

GEOLOGY AND MINERALOGY OF THE WELLINGTON MINE,
BRECKENRIDGE, SUMMIT COUNTY, COLORADO

by

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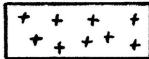
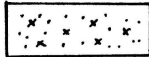
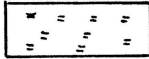
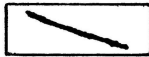

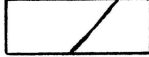
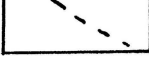
*Approved May 15, 1916,
W. A. Farr*

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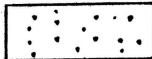

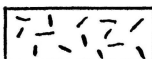
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EXPLANATION OF CONVENTIONS USED ON LEVEL MAPS AND ON
 CROSS SECTIONS (PLATES 2 TO 11 INCLUSIVE).

| | |
|---|------------------|
|  | Diorite |
|  | Quartz porphyry |
|  | Cretaceous shale |
|  | Ore |
|  | Probable ore |
|  | Fault |
|  | Probable fault |

ADDITIONAL FOR PLATE 12

| | |
|---|------------------|
|  | Dakota formation |
|  | Cretaceous shale |
|  | Pre-Cambrian |

On Plate 13, the colors have the same significance as
 on Plate 1.

ACKNOWLEDGMENTS.

The writer feels greatly indebted to certain persons connected with the Wellington Mines Company for their kind assistance in the work on which this report is based. Mr. R. M. Henderson, manager of the property, not only gave permission to examine the mine, but extended the use of the company's maps and other materials. Charles Altland, mine superintendent, gave much helpful information and advice. The miners were invariably courteous in answering questions and giving directions.

Acknowledgment is due R. A. Terry, of Chicago University, for his company and assistance during part of the time spent in the mine. Especial credit must be given Professor W. A. Tarr, under whose direction the field work was done, and who gave valuable aid and suggestions in writing the report.

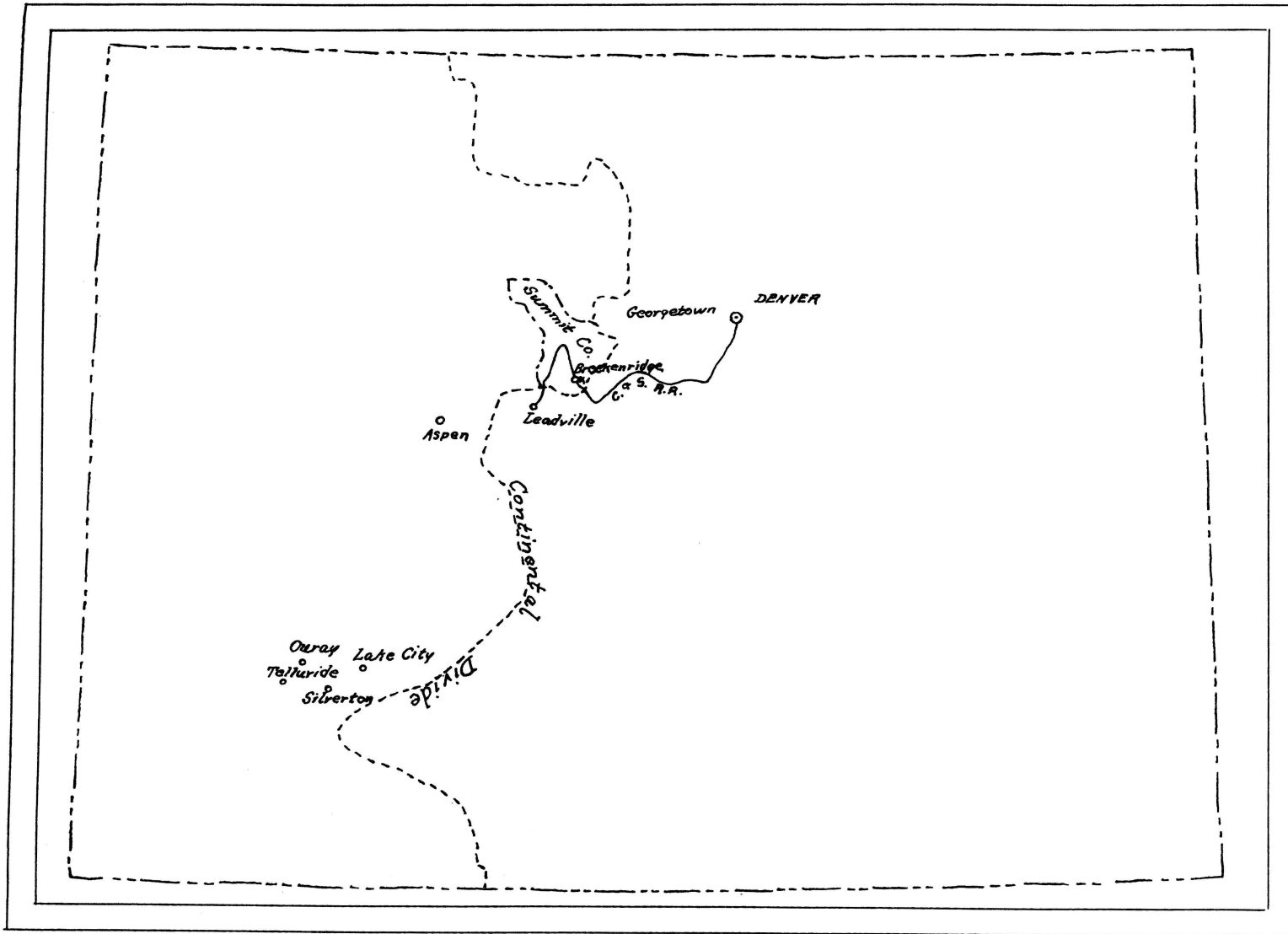
INTRODUCTION.

This paper is based on work done during the summer of 1915, while the writer was a member of a field party engaged in geological work in the vicinity of Breckenridge, Colorado. Through the kindness of Mr. R. M. Henderson, manager of the Wellington Mines Company's property, permission was secured to examine the underground workings of the Wellington mine, the most important zinc-lead mine in the Breckenridge district. Plans showing the location of the principal drifts and stopes were furnished by Mr. Henderson, and, with these maps as guides, the writer made quite a thorough survey of the workings, determining, as far as possible, the geology and mineralogy of the mine. Many specimens of the country rock and the minerals were secured, and intensive study was made of them in the laboratory during the past winter.

The maps and structure plans which accompany the paper represent in part actual facts and in part interpretations based on evidence found in the workings. These interpretations are discussed in the text. In many cases evidence badly needed could not be obtained, because of caved drifts or stopes, timbered walls, and other conditions which prevented free examination of actual relations. Such difficulties are, of course, frequently met by the mining

geologist. They are mentioned here, not as excuses, but merely to emphasize the statement that the structure of the mine as represented is based largely on the writer's opinion and may be found erroneous by further development.

Concerning the real value of the descriptions and suggestions contained herein, the writer is well aware that the benefit to himself through having done the work is probably much greater than the benefit to others through the publication of the results. However, it may not be too presumptuous to assume that the paper will be of interest to some, since it aims to describe somewhat in detail a deposit which in many respects is characteristic of a large group of ore deposits found in the Cordilleras. If by chance any part of the paper proves to be of help to the management of the Wellington mine, the author will feel greatly flattered and doubly repaid for his work.



Map of Colorado. (The X shows the location of the Wellington mine)

LOCATION AND HISTORY OF THE MINE.

The Wellington mine is located two and one-half miles east of Breckenridge, Summit County, Colorado, on the north side of French Creek, a tributary of Blue River. The location is just west of the Continental Divide, and has an elevation of about 10,000 feet. The region has the rough topography to be expected near the summit of the Rockies. Streams have deeply gashed the surface, giving rise to steep slopes and high relief. High peaks rise on all sides. To the southeast, forming part of the divide, are Mt. Guyot and Bald Mountain, both reaching above 13,000 feet. Immediately west of Breckenridge lies the Ten Mile Range, with its summit far above timberline. French Gulch is flanked on either side by steep slopes. Prospect Hill, in which the Wellington workings are located, rises more than 500 feet above the creek.

The property owned by the Wellington Mines Company comprises zinc-lead veins, part of which were first worked nearly thirty years ago. The old Oro mine began to produce in 1887, and the original Wellington was opened a year or two later. The Oro, which was located near the west end of the present holdings, was for several years the most productive mine in the region. Both mines shipped only lead ore, since at that time sphalerite was considered waste, and smelters assessed a penalty for its presence in considerable quantity in the ore.

In 1902 the old Wellington and Oro were brought together under an organization known as The Colorado and Wyoming Development Company. In 1907 the property was transferred to the Wellington Mines Company, a corporation capitalized at \$10,000,000, the stock of which is held for the most part in Kansas City, Missouri. This company built a new mill, and rapidly pushed the development of the mine. The present shaft has been sunk and the three lower levels established since 1909. Due to the high price of spelter, work is now largely confined to the vein richest in zinc. The old Oro drifts at the west of the property have been abandoned. Only the workings shown in the accompanying plan are considered in the descriptions which follow.

During the past six years, 160,000 tons of ore have been taken from the mine. The previous record is not obtainable.

See supplemental file for unfolded version.

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PLATE I

GENERAL PLAN OF THE MINE WORKINGS.

Since in the following discussions it will be necessary to refer to various drifts, levels, and other features, a general idea of the underground development will here be given. Only those parts of the mine now in use will be described in detail, but the general location and extent of the old abandoned workings deserve some mention.

The old Oro workings, which were mentioned above and parts of which will be referred to again, are entered by means of the Oro shaft. The collar of this shaft is about 200 feet east of the mill, and five feet higher than the Mill tunnel. According to the company's maps the shaft connects with four levels, at successive depths of 116.5, 185.6, 245.8, and 323.8 feet. Main drifts on these levels extend in a northeast-southwest direction, approximately parallel to the present Mill tunnel. The longest drift, on the first level, formerly reached to a point 1,000 feet northeast of the shaft. About 100 feet southwest of the shaft was the portal of the old Oro tunnel, which was on a level with the present Mill tunnel, and which extended northeast, parallel to the lower drifts. Thus there were five Oro levels, connected by raises and stopes. A large part of the ore secured in this section of the mine is reported to have come from stopes above the first shaft level. At the time the writer visited the mine, part of these workings were full of

water, part were badly caved, and none were being developed. Hence, no attention was given them, except that one drift was entered by means of a raise from the fourth X-10-U-8 level. A map of the underground workings showing their relation to the present development is to be found on Plate XXVIII of Professional Paper No. 75. It was not considered worth while to copy the plan in this paper.

The original Wellington mine may still be entered by the old Wellington tunnel, the portal of which is some 600 feet north of and 240 feet above the X-10-U-8 portal. The tunnel is practically parallel with the X-10-U-8 cross-cut, and sends out right and left hand drifts, which were stoped upward on the ore bodies. Only assessment work is being done there at the present time. A direct connection with the X-10-U-8 level formerly existed by the Iron raise, which followed the Iron vein; but this opening is no longer in condition to be used. The old Wellington workings are also mapped on Plate XXVIII of Professional Paper 75.

There are other old superficial workings, consisting mostly of short tunnels and shallow shafts, on the Wellington property; but practically all are in bad condition, and could not be examined thoroughly when the mine was visited.

The main entrance to the present workings is by way of the X-10-U-8 tunnel, the portal of which is 1,650 feet northeast of the mill. This tunnel, which is a

straight crosscut running N 25° W, sends out drifts on the intersected veins. These workings constitute the present first level. At a point 600 feet from the portal, a shaft is sunk at an inclination of about 60°, corresponding to the dip of the Wellington vein. This shaft gives access to the lower levels by a ladderway, and also by means of skips, operated from a station located as shown on the map. The lower levels, of which there are four, lie at successive depths of 86.2, 186.6, 320, and 450.3 feet below the X-10-U-8 level. The second level connects directly with the mill through the Mill tunnel, in which a track runs from the mill to the shaft. A branch track follows the Orthodox drift and connecting crosscuts to the Great Northern workings. Practically all the ore goes to the mill over this track by means of mule trains. Where the principal ore bodies occur the levels are connected by stopes. Ore taken from the stopes above the second Oro level is loaded directly in the mule trains from chutes. That secured in lower workings is sent in cars to the shaft, raised in skips, and loaded from a chute beside the shaft. The waste taken out above the second level also goes through the mill tunnel to the dump; but that taken from lower in the mine is raised to the first level and sent out through the X-10-U-8 tunnel. Formerly some ore also came from this tunnel and reached the mill by means of an electric tramway; but, though the track still remains, the tramway is little used at the present time.

Besides the two adits mentioned, there is another, the Brown tunnel, the portal of which is some 300 feet east of and a few feet below the X-10-U-8 portal. This tunnel is a straight crosscut running almost north and connecting with a stope of the Great Northern vein slightly below the first level. This crosscut is part of an old property and is now used by the miners merely as a convenient way of reaching work in the Great Northern stope.

Considerable timbering has been found necessary in the mine. In part, drifts are in self-supporting rock, requiring little timbering; but in many places broken ground is encountered both in the main drifts and in the crosscuts, calling for tunnel sets and, quite frequently, lagging for walls and roof. Stopes are kept open merely by stulls to support the hanging wall, which seldom requires more than such simple timbering.

Water occurs in places on all the levels. It is most abundant, of course, in the lower drifts. The wettest part of the mine is at the western end of the fifth level, where the drift penetrates shale. It will be noticed that this is very near the Oro shaft and connected drifts, which are full of water. To keep the mine clear, a large pump has been installed at the bottom of the shaft, and this is aided by smaller relay pumps on the third and fourth levels. Last summer these pumps, running continuously, were lifting 130 gallons per minute. The water is expelled through the Mill tunnel.

It is not the purpose of this paper to go into detail concerning the handling of the ore taken from the mine. A few general statements will suffice. All of the ore now secured is concentrated before shipping. Two mills, one of 115 tons capacity using wet methods and another of 55 tons capacity using dry methods, stand near the portal of the Mill tunnel. The wet mill is equipped with jaw crusher, rolls, screens, ball mills, jigs, and Wilfley tables, while the dry mill uses a roaster and a magnetic separator. Concentrates from the jigs, containing 40 per cent or more of zinc, are shipped to eastern smelters. Lead concentrates are sold to the Chamberlain-Dillingham Ore Company.

GENERAL GEOLOGY OF THE REGION.

Breckenridge lies in that northeast-southwest belt of Tertiary monzonite intrusions which reaches from Boulder, through Georgetown and Leadville, to the San Juan region. In the Breckenridge quadrangle, the intrusions broke into a series of thick Mesozoic sandstones and shales, which lay on a pre-Cambrian basement. The geologic succession is as follows:

| | |
|--|--------|
| Upper Cretaceous shale (Mancos?) . . . | 5,000' |
| Dakota sandstone (chiefly quartzite) . | 400' |
| Triassic sandstone (Wyoming) | 1,000' |
| Pre-Cambrian complex | |

The sediments have been folded and faulted, and now lie tilted at many angles but dipping chiefly to the northeast. The beds are irregularly cut by monzonite porphyries, the predominating surface rocks of the region, which occur as dikes, sills, and large masses of indefinite shape. Isolated bodies of sandstone and shale are frequently found forming inclusions in the igneous rock.

Crustal disturbance did not cease with the Tertiary intrusions. Later fissuring and faulting have affected both the sediments and the porphyries. An important system of fissures extends in a general northeast-southwest direction and includes nearly all the principal mineral veins. Lead-zinc veins on both sides of French Gulch as well as gold veins in Francomb Hill have a northeast strike. Another main fissure system has a north-south trend, and minor systems strike in various directions. Considerable movement has taken place along some of the fissures.

FIRST LEVEL.



0 50' 100' 200' 300'
Scale

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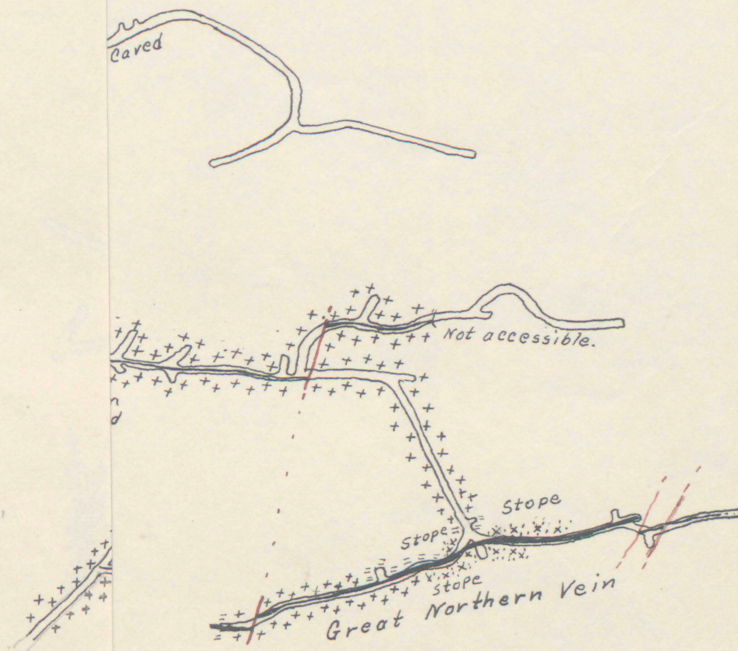
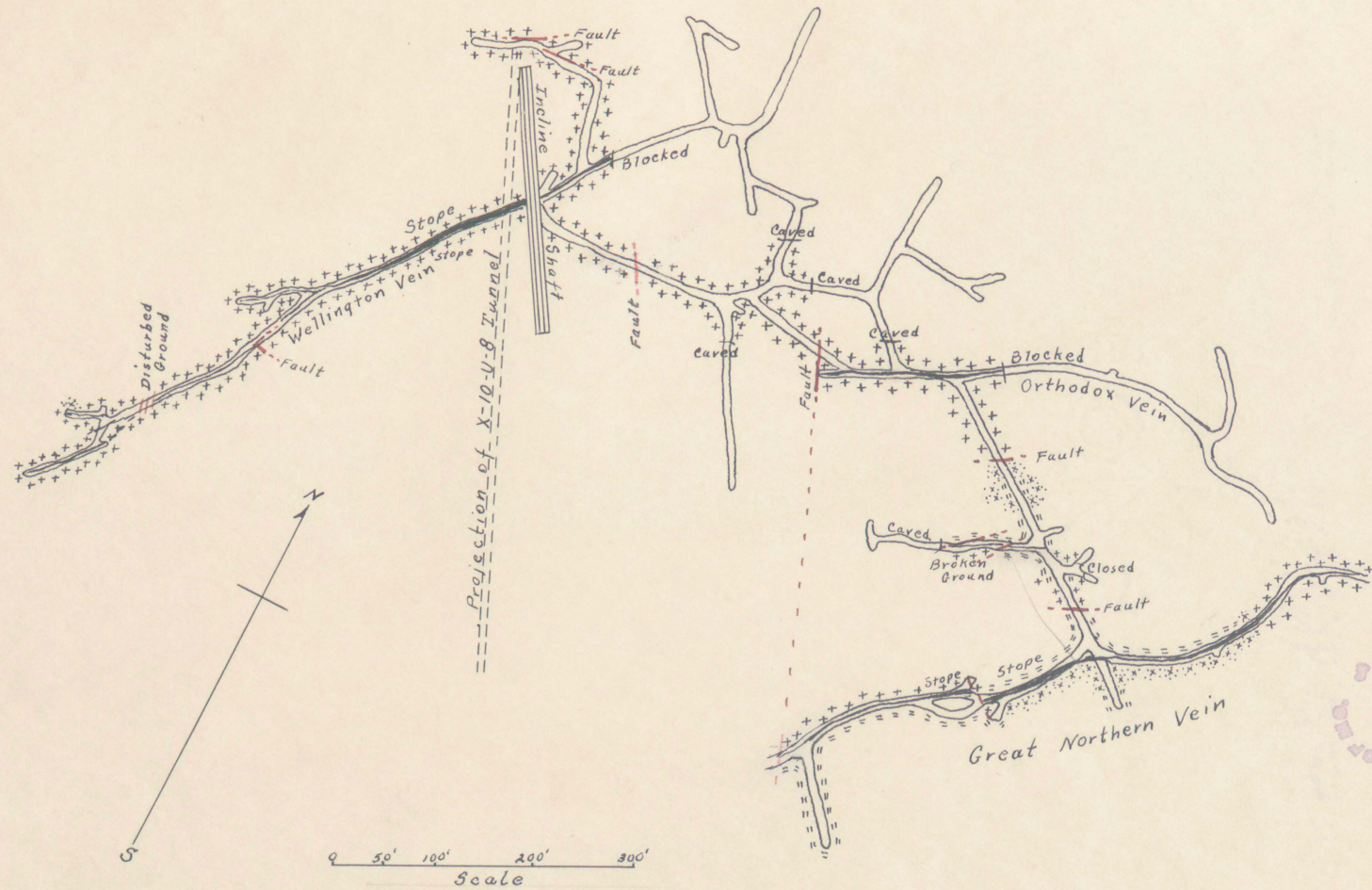


PLATE 3

THIRD LEVEL



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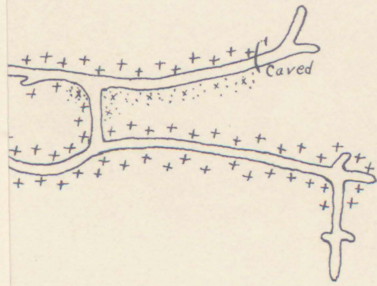
FOURTH LEVEL



PLATE 5.

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50' 100' 200' 300'
Scale

PLATE 6

GEOLOGY OF THE MINE.

Introduction.

A discussion of the Wellington mine is given by Ransome in his professional paper on the Breckenridge mining district.* At the time Ransome's work was done, however, only two levels were being worked, and the vein which now furnishes most of the ore was hardly known. Extensive development since that time serves to give a better idea of the geologic relationships and the extent of the veins.

1. The Rocks.

Three types of rock are recognized in the underground workings of the mine. These are diorite porphyry, quartz monzonite porphyry, and shale. A metamorphosed member of the Dakota formation is also encountered at one point in the Brown tunnel, but is not near an ore body, and appears in no other part of the mine. The diorite is the prevailing country rock. It forms a large, irregular mass, cut by small bodies of quartz porphyry, and shows in a number of places intrusive contact with the shale. Further relationships will be dealt with later. Each type of rock will now be considered in detail.

*"Geology and Ore Deposits of the Breckenridge District, Colorado," by F. L. Ransome. Professional Paper No. 75, United States Geological Survey.

The diorite is quite evidently a facies of the monzonite porphyry which is the prevailing igneous rock on both sides of French Gulch. As usually encountered in the region, it is a distinct porphyry, consisting of a dense gray groundmass containing small but easily recognized phenocrysts of hornblende and biotite. There are, however, a great number of variations in the rock, ranging from a light-colored phase with phenocrysts forming a considerable percentage of the whole to a dark, dense variety which, on megascopic examination, one is tempted to call a basalt. Although many of these gradations are found in the mine, the fresh rock encountered is prevailingly fine-grained, dark, and without conspicuous phenocrysts. Near the sulphide veins, the dark color is never seen, for the rock there has been altered and bleached by the ore-bearing solutions. In crosscuts well removed from the veins, however, the original dark color is always found. When the coarser-grained phases of the rock are encountered, biotite frequently forms an unusually large percentage of the phenocrysts as compared with the normal porphyry in the region.

Megascopically, the term diorite porphyry would not be applicable to this rock. Study of thin sections, however, gives the following average composition for the fresh porphyry:

Primary essential constituents -

| | |
|---|-----|
| Plagioclase (andesine, albite, labradorite) . | 60% |
| Orthoclase | 5% |
| Hornblende | 15% |
| Biotite | 12% |
| Quartz | 8% |

Accessory constituents -

- Magnetite (abundant, in small grains)
- Apatite (a number of good hexagonal cross sections
and some longitudinal sections)
- Pyrite (a few small grains)

Secondary minerals -

- Kaolin (a small quantity from altered feldspar)

The quartz monzonite porphyry is more distinctly porphyritic than the calcic type. Unless it is badly altered, it is easily recognized by conspicuous phenocrysts of orthoclase and smaller phenocrysts of quartz. Where alteration has obscured or destroyed the orthoclase crystals, the quartz remains unaltered and serves as a means of identification.

Megascopically, this porphyry shows a dense ground-mass, usually light gray in color, imbedding the quartz and feldspar phenocrysts. The orthoclase usually has perfect crystal forms, those commonly seen being single crystals and Carlsbad twins. A number of Manebach twins were also

found in the region, but search for Bavenos was vain. The crystals range from a fraction of a centimeter to three inches in length. Many of the smallest are plagioclase instead of orthoclase. The quartz sometimes occurs as rough bipyramids, but more often as rounded grains, which range up to a centimeter in diameter. Occasional grains of hornblende and biotite occur.

Slides of this rock studied by the writer were all badly altered. The following composition of the fresh porphyry is taken from Ransome:

| | |
|-------------------|--------|
| Quartz | 24.42% |
| Orthoclase | 23.91% |
| Albite | 30.39% |
| Anorthite | 13.62% |
| Diopside | .42% |
| Hypersthene | 1.82% |
| Magnetite | 2.09% |
| Ilmenite | .61% |
| Apatite | .34% |

This composition is calculated from the chemical analysis of a specimen taken in another part of the region. However, the character of the rock is quite similar to that found in the Wellington mine.

The shale in the mine is evidently the Cretaceous shale found abundantly in the region. Its color is dark gray or bluish to black. It is always fine-grained, and

frequently it is quite calcareous. Occasionally thin lamination is present, but more often it is in massive beds and breaks into blocks along joints, some of which may easily be mistaken for bedding planes. Much of the shale is a hard, brittle rock, which rings under the hammer and is difficult to drill.

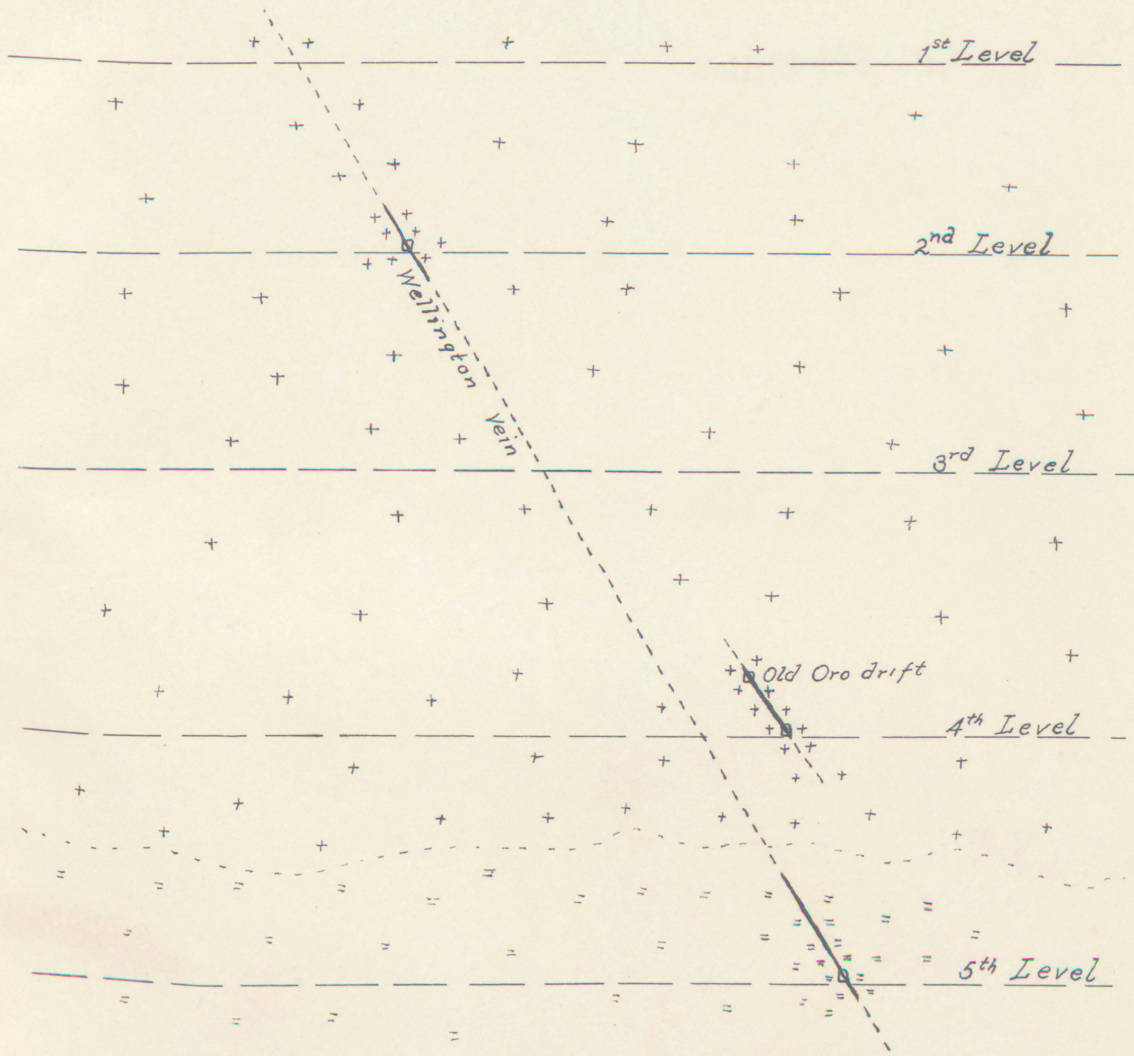
Under a high power microscope, the greater part of a thin section of the shale still appears dense. Small rhombs of calcite and particles of pyrite are scattered through the mass.

2. Structure.

General Statement.

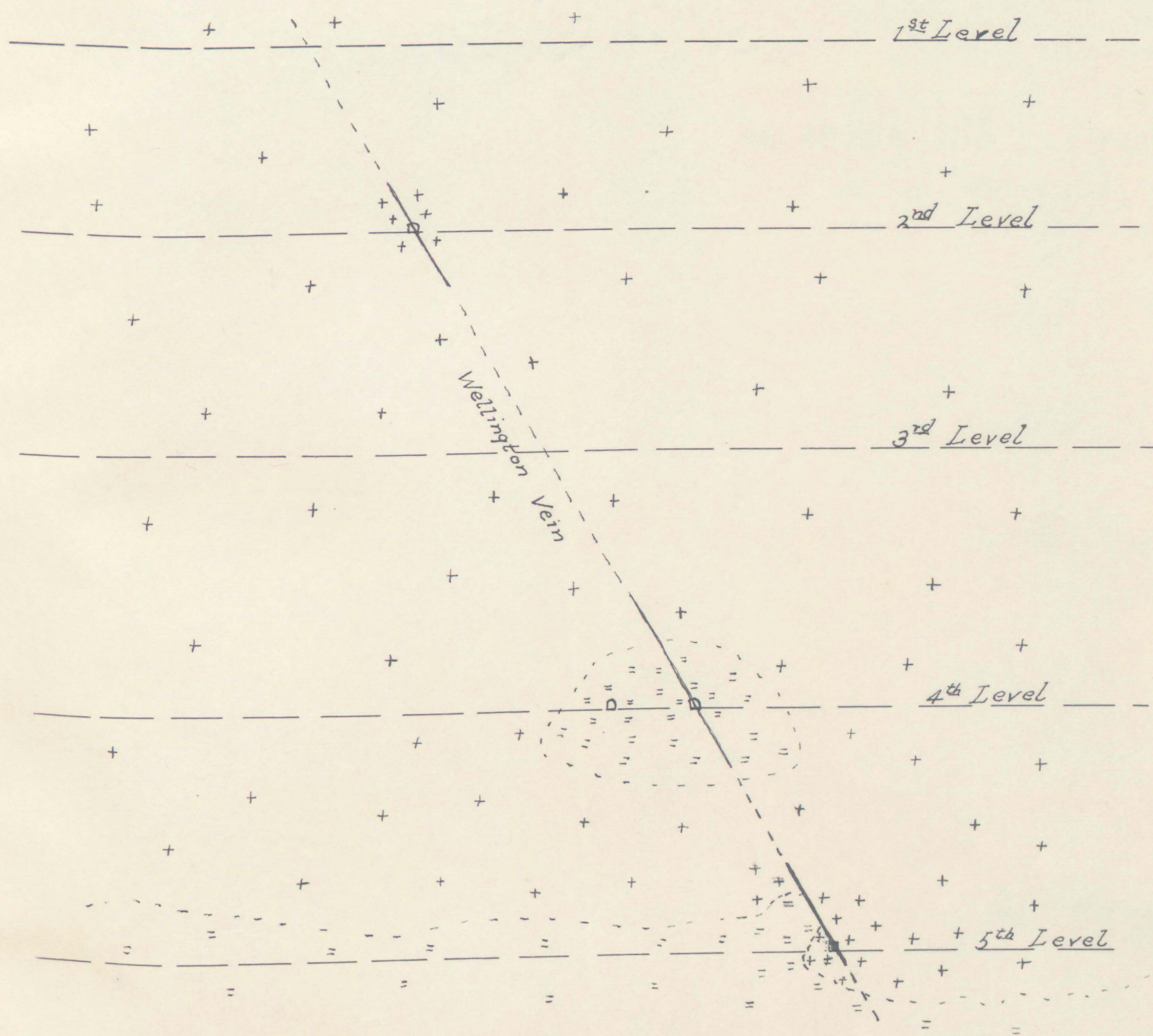
The structure of the Wellington presents many difficult problems. With the sediments cut and wedged apart by the intrusives, and the resulting complex intricately faulted, it seems almost impossible to work out a detailed structure plan which is entirely satisfactory. In running drifts, the miners pass suddenly from porphyry into shale, or vice versa. Sometimes the contact is intrusive, sometimes it is a fault surface. In the former case, the shale may form an inclusion, floated up in the magma at the time of intrusion, or it may be part of a bed, still intact, but tilted from its original position by the intruded material. Dikes of quartz porphyry cut across both diorite and shale. Fault

CROSS SECTION NO. 1 (S₁S₁, PLATE 1)



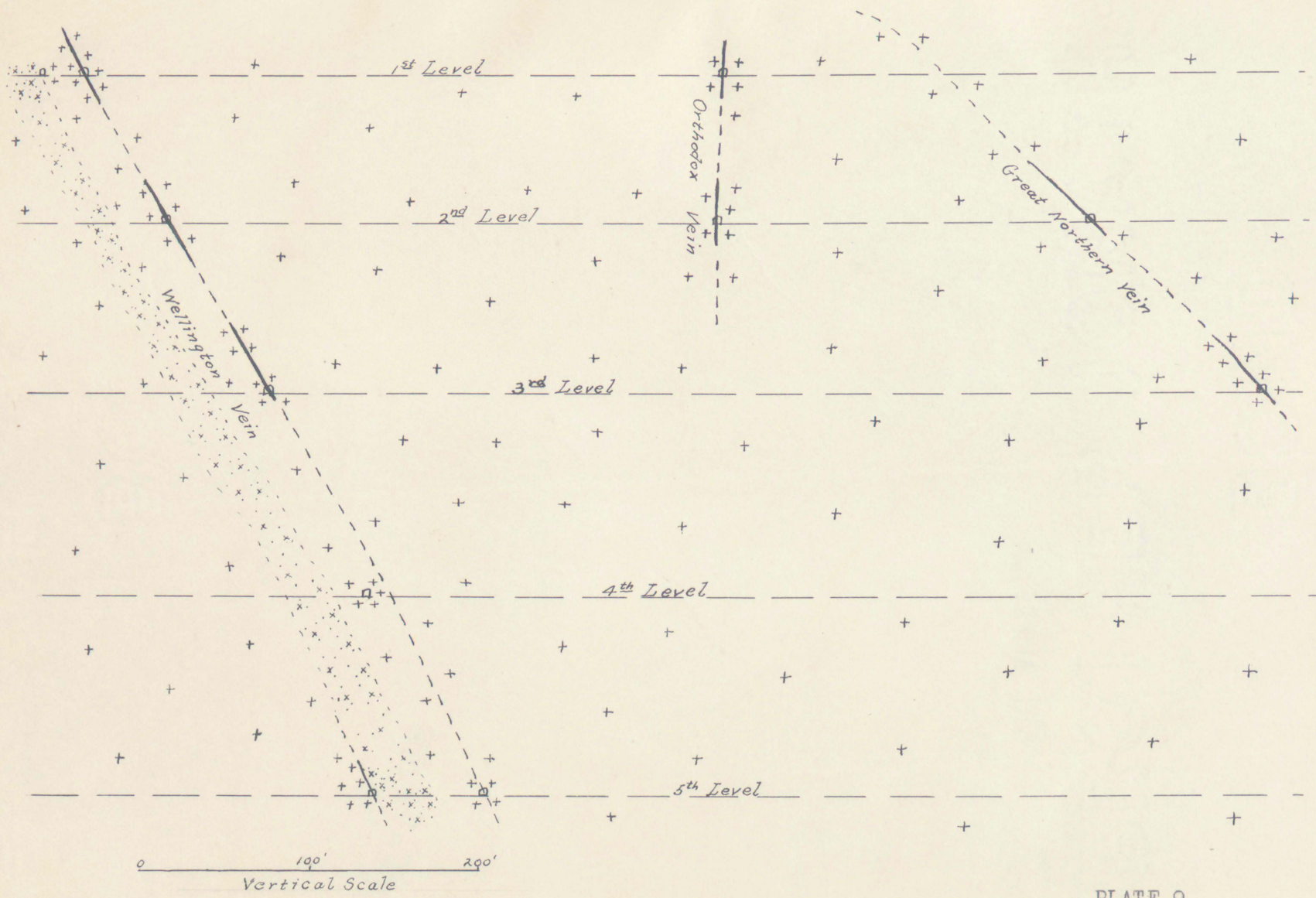
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Vertical Scale.

CROSS SECTION NO. 2 (S₂S₂, PLATE 1)

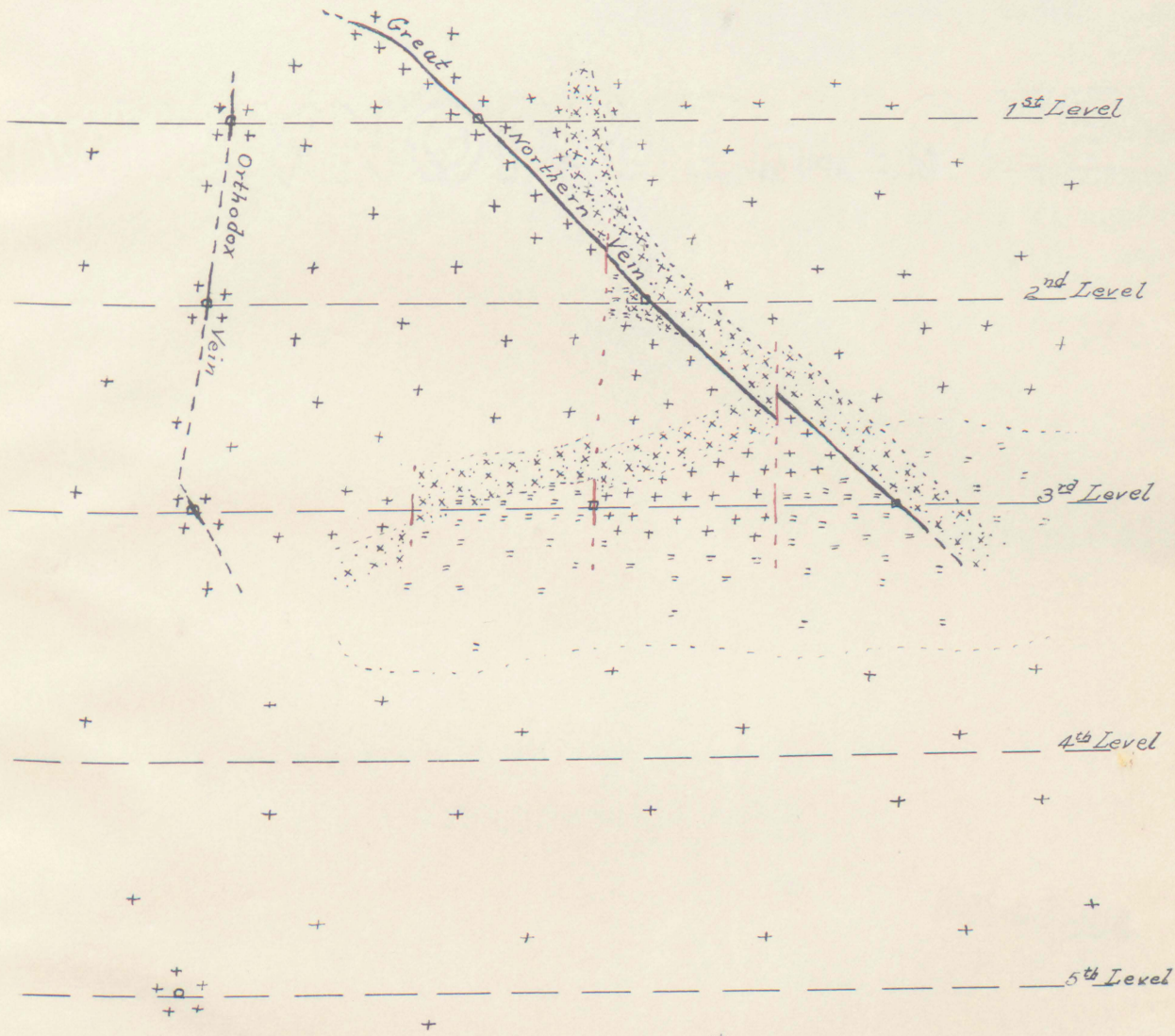


0 100' 200'
Vertical Scale

CROSS SECTION NO.3 (S₃S₃, PLATE 1)

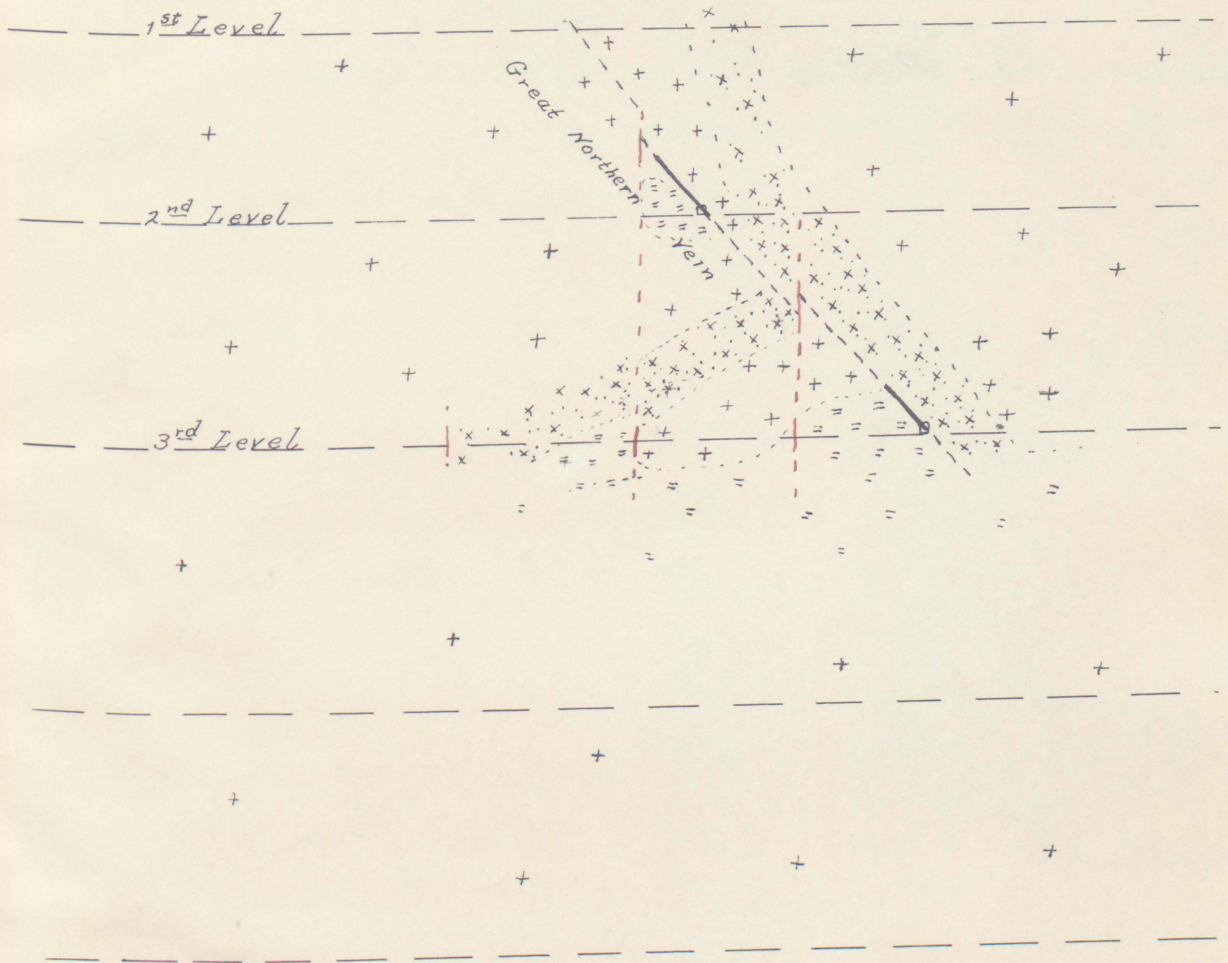


CROSS SECTION NO. 4 (S₄S₄, PLATE 1)



0 100' 200'
Vertical Scale.

CROSS SECTION NO. 5. (S₅S₅, PLATE 1)



0 100' 200'
Vertical Scale

planes, striking in various directions and dipping at many angles, affect all parts of the mine. In most cases movements have been small, but frequently where veins are intersected the faults cause considerable annoyance.

Relations of Rock Masses.

In spite of the complexity mentioned above, however, the relations of the rocks observed on the surface and in the mine drifts indicate at least the larger features of structure, and make possible plausible speculations as to certain details. Reference to the geologic map of the region shows the following surface conditions:

Running westward from the mill is a large area of Dakota quartzite with practically horizontal bedding. This is in intrusive contact with the monzonite porphyry which outcrops on the surface of the greater part of Prospect Hill. No other sedimentary outcrop is seen in the vicinity of the mine except a small exposure of quartzite about three hundred feet east of the X-10-U-8 tunnel. The Brown tunnel reveals an intrusive contact between this quartzite and the porphyry. Near the top of the hill a long, narrow quartz porphyry dike may be traced from Prospect Gulch to the top of Mineral Hill. (Ransome maps the dike in three sections. It is really continuous.) No other rock units are exposed on the hill.

Ransome states that a tunnel near the mill, open in 1908 but since closed, penetrated black shale for a distance of 300 or 400 feet to the face. He states further

that the second Oro level in the vicinity of the shaft (just southeast of the mill) is in shale according to the company's old maps. Unfortunately the writer could not verify these statements, since the old workings were not accessible when the mine was visited. It seems evident, however, that there is considerable shale not far below the surface to the east of the mill.

Referring now to the general plan of the mine and to the second level plan, we see that the present fifth level has been driven to a point which is horizontally less than 200 feet east of the mill, while the face of the fourth level drift is only some 200 feet further east. The western 700 feet of the fifth level drift is in shale, which at its eastern limit shows an irregular contact with the diorite. No other shale is encountered in the eastward extension of this level. The western face of the fourth level drift is in diorite. The writer climbed the raise to the old second level Oro drift, and followed it a hundred feet or more to the west and several hundred feet to the east. Only diorite was found. Five hundred feet eastward on the fourth level the drift penetrates shale for 200 feet, and a spur drift to the northwest is entirely in shale. Both contacts are evidently intrusive. The beds dip to the northeast. This body probably is an isolated inclusion, though it may be continuous with the larger mass found on the fifth level.

The third level, as far as it runs west of the shaft, is entirely in diorite, as are the second and first levels. East of the shaft, shale is limited in amount. It occurs on the second level in the footwall of the Great Northern vein, apparently as an isolated body of small size, and in the southeastern workings of the third level in a mass which, though broken, is evidently of considerable size. The beds in this part of the mine have no consistent attitude, the varying dips furnishing strong proof of the disturbed condition of the strata.

We may now attempt the interpretation of these facts. Only the large body of shale on the fifth level shows good evidence that it occupies practically its original position. It lies in an unbroken mass, and the dip of the beds is apparently consistent with that common to the sediments of the region - that is, to the northeast. Since the fifth level drift reaches very near the position of the Oro shaft, the shale probably is a continuation of that reported in the Oro workings. Just how far eastward it extends we have no way of knowing; but, since its dip would keep it below the fifth level east of the point where it is last seen, we may assume that it continues beneath the diorite for several hundred feet - in fact, that it underlies practically all the present workings. Immediately both to the east and to the west of this area, however, we find Dakota quartzite on the surface. This may be explained in

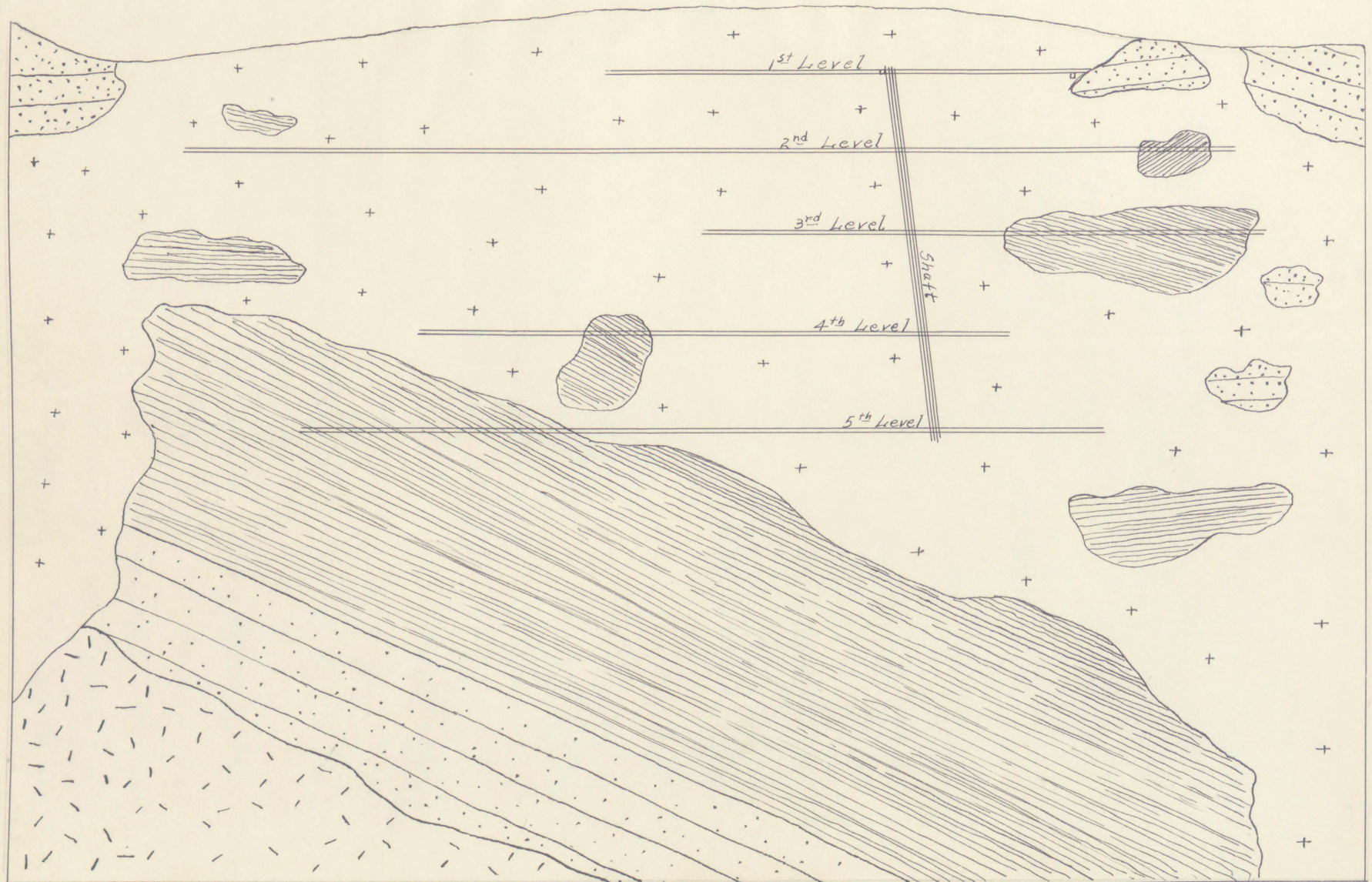
two ways, perhaps the most obvious explanation being that the Wellington mine lies in a large downward-faulted block. Such faulting, however, would involve displacement of at least several hundred feet and the fault planes could hardly escape detection. No trace of them was found. Moreover, as noted above, the quartzite masses on both sides of the mine are clearly in igneous contact with the intervening diorite. This fact, in connection with those discussed above, suggests the following interpretation of the igneous history and consequent geologic relations:

The intruding magma, forcing its way along bedding planes of the sediments on either side of the Wellington mine area, broke across the beds along lines indicated by the quartzite exposures. The shale now underlying the Wellington was little disturbed, there being no magma beneath it, but the edges of the sediments on either side were forced upward several hundred feet along the breaks. At a higher level the lava gained access to the bedding of the shale, forcing up the higher beds and forming the large mass of diorite in which the Wellington workings are located. Along the breaks the ascending magma tore off and floated up masses of shale of varying sizes. Such are the isolated bodies of shale found on the second and third levels. The shale penetrated near the west end of the fourth level may be another inclusion, or it may represent merely an irregularity in the upper surface of the lower shale caused by the lava's breaking

across the bedding. The quartzite masses west of the mill and east of the Brown tunnel are probably not inclusions, strictly speaking, but merely the edges of extensive beds wedged upward by the force of the intruding material.

It will be seen that the general relations due to the conditions assumed above would be similar to those caused by the downward faulting of a block extending from the mill to the Brown tunnel. The hypothetical east-west cross section on the next page will make the explanation clearer. The section takes no account of the quartz porphyry, nor of the veins, faults, and other structural features. It is merely an attempt to explain the general relations between the diorite and the Cretaceous sediments. Of course there are many uncertain factors involved. We have no way of knowing the horizon of the shale found on the fifth level. In parts of the region not far from the Wellington the upper Cretaceous shale has a thickness of some 5,000 feet. If the magma which formed the diorite mass of Prospect Hill intruded near the bottom beds of the shale, the greater part of the latter was raised and has since been eroded at the surface. In this case, only a thin section of the beds remains beneath the igneous rock. On the other hand, if only the upper beds were carried up by the magma, several hundred feet of shale may be left below. The thickness of the underlying quartzite is also hypothetical; and perhaps

HYPOTHETICAL EAST-WEST SECTION THROUGH THE WELLINGTON MINE. (See p.22)



Wyoming sandstone lies between the Dakota and the Pre-Cambrian. Moreover, the body of sediments shown intact may be cut by sheets and dikes of considerable size. The section merely presents a probable explanation of general conditions in the depths of the mine.

The quartz porphyry is evidently younger than the diorite, which it cuts in several parts of the Breckenridge quadrangle. In the mine, the quartz porphyry is encountered in only a few places, and then in comparatively small bodies. The most extensive mass is penetrated on the first level, northeast of the shaft, by the drift following the Iron vein and by the crosscut to the East vein. The exact limits of the mass are difficult to fix. Its eastern termination along the drift to the East vein is about as shown on the first level map, although the contact with the diorite is concealed by lagging. On the south it is bounded by the Fault vein except in the vicinity of the Wellington drift, where both walls of the fault are in quartz porphyry. In the long northeast drift marked "closed" Ransome reports diorite immediately east of the first short branch. This drift was completely closed at the time of the writer's visit. West of the Iron vein in the Fault drift, the two porphyries are in igneous contact. In the first short branch running west from the Iron drift, diorite was found at the face. From there eastward quartz porphyry forms both footwall and hanging wall of the vein to near the face of the drift, where diorite is encountered. The branch drift to the south is all in quartz porphyry.

Evidently the porphyry mass described above is of very irregular shape. It lies partly within the X-10-U-8 fault zone, and has suffered shattering and shifting, which may account for some of the irregularities. Judging from what can be seen on the first level, however, one cannot feel satisfied that the porphyry is part of a dike. Referring now to cross section No. 4, it is seen that on the fifth level there is a narrow body of quartz porphyry, lying northeast of the shaft. The possibility is suggested that this occurrence and that on the first level represent a continuous dike. A line connecting the two bodies is nowhere intersected by an accessible drift, though some of the third and fourth level drifts pass near it. Hence, there is no direct way of confirming the suggestion. The writer has tested the relation, however, in the following way: Assuming that the bodies are parts of a dike, it must dip to the south at an angle of about sixty degrees. Projecting it to the surface at this same angle, it there coincides exactly with the outcrop of the long northeast-southwest dike near the top of Prospect Hill. Thus, we have good circumstantial evidence, not only that the porphyry masses on the first and fifth levels belong to a dike, but that they are actually parts of the long dike exposed at the surface.

Now referring again to the first level plan, we may wonder that no further evidence of the porphyry dike is seen to the west of the X-10-U-8 tunnel. The west end of

the Fault vein lies entirely in diorite. The extension of the X-10-U-8 tunnel north of the Fault vein was not accessible when the mine was visited; but Ransome reports quartz porphyry near the tunnel face. A line drawn from this point to the easternmost exposure of quartz porphyry in the Iron drift gives a course north of east which, in its western extension, does not intersect the Fault drift. This, then, may represent the position of the dike on the first level. It is true that this course deviates a few degrees from the general trend of the dike as exposed on the surface; but such a slight irregularity is to be expected. The deviation is not more than is found in some of the veins. The quartz porphyry at the west end of the Iron vein and along the crosscut to the east may represent material forced into the shattered rock from the main fissure at the time the dike was formed. A knowledge of conditions in the extreme northeast workings of the first level would be helpful in connection with this problem, but the drifts are not accessible. In the workings west of the shaft on the lower levels, none of the drifts extend far enough north to intersect the dike. The small exposure of quartz porphyry seen near the west end of the main third level drift and also the sill in the western part of the fifth level may be connected with the dike, though they must be some distance south of it.

The other exposures of the silicic porphyry are in the southeastern workings on the second and third levels. On the third level, it forms the hanging wall of the Great

Northern vein for a distance of nearly 300 feet. The southeast crosscut penetrates the porphyry south of the vein and reveals shale behind it, indicating that the igneous rock forms a dike some twenty feet wide. To the east of the crosscut, the porphyry finally crosses to the footwall of the vein, and then disappears. About 100 feet west of the crosscut the porphyry suddenly disappears in the hanging wall. Apparently faulting has affected the vein at about the same point; but the same faulting cannot be made to explain the disappearance of the porphyry, for the vein is found, displaced only a few feet to the north, with shale instead of porphyry in the hanging wall. We might assume that a fault, occurring before the formation of the vein, displaced the dike to the south; but if this is the case the displacement was considerable, since the southeast crosscut farther west does not find quartz porphyry. It is more reasonable to suppose that the dike ends at the point where it is last seen in the hanging wall.

Following the Great Northern stope upward from the third level, the porphyry remains in the hanging wall to the second level, where it occurs in both hanging and foot walls. As shown by the map, however, the rock has no large extent on this level. Evidently it does not continue far in the footwall, for no trace of it can be found in the stope above the second level, and on the first level the vein is wholly

in diorite. Cross section No. 5 interprets the second and third level porphyry as belonging to the same dike, which is continuous with a dike found intersecting the Brown tunnel just south of the Great Northern vein. The small body in the footwall on the second level represents merely a local thickening of the dike.

Another occurrence of quartz porphyry is found on the third level, intersected by the long southeast crosscut about 100 feet south of the Orthodox vein. At its northwest limit it is faulted against diorite. The mass rises to the southeast, showing an irregular intrusive contact with the shale, and finally disappears in the roof of the crosscut. This porphyry is shown in cross section No. 4 as having some connection with the dike described above. Just what this connection is can only be surmised.

General Features and Relations of the Veins.

Seven principal veins are recognized in the present Wellington mine. These are the Wellington, Orthodox, Great Northern, East, Fault, Iron, and Spur veins. In the summer of 1915, only two of these, the Wellington and Great Northern, were being worked; but the others were accessible, at least in part, and some examination was made of all.

The veins fall into two groups according to the directions in which they extend. The Wellington, Iron, and Great Northern have a decided northeast strike, and hence

appear to belong to the principal fissure system of the region. The others belong to an intersecting system extending more nearly east and west. All of the veins dip toward the south except the Orthodox, which, on the upper two levels, is almost perpendicular. At greater depth, however, it changes direction, assuming a southward dip.

All of the veins may be classed as fissure veins, each showing fairly well-defined footwall and hanging wall. Nearly all show that they have been planes of movement either before or after mineralization, since well developed slickensides occur in places on the walls. No vein is uniform in width for any considerable distance, but swells and pinches frequently along both the strike and the dip. The maximum width is perhaps 15 or 16 feet, the average being very much less. In stopes, the space between walls ordinarily varies from 3 to 12 feet.

The main Wellington vein appears to be the most consistent both in extent and in direction. Under different names, it has been followed more than a quarter of a mile along the strike, and at least 700 feet along the dip. The unusual consistency of the dip is shown by the fact that the incline shaft, descending in a straight line at an angle of about 60° , hardly loses sight of the vein between the first and fourth levels. The strike varies somewhat along its course, but averages 45° to 50° east of north. Workable

ore occurs in swellings of the vein, which pinch out, giving place to barren or lean stretches. The positions of the principal ore bodies are indicated on the maps of the different levels.

Referring to the general plan map, it is seen that the fourth level drift near its western extension does not run consistently with the drifts above and below. At its face, the fourth level tunnel lies almost directly above the fifth level tunnel. This cannot mean a change in dip of the vein, for on both levels the dip is about 60° south. The most probable explanation is that the western 400 or 500 feet of the fourth level workings follow a branch of the main vein. Ransome states that the old Oro workings are apparently on a fork of the main vein, the northern branch being followed by the Mill tunnel. As noted above, the second Oro level is reached from the western end of the fourth X-10-U-8 level by climbing a raise, which follows the vein. Hence, the western end of the fourth level is without doubt following the branch of the vein formerly worked by the Oro shaft. The point of junction with the northern branch was not seen; but evidently it occurs near the fork in the drift some 500 feet east of the face. The short northern drift at this place follows a barren seam, which in all probability represents the northern portion of the divided vein.

On the fifth level, the vein is affected considerably in the vicinity of the shaft by faulting. Southwest of the shaft ore was found in the first two branches to the south, but was soon cut off by faults. In the crooked course followed for 300 feet practically no ore was discovered. Just why the long crosscut to the south does not intersect the vein is not clear, since it crosses the course of the vein as it appears not far to the west. Probably the explanation is that the vein exists in the vicinity of the crosscut only as a barren closed fissure. East of the shaft the relations are again obscure. The small vein found in the northern drift does not occupy the proper position for the main vein, and must represent either a faulted portion or another branch. Just above, to the west of the shaft on the fourth level, the vein appears in two parts. The northern branch has been stoped upward, but its extent is unknown. East of the shaft on the same level the vein does not appear, evidently because of faulting. These relations will be taken up at greater length in the discussion on faults.

On the first level the Wellington vein terminates abruptly against a large fault plane about 150 feet east of the shaft. The end of the vein is bent toward the west, indicating that the northeast continuation was displaced in that direction. Going about 50 feet along the course of the fault, one finds the Iron vein running northeast. The

strike and dip of this vein correspond to those of the Wellington, of which it is undoubtedly the northeast extension, offset to this position. Good ore has been secured above the first level on this vein, but it is not strongly mineralized on the level, and gets leaner as it is followed to the northeast.

The Spur vein is a branch of the Wellington, joining the latter some 200 feet west of the shaft. This short vein has its best development above the first level, where it strikes N 70° E and dips 55° south. A good body of ore has been taken out just west of the junction, and some ore still remains. In the vicinity of the crosscut to the north the vein practically disappears. No sign of it is seen in the south wall of the Wellington, though it may continue across as a closed fissure. Ransome suggests that it is continuous with the East vein, but there is little reason to suppose this is the case. It is not found crossing the X-10-U-8 tunnel. The Spur vein appears again in the second and third levels, and possibly on the fourth, but it is practically barren at these depths. It is significant that on none of these lower levels is the vein recognized on the south side of the Wellington. This fact argues that the fissure terminates at the junction with the larger vein.

The Fault vein is a poorly mineralized fault space representing the plane of greatest movement in a shear zone. It strikes N 80° E, and dips about 75° to the south near the

end of the Iron vein, flattening to 55° where last seen at the west. The vein is of no importance as an ore body, but is of considerable scientific interest. It will be mentioned again in discussing faults.

The exact relations of the East vein are obscure. The drift at the west end of the vein is in broken ground, and the walls and roof are obscured by lagging. Some believe it a faulted branch of the Wellington, and, as noted above, Ransome suggests it is the eastern extension of the Spur vein. In the writer's opinion, it is a continuation of the Fault vein, to which it corresponds very closely in strike and dip. It is true there is not evidence of extensive movement in the East vein as there is along the great fault, but there has been some movement, for several large slickensided surfaces were found in the drift. It may be that this part of the fault was more open, and the walls escaped the excessive friction which caused the polishing and grooving farther west. Moreover, there is no necessity to assume the same amount of movement along this part of the plane, since the western slipping of the north wall may have been confined largely to a block whose eastern limit lies in the broken ground near the contact of the two porphyries.

The East vein was much better mineralized than the Fault vein. Old stopes indicate that some good ore bodies were found. The vein has not been worked recently, and the drifts were in bad condition when visited. Only on the first level were they accessible.

The Orthodox vein is roughly parallel to the Fault and East veins, its average strike being about N 70° E. On the second level it appears to be a branch of the Wellington, though the two may really intersect. However, no sign of the Orthodox appears west of the point of junction. On other levels the vein has not been followed to the junction. On the first level the map shows in the inaccessible west portion of the Wellington drift a branch which corresponds in direction to the Orthodox farther east, suggesting that in this place the Orthodox fissure actually continues to the west.

On the first and second levels the Orthodox vein is almost perpendicular, in places dipping 80° to 85° toward the north. In this respect it is peculiar, all the other large veins pitching to the south. On the third level, however, the Orthodox also dips 60° south. The change in direction occurs somewhere between the second and third levels, but no stopes or raises were available to show just what the actual conditions are. It seems hardly possible that a fissure changes its course so suddenly. A more plausible explanation is that the vein represents two intersecting fissures. The ore-bearing solutions, rising along one opening, found the other the more open at the line of junction and followed it as the course of least resistance. It should be interesting to see the attitude of the vein at greater depths, but it has not been located on either the

fourth or fifth levels. Apparently the southeasternmost crosscut on the fifth level was run with the idea of intersecting the Orthodox vein; but, if the 60° dip continues from the third level, the crosscut was not continued far enough to accomplish the purpose. The writer did not explore this crosscut to the end, because it contained considerable water. Apparently, however, it does not intersect a vein.

The Great Northern vein is characterized by a lower angle of dip than the other veins show. The maximum dip observed was 50° , on the third level. Cross section No. 5 shows that the average dip below the first level is about 45° . Above this level it flattens rapidly, showing an inclination of only 25° in the uppermost stope. In strike it is roughly parallel to the Wellington. Work on the Great Northern has not proceeded far enough to indicate its extent. Practically all its development has come since February, 1915. At the time of the writer's visit, trouble was being experienced in following the vein both to the east and to the west. Probably this was due to pinching and faulting, and not to actual disappearance of the ore.

Faulting.

The faults of the Wellington mine strike in many directions, and it is hardly practicable to group all of them into distinct systems. Apparently, however, there are two groups which include most of the important movements. Those belonging to one system have a general east-west trend, roughly parallel to the Orthodox vein, and include the Fault vein. The other system is nearly at right angles to the first, and is the younger, since movements belonging to it have offset the planes of the first group in a number of places, whereas, so far as the writer observed, the north-south fault planes are never offset to the east or west. Some minor faults are apparently independent of both systems.

The most interesting and most easily studied of the faults is that following the so-called Fault vein. For a distance of nearly 400 feet a drift follows the plane of movement, exposing the slickensided hanging wall to excellent advantage. In many places the surface is deeply grooved with striations, which pitch to the east at various angles, indicating movement in more than one direction. The most prominent striations pitch eastward about 35° , and apparently feather out upward, indicating that the south wall moved down. Since the plane dips to the south, the faulting was evidently normal. Other grooves cross the set mentioned, making angles with the horizontal ranging from 12° to 47° .

It is not practicable, of course, to say which represent the main movement; but in any case the movement had a large horizontal component, and the hanging wall moved east. This agrees with the other evidence given to show that the Iron vein is merely the offset northeast continuation of the Wellington. The total slip necessary to give the Iron vein its present position - about 50 feet west of the Wellington - depends of course on the pitch of the movement. Since each set of striations represents part of the displacement, we may take the average pitch, about 25° , in making the computation. Then taking 60° as the average dip of the Wellington and Iron veins and 65° as the dip of the fault plane, the net slip is found to be 55 to 60 feet. The throw corresponding to such a slip would be about 25 feet. If the steeper striations represent the direction of principal movement, the slip and throw must be considerably greater than the figures given above.

About 35 feet north of the Fault vein, in a short branch of the Iron drift, a plane of movement occurs striking parallel to the great fault. This, together with the shattered condition of the intervening porphyry, indicates that movement occurred in a shear zone rather than along one surface.

In discussing the veins, mention was made of the fact that the fault just described is mineralized. Sulphides are found as stringers, sometimes a foot in width. Without doubt this mineralization took place simultaneously

with the filling of the other veins, and there must have been a fissure previous to the time of greatest movement, since the fault cuts the ore of the Wellington vein. Moreover, in many places the ore in the Fault vein itself is slickensided, indicating slipping after deposition.

A fault so important on the first level should show some effects in other parts of the mine. Ransome reports that it appears in part of the old Wellington workings reached by the Iron raise, and also on the second level, where the exact course is obscured by lagging in the broken ground. Neither of these places could be visited in the summer of 1915 because of caved drifts. An attempt has been made to calculate where the fault plane cuts drifts on the lower levels, assuming that the strike and dip of the plane remain constant. The hypothetical intersections are shown in Plate 13, where some interesting relations are brought out. On the second level the fault should cut the Wellington vein near the bend in the drift 175 feet east of the shaft. The turn to the south indicates that trouble actually was encountered at this point; and, according to the company's maps, the East vein was found to the southeast in its normal position. Evidently no attempt was made to follow the fault toward the west on this level, although the offset portion of the Wellington vein - that is, the Iron vein - should lie in that direction. It may be that the poor showing of this vein on the first level discouraged the idea of searching for it at greater depths.

KNOWN AND HYPOTHETICAL INTERSECTIONS OF THE FAULT VEIN AND OF THE J FAULT
(Purple lines represent the Fault vein; yellow, the J fault)



0 50' 100' 200' 300'
Scale

The eastern extension of the third level drift is also blocked a short distance east of the shaft. According to computation, the fault should cut at the point where the drift divides into several branches, and this division again indicates that the vein really disappears there. The branches running to the north should intersect the Iron vein, but apparently if it was found it did not encourage further work. If the writer's idea of the East vein as an extension of the Fault vein is correct, the crosscutting to the south on this level in an effort to locate the East vein extends in the wrong direction. A long crosscut to the north from the Orthodox workings should reach near the position of the East vein. Apparently it should have been continued farther, to make allowance for a possible variation in the dip or strike of the vein.

An examination of the long branch drift northeast of the shaft shows several good slickensided surfaces, with average strike N 85° E and average dip 65° south. Several sets of striations on the hanging wall pitch toward the east and feather out upward, indicating normal faulting. The amount of movement is not evident, since no vein is affected and the rock in both walls is diorite. This plane occupies the proper position of the Fault vein as calculated. Stringers of ore occur along its course, as on the first level.

On the fourth level there is a small sulphide vein in the northwest crosscut near the point of calculated intersection by the fault. Some evidence of slipping was seen on the walls of the vein, and small offsets have been caused by cross movements. This may actually represent the great fault. If this is true, then the dip continues downward with remarkable consistency.

On the fifth level, the drift is caved near the point where the fault presumably cuts it. No evidence of the plane was found on this level.

West of the X-10-U-8 tunnel on the first level several north-south faults intersect the Fault vein, but in no case has the offset been more than a few feet. A stringer of sulphides in the Fault vein makes it possible to work out the general structure, though there are many minor complications which are not shown in Plate II.

Many faults of the north-south group are evidently local, and the relations of others are obscure because of difficulty in securing data concerning them. A number of flat planes showing little movement intersect the Great Northern vein. One cutting near the west face of the second level drift is correlated with the fault which offsets the Orthodox just to the north, because the general courses and directions of offset are practically the same in both cases. The actual courses and dips of the fault planes cutting the Orthodox vein on the first level are made uncertain by lagging on the walls of the drift. No doubt some

continue across to the East vein, where broken ground has also necessitated extensive lagging. There is reason to believe that the easternmost of the faults affecting the Orthodox on this level is continuous with that on the second level mentioned above and also with that one which marks the western limit of the Orthodox on the third level. In 1915 no attempt had been made to locate the continuation of the vein west of this plane on the third level; but if the interpretation given is correct it should lie a short distance to the south - probably less than 40 feet.

The fault which was causing the greatest trouble in development last summer intersects the Wellington vein at the shaft on the fourth level. Observations taken on the surface exposed here show a strike N 15° W and a dip 60° S 75° W. No other satisfactory data could be obtained. Assuming that these figures are correct and that the plane continues consistently, this fault - called the J Fault - should cut on the other levels as represented on Plate 13. Some indication that the computations are approximately correct is found on the third level, where, about 100 feet southeast of the shaft, the crosscut is intersected by a fault corresponding in strike and dip to the J Fault. Reference to Plate 13 shows that this agrees closely with the hypothetical intersection of this crosscut. As in the case of the Fault vein, direct observations could not be made in the place where the J Fault should affect the Wellington vein on the third level.

On the fifth level, the fault should cut in the disturbed region southwest of the shaft. It is unfortunate that better observations were not possible in this vicinity. The walls were concealed by lagging where the fault should cross the main tunnel. Moreover, both branches to the south which contain ore were caved, and hence an examination of conditions where the vein is affected was prevented. If the fault plane actually cuts as shown in Plate 13, the hanging wall moved north and the offset was slight. In this case the eastern extension of the vein on the fourth level should be found a short distance southeast of the shaft. When the mine was visited a crosscut in this direction was just being started, and the writer has not learned the result.

It is interesting to note that the J Fault, if it reaches the second level, should intersect the Wellington and Fault veins in the same place. If it cuts the Orthodox vein on the two upper levels, the offset has been slight; but if the greater component of displacement was vertical, the net slip might be considerable without materially offsetting the Orthodox, which is almost perpendicular on these two levels.

No other important faults were recognized in the mine. Movement shown in the southeast crosscut on the third level apparently represents block faults local in extent. It was mentioned in the discussion on veins that all

the main fissures have been planes of more or less movement. Slickensides observed on their walls probably were formed, in most cases, later than the vein filling, since fresh polished surfaces could hardly be left by the ore solutions. In fact, the ores themselves are frequently slickensided, and thus we have direct evidence that the fault surfaces are later than the vein materials.

MINERALOGY OF THE MINE.

The vein filling of the Wellington mine consists of sulphide minerals mixed with more or less carbonate gangue. The ores are massive, and contain many vugs which are usually lined with crystals. There is considerable variation in the proportions of ore and gangue, but as a rule the sulphides greatly predominate. Occasionally, the gangue equals or exceeds the ore in quantity. Where the veins are several feet in thickness masses of country rock are frequently included in the vein materials. In places several inches of gouge separate the ores from the wall rock; but usually altered porphyry is found directly in contact with the vein minerals.

Ore Minerals.

The ore minerals are pyrite, sphalerite, and galena, mixed in varying proportions. In the old superficial workings smithsonite and cerussite were also of importance; but these minerals are not found at the depth of present operations. Pyrite is seldom absent, but sphalerite occurs with little or no galena, and in some pockets the lead sulphide is practically free from the zinc. However, the sphalerite is almost as universal as the pyrite.

Galena was originally the only valuable sulphide obtained. Early work was on the present Wellington vein or its branches; and this vein contains the greater part of the galena found in the mine. It is nearly always intergrown with sphalerite, and in the present development of the Wellington vein the zinc sulphide greatly predominates. In certain places, as near the shaft on the fifth level, lead sulphide is almost absent, sphalerite being the principal ore mineral.

The galena usually occurs coarse and massive, showing typical cubical cleavage. In large vugs, handsome crystals are found, some of them two inches across the face. Sometimes the crystals are simple cubes, but more often they are modified with octahedral faces. Especially fine masses were found just east of the shaft on the second level and about 100 feet west of the shaft on the third level. Men working in the mine stated that in the place first mentioned the vein contained about three feet of practically pure galena.

Sphalerite occurs almost entirely as massive "black jack," and seldom as the rosin-colored mineral so common in the Missouri zinc region. Crystal faces are not common, occurring only in open vugs, and then usually so small as to require a lens for study. Vugs lined with these almost microscopic sphalerite crystals give a brilliant reflection in the light. Where they can be identified, the faces belong to the usual dodecahedrons and combinations of the tetrahedron and the cube.

In the Great Northern vein, sphalerite is practically the only sulphide except pyrite. Because of the high zinc content, most of the work in the mine is concentrated on this vein while the price of spelter is high. Without doubt the predominance of sphalerite is also responsible for the late development of the Great Northern vein. As noted above, the Brown tunnel penetrates to the vein, but very little ore was taken out until the present company acquired the property. In fact, practically all development of the vein dates from February of 1915. When the Brown tunnel was constructed lead was desired rather than zinc.

The dark color of the sphalerite is due to the presence of iron, as in the case of other western camps. The small amount of rosin-colored ore found apparently belongs to a later generation than the "black jack." A little "rosin ore" was secured in the stope of the Spur vein, where it filled a fissure in the massive "black jack."

Pyrite occurs abundantly in the veins as well as in the altered country rock. In places it is the most abundant material in the veins. More often it is intergrown with the other sulphides, sometimes in massive form, with no crystal faces, sometimes in fairly well-developed crystals. The best faces of course occur in vugs. The common form is the cube, with prominent striations, but imperfect pyritohedrons also are found.

Much of the pyrite is decidedly cupriferous. In many parts of the mine it has a deep yellow color, much like the color of chalcopyrite. This is especially noticeable in thin seams of pyrite found near the west end of the Fault vein. On the roofs of old drifts, where the vein has been long exposed to oxidizing influences, the ore often shows colors similar to bornite. Without doubt this is due to copper in the pyrite.

The greater part of the pyrite is regarded as waste, though some is included in the "middlings" and sold for acid manufacturing.

Gangue Minerals.

The only important gangue is a carbonate which approaches ankerite in composition. A rough analysis shows calcium, iron, and manganese, and Ransome reports that it contains another base - magnesium. The average analysis given shows 63.9% FeCO_3 , 29.6% MgCO_3 , 5.2% MnCO_3 , and 1.3% CaCO_3 . Probably it cannot properly be called by any definite mineral name, but is an isomorphous mixture of the four carbonates. Since iron is the predominant base, it may be referred to as siderite, for convenience.

This gangue is rarely found intergrown with the sulphides, but practically always fills seams and vugs in the ore. In places, the seams are narrow and irregular, cutting the vein materials at various angles. Again, they are of considerable size, and conform closely to the general

course of the vein, giving the ore a roughly banded appearance. If this occurrence were universal, the carbonate might be considered as deposited alternately with the sulphides, the bands representing a number of openings of the vein for solutions. However, the seams and gangue cut across the sulphides and contain fragments of ore in so many places that the carbonate is evidently later than the other materials.

In the main the siderite is in massive form, showing lustrous cleavage surfaces on a fracture. The color varies from pink to almost white; but most specimens show at least a suggestion of the pink, probably because of the manganese present. In vugs the siderite has botryoidal structure, and sometimes forms fantastic figures which, on magnification, are seen to be covered with points, probably the corners of minute rhombs.

In a number of places the Great Northern vein is traversed by irregular seams which are apparently of recent date. These seams are always narrow - less than an inch in width, so far as observed - and are filled with crushed sulphides, partially cemented with carbonate. The brown color of the material is no doubt due chiefly to powdered sphalerite. The seams intersect the vein in all directions, cutting both ore and gangue minerals. No doubt the vein was slightly fractured by rather recent movements and the crushed ore in the breaks has been partially cemented by material from solutions which found their way along the cracks.

Other gangues are unimportant. Ransome mentions the presence of barite; but, as far as the writer could determine, it is very rare, occurring in small, isolated pockets, and never forming continuous bands. Quartz is also rare. The only occurrence, so far as could be determined, is in the Wellington drift, some 400 feet west of the shaft, where a small amount of massive vein quartz was seen near the footwall in contact with the sulphide ore.

Tenor of the Ore.

The values in the metals vary greatly in different veins and from place to place in the same vein. The Wellington vein has always produced considerable lead, but on the lower levels zinc predominates. Assays of several years ago, made for the ore in the upper levels of this vein, gave 40 to 45% lead, with subordinate zinc, 10 ounces per ton of silver, and .02 ounce per ton of gold. With depth the percentage of lead decreases markedly, and the silver and gold become negligible. Recent assays show for the crude ore 16% zinc and 5% lead. The Great Northern vein is essentially a zinc vein, the crude ore averaging 19% zinc and 1% lead. The percentage of iron is high for much of the vein. Since silver and gold occur with the galena, these metals are practically absent from the Great Northern ore.

The other veins have not been worked recently, and no exact assays for them were obtained. In the Spur, Iron, and East veins, the character of the ore is similar to that in the Wellington. The Orthodox, like the Great Northern, furnishes chiefly zinc, although locally, in the upper levels, it contains some lead.

Oxidation and Secondary Enrichment.

The old Wellington workings were unfortunately in such bad condition that no study of the oxidized zone could be made. Indications of the existence of such a zone were seen near the surface in some superficial workings on the slope of Prospect Hill, where several pieces of cerussite were secured. Records show that in the early history of the mine the carbonate of lead was an important ore mineral. A miner who had worked in the old upper stopes informed the writer that the boundary between the oxidized and the sulphide ores was quite well defined. Ransome reports that the change to essentially sulphide ores takes place at a depth of about 200 feet below the surface. There is no suggestion of oxidation in any of the present workings, except some slight effects on the walls of drifts and stopes due to exposure since the ores were removed. The vertical extent of the oxidized zone is limited, not only because the ground water level is rather high, but also because the rate of erosion is rapid. There is no appreciable gossan at the outcrop of the vein, no doubt because it is removed practically as fast as formed.

Ransome gives the following downward sequence in the oxidized zone as he determined it in 1909:

1. A soft, heavy, yellowish, clay-like ore consisting largely of earthy cerussite, and containing residual nodules of galena.
2. Lead-silver ore, with galena only partly oxidized, pyrite largely altered to limonite, sphalerite to smithsonite.* Much zinc evidently removed in solution.
3. Lead-silver-zinc ore in which galena predominates, with sphalerite altering to smithsonite.

This is a normal sequence, indicating the following history: The pyrite and sphalerite alter first, the former changing to limonite, in the main, and the sphalerite to smithsonite and limonite. Galena is more resistant, but finally alters partly to cerussite, some of the sulphide remaining for a time as unaltered nodules. Smithsonite is more soluble than cerussite, and hence is removed, leaving the upper part of the zone practically free from zinc. The lead carbonate is also carried down finally, though much more slowly than the zinc carbonate. As usual, the small silver content of the galena is concentrated in the oxidized zone.

*Ransome states that the dark sphalerite contains from 10% to 15% iron.

Nothing is said in this explanation of the formation of sulphates. Ransome reports no occurrence of anglesite or other sulphates, and the writer has been unable to find any record of any secondary lead mineral except cerussite in the oxidized ores. It seems, however, that with the exodation of the pyrite contained in the Wellington veins, there should be good opportunity for the union of the metals with the sulphate radical. The presence of this radical in the descending solutions is well shown by the deposition of hydrous copper sulphate in some of the old drifts. A considerable mass of this mineral, associated with slender crystals of selenite, was found in the Iron drift. Probably a search of the old workings in the oxidized ores would result in the discovery of still other sulphates. At any rate it is probable that the metals are carried down partly in sulphate solutions.

With these solutions of the metals moving downward, we naturally look for a zone of secondary enrichment at lower levels. The existence of this zone in the Wellington mine is indicated by the following evidence:

1. The Wellington vein is rich in galena in the upper levels, but the lead content rapidly decreases downward. This condition is precisely what one expects in the enriched zone of a lead-zinc vein. The lead lags behind the zinc in the downward journey through the oxidized zone.

Re-precipitation takes place in reverse order, the lead readily combining with the sulphide radical near the ground water level, and the zinc penetrating to greater depths.

2. Vugs in the massive ore above the fourth level are commonly lined with crystals of pyrite and galena. In many cases, these crystals may be original: but where they occur so abundantly in the massive sphalerite, with few crystals of zinc sulphide developed, there is strong indication of deposition from later solutions, such as would occur with secondary enrichment.

3. In the upper levels of the Wellington vein, there are bands of galena of various widths. Sometimes the bands are near one wall or the other, but more often they are near the middle of the vein. Apparently they represent the filling of openings formed in the vein subsequent to the original deposition of ore. The fact that these occurrences are not found in the lower part of the mine suggests deposition by descending solutions.

It is true that there is nothing in this evidence which is necessarily inconsistent with the idea of original deposition of the galena in the upper zone. The high lead content in the upper part of the Wellington vein might be explained by the view, now gaining favor, that lead travels farther from the parent magma than does the associated zinc. Conditions in the Great Northern vein, however, do not support such an hypothesis. As shown in cross sections, this

vein flattens out above the first level. At the same time, it pinches rapidly, apparently terminating beneath the present surface. Under the hypothesis mentioned above, we might expect this vein to be even richer in lead than the Wellington; but, as previously noted, the Great Northern ores carry on the average only one per cent of lead. To be sure this may be explained by assuming that the solutions entering the two veins contained markedly different proportions of lead; but it seems even more plausible to suppose that the Great Northern lacks an enriched zone because the ores have never been exposed by erosion. On the whole, the evidence favors a secondary rather than a primary origin for the rich galena deposits in the mine.

It would be hard to fix definitely the lower limit of the secondary galena, but there is little evidence of it below the fourth level - that is, approximately 600 feet below the oxidized zone. Probably much of the sphalerite in the upper levels is also secondary, the enriched zones of lead and zinc overlapping considerably.

Rock Alteration.

Near the veins, the country rock usually shows marked alteration. The extent of the altered zone varies with the size of the vein and with the kind of rock. In places, the porphyries are noticeably changed to a distance of 20 feet from the vein wall.

Megascopically, diorite shows the most marked alteration. Near the veins it loses its dark color, and often becomes practically white. In contact with the ore the rock is often quite soft, even where no gouge is developed. Crystals of pyrite are disseminated through the altered rock, sometimes several feet from the wall. Near the vein, all of the sulphides replace the porphyry. This is especially apparent in the case of horses included in the vein; but without doubt considerable replacement has taken place in the walls of all the larger ore bodies. Probably the pyrite developed at a distance from the veins does not represent actual replacement, but merely an alteration of original magnetite by hydrogen sulphide penetrating the wall rock. Magnetite is abundant in the fresh diorite.

The diorite wall rock is replaced by carbonate even more than by the sulphides. Practically any specimen of the altered rock taken near a vein will effervesce with acid. Evidently the ore solutions were heavily charged with carbon dioxide.

An excellent opportunity to study the effects of the solutions on the country rock was found last summer on the third level, at the east end of the Great Northern drift. There the sulphide vein was small - about six inches in width - and the gradation from the ore to fresh diorite could be seen on the face of the drift in a space

of two feet. In contact with the ore the rock was soft, and partly replaced by carbonate and sulphides. Outward the alteration gradually became less marked, the rock increasing in hardness, the pyrite decreasing in amount and the color becoming darker, until the normal diorite appeared. Slides of the altered rock show that the original texture has been almost completely lost, and that the primary constituents have given place to sericite, pyrite, quartz, and kaolin. Rhombs of carbonate also appear in the sections.

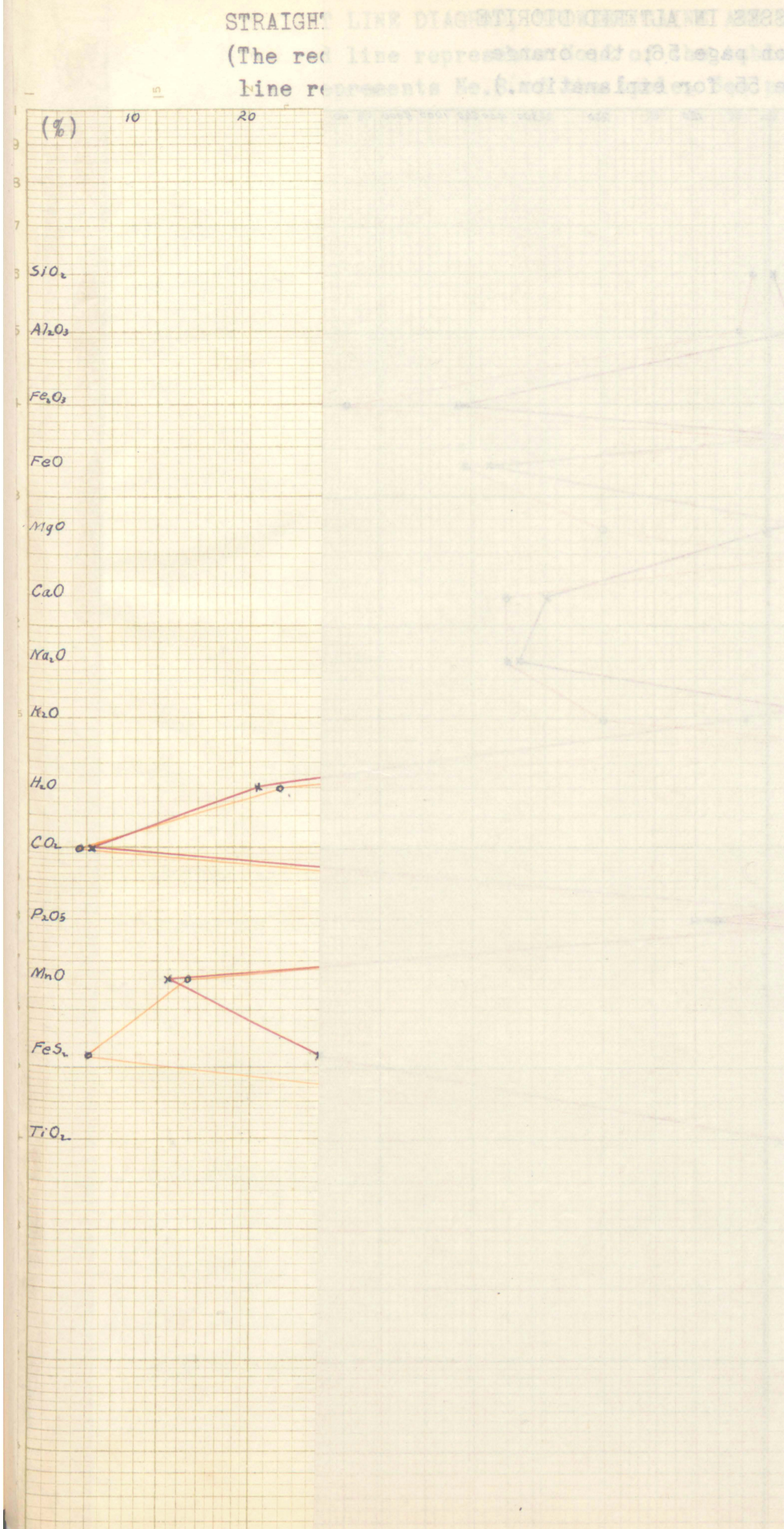
Ransome has described the alteration at different distances from a large vein, and has given chemical analyses of the specimens. These analyses are copied on page 56 and are interpreted graphically in the straight-line diagram which follows. In this diagram, the vertical line marked "100" represents the original rock. Positions of points representing constituents in the altered specimens were found by dividing the percentage of that constituent in the unaltered rock by the percentage in the altered specimen, and multiplying the result by 100. Points falling to the right of the 100 line represent losses, while those on the left represent gains. It should be borne in mind that the distances of the points from the vertical line indicate changes in terms of the constituents themselves, and not in terms of the entire rock mass. Changes in substances present in small amounts show just as conspicuously as changes in the more important constituents.

TABLE SHOWING ALTERATION OF DIORITE PORPHYRY

| No. | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | FeO | MgO | CaO | Na ₂ O | K ₂ O | H ₂ O | CO ₂ | P ₂ O ₅ | MnO | FeS ₂ | TiO ₂ |
|-----|------------------|--------------------------------|--------------------------------|-------|------|------|-------------------|------------------|------------------|-----------------|-------------------------------|------|------------------|------------------|
| 1. | 57.35 | 16.29 | 3.15 | 4.36 | 2.41 | 5.66 | 4.50 | 3.39 | .85 | .46 | .70 | .12 | .09 | 1.07 |
| 2. | 49.59 | 14.91 | .52 | 10.46 | 2.02 | 1.96 | 1.33 | 3.51 | 3.33 | 9.4 | .47 | 1.10 | .36 | 1.03 |
| 3. | 46.62 | 12.66 | | 11.2 | 4.02 | 1.55 | 1.35 | 1.68 | 3.7 | 11.5 | .5 | .92 | 1.09 | 1.01 |

1. Fresh diorite porphyry, 25 feet from Wellington vein.
2. Altered diorite porphyry, 10 feet from Wellington vein.
3. Altered diorite porphyry, less than 6 inches from Wellington vein.

See supplemental file for unfolded version.



The quartz porphyry is also radically changed by the ore solutions. The feldspar phenocrysts are often altered to a soft, white, clay-like material even where the groundmass is unaffected. In contact with the veins, the entire rock is reduced to a soft, light-colored mass, in which the quartz crystals are unaltered.

With the idea of observing the gradation in alteration from the vein outward, a series of specimens of quartz porphyry was taken from the hanging wall of the Great Northern vein on the third level. These samples were secured at two, four, eight, and twelve feet from the vein. Megascopically, the specimens show a decrease in alteration from the vein outward; but under the microscope little difference can be seen. All show intense sericitization. Masses of sericite occur in the groundmass, and the feldspar phenocrysts are replaced with sericite and kaolin, though the outlines of the crystals still remain. The quartz crystals are of course unaltered, as are crystals of apatite and spinel. Small cubes of pyrite are abundant in some of the sections.

The Cretaceous shale is less subject to change than the porphyries. Near the vein some of the rock may be softened. In most cases, however, there is little apparent change except the development of small grains of pyrite. The calcareous phase shows some replacement by the other sulphides also.

GENESIS OF THE ORE BODIES.

In attempting to account for the ores in the Wellington mine, the following questions have been considered:

How and when did the fissures originate?

Were the ore-bearing solutions meteoric or magmatic?

Were the metals extracted from nearby rocks, or brought in from a distance?

Has the wall rock had appreciable influence in determining the nature of the veins?

In a region so disturbed and broken as that around Breckenridge, the general cause of the fissuring is not difficult to find, though the immediate cause may be more obscure. Ransome, following Spurr and Garrey, suggests that the principal fissures are due to the east-west stresses responsible for the Rocky Mountain uplift in post-Laramie time. This may be true, provided the orogenic movements continued well into the Tertiary. This provision is essential, since the fissuring affects the intrusive porphyries, which are conceded to be Tertiary in age. Certainly there has been considerable diastrophic movement in the region since that time, but it will be difficult indeed to fix the age of the Wellington fissures any more definitely than to call them Tertiary or later. Probably the main fissuring took place soon after the monzonite porphyry was intruded. The quartz porphyry evidently found breaks in the earlier intrusive, which

it crosses as dikes. It will be recalled that one of these dikes lies just north of the Wellington vein, which it roughly parallels. It seems probable, therefore, that the vein fissures were initiated at the same time as the dike fissures. Certainly still later movements have occurred, probably in connection with recurrent slipping along the Mosquito and other great fault planes.

The vein filling took place subsequent to the latest igneous intrusion, since the ores intersect the dikes of quartz porphyry. The exact time of mineralization is of course largely a matter of speculation. In almost every report on Tertiary ore deposits in the Cordilleras, the opinion has been expressed that mineralization was intimately connected with and closely followed the porphyry intrusions.* This appears probable, but the evidence does not seem conclusive. So far as may be determined definitely, the ores may have been deposited at a considerably later time.

In considering the origin of the ores, probably the most interesting subjects for speculation concern the sources of materials and the method of their deposition. Here we are confronted with a question which has caused much debate: Did the solutions come from above or below? In

*Emmons, Ten Mile Folio, p. 6.

Spurr and Garrey, P. P. U. S. G. S., No. 63, pp. 129-135.

Ransome, P. P. U. S. G. S. No. 75, p. 171.

his work on the Leadville deposits Emmons expressed the view that meteoric and not magmatic waters were responsible for their concentration. Since that time, many geologists have expressed a different opinion. The Aspen, Rico, Georgetown, and other Colorado deposits have been interpreted as of magmatic origin.

In the case of the Wellington ore bodies the problem has been looked at from the following viewpoints:

1. The association of the ore bodies.
2. The nature of the deposits.
3. The character of the wall rock alteration.

Surely it is of some significance that the ore deposits occur in the Rocky Mountain region, associated with intrusive rocks, and that they probably were formed during or shortly following a period of igneous activity. Moreover, at the time the veins were filled, no doubt the fissures were at considerable depth below the surface. Judging from the present relationships of intrusives and sediments, erosion has removed several thousand feet of material since Tertiary time. We cannot tell, of course, the vertical extent of the fissures; but in view of their limited lateral range, it is improbable that they reached very near the original surface. Under these conditions, rising solutions afford a far more probable explanation for the ores than descending waters.

Moreover, the nature of the deposits themselves point to a magmatic rather than a meteoric origin. The mineralogy of the veins is very simple, the minerals consisting essentially of three sulphides and one carbonate. Waters descending through several kinds of igneous and sedimentary rock thousands of feet in thickness should collect materials for the formation of a number of common gangue minerals, at least in small amounts. A complex mineralogy might also come from a magmatic origin, to be sure; but the simplicity found in the Wellington veins is characteristic of the well known tendency for magmatic products to segregate. The fact that the veins are so close together and yet show such marked differences in proportions of certain sulphides as exist between the Wellington and Great Northern veins also points to a deep seated source. Meteoric waters should have deposited essentially the same materials in all the veins, since the nature of the rock through which they traveled must have been practically the same in all cases.

Probably the most convincing evidence of a magmatic origin for the ores is found in the character of the alteration of the wall rock. Both diorite and quartz porphyry, especially the latter, show intense sericitization near the veins. This change is conceded to be a hydrothermal effect, requiring temperatures above 100° C. Meteoric waters should normally form kaolin rather than sericite. To be sure,

kaolin is an abundant alteration product; but it is evidently later than the sericite, and no doubt has resulted from the effects of surface water which has found its way along the veins since erosion exposed them.

To argue that the waters which brought in the ore materials were originally meteoric, but became heated by circulating near hot rocks, is to take a decidedly weak position. The simple facts are these: Magmas give off hot aqueous solutions. So far as can be determined, all conditions favored the entrance of such solutions into the Wellington fissures. The wall rock shows hydrothermal effects. The only logical conclusion is that the ores were deposited from magmatic solutions.

But assuming that the solutions were ascending, what was the source of the metals? Did they also come from a deep seated magma, or were they leached from the solid rocks? Ransome thinks the latter view is tenable. He argues thus:* The solutions probably did not come into the present fissures directly. Rather, we should picture these openings as semi-isolated spaces, connected with others by a network of small branches, through which the solutions must work their way slowly, reaching their final destination by a devious route. It is hardly conceivable, he says, that heated waters charged with gases could traverse small crevices in the rock for long distances without

*Professional Paper 75, pp. 172, 173.

dissolving considerable material on the way. Then, since most rocks contain small amounts of the metals, it is quite possible that at least a part of the lead, zinc, and iron now found in the Wellington veins were picked up by the waters in transit.

Against this theory, the following objections may be urged: Since metals exist in solid igneous rocks, they are also present in magmas; and juvenile waters should have a better chance to receive them in solution in the parent magma than in the solid rocks traversed later. Moreover the waters in ascending from the magma by a long, devious route would constantly find conditions of diminishing temperature and pressure, lessening their solvent power and favoring deposition rather than additional solution. Finally, in giving chemical analyses of the rocks associated with the veins, Ransome makes no mention of any lead or zinc found in their composition.

It should be said, however, that Ransome does not insist on the explanation he suggests, but admits the possibility that the metals came in solution directly from the magma. However, he urges strongly the probability that the bases of the carbonate gangue were obtained from the rock through which the solutions traveled. There is evidence that this view is at least in part correct. Experiments of Henrich are cited which show that hot water charged with

carbon dioxide extracts calcium, iron, manganese, and magnesium from silicate rocks rich in these bases. Referring to the diagram indicating rock alteration in the Wellington mine, it is seen that calcium has suffered noticeable loss, while magnesium shows a decrease in one case and an increase in the other. On the other hand, there is a marked gain in both iron and manganese. Referring now to the composition of the carbonate gangue (63.9% FeCO_3 , 29.6% MgCO_3 , 5.2% MnCO_3 , 1.3% CaCO_3), we see that calcium, the only one of the bases consistently removed from the rock, is a negligible constituent, whereas the bases of great importance in the carbonate are actually added to the wall rock. Of course changes in the actual wall rock of the veins may not correspond to those which occurred at a greater depth, where ore deposition was not in progress. There all of the bases mentioned may have been taken from the rock. It seems unnecessary, however, to account for these materials in this way, since they may well have accompanied the solutions from the magma.

The exact influence of the wall rock on the nature and quantity of sulphide ore deposited is a matter difficult to determine; but certain observations made in the mine are at least quite suggestive in this connection. Obviously, the following properties of the rock might have an influence on the ore deposited in contact with it:

1. The behavior of the rock in fracturing.
2. Its susceptibility to metasomatic replacement.
3. The effect of its mineral and chemical composition on the ore solutions.

With respect to the first point, it is clear that the rock breaking with the cleanest and most regular fracture should be most favorable toward ore deposition. Of the three kinds of rock in which the Wellington ores are found, the diorite best meets this requirement. It is rigid and brittle, thus favoring the opening of large, simple spaces. Quartz porphyry, on the other hand, apparently has a tendency to shatter under stress, forming complex fissures, although the amount of this rock in the mine is hardly sufficient to form a judgment of its behavior in general. The Cretaceous shale, while it is softer and less rigid than the porphyries, forms better fissures than might be expected of a shale. Most of that encountered in the mine is hard and brittle, and lies in thick beds. In the large mass on the fifth level the Wellington vein, while it is not wide, continues rather consistently between firm walls; but while the ore is not cut off by the crushing of the shale, abundant broken rock is mixed in the vein materials.

It appears that the ore bodies lying in the shale are never large, and that they do not contain high grade ores. On the fifth level the Wellington vein swells to good width in the diorite, and there the ores are evidently

of fair tenor; but farther west, between shale walls, the vein is never more than two feet wide, and contains an unusual proportion of pyrite. Also on the second level, at the western face of the Great Northern drift in 1915, the ore found in shale was almost pure pyrite. These facts may be accidental, but apparently they have some significance. Probably both the poorer fracturing of the shale and its resistance to metasomatic replacement furnish at least part of the explanation. Shale from the vein walls and even from inclusions in the ore is never materially affected by the solutions. Thin sections show only small particles of pyrite in the rock, and these may be in large part original rather than due to later changes. The porphyries, on the other hand, lend themselves quite readily to replacement. These facts serve to explain the relatively small size of the veins in the shale, but do not throw much light on the predominance of pyrite over the other sulphides. The solution of this problem may lie in some influence of the wall rock on the ore solutions; but the nature of this influence is not apparent.

Lindgren includes the Wellington veins among the deposits formed at intermediate depths (4,000 to 12,000 feet) by ascending thermal waters.* The temperature range

*Waldemar Lindgren, "Mineral Deposits," pp. 527-529.

given for such deposits (175° to 300° C) appears to fit the Wellington ores; for there are no extremely high temperature effects, such as the development of magnetite, specularite, and similar minerals, and yet the solutions were hot enough to develop sericite in large amounts.

THE FUTURE OF THE WELLINGTON MINE

It is rather hazardous, perhaps, to attempt a prediction of the conditions any mine will encounter on further development. However, the geologist is prone to draw at least tentative conclusions, even where the evidence is not all that is desired; and from what is known of the Wellington mine, it may not be amiss to venture an estimate of the quantity and nature of the ore in unexplored parts of the veins.

It is evident that development on the Wellington vein has reached near the lower limit of the zone of secondary enrichment for galena, if not entirely below it. Considerable lead sulphide occurs in the ore even on the fifth level; but there are no rich masses such as that found east of the shaft on the second level. It is extremely probable, then, that any deeper working of the vein will find a comparatively low percentage of lead - even lower than the five per cent shown by assays of the present ore. On the other hand, the zinc content may remain constant or even increase with greater depth. Normally, the enriched zone for sphalerite extends considerably below that for galena. Hence, the Wellington vein may continue for a time to be a good zinc producer, provided there is not a rapid pinching of the vein below the fifth level.

The extent and nature of the fissure are of course difficult to predict. According to Ransome, the lateral and vertical dimensions of the normal fissure are subequal. If this is correct, and if we take the present development along the strike as representing approximately the total length of the fissure, the original dimension along the dip should have been about 2,000 feet. But even if we were certain of this figure, there is no way of knowing how much of the vein has been removed by erosion. Judging from the extent and the degree of secondary enrichment, however, we may say with some confidence that the vein has been truncated to the extent of several hundred feet; for the excess of galena in the upper levels over that found in the depths of the mine surely indicates the oxidation and concentration of a large amount of ore. Since the fifth level is at least 700 feet below the oxidized zone, only a small part of the 2,000 feet can remain at greater depth. Of course, there are many uncertain factors in this estimate. The lateral extent of the fissure may greatly exceed 2,000 feet, though the entire length may not be mineralized. Moreover, the vertical dimension may be considerably greater than the lateral.

Next in importance to the question of the extent of the vein is the problem of its nature below present levels. Apparently, the kind of country rock should be a controlling factor. We have seen that the diorite seems to be a more favorable location for the veins than is the shale. If the interpretation of the structure as shown in Plate 7 is correct,

the extent of the shale will increase with each additional level, until within 200 feet practically the entire vein will be in shale. The section shows diorite in greater thickness to the east; but the continuation of the vein to any great distance east of the shaft is not indicated on any of the present levels.

From the evidence at hand, then, it is improbable that the Wellington vein will be as productive at greater depths as it is in the present workings.

The case of the Great Northern vein is quite different. As noted above, the upper limit of this vein is apparently below the present surface. The extent along the strike is uncertain, for it had been followed only about 600 feet up to August of 1915. Judging from the good width of the vein, however, there is excellent reason for believing that it reaches at least several hundred feet lower than the present development. Apparently there is no decrease in quantity or tenor of ore on the third level.

The Orthodox vein, where last seen on the third level, showed a good body of zinc ore, which should encourage deeper development. No estimate of its nature in depth will be attempted, since satisfactory data are lacking.

In conclusion, it may be said that the prospects of the Wellington mine as a future zinc producer are favorable. The output of lead from the present veins will probably grow constantly smaller. The quantity of ore in depths is uncertain, but probably will decrease below the present fifth level.

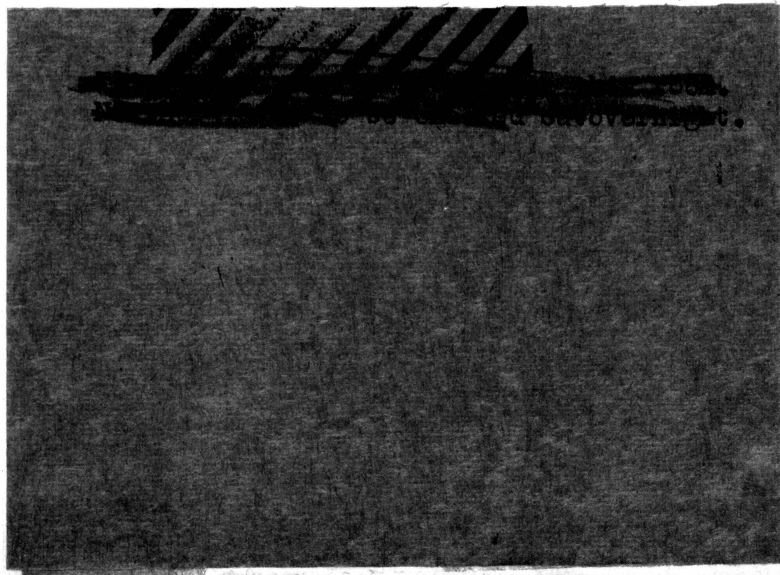
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