tral body fingers out into sill-like and ramifying crosscutting bodies, whereas on its south and southwest sides its form is regular. There is little evidence regarding the nature of its basal contact, whether conformable with the bedding or essentially crosscutting. This mass, as shown even at its center of outcrop is texturally similar to the Elk Mountain porphyry in the sills, indicating relatively rapid chilling and crystallization, and it is presumably a shallow body.

The small body of porphyritic quartz monzonite on Tucker Mountain is a stock from the south side of which several apophyses project. Its crosscutting relation with the sedimentary rocks is indicated by its steep west contact as well as by its apophyses. The northwest border of a second stock is exposed in Tenmile valley along the main highway between Cresson and Tucker Gulches. It consists of quartz monzonite and is probably part of the stock of similar quartz monzonite on Bald Mountain which was intruded into the pre-Cambrian rocks[30]. The Bald Mountain stock lies immediately southeast of the exposures in Tenmile valley. As the exposures along Tenmile valley are poor in the mapped area the form and structural relations of the body to the enclosing strata have not been determined, but the coarse texture of the rock suggests that it is a deep-seated intrusive.

The position of the stocks and the chonolith at the approximate center of an extensive area of metamorphosed Pennsylvanian and Permian (?) rocks suggests that these exposed crosscutting igneous bodies lie above a center of deep-seated igneous activity. Collectively they have a northwesterly alinement which may reflect the general direction of a major zone of weakness. As shown below, the area between Jacque and Copper Mountains marks the northeastern border of a basin of deposition along which intermittent differential movement occurred through a large part of Paleozoic time and probably also later. From the

[30]Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, p. 372, 1924.

meager field evidence it would appear that the stocks and chonolith and subsequently the hydrothermal solutions worked their way upward along the margin of this basin.

Classification

General features.—With the exception of the rhyolite tuff and breccia of Carboniferous and Permian (?) age, described on pages 70-74, and the mass of rhyolite on Chalk Mountain, the igneous rocks in the Kokomo district in common with the intrusive rocks of nearby mining districts[31] are quartz monzonites and porphyritic equivalents of quartz monzonite. Although available analyses[32] of the rocks in the Tenmile district, which includes the Kokomo district, show only a minor range in chemical composition, different masses of these rocks show differences of mineral composition, texture, and structure, on the basis of which Emmons[33] recognized, mapped, and named three varieties: (1) the Elk Mountain porphyry, (2) the Quail porphyry, and (3) the Lincoln porphyry. In the Climax district, which is contiguous with the Kokomo district on the southeast, Butler and Vanderwilt[34] found that "some dikes of Lincoln porphyry have middle portions of quartz monzonite and margins of quartz diorite, or middle portions of granite and margins of quartz monzonite," a fact which demonstrates that the mineralogic and textural differences in the igneous rocks of this general region represent inconsiderable differences in chemical composition. From what has been said it follows that in places these rocks grade into each other, but in spite of the fact that such gradations exist most of the rocks can be distinguished mineralogically in hand specimens. In this report the classification of Emmons is therefore retained, though in addition to the three types recognized by him two others, porphyritic quartz monzonite and quartz monzonite are recognized. These form,

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[31]Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, pp. 43-62, 1911.
[32]Idem., p. 62.
[33]Op. cit., pp. 2-3.
[34]Op. cit., p. 213.

respectively, the stock on Tucker Mountain and the smaller intrusive mass in the valley of Tenmile Creek.

Age.—The geologic age of the igneous rocks, including the rhyolite on Chalk Mountain, is inferred to be late Cretaceous or early Tertiary. As no sedimentary rocks younger than the Pennsylvanian and Permian (?) occur in the mapped area this dating is based on field evidence in the neighboring areas, a discussion of which will be reserved for the final report on the Kokomo district.

Elk Mountain porphyry.—The Elk Mountain porphyry, as mapped by Emmons, comprises several facies, expressed on the one hand by slight variations in mineralogy and on the other by coarseness of grain. Typically it is a porphyry consisting of well-defined phenocrysts embedded in a fine-grained groundmass, but grades into the coarser and more even-grained porphyritic quartz monzonite, described below. Most of the sills in the Kokomo district consist wholly of Elk Mountain porphyry and though the chonolith and some of the larger sills on Jacque, Tucker, and Copper Mountains consist chiefly of the typical Elk Mountain porphyry, towards their centers they grade into the porphyritic quartz monzonite. The stock on Tucker Mountain consists chiefly of the porphyritic quartz monzonite but has a chilled border of porphyry closely resembling the Elk Mountain porphyry.

The Elk Mountain porphyry is by far the most widely distributed and most abundant of the igneous rocks in the district. It was named by Emmons[35] after Elk Mountain in the northwest corner of the mapped area, whose principal mass he regarded to be "the largest eruptive channel of the rock." The typical Elk Mountain porphyry is pale gray and is characterized by phenocrysts of quartz and plagioclase up to 8 millimeters in length, embedded in a fine-grained groundmass. The ferromagnesian minerals vary considerably in abundance from place to place and are small. Biotite appears to be the most common but long

[35]Op. cit., p. 2.

prismatic phenocrysts of hornblende are commonly present.

Microscopic study shows that the feldspar phenocrysts have a composition of albite-oligoclase and are considerably altered to sericite and to calcite. The phenocrysts of quartz are rounded and deeply embayed. The ferromagnesian minerals have been completely altered, commonly to a dark green chlorite, penetrated by shreds of sericite, less commonly to an aggregate of chlorite, zoisit, and calcite, or chlorite, epidote, and calcite. The groundmass ranges from a microgranular to micrographic intergrowth of quartz and orthoclase, which varies considerably in coarseness of grain in the different sills and even in the same sill. Most of the very fine-grained groundmass is fresh but in relatively coarser-grained groundmasses areas of alteration are found in which zoisite, chlorite, and calcite have formed. Accessory minerals, in order of decreasing abundance, are apatite, allanite, and zircon.

Porphyritic quartz monzonite.—The porphyritic quartz monzonite constitutes the larger part of the small stock on Tucker Mountain. A similar facies of rock, not indicated on the map, is exposed in the central part of the chonolith on the southwest side of Tucker Mountain and in some of the thicker sills on Union and Copper Mountains. In all these masses, including the stock, the porphyritic quartz monzonite grades imperceptibly into typical Elk Mountain porphyry. The typical porphyritic quartz monzonite is gray, but the weathered rock is brownish gray to buff. In mineral composition it is identical with the Elk Mountain porphyry, but its groundmass is distinctly granular and the phenocrysts are less distinctly set off from the groundmass. The phenocrysts consist of plagioclass (oligoclase-andesine), quartz, biotite, and locally hornblende. The groundmass consists of orthoclase and quartz. In altered facies the plagioclase and some orthoclase are partly replaced by sericite, the biotite and hornblende are altered to chlorite, and a few grains of epidote and calcite are scattered through the groundmass. The minor accessory minerals are apatite, allanite, iron oxide, and titanite.

Quartz monzonite.—The quartz monzonite crops out along the highway on the north side of Tenmile Creek just west of Tucker Gulch. It is in contact with small outcrops of sedimentary rocks of the lower unit of the Pennsylvanian into which it presumably is intruded. In general, however, its borders are concealed beneath glacial till and alluvium which cover the valley floor of Tenmile Creek. Similar rock crops out on the southeast side of Tenmile Creek on Bald Mountain, just northeast of Humbug Creek. According to Crawford[36] this mass forms a stock "whose exposure forms a rough triangle having sides each about 3 miles long. Most of the outcrop is on the west slope of the Mosquito Range, but the rock forms the crest of the range for about a mile and extends down the east slope about a quarter of a mile." The exposure in the mapped area may be continuous with the stock on Bald Mountain, but it more probably forms a small cupola protruding from a large buried stock.

In mineral composition the quartz monzonite is very similar to the porphyritic quartz monzonite and the Elk Mountain porphyry but is granitic in texture. The typical quartz monzonite is whitish-gray in color and in general is medium grained and somewhat porphyritic. It consists of plagioclase (oligoclase-andesine), orthoclase, quartz, and biotite. Thin sections show plagioclase to be slightly in excess of orthoclase. The plagioclase is zoned, but differences in composition are small. The phenocrysts consist of orthoclase enclosing smaller grains of plagioclase, quartz, and biotite. The minor accessory minerals are apatite, magnetite, allanite, titanite, and small zircons. A specimen from the north end of the quartz monzonite outcrop is finer-grained than the typical rock, and under the microscope resembles the porphyritic quartz monzonite. The phenocrysts of orthoclase with their inclusions, however, show its genetic relation with the typical granitic quartz monzonite. A similar porphyritic facies from the stock on Bald Mountain has been described by Crawford[37] which he in-

[36]Op. cit., p. 372.
[37]Op. cit., p. 372.

terpreted as a chilled facies "not far below the original top of the stock."

Quail porphyry.—The Quail porphyry is named after the Quail group of claims on the south end of Elk Ridge where it forms a sill and is exposed in many of the mine workings. To the north of these workings its surface exposures end abruptly at the Little Chief fault; to the south it has been displaced eastward by a concealed fault in Kokomo Gulch but continues across the east slope of East Sheep Mountain to the crest where its surface exposures end abruptly at an unnamed fault. A sill of Quail porphyry has also been mapped on the southeast slope of Tucker Mountain, and dikes of this porphyry are exposed on the east side of Chalk Mountain, and on the southwest slope of Jacque Mountain. It is probably the least abundant of the igneous rocks in the district.

The Quail porphyry is a dark-gray to greenish-gray rock with well-formed phenocrysts of hornblende and poorly developed phenocrysts of whitish feldspar. In general its texture is finer-grained than either the Elk Mountain or Lincoln porphyry, but its diagnostic feature is the absence of phenocrysts of orthoclase and quartz. Under the microscope the feldspar, in grians 0.4 to 2.0 millimeters in diameter, is seen to be in part replaced by sericite and epidote. The hornblende, in grains mostly less than 0.5 millimeter but ranging up to 2.0 millimeters in larger dimension, has been almost entirely replaced by aggregates of epidote, chlorite, and calcite. The groundmass consists of a micrographic intergrowth of quartz and feldspar. Small areas of chlorite and less commonly epidote are scattered through the groundmass and impart a greenish color to the rock. Allanite and apatite are the minor minerals.

Lincoln porphyry.—The Lincoln porphyry forms sparsely distributed sills and dikes throughout the mapped area. It is present in sill-like masses especially in the lower end of Searle Gulch immediately adjacent to the village of Kokomo and in the valley of Tenmile Creek south of Kokomo. The most persistent mass is the thin sill along the middle west slope of Jacque Mountain, which can be followed for about 6,000 feet. A dike about 4,000 feet long is present on the east slope near the middle of Elk Ridge and several dikes and sill-like masses are found on Tucker Mountain and on the southwest slopes of Copper Mountain.

The Lincoln porphyry is characterized by its large well-formed phenocrysts of orthoclase, which attain a maximum length of 2 inches. Present also are much smaller but distinct phenocrysts of quartz, plagioclase, and biotite. The orthoclase phenocrysts are most commonly gray though locally and at the type locality on Lincoln Mountain they are pink[38]. They are glassy, of pearly luster, and contain recognizable small inclusions of biotite. Locally orthoclase phenocrysts are sparingly disseminated. Quartz, in rounded grains, as in the Elk Mountain porphyry, is also prominent. Plagioclase, in white subhedrons, is very abundant. Biotite, in small hexagonal flakes, is commonly altered to a green chloritic mineral. The Lincoln porphyry most commonly has a gray groundmass, but in some facies it is dark brown, almost felsitic. Alteration of the groundmass includes general sericitization of the plagioclase, which locally may be altered to epidote or calcite. Biotite may be sericitized though more commonly it has been altered to chlorite or epidote. Cross[39] reports that secondary chlorite in some places is disseminated throughout the groundmass, giving a green color to the rock.

Rhyolite.—Chalk Mountain, a prominent ridge on the Continental Divide on the southwest edge of the Kokomo area, derives its name from the dazzling white exposure of rhyolite that forms the top, south, and west sides of the ridge. The rock does not occur elsewhere in the district. The mode of occurrence of this isolated mass is obseure. On the top and east side of Chalk Ridge the rhyolite is thinly sheeted in half-inch slabs, but elsewhere the sheeting,

[38]Cross, Whitman, Geology and mining industray of Leadville, Colorado: U. S. Geol. Survey Mon. 12, appendix, p. 328, 1886.

[39]Op. cit., p. 329.

though present, is more widely spaced. The thin sheeting of the rhyolite, as well as the low dip of the sheeting are suggestive of a surface flow. Its structure and the fact that neighboring sediments dip outward at increasingly steeper angles as the rhyolite is approached, on the other hand, are more indicative of an intrusive relation. Emmons[40] cites conditions on the east side of Chalk Mountain as proof of an intrusive relation, but the writers believe that flows covering a rough terrane would show the same relations. The crosscutting relation exposed in a railroad cut on the south side of Chalk Mountain beyond the confines of the mapped area definitely proves the intrusive relation there. It is probable that the rhyolite reached and in part flowed out on the surface existing at the time of intrusion and that this surface was little if at all higher than the present top of Chalk Mountain.

The rhyolite is characterized by phenocrysts of feldspar and slightly smoky quartz, which stand out in a white felsitic groundmass. In any hand specimen three or four small grains, 1 or 2 millimeters in diameter, of altered biotite surrounded by a halo of iron staining can be seen. This is the only dark mineral present. The feldspar phenocrysts vary considerably in size and shape. On the west edge of the area mapped, individuals 2 centimeters long are common, but in general they are only a few millimeters long. Under the microscope it is seen that the phenocrysts are present in three sizes: large phenocrysts 2 to 5 millimeters long; medium-sized phenocrysts about 1 millimeter long; and small phenocrysts about 0.5 millimeter long. The large phenocrysts are chiefly sanidine and quartz, though a few large albite phenocrysts are present. Commonly, small crystals of albite are enclosed in the sanidine phenocrysts. The plagioclase phenocrysts are most commonly of intermediate or small size. The groundmass, which constitutes about 50 percent of the rock, consists of a microgranular aggregate of quartz and feldspar. The apparently unaltered condition

[40] Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. 12, pp. 195-196, 1886.

of the rock is verified under the microscope, both phenocrysts and groundmass being quite fresh. However, the small biotite grains are bleached and studded with magnetite. Apatite and zircon are other accessory minerals but both are much less abundant than is usual in the rocks of the district.

Cross[41] observed drusy cavities in the rock lined with minute crystals of sanidine, quartz, biotite, and topaz. As alteration products are absent, he regarded them as sublimation products.

STRUCTURE

The geologic structures of the Kokomo district are products of recurrent deformations probably dating back to early Paleozoic time. As a result of early studies of the Tenmile district, of which the mapped area is a part, Emmons[42] regarded the dominant structure of the region as a shallow northward-plunging syncline which is now believed to be of Laramide age. Recent detailed studies of the region have shown, however, that this syncline lies superimposed upon a structurally complex foundation which it obscures and partly conceals. This structurally complex foundation comprises folded and faulted sedimentary rocks of the lower unit of the Pennsylvanian rocks, and as the overlying rocks are not similarly affected the deformation which produced it is clearly of Pennsylvanian age. The unconformity at the base of the Pennsylvanian rocks, discussed on pages 84-85, indicates deformation in early Pennsylvanian or pre-Pennsylvanian time.

In this summary report the structures of the Kokomo district will be described in chronological order as follows: (1) Pre-Pennsylvanian, (2) Pennsylvanian, and (3) Laramide structures.

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[41] Op. cit., p. 347.
[42] Op. cit., p. 3, Economic geology sheet, and structure-section sheet No. 1, 1898.

Pre-Pennsylvanian Structures

No pre-Pennsylvanian structures have been recognized in the Kokomo district, but their presence is inferred from localized uplifts and downwarps which have affected the distribution of the pre-Pennsylvanian and Pennsylvanian and Permian (?) rocks and profoundly influenced their structures. Later in Cretaceous or early in Tertiary time these early structures also influenced the intrusion of the chonolith and stock of porphyritic quartz monzonite on Tucker Mountain which took advantage of the zone of weakness along the margin of a Pennsylvanian basin of deposition, already discussed on pages 75-76.

The overlap of the Pennsylvanian strata onto the pre-Cambrian rocks on Copper Mountain in the northern part of the mapped area shows that the site of Copper Mountain had been elevated to form a landmass in pre-Pennsylvanian or early in Pennsylvanian time. Pre-Pennsylvanian rocks crop out a short distance to the west of the mapped area along the valley of the Eagle River[43], and their absence on Copper Mountain shows that they pinch out either in the southwestern part of the mapped area or immediately to the southwest of it. Although within the Kokomo district there are no direct criteria for determining whether or not the pre-Pennsylvanian sedimentary rocks were subsequently eroded from Copper Mountain, the arkosic and highly micaceous character of the Pennsylvanian and Permian (?) rocks and the absence of appreciable numbers of sedimentary rock fragments imply that these sediments were derived from the landmass of pre-Cambrian rocks. The numerous beds of conglomerate and the presence of numerous pebbles and cobbles of pre-Cambrian rocks in many of the finer-grained clastic rocks and even in the limestones are indicative of a nearby source. It is thus inferred that the site of Copper Mountain and the area immediately surrounding it where the Pennsylvanian rocks rest on the pre-Cambrian rocks was elevated to form a highland

[43] Emmons, S. F., Op. cit., p. 1, 1898.

in pre-Pennsylvanian times. Similar stratigraphic relations have been found in other parts of the Gore Range and are in accord with the conclusions by Lovering and Johnson that[44] "the region was persistently high or repeatedly uplifted."

From Copper Mountain westward and southward the Pennsylvanian and Permian (?) rocks thicken abruptly. The great thickness of this section of strata, 5,000 feet and more, and the occurrence of pre-Pennsylvanian rocks southwest and west of Copper Mountain would be consistent with accumulation in a basin of deposition immediately in front of the highland described above.

The area may be divided into two major structural units or blocks which moved independently of each other. The accumulation of so great a thickness of sediments close to the landmass suggests a sharp line of demarcation and probably a steep rise between them, but whether these blocks are separated by a fault or a monoclinal flexure, now masked by Pennsylvanian and Permian (?) sediments, is not clear. As shown below, however, these structural features have greatly influenced later deformations of the region, for the localized complex structure in the overlying Pennsylvanian rocks was apparently produced by intermittent movement along this zone.

Pennsylvanian Structures

Some of the major structural features of the mapped area are referred to deformation that occurred intermittently in Pennsylvanian time and produced a structurally complex foundation on which the rocks assigned to the upper unit were deposited unconformably. The precise age of the rocks affected has not been determined and therefore the local deformation cannot be assigned to definite geologic epochs. The inability to determine the precise age of the rocks also precludes the correlation of the structures

[44] Op. cit.,

in different parts of the mapped area. The structures therefore will be tentatively discussed on a geographic basis. Structural features formed during Pennsylvanain time include folds, faults, and unconformities within the stratigraphic section assigned to the lower unit of the Pennsylvanian rocks, and include also an unconformity between the lower and upper rock units. The unconformity between the lower and upper rock units has already been described on pages 69-70 and will not be further considered here.

Pennsylvanian structures northwest of Searle Gulch

A critical study of the strikes and dips shown on the accompanying geologic map (pl. 2) reveals discordant structural relations within the strata assigned to the lower unit of the Pennsylvanian rocks, especially on Copper and Tucker Mountains. On the basis of these measurements three structural units have been recognized, which tentatively will be referred to as the lower, middle, and upper homoclinal masses. The lower homoclinal mass is characterized by northerly strike and moderate west dip, the middle by northwest strike and moderate to steep northeast dip, and the upper, as in the lower, by northerly strike but low west dips. The contacts between these homoclinal masses are indefinite, and those drawn on the map are therefore rather arbitrary. The lower homoclinal mass is most widespread, as it occurs on the lower southwest slopes of Copper, Tucker, and Jacque Mountains. The middle mass is present on Copper and Tucker Mountains, but absent on Jacque Mountain; and the upper was recognized only on Tucker Mountain. The contact between the lower and middle homoclinal masses, especially on Tucker Mountain, is extremely irregular. Along the lower east side of the mountain it falls at an altitude of about 10,900 feet but on the west side, in a distance of about 2,500 feet, it crops out at an altitude of about 11,500 feet. This may represent either a relief of about 600 feet on its surface on which the younger sediments were deposited or a later warping of that surface, but it more likely is due to warping. Although the lower and middle masses are both present on Tucker and Copper Mountains, their outcrops on Tucker Mountain relative to their outcrops on Copper Mountain show a pronounced discordant areal relation. On Copper Mountain the entire lower southwest slope consists of the lower homoclinal mass and thus in part flanks the middle homoclinal mass on the northeast side of Tucker Mountain. A cover of alluvium and glacial till in Copper Gulch conceal the rocks here, but the abrupt discordant relations on opposite sides of the gulch suggest a concealed fault.

The discordant structures within the strata assigned to the lower unit are too obscure to form a reliable basis for the interpretation of the structure at this time. Nevertheless, the local evidence is in keeping with the concept that the Copper Mountain area falls within a zone of crustal unrest along which the rocks were intermittently deformed, and in different ways. Related structures are not found in the overlying rocks, assigned to the upper unit of the Pennsylvanian and Permian (?) rocks. This fact and the major unconformity between the lower and upper units of these rocks clearly indicate that this period of deformation preceded the deposition of the rocks of the upper unit. Subsequent warping and faulting of Laramide and Tertiary age may have modified these Pennsylvanian structures but to what extent is not clear.

Pennsylvanian structures south of Searle Gulch

Pennsylvanian structures south of Searle Gulch are less conspicuous than those in the northern part of the area. As only the upper part of the section belonging to the lower unit of the Pennsylvanian rocks is exposed in the mapped area, only the structures in these upper beds will be described here. The most obvious structure is the homocline which involves all the Pensylvanian and Permian (?) rocks and is chiefly post-Paleozoic in age, but faults that are clearly restricted stratigraphically and local unconformities indicate that folding accompanied by faulting occurred during Pennsylvanian time. The structures described below are found at different stratigraphic horizons and clearly indicate that deformation during Pennsylvanian time was recurrent, as in the northern part of the district, though less intense than there.

The earliest recognized deformation in the southern part of the area is marked by two transverse faults about 300 feet apart on the crest of North Sheep Mountain. They have displaced two prominent limestone beds and have implaced a sandstone along their strike. As the beds involved cannot be correlated with known horizon markers their relative displacement cannot be determined. These faults terminate sharply against a lens of conglomerate which rests unconformably on the faulted surface. An unconformity, probably somewhat higher in the stratigraphic section, is also suggested by local folds found in the area between North Sheep and Sheep Mountains near the head of the south fork of Kokomo Gulch and on the lower east slope of Sheep Mountain which are not represented in the overlying beds. Locally also, angular discordance in strike and dip may be due to arching or warping of beds that were beveled by erosion prior to the deposition of the overlying beds.

A shallow easterly trending synclinal flexture at the site of the old town of Robinson is likewise probably of Pennsylvanian age. The beds at the foot of East Sheep Mountain strike northeast and dip southeast, and the beds on the north slope of Chalk Mountain strike about east and west and dip towards the north. Exposures are not continuous enough to determine the details of this structure, but its general synclinal form is obvious, and Emmons[45] called it the Robinson syncline. Involved in this structure are the lowest strata assigned to the middle unit of the sedimentary rocks, including the Robinson limestone; consequently it is not definitely known whether this deformation

[45]Op. cit., p. 5, 1898.

is of Pennsylvanian age or later. The easterly strike of the axis of the Robinson syncline, however, is at right angles to the larger Kokomo syncline, the dominant fold of Laramide age described below. Because of this discordance in direction and the major unconformity below the strata assigned to the upper unit of the sedimentary rocks northeast of Searle Gulch (see pp. 69-70), the Robinson syncline is tentatively regarded as a product of Pennsylvanian deformation.

Laramide and Tertiary Structures

The Laramide and Tertiary structures are the most conspicuous structural features of the district. Chief among them are the shallow northward-plunging syncline referred to above as the Kokomo syncline, and the Mosquito fault which has cut off a large part of the east limb of the syncline. Also within the syncline the rocks have been much faulted and fissured.

Kokomo syncline

Except in the northeastern part of the area and north and south of Robinson Flat (refer to topographic map), the prevailing trend of the sedimentary rocks and the intercalated porphyry sheets strike north-northwest and dip consistently to the northeast. Such a homoclinal structure could result from faulting, folding, or both. The westerly dip of the beds assigned to the upper unit of the sedimentary rocks in the northeastern part of the mapped area, however, suggests that the overall structure of the Kokomo district is part of a syncline, and the work of Emmons[46] to the east of the mapped area clearly confirms this interpretation.

The Kokomo syncline extends from a point between Fremont Pass and Bartlett Mountain, which lie about one-half mile south of the mapped area, northward beyond the north boundary of the Tenmile quadrangle. Included on

[46]Op. cit., p. 3, 1898.

its east limb are a few subordinate flexures, which are well illustrated on Union Mountain. The syncline pitches northward, and its axis, which is slightly bent, strikes north or a few degrees west of north and passes just east of the town of Kokomo and Jacque Peak. The normal dips on the limbs of the syncline range from 20° to 40°, but locally on the east limb near the Mosquito fault dips may be steeper and even overturned. According to Emmons[47], the steep and locally overturned dips of the strata and their generally crumpled character indicate a considerable compressive strain. He concluded that this compressive movement with its accompanying folding and faulting may have antedated ore deposition. It is now known, however, that part of the movement on the Mosquito fault occurred after mineralization[48].

Mosquito fault

The Mosquito fault is one of the dominant structural features of this general region. Only a small part of it is exposed in the area mapped on Copper Mountain, but it extends for many miles beyond the mapped area both to the north and south. It strikes slightly east of north, and the dip as determined at the Climax mine, is from 71° to 80° west[49].. Its throw cannot be accurately determined but in most places is probably several thousand feet. The field relations of the Mosquito fault in general are those of a normal fault, but Behre[50] has shown that in part it is a reverse fault. Through most of its extent the Mosquito fault has brought pre-Cambrian rocks on the east against Pennsylvanian rocks on the west, but northeast of the Noma mine on Copper Mountain the fault probably passes into the pre-Cambrian rocks which thence form both wells along its northeastward extension.

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[47]Op. cit., p. 4, 1898.
[48]Butler, B. S., and Vanderwilt, J. W., op. cit., p. 218.
[49]Idem.
[50]Behre, C. H., Jr., Preliminary geologic report on the west slope of the Mosquito Range in the vicinity of Leadville, Colo.: Colorado Sci. Soc. Proc., vol. 14, no. 2, p. 70, 1939.

The trace of the Mosquito fault across Copper Mountain, however, is not obvious. Here the contact between the pre-Cambrian and the Pennsylvanian rocks is peculiarly sinuous and irregular, and, as the contact between these rock systems south of here is everywhere a fault contact, Emmons[51] attributed their peculiar relations on Copper Mountain to faulting. He regarded the contact along the north side of the embayment of sedimentary rocks and along the crest and west side of Copper Mountain either as a part of the main Mosquito fault or a distinct northwest branch of the fault. If it were a branch, he postulated that the Mosquito fault proper must continue into the pre-Cambrian rocks approximately along the line of the valley of Tenmile Creek. Regarding the peculiar "bay-like intrusion" of the pre-Cambrian rocks on the east side of Copper Mountain Emmons[52] states "that it appears to be in the nature of an overthrust, but that sufficient detailed and accurate data are not available to explain satisfactorily the mechanism by which it was produced."

As a result of recent detailed mapping it is concluded that the irregular and curved contact between the pre-Cambrian and Pennsylvanian rocks is a combination of several structures as follows:

(1) The contact between the pre-Cambrian and Pennsylvanian rocks along the southeast side of the peculiar embayment of sedimentary rocks cropping out on the southeast slope of Copper Mountain is a fault contact and marks the extension of the Mosquito fault. A short distance northeast of the Noma mine the Mosquito fault, as surmised by Emmons, continues into the mass of pre-Cambrian rocks. Although it has not been traced to the northeast, it probably continues along its projected course along the general line of the valley of Tenmile Creek.

(2) The contact between the pre-Cambrian and Pennsylvanian rocks along the crest and west side of Copper

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[51]Op. cit., p. 3, 1898.
[52]Op. cit., p. 4, 1898.

Mountain is a depositional contact, the Pennsylvanian rocks resting unconformably on the pre-Cambrian rocks, as already discussed above.

(3) The relations between the pre-Cambrian and Pennsylvanian rocks on the north side of the embayment of sedimentary rocks are obscure and cannot at present be explained satisfactorily. Rock material on the dumps of some of the tunnels along the contact consists of sedimentary rocks and suggests that the contact may be overhanging. Outcrops along the contact are few and poor, but a white, fine grained, glassy quartzite about 10 feet thick, tentatively correlated with Sawatch quartzite of Cambrian age, appears to be present everywhere along this contact. It is exposed in a few poor outcrops but in most places is indicated by a narrow zone of float. The strikes and dips of the adjacent sedimentary rocks where reliable are discordant with the strike of the adjacent contact, and hence also with the strike of the quartzite. These features are indicative of a fault contact; but even so, the occurrence of the band of quartzite along the contact is difficult to explain. An alternative interpretation is that the relations here found mark an overturned fold and that the Mosquito fault has cut off part of this fold. This interpretation would explain the band of quartzite, but it would not account for the discordant relations between the dips and strikes of the sedimentary rocks and their contact with the pre-Cambrian rocks. In general, the data are too meagre to decipher this structure, and a satisfactory explanation must await more detailed and accurate data.

Other faults

Within the Kokomo syncline the rocks have been much faulted and fissured. Though the displacement on these faults is small, usually amounting to a few feet and never exceeding a few hundred feet, these breaks have been a most important factor in ore formation. They furnished channels along which ore solutions could pass and were a factor in the localization of ore shoots. These faults fall into three groups: (1) transverse faults which trend from N. 30° to 70° E., (2) faults which parallel the strike, or longitudinal faults. and (3) bedding-plane faults.

Transverse faults.—An examination of the geologic map shows that wherever outcrops are good. faults striking N. 30° to 70° E. are numerous. There are also many more faults in the area with displacements of less than 15 feet, that could not be traced beyond single outcrops and are therefore not shown on the geologic map. A number of small northeasterly trending faults not shown on the map have also been found in mine workings. It may be that zones in which faults are quite numerous are separated by zones in which faults are few. A diagram by Emmons shows a zone of sheeting in the Queen of the West group of mines, in which eight parallel faults occur within one hundred feet. These northeast-striking displacements are all normal faults. They dip at angles from as low as 35° to vertical either toward the northwest or toward the southeast, although apparently the larger number, and certainly the faults of largest displacement, dip toward the southeast.

The northeasterly trending faults, as well as fissures without noteworthy displacement of their walls, were formed at three or more periods. The earliest datable faulting occurred either just prior to or during the intrusion of the sills, and a few of the earliest faults were occupied by dikes. Faults of the second period displaced some of the porphyry sills and formed fracture zones, some of which were occupied by dikes and some were later mineralized. The mineral deposits are a product of three stages of deposition with intervening stages of renewed movement along faults and fissures. The final period of faulting is post-mineral, and the faults of this period displaced pre-existing ore bodies as shown by ore dragged along in the fault gouge. Some faults are products of several periods of movement.

Of the profusion of faults in the mapped area only the Little Chief and Tenmile faults will be briefly described here, as they appear to have exercised a major influence on ore deposition. In the productive part of the district probably many other faults, both large and small, as well as fissures with no appreciable relative displacement of their walls, have played an important role as access channels for ore solutions; but data now at hand do not permit precise determination of their influence on ore deposition.

Little Chief fault.—The Little Chief fault, named after the Little Chief claim, is exposed in the Wilfley, Delphos, and White Quail workings and in the Belcher and Smuggler shafts, and is discontinuously exposed along its strike across Elk Ridge. Its trace probably continues across Searle Gulch and up the slope of Jacque Ridge but there is no reason for assuming that the Queen of the West sheeted zone is the northeastward continuation of this fault, although the belief that this is true is commonly held in the district. The fault appears to split at the Belcher shaft. It dips 65° south, has a vertical displacement of about 160 feet, and has dragged the beds on the south side of the fault upwards. The fault is marked by a 30-foot zone of sheared and comminuted rock. The comminuted rock is kaolinized, and hence is white. Much of it appears to consist of porphyry, but it may be arkosic sandstone, which, when ground up and kaolinized, would resemble ground-up porphyry. For this reason the miners commonly call the faults porphyry dikes. Nests of sulfide minerals usually with high silver values are found in the fault zone. Emmons[53] states that "ore is found on the fault, but apparently only as fragments that have been dragged in." But the descriptions of the nests of sulfides given by the miners would lead one to believe that some of these sulfides were deposited along the fault rather than that they were "drag ore."

The Little Chief fault marks the approximate northwest limit of the productive area. Although ore has been found along this fault, no ore bodies of consequence have been found to any appreciable extent northwest of it. Pos-

[53]Op. cit., p. 5, 1898.

sibly the Little Chief fault served either as an effective barrier to the northward migration of ore solutions, or as the northwesternmost access channel along which ore solutions flowed and from which they migrated laterally to replace the favorably constituted limestone beds.

Tenmile fault.—The Tenmile fault is completely concealed by glacial till and alluvium in Tenmile Valley and is known only from discordant structural relations in mine workings. Emmons[54] wrote that in the workings of the New York mine "the ore body was cut off by a fault, under and approximately parallel with the bed of Tenmile River beyond which it has not yet been found." As shown on the geologic map, this fault ranges in strike from N. 30° to 40° E. and the trace of it is somewhat sinous. It dips about 75° southeast and drops the southeastern block 335 feet vertically with reference to the northeastern block. The zone of breccia along the fault is about 220 feet wide, and it seems probable that the displacement is distributed on many parallel faults each having only a few feet of displacement.

Another fault, very probably a member or part of the Tenmile fault or fault system, was disclosed in the workings from the Champion shaft. This fault approximately parallels the Tenmile fault and gives further evidence of the highly disturbed condition of the rocks under Robinson flat. Proof of the continuation of this zone of faulting to the southwest is found in the Daughenbaugh shaft[55], in which a fault plane was exposed, and also in the greatly broken condition of the rocks reported to exist in the Juniata, Columbine, and Half-Moon workings[56].

As most of the productive ore bodies lie in a relatively narrow zone of northeasterly trend on the northwest side of Tenmile Creek, the Tenmile fault or fault zone was apparently influential in the localization of some of the productive ore bodies of the district. A relatively unimport-

[54]Op. cit., p. 5, 1898.
[55]Emmons, S. F., op. cit., p. 5, 1898.
[56]Rich, B. F., of Kokomo, Colo. Personal communication.

ant mineralized area lies east of the Tenmile Valley also, indicating the medial position of Tenmile fault relative to the mineralized belt of the district. From these areal relations it seems probable that the Tenmile fault zone is a deep-seated trunk channel along which the ore solutions rose towards the surface and thence spread along subsidiary structures.

Longitudinal or strike faults.—No strike faults have been definitely recognized on the surface, but the extreme width of outcrop of some of the strata of the middle unit of the Pennsylvanian rocks near the middle of Elk Ridge may have been caused by duplication of its beds by strike faults. Strike faults have been reported by miners. Emmons[57] describes them as follows: "A series of small longitudinal or strike faults, i. e., running northwest, is observed in the lower part of the White Quail workings, which is undoubtedly later than the ore deposition. Their throw is uniformly upward on the southwest side, and from 2 to 15 feet in amount. They thus produce a gradual shallowing of the average dip of the ore horizon from 25° to 17°, though the actual dip of the formation between the faults remains substantially constant."

Bedding plane faults.—Displacements parallel to the bedding are difficult to detect, but the thin layers of clay-like material observed between some of the beds in all the accessible underground workings are indicative of bedding plane faults. Emmons[58] recognized bedding plane faults in the Queen of the West group of mines. Here the faulting along bedding planes is post-mineral and has been detected because it offsets the veins deposited in the northeasterly trending faults.

MINERAL DEPOSITS

General Statement

The mineral deposits of the Kokomo district are restricted to a relatively narrow zone of north-northeasterly

[57]Op. cit., p. 5, 1898.
[58]Op. cit., p. 5, 1898.

trend adjacent to the valley of Tenmile Creek. The most productive area lies on the northwest side of Tenmile Creek, including the south end of Elk Ridge, East Sheep Mountain, and the southern end of Jacque Mountain. Effects of mineralization, however, extend over a much wider area but though extensively explored by tunnels and prospect pits, production from the outer part of the area has been relatively small.

The mineral deposits of the Kokomo district as a whole show wide differences in mineral composition and form, and accordingly they are classified in this report as follows: (1) high temperature deposits, (2) replacement ore deposits in limestone, and (3) vein deposits. Production has come chiefly from the replacement deposits in the limestone. The veins have been mined in places, but their production has been relatively small. The high temperature deposits, consisting chiefly of silicate minerals, have been essentially unproductive and are at present of little or no economic value

The following brief descriptions of the character, distribution, and geologic relations of the mineral deposits are intended to give a perspective of their general features from which their origin and future possibilities may be inferred. Descriptions of the mines, the investigations of which is not completed, will be reserved for a later report.

High-Temperature Deposits

The character of the high-temperature deposits differs from place to place, and the assemblage as a whole represents several stages or epochs of deposition though no attempt is here made to subdivide them on that basis. These deposits are restricted to the area northeast of Searle Gulch. They are most common on Tucker Mountain and adjacent parts of Jacque, Union, and Copper Mountains. From this general locality they fade out so that their outer limits are irregular and cannot be closely defined. Detailed study of their mineralogy has not been completed but they comprise essentially (1) aggregates of silicate minerals—wollastonite, garnet, epidote, biotite, sericite, some chlorite, and locally hornblende; (2) oxides—magnetite and specularite; and (3) sulfides—chalcopyrite, molybdenite, and pyrite. Locally limestone beds are converted into white crystalline limestone or marble.

The process of mineralization represented by these deposits affected chiefly the limy and shaly beds and to a lesser degree the quartzose sediments and igneous rocks, except that biotitization and sericitization affected only the quartzose rocks. Wollastonite was found only in a shaly rock near the Stormking shaft on Copper Mountain. Garnet (andradite) is present throughout the area affected. In the upper D. and G. tunnel on the lower southeast slope of Jacque Mountain it forms a bed 2½ to 5 feet thick impregnated with molybdenite which was followed in the tunnel for about 300 feet. More commonly garnet forms local aggregates with epidote and calcite, generally accompanied by magnetite, specularite, and a little pyrite. Epidote is probably the most abundant of the silicates formed by replacement and is present in all the altered rocks. Where mineralization is most intense epidote with accessory amounts of garnet, chlorite, and sulfides, has replaced whole bedding-laminae, producing banded rocks in which the green bands of epidote-bearing rock alternate with fine-grained pinkish gray to red bands of hornstone or shaly rocks. In the less intensely altered shaly and limy rocks and especially in the sandstones and conglomerates epidote in association with biotite and sericite forms disseminated grains and irregular clusters.

Biotite and sericite are probably the most widely distributed of the high-temperature minerals. Although they most commonly are associated in the same rock they also occur exclusive of one another. Biotite is distributed throughout the thick section of gray sedimentary rocks and tuff and breccia of the lower sedimentary unit on Tucker and

Copper Mountains, and probably also in the gray sedimentary rocks on the lower southeast slope of Jacque Mountain. Where the biotite is most profuse the strata are blackish gray. The biotite occurs in small disseminated flakes and in clusters or bunches of small flakes in the matrix between the quartz and feldspar grains, and less commonly in veinlets along cleavage cracks in the feldspar grains and rarely in cracks of quartz grains. Sericite is most abundantly developed in the feldspathic sandstones and porphyries, in which it has extensively replaced the feldspars, but in the most altered rocks it has also partly replaced the quartz.

Chlorite is most commonly associated with epidote, and occurs chiefly in the shaly rocks. Green hornblende, intergrown with epidote and chlorite, was found only on a dump near the lower end of Tucker Gulch.

The high-temperature ore minerals are less abundant than the silicate minerals, and no deposits of them are known to be large enough or of a good enough grade to form commercial ore bodies. Magnetite and specularite are commonly associated with garnet and epidote and are coextensive with them. They have been found on the dump of the upper Lillie G prospect on Copper Mountain, at several places on Union Mountain, on the east slope of Jacque Mountain, and in Searle Gulch about a mile northwest of the Wilfley mine. In most places magnetite and specularite occur as disseminated grains in the silicated rocks and only at the Lillie G prospect do they form masses several feet in diameter. Their occurrence in Searle Gulch in association with garnet and epidote is of special interest as it implies the existence here of a center of mineralization somewhat remote from other high-temperature deposits and in a locality where the ore-bearing limestone beds are within depths that can be explored at relatively low cost. Chalcopyrite has been found only as sparsely disseminated grains in association with epidote. Locally also specks and films of the blue and green carbonates of copper have formed from oxidation of a copper sulfide, probably chalcopyrite. Molybdenite-bearing rocks has been found on many prospect dumps on the lower southeast slopes of Jacque and Tucker Mountains, and molybdenite-bearing quartz veinlets one-quarter inch thick cut the bluish-gray quartzites on Tucker Mountain. In the upper D and G tunnel on Jacque Mountain, already referred to, disseminated molybdenite grains occur in the garnetized rock and also in quartzite. The molybdenite deposits found in the mapped area have proved to be of insufficient size or grade to exploit.

Besides these more typical high-temperature minerals, which are commonly found in contact metamorphic deposits, the high-temperature deposits in the Kokomo district contain disseminated pyrite. Pyrite associated with pyrrhotite also forms massive replacement bodies in the limestones, discussed below, but the disseminated pyrite appears to be free from pyrrhotite, and tentatively is considered a part of the high-temperature assemblage of minerals. Although pyrite forms disseminated grains and bunches in the sedimentary rocks it occurs profusely in the porphyry masses both as disseminated grains and in discontinuous veinlets. On the northern end of Tucker Mountain and adjacent parts of Jacque and Union Mountains both the sedimentary rocks and igneous rock masses have been locally so thoroughly impregnated with pyrite that it is difficult to distinguish the rock types. The outcrop here is weathered and thereby forms a huge mass of rock stained yellow to buff by the iron oxide formed by oxidation of the disseminated pyrite.

Replacement Deposits

By A. H. Koschmann, F. G. Wells, and James W. Odell

The replacement deposits, which are the most productive in the district, occur in the limestone beds of the middle unit of the Pennsylvanian and Permian (?) sedimentary rocks. Some of the underground workings near the head of Kokomo Gulch may be in limestone beds in the lower unit of these rocks, but as these workings are inaccessible