Preliminary Report on the Kokomo Mining District, Colorado

by

A. H. Koschmann and F. G. Wells

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by

A. H. KOSCHMANN AND F. G. WELLS[2]

INTRODUCTION

The Kokomo district, at the junction of Summit, Eagle, and Lake Counties, is part of an extensive mineralized area in the Rocky Mountains of north-central Colorado. The ore deposits include commercially important zinc-lead-silver replacement bodies in rocks of Carboniferous and Permian (?) age. The town of Kokomo, about which the mining activity has centered, is about 5 miles north of Climax, where the world's largest known molybdenum deposit is mined, and is about 22 miles north of the Leadville district. The country is drained by the headwaters of Tenmile Creek rising at the south end of the Gore Range and on the west side of the Tenmile Range (also called Mosquito Range). Situated near the Continental Divide, which follows the crest of the Tenmile Range, the country is mountainous though not very rugged and has a high average altitude. The highest altitude in the mapped area is 13,201 feet on Jacque Peak, and the valley of Tenmile Creek ranges in altitude from about 10,000 feet to 11,000 feet.

Kokomo, the main settlement within the district, lies on State Highway 91, which leads south from Dillon to Climax and Leadville. A short spur of the Denver and Rio Grande R. R., formerly extended from Leadville through Climax to Kokomo, but the part between Climax and Kokomo has recently been abandoned. The ore from the Kokomo district is now hauled by truck to Leadville, where it is treated by the Arkansas smelter or is shipped by rail to smelters in other parts of the country.

The first geologic study of the district was made during the boom period of 1881-1882 by S. F. Emmons, Ernest Jacob, and Whitman Cross, of the United States Geological

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[1]Published by permission of the Director of the Geological Survey, United States Department of the Interior, in cooperation with the State of Colorado through the Colorado State Geological Survey Board and the Colorado Metal Mining Fund.

[2]Geologists, U. S. Geological Survey.

Survey, as part of their investigation of the greater Leadville area. In 1936, F. G. Wells, assisted by Joseph Lindner, began a restudy of this area as part of a general investigation of the mineral resources of the State of Colorado that was inaugurated in 1926 and carried on by the Geological Survey in cooperation with the State Geological Survey Board and the Colorado Metal Mining Fund. As none of the mines were accessible to Wells during his field work, only surface mapping in the most productive part of the area was accomplished. More recently the extraordinary demand for base metals needed for war purposes has stimulated renewed interest in these zinc-lead deposits, and in 1942 several mines became active. In order to provide information useful to the mine operators. the Geological Survey continued the detailed geologic study of the district, and A. H. Koschmann was assigned to the project. An excellent topographic map of the Tenmile mining district, Colorado (in two parts, northern half and southern half),[1] on a scale of 1:12,000 (1 inch = 1,000 ft.), contour interval of 25 feet, had been prepared by R. R. Monbeck, Max J. Gleissner, F. L. Gregg, and J. M. Stricklin of the Topographic Branch of the Geological Survey, and with this as a base the geology was mapped in detail and the ore deposits studied during the field seasons of 1943 and 1944. J. C. Haff and James W. Odell assisted Koschmann in 1943, and James W. Odell in 1944. During the winter of 1944-45, Odell mapped some of the mines in detail.

The writers are much indebted to mine owners, operators, and many of the residents of Kokomo and Climax for their cordial and wholehearted cooperation.

HISTORY AND PRODUCTION

The rush of prospectors into Colorado in 1860 extended into the upper part of Tenmile valley, which includes the Kokomo district, and in 1861 placer deposits were located

[1]Copies of these maps at 10 cents each may be purchased from the Director of the Geological Survey, Washington 25, D. C., to whom remittance should be sent by money order.

in McNulty Gulch.[2] The first lodes were discovered in the Sixties in the pre-Cambrian rocks in the Tenmile Range on the east side of Tenmile Creek, but the district did not become active until the discovery of bonanza silver ore in the sedimentary rocks at Robinson and Kokomo in the late Seventies. According to Henderson,[3] silver was discovered in the district during the summer of 1878 and as a result of this discovery many prospects were located and the district developed rapidly. In 1879 activity increased, and between two and three thousand people flocked to the district. According to reports[4], the early operations proved "so satisfactory as to warrant an amount of prospecting equal to that done at Leadville." The Engineering and Mining Journal[5], in March 1879, reported that "On Sheep Mountain there are said to be 50 mines which show mineral in veins from 3 to 34 feet in thickness . . . . . . The ore so far shipped has averaged 280 ounces of silver." By August 1879, many mines, showing assay values of ore ranging from 50 to 130 ounces of silver, were also being developed on Elk Mountain[6]. In 1880, according to Henderson[7], the production of lead and silver was worth $200,000. The Robinson Consolidated Mining Company (the most productive mine in the district) paid its first dividend in June 1880.

By the spring of 1881 all of the properties that were to become the larger producers had been located. According to Henderson[8], the mine output in 1881 was estimated to be worth about $2,000,000, and the district became the leading producer in Summit County.

Mills and smelters had been built in the district as early as 1880. It would appear that the Pittsburg Smelter at Kokomo began operation early in 1880, and the smelter of the Robinson Consolidated Mining Company in October;

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[2]Hollister, Orando J., The Mines of Colorado, p. 326, Springfield, Mass., 1867.
[3]Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, p. 11, 1926.
[4]Eng. and Min. Jour., vol. 27, p. 132, Feb. 22, 1879.
[5]Idem, p. 206, March 22, 1879.
[6]Idem, vol. 28, p. 95, Aug. 9, 1879.
[7]Op. cit.
[8]Op. cit., p. 237.

much ore also was shipped to Argo and the Leadville smelters. According to Henderson[9], additional smelters in the district began operations in 1881. These included the White Quail lead smelter, the Greer lead smelter at Kokomo, and the Summit smelter at Robinson.

The first road into the district, a toll-road from Georgetown via Argentine Pass, was opened in the spring of 1879[10], and on August 9 of that year, the stage from Georgetown made its first run to Kokomo[11]. On August 1, 1881, the Denver & Rio Grande Railroad was completed from Leadville to Robinson, and served to lower the cost of hauling ore to the Leadville smelters. In 1883, the district received its second railroad when the Denver, South Park, and Pacific Railroad (which later became part of the Colorado & Southern) was completed to Leadville by way of Como, Breckenridge, and the Tenmile valley.

The blanket of oxidized and secondarily-enriched ore in the district was rapidly mined out, bringing the bonanza period of the camp to an early close. Before the end of 1881, the Robinson mine could not fulfill its contracts with the smelters, and the other mines likewise soon exhausted their bonanza ore. Mining activity ebbed, and data for the ensuing twenty years are meagre and fragmentary. The price of lead had begun to fall in 1890, and reached a low of 2.65 cents in August 1896[12]. Likewise the price of silver dropped from more than a dollar an ounce in 1890 to about 60 cents in 1897. Because of such low metal prices it is probable that production in the Kokomo district was at a low level during the years from 1893 to 1897. Though it is impossible to give any details, it is known that mining activity was confined chiefly to shoots sufficiently high in lead, silver, and iron, and low enough in zinc to yield ore that could be smelted directly.

From the earliest days of mining in the Kokomo area, roasting plants and smelters had been built that were de-

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[9]Op. cit., p. 11.
[10]Eng. and Min. Jour., vol. 27, p. 132, Feb. 22, 1879.
[11]Idem, vol. 28, p. 95, Aug. 9, 1879.
[12]Kirchoff, Charles, U. S. Geol. Survey Ann. Report, vol. 18, part 5, p. 254, 1897.

signed to treat the complex oxidized ore. In order to treat the primary complex ores that were everywhere found below the blanket of the rich oxidized ores, milling procedures also were developed for obtaining concentrates that could be profitably smelted. Early and persistent attempts were made to devise milling means especially to free the ores of the zinc (sphalerite) which was penalized by the smelters. The most successful of these attempts was made by Robert A. Wilfley, who took leases in 1886[13] on some of the properties on Elk Mountain and operated them more or less continuously until June 30, 1907[14]. It was at the Wilfley mill in Kokomo that he invented and first put into operation in May 1896, the famous Wilfley table [15] so widely used in ore dressing prior to the advent of flotation. Though the zinc concentrate was not saved during the first few years, it seems probable that the zinc production from Summit County listed by Henderson[16] from the period 1883 to 1905 was largely derived from the Kokomo district. Production of zinc from Summit County increased in 1898, and has since remained an important metal in the output of the Kokomo district.

Rising prices of silver, lead, and zinc stimulated mining from 1903 to 1907, but in 1908, owing to the decreasing metal prices, production again fell off heavily and mining activity fluctuated for several years. The abnormal prices for metal that resulted during World War I caused a temporary increase in production.

On September 1, 1923, mining in the district practically ceased when the Michigan-Snowbank-Uthoff Tunnel group, which had been the largest producer in the area since 1920, closed its mine. However, one or two cars of ore were shipped from the Wilfley property in 1925, 1926, and 1927. The American Metals Company in 1925 leased a large block of claims on Elk and Sheep Mountains and started cleaning

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[13]Emmons, S. F., U. S. Geological Survey Geol. Atlas, Tenmile district special folio (No. 48), p. 5, 1898.

[14]Personal communication from Mr. Armstrong, Kokomo, Colo.

[15]Richards, R. H., A textbook of ore dressing, p. 326, New York, 1909.

[16]Op. cit., pp. 91-97.

out the Wilfley, Kimberly and Uthoff adits in preparation for development work and a search for lead and zinc ores. By 1926 this company decided that insufficient ore had been found to warrant continuation of development work and relinquished its claims. From 1927 to 1942 little more than assessment work was done in the area.

The recent demand for base metals needed for war purposes again aroused interest in these zinc-lead deposits. During 1942 the Wilfley and Lucky Strike mines were opened and actively worked, and in 1943 the Kimberly was reopened.

Few figures are available on the production of the Kokomo district as neither governmental nor private agencies kept any systematic record of the metal mined during the period of greatest activity from 1880 to 1902. Emmons[17] states No. 1 Chute of the Robinson had produced ore valued at $6,000,000 by 1896. The output from Chute No. 2 of the Robinson mine must have been a small fraction of this amount. Chute No. 3 yielded ore valued at $27,842, and the value of the ore mined from Chute No. 4 was probably of the same order of magnitude. Incomplete data show a minimum production from the White Quail limestone on Elk Mountain valued at $1,728,158 prior to 1902, and the total metal output is known to be much in excess of that.

Henderson[18] places the value of the metal production from Summit County during the period 1880 to 1902 at $19,619,000. What part of this value came from the mines within the Kokomo-Robinson area is not recorded, but the writers believe that ten million dollars can safely be assumed as the approximate production from the area during that period. During the period 1902 to 1936, 136,100 tons of ore was produced from the area. This contained 17,960.21 fine ounces of gold, 1,111,056 fine ounces of silver, 9,172,600 lbs. of lead, 9,138,800 pounds of zinc, and 193,700 pounds of copper.

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[17]Op. cit., p. 4.
[18]Op. cit., p. 245.

GEOLOGY

General

The Kokomo district lies along the east margin of a north-northwest-trending belt of Paleozoic rocks that is bounded by extensive masses of pre-Cambrian rocks in the Sawatch Range on the west and in the Gore and Tenmile (Mosquito) Ranges or the east[19]. The relation of the Paleozoic rocks to the core of pre-Cambrian rocks of the Sawatch Range is one of normal superposition, and the easterly-dipping formations of Cambrian, Ordovician, Devonian, Carboniferous, and Permian age are exposed in succession along the east side of the range. On the east side of the north-northwest-trending belt of Paleozoic rocks, in the Gore and northern part of the Tenmile Ranges, however, only Pennsylvanian and Permian (?) rocks are exposed, except a few isolated remnants of the older Paleozoic rocks. According to Lovering and Johnson[20], the western border of the Gore Range "marks a zone characterized by great unconformities and unsystematic overlaps" with abrupt changes in the Paleozoic stratigraphy and in the thicknesses of the formations. Therefore, the distribution of the pre-Pennsylvanian sedimentary rocks beneath the Pennsylvanian and Permian (?) rocks in the Kokomo district has not been determined and their presence this far east of their outcrop is uncertain.

The consolidated rocks exposed in the Kokomo district comprise three main groups: (1) the pre-Cambrian basement rocks; (2) a thick series of Paleozoic sedimentary rocks, all of Carboniferous and Permian (?) age, except for a thin bed of quartzite, probably a remnant of the Sawatch quartzite of Cambrian age, on Copper Mountain; and (3) intrusive igneous rocks probably of late Cretaceous or early Tertiary age. The valleys and lower slopes

[19] Geologic map of Colorado, by Burbank, W. S., Lovering, T. S., Goddard, E. N., and Eckel, E. B., U. S. Geol. Survey, 1935.

[20] Lovering, T. S., and Johnson, J. Harlan, Meaning of unconformities in stratigraphy of central Colorado: Bull. Amer. Assoc. Petrol. Geol., vol. 17, p. 356, 1933.

are covered with glaciofluvial deposits that are not discussed in this report. The distribution of the rocks exposed in the Kokomo district is shown on the accompanying geologic maps, plates 1 and 2.

Pre-Cambrian Rocks

The pre-Cambrian rocks occupy only a relatively small area on Copper Mountain in the northeastern part of the district. They are, however, part of the much larger mass of pre-Cambrian rocks which extends northward from the mapped area along the Gore Range and southward along the Tenmile Range. Although these rocks in the Gore and Tenmile Ranges in general comprise granite, gneiss, and schist, abundantly intruded by pegmatite dikes, those in Copper Mountain consist almost exclusively of schist and gneiss with but little pegmatite. As these have relatively little bearing on the main problems in the mapped area, they have not been mapped or studied systematically. The pre-Cambrian rocks in the Mosquito Range have been briefly described by Emmons[21], and those exposed in the Climax district, which is part of the Tenmile Range and adjoins the Kokomo district on the southeast, are described in detail by Butler and Vanderwilt[22].

Paleozoic Sedimentary Rocks

Sawatch (?) quartzite (Cambrian ?)

Probably the oldest Paleozoic rock in the district is a fine-grained, glassy quartzite, about 10 feet thick, that intermittently crops out on the south slope of Copper Mountain between areas of pre-Cambrian and Pennsylvanian rocks. It is too poorly exposed for satisfactory determination of its stratigraphic position or structure. The trend of its outcrops is discordant with the northerly strike and westward dip of the adjacent Pennsylvania strata. The

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[21] Op. cit., p. 1.
[22] Butler, B. S., and Vanderwilt, J. W., The Climax molybdenum deposit, Colo.: U. S. Geol. Survey Bull. 846-C, pp. 205-210, 1933.

discordance thus shown and its relatively pure glassy character, which is unlike that of any known Pennsylvanian rocks in the district, imply that it is a remnant of a formation that does not belong to the Pennsylvania series of strata. From its position adjacent to the pre-Cambrian rocks it is presumed to be a remnant of a pre-Pennsylvanian formation. As similar quartzite in the Climax district[23] and at Mt. Lincoln[24], about 5 miles east-southeast of Kokomo, is correlated with the Sawatch quartzite of Cambrian age, the quartzite on Copper Mountain is also tentatively correlated with this formation.

Pennsylvanian and Permian (?) rocks

General character and classification.—The Pennsylvanian and Permian (?) rocks of the Kokomo district comprise a series of folded and faulted strata which total from 5,000 to 5,900 feet in thickness. They consist predominantly of interbedded coarse- and fine-grained clastic rocks—conglomerates, grits, sandstones, siltstones and mudstones—in which relatively thin beds of fossiliferous limestone and shale are intercalated at widely spaced stratigraphic intervals. Most beds are thin and lenticular, and the siltstones and mudstones are laminated. Mudcracks, raindrop impressions, and crossbedding are common, and obviously much of this great thickness of strata consists of continental deposits.

The relatively coarse clastic rocks consist chiefly of detritus of the adjacent pre-Cambrian rocks. The pebbles in the conglomerates, up to 6 inches and more in diameter, are almost exclusively granite, gneiss, pegmatite, quartz, and schist and, rarely, fragments of sedimentary rocks. Muscovite and feldspar grains are abundant constituents of most of the strata, and in some feldspar predominates. Of special interest in the Kokomo district are a few lenses of volcanic breccia and subangular fragments of white rhy-

[23]Butler, B. S., and Vanderwilt, J. W., op. cit., p. 210.
[24]Singewald, Quentin D., Unpublished report.

olite in the conglomerates and grits on Tucker Mountain. Their origin and significance are briefly described on pages 70-74.

Noteworthy also in this thick series of rocks is the vertical change in color; in the lower part of the series the rocks are predominantly gray to white, with some interbedded red strata, whereas in the upper part the rocks are characteristically red. As noted by Emmons[25], the red color in the conglomerates, grits, and some sandstone, results from the presence of abundant pink feldspar, and the red color in the siltstones and mudstones results from an abundance of iron oxide in the matrix. The change in color is irregular, however, and therefore cannot be used for stratigraphic purposes.

No entirely satisfactory paleontologic, lithologic, or structural features have been found in this series of strata to serve as a basis for subdividing it into well-defined mappable units. Emmons [26], who first described these rocks, divided them into three formations which he called the Weber, Maroon, and Wyoming formations. As a basis for his subdivisions he arbitrarily used limestone beds and major vertical changes in color. He assigned to the Weber formation the rocks in the lower part of the section, which are predominantly gray in color. He arbitrarily took as the base of the Maroon formation a fossiliferous limestone, which he called the Robinson limestone, and for the top of the formation, another limestone to which he applied the name Jacque Mountain limestone after Jacque Mountain along the west slope of which it is well exposed. The sedimentary rocks above the Jacque Mountain limestone he correlated with similarly constituted rocks in the Rocky Mountain region, believed to be of Triassic age, to which the name Wyoming formation had been given[27].

The Pennsylvanian and Permian (?) rocks in central Colorado vary in lithology and in thickness from place to

[25]Op. cits., pp. 1-2.
[26]Idem.
[27]Emmons, S. F., op. cit., p. 2.

place and in relatively short distances. Therefore, in the Kokomo district no well-defined boundaries can be established and generally applied, and local units cannot be correlated with assurance over a large area. In order to map the structure in the district more accurately than would be possible if the entire series had been considered as a unit, the Pennsylvania and Permian (?) rocks have been subdivided in this report, following Emmons, into three lithologic units. The lower unit, which consists of sandstone and shale, is equivalent to his Weber formation; the middle unit, which consists of sandstone and mudstone that are largely dark red. is essentially the Maroon formation of the earlier report; and the upper unit, which consists of sandstone and mudstone that are mostly reddish. but lighter colored than the rocks of the middle unit, is the Wyoming formation of the earlier report. Although these subdivisions are the same as those made by Emmons, the correlations made by him are in doubt and the names that he used—Weber, Maroon, and Wyoming—have therefore been dropped.

The lower unit and most of the middle unit are now established by fossil evidence to be of Pennsylvanian age. In the northeastern part of the mapped area the upper unit clearly overlies the lower units unconformably. No fossils have been found in the upper unit to establish its age, but because of the unconformity separating it from the middle unit, it is regarded as of probable Permian age.

The general stratigraphic section of the Pennsylvanian and Permian (?) rocks and its subdivisions in the Kokomo district are shown in table 1.

TABLE I

Table showing general stratigraphic section of the Pennsylvanian and Permian (?) rocks of the Kokomo district, Colorado.

Age	Major lithologic divisions	Lithologic subdivisions	Thickness (feet)	Character
Permian (?)	Upper unit (sandstone and mudstone).		2,000 ±	Predominantly thin-bedded sandstone and mudstone of brick-red color, with a few conglomerate beds 1 to 2 feet thick.
Carboniferous (Pennsylvanian)	Middle unit (sandstone and mudstone).	Jacque Mountain limestone of local usage.	15-25	Bluish-gray to dark-gray oolitic limestone. Most exposures show a single bed, but near south end of Searle Gulch there are several closely spaced thin beds with shale partings.
		Sandstone	800-900	Thin-bedded red to maroon sandstone and mudstone, with a little conglomerate.
		White Quail limestone of local usage.	175 ±	Locally includes three limestones but in most places the uppermost is absent. Upper limestone, gray and argillaceous and 5 to 15 feet thick, is separated from the middle limestone by 25 to 50 feet of white to pinkish grits and red mudstone. The middle limestone is separated from lower limestone by 100 to 150 feet of thin-bedded red sandstone with some beds of pinkish conglomerate. Middle limestone bed 20 to 30 feet thick, blackish-gray in color, is overlain by seam of black carbonaceous shale; lower limestone bed 15 to 20 feet thick is dark bluish-gray in color.
		Sandstone	250-400	Chiefly white to cream-colored micaceous sandstone.
		Elk Ridge limestone of local usage.	250 ±	Includes two limestone beds, separated by 200 to 225 feet of thin-bedded red sandstone and conglomerate; shown as key horizon on map. Upper limestone bed is 5 to 7 feet thick, is dark bluish gray in color, and is overlain by 10 to 12 feet of black micaceous shale; lower bed is 12 to 15 feet thick; upper 7 to 8 feet crystalline and light gray, lower 6 to 7 feet mottled dark bluish gray.
		Sandstone and shale.	300-500	Cream-colored to gray micaceous sandstone interbedded with black carbonaceous shale.
		Robinson limestone of local usage.	200-250	Generally includes three beds of limestone but locally only two. Upper bed, about 15 feet thick, is separated from midde or main Robinson bed, about 35 feet thick, by 100 to 200 feet of sandstone.
	Lower unit (sandstone and shale).		1,200 ±	Interbedded whitish to gray sandstone, grit, arkose, and conglomerate, all micaceous, black carbonaceous shale, and a few beds of dolomitic and cherty limestone.

Lower unit (sandstone and shale).—Beds assigned to the lower unit are exposed in two widely separated areas, which lie along the limbs of a shallow northward-trending syncline, one along the southwestern part of the mapped area and the other in the northeastern part. In the southwestern part of the area these beds are extensively exposed from North Sheep Mountain southward beyond the south boundary of the district. Only the upper 800 feet are exposed here, but according to Emmons[28] their average total thickness is about 2,500 feet. In the northeastern part of the district they are exposed along the northwest side of Tenmile Creek on the lower slopes of Jacque. Tucker, and Copper Mountains. Near the crest of Copper Mountain they rest unconformably on pre-Cambrian rocks.

The rocks of the lower unit comprise white to gray sandstone and black carbonaceous shale, interbedded with gray and occasionally red conglomerates and grits and several beds of dolomitic limestone. The beds vary laterally in composition and thickness, and some pinch out within the mapped area. Pebbles are generally sparsely scattered and average less than ¾ inch in largest dimension, with a maximum of about 1½inches, but in one bed abundant large pebbles and cobbles six inches in largest dimension were seen. The pebbles are almost exclusively quartz, gneiss, or schist, but in a few places fragments of red mudstone occur. In the grits the grains are either quartz or feldspar; in many beds, pink microline grains predominate. Muscovite is abundant in most beds.

Four or five beds of dolomitic limestone are present in the mapped area. They are generally less than 50 feet thick, though one is about 100 feet thick. The dolomitic limestones are sandy and clayey, and are characterized by abundant nodules and irregular large and small lenses of dark gray to black chert. Their outcrops are of a dirty-brown color, with surfaces roughened by projecting sand grains and chert. These limestones, as Emmons pointed out, are

[28] Op. cit., p. 1.

dolomitic in contrast to the limestones in the middle division, which are nondolomitic.

At several horizons near the top of this series of strata on Sheep and North Sheep Mountains several local unconformities are present. In the absence of good horizon markers they cannot be extensively traced, but they give evidence of repeated deformation and erosion which are further discussed on pages 88-89.

In the northeastern part of the mapped area the strata assigned to the lower unit of rocks have been metamorphosed and are bluish to dark gray rocks. The sandstones and grits have been converted to quartzite, and all the rocks have been impregnated with abundant greenish-white biotite and locally with epidote, chlorite, garnet, and wollastonite. On Tucker and Copper Mountains they contain an abundance of pyrite.

Identifiable fossils in the rocks of the lower unit are few. Four collections were made from these beds in the southwestern part of the district, and eight from Copper Mountain in the northeastern part of the district. These have been identified by J. S. Williams and Lloyd G. Henbest, and will be listed in the final report. Only one collection from the southwestern part of the district contained fossils which could be identified with enough certainty to provide stratigraphic data of value, and according to Mr. Williams, "the fauna places the bed from which it came as old or as older than Des Moines age (lower Pennsylvanian) and younger than Morrow." The fossils from the limestone on Copper Mountain are regarded by both Williams and Henbest as of Des Moines age.

Middle unit (sandstone and mudstone).—The middle unit includes the strata between the base of the Robinson limestone and the top of the Jacque Mountain limestone. These strata are exposed in a broad belt that extends southeast from Searle Pass at the northwest edge of the mapped area to the Tenmile valley, where they are covered by a broad expanse of glacial till and alluvium. Southeast of

Tenmile valley, along the extension of this broad band, they are exposed on a hill south of McNulty Gulch and on the lower west slope of Carbonate Hill. None have been recognized with assurance in the northeastern part of the district on the east limb of the syncline. The poorly exposed fossiliferous limestone beds on Copper Mountain might be correlated with the Robinson limestone, but in the absence of conclusive evidence they are tentatively assigned to the lower unit.

The middle unit, which has a maximum thickness of about 2,000 or 2,500 feet, consists of interbedded micaceous sandstone, conglomerate, limestone, mudstone, and shale, named in order of decreasing abundance. The rocks of this division are lithologically similar to those of the lower division, but contain a large proportion of red rocks. The lower part of the middle division consists of alternating red and white to gray beds; the upper part consists entirely of red to maroon beds.

Four groups of closely spaced beds of limestones in the middle unit have been mapped in detail because of their importance as ore horizons. Named in order from the oldest to the youngest they are: (1) the Robinson limestone, (2) the Elk Ridge limestone, (3) the White Quail limestone, and (4) the Jacque Mountain limestone.

The Robinson limestone, named after the Robinson mine, has been one of the most productive ore horizons in the district. It is best exposed on East Sheep Mountain, but it is fairly well exposed on the southwest side of Elk Ridge, east of Kokomo Pass. In most places it comprises three beds of limestone, but locally, as on the crest of East Sheep Mountain and at the Wheel of Fortune mine, there are only two beds. Outcrops of the Robinson limestone are not continuous; they are interrupted by faults in several places, and elsewhere are concealed by surface debris. For these reasons the limestone exposures in some fault blocks, such as the block west-southwest of East Sheep Mountain, are only tentatively correlated with the Robinson. The lowest bed of the Robinson limestone is an almost black limestone, called the "black lime" by the miners; the middle or principal bed is known as the "Robinson bed," and the upper is called the "upper lime." The "black lime" is separated from the "Robinson bed" by sandstone of varying thickness, probably nowhere exceeding 18 feet, and in places these two limestone beds apparently merge. According to Emmons, the "Robinson bed" has an average thickness of about 35 feet in the Robinson mine, where the upper 20 feet is almost pure carbonate of lime, of light-gray color; the lower part is darker in color, in places almost black, and contains nearly 7 percent of magnesium carbonate. The upper member is about 15 feet thick and is separated from the middle member by 100 to 200 feet of sandstone. It apparently becomes argillaceous toward the north, and it may locally pinch out.

Fossils from the Robinson limestone have been identified by J. S. Williams and Lloyd G. Henbest, who regard them as Des Moines (Pennsylvanian) in age. Williams, on the basis of the larger fossils, has reached the following conclusion regarding their age: "Several distinctive index fossils are present and the age of the Robinson limestone zone can be stated with some certainty as Des Moines, which I consider lower Pennsylvanian. The Des Moines age of the Robinson limestone is based on the occurrence together in it of the following index fossils: *Marginifera inflata* Girty, *chonetes (Mesolobus) mesolobus lioderma* (Dunbar and Condra), *Spirifer rockymontanus* Marcou and *Spirifer occidentalis* Girty and on the occurrence in it of many other species, which though not restricted to beds of this age, do when grouped together make up assemblages that are characteristic of faunas of Des Moines age, post-Morrow and pre-Kansas City."

The fusulinids collected from the Robinson limestone were determined by Henbest, who states that they "characterize a zone that occupies the middle of the lower half of the Des Moines series in the Central States."

The ore in the Robinson limestone has been exploited in the Robinson, Felicia Grace, New York, Champion, and Wheel of Fortune mines and probably in the Eldorado and East mines.

The Elk Ridge limestone consists of two beds of limestone separated by 175 to 225 feet of red sandstone and conglomerate. The upper bed, which is 5 to 7 feet thick, is dense and dark bluish gray. It is overlain by 10 feet or more of black carbonaceous shale followed by massive white to cream-colored sandstone. Locally the limestone is absent but the shale persists and may have a maximum thickness of about 40 feet. The lower bed of limestone, which is about 12 to 15 feet thick, is divisible into an upper pale-gray crystalline member, about 7 to 8 feet thick, and a lower member of mottled bluish-gray limestone, about 6 to 7 feet thick, underlain by thin-bedded gray sandstone. This lower bed of limestone forms conspicuous outcrops on the crest of Elk Ridge.

The White Quail limestone, probably the most productive ore horizon in the district, is named after the Quail group of mines on the southeast slope of Elk Ridge. In the White Quail mine, according to Emmons, this limestone is a single bed which "has an average thickness of 10 to 15 feet, with a maximum of 22 feet." There the limestone is in places underlain by a seam of black shale and overlain by a thin seam of black carbonaceous shale "succeeded by 10 to 15 feet of white sandstone over which is found 15 feet of black shale, followed by massive sandstone separated by shale beds."

In most places the White Quail limestone consists of two limestone beds, and locally there is a third. These are interbedded with red to gray sandstone, mudstone, and conglomerate, and are well exposed on the east side of Searle Gulch near its head. The lowest bed of the White Quail limestone, about 15 to 20 feet thick, consists of dark blue mottled limestone. The middle bed, the principal ore horizon, consists of a dark gray to blackish fossilferous limestone 20 to 30 feet thick, with a persistent bed one to two feet thick of black shaly limestone containing sandy and micaceous partings in its middle part. It is overlain by a thin seam of black carbonaceous shale. The upper bed is a lenticular gray argillaceous limestone 5 to 15 feet thick, separated from the middle bed by about 25 to 50 feet of white to pinkish grits and red mudstone.

Regarding the fossils from the White Quail limestone, J. S. Williams makes the following comment: "The faunules of the White Quail limestone are not certainly distinctive of any part of the Pennsylvanian, because distinctive species are few and these cannot be definitely identified. The aspect of the fauna is that of the Hermosa formation, and the general resemblances are definitely to beds of Des Moines or early Kansas City age, rather than to later Pennsylvanian or to Permian."

The middle or main White Quail limestone bed contains the ore of the White Quail, Colonel Sellers, Wilfley, Kimberly, Breene, and Delaware mines on the south end of Elk Ridge, and that of the Uthoff, Lucky Strike, Washington, and Michigan mines on East Sheep Mountain.

The Jacque Mountain limestone, stratigraphically the highest persistent limestone in the area, is exposed on the western slope of Jacque Mountain. Its massive beds of bluish-gray to dark-gray limestone are characterized by a pronounced oolitic structure. At most places it consists of a single relatively thick bed of limestone about 15 to 25 feet thick. Locally, however, and notably near the south end of Searle Gulch, several closely spaced thin beds of limestone, which alternate with beds of fissile chocolate-colored shale 3 feet or more in thickness, are exposed at this horizon. Although according to local usage only the lowest and thickest of these limestone beds is called the Jacque Mountain limestone, the several overlying beds are here also included. The Jacque Mountain limestone is generally well exposed and forms prominent outcrops. The upper part of the limestone locally carries fossils, chiefly orthoceroid and nautiloid cephalopods, and several fragments and steinkerns of gastropods. According to J. S. Williams, "the general impression gained from this fauna is that the rocks are more likely of Des Moines (lower as against upper Pennsylvanian age) than of younger age, but certainly there are no adequate data to restrict the age to Des Moines or for that matter, to the Pennsylvanian." The cephalopods have been identified by Prof. A. K. Miller, who refers them to three genera: *Domatoceras, Pseudorthoceras,* and *Mooreoceras.* Concerning the age of these, Prof. Miller stated: "None of these is very distinctive, and all are abundantly represented in both the Pennsylvanian and Permian. Accordingly, I am, unfortunately, not able to determine the age of the containing beds. If I had to express an opinion, I would say that the Jacque Mountain cephalopods are probably Pennsylvanian in age, but they could just about as readily be Permian."

Ore deposits in this limestone have been exploited in the Wintergreen, Free America, and Selma mines.

Upper unit (sandstone and mudstone).—The upper unit includes all the sedimentary strata above the Jacque Mountain limestone. Although it rests with apparent conformity upon the middle unit on the west slope of Jacque Mountain, in the northeastern part of the mapped area at least most if not all of the middle unit is absent, and there the upper unit rests unconformably on strata tentatively assigned to the lower unit. The general absence of definite horizon markers in the northeastern part of the mapped area prevents a definite statement regarding the extent of the hiatus represented there. If the fusulinid-bearing limestone beds on Copper Mountain ultimately prove to be the equivalent of the Robinson limestone, the hiatus is equal to that part of the middle unit above and including the Elk Ridge limestone.

The greatly altered condition of the sedimentary rocks on Tucker and Copper Mountains has obscured their identity and the position of the contact between the upper and the lower units. Lithologically and in color the rocks of the lower unit grade into those of the upper unit, and the relations are further obscured by intervening sills and irregular intrusive bodies. In the absence of more reliable data the contact was tentatively drawn along sills or where the most noticeable color change occurs; that part of the section predominately gray in color was placed in the lower division, and that predominately red in the upper.

The most complete and typical section of the upper unit is that on the southwest slope of Jacque Mountain, where about 2,000 feet are exposed. It is predominantly sandstone and mudstone of brick-red color, but includes conglomerate beds 1 to 2 feet thick. Nonpersistent thin beds of limestone have been found locally, and some of the mudstone beds are calcareous. Some beds west and southwest of Jacque Peak have a greenish cast owing to the presence of epidote and chlorite, which were formed as a result of mild metamorphism. Metamorphism becomes more pronounced and intense northeast of Jacque Peak and is most intense on the ridge between Jacque Peak and Union Mountain. Shaly and calcareous beds are most altered, though arkosic sandstones are replaced in places. The shaly beds become vuggy and are irregularly streaked green. Rudely lenticular or elliptical lumps or irregular streaks of green minerals are developed. They consist chiefly of aggregates of epidote accompanied by smaller amounts of chlorite, and in arkosic beds feldspars are considerably replaced by sericite. On Union Mountain there are local clusters of garnet associated with magnetite, specularite, pyrite, and rarely chalcopyrite.

No fossils have been found in the strata of the upper unit, but on the basis of the unconformity at the base, they are presumed to be Permian in age.

Volcanic rocks.—Interbedded with the Pennsylvanian and Permian (?) rock strata on Tucker and Union Mountains are lenses of rhyolite tuff and breccia, isolated blocks and fragments of volcanic rock as much as 12 feet long and 3 feet thick, and beds of blackish-gray feldspathic rocks.

Also tentatively assigned to the Pennsylvanian and Permian (?) volcanic rocks are dikes of white rhyolite, 600 feet and more in length, found on Tucker Mountain. These volcanic rocks occur at several stratigraphic horizons and can be intermittently traced from the cover of glacial till and alluvium in Tucker Gulch northeastward for about one-half mile.

The volcanic breccia consists of volcanic rocks mixed in various proportions with fragments of sedimentary rocks and mineral fragments derived from the pre-Cambrian rocks. The volcanic rock fragments are almost exclusively of white rhyolite, but a few fragments of darker felsites, probably andesitic in composition, and of a pale green glassy rock, are also present. The prevailing color of the rhyolite fragments as well as the rhyolite in the dikes is whitish gray. The rhyolite consists of a dense groundmass in which are embedded well-formed crystals of glassy orthoclase and rounded grains of quartz. Under the microscope smaller grains of embayed plagioclase (oligoclase) are also recognizable. Other crystals whose outlines suggest biotite are represented by shreds of chlorite peppered with iron oxide. The groundmass consists of a microgranular aggregate of quartz and feldspar.

The fine-grained tuffs range from an extremely dense, hard rock, light gray in color, resembling chert, to a fine-grained rock in which small rock and mineral fragments are embedded in a tuffaceous matrix. Under the microscope the dense tuffs are seen to consist of a microgranular to submicroscopic material that is similar to the matrix of the rhyolite, and is evidently an aggregate of quartz and orthoclase. The fine-grained tuffs consist of a mixture of small fragments of rhyolite and sedimentary rocks as well as angular to rounded fragments of quartz, plagioclase, and microline. The latter is clearly detritus from the pre-Cambrian rocks that was embedded in the fine-grained volcanic matrix.

The very intimate mixture of foreign rock and mineral fragments in a groundmass devoid of features which would indicate its fragmental character obscures the true nature and origin of these rocks. The homogeneous character of the material composing the groundmass would imply that these rocks are flows which incorporated foreign rock and mineral fragments as they flowed over a surface of unconsolidated sediments. The proportion of foreign fragments which in many is greater than the matrix, indicates a fragmental origin, and suggests that most of these rocks are probably recrystallized tuffs.

Beds and lenses 2 to 5 feet thick of blackish gray feldspathic rocks, resembling altered basalt or greenstone, are exposed on the crest of Tucker Mountain immediatly west of the stock of porphyritic quartz monzonite. These beds can be traced down the south slope of the mountain for a distance of several hundred feet, but they have not been found on the north slope. Microscopic examination reveals that this blackish rock consists essentially of fine-grained, interlocking grains of potassic feldspar and greenish-brown biotite. The biotite, like that in the metamorphosed sedimentary rocks, is clearly secondary and accounts for the dark color of the rock. The rock is rudely banded, owing to slight differences in the coarseness of grain. In some bands irregular plagioclase grains occur which are somewhat larger than the grain of the matrix, and may represent phenocrysts, but none are euhedral. Abundant coarse-grained interlocking aggregates of quartz, and more rarely of quartz and feldspar are present and clearly represent included foreign material. Vein-like areas of feldspar, similar to that of the remainder of the rock, cut the feldspar-biotite aggregate. Although unlike the other volcanic rocks in composition, it is believed to represent a volcanic product because of its restriction to Tucker Mountain where other Pennsylvanian and Permian (?) volcanic rocks are present.

Data on the extent and source of the assemblage of volcanic rocks of Pennsylvanian and Permian (?) age are meager. Within the mapped area they have been observed only on Tucker, Union and Copper Mountains. This restricted distribution, and the presence of white rhyolite dikes, which also are similar in character to the rhyolite fragments in the breccia, suggest the center of eruption to have been either beneath Tucker Mountain or in its immediate vicinity. Their distribution throughout a thick section of Pennsylvanian and Permian (?) rocks implies that volcanic activity continued through a large part of Pennsylvanian time and probably extended into Permian time, and that these volcanic rocks had a wide areal distribution. Brill[29], found "a 3-inch layer of altered bentonite, containing some quartz and biotite as well as shards" in rocks of Pennsylvanian age in two localities 7 miles apart northwest of Kokomo. Although this bed has not been traced into the Kokomo district, it seems possible that the bentonite marks an outlying ash deposit of the volcanic center here described, and indicates a wide distribution of these volcanic products far beyond the confines of the mapped area.

Late Cretaceous or Tertiary Igneous Rocks

Structures

Igneous rocks are extremely abundant throughout the district and occur in a large number of relatively small intrusive bodies of diverse forms, ranging from typical sills and sill-like bodies and dikes to extremely irregular crosscutting bodies. Sills with a few scatttered dikes are the common form of intrusion in the southwestern part of the district, whereas the irregular crosscutting bodies, including a chonolith, stocks and dikes are restricted to the northeastern part, apparently the eruptive center of the district.

Sills, intruded along stratification planes, can be observed at many places and some can be followed for thousands of feet. They range in thickness from 20 feet to 300 feet or more. Although some are typical tabular bodies con-

[29]Brill, Kenneth, G., Jr., Late Paleozoic stratigraphy of Gore area, Colorado: Bull. Am. Assoc. Petrol, Geol., vol. 26, No. 8, p. 1388, 1942.

formable to the same stratum throughout their extent, many deviate from this simple form and follow one horizon for a distance and then gradually cut across bedding and continue at a slightly different horizon. This is well shown by the sill near the head of Searle Gulch which follows the basal contact of the Jacque Mountain limestone for 1,800 feet but gradually leaves the basal contact as it is followed northward. Another sill here follows the upper contact of the upper bed of the Quail limestone, but it forks 1,700 feet southeast of the northern boundary of the mapped area; one prong of the fork continues along the upper contact of the limestone bed, whereas the other cuts across the limestone bed, follows its basal contact for a short distance and then gradually leaves this contact as it is followed southward. Still other forking sills have been observed in Searle Gulch, both on the southwest slope of Jacque Mountain and on the northeast slope of Elk Ridge. In addition to these more or less normal sills, some of the igneous bodies, though tabular as a whole, have local bulges or protuberances along their surfaces; some are distinctly laccolithic in outline and pinch out within relatively short distances. The thick sill which covers a large part of the eastern slope (essentially a dip slope) of Elk Ridge, has an extremely irregular basal contact although its upper surface appears to be rather regular. Such irregularities, with further complications introduced by faulting and the gaps in outcrop caused by talus and glacial till, introduce many uncertainties in the correlation of sill-like segments of igneous bodies and prevent the determination of their outline and size.

Transgressive or crosscutting igneous bodies are especially common on the east slope of Jacque Mountain, on Tucker Mountain, and on the south end of Copper Mountain. A large irregular mass of Elk Mountain porphyry, which centers at the head of Tucker and Sawmill Gulches, and extends across the west end of Tucker Mountain and the southeast side of Jacque Mountain, is probably a chonolith. On its northwest and northeast sides the main cen-