DESCRIPTION OF THE TENMILE DISTRICT QUADRANGLE.

GEOGRAPHIC RELATIONS.

The area shown on the Tenmile district special map is included between the meridians 106° 8′ and 106° 16′ of longitude west from Greenwich and the parallels 39° 22′ 30″ and 39° 30′ 30″ of north latitude. It covers about 55 square miles, and adjoins on the north the western portion of the area represented on the map of the Mosquito Range, Sheet VI of the Leadville atlas, Monograph XII. This special district lies immediately north of the Continental divide, which here runs east and west, connecting the Mosquito Range with the northern part of the Sawatch Mountains, and is bounded on the east by the steep western slope of the Mosquito Range. Immediately north of it is the little-known mountain group called the Gore Mountains, which is a northern extension, set off en echelon somewhat to the westward, of the Mosquito Range.

Drainage.

The principal drainage is northward through Tenmile River, which flows around the northern end of the Mosquito Range into Blue River, the main south fork of Grand River in Middle Park. The southwestern portion of the area is drained by the east or main fork of Eagle River, which flows westward across the northern flanks of the Sawatch Range and joins Grand River just before it enters its great canyon on the southern edge of the White River Plateau.

Elevated situation.

Situated as it is near the crest of the Rocky Mountains this district is one of the most elevated mining regions in the West, being on the average nearly a thousand feet higher than the neighboring Leadville district. Its larger valleys are between 10,000 and 11,000 feet above sea-level, the bottoms of the small side valleys often reaching 12,000 feet, while its culminating peak, Jacque Mountain, in the center of the area, has an altitude of 13,235 feet. The only higher point within this area is Fletcher Mountain (13,917 feet), a projecting portion of the main crest of the Mosquito Range, the slopes of which rise at an angle of 35° from the glacial amphitheaters and valleys at its base.

In contrast with these steep and rugged slopes, which form only a narrow strip along the eastern edge of the area mapped, the rest of the region is characterized by smooth and rounded topographic forms, the surface being made up of gently dipping beds largely covered by glacial gravels and soil. The soil supports in places a considerable growth of coniferous trees of hardy alpine varieties, which sometimes, especially in the northwestern portion, form a forest covering sufficiently dense to obscure the rock outcrops.

Towns.

The main valley of Tenmile River, which rises in a fine glacial amphitheater just south of this quadrangle, traverses the eastern portion of the area from south to north, at first broad and open, but becoming narrower and deeper as it descends. In the upper part of this valley are situated the small mining towns of Robinson and Kokomo-Recen, which are about 15 miles north of Leadville and 9 to 10 miles west and a little south from Breckenridge, on the further side of the Mosquito Range. The earlier town of Carbonateville, once situated still higher up the valley, at the mouth of McNulty Gulch, has now entirely disappeared. Since the completion of the map a second railroad, the Denver, Leadville, and Gunnison, has been built through this valley, nearly parallel with the tracks of the Denver and Rio Grande.

That portion of the area which drains into Tenmile River is in Summit County, and the much smaller southwestern portion which drains into Eagle River is in Eagle County, Colorado.

DEVELOPMENT.

Discovery of silver ores.

Gold-bearing placers were discovered in the valleys of this region in the early sixties by prospectors who came from the placer diggings around Breckenridge, and it was probably by them that the name Tenmile was given to the stream, this being about its distance from that town. A few vein deposits in the Archean rocks were afterwards opened, but no important mining development took place until 1878, when the discovery of rich silver deposits in stratified limestones around Leadville had directed the attention of prospectors to this, then somewhat novel, class of ore deposits. A very considerable number of more or less oxidized bodies of pyrite, blende, and galena were opened along the eastern slopes of the Tenmile Valley, but the most important and the richest ore bodies were found in the Robinson mine, which is said to have produced, in all, ore to the value of over $6,000,-000. During the decade from 1880 to 1890, after the richer oxidized ores had been for the most part exhausted, many of the mines were closed down, the unaltered pyritous ores being too poor for profitable exploitation. Since 1890 there has been a partial revival of mining activity, as ore dressing and concentration plants have been built to enrich the ore as it comes from the mine, and the demand for pyritous ores by the smelters has greatly increased.

The severity of the climate and the consequent disproportionate length of the winter season has always been an obstacle to the ready development of the very considerable mineral resources of the district.

GENERAL GEOLOGY.

Nature of uplift of the Mosquito Range.

The Mosquito Range, which adjoins this area on the south, is, as has been shown in the report on the region around Leadville, a recent uplift on the flanks of the older Sawatch Range. This uplift has been produced as the result of lateral compression acting upon a series of Paleozoic and Mesozoic sediments together with interbedded or intrusive sheets of igneous rock; the whole have been pushed up into a series of corrugations or folds, and finally broken by great faults. In the vicinity of Leadville and southward the displacement has been distributed along a number of more or less parallel fault planes, on which the upthrow is almost invariably to the east. To the north of Leadville this movement, which averages about 5000 feet, has been concentrated on a single plane—the great Mosquito fault, which has a direction nearly due north along the steep western face of the Mosquito Range as far as the northern edge of the area included in the present map, and then bends sharply westward, following a northwest course along the southwest base of the Gore Mountains, nearly to Grand River.

From the uplifted area immediately east of this fault the overlying sedimentary formations have, for the most part, been removed by erosion, and the underlying complex of crystalline pre-Cambrian rocks is now exposed. West of the fault plane the post-Cambrian sedimentary beds, with their interbedded igneous sheets, dip at gentle angles away from the Sawatch uplift and are more or less plicated and broken in the neighborhood of the Mosquito fault.

ARCHEAN.

The areas east of the Mosquito fault are made up of rocks belonging to the crystalline complex described in the Leadville report (Monograph XII) as of probable Archean age. In the preparation of the present map no systematic study of these areas was made, the only portions coming under observation being those nearly adjoining the fault; and no attempt has been made to discriminate upon the map the different types of rock, or to outline such of the numerous dikes of eruptive rock as were observed to traverse them.

Structure planes in the crystalline complex.

The rocks consist of granites, granite-gneisses, mica-schists, and amphibolites, with a considerable development of pegmatite veins traversing them in every direction. The younger rocks of undoubted igneous origin that form the dikes are diorite-porphyries and rhyolites, of the same general types as those which form intrusive sheets in the sedimentary rocks to the west of the fault and which will be described later. Among the older rocks adjoining the fault, gneisses and schists are the prevailing types. The structure planes in the interior of the crystalline area are often so regular, even in the massive rocks, as to simulate bedding. These planes generally stand at a high angle and have no relation to the bedding planes of the distinctly sedimentary rocks. On the other hand, immediately under the patches of Cambrian quartzite that still rest upon the crystalline complex in the vicinity of the fault, structure planes parallel with the bedding planes of the superincumbent beds occur for a certain distance in the crystalline schists, apparently even beyond the limits of secular disintegration.

SEDIMENTARY ROCKS.

Of the Paleozoic sedimentary series, there are exposed at the surface in the Tenmile district outcrops of a portion only of the Carboniferous formation and a small patch of Cambrian is left resting on the Archean, east of the Mosquito fault. Inasmuch, however, as the whole lower Paleozoic series is found at short distances beyond the limits of the quadrangle—to the east and south in the Mosquito Range, and westward along the valley of Eagle River—a brief description of the more common characteristics of the respective formations will be given here.

CAMBRIAN SYSTEM.

Sawatch quartzite.

Sawatch quartzite.—This formation is made up of a series of remarkably pure, white, evenly bedded quartzites, with a fine-grained conglomerate of small rounded pebbles of quartz and chalcedony at the base. In the upper part the beds contain more impurities and pass into reddish and greenish argillaceous and calcareous shales, in which have been found fossils belonging to a Dikellocephalus fauna of Upper Cambrian age.

The only observed exposure of these rocks in the present area is a small remnant of the basal quartzite and conglomerate, with an included sheet of porphyry, on the summit of Little Bartlett Mountain. The thickness of the Cambrian averages from 160 to 200 feet.

SILURIAN SYSTEM.

Yule limestone.—This formation is represented by a series of light drab-colored, generally rather thin-bedded limestones, which are often magnesian and always more or less siliceous, sometimes passing into calcareous sandstones. They are inclined to be crystalline and in places form fine marbles. The few fossils that have been found in these beds indicate a probable lower Silurian or Ordovician age. Their thickness averages from 120 to 160 feet.

Parting quartzites.

Above them is a series of siliceous beds, generally quartzites, which are known as the *Parting quartzites*, from their position between two limestones which, in the absence of fossil evidence, they serve to delimit. Their thickness is quite variable, ranging from 15 to 60 feet, and near Leadville evidence has been found of an unconformity by erosion between them and the overlying beds. While no fossils have been found which would connect them with either the Silurian or the Carboniferous system, they have hitherto been mapped under the Silurian color, mainly because of this unconformity, which might account for the apparent absence of Devonian strata.

Probably Devonian.

Within the last few years, however, Devonian fossils, principally fish remains, have been found in other parts of the Rocky Mountains in beds that occupy a stratigraphic position so closely corresponding to that of these quartzites that it has become probable that the latter are of Devonian age also. Nevertheless, in the absence of direct evidence, it has not been judged wise to designate them by Devonian color on the sheet showing structure sections. Neither they nor the Silurian beds outcrop at the surface within the area mapped.

CARBONIFEROUS SYSTEM.

Blue or Leadville limestone.—This is the distinctly calcareous member of the Carboniferous system which corresponds to the Lower Carboniferous or Mississippian limestone of the Mississippi Basin. It is the principal ore-bearing horizon of the Leadville, Red Cliff, Aspen, and other mining districts. Although not exposed at the surface in this district, it outcrops not far westward, in the Eagle River Valley. In the Mosquito Range it is a typical dolomite, of bluish-gray or black color near the top, and lighter colored near the base. It is in general heavily bedded and of granular structure. It contains characteristic concretions of black chert, is often fossiliferous near the top, and passes upward into alternations of shale and sandstone. The average thickness of the Leadville limestone is about 200 feet; it is sometimes considerably less, but rarely greater.

Weber formation.—This formation constitutes the most siliceous member of the Carboniferous system, and corresponds in a general way to the Weber quartzite of the Wasatch Mountain section and to the Lower Aubrey of the Colorado Canyon section. It includes a lower calcareo-argillaceous member, designated in the Leadville report the Weber shales, the main siliceous formation being there called the Weber grits.

Weber shales.

The Weber shales constitute a transition series between the massive limestones below and the coarse sandstones of the Weber grits above. They consist in the Mosquito Range of argillaceous and calcareous shales, alternating with quartzitic sandstones. The former are generally very carbonaceous and often contain seams of impure anthracite, up to several feet in thickness, but of no commercial value. The calcareous members sometimes develop considerable beds of impure limestones, generally fossiliferous, which are distinguished from those of the lower formation by fossils that are exclusively of Coal Measure aspect. The thickness of this series, which is very variable, is assumed in this region to be about 300 feet. It occurs in the valley of Eagle River, just west of the limits of the quadrangle.

Arkose character of the Weber grits.

To the Weber grits belong the lowest beds exposed in the Tenmile district west of the Mosquito fault. Their average thickness here, as in the Mosquito Range, is about 2500 feet. They consist mainly of coarse sandstones or grits, often very micaceous, with a subordinate development of shales and a few thin and non-persistent beds of dolomitic limestone. The sandstones are generally light gray in color, but near the base of the series are sometimes quite dark from the presence of finely divided carbon, probably in the form of anthracite or graphite. Their prominent constituents are quartz and feldspar, evidently derived from the Archean; pink orthoclase is sometimes so abundant as to impart a reddish tinge to the rocks. The abundant mica is mostly muscovite, biotite being present in subordinate quantity. The muscovite is probably of secondary origin, for it is present in much greater quantity than could reasonably be expected if it were directly derived from the Archean, and in larger leaves than is common among the gneisses observed.

Limestone beds in the Weber grits.

In the Mosquito Range two beds of limestone, each about 50 feet in thickness, are found about the middle of the formation. In this district the limestones are more prominent in the upper part, but are very irregularly developed. Six different beds were observed on the south face of Sheep Mountain, but at other points not over two could be detected. They are generally rather thin, but the principal bed in the northwestern part of the district is 60 or 80 feet thick. At the southern boundary of the area this bed can not be detected, and has apparently thinned out. The great variability of the many thin beds of limestone in this and the succeeding formation is so remarkable that these have been designated on the map by a special color, which shows approximately the variable extent of calcareous sedimentation in the midst of a great thickness of prevailingly coarse siliceous deposits. The limestone beds are also important in defining horizons, and to them are confined a large and important class of the ore deposits of the district.

The limestones in the Weber grits are all typical dolomites, with a small but persistent admixture of carbonates of iron and manganese ($1\frac{1}{2}$ to 5 per cent) and up to 10 per cent of insoluble matter.

Maroon formation.—This name is here applied to about 1500 feet of beds which in many respects resemble the Weber grits, but which in the Mosquito Range have a much larger proportion of

Distinction between Weber and Maroon sandstone.

calcareous and argillaceous beds. This formation in the Tenmile district consists predominantly of coarse gray and red sandstones, in some places passing into conglomerates, with many irregularly developed beds of limestone. As contrasted with corresponding members of the Weber grits the following distinctions have been noted. The red color of the sandstones, which is more common than in the lower formation, though less pronounced than in the beds of the next above, results not from the presence of pink feldspar, as in the Weber grits, but from abundant iron oxide impregnating the cement. Hence in depth, as shown in underground workings, the red color generally gives way to a greenish gray. The strata in which the red color is most pronounced are fine grained and often somewhat schistose. These sandstones also contain a large proportion of feldspar fragments. In one case it was found that a mixture of carbonates had almost wholly replaced the abundant feldspars, which, nevertheless, were to all outward appearances quite fresh.

The argillaceous shales are often black, but seldom contain actual coal; they are much more abundant than would appear from a hasty inspection of the hill slopes, where their outcrops are readily obscured by the débris from the harder rocks.

Non-magnesian character of Maroon limestones.

The limestones of the Maroon formation constitute, however, its most characteristic feature, and, independently of color, seem to afford the safest means of distinguishing it from the Weber grits. In outward appearance they are purer and are evidently freer from arenaceous material. They are light bluish gray or drab in color, becoming white on weathered surfaces, in strong contrast with the dirty brown weathered surface of the dolomites. They have also a conchoidal fracture and lithoidal structure, instead of the rough granular fractured surfaces which characterize the latter. Chemical analysis confirms these indications, an examination of nine specimens proving that, with one exception, they are non-magnesian limestones with a variable but generally small percentage of insoluble material, and less than 1 per cent of $(Fe\ Mg)\ CO_3$. In the limestone from Tucker Mountain, which forms the exception, the dirty brown weathered surface and granular texture already noted suggest the dolomitic character and the presence of iron and manganese carbonates. Furthermore, in the absence of definite faunal distinctions the limestone beds have been used to define the limits of the formation, the base being taken at the limestone belt known as the Robinson limestone, and the top of the formation at the Jacque Mountain limestone. Both these limestones contain an invertebrate fauna of upper Coal Measure type. The Robinson limestone is somewhat dolomitic at the base, containing nearly 7 per cent of magnesium carbonate. The Jacque Mountain limestone is characterized in certain layers by an oolitic structure. The rock is light bluish gray in color, and the oolitic grains are embedded in a finely granular matrix of similar color. They are about the size of mustard shot, and have a normal concentric structure and sometimes a radiate appearance; grains of sand or crystal particles serve as nuclei. This structure disappears with recrystallization, and is entirely wanting in certain layers.

Wyoming formation.—The beds above the Jacque Mountain limestone, which have a maximum thickness of about 1500 feet, have been given this name, not because of any fossil evidence of their age that could be found, but because by their position and petrological character they most nearly correspond to the beds of this formation which elsewhere in the Rocky Mountain region have, on fossil evidence, been determined to be Triassic. If the Permian is represented in Colorado, the evidence of which appears to the writer as yet very uncertain, it would be included in these beds, which have evidently been deposited in direct and unbroken succession over the upper Carboniferous.

Coarseness of Wyoming sandstones.

Effect of metamorphic action on Wyoming sandstones.

They consist principally of sandstones, of intensely brick-red color where not metamorphosed, with a moderate development of thin shales between their more massive beds. Limestones are practically absent, having been found only at a few isolated points, generally at about the same horizon, showing that the conditions favoring calcareous sedimentation, which had hitherto prevailed so irregularly throughout the region, had at this time almost entirely ceased. The sandstones are often coarse, sometimes conglomeratic, and are composed mainly of distinctly recognizable Archean débris. Feldspar and mica are the most abundant constituents next to quartz. Near the top of Jacque Mountain there is a conglomerate bed containing Archean bowlders as large as 2 feet in diameter; finer conglomerates are abundant, in beds usually not over 1 or 2 feet in thickness. In one place, on the Tenmile slope of Mayflower Hill, a conglomerate bed was observed where the pebbles were entirely of white quartzite in a matrix of nearly pure quartz sand. On the slope of the hills bordering Tenmile Valley on the west, especially of Jacque, Tucker, and Copper mountains, where metamorphic action has been most pronounced, the red color has disappeared from the Wyoming sandstones, and the rock has become dark and quartzitic and contains much bright-green epidote. The development of the epidote is contemporaneous with the disappearance of the red color and in most cases with a silicification of the rock. When fresh and altered rocks are exposed together, only the bleached or silicified strata carry epidote. In some places, notably on Tucker Mountain and near the summit of Jacque Mountain, metamorphism has produced considerable thicknesses of bluish or brownish quartzites, more or less impregnated with ore particles. By extreme silicification some strata become hornstone-like and lose their stratification. Partial mineralization, such as an impregnation with pyrite, seems to accompany silicification, and a number of prospect holes on Jacque and Tucker mountains are in hornstone-like material containing thin seams of metallic sulphides. This metamorphism also extends into the igneous rocks, which become impregnated with secondary quartz in fissures, and occasionally throughout the whole mass, so that it is sometimes difficult to distinguish the altered porphyries from metamorphosed sandstones, especially when the latter contain a large portion of feldspar grains among their constituents. The development of epidote has gone so far in some cases as to mark certain strata as distinctly green, so that prospectors have taken it for indication of copper ore. To this fact Copper Mountain may owe its name.

RECENT DEPOSITS.

Extent of ancient glaciers.

As might be expected from its great elevation, the district abounds in evidences of its former occupation by glacial ice. Large glaciers headed in glacial amphitheaters in the Mosquito Range opening out to the northwest. That from the Tenmile amphitheater, a short distance south of the limits of the quadrangle, flowed down the upper Tenmile Valley and split at the flat above Robinson, its main branch extending down Eagle River about 12 miles, as is proved by the terminal moraine which now stretches across the valley. Erratics from this glacier are also found on the divide between Eagle and Tenmile rivers west of the Robinson flat. A branch of this glacier probably went down Tenmile Valley also, but the main tributaries of the Tenmile glacier, as shown by their lateral moraines, came from Clinton, Mayflower, Humbug, and other gulches on the west flank of the Mosquito Range. The lateral moraine in Clinton Gulch has been pierced by tunnels as much as 300 feet without reaching solid rock beyond. Relics of moraines in the deeper valleys around Jacque Mountain show that glaciers tributary to the Tenmile came from the west also, and the moraines on either side of West Tenmile River (Good Harbor Creek of the Hayden map) form prominent ridges above the flat that can be recognized in the contours of the map. A moraine shelf on the eastern slope of Copper Mountain, 500 feet above the present valley bottom, can also be recognized in the topography. The only Pleistocene features that have been indicated on the geological map are the alluvial flats above Robinson and those at the junction of West Tenmile with the main Tenmile River, known respectively as the Robinson and Wheeler flats. They have been formed by the silting up of glacial lakes by detrital material, and are now covered by a peaty growth, which effectually obscures the rock outcrops beneath.

ERUPTIVE OR IGNEOUS ROCKS.

Multiplicity of intrusive sheets of eruptive rock.

Prevalence of allanite.

Igneous rocks play a most important part in the geological structure of this district. As many as sixty bodies of considerable size are represented on the map. A few of these are in the form of small dikes, or of stocks cutting across the stratification of the inclosing beds, but the great majority appear as intrusive sheets conformable with the stratification. The intrusive character is in most cases readily shown by the contact phenomena on both lower and upper faces and by slight divergences here and there from the exact plane of stratification. In no case, moreover, were phenomena observed in them which afford certain evidence of an effusive character. They belong, for the most part, to one large group of closely allied varieties; and a certain connection can be observed between transitions in composition and structure and the geological or geographical positions occupied by the various bodies. The intimate connection of the members of this group is emphasized in a very interesting way by the presence in all of them of crystals of allanite, a silicate of the rare earths cerium, lanthanum, and didymium. This mineral is now known as an original constituent of many igneous rocks, but its identification in the Tenmile district by Mr. Cross was one of the first placed on record. The rocks are nearly all porphyritic equivalents of mica- and hornblende-bearing diorites, which may be included under the general term diorite-porphyry. There are also a few bodies of rhyolite which differ materially in composition and structure from the porphyries. The porphyries were all erupted prior to the orographic movement which produced the Mosquito fault. The rhyolites are all later and probably of comparatively recent age. The leading varieties of these rocks are closely connected with prominent ones of the Mosquito Range which have already been described in the Leadville monograph.

DIORITE-PORPHYRIES.

These rocks of similar character assume differing habits, according to the varying development of the component minerals, especially of orthoclase, hornblende, and quartz. Three varieties are distinguished upon the map—the Lincoln, Elk Mountain, and Quail porphyries. The Elk Mountain type of the map embraces several minor subdivisions, forming a transition series between the Lincoln and Quail types, which it has been considered unnecessary to express in color.

Lincoln porphyry.—This rock was described in the Leadville monograph as the Lincoln porphyry, from its typical occurrence on Mount Lincoln. From Chicago Ridge, its typical locality in this district, the rock has been traced continuously to a connection with the Gray porphyry of Leadville, a local variety of the Lincoln porphyry, so called from its color when altered.

Large orthoclase crystals in Lincoln porphyry.

It is composed of quartz, plagioclase, orthoclase, and biotite, all developed in crystals easily distinguishable by the naked eye, lying in a groundmass of homogeneous gray appearance, which is resolved by the microscope into a granular mixture of quartz and the two feldspars. The most striking feature of the rock is formed by the large crystals of pink orthoclase, frequently an inch in length and so abundant that from two to six are ordinarily shown in a hand specimen (3 by 4 inches). They are usually fresh and glassy. The other minerals named are more numerous, but always smaller. The triclinic feldspar is distinguished by its white color and general dullness of surface, as well as by the twinning striation on the basal cleavage face. The quartz crystals are commonly double pyramids, with narrow faces of the prism developed in some cases, and the edges not uncommonly rounded. Accessory constituents of this rock are magnetite, apatite, zircon, and allanite.

Its chief masses are found on Chicago Ridge and on the slopes around the head of Eagle River, where it constitutes nearly all of the intercalated sheets from the lowest horizon up to that passing through the summit of Sheep Mountain. The large laccolithic mass of Chicago Ridge is probably at a center of eruption, and the Gray porphyry of Leadville, with which a direct connection has been traced, is supposed to be an offshoot from this. Smaller sheets occur in McNulty Gulch and in the Cambrian remnant on Little Bartlett Mountain. Dikes of similar rock occur in the Archean. Also on Tucker and Jacque mountains are small sheets and dikes of the same general type, often so metamorphosed as to differ greatly in external appearance. A dike on the northeastern slope of Chicago Ridge shows a gradual change from the type rock to a dense, dark-brown, almost felsitic mass, which results from the suppression of the large crystals of orthoclase and quartz and a predominance of the groundmass.

Coarse crystallization not a function of depth.

In passing upward across the beds, through Sheep Mountain to Elk and Jacque mountains, one finds that the large orthoclase crystals become less frequent as megascopic constituents and finally disappear. It does not follow from this fact, however, as might at first be supposed, that the development of these large crystals is chiefly a function of depth, for the crystals vary in amount in one and the same mass, and while above a certain horizon they are rarely seen in the sheets, there are dikes at these higher levels which do contain them. Where orthoclase is most abundant it is possible that the rock may become a granite-porphyry.

Eruptive channel on Elk Mountain.

Elk Mountain porphyry.—This type is named after the mountain whose principal mass seems to be the largest eruptive channel of the rock. The type variety is a light-gray porphyritic rock with rounded quartzes, white plagioclase crystals, and hexagonal biotite leaves, embedded in a fine-grained groundmass. No megascopic orthoclase is found except in irregular patches in the groundmass of one or two rocks. Except for the large crystals, it is intimately related from every point of view to the Lincoln porphyry. Chemical and microscopic examinations show that it usually contains as much potash feldspar, but that this mineral is confined to the groundmass, the conditions of consolidation having prevented its development in porphyritic crystals.

Variations from the type rock are relatively rare. Some smaller dikes, as on Elk Mountain, are finer grained, darker in color, and contain but few porphyritic crystals. On the border of the large sheet west of Elk Mountain, near the boundary of the map, a gradual transition is observable from the dark compact rock at the contact with sandstone to the type rock 5 feet distant from that contact. In almost every other case no modifications of composition or structure were observed in the porphyry bodies at their contact with the inclosing sedimentaries, nor was any reciprocal change in the sedimentary beds observable beyond a slight baking or hardening, rendered evident by greater resistance to weathering.

To this type of rock belong by far the greater portion of the intrusive bodies in the district. Almost all the bodies on the Sheep, Elk, and Jacque mountain ridges, and all on their northern slopes toward West Tenmile River, belong to it. Eastward it is replaced to some extent by the more basic types and is represented on the east side of the Tenmile Valley by but two important sheets.

In some of the sheets of Jacque Mountain and in isolated occurrences of other localities some hornblende prisms are to be seen in association with the biotite. In Tucker and Union mountains there are a few minor sheets in which these two dark silicates are approximately equal in prominence. These bodies represent the transition to forms which, while represented by the color of the Elk Mountain porphyry on the map, may be given distinctive local names.

Copper Mountain porphyry.

The Copper Mountain porphyry is darker than the preceding type, and the porphyritic crystals are smaller and less plainly distinguishable from the groundmass. Except for the development of hornblende in addition to biotite, the rock is in point of composition about the same as the normal Elk Mountain porphyry. Quartz is less common in megascopic individuals, and chemical determinations prove that the silica percentage is lower, while the relation of the alkalies remains the same.

But few bodies consist of this type of rock. By far the most important is that of Copper Mountain, the next being the lowest sheet exposed in Tucker Mountain, besides which there are only two or three small lenticular masses, in the immediate vicinity of the larger bodies.

Gold Hill porphyry.

The Gold Hill porphyry is darker than the one previously described, owing to the development of smaller crystals of both hornblende and biotite. The groundmass is subordinate: quartz grains are present, but are smaller and less numerous than in preceding types. Plagioclase crystals with very distinct basal striation are the most noticeable constituents. The usual accessory minerals are all found in this rock. To this type belongs the large body which covers a great part of Gold Hill, on the east of Tenmile River, and is cut off by the Mosquito fault, together with smaller sheets in the vicinity, probably offshoots from the same source.

Quail porphyry.—This type differs from all those previously described in being a decided hornblende rock, in which quartz has disappeared as a noticeable megascopic constituent. It still carries 61 to 63 per cent of silica, but the quartz is confined to the groundmass, except for occasional occurrences in rounded grains. The crystals are all smaller than in other types described, and the rock has a dark-green color, because the darker silicates are developed in the groundmass.

This rock forms several small sheets and dikes at the head of McNulty Gulch, where the synclinal structure produces a curved outcrop in the larger sheet which extends across the boundary of the present quadrangle into that of the Mosquito Range in the Leadville atlas. The largest sheet occurs below the Snowbank group of mines on East Sheep Mountain and on the northeastern slope of Elk Ridge under the White Quail group of mines. An isolated mass of the same general composition has been observed on Tucker Mountain.

RHYOLITE.

Chalk Mountain nevadite.—Chalk Mountain, the table-topped mass on the continental divide between the head waters of the Arkansas and Grand rivers, of which only the northern point projects within the present quadrangle, consists mainly of a white rhyolitic rock, in the main so coarsely crystalline that it has been classed as nevadite.

Later age of rhyolitic eruption.

The large crystals of sanidine have frequently a peculiar satiny luster which has been shown by Mr. Cross to be due to an actual parting, analogous to cleavage, such as that which in its incipient stage produces the blue color of labradorite feldspar. The large quartzes are often smoky and contain fluid inclusions. Topaz occurs in drusy cavities here and there throughout the mass. A small glass remnant is found in the groundmass, which indicates that the rock consolidated near the surface at the time of its eruption. It breaks irregularly across and through both sedimentary beds and included sheets of diorite-porphyry. From these facts it would appear that it is not only of later age than the porphyries, but probably of much more recent date. The rock is not known in this district except at Chalk Mountain.

McNulty rhyolite.—This is a fine-grained porphyritic rhyolite, light gray in color, with many small white feldspars and locally some small smoky quartz crystals. It is probably allied to the nevadite in time of eruption, or it may be later. It cuts both the Lincoln and the Quail diorite-porphyry. It occurs in small irregular masses in McNulty Gulch, and extends southward beyond the present quadrangle. In one mass above the Railroad Boy tunnel (45)* are small drusy cavities containing little tablets of tridymite.

STRUCTURAL RELATIONS.

Oscillations in sea-level without deformation of sea bottom.

The above-described series of sedimentary beds was deposited on a basement of crystalline pre-Cambrian rocks between the Colorado and Sawatch islands, but nearer the last named, from which the large amount of coarse material in these sediments was probably, in great measure, derived. This deposition during the time represented by sediments in this region — viz., from the upper Cambrian to the Trias — was more or less continuous; that is, there is no evidence of any change in the relations of the sea bottom to the successive sediments. Nevertheless, it is probable that there were oscillations in the level of the sea due to continental movements, which in other parts of the Rocky Mountain region were accompanied by a certain amount of deformation of the sea bottom and a corresponding change in the relations of the sea and land areas. For instance, a decided shallowing of the sea waters is indicated by the carbonaceous shales at the base of the Weber grits, and the character of the upper part of the Wyoming beds indicates that shallow-water conditions again prevailed in the sea in which they were deposited. After these beds had become consolidated, there came a period of eruptive activity during which the magmas that produced the various porphyry bodies now found in the district were forced up through and spread out between the strata. During or after this time the Sawatch Mountains were gently raised, so that the beds once deposited horizontally around their base acquired a slight inclination away from them in radial directions, which in the case of this district was to the northeast.

First orogenic movement in this region.

The first orogenic disturbance in this region was that which inaugurated the uplift of the Mosquito Range and produced the Mosquito fault. That this movement took place after the porphyry sheets had become an integral part of the sedimentary series is proved by the fact that the sheets are folded and faulted with the strata. At the time the Leadville monograph was written (1885) it was not known that any important orographic movements had taken place in this region between Cambrian and Eocene time, and the uplift of the Mosquito Range was provisorily assumed to have been one of the effects of the great movement at the close of the Cretaceous, which was well known to have been accompanied by great eruptive activity. More recent observations have shown, however, that between Triassic and Cretaceous times, and probably within the Jurassic period, an orogenic movement took place in the Rocky Mountain region whose effects were second in importance only to the post-Cretaceous movement. Although within the area of the Leadville and Tenmile districts there are no criteria by which one can determine whether the faulting was first produced by pre-Cretaceous or by post-Cretaceous movement, since no Cretaceous or Eocene beds are found within that area, there are certain phenomena beyond its borders that seem most readily explainable on the former assumption.

Cretaceous resting directly on Archean.

Thus along the valley of Blue River below Breckenridge, on the eastern spurs of the Mosquito Range and of the Gore Mountains, to the east and north respectively of the Tenmile district, there are sandstone beds resting directly on the Archean which belong to the Dakota and probably also to the Gunnison formation. No older sediments are interposed between these sediments and the Archean basement, such as are found along the Mosquito Range south of Breckenridge.

Alternative hypotheses to account for this fact.

There seem to be but two possible explanations of this phenomenon. The one is that previous to the pre-Cretaceous movement the area which now forms the northeast flanks of the Mosquito and Gore mountains was already elevated above the Paleozoic and early Mesozoic seas, so that it received no sediment, and that by this movement it was depressed without faulting, so that its eastern edge became subject to Cretaceous sedimentation, while the area on the west remained above the Cretaceous waters. The other explanation would be that the displacement of the Mosquito fault was inaugurated by the pre-Cretaceous movement, and that as a result of this movement the area occupied by the Mosquito and Gore mountains was tilted up above sea-level, so that it formed a barrier to the Cretaceous seas. Thus whatever earlier sediments might have been deposited on the area were denuded down to the Archean basement before the Gunnison and Dakota formations were deposited on its eastern flanks.

Doubt about age of the Mosquito fault.

The latter hypothesis is the only one that satisfactorily explains the conditions shown on the geological map of the Hayden atlas of Colorado as existing around the northern end of the Gore Mountains and south of the canyon through which Grand River emerges from Middle Park. Here the Dakota formation is represented as transgressing from the east westward across the northern extremity of the Mosquito fault, passing without a break from a floor of Archean to one of Mesozoic sediments, which implies, if the geological outlines are accurate, that the fault must have been there before the Dakota sediments were deposited. If this supposition be correct, however, it makes the intrusions of porphyry much earlier than they have been proved to be in any other part of Colorado. It seems advisable, therefore, to postpone the final determination of the age of the Mosquito fault until opportunity shall be had to study these outlying debatable regions anew, in the light of modern investigations.

It is to be noted, however, that if the faulting commenced in pre-Cretaceous time, it must have continued during the post-Cretaceous movement, and mainly on the same lines, so that it is now impossible to determine how much of the displacement was accomplished during the one and how much during the other movement. It was noticed in Leadville, and has since been observed in the Aspen district, that the movement of displacement along these great faults has continued down to post-Glacial and even to recent times, so that in some instances modern mine workings show the effects of it.

SAWATCH UPLIFT.

General northeast dip due to Sawatch uplift.

In the present structure, as shown by the geological map, the most prominent feature is the general northwest direction of the formation outlines except in immediate proximity to the Mosquito fault. Throughout this region the sedimentary beds have an average strike of N. 40° W. and a dip of 15° to 25° NE. The frequent curving variations from this direction observable in the outlines represented on the map are for the most part due to unequal erosion, which in the valleys throws the outcrops back to the northeast, and on the intervening ridges produces a curve in the opposite direction. A part of the variation from the straight northwest line is due to minor folds in the strata at right angles to the strike, the most notable instance of which is the synclinal fold between Robinson and Chalk Mountain, which runs under the Robinson flat and on to the ridge connecting Chalk Mountain with Chicago Ridge. There is also a certain amount of cross faulting in the same direction. Many of these faults, which rarely have a throw of over 100 to 200 feet, can be detected as interruptions in the continuity of the outcrops. In other cases, as on the west side of the Robinson syncline above noted, they are detected only in the underground workings.

The unequal development of the eruptive bodies also produces local divergences in the geological outlines. Thus the laccolithic body of Chicago Ridge, which is nearly 2000 feet thick, produces a sensible bowing up of the strata above it, and the eruptive stocks or necks of the Elk and Sugar Loaf mountains, which in part cut across the stratification, break the continuity of the outlines.

This northwest strike and northeast dip of the formations probably already prevailed before the time of the Mosquito uplift. It is traceable to and beyond the Leadville district to the south, where it is independent of the abundant faulting, and it continues northwestward along Eagle River Valley to and beyond the Red Cliff Mining district, where the full Paleozoic series is exposed resting at an angle of 15° on the granites and gneisses of the Archean. Still farther west the strike becomes east and west, then bends to southwest and northeast on the farther side of the Sawatch uplift, and so continues as far as Aspen. It seems natural, in view of the radial character of these dips, to assume, as has been done above, that this structure was due to a rise in the general mass of the Sawatch Mountains or — what would in this case have produced the same results — to the settling down of the sediments that have been deposited on its periphery.

MOSQUITO UPLIFT.

Influence of Mosquito uplift on existing structure.

As the Mosquito fault is approached a modification in the above structure is observed. The average strike of the beds becomes more nearly north and south, and a series of synclinal folds is developed, in which the western limb retains the gentle dips of the western region, while the eastern limb is more sharply upturned, the beds becoming vertical at the fault.

The character of these folds will be better understood by reference to the series of east-west sections on the structure-section sheets. The best-developed fold is that whose axis follows the crest of Carbonate Hill, pitching northward, and which extends beyond the southern limit of this quadrangle as far as the valley of the Arkansas. In its trough remains a portion of the Wyoming beds, and, opposite Kokomo, an included porphyry sheet. Near McNulty Gulch, which cuts partially across the fold, a sheet of Lincoln porphyry is so infolded with the beds that its outcrops form a U-shaped loop beyond the limits of the quadrangle. Here the normal dip of the beds included in the syncline is from 25° to 40°, but near the fault they are upturned at an angle of 70° to 90°. That a corresponding but much broader anticlinal fold once arched over the Archean to the east of the Mosquito fault is proved by the remnant of Cambrian quartzite, with included intrusive sheets of Lincoln porphyry, once part of its steep western limb, that is found dipping 45° W. on the summit of Little Bartlett Mountain. A remnant of Cambrian quartzite dipping 15° E., which is a portion of the eastern limb, may be seen on the summit of Quandary Peak, the highest point in this part of the range, which lies about 2 miles in a straight line east of Fletcher Mountain.

In Gold Hill, by the eastward divergence of the line of faulting, a much broader area is included between it and the axis of the syncline, and the whole thickness of the upper Carboniferous formation is exposed, the Robinson limestone at the base being opened by the Boston (31) and adjoining mines in Mayflower Gulch, and by the Old Mast tunnel on Mayflower Hill. The greater part of the surface of Gold Hill is covered by a sheet of Gold Hill porphyry, so that the structure of the underlying rocks is not clearly seen, but there is a probable tendency to form a second syncline en echelon with that of Carbonate Hill. The beds on the east slope of the hill dip 25° to 40° a little south of west.

On the north end of Mayflower Hill similar conditions of dip prevail, but the hill is much steeper—so much so that in one place on the west point of the spur an isolated portion of a sheet of porphyry is left on the upper part of the steep slope, the angle of slope of the hill being steeper than the dip of the beds.

Farther north the single syncline merges into several minor waves or folds, which form a part of a broad syncline or synclinorium, extending over nearly the entire width of the area. At Copper Mountain there are within this synclinorium both anticlinal and synclinal folds, the former being developed on the top of the mountain adjoining the fault, and the latter being exposed by the erosion of Wheeler Gulch on its western flank.

MOSQUITO FAULT.

In the southeastern portion of the area the position of the fault is readily seen on the hills by the sharp contrast between the rugged slopes afforded by the Archean rocks to the east and the softly rounded forms of the sandstone hills to the west. As represented on the map its line of outcrop has been most carefully traced by surface exposures and underground workings.

Irregular line of outcrop of Mosquito fault.

On the steep slope of Copper Mountain, where this line is so remarkably curved and broken, it is unusually distinct, as, owing to the steepness of the slopes, there is but little covering of loose material. Although several prospect holes have helped to define the line here, by showing the juxtaposition of different rock varieties, none have exposed the fault plane sufficiently to afford means of determining its hade by actual observation. The variations in the line of outcrop of the fault plane as it crosses depressions indicate that this plane hades to the east, and from this fact and the form of the outcrops on the south spur of the mountain it is assumed that the peculiar outline of the fault in this region is due to overthrust faulting, which has actually carried a portion of the Archean over the Carboniferous beds. On the other hand, south of the point where it crosses Tenmile River the fault is a normal fault and hades to the west. This is proved not only by the tracing of its outcrops as it crosses ridges and valleys, but by actual demonstration in the underground workings of mines, especially the Treasure vault (30) on Mayflower Hill, and the Boston (31) in Mayflower Gulch. The limestone beds in the latter mine stand nearly vertical, and in the Old Mast tunnel, near the former, they

*Numbers in parenthesis in the text are those used on the map to denote the several shafts or tunnels mentioned.

have a reverse dip of 65° E. These facts, and the general crumpling of the mass of the sedimentary beds, show that the faulting was accompanied by a compressive strain on the region to the west, even where the upward movement produced a normal fault. Copper Mountain lies within the point of the angle made by the fault plane as it changes from a northerly to a northwesterly direction, and in this angle the westward push of the rising block would be greater than anywhere else, and might have caused a change of hade in its plane and a local overthrust.

Compressive effect of faulting.

Beyond the west fork of Tenmile River it appears that the fault plane separating Carboniferous from Archean extends about 25 miles in a general northwesterly direction. It may be that this is not simply a continuation of the Mosquito fault, as has been assumed above, but a distinct northwest-branching fault, like the London fault in the Leadville area, and that the Mosquito fault proper continues its northerly direction into the Archean area along the general line of the narrow gorge of lower Tenmile River. As regards the peculiar bay-like intrusion of Archean to the east and south of Copper Mountain, it can only be said 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.

In addition to the folding in the disturbed zone parallel to the Mosquito fault, there has been a certain amount of minor faulting, notably on Gold Hill, along Tenmile River near Robinson, and in the hills adjoining the lower part of Searle Gulch. What evidence there is goes to prove that this faulting has been subsequent to the epoch of ore deposition. If the faults were formed contemporaneously with the Mosquito fault, the ore deposition must have taken place prior to the Mosquito uplift. The phenomena along the Mosquito fault do not, however, afford any decisive evidence on this point, and it may be that these faults were produced during the post-Cretaceous movement, in which case the epoch of ore deposition may have been subsequent to the pre-Cretaceous movement.

Relation of ore deposition to faulting.

It is only in the latter contingency that the ore deposition could be connected with the Mosquito uplift, and this connection would be simply that the fracturing accompanying the movement had produced the water channels that had admitted the ore-bearing solutions to the locus of the ore deposit. On the other hand, the important deposits of the neighboring district of Leadville are definitely proved to have been formed earlier than the Mosquito uplift; and if it is assumed, by analogy, that the epoch of deposition of the Tenmile ore was contemporaneous with these, it follows that the fractures that admitted the ore-bearing solutions must have been made before the Mosquito uplift, and were probably connected with the intrusion of the igneous rocks.

ORE DEPOSITS.

GEOGRAPHICAL DISTRIBUTION.

The ore deposits of the Tenmile district that have proved economically valuable have been found in the sedimentary rocks and included porphyry sheets that form the various hills west of the Mosquito fault. The fissure veins that were opened by the earlier explorers in the Archean rocks of the Mosquito Range east of the fault were generally so thin and so difficult of access that they did not pay to work and were soon abandoned. It is in the hills immediately adjoining the Tenmile Valley, especially in the part below the Robinson flat, that the principal concentration of metallic minerals seems to have taken place. The relative distribution of shafts and tunnels, which is a fair criterion of the development of useful minerals near the surface, proves, as may be verified by reference to the map, that the town of Kokomo-Recen lies about in the center of the area of greatest mineral development. In the hills along the Eagle River Valley and in those forming the northern and western portion of the area mapped no ore bodies of sufficient size or value to encourage exploitation have yet been developed.

Center of ore deposition.

The most important ore bodies have been opened on the ridges or spurs known respectively as Sheep Mountain, Elk Ridge, and the south shoulder of Jacque Mountain. Numerous prospects have been opened on the east side of the Tenmile Valley, in Mayflower, Gold, and Carbonate hills, and also farther south in McNulty Gulch, but none, so far as known, have reached the stage of paying mines. A single mine, the Grand Union, formerly known as the Silver Bowl (44), has developed some irregularly shaped bodies of silver ore of commercial value on the northeast base of Chalk Mountain, along the line of contact of the nevadite with the Weber grits.

GEOLOGICAL DISTRIBUTION.

Although outcrops of ore have been found in rocks of other horizons, the ores from actually developed mines have been mostly taken from beds of the Maroon formation. They occur generally in some of the numerous thin limestone strata that characterize the formation; to a limited extent, also, they are found in veins that traverse both the sedimentary rocks and the included eruptives. The limestone strata, as has already been remarked, are extremely variable, and are frequently non-persistent, but the fact that they are the ore carriers gives them special economic importance and renders it necessary to trace them with unusual care. For this reason they have been indicated on the map by dark-blue lines, these lines being continuous where outcrops are actually traceable, but broken when for some reason the outcrops are obscured and their continuity can not be verified.

There are three principal groups or series of limestone strata in the Maroon formation of this district: first, that which is taken as the bottom of the formation, called, from the principal mine of the region, the Robinson limestone; second, a series of limestone strata, about midway in the formation, called, from the principal mine whose ores occur in it, the White Quail limestone; and third, the assumed top of the formation, called, from the region where it is best developed, the Jacque Mountain limestone.

Near the town of Robinson the limestone consists of three distinct beds from 80 to 100 feet apart. Here it is the middle member which is the principal ore carrier, and constitutes the Robinson limestone proper. This has an average thickness of about 35 feet, of which the upper 20 feet are of light-gray color, the rock being almost pure carbonate of lime, while the lower portion is darker in color, sometimes almost black, and contains nearly 7 per cent of magnesium carbonate. On the crest of Sheep Mountain Ridge, at the Wheel of Fortune mine (36), only two limestone beds are found, and it is the lower which is the ore carrier.

Robinson limestone.

In the White Quail limestone on the northeastern slope of Elk Ridge are the extensive pyritous deposits of the White Quail group of mines, and on the east slope of Sheep Mountain, above the town of Kokomo, those of the Snowbank group. At these points only a single limestone bed, about 20 feet thick, is found, but farther northwest, along the strike, are several beds at about the same horizon, direct connection between which is broken by cross-cutting sheets porphyry.

White Quail limestone.

Less extensive but similar pyritous ore bodies occur on the southern slope of Jacque Mountain, in the Jacque Mountain limestone, notably in the Selma (14), Free America (15), and Wintergreen (16) mines. At most places only a single bed of limestone is distinguishable at this horizon, and this has frequently an oolitic structure. At the head of Searle Gulch, however, is a bed of calcareous black shale near to but distinct from the limestone, which abounds in upper Carboniferous fossils.

Jacque Mountain limestone.

In the sandstones of the Wyoming formation are found mineral veins cutting across the stratification, of which that opened in the Queen of the West (9) and Mayflower (8) mines is the most important. This formation is mostly barren of limestone beds, but the few that do occur are generally more or less impregnated with mineral, as in the Little Rex mine (4). At the same horizon on Carbonate Hill and along the slopes of Clinton Gulch good indications of ore have been found, but no important mines have yet been opened. Thin veins, as already noted, occur in the Archean of the Mosquito Range, but, though the ore may be rich in places, they have not yet proved of economic importance.

Vein deposits.

CHARACTER OF ORES.

The ores of the district are prevailingly pyritic. Enormous beds of almost solid sulphide of iron are found, generally as bisulphide, pyrite or marcasite; in some cases, however, in the form of pyrrhotite, or monosulphide. These ores are generally of too low grade to pay for working. Associated with them, however, or in bodies by themselves, are less extensive accumulations of galena and zinc blende carrying silver, and in some cases other silver ores, sulphides, antimonides, and arsenides, which constitute the commercially valuable ores of the region. The manganese spars, rhodochrosite or rhodonite, are frequently associated with them, while quartz, calcite, and barite are the ordinary gangue minerals.

These sulphide ores are found unaltered at a very short distance from the surface, showing that the oxidation by surface waters has penetrated to very slight depth. This is doubtless due, as in the more elevated portion of the Leadville region, to the great altitude of the deposits and the consequently short period in each year that surface waters are not imprisoned by frost, and thus rendered inactive.

Slight oxidation of the ores.

MINES.

As shown by the workings of actually developed mines, there are three principal types of ore deposit in the region, whose character and manner of deposition will be best understood by a brief description of the principal mine in which each type is developed.

ROBINSON MINE.

History.—The various claims afterward consolidated into the Robinson mine were located in the summer of 1878, by prospectors in the employ of George B. Robinson, then Lieutenant-Governor of Colorado. In the following year, while awaiting the legal decision of adverse claims upon his property, Governor Robinson was shot by one of his own guards, who were holding armed possession of the mine against a possible attempt to seize it by the contesting parties. The mine was later incorporated at a large capitalization, and the fame of its great wealth was an important factor in the prosperity of the region. It has suffered, as have many other mines, from defects of management, one great mistake being the building of smelting works at the mine. As it changed hands several times, it has been quite impossible to obtain accurate data in regard to the amount or value of the ore that has been taken from it. Common report gives at about $6,000,000 the product of the original Robinson ore shoot.

Character of deposits.—The deposits on this property are along narrow ore shoots having a general northeast direction, and result from the impregnation and replacement of the upper part of the Robinson limestone on either side of a series of vertical fractures or faults of slight displacement, which have a general strike N. 60° E. The ore in its unaltered form is usually a coarsely crystalline aggregate of galena, zinc blende, and pyrite, with rhodonite, calcite, barite, and quartz as gangue minerals; the latter is generally granular or amorphous. The silver occurs mainly in the galena, to some extent in the zinc blende, and in the richer portions of the main ore shoot, which in spots averages several hundred ounces to the ton, probably in combination with sulphur, antimony, or arsenic. The oxidation products are mainly hydrous oxides of iron and manganese, with a little cerusite and chloride of silver. The oxidized ores are mostly red or black, but sometimes of lighter and more brilliant colors.

Mine workings.—The mine was first opened by an incline (39) starting about 300 yards northwest of the town of Robinson, and following the main ore shoot down on the dip. A working tunnel (40) was afterwards run in just back of the town, following the strike of the limestone in a direction N. 10° W., which at 800 feet cut the main ore body about 140 feet vertically below the surface. From this a working incline followed the ore shoot down on the dip in a northeasterly direction, and a new shaft (42) was sunk to meet it. The incline was continued farther on the dip, until, at latest advice, a length of about 1700 feet from the head of the incline had been explored. Later a second ore body was discovered about 250 feet north of the tunnel, which had escaped observation before because it passed above the roof of the drift, which at that point was cutting through the beds beneath the limestone. The tunnel has since been driven 1700 feet along the strike beyond the main ore shoot, cutting two smaller parallel ore shoots.

Ore bodies.—As shown by the above-described workings, there are four ore shoots, three of which are about 500 feet apart, respectively, the other being 1000 feet distant, and all have a common direction about N. 50° to 60° E.

The peculiarity of these ore shoots is that they have been formed by mineralizing waters which entered the limestone beds from vertical fractures or fault planes having the same general direction as the ore shoot. These waters have replaced the upper and purer part of the Robinson limestone with vein materials through a varying distance on each side of the vertical fissure, the lateral limits of the ore body often being defined by fault-planes or cracks parallel to the central one.

Ore deposition from vertical fissures outward.

The resulting ore bodies have widths of 10 to 100 feet, their greatest extension being at the upper part of the limestone. The lower surface of the ore body is of very irregular form; the thickness is also extremely variable, the maximum observed being about 20 feet, which is the total thickness of the upper member of the Robinson limestone. The replacement action does not appear to have extended into the darker and slightly magnesian limestone below. Above the ore body is a roof streak, 1 to 2 feet thick, of fine-grained, highly micaceous sandstone, impregnated with marcasite, or "white iron" as it is called by the miners. The ore is a replacement of the limestone and not a filling of pre-existing cavities, as it has no concentric or layer structure ("crustification," so called by Pošepny), but grades off insensibly, passing gradually from solid ore through limestone containing crystalline patches of metallic minerals in varying frequency into solid unaltered limestone. The rock fractures which have admitted the ore-bearing solutions can usually be readily distinguished in the roof of the ore body. They are generally situated at about its middle, but are not continuous throughout its length; they probably consist of a series of fractures having one general direction, arranged more or less en echelon. In fig. 1 is shown a diagrammatic cross section of the No. 2 or easternmost ore body, in which there is one central fracture, and minor fractures accompanied by some replacement on either side, which define, approximately, the lateral limits of the ore body. On the right or eastern side is observed a tendency of the strata to bend downward in a monocline, showing that fracturing probably accompanied a movement of compression which tended to plicate the sedimentary beds and the included sheets of porphyry. The floor of the ore bodies has the irregular, frequently somewhat wavy form shown by the diagram, and the fractures have not been traced below this for the reason that experience has taught the miners that no ore could be expected below this floor. The tunnel had passed under this particular ore body, and though several small fault planes had been crossed, none were observed to carry ore in any appreciable amount. The fractures in the roof were generally found to be lined with pyrite, and in the case of the original or No. 1 ore shoot, which is the richest as well as the most extensive, the vertical ore-lined fracture was traced upward to the upper limestone bed, 80 to 100 feet above the main Robinson limestone, which was cut lower on the dip by the Champion tunnel (43). Some ore was found in this bed by the Felicia Grace shaft (41), but as a rule it does not appear to have been mineralized to any great extent.

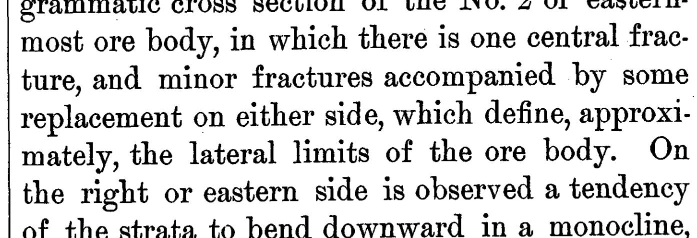

FIG. 1.—Section through No. 2 ore shoot, Robinson mine.

A later set of fault fractures, running about N. 40° E., or making an angle of about 20° with the main system, has been developed in the lower portions of the ore bodies and is said to have faulted them. As a rule these fractures have only a slight displacement, 70 feet being the maximum noted, but in

Later or minor fault fractures.

the workings from the New York shaft, which is situated about 100 feet south of the Champion tunnel, 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. This fault is not detected on the surface, being concealed by valley gravels, but in tracing the outline of the different geological formations, it was observed that they apparently make a sharp bend in strike to the southwestward under this valley; it appears probable that this bend is structurally connected with the fault. In the Daughenbaugh shaft, on the west side of Robinson flat, a fault plane has been developed which appears to be a part of this same fault, or at least of this same system of faults.

Ore deposits in sedimentary beds extending along or parallel to stratification planes from cross fractures or fault planes outward are by no means uncommon. Such fractures have received the local name of "verticals," as applied to the gold deposits in the Cambrian strata of the northern portion of the Black Hills of Dakota.

QUAIL GROUP.

History.—Soon after the discovery of the Robinson mine attention was called to the ocherous outcrops near the crest of the southeastern end of Elk Ridge, just north of Kokomo Gulch, and by the summer of 1879 a series of mine openings had been made extending nearly down to Kokomo Gulch. These were the White Quail (17), Aftermath (18), Milo (19), and Badger (20) inclines, the Raven and Eagle (21) tunnel, and the Colonel Sellers (22) shaft and incline. As finally developed, the Raven tunnel, which started 350 feet vertically below the mouth of the White Quail incline, drained the ground above its level in the various mines to a depth reaching a maximum of about 750 feet on the White Quail incline. From the mines thus opened oxidized pyritous ores carrying some galena and zinc blende, with varying values in silver, were extracted, and the richer portions were shipped to smelters at Leadville, to be mixed with galeniferous and siliceous ores from that camp and from the Red Cliff mining district.

With increasing depth and consequent greater expenses of extraction, the proportion of oxidized ore, and with it the yield in silver, fell off, while the price of silver also began to decrease, so that gradually work in the various mines was suspended.

After a lapse of several years, W. R. Wilfley, whose study of the deposits convinced him that by judicious development and concentration of the ores the mines might be made to pay, took a lease on some of these properties, and in 1886 drove a tunnel (17) to reach the ore-bearing horizon from the lower part of the ridge on the Searle Gulch side. At 1500 feet from its mouth this tunnel cut the Quail ore body 2100 feet on the dip below its outcrop. Since the completion of this tunnel two others have been driven at vertical depths below the first of about 125 and 225 feet respectively. An area in round numbers 3000 feet in length by nearly 1200 feet in width has thus been opened, a very large proportion of which has been found to be mineralized to some extent, though but a limited proportion of the ore has proved rich enough for profitable extraction.

Geological structure.—From the White Quail incline southeastward the Quail limestone has a regular NW.-SE. strike, and a dip of 25° to 28° NE., or toward Searle Gulch, and can be traced continuously nearly to Kokomo Gulch. In this extent it is underlain by a sheet of fine-grained hornblende-diorite-porphyry, called the Quail porphyry, which is also found in the same geological position beyond Kokomo Gulch on East Sheep Mountain. The limestone has an average thickness of 10 to 15 feet, with a maximum of 22 feet. There is generally a thin seam of black carbonaceous shale over the limestone, succeeded by 10 to 15 feet of white sandstone, over which is found 15 feet of black shale, followed by massive sandstones separated by shale beds. In like manner a sheet of black shale occurs under the limestone, part of which is sometimes included between it and the porphyry sheet.

A short distance north of the Quail incline a transverse dike of coarse-grained Elk Mountain porphyry cuts off both the limestone and the Quail porphyry sheet. Beyond this, toward Elk Mountain, the numerous and irregular intrusions of porphyry complicate the structure, so that it is difficult to decipher it correctly from surface outcrops alone. An outcrop of limestone resembling the Quail limestone follows the crest of Elk Ridge northwestward till cut off by the main body of Elk Mountain porphyry. A similar outcrop runs down the hill in direction a little east of north until cut off by another body of porphyry beyond the Sabbath Rest mine.

Complications of structure due to porphyry intrusions.

It is assumed that these outcrops each represent a portion of the White Quail limestone which has been split and spread apart by the intrusion of the porphyry sheet as shown in the following diagram.

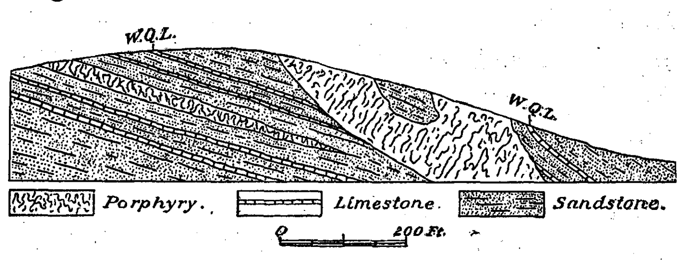

FIG. 2.—Section showing spreading of White Quail limestone (W. Q. L.) by porphyry. Northeast slope of Elk Ridge.

In the workings of the White Quail mine the ore bodies are cut off on the north, not only by the dike above mentioned, but also by a fault which runs northeastward in the same general direction as the dike, and has been traced almost to a connection with it. By this fault the ore-bearing limestone has been raised about 150 feet on the north. Ore is found on the fault, but apparently only as fragments that have been dragged in. Moreover, the ore sheet is found to be turned up by the fault movement; hence it is concluded that this fault is of more recent date than the ore deposition.

Faulting of the ore bodies.

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 southeast 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.

Characteristics of the ore.—The ore is mainly pyrite or marcasite, with small but varying admixtures of zinc blende and galena, all more or less argentiferous, but the principal values occur with the latter mineral. The richer ores also carry some gold. Calcite and barite are found to a limited extent. Quartz in granular form also constitutes an important vein material. These materials occur, like the Robinson ore, as a replacement of the limestone, and, like that, extend from its upper surface, or roof, irregularly downward, forming a thickness of 4 to 9 feet of ore. Laterally, however, they are not so well defined as the Robinson shoots, nor can the cracks or fissures through which the ore-bearing solutions reached the limestone bed be so readily detected. Nevertheless, there is evidence of the existence of an earlier system of NE.-SW. fractures, which may have served as entrance channels for the ore-bearing solutions. Tongues of the underlying porphyry in places protrude up into the body of the limestone, without, however, reaching the roof, and near them there are generally concentrations of rich ore.

Ore shoots.

The longitudinal extension of the ore shoots is in the direction of the dip, and their width varies in the unaltered zone from 10 to 50 feet, being often much greater in the oxidized zone above the tunnel level (100 to 150 feet).

In this oxidized portion the pyrite is changed to limonite, the zinc has been not only altered but almost entirely dissolved out and removed, while the galena when in considerable amount is often only partially altered to carbonate or sulphate. Silver seems to occur mainly as chloride. Oxide of manganese often forms an important constituent of the oxidized ore bodies, though no manganese minerals were observed in the unaltered zone. The quartz vein material or jasperoid resembles, both in color and in texture, the limestone which it has replaced. It generally occurs on the outer edge of the ore shoots, forming a transition zone between ore and unaltered limestone. It contains up to 98 or 99 per cent of silica. The succession is from solid sulphide through quartz impregnated with sulphides to barren jasperoid, and then through what the miners call "short lime" to pure limestone. Including this siliceous material, the width of this replaced zone is in one place as much as 500 feet.

Jasperoid or secondary quartz replacement.

The principal values of the ore are in gold, silver, and lead. The gold ranges from one-fifth ounce up to 2 ounces to the ton, the average probably being nearest the lower figure. The silver in the ore extracted ranges from 16 to 80 ounces to the ton in the unaltered ores; lead varies from 3 to 20 per cent, and zinc about the same amount. In a concentration of 6 to 1, the resulting product contains about 62 per cent of lead, 3 or 4 per cent of zinc, and 23 ounces of silver to the ton. Singular variations occur in the silver contents on either side of the small strike faults; as, for example, from 28 ounces on one side to 7 ounces on the other, which would seem to indicate a transposition of silver since the second period of fracturing.

Values in the ores.

Ore bodies of similar character occur at the same horizon on East Sheep Mountain in the Snowbank group of mines, and in the Jacque Mountain limestone on the south slope of Jacque Mountain in the Selma (14), Free America (15), and Wintergreen (16) mines. In the latter the sulphide of iron is largely in the form of pyrrhotite.

QUEEN OF THE WEST GROUP.

On the steep slope of the southeast spur of Jacque Mountain, overlooking the town of Kokomo-Recen, the Queen of the West and adjoining mines find their ore on a series of transverse fissures crossing the strata at right angles and having a strike N. 60° to 70° E., which is about the same as that of the principal line of displacement in the White Quail ground, and nearly in a line with it. These deposits belong to the class of fissure vein deposits, but, owing to peculiar geological conditions, present a rather unusual phase of this type of deposit.

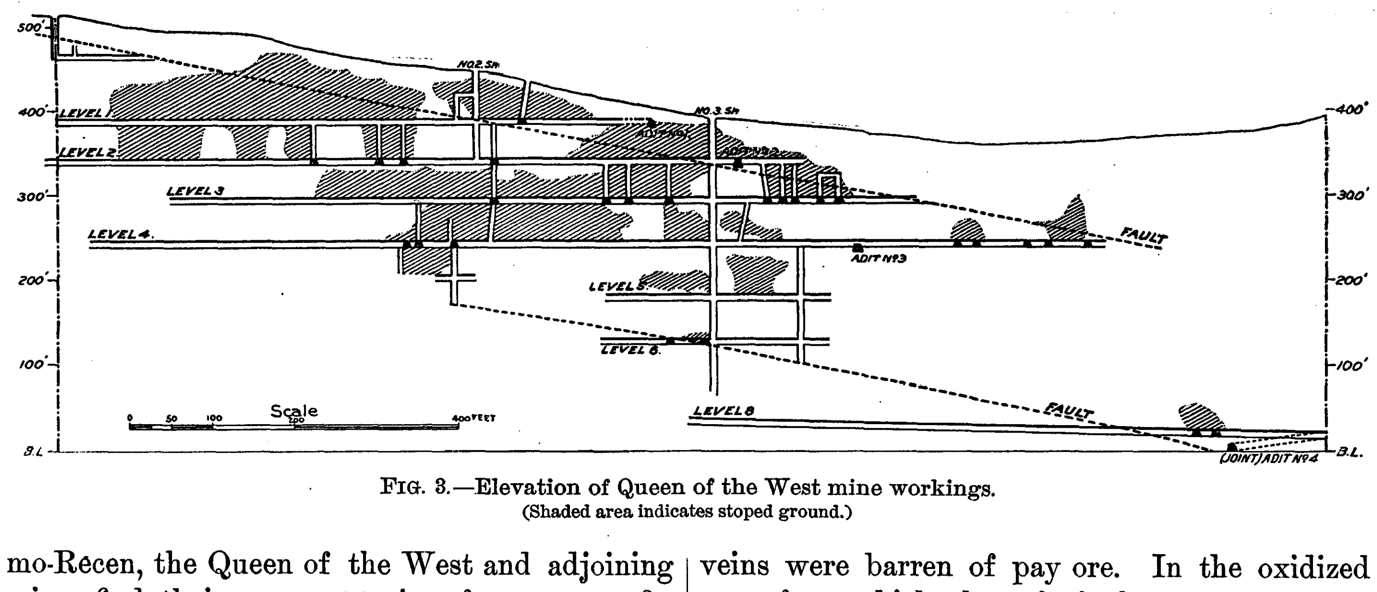

FIG. 3.—Elevation of Queen of the West mine workings. (Shaded area indicates stoped ground.)

Geological relations.—The outcropping rocks here consist of coarse sandstones, with some thin shale beds, of the upper Carboniferous or Maroon formation, alternating with numerous intrusive sheets of porphyry. The beds lie nearly horizontal, or with a slight dip to the eastward, as well as to the north, this portion of the hill being on the west side of a shallow syncline, as shown in Section C. There are probably a greater number of these porphyry sheets than are represented on the geological map and sections, since, owing to the large amount of feldspar fragments contained in the sandstones, it is not always easy, among rocks near the surface that have been much altered, to distinguish porphyry from sandstone, especially where, as in the vicinity of the Queen of the West mine, both series have been repeatedly faulted. The deposits of this mine are on fault planes crossing the bedding at right angles, or with a dip of 80° to 85° NW. Since the deposition of the ore there has been further faulting on planes parallel with the bedding, which has displaced the vein, throwing the upper portion southeastward, or down the hill.

Faulting before and since ore deposition.

Development.—The deposits were originally developed by the Enterprise shaft (10), the Queen of the West shaft and tunnel (9), and the Mayflower tunnel (8). Rich ore was first found in the Mayflower mine; later the Queen of the West mine developed ore almost the full length of its claim (1500 feet), and this mine was opened finally by three shafts following the general inclination of the vein and four tunnels or adit levels, the lower of which at its mouth was 500 feet below the collar of the Enterprise shaft on the boundary line between this and the adjoining claim.

The relative disposition of the workings and the distribution of the rich ore may be best understood by reference to the elevation given in fig. 3.

A noticeable feature in the workings is the frequency of cross-cutting drifts, of which there were 15 to 20 on each level, averaging 10 to 50 feet in length. In each of these cross-cut drifts were found one or more of a series of fracture planes parallel with the main fissure, the rock on either side of each plane being frequently different, and on many of these secondary fault planes were found considerable developments of ore. Down to the sixth level the ore was mostly oxidized, but on the next or eighth level, the No. 4 adit, which was driven 800 feet before reaching the vein, found only sulphide ore which was so inferior both in quality and quantity to that found in the upper levels of the mine that the mine was not long after closed down.

The unaltered ore was mostly galena, zinc blende, and pyrite, with some sulphides and antimonides of silver. Calcite was the only prominent gangue material besides the altered country rock. The ore seemed to be largely a replacement of the country rock—porphyry or feldspathic sandstone, as the case might be—but in the main or central fissure there was often found a vein, 1 to 2 feet thick, of crystalline calcite with curved faces, which was evidently the filling of a preexisting open cavity. Similar "spar veins," as they were called, were sometimes found in the secondary fissures; but all such veins were barren of pay ore. In the oxidized zone from which the principal part of the pay ore was taken, metallic minerals could rarely be distinctly seen, the ore consisting of decomposed and iron-stained sandstone or porphyry, as the case might be. In the mine workings the changes from decomposed sandstone to porphyry, and vice versa, were rapid and frequent. In the cross-cut drifts it was readily apparent that these changes were caused by the slipping past each other of alternate sheets of

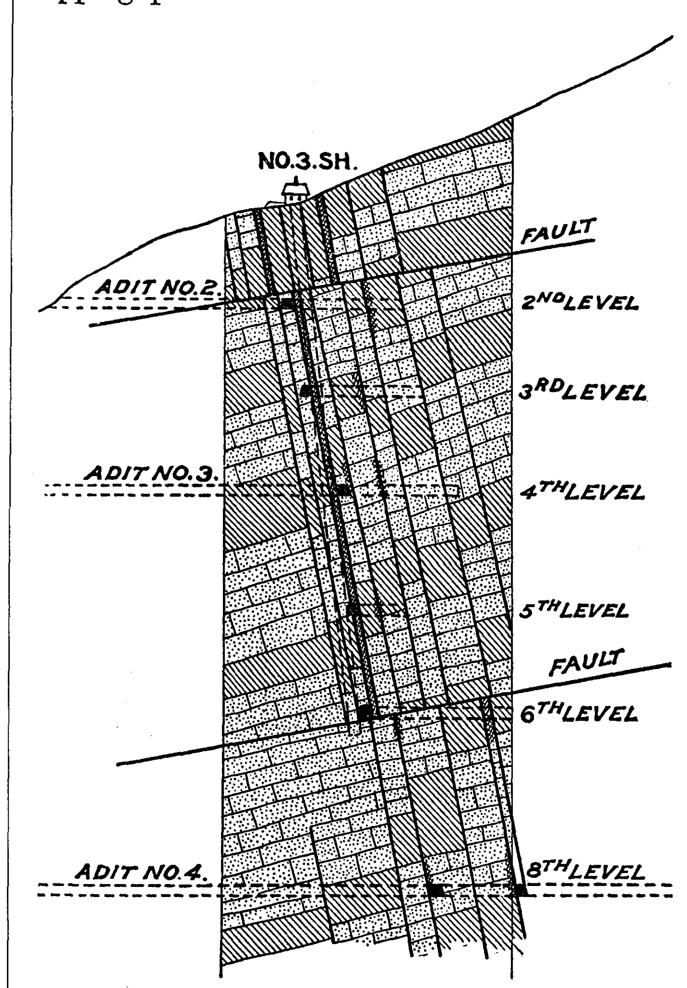

FIG. 4.—Cross-section of Queen of the West vein. (Rich ore is indicated by dense cross-hachuring.)

country rock, produced by faulting or shearing. Similar changes were also noticed in the longitudinal drifts, but as these drifts followed a zone where the decomposition and alteration had been carried to its greatest extent, the structure planes were less readily recognizable. The latter changes were evidently due to the fact that the strata had an inclination northward, and thus the drift passed gradually from a lower to a higher bed, in some cases from sandstone to porphyry, or vice versa. At the same time it might also have crossed one of the vertical fault planes, by which a change of country rock would also be brought about. It was assumed by some of those working the mine that the vein was following a porphyry dike, but no certain evidence of the existence of such a dike could be found, and the explanation here adopted seems to account for existing conditions in a satisfactory manner. This is that the alternating layers of sandstone and porphyry have been cut by a series of parallel and closely spaced fault planes of slight displacement, the average distance between which is about 10 feet and increases from the medial zone outward. The throw of the individual faults in this fault zone is in most cases downward on the southeast; it could not be determined whether this is universally the case. The mineral solutions have entered along these fault planes, more abundantly in the medial zone, and have filled the interstices and decomposed and, to a certain extent, replaced the country rock on either side. In fig. 4 is given a section across the vein, somewhat diagrammatic in its nature, though based on observations and measurements taken at the different levels of the mine.

Peculiar structure of the vein.

The figure also shows the horizontal faults made since the ore deposition, which apparently conform to the stratification planes, though, as represented in the section, they diverge slightly from them. As is usually the case with faults of this nature on a hillside, it is the upper part of the ground, nearest the surface, that has moved downhill relatively to the rock masses beneath. The positions of these horizontal faults as given on the elevation (fig. 3) are represented by broken lines, since they have been observed at only a few points on this plane, and their actual location between these points is more or less hypothetical. It is probable that the actual movement has taken place on some of the thin shale beds that occur between the sandstone strata, and is very possibly not confined to a single plane, as represented in the section. The movement of the lower fault is apparently much greater than that of the upper, and it is possible that the true continuation of the main ore-bearing fissures below this plane was not discovered, although considerable cross-cutting has been done on this level.

The most important lesson to be drawn from a study of this vein is the importance of cross-cutting in fissure veins, whether or not the walls of the main fissure are defined by distinct walls or clay selvages.

The ore in this mine was much richer than that derived from the deposits in limestone, carrying often over 100 ounces of silver to the ton, and some values in gold. This is also true of other vein deposits in the district, of which, however, but few have been worked to any considerable extent.

Small fissure veins in porphyry have been found on East Sheep Mountain, in the little Chicago (35), and on Gold Hill, in the Grand View (32) and adjoining shafts, which carry a little argentiferous galena ore. The Grand View (34), Chicago Boy (33), and other tunnels, driven to prospect the veins on the latter hill, found some ore on the Gold Hill fault, which they cut on passing from sandstone into porphyry, but this ore was apparently dragged into the fault plane from some undiscovered ore body.

CONCLUSIONS.

The evidence afforded by the mine workings thus shows that there have been two periods of faulting in the district, one previous to the ore deposition and one subsequent to it. During the first were formed the transverse fissures, which later became fissure veins where they traversed only sandstones and porphyry sheets, but which, when crossing limestone strata, merely served as water channels to admit the ore-bearing solutions that attacked and replaced the limestone. The evidence shows further that the deposits formed in the latter manner are by far the largest and most important ore bodies in the district; that these ore bodies have produced only a comparatively small proportion of ore which would yield a profit under previously existing conditions, and that enormous amounts of low-grade pyritous ore still remain untouched in the mines, which it may yet be found profitable to work under improved methods of treatment.

It is to be remarked in a general way that, throughout this portion of Colorado, wherever there has been a considerable development of intrusive porphyries there has been a large concentration of metallic sulphides somewhere in the vicinity, and that the favorite locus of deposition of these minerals has been in the limestone strata, rather than in the less soluble sandstones and porphyries. In the neighboring districts of Leadville, Red Cliff, and Aspen, where the ores are both richer and in greater amount, this concentration has taken place mainly in the lower Carboniferous or Leadville limestone, and in some cases also in the beds immediately under it. In the greater part of the Tenmile district, however, the Leadville limestone occurs at a depth of over 2500 feet from the surface, and it is questionable whether it would pay even to prospect for it with the diamond drill, for while this limestone may be mineralized to some extent, the probability that the drill would reach it where there are ore bodies is only one among a number of adverse chances, and if ore were found in this way, it would still be an open question whether it would pay to work it at so great a depth.

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Geologist.

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