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RELATION OF THE ORE DEPOSITS OF THE SOUTHERN ROCKY MOUNTAIN REGION TO THE COLORADO PLATEAU

By B. S. Butler[1]

Summary

In the first part of this paper it is pointed out that the ore deposits of the southern Rocky Mountain region are concentrated in a narrow belt surrounding the Colorado Plateau. It is shown that the ore deposits are associated with volcanic fields which are also largely confined to the same belt surrounding the Colorado Plateau. It is further shown that the major folding, faulting and mountain building of the Tertiary revolution was concentrated in the belt around the Colorado Plateau. In an attempt to explain these relations in the latter part of the paper it is shown that the sedimentary rocks around the northern portion of the plateau, at least, are much thicker than within the plateau. It is suggested that the plateau region was long a positive area undergoing erosion or moderate deposition while the surrounding area was a negative area of deposition. At the time of the Tertiary revolution the basins of deposition underwent folding and faulting with accompanying igneous activity, a part of which was the formation of ore deposits.

Introduction

In the southern Rocky Mountain region and the Colorado Plateau geologic work has been in progress since the sixties

[1]Geologist in charge, Colorado Co-operative Geological Survey. This paper is published by permission of the Director of the U. S. Geological Survey and the President of the Colorado Mining Association.

of the last century, and in this period of about 70 years a vast amount of information has been accumulated. Few other regions in America have engaged the attention of so large a number of geologists or have contributed more to our knowledge of geologic processes. A list of the men who have worked in the region would include the names of a large proportion of the distinguished American geologists of the older generation, as well as many of the present day, and a list of the published papers setting forth the results of their work would include several that are classics in American geologic literature.

It has fallen to the lot of the writer to work in or to visit many of the mining districts of the southern Rocky Mountain region, and during this work his interest has been aroused in the relations of the ore deposits to the regional geology. Although many data had been gathered, they could not, until recently, be brought together on a map of adequate scale to show clearly the broad geologic features. In 1913 the Colorado Geological Survey published a geologic map of Colorado; in 1918 the Geological Survey published a geologic map of Utah as a plate in Professional Paper 111; in 1924 the Arizona Bureau of Mines, in cooperation with the Geological Survey, published a geologic map of Arizona; and in 1928 the Geological Survey published a geologic map of New Mexico, thus completing the geologic map of the southern Rocky Mountain states. The maps of Colorado and Utah are already in need of revision, but they give a general picture of the broader geologic relations.

It is the purpose of this paper to present some of the general features of the geology of this region, especially the relation of the mining districts to the Colorado Plateau, even though it is not yet possible to give very conclusive and convincing evidence to account for the relations set forth.

Importance of Ore Deposits of the Southern Rocky Mountain Region

The southern Rocky Mountain region is one of the great metalliferous provinces of the world. It has yielded gold, silver, copper, lead, and zinc to the value of more than $5,000,000,000, and the rate of yield is still as large as at any time in the past. In 1928 the region produced more than $230,000,000 worth of the five metals named, besides a considerable quantity of molybdenum, vanadium, and tungsten. There seems little doubt that this order of production will continue for many years.

The metal-mining industry has exerted a large influence in the settlement and development of this region, though the earlier settlements—those of the Spanish missionaries in Arizona and the Mormon pioneers in Utah—were based on other inducements. The settlement of Colorado was directly due to the presence of placer gold with abundant water for washing the placers and of rich lode deposits that were susceptible to simple metallurgical treatment. There was some mining in New Mexico at an early period, but in the main the strong influence of the presence of minerals in the settlement and development of New Mexico, Arizona, and Utah was not felt until the building of railroads made it possible to mine and treat the ores that yielded copper, lead, and zinc as well as gold and silver. For the region as a whole, metal mining has been a steadily growing industry though the relative importance of agriculture and other industries has increased. The metal-mining industry thus not only warrants but compels the interest and attention of everyone concerned with the prosperity of the region.

Geographic Distribution of the Mineralized Districts

The accompanying map shows the distribution of some of the more productive mining districts of the southern Rocky Mountain region. The districts that are not shown have a similar distribution.

Plate 1. Generalized map of the Colorado Plateau and surrounding region compiled by Eldred Wilson, Arizona Bureau of Mines, from U. S. Geological Survey Professional Paper 71 and State maps. An inspection of the map shows

that in the central part of the region there is a great area nearly 500 miles in diameter (the Colorado Plateau) that contains no large mining districts. The chief producing districts are grouped in a relatively narrow belt around this area. North of this belt there are no important mining districts for several hundred miles, to Montana, central Idaho, and the Black Hills. To the east metals are lacking in a wide area extending to the Mississippi Valley. To the south the belt joins the Mexican metalliferous province, and to the west it probably overlaps the Sierra Nevada province. Ferguson[2] has pointed out the difference between the ore deposits of western and eastern Nevada and placed the boundary in central Nevada, with probably some overlap. The San Juan area of Colorado and the San Francisco-Marysvale area of Utah lie somewhat inside the main productive belt.

In this belt surrounding the Colorado Plateau are several of the large copper districts of the world, several of the country's greatest lead and silver districts, one of the world's great gold districts, and the world's largest molybdenum deposit. Zinc is also found abundantly in this belt.

Does this concentration of mining districts around the Colorado Plateau represent a real concentration of mineral wealth? It is unlikely that the symmetrical arrangement exhibited is the result of chance discovery and it seems worth while to attempt to find the cause or causes that may explain it.

Association With Igneous Activity

Students of ore deposits are generally agreed that many deposits are closely associated with igneous rocks and that there is a causal relation between igneous activity and ore deposits. On the margin of the Colorado Plateau region and extending around it in considerable part are the great volcanic fields of the southern Rocky Mountains. It is in close association with these volcanic fields that the ore deposits

[2]Ferguson, Henry G., Mining Districts of Nevada; Econ. Geology, vol. 24, pp. 115-148, 1929.

which are of Tertiary age occur. In the plateau region itself igneous activity, though occurring, as indicated by the laccolithic intrusions of the La Sal, Abajo, Henry, and other mountain groups, has not been vigorous. Outside the belt surrounding the plateau there is also a lack of igneous rocks other than pre-Cambrian, except to the south and west, where the igneous rocks of the southern Rocky Mountain region merge with those of Mexico on the one hand and overlap those of the Sierra Nevada on the other.

It seems reasonable to assume that the ore deposits in this belt are due to the igneous activity and that the igneous activity was concentrated around the plateau region, but this assumption leads us back only one step in the search for a cause, and it may well be asked, "Why are these centers of great igneous activity grouped around the plateau?"

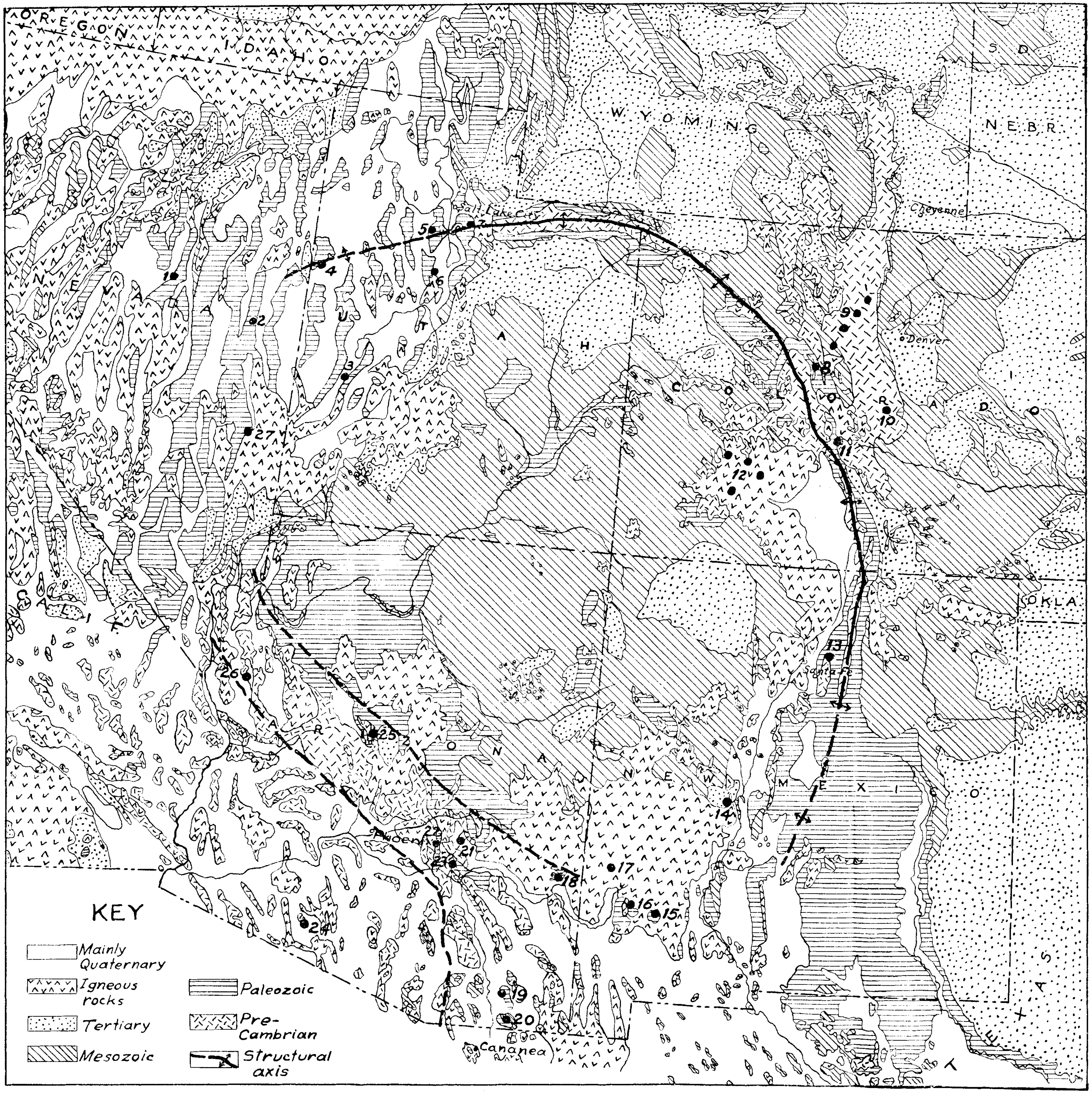
Relation of Igneous Activity to Structure

As possibly bearing on the cause of igneous activity we may examine the broader structural relations of the region. Within the plateau area the rocks are relatively flat lying. There are numerous great swells, such as the San Rafael Swell, the Monument Valley uplift, and the Defiance uplift, and a multitude of minor structural features of similar character, as well as many faults, but as a whole the rocks are comparatively undisturbed. At the margin of the plateau, however, throughout its circumference the rocks are much folded and faulted and the pre-Cambrian rocks, for example, have been raised several thousand feet above their altitude within the plateau. In Utah, Colorado, and New Mexico, the pre-Cambrian rocks in the belt surrounding the plateau reach altitudes of 13,000 to 14,000 feet, without allowance for the portions removed by erosion, and in Arizona, but a few thousand feet less. This is thousands of feet higher than they reach in most of the plateau region. In the Defiance uplift and probably in other uplifts within the plateau, the pre-Cambrian has been raised to somewhat higher altitudes than the average for the plateau.

Extending half way around the Colorado Plateau from central New Mexico through Colorado and eastern Utah, the broader structural features have a clearly concentric arrangement. One great series of anticlinal folds can be traced through this whole distance. The Sangre de Cristo anticline extends in a direction east of north from central New Mexico to Colorado, whence it runs in a northwesterly direction through the Collegiate Range and the Sawatch or Park Range, and is succeeded in turn by the White River Plateau anticline, the Axial Valley anticline, and the Uinta anticline, which extends in a west to south of west direction to central Utah. From the front of the Wasatch Range the continuation of this structure in a southwesterly direction across western Utah is suggested by the elevation of the older rocks in Oquirrh, Granite, and Deep Creek Ranges.

Inside this great series of anticlines and paralleling it are a series of nearly continuous synclines. The Uinta Basin, south of the Uinta anticline, passes eastward into the Grand Junction Basin, which in turn gives place to the Anthracite-Crested Butte Basin. Beyond an area covered by the late lavas of the San Juan volcanic field the synclines are continued west of the Sangre de Cristo Range in the San Luis Valley, which in New Mexico merges into the Rio Grande Valley. Outside of the anticlinal folds, north of the Uinta Mountains, is the Green River Basin, which on the east joins the Yampa Basin. To the southeast the structure is not yet so clearly worked out, but there is a strong suggestion of a connection with the down-folded and faulted areas that form South Park and the Canon City syncline. East of the Sangre de Cristo Range in southern Colorado is the Wet Valley syncline, but farther south the evidence of an outer syncline if one is present is not so apparent.

In Arizona, "the Mountain region," as indicated by Ransome, extends across the State in a northwesterly direction between the plateau on the northeast and the desert ranges on the southwest. The general trend of the structure in the mountain region is northwest, parallel with the border of the



MINING DISTRICTS AROUND COLORADO PLATEAU—

PLATE 1

1. Eureka, Nevada.
2. Ely, Nevada.
3. San Francisco, Utah.
4. Gold Hill, Utah.
5. Bingham, Utah.
6. Tintic, Utah.
7. Park City-Cottonwood, Utah.
8. Leadville, Colorado.
9. Breckenridge-Georgetown-Idaho Springs-Central City, Colorado.
10. Cripple Creek, Colorado.
11. Monarch, Colorado.
12. San Juan Region, Colorado.
13. Pecos, New Mexico.
14. Magdalena, New Mexico.
15. Santa Rita-Hanover, New Mexico.
16. Silver City, New Mexico.
17. Mogollon, New Mexico.
18. Clifton, Arizona.
19. Tombstone, Arizona.
20. Bisbee, Arizona.
21. Globe, Arizona.
22. Superior, Arizona.
23. Ray, Arizona.
24. Ajo, Arizona.
25. Jerome, Arizona.
26. Kingman-Oatman, Arizona.
27. Pioche, Nevada.

Generalized Geological Map of Colorado Plateau and surrounding region. Compiled by Eldred Wilson, Arizona Bureau of Mines, from U. S. G. S. pp. 71 and state maps.

plateau.[3] In southwestern New Mexico and southeastern Arizona the trend of the structure seems to be southward into Mexico rather than parallel to the border of the plateau. Eastern Nevada, where the continuation of the structural features from Arizona and Utah would be expected, has been profoundly affected by the later basin-range structure, and the earlier structure if it still remains is concealed. In western Utah also the earlier structure has been much obscured by the basin-range structure west of the Wasatch fault, which cuts off the westward continuation of the Uinta anticline. In south-central Utah the basin-range structure has encroached on the plateau structure and merges with it in the series of great blocks produced by the faults that fan out toward the south from the Wasatch fault.

From the foregoing description it seems clear that there is a tendency for the major structural features surrounding the relatively undisturbed block of the Colorado Plateau to parallel its margins and to be concentric around it. Through about 180 degrees of a circle the concentric arrangement is well defined. Besides the folds mentioned above there are numerous faults, some of them large. Recent work[4] has disclosed the presence of extensive thrust faults in Colorado, and further work will doubtless bring to light more in the structural belt surrounding the plateau.

The major structural features surrounding the Colorado Plateau are of post-Cretaceous age, and were contemporaneous with or but slightly earlier than the beginning of the igneous activity that probably started in early Tertiary time and continued for a long period, and as these features are in the belt in which the greater igneous activity was concentrated, it seems reasonable to suppose that there was a causal relation between the production of the structure and the igneous activity. It would perhaps be difficult to prove that the igneous

[3] Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U. S. Geol. Survey Prof. Paper 115, p. 27, 1919.

[4] Burbank, W. S., Preliminary report on some thrust faulting involving the Paleozoic formation in the Kerber Creek region of southern Colorado: Geol. Soc. America Bull., vol. 39, p. 172, 1928. Lovering, T. S., Williams thrust fault: Idem, p. 173.

activity resulted from the folding rather than that the folding resulted from the igneous activity. However, if we assume that the igneous activity was the result of the folding we are pushed back one more step and confronted with the question, "Why did the folding occur in a belt surrounding the Colorado Plateau?" The answer to this question is certainly not clearly apparent. There are, however, some suggestions that may lead to an answer when more facts are known and correlated.

THICKNESS OF THE PRE-TERTIARY SEDIMENTARY ROCKS

In this connection it is interesting to examine the thickness of the pre-Tertiary sedimentary rocks in the region, with a view to determining the areas of large deposition and the areas of slight deposition or of erosion. In general in the northern portion of the region sedimentation was greater around the margin of the plateau than it was within the plateau, and in certain of the Paleozoic periods a great thickness of sediment was laid down around the margin but relatively little or none in parts, at least, of the plateau area.

At Pioche, Nevada, on the margin of the plateau, Westgate and Knopf[5] report about 18,000 feet of Paleozoic sedimentary rock. Of this thickness over 8,000 feet is of Cambrian age, and the Ordovician, Devonian, and lower Carboniferous are well represented, but there is only a few hundred feet of the Pennsylvanian. The San Francisco district, Utah,[6] contains about 18,000 feet of sedimentary rocks of which about 10,000 feet is Cambrian, Ordovician, and Silurian; 3,000 feet, Devonian and Carboniferous; 5,000 feet, Triassic. In the Gold Hills area, Utah, Nolan[7] found more than 24,000 feet of pre-Tertiary sedimentary rocks, in which the Cambrian, Ordovician, Silurian, Devonian, and Carboniferous are all well represented, and the base of the section is not exposed. The Oquirrh Range[8] has a thickness of 25,000 feet of sedimentary

[5]Westgate, L. G., and Knopf, Adolph, Geology of Pioche, Nevada, and vicinity, Am. Inst. Min. and Met. Eng., 1927.
[6]Butler, B. S., The San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 29, 1913.
[7]Nolan, T. B., Stratigraphy and structure, Gold Hill, Utah: Geol. Soc. America Bull., vol. 39, p. 183, 1928.

rocks, with the base not exposed. A large part of this section is of Carboniferous age. In the neighboring Wasatch Range[8] there is a thickness of about 10,700 feet of sedimentary rocks above the pre-Cambrian. Only a relatively small part of this is pre-Carboniferous, and of the early Paleozoic periods, probably only the Cambrian is represented. The thickness of the pre-Cambrian sedimentary series is not well known, on account of thrust faulting that has not been fully worked out, but it is probably as great as that of the post-Cambrian. The sedimentary rocks in the vicinity of the Uinta Mountains and the basin to the north are probably fully as thick as those in the Wasatch Range. Lawson[9] states that their thickness probably exceeds 35,000 feet, of which 20,000 feet is Cretaceous. To the southeast the pre-Tertiary sedimentary rocks in the Anthracite-Crested Butte area[10] and the Aspen district[11] attain thicknesses of about 12,000 and 14,000 feet. The lower Paleozoic formations here make up a relatively small proportion of the section. In the Sangre de Cristo Range there is probably 20,000 feet of pre-Tertiary sediments, of which Pennsylvanian makes up a large part.[12] Southward into New Mexico less definite data are available regarding the thickness, but the sedimentary rocks seem to be thinner. It seems evident, then, that around the northern half of the plateau region there was a thick accumulation of sedimentary rocks in pre-Tertiary time.

Within the plateau the thickness of the sedimentary rocks varies greatly from place to place. In the northern part of the San Juan volcanic field the Tertiary lavas in places rest directly on the pre-Cambrian and northwest of the La Sal Mountains in Utah and Colorado the Triassic rocks rest directly on the pre-Cambrian. In the Grand Canyon Noble[13]

[8]Butler, B. S., Ore Deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pl. 5, 1920.
[9]Lawson, A. C., Folded mountains and isostasy: Geol. Soc. America Bull. vol. 38, p. 269, 1927.
[10]Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.
[11]Spurr, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, 1898.
[12]Johnson, J. H., Colorado Sci. Soc. Publ. Vol. 12, pp. 3-21, 1929.
[13]Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, p. 36, 1923.

measured 4,000 feet of Paleozoic sedimentary rocks, from which the Mesozoic had been removed. Darton[14] states that in the deepest part of the San Juan Basin there may be a thickness of 15,000 feet of sedimentary rocks, but this has not been shown and is certainly an unusual thickness for the plateau region. For the Navajo country Gregory[15] gives a thickness of pre-Tertiary rocks ranging from 3,500 to 7,500 feet. In the Moab region, Utah,[16] pre-Tertiary section, not including the Mancos shale and with the base not reached in the Hermosa formation, ranges from 2,775 to 6,250 feet. Gilluly and Reeside[17] find a comparable thickness in the San Rafael region, with about 4,000 feet of Mancos shale. In few places in the plateau region is the base of the sedimentary series exposed. Published reports, therefore, do not indicate how thick the sedimentary rocks may be within the plateau region, though one or more wells drilled for oil are known to have reached pre-Cambrian rocks. So far as can be judged from the available data, however, the sedimentary rocks within the plateau seem much thinner than those around the northern margin. Moreover, there are in the section many unconformities representing periods of erosion or nondeposition, and the early Mesozoic sediments seem to be in large part continental rather than marine deposits. This suggests that for much of pre-Tertiary time the plateau region may have either stood above sea level and been actively eroded or was the site of only relatively moderate deposition, a considerable part of which was continental.

The thicker sections within the plateau region, with the possible exception of the section in the San Juan Basin, appar-

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[14]Darton, N. H., Red beds and associated formations of New Mexico: U. S. Geol. Survey Bull. 794, p. 3, 1929.

[15]Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 195, 1917.

[16]Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 2, p. 785, 1927.

[17]Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, pp. 61-110, 1928.

ently do not nearly attain the thickness of the thinner sections around the north margin. The average thickness within the plateau does not seem to be more than half and is possibly much less than half that of the average around the north margin. This relation may be interpreted as indicating that the plateau has been a positive area which has undergone much erosion with only moderate deposition and which was bordered along its north and east margins by a negative area of deposition. It is not to be supposed that all the material for building up the thick series of sedimentary rocks around the margin came from within the plateau region. There is ample evidence that there were, also, positive areas outside the area of heavy deposition. The Front Range of Colorado has been shown by Lovering[18] to be such an area and others were doubtless present. Within the plateau some areas were more persistently areas of erosion or non-deposition, for example, the Defiance uplift, in which the sedimentary formations lap.

Relation of Sedimentation to Structure

It may be supposed that the folding around the northern part of the plateau area resulted when the basins of sedimentation, owing to long-continued subsidence, finally collapsed in early Tertiary time, so that the rocks were folded into mountain ranges. The continued settling of the surrounding basins and rising of the plateau region may be regarded as due to isostatic adjustment, with material moving from the basins to the plateau in the zone of flowage. This idea is so generally recognized and largely accepted by geologists that it hardly needs extended discussion so far as the principle is concerned. In its application, however, there is less unanimity. Most geologists probably accept it for regions of continental and oceanic dimensions, but there appears to be a distinct difference of opinion as to how small an area can be safely assumed as affected by it.

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[18] Lovering, T. S., Colorado Sci. Soc. Proc., vol. 12, 1929.

The general subject and especially the evidence relating to the effect produced by the removal of the Quaternary ice sheet has recently been discussed by Swanson,[19] who reached the conclusion that "the earth crust can sustain inequalities of load amounting to 1,500 or 2,000 feet of ice or the equivalent weight of rock where the width of the region in question is not greater than 75 miles, the load decreasing from a maximum at the two sides to nothing in the center * * * but the earth's crust is not strong enough to resist isostatic adjustment where the area affected is 200 miles wide."

If this evidence as to the effects produced by the removal of the continental ice sheet is to be trusted it would seem that the Colorado Plateau, some 500 miles in diameter, is of ample size to be affected by isostatic adjustment. It may be inferred that the Rocky Mountain region is made up of several elements that may act isostatically, perhaps in a secondary order, to the main Rocky Mountain belt.

Can it be reasonably inferred, then, that the concentric folding around the northern portion of the Colorado Plateau had its origin in the collapse of a bordering basin of sedimentation? It is not the intention to imply that the folding in the local basins of sedimentation was entirely due to the weakness produced by continued sedimentation and deep burial. The Tertiary revolution evidently occurred at nearly the same time over a wide area and affected basins that had reached different stages of development. It would seem that the primary cause was one that affected a very large area, and that within this area the degree of folding in individual basins was dependent on the stage of weakness that they had reached. Had the collapse been due entirely to sedimentation in the individual basins it would seem logical that they should have collapsed at different times. All the basins, however, were points of weakness, though of different degree, and responded in different degree to the widespread cause of the Tertiary revolution. This cause can not be discussed here.

[19]Swanson, C. A., Isostasy and mountain building: Jour. Geology, vol. 36, pp. 411-433, 1928.

If the structural features were due to collapse, we are carried back another step in our search, but still the question may be asked, "Why was the Colorado Plateau area for long geologic periods a relatively positive element?" The writer is not going to attempt an answer to this question—at least not at this time.

To summarize, we may infer that the Colorado Plateau region has been for a long period relatively a positive region —one of erosion or moderate deposition—and that it was bordered around the north by a negative region of heavy deposition. In Tertiary time the regions of heavy deposition reached the point of weakness that caused collapse under the strain that produced the widespread Tertiary revolution. The folding and faulting that ensued were accompanied by igneous activity, and a part of this igneous activity resulted in the deposition of metallic ores. It may be remarked that the certainty of these steps is in the reverse order of that in which they are here mentioned.

In the discussion of the earliest steps in this series the northern part of the Colorado Plateau and the bordering area were considered. The southern part of the region does not present the conditions so clearly, if indeed they occur there. In Arizona the plateau is bounded by the mountain belt, outside of which is the region of desert ranges of southwestern Arizona, which contains few sedimentary rocks and may be regarded as long an area of erosion or non-deposition. The mountain belt contains sedimentary rocks, but there seems to be no evidence that it was an area in which the sediments were unusually thick. Does this mean that the argument as applied to account for the mountain building around the north margin of the plateau has no force in this southern portion, or was there a negative area between the positive areas of the plateau and the desert ranges of southwestern Arizona?

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