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GENERAL GEOLOGY AND TECTONICS OF THE WESTERN SAN JUAN MOUNTAINS, COLORADO

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INTRODUCTION

No other area of comparable size on the North American continent possesses as great an age sequence or as great a variety of rock types and mineral resources as the western part of the San Juan Mountains. Within this area of only one degree on a side there are Precambrian metamorphic rocks of at least three series invaded by several large and differing granitic batholiths as well as smaller basic alkaline intrusives. There are sedimentary formations ranging from middle Paleozoic to early Tertiary in age which aggregate some 17,000 feet in thickness and include a wide variety of marine and continental types. Several igneous centers appear to have formed during late Cretaceous and early Tertiary times within the area.

The late Tertiary rocks are comprised of several thousand feet of rhyolitic to basaltic flows, breccias, and tuffs which have been divided by mapping into some 20 formations. These are intruded by stocks, plugs, sills, and dikes of several ages and compositions.

Hydrothermal activity accompanying and following the intrusions has produced enormous alteration areas in the invaded rocks and an array of veins probably totalling more than a thousand miles in length, which may be without parallel on the face of the earth. Commercial coal and gas occur in the southern part of the area in Cretaceous rocks and gold, silver, copper, lead, zinc, tungsten, and fluorspar have been produced from deposits in the Precambrian, sedimentary, and volcanic rocks. In addition to bedded replacement, pyrometasomatic, and fissure-vein deposits there are disseminated and vein stockworks, breccia-pipes, and breccia-collapse deposits. Deformational structures are also in variety and in addition to open folds include overturned belts, thrusts, wrench faults, gravity faults, monoclinal flexes, and two great calderic collapse structures between Silverton and Lake City.

This is the "Switzerland" of America, and the Quaternary epochs of glacial and interglacial erosion have produced a marvelous display of U-shaped valleys, cirques, horns, grooved and polished surfaces, roche moutonnees, erratics, and other glacial features. Post-glacial talus piles, rock glaciers, and mudflows are abundant.

After seeing the varied and remarkable display of geological features of the western San Juan Mountains one is usually left with the conviction that here is one of the best-equipped and finest out-of-doors laboratories for study that could be found anywhere.

PRECAMBRIAN DEFORMATION AND GEOLOGIC HISTORY

Precambrian rocks of the western San Juan Mountains are strikingly exposed in several areas, the largest and most diverse of rock types being in the Needle Mountains region (Fig. 1; in guidebook pocket). The rocks of the Precambrian are of four main groups:

(1) schist and gneiss of several kinds and origins.
(2) granitic batholiths of several origins.
(3) greenstone masses.
(4) quartzite, argillite, and conglomerate.

The foliation trends of the ancient schist and gneiss are diverse and the orogenies which undoubtedly accompanied the metamorphism are equally difficult to orient. Furthermore the foliation trends appear to be modified considerably by later faulting and the shouldering of batholithic emplacement (Fig. 2). The principal tectonic actions are incorporated in the following sequence of events during Precambrian time:

(1) Subsidence, sedimentation, and igneous action of earliest pre-schist and gneiss age (Animas Canyon).
(2) Granitic intrusion, followed by metamorphism (Twilight, Tenmile, and Pine River gneissoid granites).
(3) Deformation, metamorphism, and uplift.
(4) Deep denudation exposing the ancient schist and gneiss.
(5) Andesitic volcanism, locally preserved along Vallecito Canyon (Irving greenstone).
(6) Erosion followed by broad subsidence.
(7) Accumulation of conglomerate, sandstone, and mudstone (Needle Mountains group) as a part of a wide area of geosynclinal subsidence and deposition that may have been coextensive with all or parts of the Grand Canyon, Farmington, Uinta, and Apache Algonkian sequences.
(8) Orogeny along west-northwesterly lines involving folding that is asymmetrical and overturned in some places toward the south; southward over-

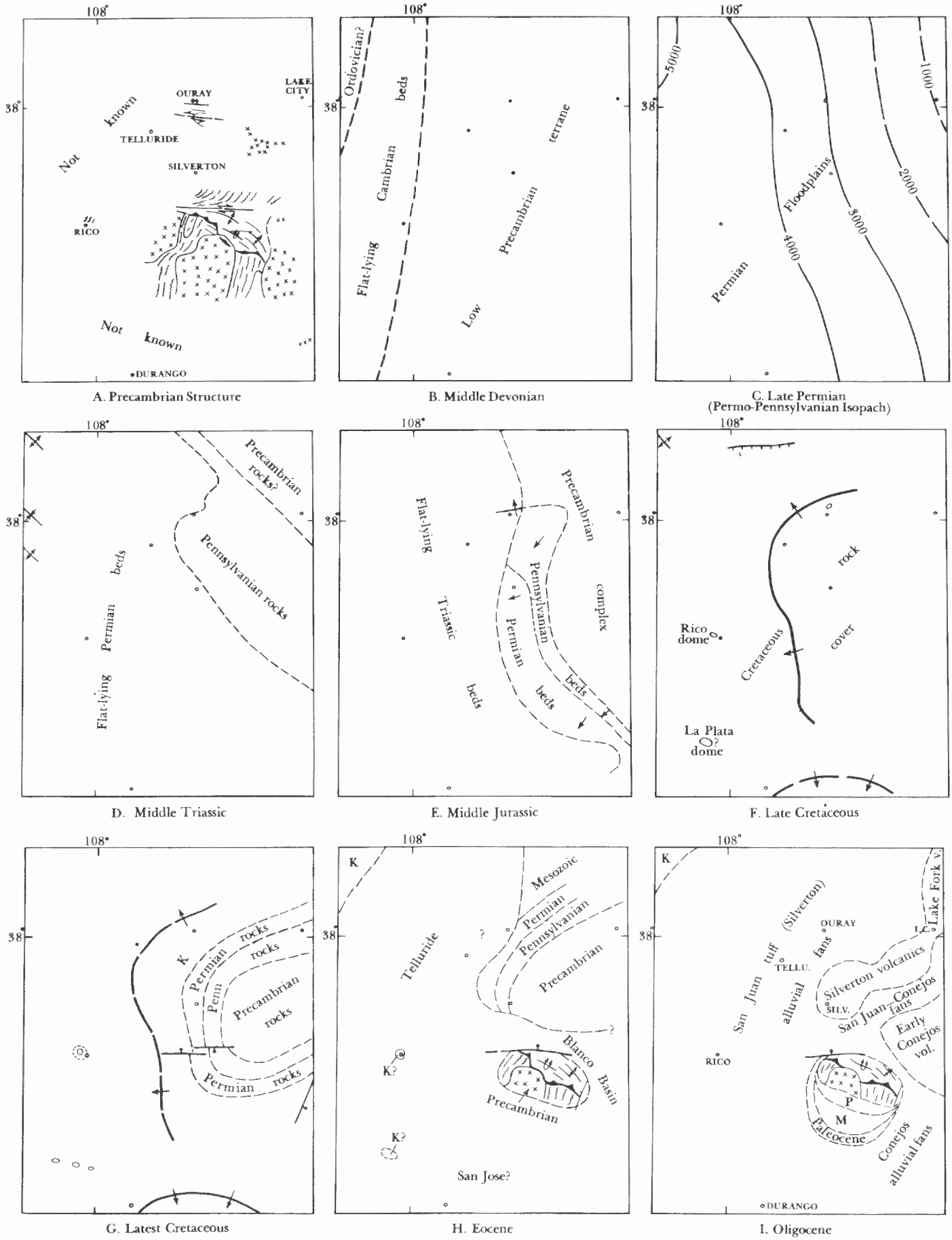


Fig. 2. Paleogeologic diagrams of the western San Juan Mountains, Colorado.

thrusting in the northern Needle Mountains area; and similar fold trends south of Ouray.

(9) Batholithic intrusion (Eolus granite) and doming and uplift; some high-angle faulting around the "Eolus dome".

(10) Widespread peneplanation that may have prevailed from late Precambrian through Ordovician time and possibly into Devonian time.

The westerly swing of the folds and faults of the Needle Mountains group into the east-west faults north of the Grenadier Range may be a regional left-lateral drag along a Precambrian wrench zone. Wrenching of the same sense occurs on the Dunmore fault zone in the Precambrian quartzite of the Uncompahgre formation (Needle Mountains group) south of Ouray.

PALEOZOIC DEFORMATION

Although it has been long accepted that the oldest Paleozoic strata to lie nonconformably on the peneplained Precambrian rocks were late Cambrian in age (Ignacio quartzite; Cross and Spencer, 1899, p. 8), Barnes (1954) has recently concluded that the Ignacio beds are probably Devonian in age and in a sense a basal part of the Elbert formation. It has been concluded from this work that the region of the western San Juan Mountains was a lowland positive area during most of lower Paleozoic time (Fig. 2B). However, the subsurface data are not so complete as to preclude the possibility of deposition of Cambro-Ordovician strata which were subsequently stripped as a consequence of broad rise of the area during Silurian and Devonian time.

During Devonian and Mississippian times the region appears to have been a rather stable shelf upon which first clastic (Elbert) and then carbonate (Ouray and Leadville) beds slowly accumulated to an aggregate thickness as now preserved of only about 400 feet. During this time, however, the stable shelf was probably not without minor vertical oscillations resulting in both some nondeposition and erosion, for some ages (late Mississippian) are not represented. The upper surface of the Kinderhook (?) Leadville limestone is widely modified by karst structures.

During Pennsylvanian and Permian times the region gradually subsided as some 1500-2000 feet of marine and continental sediment (Hermosa and Cutler) accumulated. These rocks are relatively finer grained toward the south and coarser grained and conglomeratic toward the north. The southwestern part was deposited in the eastern part of the Paradox "evaporite" basin during early Pennsylvanian time. During middle and late Pennsylvanian time shelf limestone, sandstone, and mud became the principal accumulations during continued subsidence of the basin and more rapid rise of the source areas to the northeast. In the northwestern and north parts of the area both the Pennsylvanian and Permian sites of deposition were in the shadow of the steadily rising Uncompahgre positive, which at times shed considerable very coarse, fanglomerate-type material into the basin. Just where the source area, or shoreline, lay in the eastern San Juan region is not so clear, and it is possible that Pennsylvanian and Permian beds covered the entire western San Juan region. Although it is commonly thought that the Uncompahgre positive area was continuous southeastward into the ancient San Juan (San Luis) positive, subsequent erosion and burial by volcanic rocks, together with the lithology of the present easternmost Hermosa and Cutler strata, are such as to leave the possibility that the Permo-Pennsylvanian beds of the western San Juans were once continuous northeastward from the Ouray area with similar rocks in the Colorado sag west of the present Sawatch Range. (Kelley, 1955a, Fig. 13).

During late Permian time the San Juan region appears to have been low and undergoing some widespread slow stripping or pedimentation of the early Permian terrane.

MESOZOIC DEFORMATION

Triassic

No lower Triassic rocks are known in the western San Juan Mountains and the late Triassic Dolores (Chinle) formation is thin. Furthermore, the conglomeratic basal Shinarump or Mossback formations that are widespread in the areas to the west and south are not present in the mountain area. It appears, therefore, that the San Juan area although generally low during early Triassic time was not in a position to have received coarse material from adjoining higher areas (Fig. 2D).

In the Paradox basin to the west the salt anticlines and accompanying salt piercements were in their early stages of development and slight expressions of the structures may have extended into the western edge of the San Juan Mountains area during Triassic time.

The principal deformation of Triassic time, however, was an east-trending monoclinal flex at Ouray. This may have been one limb of a low uplift. By late Triassic time stripping on the uplift had removed the Permian Cutler, and the uppermost Triassic Chinle beds lapped across the monocline and onto the Pennsylvanian Hermosa

strata. Either as the result of this uplift or early Jurassic uplift Precambrian rocks may have been exposed in the extreme northeastern part of this area before latest Jurassic overlap of the entire region (Fig. 2E). By the end of Chinle time most of the western San Juan Mountains, with the possible exception of a small area in the northeastern corner, was low and blanketed by a thin (100 feet) layer of late Triassic muds.

Jurassic

Early Jurassic (Glen Canyon) beds are absent in the western San Juan Mountains, but if they were present, then in either late Glen Canyon or early San Rafael time the region was broadly although only slightly elevated and stripped, because throughout the area the late Jurassic Entrada sandstone rests upon the late Triassic mudstones, or older rocks. Thus, in the southeastern corner of the western San Juan Mountains in the Piedra River area, the Entrada sandstone successively overlaps gently folded Triassic and Paleozoic rocks and locally lies directly upon Precambrian rocks (Read et al., 1949). A similar situation is suggested by exposures in the northern part of the mountains and the general line of overlap appears to have trended nearly north across the mountains from the Piedra River. Along the Gunnison River north of the mountains, the Entrada is in turn overlapped by the Morrison for in that area Morrison beds rest directly upon Precambrian rocks.

Cretaceous

During Cretaceous time the low floodplain that had been been blanketed by Morrison beds slowly subsided as an integral part of the Rocky Mountain geosyncline and it is most probable that all the western San Juan area was gradually depressed and buried by several thousand feet of marine and terrestrial sediment. Probably about in Montanan time porphyry stocks and laccoliths were emplaced at several centers such as in the La Plata Mountains, near Ouray, and at Rico. In late Montanan time the San Juan dome began to form, as did the San Juan Basin and portions of the Rocky Mountains. Sediment from the rising dome, including igneous materials derived from the porphyry and some volcanic centers, accumulated in the latest Cretaceous rocks (Kirtland and Animas) of the San Juan Basin.

CENOZOIC DEFORMATION

During Paleocene and Eocene time the San Juan dome continued to rise and by late Eocene time Precambrian rocks may have been exposed in the central part. Judging from the amount of stripping that occurred from late Cretaceous to Eocene time the dome may have risen nearly 10,000 feet. In the end the relief of the dome may have been greatly reduced. Whether the Eocene sediments completely covered the dome or just how far they have lapped upon the dome pose several probabilities. Beneath the great pile of volcanic rocks that now forms the higher parts of the San Juan Mountains there are two formations of uncertain age that bear on this problem. These are the Telluride conglomerate and the Blanco Basin formation. Irving (1904, p. 75-76) considered the Telluride conglomerate, as well as the overlying San Juan tuff, to be Eocene. Larsen and Cross (1956, p. 60) have supposed that these formations are as young as Oligocene or early Miocene. If this is correct, then if the older San Jose (Wasatch) formation covered the fringes or the center of the dome, it was stripped away as the result of further doming possibly during late Eocene or early Oligocene time. On the other hand, it is possible that the Blanco Basin and Telluride conglomerate formations are Eocene in age and are outlier facies of the once more extensive San Jose formation (Fig. 2H). South of Ouray there is a locality where the Telluride pinches out in talus against Precambrian rock (Kelley, 1946, p. 298), indicating that Precambrian rock was exposed that far west in Telluride time, whether Oligocene or Eocene. No volcanic debris is present in the main part of the Telluride conglomerate. It is composed mostly of Precambrian rocks and Paleozoic limestone.

The San Juan tuff overlies the Telluride conglomerate with apparent conformity across a transitional boundary. The tuff, however, extends east of the easternmost edge of the conglomerate where it lies on all pre-Tertiary rocks, in places with considerable irregularity. The San Juan tuff reaches a maximum thickness of about 3,000 feet near Ouray, but elsewhere is considerably thinner. The source of the San Juan tuff, which is principally a fanglomerate, is obscure. Larsen and Cross (1956, p. 69) have believed that the only pre-San Juan igneous rocks exposed in the mountains are the Lake Fork volcanic and intrusive masses. Since only a small percentage of the San Juan fragments are similar to the Lake Fork rocks, which the San Juan tuff overlaps, it was concluded that the principal source had either been eroded, in San Juan or pre-Silverton times, or lay buried beneath the Silverton and Potosi volcanics. There is, however, some good evidence that the Silverton volcanics, especially the Picayune quartz latite, Eureka rhyolite, and possibly later units, were contemporaneous with parts of the San Juan tuff (Kelley, 1946, p. 298, pl. 2). Along Uncompahgre Canyon near the junction with Poughkeepsie Creek, intertonguing between San Juan tuff and the Silverton flows and breccias is clearly shown. In general the San Juan tuff intertongues with or grades into several of the Silverton flows and

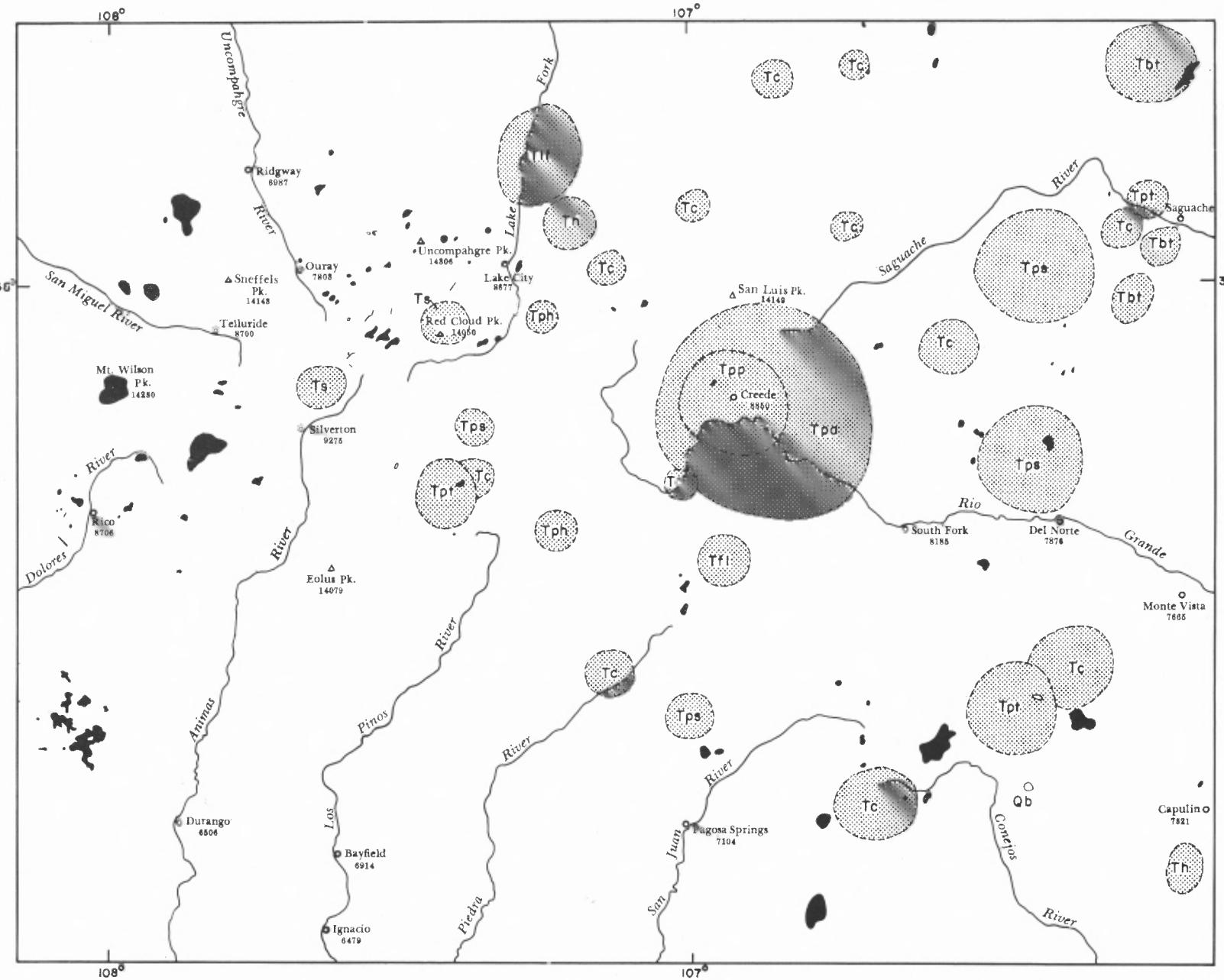
flow breccias from Eureka rhyolite to Burns latite in a band 1-2 miles wide extending from north of Mount Abrams across Ironton Valley into the eastern slopes of Hayden Mountain and southward along the slopes above the Treasury tunnel. Nearly everywhere around this edge of the Silverton rocks they lie horizontally in juxtaposition to the San Juan tuff through 1,000-2,000, feet of altitude, so that the San Juan tuff is best considered a facies of the Silverton volcanic group. Cross and Larsen (1935, p. 59) and Burbank (1933, p. 140-141) believed that this relation resulted from great post-San Juan tuff erosion or possibly subsidence in the area where the Silverton group of volcanics now exists, and that the tongues of San Juan beds that extend into the Silverton flows and beds were reworked eastward from the eroded escarpment in the San Juan beds. Products of this postulated large amount of erosion of the San Juan tuff are not evident, nor are the subsidence structures. The San Juan tuff tongues do not dip to the east as one would expect if they were reworked, and in general the evidence is clear that as the Silverton volcanics built up, outwash and pyroclastics from them formed the fanglomeratic San Juan tuff-breccia. Locally there are latite flows in the San Juan tuff southwest of Ouray (Kelley, 1946, pl. 1). In late Silverton time and early Potosi time the more expansive eruptions of the Silverton pyroxene-quartz latite and Potosi Treasure Mountain rhyolite spread far to the west over the alluvial plains of the San Juan tuff. Probably a great range of volcanoes extending from near Silverton to the Lake Fork area were in eruption during San Juan time (Fig. 21). This range included all the Silverton volcanic eruptions aggregating several thousand feet and the Lake Fork quartz latite volcanics.

The eastern part of San Juan Mountains is made up of a thick sequence of volcanics consisting predominantly of a lower group known as the Potosi volcanics (rhyolite and latite flows, tuff, and breccia) and an upper group dominated by the extrusive Hinsdale formation (rhyolite and rhyolite-basalt flows). The Potosi volcanics also occupy considerable areas in the eastern part of the western San Juan Mountains, and even though the numerous divisions are best represented in the central and eastern parts of the Mountains the group first got its name from exposures at Potosi Peak about 5 miles west-southwest of Ouray. At Potosi Peak a sequence of some 1,300 feet of the Treasure Mountain rhyolite lies upon Silverton volcanics. The Potosi Treasure Mountain rhyolite is separated 15 miles from similar rhyolitic sequences also designated Treasure Mountain by Larsen and Cross (1956, pl. 1) which lie to the east of Silverton and northeast of the Needle Mountains. In the latter area, on either side of a ridge only one mile wide, the Treasure Mountain rocks lie on San Juan tuff on the one side and Potosi (?) Conejos quartz latite flows and breccia of Larsen and Cross on the other. The San Juan and Conejos, although very near to each other and at the same altitude, to my knowledge have never been mapped in contact. The Conejos sequence is very widespread in the southeastern part of the San Juan Mountains and constitutes the greatest volume of any of the volcanic formations, covering some 10,000 square miles to a maximum thickness of 4,000 feet (east of Pagosa Springs) and aggregating some 3,000 cubic miles of rock (Larsen and Cross, 1956, p. 97).

Although the Conejos formation, consisting of quartz latite, flows, breccia, and gravel, is designated by Larsen and Cross as younger than the Silverton volcanics believe that its field relations as well as composition suggest an age equivalence with much of both the San Juan tuff and the Silverton volcanics. The clastic beds of the Conejos are dominant and these increase southward and become more fluvial in aspect. It is probable that the fanglomeratic outwash from the great domes of Conejos eruptions spread southward for many tens of miles across the San Juan Basin at the same time that the bulk of the San Juan tuff accumulated near Ouray.

The correlation of Conejos rocks with the San Juan tuff and with the Silverton rocks as suggested here raises also the question of their possible age. It has been suggested herein that the Telluride and Blanco Basin formations might be Eocene and somewhat older than indicated by Larsen and Cross and similar to the suggestions by Irving (1904, p. 76) and Van Houten (1957, p. 387). The Conejos along the south side of the Mountains rests in near conformity upon the Blanco Basin beds in a manner similar to the San Juan tuff on the Telluride beds. It is, therefore, possible that much of the Conejos as well as San Juan tuff and parts of the Silverton group may be Oligocene.

The Needle Mountain dome appears to have stood high during San Juan-Conejos time and in fact may have risen some during this time. However, both San Juan and Conejos rocks lapped upon the Precambrian. At the end of the early period of volcanic eruptions (Silverton and Conejos) the region probably stood as a volcanic plateau, above which rose the Precambrian Needle Mountain dome and probably other broad volcanic domes. Youthful canyons, several thousand feet deep, appear to have dissected this highland area. At least three sequences of Potosi latite-rhyolite eruptions poured into and across these canyons, the later sequences in places filling deep



EXPLANATION

Tps

Central areas of the volcanic piles

Pliocene?
- Th Hinsdale rhyolite and basalt
- Tf Fisher quartz latite
- Tpp Piedra rhyolite

Miocene?
- Tph Huerto quartz latite
- Tpa Alboroto rhyolite
- Tps Sheep Mountain quartz latite
- Tpt Treasure Mountain rhyolite

Oligocene?
- Ts Silverton quartz latite and rhyolite
- Tc Conejos quartz latite*
- Tl Lake Fork quartz latite
- Tbt Beidell and Tracey Creek quartz latite

*Several possible and hypothetical centers given for this thick, expansive group which may include some units younger than some of those of the Silverton group

Intrusives younger than Silverton or Conejos

Intrusives of Conejos, Silverton, or late Cretaceous ages

SCALE
0 10 20
Miles

Fig. 3. Map of the San Juan Mountains, Colorado showing intrusives and central portions of the volcanic piles

canyons or overlapping steep slopes of the earlier sequences. These eruptions occurred mostly in the central part of the mountains but they are present locally in the northern and eastern parts of the western San Juan Mountains (Fig. 3). Following the long and extensive Potosi eruptions, canyons several thousand feet deep again may have been cut into the volcanic plateau and these filled locally by Fisher quartz latite mostly in the central part of the Mountains.

According to Atwood and Mather (1932, p. 21-23), also Larsen and Cross (1956, p. 63), after the great latite and rhyolite eruptions of late Miocene time the entire area was eroded to a lowland, the San Juan peneplain, and then the Pliocene Hinsdale rhyolite and rhyolite-basalt flows were spread widely across the peneplain. These flows, present only locally along the eastern side of the western San Juan Mountains, are now preserved mostly in the eastern and southeastern parts of the Mountains.

Larsen and Cross (1956, p. 245) summarize the deformations during the principal volcanic eruptions as follows:

> The conclusion is reached that after the eruptions of the Silverton volcanic series the northwestern part of the area, where the Silverton and San Juan rocks are present, was depressed several thousand feet. Erosion reduced the area to a rather mature surface before the Potosi volcanic series was erupted.
>
> During the long time in which the Potosi and Fisher rocks were erupted the central part of the mountains was built up and maintained as a high plateau or dome. There was some local faulting, but so far as known no widespread depression or elevation of the area. The borders of the area of volcanic rocks, notably in and near the Conejos quadrangle, seem to have been progressively depressed during the volcanic eruptions so that its surface remained about base level throughout Potosi and Fisher time. The total depression of this bordering area was several thousand feet.
>
> Following the eruptions of the Fisher quartz latite the central area was depressed several thousand feet and the border area was little disturbed. The San Juan peneplain was then cut and the eruptions of the Hinsdale formation were spread over the peneplain.
>
> Beginning in late Pliocene and continuing into the Pleistocene the area was elevated to an asymmetric, deformed dome. The highest part of the dome was in the Needle Mountains where the base of the volcanic rocks was at an altitude of more than 14,000 feet and the base of the Potosi volcanic series may have been several thousand feet higher.

It is difficult to follow their reasoning in supposing the considerable depressions following Silverton and Fisher times, except for the fact that the base of the volcanics in the central part of the Mountains appears to be much lower than along the margins (Larsen and Cross, 1956, pl. 4). It appears also they believe that otherwise most of the volcanics would have eroded as a result of the recurrent uplifts that are suggested by the ancient canyon profiles within the volcanic sequences. Burbank (1941, p. 149) has concluded that the area of the Silverton eruptions formed in a subsiding basin and that "the basin became accentuated with the thickening of the series" and "ring faults and associated radial fractures developed." No Potosi rocks occur with Silverton or Lake City caldera collapse structures and this fact also may lend support to the concept of pre-Potosi subsidence.

Faults are exceedingly abundant throughout the volcanic rocks; most of these, however, have thraws of less than one or two hundred feet. Probably some faulting accompanied nearly very epoch of volcanic eruption. Some faults may be established as pre-Potosi in age; a great many more appear to have formed at the end of Potosi time; and some fairly large ones are post-Hinsdale (Pliocene?) in age (Atwood and Mather, 1932, pl. 2).

The sequence of intrusions is at least as long as that of the volcanic eruptions. Best dated of the intrusives are the stock and laccoliths near Ouray. Burbank (1930, p. 199-206) found that the laccoliths intrude Upper Cretaceous Mancos shale and are overlapped by Telluride conglomerate in which are found boulders of the intrusive porphyry. Thus, the intrusive may be late Cretaceous to Oligocene in age depending upon the age of the Telluride. South of the mountains the late Cretaceous Animas formation and its McDermott member contain igneous fragments that have been interpreted as derived from the La Plata intrusives, suggesting a late Cretaceous age for them. Atwood and Mather (1932, p. 20), on the other hand, believed the La Plata and Rico centers to be undoubtedly late Tertiary. Some of the intrusives east of Pagosa Springs may be pre-Conejos; others, Conejos; and others, post-Conejos in age. Numerous intrusives in the Silverton area are post-Silverton and others of a more obscure nature may be Silverton in age. Post-Potosi intrusives are fewer in number and include principally small plugs and dikes of Fisher age. Intrusives of Hinsdale (Pliocene?) age are probably confined to the eastern part of the San Juan Mountains (Fig. 3).

Most of the veins and other mineral deposits of the western San Juan Mountains may be late Potosi in age. Some deposits are probably late Cretaceous or early Tertiary and others may be as young as early Pliocene.

Some of the most interesting aspects of the tectonic

history of the San Juan Mountains arise out of the concept of a San Juan peneplain (Atwood and Mather, 1932, p. 21-26). In late Miocene and/or early Pliocene time it is though that a long period of erosion ensued following the epochs of volcanism. On the basis of flanking positions of gravel-capped (Bayfield and Los Pinos) mesas and ridges and the extensions of outliers into summit valleys the concept of a "summit peneplain" across the San Juan Mountains has been developed. Above this old age erosion surface numerous monadnocks rose, some as much as 1,000 feet. Basalt flows of the late Pliocene (?) Hinsdale lie on the gravel-covered erosion surface, in many places in the central part of the mountains at altitudes of about 11,000 feet. The interpretation of many of the summit valley and ridge shoulders as extensions of the surface, especially after much subsequent river and glacial erosion, is of course open to debate in many places; but the surface at the base of the many Hinsdale outliers is essentially irrefutable evidence. The existence of the erosion surface across the dome is not in itself so unusual, but what is remarkable is the subsequent deformation that is interpreted by Atwood and Mather to have taken place (1932, pl. 2). According to them (p. 24) the surface of the dome is "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." Most of the present relief of the peneplain surface is thought to be due to deformation during late Pliocene and Pleistocene uplifting of the mountains. The configuration of the surface is a curious combination of "residual highs", "domes", "arches", "sags", "basins" all of which are surmounted locally by "monadnocks". The total reconstructed surface that now stands more than 8,500 feet above sea level is referred to as the San Juan dome. The highest of the "residuals", Eolus or Needle Mountain, is about 13,500 feet. This means that since the development of the San Juan peneplain the dome area including most of the mountains has risen about 8,500 feet by broad regional uplifting, while an extra 5,000 feet was accomplished by the mountain doming (San Juan dome). Probably, however, only about 4,000 feet of the latter figure should be attributed to over-all general doming, owing to the gradients that must have existed on the summit peneplain.

The uplift that deformed the San Juan peneplain initiated the subsequent stream and glacial erosion which ultimately resulted in the present rugged landscape. The doming, however, is thought to have continued through this epoch and some 1,500-2,000 feet of the uplift is thought to have occurred after the early stage (Florida-Cerro) and several hundred after the second stage (Canyon-Durango). Additional erosion, not necessarily initiated by uplift, occurred in late Pleistocene (Wisconsin) and Recent times.

SUMMARY AND CONCLUSIONS

Two principal orogenic trends of Precambrian age may be noted in the western San Juan Mountains – an earlier one of northerly direction and a later one of westerly direction. Both of these have been modified by batholithic emplacements. The earliest covering of the deeply peneplaned Precambrian appears to have occurred in Devonian time. Some stripping and karst development may have occurred in late Mississippian time. Considerable subsidence and deposition continued with minor and local interruption through Triassic time. Uplift followed by erosion removed Triassic to Precambrian rocks in the eastern part of the area before Jurrassic Entrada time. During Cretaceous time the entire area subsided several thousand feet as the thick blanket marine and floodplain deposits accumulated in the Rocky Mountain geosyncline. In about Montanan time the area was again uplifted and intrusive porphyry and volcanic debris became available to Kirtland and Animas beds accumulating marginally. High-angle faulting occurred around the Needle Mountain dome and the ensuing erosion again laid the Precambrian rocks bare in the central and southern parts through Paleocene and early Eocene times. Overlapping by Eocene San Jose, Blanco Basin, and Telluride beds covered the pedimented flanks of the uplift.

Probably in Oligocene time volcanism (Silverton, Lake Fork, and Conejos), in great force, developed throughout much of the San Juan Mountains and as these piles accumulated great volcanic-laden alluvial fans spread away in all directions. The Needle Mountain Precambrian dome, as well as the La Plata, Rico, and possibly other laccolithic domes, probably stood as prominent topographic features against and around which the volcanics and especially alluvial materials of the San Juan, Silverton, and Conejos accumulated.

With cessation of the early eruptions erosion worked vigorously on the high parts of the volcanic plateau and the nonvolcanic eminences. This was followed by the thick and expansive rhyolite and latite eruptions of the Potosi and Fisher groups accompanying and following which there was further vigorous erosion as well as some faulting, warping, local subsidence and probably much fumarolic, hot-spring and hydrothermal activity. This was followed by erosion which developed the San Juan "peneplain". Upon this surface gravel and rhyolite-basalt eruptions of the Hinsdale formation were spread.

This in turn was followed by broad regional uplift, some further local warping and faulting which brought the terrane to its present high position where it has been carved into the present rugged landscape since late Pliocene time.

There are many problems that remain to be solved concerning the geomorphology and the volcanic stratigraphy. These pertain principally to the great Potosi group of volcanics and especially to the Conejos formation. It has been suggested here that the thick Conejos breccias and flows may consist of some units older than and equivalent to some of the Silverton eruptions, as well as younger, as has been proposed previously. It is also believed that the lower Conejos may have been contemporaneous with some of the San Juan tuff, which in turn intertongues with much of the Silverton flows and flow breccias. The sum and substance of these proposals suggest more concentration and equivalence in time for the many of the widely separated eruptions. A greater age is also suggested. It is also thought that many of transections of younger flows across older ones, that have been interpreted as conyon fillings following prolonged erosion, may be simply fillings of original depressions and saddles that resulted from the irregular coalescence of nearby volcanic eruptions. It is also proposed that during and following the most active epochs of volcanism great alluvial fans and plains spread for several tens of miles away in all directions from the centers. These great alluvial blankets have been since exhumed. The San Juan tuff is a large remnant, perhaps preserved because of the protecting cap of younger flows and by the vagaries of regional headward erosion. During Oligocene and Miocene times the alluvial blanket of volcanic outwash, similar to that now preserved as the San Juan tuff, may have been a hundred times the volume of that remaining and may have been spread once far across the San Juan Basin as well as far to the west in certain places.

LITHOLOGIC CONTROL OF ORE DEPOSITS IN THE SOUTHWESTERN SAN JUAN MOUNTAINS

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INTRODUCTION

The selection of favorable beds by ore-bearing solutions has long been of great interest to geologists and miners. The ability to predict which beds were or were not favorable for ore deposition can greatly facilitate prospecting and the development of a district.

In this study the following techniques for judging favorableness were used: 1. The opinions of authorities for the districts which they studied, 2. Independent conclusions by the writer from close scrutiny of available published information, and 3. The statistics showing the total value of ore produced, the number of mining years, and the total number of mines in a particular formation.

This report is based primarily on published information listed in the bibliography. The author's familiarity with the western San Juan Mountains was obtained during two field seasons with the U.S. Geological Survey. Only the camps of Silverton and Ouray are treated in specific detail.

THE SAN JUAN MOUNTAIN REGION

The San Juan Mountain region of southwestern Colorado has an area of about 12,000 square miles, about the size of Massachusetts and Connecticut combined. The greater part of the region is occupied by high rugged mountains, with many of the peaks exceeding 13,000 feet in altitude. These mountains are formed chiefly of Tertiary volcanics and Precambrian rocks but some Paleozoic and Mesozoic sedimentary formations also crop out.

Table 1 is a tabular summary of mineral deposits of the San Juan region that gives the environmental conditions of ore deposition and the production value of the metallogenetic epochs.

The geographic location of the several mining districts and an outline of the San Juan Mountains are shown on Figure 1.

The geological formations found in this area range from Precambrian rocks through Paleozoic and Mesozoic sediments to a thick capping of Tertiary volcanics. See generalized stratigraphic section of the western San Juan Mountains.

GEOLOGIC HISTORY

At the beginning of volcanic activity in Late Cretaceous or early Eocene time the western San Juan region was covered by Upper Cretaceous formations at least 4,000 feet in thickness (Burbank, 1930, pp. 208–210). These beds were unconformably covered by Late Cretaceous or early Eocene formations which contain volcanic debris and so overlap the older formations as to indicate a domal uplift of the region. This uplift was accompanied by the intrusion of monzonite