ago when the glaciers had completed their sculpturing of cirques and glacial troughs.

Correlation of Pleistocene Glacial Stages

Any correlation of the Pleistocene glacial stages recognized in parts of the Rocky Mountain System with those of the northern Mississippi Valley must still be considered as very tentative, in spite of the many efforts that have been made to solve this problem. Now that the lowan glaciation is generally recognized as earliest Wisconsin, the following correlations are highly probable. The glaciers responsibe for the terminal moraines at Animas City and near Ridgway, and others of obviously identical age, are presumably the Cordilleran equivalent of the Tazewell substage of the Wisconsin of the eastern interior of North America. The Durango glaciers are probably the equivalent of the continental ice sheet responsible for the lowan substage of the Wisconsin. The Cerro till may not all be of the same age, but probably most of it is the time equivalent of the Illinoian drift of the Mississippi Valley.

PRE-PENNSYLVANIAN STRATIGRAPHY OF THE SAN JUAN MOUNTAINS AND FOUR CORNERS AREA*

By

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INTRODUCTION

The San Juan Mountains of southwestern Colorado provide an excellent opportunity to examine pre-Pennsylvanian stratigraphy. In a short distance excellent exposures of rocks of Precambrian to Mississippian in age can be examined. These outcrops do not represent the maximum development of the formations; therefore, they are related to the subsurface units in adjacent parts of New Mexico, Utah, and Arizona to show their regional significance. Figure 1 shows the San Juan Dome and the general area under consideration.

For this study numerous outcrops have been visited and five studied in detail. Three little-known sections, Stag Mesa, Endlich Mesa and Overlook Point (Mountain View Crest), on the flanks of the Needle Mountains were visited in the summer of 1955. Over 100 well logs were studied relative to lithology, correlation, and faunal data where available. A number of these lithologic logs, especially in central Utah, were prepared by C. A. Barkell, J. A. Peterson, Seymour Sharps, and George Herman. The chapters on pre-Pennsylvanian outcrops were written by D. L. Baars; R. L. Knight described the subsurface studies.

Regional Stratigraphy

Figure 2, the correlation chart, compares the section found in the San Juan Mountains with those of adjacent areas.

Cambrian rocks in the San Juan Mountains are called the Ignacio quartzite. The unit is considered Upper Cambrian on the basis of apparent equivalency to the Peerless and Sawatch formations of central Colorado. The thin Ignacio

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