

Montana-Tonopah Mining Co.  
Report on the Geology of the  
Property.

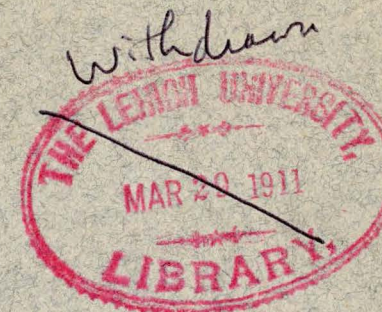


557.3  
N499m



Lehigh University  
Library

Bethlehem, Pennsylvania



---

REPORT ON THE GEOLOGY  
OF THE PROPERTY OF THE  
MONTANA-TONOPAH  
MINING COMPANY  
TONOPAH, NEVADA

---



557.3

N499m



REPORT ON THE GEOLOGY

OF THE PROPERTY OF THE

DONATED BY

MONTANA-TONOPAH

MINING COMPANY

TONOPAH, NEVADA



## General Report

### SYNOPSIS OF FINAL GENERAL RESULTS.

At Tonopah the oldest rock is a trachyte flow highly altered to quartz, sericite, and adularia. The lower part of this flow is a fine flow-banded glassy trachyte. The main body of the trachyte contains the oldest and by far the most important group of mineral veins; the glassy trachyte appears practically barren.

Stresses subsequent to the trachytic extrusion produced horizontal faulting near the zone of transition between the main body of trachyte and its glassy lower portion; and along here a glassy trachy-alaskitic intrusion, very full of inclusions, took place. Subsequent movement reopened this line of weakness, and a second trachy-alaskitic intrusion came in—the West End rhyolite sheet. At a subsequent epoch came an eruption of andesite (Midway andesite), largely as a surface flow, but largely also as an intrusive sheet along the old zone of weakness, but typically below the West End rhyolite sheet; at a still later epoch there was a series of rhyolitic and alaskitic surface flows and intrusions, of which the most important in the mine workings is a great intrusive mass called the Tonopah rhyolite.

The principal veins were formed after the trachyte eruption and before the Montana Breccia-West End Rhyolite intrusions. They are quartz veins carrying silver and gold. A second set of veins was formed after the West End Rhyolite intrusion and before the Midway andesite eruption. This second set is divided into four successive groups—**A**, large typically barren quartz veins; **B**, tungsten-bearing veins; **C**, mixed quartz and adularia veins, typically barren; **D**, small productive veins like those of the first set, following the trachyte. A third set of veins was formed after the Tonopah Rhyolite intrusion. They are quartz veins containing occasional lead, zinc and copper sulphides.

All of these veins formed at shallow depths, and the different types represent various stages of temperature. The First Period veins represent the normal shallow-seated type, and followed the trachyte eruption; the Second Period B veins represent an abnormally intense shortly-sustained temperature, following the trachy-alaskitic intrusion; the Second Period D veins a directly subsequent briefly-sustained stage of temperature more normal to shallow depths; the Third Period a relatively high but briefly-sustained temperature, following the alaskitic (Tonopah rhyolite) intrusion. No vein-formation followed the andesite eruption.

The history of faulting is long and complex; important movements have taken place at every stage of the geologic history. These movements accompanied and were due to the volcanic paroxysms; and were so intense that locally the rocks are ground almost to a powder.



## TABLE OF CONTENTS

	Page
History of Geologic Investigation at Tonopah.....	5
Conclusions in 1902.....	5
New Information Obtained in 1903.....	5
Progress of Development Work and Modifications of Geological Veins.....	7
Outline of Results of Recent Study.....	8
Rock Formations .....	10, 11
Table of Analyses.....	10
The Mizpah Trachyte.....	12
Chemical Composition.....	12
Significance of New Classification.....	13
Mineral Composition.....	14
Alteration .....	14
Thickness .....	14
Age .....	15
The Glassy Trachyte.....	15
Definition .....	15
Age and Physical Peculiarities.....	15
Silicification and Barrenness of Formation.....	16
Thickness .....	17
The Montana Breccia.....	17
Description .....	17
Relative Age .....	18
Relation to West End Rhyolite.....	18
The West End Rhyolite.....	19
Description .....	19
Relative Age .....	19
Occurrence .....	19
Thickness .....	20
Relation to Veins.....	20
Chemical Composition and Classification.....	20
The Midway Andesite.....	21
“Later Andesite” .....	21
Alteration .....	21
“Calcitic Andesite” Sheet.....	21
Correlation of “Later Andesite” and “Calcitic Andesite” .....	22
Method of Distinguishing Andesite and Trachyte Chemically....	22
The Tonopah Rhyolite.....	23
Distribution and Age.....	23
Relations of Tonopah Rhyolite and Oddie Rhyolite.....	25
Correlation of “Lower Rhyolite” with Tonopah Rhyolite..	25
Origin and Characteristics of “Lower Rhyolite”.....	26
Alteration and Relation to Vein Formation.....	28
Glassy Dikelets .....	28
Chemical Composition .....	28
Mineral Veins .....	28
Veins of First Period.....	28
Veins of Second Period.....	30
Second Period “A” Veins.....	30
Second Period “B” Veins.....	30
Second Period “C” Veins.....	31
Second Period “D” Veins.....	32
Veins of the Third Period.....	32
Conditions of Three Periods of Vein-Deposition.....	34
Faults .....	37
Rock Grinding .....	39

### HISTORY OF GEOLOGIC INVESTIGATION AT TONOPAH.

#### Conclusions in 1902.

When the writer made his first study of the mines of Tonopah, in the summer of 1902, he identified the highly altered and variable-appearing rock in which the principal veins were found as andesitic; and found that this rock was frequently covered by another andesite, later than the principal ore-deposition, and therefore barren of ore and forming a “cap-rock” to the ore-bearing veins. The formation which enclosed the veins he called the “earlier andesite” (although his recent investigation shows the rock to be really a trachyte); the younger rock the “late andesite.” Still younger than the “later andesite” he found a variety of volcanic rocks, largely extrusive surface formations including tuffs, explosive breccias, and flows, but also partly intrusive. These younger rocks were chiefly rhyolitic in composition. One of the most conspicuous of these rhyolitic rocks was a rock with a glassy ground mass, usually packed full of angular inclusions of similar glassy rhyolite, so that the whole had usually the structure of a breccia. This rock occurred chiefly as surface flows in the district south of the town of Tonopah; to the north of the town, however, it was found to outcrop abundantly in the guise of an intrusive rock, younger than the later andesite. To this rock the name Tonopah rhyolite-dacite was given; it appeared to be plainly an autoclastic volcanic breccia. The origin seemed to be due to periods of quiescence and of partial congelations in a volcanic vent, alternating with periods of upward propulsion of the viscous lava, so that the hardened glassy exterior crusts were shattered and carried along in the upwelling still fluid portion of the same lava; and these incidents repeated a number of times produced the peculiar and characteristic structure of the finally solidified rock as we find it.

Also later than the ores, and roughly contemporaneous with the Tonopah rhyolite-dacite eruptions and related intrusions (the span of the period of activity of this lava was considerable), he found a series of waterlaid tuffs formed in a lake of vast extent. Later than these tuffs, he found a number of volcanic necks, formed of distinct but closely related lavas of rhyolitic composition merging toward dacitic composition.

In sum, it appeared that the productive veins had formed after the eruption of the “earlier andesite” (which was and is still believed to be in large measure at least a surface flow) and before the advent of the numerous other volcanic and volcanic-detrital mentioned. The whole volcanic history, including the formation of the ore-deposits, was found to belong to the Tertiary, probably Miocene-Pliocene.

#### New Information Obtained in 1903.

Returning to Tonopah in the summer of 1903 for a brief examination of recent developments before the publication of his report, the writer found that a number of shafts had, after passing down through the earlier andesite, encountered, at a depth of a few hundred feet, a dense



greenish glassy rock, highly altered, an essentially aphanitic, but evidently of rhyolitic nature. This rock is characterized by numerous angular light-colored or white inclusions, apparently of altered rhyolitic glass of much the same nature as the matrix, so that the whole rock appears to be an autoclastic glassy rhyolite. The most important veins seemed to be cut off by this rhyolite, whence it was concluded that the rhyolite was an intrusive sheet, younger than the "earlier andesite" and the principal ore-deposition; and this view, after recent exhaustive investigation, is still held. Since this rock was closely similar to the outcropping intrusive Tonopah rhyolite-dacite in the vicinity, it was correlated with this formation. This correlation has now been definitely abandoned, as subsequent extensive development work has proved that this underground rhyolite is of distinctly greater age than the Tonopah rhyolite-dacite (or Tonopah rhyolite, as it may be called with more simplicity and as much accuracy) and nowhere in the surveyed and mapped district outcrops at the surface. Thus it constitutes a new formation, unexposed at the time of the original investigation. It is commonly referred to in Tonopah as the "Upper rhyolite," but will be here more conveniently designated as the "West End rhyolite."

It was observed by the writer, in the summer of 1903, that there was evidence of a second period of vein-formation, later than the West End rhyolite. The description of these later veins still holds, and will be referred to more particularly later. They are less definite and persistent than the veins of the first period, contain great quantities of low grade or barren quartz, and the pay-ore, where it does occur, is spotty and usually of low grade.

The developments observed in the summer of 1903 also showed that several shafts had passed through the sheet of West End rhyolite into andesite, having apparently the general composition of the "earlier andesite" above the sheet, and highly altered by hot-water action. No development work whatever had been done in the lower andesite body, but it was especially remarked that the alteration of this rock was entirely of the sort sometimes designated as "propylitic"—i. e., to calcite, chlorite and pyrite, so that the rock took on a characteristic dark-green color; while the "earlier andesite" above the West End rhyolite sheet was mainly altered to quartz, sericite, and adularia. Evidences of this propylitic alteration in this original "earlier andesite" mass were, however, abundant in many places, so that this lower andesite was correlated with the "earlier andesite," although it was pointed out that this "calcitic phase of the earlier andesite" was not associated with the ores.\*

At the time of this second examination in 1903 a vertical drill-hole downward from the bottom of the Mizpah shaft had encountered a rock which the writer identified as rhyolite, and correlated it with the "Tonopah rhyolite," and on this basis interpreted it as a barren formation, in which no pay-ore would be found. This correlation and interpretation have been confirmed by the writer's recent exhaustive investigation. In the Mizpah Extension shaft part of probably the same underground rhyolitic body was observed, and, as it still appears, correctly correlated. This deep-seated sheet became subsequently locally known as the "Lower rhyolite."

\* Professional Paper No. 42, U. S. G. S., p. 32.

#### Progress of Development Work and Modifications of Geological Views.

The extensive underground development of the succeeding years emphasized the distinction between the lower andesite body, or the "calcitic phase of the earlier andesite," and the upper or original "earlier andesite" mass. The first-named rock, whose designation became usually locally abbreviated to "calcitic andesite," was found to have a considerable lateral extent, with the general form of a sheet underlying the West End rhyolite sheet, and overlying the deeper Tonopah rhyolite (usually called locally the "lower rhyolite") mass, which was also found to have considerable lateral extent. The green color due to the type of alteration of the "calcitic andesite" was found to be quite uniform, and the scarcity of silicification or veins in this rock became increasingly apparent. Therefore there was an increasing tendency on the part of the local Tonopah geologists, who were watching the development, to question the correlation of the "calcitic andesite" with the "earlier andesite," and this increasing doubt was shared by the writer.

These doubts took more definite form in the mind of the writer in the summer of 1908, when he returned to Tonopah for an examination of the West End and MacNamara mines. At that time he determined the fact that the "West End rhyolite" sheet could not be correlated with the "Tonopah rhyolite" but was distinctly older. One of the strong arguments for the intrusive nature of the West End rhyolite sheet was therefore withdrawn, and a renewal of the whole argument became necessary, for if the rhyolite sheet were not intrusive, the main argument for the correlation of the underlying "calcitic andesite" with the overlying original "earlier andesite" was also withdrawn. The now more clearly exhibited (on account of new development work) uniform points of distinction between the two andesitic rocks led finally to the conclusion that the two andesitic sheets were indeed distinct and independent rock-formations.

In this new light, a very possible explanation appeared to be that the different formations were merely a series of regularly successive surface flows. This explanation was regarded by the writer with some favor, although it by no means explained the peculiar relations of the rocks to the mineral veins, as it still appeared that the most important veins in the "earlier andesite" were cut off by the West End rhyolite sheet; and that the large but relatively low grade veins of the second period, found in the West End rhyolite, did not penetrate the "calcitic andesite" and, apparently, had not been found in the Tonopah rhyolite beneath.

In December, 1909, the thesis that the different rock formations at Tonopah were a series of successive surface flows was brought out in a publication by Mr. J. A. Burgess, geologist for the Tonopah Mining Company.

As a strong point in favor of this view mention was made of the discovery, in the Mizpah mine and in the uppermost portion of the "lower rhyolite," of white dense banded rocks having the appearance of stratified tuffs, alternating with the coarser breccia such as is more common in this formation. Further specimens were found in cores obtained by deep drilling which could be easily interpreted, on account of their definitely banded character, as stratified. Microscopic examinations made by Mr. E. S. Larsen of the Carnegie Institute showed an essentially fragmental character of these rocks, and this led to their designation as well-



bedded tuffs. These considerations made the thesis that the rocks of the district were a series of successive surface formations, occurring in their normal order, with the oldest at the bottom and the youngest on top, a plausible one, which the present writer had no difficulty in believing might prove to be correct.

#### Outline of Results of Recent Study.

In the early part of 1910 arrangements were made with the writer by the principal mining companies of Tonopah for a thorough geological investigation, to supplement his original report published by the Geological Survey, and to investigate the import of data subsequently exposed by development, with its bearing upon the future method of development work in the camp. Accordingly the writer has spent a number of months in close detailed underground studies and mapping, and has already investigated in detail the mines of the Tonopah Mining Company, the Montana Tonopah, the Belmont, and the Midway, all adjacent and forming as a group a unit. The results of this arduous work have been finally to fix definitely and beyond doubt most of the geological relations. As is so often the case, it is the unexpected which has finally proved to be the true solution. The "earlier andesite" still remains the oldest of the rocks, but turns out to be a true trachyte instead of an andesite and will henceforth be called the Mizpah Trachyte. In its lower portion it passes by transition into a dense banded glassy basal phase, called in this report the Glassy Trachyte. This "glassy trachyte" was at least several hundred feet thick, but where the exact base was, or on what older formation this flow rested, is not known. The West End rhyolite has been determined to be an intrusive sheet, mainly inserted along the zone between the "Glassy trachyte," and the "Mizpah trachyte" proper, although showing considerable irregularity. The "calcitic andesite" is a distinctly intrusive sheet of considerable irregularity, younger than the West End rhyolite, and sometimes underlying this rock, directly, sometimes separated from this rock by a variable thickness of the "glassy trachyte." It appears to be of essentially the same age and composition as the "later andesite," is correlated with it, and is probably directly connected with the main later andesite mass, which appears to be essentially a surface flow. The "lower rhyolite" is shown to be younger than the "later andesite," is correlated with the "Tonopah rhyolite," as was done by the writer at the time of his original investigation, and is younger than the "calcitic andesite" sheet, which it underlies and is locally known to intrude. This "lower rhyolite" is evidently the flatly downward-pitching extension of the great mass of intrusive "Tonopah rhyolite" exposed on the surface half a mile or so to the north of the main producing mines. The thickness of this Tonopah rhyolite is unknown, as it has never been bottomed; in the Mizpah mine a vertical thickness of over 1900 feet has been demonstrated by drilling.

Thus we have the well-substantiated and extraordinary condition of a series of four successive sheet-like formations of distinct characteristics, of which the oldest lies at the surface, and the youngest at the bottom, and the whole order of superposition is the reverse of the order of age. This inversion, striking as it is, is not so regular as an elementary view of the situation indicates; the impression of great regularity arises from the limited field of development underground, which has a major horizontal axis hardly more than a mile in length, and from the fact that the geologi-

cal conditions in this developed area are so complex that the area appears to the conception much more important in size than it actually is. Development work carried outside of this limited area would doubtless show a great irregularity of relation; and, indeed, this is already exhibited on the borders of the developed area.

The veins have finally been divided into three groups according to their age, which groups correspond essentially with those originally made by the writer. The formation of the first group followed the advent of the Mizpah trachyte and preceded the advent of the West End rhyolite. This group comprises those rich veins which have made Tonopah famous. The second group followed the intrusion of the West End rhyolite, and preceded the advent of the later andesite (including in this term the "calcitic andesite"). It includes frequently large veins, usually low grade or barren, and locally profitable. The third group followed the intrusion of the "Tonopah rhyolite" and comprises rare, essentially barren veins, never profitable.



TABLE OF ANALYSIS FOR TONOPAH ROCKS.  
IN ORDER OF ASCENDING SILICA CONTENTS

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	Total	Fe <sub>2</sub> O <sub>3</sub> FeO CaO MgO
1	43.00	16.49	2.86	6.31	5.69	6.19	0.12	0.84	81.50	21.05
2	51.64	15.58	0.16	0.58	6.25	2.79	0.27	2.46	89.73	9.78
3	53.57	.....	6.67	.....	.....	.....	2.75	5.63	68.62	.....
4	53.84	18.92	2.37	3.24	6.04	3.25	1.02	1.72	90.40	14.90
5	53.94	.....	.....	.....	7.32	.....	3.89	2.09	67.24	.....
6	54.10	19.41	3.50	2.86	4.81	2.94	2.68	4.66	94.96	14.11
7	55.60	16.70	2.23	3.51	4.27	2.60	4.08	3.17	92.16	12.61
8	56.26	16.18	5.56	1.17	5.07	2.78	3.23	3.43	93.68	14.58
9	56.40	20.12	*0.09	5.87	3.55	1.99	4.87	2.56	95.45	11.50
10	56.70	17.01	2.58	1.19	5.27	2.17	2.33	3.04	90.29	11.21
11	56.72	.....	5.58	.....	.....	.....	2.72	3.94	68.96	.....
12	56.89	18.25	3.20	2.15	4.03	2.93	2.00	3.05	92.50	12.31
13	57.04	16.55	2.27	3.00	3.08	2.14	2.62	3.15	89.85	10.49
14	57.51	16.55	3.20	2.02	6.06	2.80	2.76	2.81	93.21	13.58
15	60.53	17.89	4.14	0.77	3.13	1.63	2.05	4.06	94.14	9.67
16	61.23	16.45	5.17	0.29	2.79	1.83	2.53	2.61	92.90	10.08
17	61.65	18.64	2.96	2.61	0.29	2.73	2.74	3.98	95.60	8.59
18	66.15	.....	3.17	.....	.....	.....	2.38	5.48	77.18	.....
19	66.77	18.01	1.94	1.01	0.59	1.33	2.99	5.22	97.86	4.87
20	67.18	18.50	3.86	0.58	0.40	0.79	1.82	5.38	98.51	5.63
21	68.68	.....	3.06	.....	.....	.....	0.21	5.17	77.12	.....
22	68.86	16.33	2.21	0.38	1.30	0.68	1.76	5.00	96.52	4.57
23	69.13	16.51	1.50	0.82	0.36	0.51	2.80	4.74	96.37	3.19
24	71.14	15.24	1.77	0.26	0.09	0.16	0.24	6.31	95.21	2.28
25	71.71	14.00	1.06	0.51	2.25	0.43	3.21	4.41	97.58	4.25
26	71.79	15.24	2.00	0.10	Trace	0.08	1.21	5.51	95.93	2.18
27	72.27	16.38	1.96	0.19	Trace	0.49	0.22	3.71	95.22	2.64
28	72.31	13.79	1.54	0.26	1.08	0.56	2.56	4.66	96.76	3.44
29	72.50	.....	0.89	.....	.....	.....	0.25	4.90	78.54	.....
30	72.98	14.66	1.01	0.16	0.18	0.33	0.00	6.03	95.35	1.66
31	73.00	.....	.....	.....	1.55	.....	3.50	4.71	82.76	.....
32	73.20	14.59	.....	1.92	0.47	1.24	0.12	4.32	95.86	3.63
33	73.50	14.13	1.51	0.26	0.12	0.21	0.24	5.11	95.08	2.10
34	75.17	15.83	*0.17	0.90	0.46	0.39	2.08	3.18	98.18	2.92
35	75.44	13.77	0.80	0.05	Trace	Trace	0.27	6.39	96.72	0.85
36	75.45	.....	0.78	.....	.....	.....	1.12	5.74	83.09	.....
37	75.56	.....	.....	.....	1.16	.....	4.20	4.50	85.42	.....
38	75.66	.....	.....	.....	0.47	.....	1.70	4.94	82.77	.....
39	76.25	12.84	0.54	0.33	0.16	0.56	0.12	3.20	94.00	1.57
40	76.57	.....	.....	.....	.....	.....	0.96	5.81	83.34	.....
41	77.02	13.81	0.97	0.09	Trace	0.15	0.31	5.12	97.47	1.21
42	77.30	13.79	0.87	0.14	0.10	0.05	0.22	4.22	96.69	1.16

\*% of Fe S<sub>2</sub>

No.	NAME	LOCATION	ANALYZED BY	Collection No.
1	Midway Andesite..	Montana Tonopah Shaft.....	George Steiger, U.S.G.S.....	219 U.S.G.S.
2	" "	North Star Shaft 350 ft. from Collar.....	Dr. W. F. Hillebrand, U.S.G.S.	331 "
3	" "	700 Red Plume.....	Booth Garrett & Blair, Phila., Pa.....	233 T.M.Co. 224 "
4	" "	300 Mizpah.....	" " "	"
5	Basalt.....	Siebert Mountain (not typical Basalt).....	Dr. E. T. Allen, U.S.G.S.....	168 U.S.G.S.
6	Midway Andesite..	900 Mizpah.....	Booth Garrett & Blair.....	235 T.M.Co.
7	" "	Mizpah Shaft 670 ft. from Collar.....	George Steiger.....	408 U.S.G.S.
8	" "	Halifax Shaft 275 ft. from Collar.....	Dr. W. F. Hillebrand.....	349 "
9	" "	700 Mizpah 100 ft. East of Brougher Shaft.....	Prof. G. J. Young, Univ. of Nev., Reno, Nev.....	435 Old T.M.Co.
10	" "	515 Montana N 10150 E 10260	Booth, Garrett & Blair.....	41 M
11	" "	500 Red Plume S2700 W3370.	" " "	230 T.M.Co.
12	" "	500 Mizpah.....	" " "	225 "
13	" "	765 Montana North End of North Crosscut.....	" " "	147 M
14	" "	Mizpah Extension Shaft 245 ft. from Collar.....	George Steiger.....	225 U.S.G.S.
15	" "	400 Red Plume.....	Booth, Barrett & Blair.....	223 T.M.Co.
16	" "	515 Montana N10270 E8690..	" " "	51 M
17	" "	765 Montana at Station N9912 E9588.....	" " "	118 M
18	Mizpah Trachyte..	600 Mizpah.....	" " "	229 T.M.Co.
19	" "	400 Stone Cabin.....	" " "	231 "
20	" "	615 Montana N10260 E8965..	" " "	107 M
21	" "	300 Mizpah.....	" " "	237 T.M.Co.
22	Tonopah Breccia..	1500 Mizpah.....	" " "	228 "
23	Mizpah Trachyte..	500 Mizpah.....	" " "	238 "
24	" "	Near Mizpah Hill.....	George Steiger.....	53 U.S.G.S.
25	Brougher Dacite..	Brougher Mountain.....	" " "	359 "
26	Glassy Trachyte..	1100 Belmont S2580 W865...	Booth, Garrett & Blair.....	87 B
27	" "	765 Montana N9880 E9555...	" " "	117 M
28	Tonopah Breccia..	2700 ft. North of King Tono- pah Shaft.....	George Steiger.....	661 U.S.G.S.
29	West End Rhyolite	600 Mizpah East End of Level	Booth, Garrett & Blair.....	227 T.M.Co.
30	Mizpah Trachyte..	Lease 86 Mizpah Mine 180 ft. Level.....	George Steiger.....	194 U.S.G.S.
31	Brougher Dacite..	Butler Mountain.....	Dr. E. T. Allen.....	368 "
32	West End Rhyolite	600 Mizpah D611.....	Prof. G. J. Young.....	72 Old T.M.Co.
33	Mizpah Trachyte..	Mizpah Hill.....	George Steiger.....	390 U.S.G.S.
34	Tonopah Breccia..	1200 Mizpah at Station.....	Prof. G. J. Young.....	91 Old T.M.Co.
35	Glassy Trachyte..	Belmont Mine Breast of X-Cut S from D. S. Shaft.....	Booth, Barrett & Blair.....	236 T.M.Co.
36	" "	700 Red Plume 60 ft. S from Shaft.....	" " "	232 "
37	Brougher Dacite..	Golden Mountain.....	Dr. E. T. Allen.....	388 U.S.G.S.
38	Oddie Rhyolite...	Belmont Shaft.....	" " "	376 "
39	Mizpah Trachyte..	Wall of Mizpah Vein.....	George Steiger.....	143 "
40	Oddie Rhyolite...	G. & H. Tunnel Mt. Oddie....	Dr. E. T. Allen.....	337 "
41	West End Rhyolite	600 Mizpah at Station.....	Booth, Garrett & Blair.....	234 T.M.Co.
42	" "	600 Red Plume X-Cut 603 N of D609.....	" " "	226 "



# THE MIZPAH TRACHYTE.

## Chemical Composition.

At the time of the original examination the "calcitic andesite" underlying the West End rhyolite sheet was included with the formation above this sheet as the "calcitic phase of the earlier andesite." This calcitic andesite has now been referred to the "Later andesite," together with certain other masses of andesitic rock originally not separable from the ore-bearing formation. This rejection leaves us free to consider from a new viewpoint the rocks remaining certainly in this oldest formation originally characterized as "earlier andesite." These rocks, especially when altered, are often distinguishable with difficulty or not at all from the "Later andesite" and have a typical andesitic appearance; but large masses of the formation have a greenish glassy or semi-glassy ground-mass, a light color, and a faint flow, banding strongly suggestive of a more siliceous type of rock.

As all of this rock has been altered (by the waters accompanying mineralization), and much of it intensely; and as the result of this alteration has been a progressive increase of silica and potash, with diminution of other constituents, these more siliceous appearing types have been hitherto regarded as entirely due to this alteration.

Of the various specimens of "Earlier andesite" recently analyzed (and selected for their freshness) the following four were, after attendant microscopic examination, selected as comparatively little altered rocks:

	18	19	20	23
SiO <sub>2</sub> .....	66.15	66.77	67.18	69.13
Al <sub>2</sub> O <sub>3</sub> .....	.....	18.01	18.50	16.51
Fe <sub>2</sub> O <sub>3</sub> } .....	3.17	1.94	3.86	1.50
FeO .....	.....	1.01	0.58	0.82
CaO .....	.....	0.59	0.40	0.36
MgO .....	.....	1.33	0.79	0.51
Na <sub>2</sub> O .....	2.38	2.99	1.82	2.80
K <sub>2</sub> O .....	5.48	5.22	5.38	4.74

No. 18	600	Level Mizpah Mine.
19	400	" Stone Cabin.
20	615	" Montana N 10260 E 8965.
23	500	" Mizpah Mine.

These rocks show under the microscope a glassy to microlitic ground-mass, with scattering crystals of orthoclase and striated feldspar, partly altered to quartz, sericite, and occasionally calcite; and sparse crystals of biotite, uniformly present and always bleached, with the development of pyrite, and sometimes chlorite. The ground-mass is slightly attacked by silicification, and shows nests and irregular veins of fine quartz. It seems evident, however, that the chemical composition is not much different from the original one. The chemical analyses of these rocks are quite uniform, and the three complete analyses may be averaged as follows:

SiO <sub>2</sub> .....	67.69
Al <sub>2</sub> O <sub>3</sub> .....	17.67
Fe <sub>2</sub> O <sub>3</sub> .....	2.43
FeO .....	0.80
CaO .....	0.45
MgO .....	0.88
Na <sub>2</sub> O .....	2.54
K <sub>2</sub> O .....	5.11

97.57

These analyses represent a rock with the soda-lime feldspars almost wanting, as in typical rhyolites and trachytes; and with the alkali feldspar predominantly potassic—i. e., orthoclase. The silica percentage is somewhat high in proportion to the alkalies, and is about between the rhyolites and the trachytes, suggesting that the rock is a rhyolite-trachyte. Since, however, primary free quartz is practically never detected, either in the hand specimen or under the microscope, in this rock, and as even the least altered specimens show under the microscope a little silicification, (the result of the mineralizing waters), it is probable that the excess silica in the analyses is mainly due to this secondary action; and that the rock was probably originally a typical orthoclase rock—trachyte; and with this conclusion the appearance and composition of the rock accord.

Further alteration of the rock is attended by increase of silica and by a slight increase in potash, so that the rock assumes the chemical composition of rhyolite varying much in silica content; but these more siliceous rocks show both under the microscope and to the naked eye the proof of their silicification.

The "Earlier andesite," having, then, been subdivided into an andesitic and a trachytic rock, the original term may be dropped, and the principal ore-bearing formation referred to as the "Mizpah trachyte." This leaves the "Later" andesite the sole remaining truly andesitic formation; so that this term may also be dropped, and the rock may be conveniently called the "Midway andesite."

## Significance of New Classification.

The fact of the scarcity of true trachytes, especially on this continent, makes the above determination of the original nature of the "Lode porphyry" of unusual interest; especially in connection with the relation of ore deposits to isolated volcanic outbursts of alkaline magmas in different points in Colorado, at Cripple Creek, Silver Cliff and Rosita, and at Idaho Springs,\* where there is no connection with regional lines of weakness, and where the veins are often limited in distribution and cluster around volcanic centers. Some of the analyses of rocks representing phases of this Colorado alkaline magma, indeed, bear some resemblance to the composition of the Mizpah trachyte.†

The relation of ore-deposition to the siliceous-alkaline (alaskitic) extreme phases of magma differentiation has been repeatedly pointed out by the writer. By separation of the quartz (excess silica) from an alaskitic magma, trachyte would result. The eruption of this large potash-feldspar-rock flow, followed closely by the advent of large volumes

\* J. E. Spurr, Prof. Paper No. 63, p. 25, 122, 132.

† J. E. Spurr, Prof. Paper No. 63, p. 134.



of attenuated and aqueous magma-residue high in silica and potash\* (from which the precious-metal deposits were precipitated) may well indicate some deep-seated final act of differentiation previous to the trachyte eruption, by which act the metal-bearing residues were finally magmatically concentrated.

#### Mineral Composition.

The Mizpah Trachyte shows frequently flow-structures, especially toward the base, where it has a conspicuous and characteristic grayish-green glassy ground-mass in which are contained the not very abundant feldspar phenocrysts and the relatively sparse phenocrysts of the ferromagnesian minerals. Elsewhere it often develops a better crystallization with increase in the proportion of the phenocrysts and decrease of the ground-mass. Biotite frequently becomes more conspicuous in such cases, and the appearance of the rock becomes quite different from that of the semi-glassy phases just described, and becomes difficult to distinguish from the Midway andesite. In certain localities, as in the Red Plume property of the Tonopah Mining Company, flow-breccia bands of this andesite occur in the normal solid rock. Whether this indicates that the Mizpah trachyte consists of a number of successive flows is uncertain; there is at least no definite evidence to prove this, and to disprove the possibility that the breccias may not be flow-breccia layers in a single very thick flow. It is this view that the writer inclines to, in default of definite evidence to the contrary, and after an unsuccessful effort to separate the Mizpah trachyte into distinct members.

#### Alteration.

The Mizpah Trachyte is the enclosing rock of the principal productive veins, and is usually much altered. The most conspicuous results of this alteration are quartz, and sericite, with frequent adularia, with in some places pyrite and siderite. The alteration to abundant chlorite and calcite does not seem to be an important one, as it was supposed to be at the time of the publication of the original report, for the lower sheet of andesite originally supposed to belong to the earlier andesite (the "calcitic andesite") is now shown to belong to the later andesite. Whatever sporadic alteration of the "Mizpah Trachyte" to chlorite and calcite exists, seems to be without significance as regards the ore-deposition. It is usually noted where the rock has been crushed by movements subsequent to the vein formation, which movements have opened the rock to probably the same propylitizing solutions as those which have so profoundly altered to chlorite and calcite the later andesite (Midway andesite) of the vicinity of the productive district.

#### Thickness.

The Mizpah Trachyte has a maximum thickness of about 700 feet on Mizpah hill, where it outcrops; it does not attain this thickness in any of the developed portions of the district where it is covered by "cap-rock," as the various later rocks are called. The original thickness

\* J. E. Spurr, Prof. Paper No. 42, p. 227. This was also the conclusion arrived at concerning the composition of the metal-bearing solutions from which the gold-ores of Idaho Springs were deposited; and the the solutions which deposited the Cripple Creek ores probably had a similar composition. (See Prof. Paper No. 63, U. S. G. S., p. 127, 155.)

must have been considerably greater; and the upper part has been stripped off by erosion.

#### Age.

The Mizpah Trachyte passes by transition into the "Glassy trachyte" below, showing that the glassy trachyte was a lower or possibly even basal phase of this great mass, which is thus shown to have the character of a surface flow. These two rocks, considered jointly, represent the oldest known formation of the camp. Various satisfactory and convincing intrusive contacts of the West End rhyolite into the Mizpah trachyte were found, especially on the fifth level Montana and the 800, 900 and 1000 levels of the Belmont. Striking intrusive contacts of the underlying sheet of later or Midway andesite ("calcitic andesite") into the "glassy trachyte" are found in the Midway mine, and the main mass of later (Midway) andesite normally overlies the "Mizpah trachyte" and its veins as a barren cap-rock. The Tonopah rhyolite forms a conspicuous dike in the Mizpah trachyte on the 900-foot level of the Belmont, forms dikes in the "glassy trachyte" in the Midway, and is also intrusive into the "glassy trachyte" in the Belmont; and is in a number of places found to be intrusive into the Midway ("later") andesite.

#### THE GLASSY TRACHYTE.

##### Definition.

This formation was very little developed at the time of the original investigation. Underlying the normal "earlier andesite" as it does, it does not outcrop. What few patches were originally noted were regarded as phases of the rhyolitic intrusives. The present investigation has shown without any doubt that the rock passes upward by a gradual transition into the typical "Mizpah Trachyte," by a gradual development of the crystallization. This is best observed on several levels of the Belmont mine, particularly the 800, 900 and 1000-foot levels, but is also observable in and near the Red Plume property of the Tonopah Mining Company, particularly near the shaft on the 700-foot level; and also in the Montana. In most places, however, the "glassy trachyte" is separated from the "Mizpah trachyte" proper by the intrusive West End rhyolite sheet, which has been inserted principally along the zone of transition between the two rocks.

##### Age and Physical Peculiarities.

The "glassy trachyte" was from the beginning evidently a very brittle rock, which behaved under the enormous and repeated strains which developed in the rocks on account of the complex history of intrusion, almost exactly like a block of ordinary glass. Hence, doubtless, the breaking away of the tougher "Mizpah trachyte" above from its glassy base, along a flat fault-zone which was followed by the West End rhyolite intrusive sheet. On this account, also, the "glassy trachyte" has been demolished by later intrusion. No rock shows such complex intrusive contacts as does the "glassy trachyte" where in contact with younger intrusives. In the Midway are found a number of intrusive contacts of the lower "Midway andesite" sheet ("calcitic andesite") into the glassy trachyte. In the same mine the Tonopah rhyolite ("lower rhyolite") has sent a small regular vertical dike and



a number of smaller dikelets up into the overlying "glassy trachyte." The internal structure of the "glassy trachyte" shows that it has been thoroughly searched by silicifying waters. It is intricately traversed by veinlets of chert and quartz probably belonging to all the stages of vein formation, so that its original composition is for the most part entirely obscured.

On account, again, of the hardness and brittleness of the "glassy trachyte" it forms numerous angular and characteristic inclusions in the younger intrusives, so that its relative age is open to no question of doubt. The "Montana breccia" is an intrusive glassy rock, which will presently be described as having immediately preceded the West End rhyolite intrusion, and indeed representing the initial paroxysm of intrusion of the same or a similar magma. This Montana breccia intrusion, which had to "break the trail" for the succeeding intrusions, is full of angular inclusions of the rocks which is met and demolished in its path; and most abundant among these inclusions are those of the "glassy trachyte," varying in size from fine grains to blocks several feet in diameter. This may be observed in many places, but to the best advantage, perhaps, on the 765-foot level of the Montana. Angular inclusions of the "glassy trachyte" in the West End rhyolite, although by no means abundant, are well-known, and definitely establish the relative age of these two rocks. As already stated, the lower "Midway andesite" ("calcitic andesite") sheet is intricately intrusive into the "glassy trachyte" in the Midway, and the same Midway andesite sheet, at the Montana shaft on the 765-foot level, contains large included blocks of the "glassy trachyte." The phenomena of intrusion of the "Tonopah rhyolite" into the "glassy trachyte" in the Midway and in the Belmont have already been noted. It is thus demonstrated entirely from comparative intrusive relations that the "glassy trachyte" is older than any of the other recognized rocks save the "Mizpah trachyte" beneath which it lies; and this evidence harmonizes with the observed transition between the two rocks.

#### Silicification and Barrenness of Formation.

It is a matter of observation, based upon considerable development work underground, that the "glassy trachyte" is not an ore-bearing formation—not even to the extent that the certainly later West End rhyolite is. This is a circumstance that could hardly have been logically reasoned out, and must have resulted from the physical nature of the rocks. In spite of its intense shattering and thorough silicification, unequaled by any of the other formations, definite, well-bounded veins are characteristically lacking, and no pay-ore has been found, to the writer's knowledge.

On reflection, the reason for this circumstance seems apparent. All the phenomena of the study of mineral veins, of the shallow-seated Tertiary class which we are discussing, combine to indicate that they were formed from solutions carrying relatively small proportions of the metals. Where the channels along which these solutions circulated through the rigid rocks created physical conditions which favored precipitation of metals, there an ore-body was formed, each passing gallon of solution contributing its mite till the net result reached measurable proportions. The earthy materials with which the solutions were charged were carried onward past the locus of metal-deposition, to be deposited

as barren veins, or as replacements (chiefly silicification) of the wall-rock. In the original discussion by the writer of the origin of the veins in the Mizpah trachyte at Tonopah, it was pointed out that the metals were all precipitated from the solutions in the circulation channels offered by definite fracture-and-fissure zones; that the wall-rocks of these zones **by their reactions with the mineralizing solutions** acted as a screen, through which the metals could not pass, but through which the earthy materials in solution, especially silica and to a less extent potash, passed in abundance, producing an immense amount of barren highly silicified andesite.\* The physical combination of the definite vein-channel (fracture or fissure-zone) and the porous but little-fissured wall-rock therefore brought about in the former a progressive accumulation of the scanty metals in the solution, till a rich ore-body was formed, while the residual silica penetrated and silicified the surrounding rock.

In the case of a rock thoroughly shattered and fissured, and offering an immense amount of openings to the same solutions, no such forcible physico-chemical separation of the dissolved constituents would be brought about; and the tendency would be for the scanty metals and the greatly excess silica to remain together up to the point of precipitation, with the result that the precipitated quartz contains so little metals that it cannot be classed as an ore, especially if with it is included a great quantity of shattered rock. This was apparently the case with the "glassy trachyte." This consideration is also probably at the root of the explanation why, as a broad and general rule, the richness of the ore in any district is apt to vary inversely as the width of the vein. It may also explain why in many small fissure veins there is often a layer of nearly solid sulphides or even of metal (in the case of gold) along the walls, while the center is occupied by the usual metalliferous quartz.

In the case of the glassy trachyte, not only did its glass-like brittleness prevent the formation of definite, restricted vein-channels and bring about a complete shattering of the rock before the advent of the solutions which formed the rich veins of the first period, but the shattering was repeated by each of the numerous successive stresses, and the rock presented the same conditions as at first to the poorer circulating solutions of the second period, and to the practically barren solutions of the third period of vein-formation. The result is a rock to which an enormous quantity of silica has been added, and doubtless in the aggregate a great deal of the precious metals, yet nowhere do the latter appear to have been concentrated sufficiently to form ore-deposits.

#### Thickness.

Very little recognizable of the glassy trachyte is left in the Mizpah and the Montana mines, save in small blocks. In the Desert Queen shaft of the Belmont mine, however, it has a thickness of about 300 feet, and in the Midway at least 250 feet is indicated.

### THE MONTANA BRECCIA.

#### Description.

A breccia, whose exact nature and relations were for a long time puzzling, has a widespread distribution in the underground workings, having been studied by the writer in the Montana, Belmont, Mizpah

\* Prof. Paper No. 42, pp. 226, 234, 237.



(Tonopah Mining Company), Midway, and MacNamara mines. It is closely associated with the West End rhyolite, and frequently occurs as a zone of variable thickness along the upper or the lower contact, or both contacts, of this rock. It also occurs especially in the Montana and the Belmont, as independent masses of considerable size, though always close to the West End rhyolite. The 765-foot level of the Montana has developed a large mass of this breccia.

This rock is full of foreign angular inclusions, which are frequently so abundant as to obscure the ground-mass. In many other places the ground-mass can be seen to be a greenish glass, evidently rhyolitic or trachytic. The most abundant included rock is the "glassy trachyte," which often forms so large a part of the mass that it is doubtful whether the result should be classified as glassy trachyte with intense intrusion of breccia or breccia with an inordinate amount of trachyte inclusions. Where, in contact with the typical Mizpah trachyte, abundant inclusions of this rock are also frequently observed, so that in some cases the transition between breccia and trachyte appears a gradual one. There are also inclusions of a large variety of rhyolitic and andesitic rocks strange to the locality, and apparently derived from the depths, and even occasionally of shale (Montana Tonopah mine), derived probably from deep-seated Paleozoic rocks below.

#### Relative Age.

In the Belmont mine (1000-foot level) this rock shows in several places clean-cut and decisive intrusive contacts into the Mizpah trachyte. In a number of places, as on the 500-foot level Mizpah, the 515 and 765-foot levels of the Montana, and the 900-foot level Belmont, clean-cut intrusive contacts of the West End rhyolite into the Montana breccia are found; in the case of the Montana 765-foot level the former sends out dikes into the latter. This sharp contact between the two rocks is often found even where the Montana breccia occurs as a narrow band lying between the West End rhyolite and the Mizpah trachyte, as for example on the 515-foot level Montana.

The result of mapping and sectioning show that while the Montana breccia frequently occurs on one or both borders of the West End rhyolite, yet it may be entirely wanting on either, and large masses of either rock may be found without the other being adjacent. This, together with the mentioned intrusive phenomena, indicate that the Montana breccia was the first of the intrusives which followed the extrusion of the Mizpah trachyte; that it thrust itself horizontally as a sill along the sheeted zone between the Mizpah trachyte and the glassy trachyte; that later a resumption of the old stress split the Montana breccia sheet parallel to the intrusion, but irregularly; and that along this opening the more abundant West End rhyolite was intruded.

#### Relation to West End Rhyolite.

There are, however, some few cases (as in the Midway 435 and 530-foot levels) where there has formed on the margin of the West End rhyolite itself a breccia similar to that described, and into this the West End rhyolite seems transitional, making it a contact phenomenon. Though this variety of breccia is believed to be exceptional, it indicates the close resemblance and similarity of composition of the matrix of the Montana breccia to the West End rhyolite, which is also practically

a glassy rock; and in view of the closely succeeding periods of intrusion of the two rocks, it is regarded as probable that both are representatives of the same magma reservoir. The first intrusion, being obliged, as already stated, to "clear the trail," arrived packed with inclusions, and so forms a characteristic igneous breccia (Montana breccia); the later material expelled from the same source, however, arrived with comparatively few inclusions (West End rhyolite).

### THE WEST END RHYOLITE.

#### Description.

The West End rhyolite is an unusually uniform and characteristic rock, of a peculiar green color, and containing inclusions of some rock now altered to a white powdery state. It is massive, with inconspicuous flow-banding, and is highly altered. The rock is essentially a devitrified glass. Phenocrysts are rare and small, and include feldspar and biotite, both highly altered, and quartz. The alteration has produced abundant quartz, sericite and kaolin, together with adularia and pyrite. The white inclusions have been kaolinized till they have no original characteristics.

#### RELATIVE AGE

The age of this rock is conclusively shown by its contact phenomena, which demonstrate that the rock is intrusive into the glassy trachyte and the Mizpah trachyte. On the 765-foot level Montana a most orthodox intrusive contact of West End rhyolite into Mizpah trachyte was traced for over 200 feet. The rhyolite becomes intensely flow-banded for from 6 inches to a foot at the contact, and contains small angular inclusions of the trachyte. This same intrusive rhyolite contact also crosses a vein (belonging to the first period) in the trachyte, and cuts it off cleanly. In the Belmont mine on the 900 and 1000-foot levels, the same definite intrusive phenomena of the West End rhyolite into the Mizpah trachyte were noted. The intrusion of the West End rhyolite into the "Glassy trachyte" is, as above noted, well shown on the Belmont 800-foot level, and also frequently elsewhere. The intrusive phenomena of the West End rhyolite into the Montana breccia were reviewed in discussing this later rock.

#### OCCURRENCE

The West End rhyolite occurs principally as a single sheet of extremely variable thickness, which has followed the path of the Montana breccia, and occupies approximately the zone between the Mizpah trachyte and the glassy trachyte. Frequently, as in much of the Mizpah mine, this last-named formation has been submerged by the Midway andesite ("calcitic andesite") intrusion, so that this andesite has come into direct contact with the West End rhyolite. In the Belmont mine, the main rhyolite sheet rises, toward the east, gradually up into the Mizpah trachyte, leaving the transition between the Mizpah trachyte and the glassy trachyte directly observable; and in the eastern part of the mine the rhyolite appears to split into several sheets, intrusive into the Mizpah trachyte. This change of position is also visible in some points at the east extremity of the Mizpah workings, adjacent to the



Belmont mine, as at the east end of the 500-foot level, where Mizpah trachyte was noted beneath the West End rhyolite sheet (Section E-E).

#### THICKNESS

The greatest thickness of West End rhyolite is shown in the Mac-Namara shaft, where it is upwards of 450 feet thick. To the east this sheet thins rapidly till it becomes very thin or perhaps pinches out locally entirely; but it is found again further to the east at about the same horizon, with an extremely variable thickness. It is probable that in general the thickness tends to diminish toward the east, though locally, as in one point in the Montana, where an intrusive dome or nascent pipe has eaten its way far up into the Mizpah trachyte, the thickness of rhyolite amounts to 350 feet. In the Belmont, however, 50 to 100 feet appears to be the average thickness. The indications are therefore that the intrusion came from the northwest.

#### RELATION TO VEINS

The West End rhyolite cuts off the important veins of the first period, of which the Mizpah vein is the chief representative. It is, however, older than the veins of the second period, which consist of abundant but usually low-grade or barren quartz. Locally considerable ore has been extracted from these later veins; but on the whole the formation is a distinctly discouraging one for mining operations, and is so considered in the district.

#### CHEMICAL COMPOSITION AND CLASSIFICATION

The West End rhyolite has been intensely altered by solutions high in silica and potash, as in the case of the Mizpah trachyte. The few analyses given in the accompanying table, therefore, show a considerable range of silica content. The most siliceous ones are entirely similar in chemical composition with the most highly altered Mizpah trachyte, and correspond to an alaskitic magma. These same alaskitic characteristics mark also the analyses of the West End rhyolite samples further down in the scale of siliceous content, the lowest (Nos. 29 and 32 in the accompanying table, p. 11), being marked by high silica 72-73 per cent) and potash (4.3-4.9 per cent) low iron and magnesia, and very low lime and soda. On account of the high alteration of even the least altered of these glassy rocks, and the similarity of composition and nature of alteration to altered forms of the Mizpah trachyte, there is a possibility that the West End formation was also originally a trachytic magma. Internal evidence is extremely scanty, as phenocrysts are tiny and rare. They consist, where found, of feldspar (probably orthoclase almost exclusively) biotite, and occasional quartz. The presence of this occasional quartz alone prevents the assumption that this rock was originally practically identical with the Mizpah trachyte in composition; and leads to the final assumption that the magma had a composition intermediate between trachyte and alaskite; and so was very closely related to the Mizpah trachyte magma, but was more siliceous.

The expulsion from the deeper regions of this trachyte-alaskite magma, it will be observed, was again followed by the expulsion of large volumes of solutions high in silica and potash, and indeed altogether similar to the solution which followed the expulsion of the Mizpah trachyte; and from these solutions the veins and ores of the Second Period were formed.

### THE MIDWAY ANDESITE

#### "Later Andesite"

A large surface area is covered with an andesite which is barren of profitable veins, and which overlies as a later "cap-rock" the Mizpah trachyte, the Montana breccia, the West End rhyolite, and the veins of both the first and second periods. The greater part of this Midway andesite is evidently a flow, which was poured over a very uneven surface of erosion of the older rocks. The interval between the intrusion of the West End rhyolite and the Midway andesite eruption was considerable—enough, probably, to allow the veins of both the first and second periods to be laid bare to the surface.

#### ALTERATION

The Midway andesite is intensely altered in the vicinity of the chief ore-producing area (especially in the vicinity of the Montana-Tonopah mine), although in areas more remote it is quite fresh. Its manner of alteration is, however, quite sharply contrasted with that of the Mizpah trachyte which it overlies, a fact that was fully discussed in the original report. The alteration of the Midway andesite has been chiefly to calcite, chlorite, serpentine, quartz, siderite, pyrite, and other secondary minerals, with typically little or no silicification; hence the rock has assumed (where unoxidized) a characteristic dark, greenish color, and a relatively soft consistency. The alteration of the Mizpah trachyte on the other hand, has, as stated, been chiefly to quartz and sericite, with adularia and other secondary minerals; and the altered rock is typically hard, light-colored, and siliceous. As stated in the original report, the alteration of the Midway andesite is evidently the work of hot ascending waters, and the alteration is indeed the typical "propylitic" alteration so often characteristic of the andesitic wall-rocks of Tertiary bonanza veins like the veins of Tonopah; but at Tonopah this marked propylitic alteration took place long after the formation of the principal veins, and was unaccompanied by any save scattered, and practically barren veins (Veins of the Third period—to be described later).

#### "Calcitic Andesite" Sheet

The intrusive sheet of "calcitic andesite" which is found in depth in some of the principal mines is always highly altered. The principal secondary products are calcite and chlorite, the former produced chiefly at the expense of the feldspars, the latter from the ferromagnesian minerals. Pyrite and siderite are common. This rock does not usually show any trace of the intense silicification which has affected the adjacent Mizpah trachyte, glassy trachyte, and West End rhyolite, even when it comes into contact with these rocks; nor do the veins of these formations (belonging to the first and second periods of vein-formation) pass into the "calcitic andesite." Evidently, therefore, this andesite is younger not only than the above mentioned rocks but than the silicification which succeeded their advent; and older than the propylitic alteration which has affected the overlying main mass of Midway ("later") andesite. It is, therefore, of approximately the same age as this main body of "later andesite."



Contact phenomena support this conclusion. The "calcitic andesite" is intricately intrusive into the "glassy trachyte" on several levels of the Midway mine and it also in one place includes a large block of the Mizpah trachyte. On the 765-foot level of the Montana, near the shaft, this same andesite sheet encloses large blocks not only of the glassy trachyte, but of the Montana breccia. The Tonopah rhyolite intrudes the typical "later andesite" near the end of the long north cross-cut of the Montana 765-foot level, and at many places on the surface; the "calcitic andesite" is also intruded by dikes of Tonopah rhyolite ("lower rhyolite") on the 700-foot level of the Red Plume.

The usual texture of the "calcitic andesite" sheet is finer than that of the typical later andesite, and it often has a faint brecciated structure, probably due to autobrecciation during flowage, a phenomenon which is also frequently observed in the main mass of "later andesite." The texture of both bodies is, however, variable, varying from very dense to fairly coarse; and at the shaft on the 765-foot level Montana, the texture of the "calcitic andesite" sheet becomes coarser, like that of the typical "later andesite." Conversely, the rock at the end of the long north cross-cut of the 630-foot level Midway is physically a typical "calcitic andesite" though a part of the main mass of "later andesite." Finally, analysis shows that chemically the "calcitic andesite" and the typical "later andesite" are indistinguishable. On the 765-foot level (west) of the Montana the two bodies have been developed so that they approach one another within a few hundred feet, with trends as if they actually would be found to unite.

The thickness of the "calcitic andesite" intrusion is evidently greatest in the northwestern part of the producing area, as indicated by the developments in the MacNamara and Tonopah Extension mines. Its lower limit has not been determined in this region, but the total thickness may well be 500 feet or more. To the southeast the intrusion rises with a ragged contact against the "glassy trachyte," and thins rapidly, disappearing before reaching the Belmont mine. At the Montana shaft the thickness is only about 40 feet, and it is probably just east of this line that the sheet terminates; but the thickness increases rapidly to the west.

#### Correlation of "Later Andesite" and "Calcitic Andesite"

The final conclusion reached, therefore, is that the "calcitic andesite" is an intrusive sheet similar in age and composition to the "later andesite," and is probably identical with it—the main mass being a surface flow, and this an intrusive sheet. The locus of intrusion of this sheet seems to have been determined by the same factor as influenced the intrusion of the Montana breccia and the West End rhyolite—the brittleness of the "glassy trachyte," which rendered it an especially easy zone of intrusion, as the detailed study of the contacts in the Midway mine testifies.

#### METHOD OF DISTINGUISHING ANDESITE AND TRACHYTE CHEMICALLY

By referring to the preceding table of analyses, it will be seen that a careful chemical analysis will usually serve to distinguish the Midway andesite from the Mizpah trachyte or "lode porphyry."

The trachyte appears invariably more siliceous than the Midway

andesite; the former having a range, in the above list (including both relatively fresh and altered samples) of from 64.50 per cent to 73.50 per cent, and the latter (including both fresh and altered samples) from 43.0 per cent to 61.6 per cent. The tendency of alteration of the trachyte is to increase the silica; that of the andesite appears to be to decrease it.

The tendency of the combined ferrous and ferric oxide in the andesite is to constitute 5 per cent or over; in the trachyte these constituents are usually around 2 or 3 per cent.

The combined lime and magnesia varies above from 11.88 per cent to 3.0 per cent for the andesite, and from 1.92 per cent to 0.33 per cent for the trachyte.

The combined lime, magnesia, ferrous and ferric oxides varies from 21.17 to 10.0 per cent, for the andesite; and from 7.86 to 1.66 per cent for the trachyte. The combined lime, magnesia, iron oxide, and soda, minus the amount of potash for each sample, give an excess of lime, magnesia, iron and soda, for the andesites of 20.33 to 7.35 per cent; and of plus 2.64 to minus 4.37 per cent for the trachyte or "lode porphyry." The extreme high excess figure given above for the andesite is for an extremely altered sample.

Omitting this extreme sample, it may be stated in general terms that the andesite shows a silica range of 61.65 to 51.64 per cent or less; and the trachyte ("lode porphyry") from 66.15 to 73.50 per cent or more; that the excess of lime, magnesia, iron (oxide) and soda over potash varies from plus 7.35 to plus 14.38 per cent or more for the andesite; and from plus 2.64 to minus 4.37 per cent or less for the trachyte. A complete and careful analysis, therefore, should enable the distinction of the two rocks in nearly all cases. Unless the analysis is accurate, the results are of course worthless. The samples taken by the writer during the present examination were taken in the same manner as are ore samples. Fifty-pound samples were broken down in the mine, small veins and other unusual matter sorted out, and the sample broken down and successively quartered. The final breaking was in a crusher with jaws set to about  $\frac{1}{4}$  inch, after which the final sample was quartered out, the fines being sifted out and rejected from the sample. It was found that grinding to pulp with steel implements introduced a good deal of metallic iron into the pulp, an amount shown by comparative analyses to adulterate the rock to an important degree; but the above method obviated this difficulty, the steel flakes being practically entirely in the rejected fines.

This method of sampling for rock analysis is believed to be superior in practical accuracy to the usual method of analyzing hand samples.

#### THE TONOPAH RHYOLITE

##### Distribution and Age

The intrusive Tonopah rhyolite-dacite, or Tonopah rhyolite, as it will be called, is described in the writer's published report\* as occupying an extensive area to the north of the producing part of the district. The southern margin of the exposure of this rock is intricately intrusive into the Midway andesite ("later andesite"); and its northern extent has not been determined.

In this original report the Tonopah rhyolite was described as having a

\* Professional Paper No. 42, U. S. G. S., pp. 41-43.



glassy ground-mass, often showing flow structure, and frequently showing autobrecciation. "Angular fragments of broken glass, included in a cement of similar glass, and other phenomena, indicate that the lava moved while stiffening." The small porphyritic crystals were determined as orthoclase and andesine-oligoclase feldspars, quartz and biotite.

Lava of similar appearance and composition was described as covering much of the surface in the southern part of the area mapped, and as occurring not only as intrusions but as numerous thin surface flows alternating with pumiceous tuffs. Many of these layers were regarded as probably fragmental, the result of showers of ash and lava fragments during explosive eruptions. It was believed that the uniformly intrusive Tonopah rhyolite in the northern area represented the intrusive portions of the same lava which occurred as flows and fragmental layers in the southern area. In both areas the rock in question was provedly younger than the Midway ("later") andesite. In the southern area the beds of this rock overlie a surface formation of rhyolitic (rhyolitic-dacitic) tuffs, flows, and pumice beds, which are themselves younger than the "Midway andesite" and were called the "Fraction breccia."

The bulk of these surface rhyolite-dacite lavas in the southern part of the area were erupted just previous to the formation of a great lake basin, in which were deposited white characteristic tuffs\* ("Siebert tuffs"). This lake was considered identical with the Miocene Pah-Ute lake of King. It was, however, pointed out that the period of eruption of the Tonopah rhyolite-dacite was a lengthy one, marked by recurring spasmodic eruptions; and that thin sheets of this rock were intercalated with the lower part of the Siebert tuffs. The Siebert lake beds were determined as older than the intrusion of the volcanic necks which form the present hills around Tonopah, which consist of individually distinct but closely related rhyolitic lavas, varying from siliceous rhyolite (Oddie rhyolite) to a dacitic rhyolite (Brouher dacite). These volcanic necks were also determined as younger than the Tonopah rhyolite-dacite—both the surface formations in the southern half of the area mapped, and the intrusive masses in the northern half of the area.† The principal and most conspicuous faulting of the region was shown to have followed the intrusion of these necks. "The faulting was chiefly initiated by the intrusion of the massive dacite necks (the rhyolite necks were probably not so bulky). After this intrusion and subsequent eruption there was a collapse and a sinking at the vents. As the still liquid lava sank it dragged downward the adjacent blocks of the intruded rock, accentuating the faults and causing the described phenomena of down faulting in the vicinity of the dacite."‡ This faulting affected in a striking way the Siebert tuffs, and the surface flows and fragmental beds of Tonopah rhyolite-dacite in the southern part of the area mapped.

It is, however, a circumstance now dwelt upon by the writer for the first time that the large area of **intrusive** Tonopah rhyolite-dacite (Tonopah rhyolite), in the northern part of the area, is shown, as mapped, unaffected by this faulting, in striking contrast to the faulted condition of the surface flows of the same lava in the southern part of the area.§

\* Tertiary diatoms were found in these tuffs by the writer; and recently Tertiary gasteropods have been found, but as yet have not been studied.

† Prof. Paper No. 42, U. S. G. S., pp. 44, 49.

‡ Prof. Paper No. 42, U. S. G. S., p. 47.

§ Prof. Paper No. 42, Pl. XI.

This circumstance, together with other considerations, now leads the writer to believe that this intrusive body was not strictly contemporaneous with the surface flows; that while the lavas are probably identical, and both belong to the same extended period of eruption, succeeding the "Fraction breccia" and preceding the intrusion of the volcanic necks (Oddie rhyolite and Brouher dacite), that the purely intrusive masses in the northern half of the area belong to the very end of this period of eruption, are later than the Siebert tuffs, and are very little older than the intrusion of the volcanic necks.

#### Relations of Tonopah Rhyolite and Oddie Rhyolite.

This view is in harmony with the close magmatic relations of the intrusive Tonopah rhyolite in the northern half of the area, and the adjacent and later Oddie rhyolite in the same area. The latter, at Mount Ararat, for example, is distinctly intrusive into the former—a white rhyolite with few inclusions intrusive into a more glassy rhyolite full of angular fragments; yet certain nearby small intrusive areas are so exactly intermediate between the two in character that in the original mapping it was an open question to which rock they should be referred. Such was the case with the area lying just northwest of the Ararat mountain plug, and mapped as Oddie rhyolite; and which the writer has lately come to regard as an integral part of the great Tonopah rhyolite intrusion. The import of the difference is, however, not great, as will be shown. The recent examination of the Belmont mine, moreover, shows that the main mass of Tonopah rhyolite ("lower rhyolite"), which can be traced as a continuous sheet underground through all the workings of the district (Belmont, Mizpah Extension, Montana, Tonopah Mining, Midway, and Tonopah Extension mines), which is normally a breccia so full of large and small fragments that its appearance frequently suggests strongly a tuff (meaning thereby a surface fragmental rock), passes **gradually** into large masses of cleaner rhyolite, relatively free from inclusions, which cannot be distinguished from the Oddie rhyolite. This is best shown on the 1100 level of the Belmont.

#### Correlation of "Lower Rhyolite" With Tonopah Rhyolite.

This deep sheet of rhyolite was at the time of the writer's first examination (on which his published report was based) developed only in a drill-hole in the bottom of the Mizpah shaft, and in the Mizpah Extension shaft; and was from its lithology correlated with the intrusive sheet of Tonopah rhyolite coming up through the Midway andesite, and forming an extensive outcrop half a mile or so north of the Mizpah shaft. Subsequent development has shown that this deep-seated rhyolite has the wide distribution above mentioned; and that its thickness is enormous and as yet undetermined, a vertical thickness of at least 2000 feet having already been demonstrated in the Mizpah shaft and drill-hole. The long north cross-cut of the Montana also runs out from the provedly productive area to a point under the margin of the outcrop of the main intrusive mass of Tonopah rhyolite; and this cross-cut shows that the deep sheet of the mine workings rises to the north, cutting through the other formations, including the Midway andesite (into which rock it is found in this cross-cut to be clearly intrusive), and ascends to meet the surface outcrop. Shafts sunk at the surface just south of this outcrop show that the intrusive contact of the rhyolite into the Midway andesite



dips south, to meet the contact as traversed in the cross-cut. There appears, then, no doubt that the outcropping mass of Tonopah rhyolite and the "lower rhyolite" found in the mines is one and the same body—an intrusive mass of immense and as yet undetermined proportions, whose upper contact, though extremely irregular in detail, in general dips south from its outcrop, so that in a horizontal distance of half a mile, roughly speaking, it gains a depth of a thousand feet.

#### Origin and Characteristics of "Lower Rhyolite."

Where this rock is developed in the Tonopah Mining Company's ground, both in the workings and deep drill-holes, study shows that a strip along the contact, irregular and varying in thickness up to, say 200 feet, has distinct characteristics from the main mass beneath. This main mass, of which a minimum thickness of 1000 feet as developed in the Silver Top drill-hole, and of 1800 feet in the Mizpah drill-hole, and which has been also extensively developed by lateral drilling, is a massive uniform rhyolite breccia with usually no trace of banding, with uniform characteristics from top to bottom. Close macroscopic and some microscopic study leaves no doubt in the mind of the writer as to the nature of this rock, quite apart from the field relations above mentioned. It is an autoclastic rhyolite breccia, with a glassy ground-mass showing small phenocrysts of quartz and relatively fresh feldspar, and often an immense amount of angular inclusions, principally of the same glassy rhyolite, identical in texture with the ground-mass, or slightly more or less crystallized, together with frequent inclusions of andesitic rock, of all sizes up to immense blocks many feet in diameter. Some of these inclusions are clearly of "Midway andesite," while some are probably "Mizpah trachyte." There are also rare inclusions of shale and of probable limestone. The small phenocrysts of the ground-mass sometimes show perfect crystal outlines, but usually they have been broken. The ground-mass is typically faintly cryptocrystalline, sometimes faintly spherulitic; in most cases faint wavy flow-lines can be distinguished in it, which curve around the phenocrysts and included fragments. This ground-mass intricately intrudes the quartz phenocrysts in the familiar typical manner of a glassy matrix eating into and resorbing quartz phenocrysts; and these typical invaded quartzes were found in every section examined. This shows that the matrix is uniformly a devitrified glass, and not a "detrital paste." All phenomena indicate clearly a chilly and viscous rhyolite glass intrusion, forced upward slowly and spasmodically, with alternating partial stiffening and congelation, so that the congealed portions were repeatedly shattered and borne on as inclusions in the still fluid glass, which was itself stiff enough to disrupt in many cases even its own small phenocrysts. Where this autobrecciation is intense, the rock, with its many angular and rounded (corroded) inclusions, and its largely shattered and resorbed phenocrysts, has much the appearance on preliminary examination of a fragmental rock—that is to say, of a detrital tuff formed at the surface.

At and near the upper contact the character of the rhyolite is much more variable. The typical rhyolite breccia of the lower portions is also here present, but this is mingled with or alternates with fragments and large masses, up to many feet in diameter, of a dense white rock resembling broken stone-china. Sometimes, as in the Tonopah Extension 1050-foot level cross-cut, this rock is delicately banded, with the curving

lines characteristic of glassy rhyolite; elsewhere, as on the 700\* and 900 Mizpah, the lines are straighter and suggest without difficulty a well-banded tuff. Study of the great amount of core from the Silver Top drill-hole show that most at least of this rock is a flow-banded glassy rhyolite, showing sometimes faint but frequently beautiful and delicate flow structure, and containing usually very sparse but sometimes abundant orthoclase crystals, and occasional quartz crystals, usually unbroken by the ground-mass. These white glassy rhyolite layers locally alternate with and pass by transition into fine rhyolite breccia, belonging to and transitional into the more uniform type above described, and these layers have the usual characteristics of glassy ground-mass, broken phenocrysts, abundant angular inclusions, and typical quartz phenocrysts invaded by the corroding glassy ground-mass; but elsewhere this clean, white, glassy rhyolite occurs in considerable masses. Careful study of all observed cases of this white banded rock in the upper portion of the "lower rhyolite," including that on the 700 Mizpah, have led the writer to the conclusion that all are of the nature described. A section of similar rock from the 700 Red Plume appears under the microscope to be undoubtedly a flow-banded glassy rhyolite.

In spite of the transitions above noted between the dense white, glassy rhyolite and the glassy rhyolite breccia, it is a matter of observation that the rhyolite breccia as a whole is later than the white-banded rhyolite. Many of the small angular inclusions of the breccia, especially in the upper portion, are of white, glassy flow-banded rhyolite, evidently belonging to the formation described, and in many cases in the uppermost portion of the "lower rhyolite" formation, the minor intricate intrusive relations of the breccia into the white rock may be clearly observed. In the north cross-cut of the 1050-foot level of the Tonopah Extension large slabs of the white or pale-green, delicately flow-banded rhyolite, with a fissility comparable to that of shale or fine tuff, alternate with larger masses of rhyolite breccia of varying coarseness, and itself not unlike tuff in general appearance; but the contacts of the breccia into the banded rhyolite are evidently intrusive, and angular fragments of the latter of considerable size have been taken up by the former and are found embedded in it.

These observations have led the writer to the conclusion that the white-banded rocks as a whole represent the first-chilled upper crust of the glassy Tonopah rhyolite intrusion, chilled before the beginning of the process of autobrecciation, which progressed slowly later as the deeper portions of the glassy intrusion chilled and at the same time moved onward spasmodically with attendant intense grinding dynamic stresses, shattering the first formed clean upper crust, involving the fragments and blocks in the slowly upwelling tide, and shattering and grinding the earlier-chilled glassy autoclastic breccias and successively involving them in later surgings.

As regards its contacts with other rocks, the typical "lower rhyolite" breccia (Tonopah rhyolite) is found distinctly and intricately intrusive into the "later" (Midway) andesite, with a dense flow-banded marginal phase, near the end of the long north cross-cut on the 765 level Montana; it forms a definite vertical dike a foot wide, with smaller dikelets, into the "glassy trachyte" in the Midway; and is definitely intrusive as large dikes, in the Belmont, into both the Mizpah trachyte

\* Especially referred to and described by Mr. J. A. Burgess as a probable tuff (Economic Geology, Vol. IV., No. 8, p. 687).



and the glassy trachyte. On the 700-foot level of the Red Plume dikelets of the Tonopah rhyolite breccia are intrusive into the Midway andesite ("calcitic andesite" sheet).

On account of the relations above described the Tonopah rhyolite is believed to represent practically the same magma as the Oddie rhyolite, and to have much the same relation to this intrusion as has the Montana breccia to the West End rhyolite—representing an earlier upwelling which broke open the deep-seated vents and opened them for the later cleaner intrusion.

#### Alteration and Relation to Vein-Formation.

The Tonopah rhyolite-Oddie rhyolite intrusions were followed by the third period of vein-formation, which produced usually small but occasionally very large quartz veins, with small amounts of the metals, and commercially valueless. The attendant heated solutions altered the rhyolites considerably and are believed to have been responsible for the more pronounced "propylitic" alteration of the later andesite in many localities, especially near the Tonopah rhyolite contact. Chlorite, epidote, pyrite, magnetite and probably siderite ("leucoxene") are found as alteration products of the occasional ferromagnesian minerals in the "lower rhyolite"; and the orthoclase is partly altered to quartz and sericite.

#### Glassy Dikelets.

Where the Tonopah rhyolite forms intricate dikelets in other rocks it has often a dark, glassy phase free from inclusions, which is supposed by the writer to represent the usual glassy matrix with the included fragments rejected by filtration because the intrusion had to penetrate through tiny fissures. In some cases a first intrusion of this dark glass, and a later intrusion of the typical breccia was noted in the same dike (as on the Midway 630 level), as if the original adit-fissure had widened after the first intrusion and before the second.

#### Chemical Composition.

Chemically both the Tonopah rhyolite and the Oddie rhyolite are relatively siliceous rocks—especially the latter, and represent an alaskitic magma. The analysis of the Tonopah rhyolite is often affected by small inclusions of Midway andesite.

#### MINERAL VEINS.

##### Veins of the First Period.

The principal large and rich veins, which have "made" the mining camp of Tonopah, are confined to the "Mizpah trachyte," are older than the Montana breccia and West End rhyolite intrusions, and all the other known rocks of the district. These veins have an east to east-northeast strike and a northerly dip, at various angles. The ore is typically a fine granular quartz without noticeable quantities of sulphides, very poor in the baser metals and containing the silver minerals (and gold) disseminated. The veins have the form of "linked veins," branching and reuniting, and the vein-channels seem to have been intensely shattered zones rather than open fissures, so that crustification is not

characteristic, and the veins appear to have originated mainly by replacement of the crushed and sheeted andesite in the channel-zone. On this account the phenomenon of "cross-walls" or fracture-fissures transverse to the main vein-zone, and determining the limits of ore-deposition, are especially important.\*

The primary metallic minerals are silver sulphides, principally polybasite, stephanite and argenite, with occasional pyrite (less abundant in the veins than in the wall rock), chalcopyrite, galena, and blende. Silver selenide also occurs. Silver chlorides, bromides, and iodides† occur, mainly at least as secondary minerals. Gold occurs in the proportion to silver of about 1:100 by weight, and is occasionally seen in the free state, which may be in part primary.

The principal veins of this type are the Mizpah, the Valley View, the MacDonald-Brougner, the Tonopah-Extension, and the Belmont, which last may be an extension of the Mizpah veins. These veins are usually large and are nearly all ore of various grades; the average grade is usually high. They correspond to the best type of the Tertiary bonanza veins of the Pacific petrometallographic province;‡ and have yielded several millions of profit. These veins have been affected by the various successive rock-strains later in origin than their deposition, and largely later than the intrusion of the various later rocks; these strains have at various periods caused faulting of the veins on both a large and small scale, both transverse to the veins and along the veins. The latter form of movement brought about a slipping of one wall on the other and often effected a reopening of the vein-fissure, which opening was subsequently cemented by vein material belonging to one or several of the later stages of vein-formation. It may be stated as a definite rule, therefore, that these veins do not penetrate the West End rhyolite or any of the other later rocks; and in many cases the veins are abruptly cut off at the rhyolite, sometimes with definite intrusive phenomena, as is the case with the MacDonald vein on the 615 and 765-foot levels of the Montana. In some cases, however, at the lower portion of the original vein, the West End rhyolite forms one wall, which evidently arises from faulting along the vein after its being cut off by the rhyolite. This is often characteristic of the Mizpah vein, for example; but where the rhyolite comes in on both sides, the vein almost invariably becomes very small, or low grade and barren, or cuts out entirely. The frequent extension of the impoverished vein a little distance into the rhyolite appears to be due to the vein-material of the later periods, which has cemented the post-rhyolite openings, not only along the original vein, but also along the extension of the new fissure downward into the younger rock.

Occasional blocks of probable Mizpah trachyte and (more frequently) glassy trachyte, included in the West End rhyolite near its margin, contain quartz veinlets which do not extend into the rhyolite, and so belong to the first period. Several of these cases occur in the Mizpah mine (600-foot level, 600 intermediate, etc.).

The trachytic wall-rocks of the veins of the first period are highly altered, principally to quartz and sericite.

\* Prof. Paper No. 42, U. S. G. S., p. 85, 119.

† Iodyrite discovered by J. A. Burgess.

‡ Prof. Paper No. 42, U. S. G. S., p. 278.



### VEINS OF THE SECOND PERIOD.

The veins of the second period are younger than the West End rhyolite and older than the Midway andesite. They comprise a group of definite sequence, whose members have distinct characteristics. The volume of quartz of veins of this period is great, as was pointed out in the original report\*; indeed, in the aggregate it is probably much greater than that of the quartz of the veins of the first period; but the commercial value of the former is insignificant as compared with that of the latter.

#### Second Period "A" Veins.

The most conspicuous veins of this second period are large veins of a rather characteristic frosty lustered quartz, with a predominant northeast trend, and a predominant flat dip, usually to the southeast. These followed and occupied faults which were subsequent to the West End rhyolite intrusion (since they fault this rock) and which fault the principal veins of the First period. The later quartz which fills these veins is typically barren, or at best very low grade. In other words, these large veins of the Second (post-West End rhyolite) Period fault the veins of the First (pre-West End rhyolite) Period. Such later veins occupy the Alpha, Beta and other fault-zones in the Mizpah-Silver Top mine.

Probably belonging to nearly or quite the same age is the great MacNamara vein, which is flat, rolling, and gently east-and-north dipping and which evidently follows a flat fault-zone of some importance, lying usually between the Mizpah trachyte and the underlying West End rhyolite, but in part cutting out the West End rhyolite entirely, and lying between the Mizpah trachyte and the "Glassy trachyte" below. This large vein is usually low-grade or barren. The Red Plume vein probably belongs to this same group.

At the time of this post-rhyolite faulting, the initial movement along the Stone Cabin and Mizpah faults also took place, and the fissures thus formed were occupied by usually large low-grade or barren quartz veins (Stone Cabin-Fault vein and Mizpah-Fault vein). The Mizpah-Fault vein is developed in the Mizpah, and to a less extent in the Montana and Belmont mines. These veins are associated with frequent barite, and often carry scattered cupriferous pyrite. The silver sulphides which carry the occasional values have a very spotty distribution. As a rule these veins are large, irregular, and lack definition and persistence. They are evidently mainly the result of replacement of broad crushed and sheeted zones of rock. Quartz belonging to this period also has cemented reopenings in veins of the First Period, and forms narrow barren extensions of these veins into the West End rhyolite below their actual terminations.

#### Second Period "B" Veins.

The ores of wolfram (tungsten), hübnerite and scheelite, have been discovered in the Mizpah mine by Mr J. A. Burgess. They occur in both the Mizpah and Valley View veins, especially where one wall is formed by the West End rhyolite. Several localities afford criteria showing that this ore is closely associated with but distinctly later than the quartz described above as **Second Period A**. On the 600-foot

\* Prof. Paper No. 42, U. S. G. S., p. 96, 97.

level Mizpah, near the Beta fault, the hübnerite with its associated quartz cuts cleanly a vein of the Second Period A quartz, which is itself a barren prolongation of the Mizpah (First Period) vein at this point. Between the 500 and 600 levels Mizpah (Raise 610) where the Beta fault cuts off and offsets the Mizpah vein, a false extension (post West End rhyolite) of the vein on the other side of the fault consists of the barren Second Period A quartz with later wolfram-bearing quartz.

This tungsten occurs in many places and though not in commercial quantity, is by no means a rarity. Its matrix is a peculiar honey-combed quartz whose cavities frequently contain gypsum. The form of some of these cavities suggests that they have been formed by the dissolution of original calcite. The hübnerite also occurs filling small fissures in older quartz. Barite, which is quite characteristic of the Second Period A veins, also occurs sometimes in the quartz associated with the hübnerite.

On the 400-foot level of the Mizpah a small northeast veinlet of this peculiar quartz carrying hübnerite cuts across an east-west veinlet probably belonging to the First Period.

Perhaps the best occurrence of this mineral was found by the writer in the Midway mine, in a raise above the 265-foot level. Here there is a regular 8-inch vein of quartz apparently belonging to the Second Period A type, in which is abundant hübnerite, embedded in the quartz as an essentially contemporaneous though in part slightly subsequent mineral, and closely associated and intergrown with a mineral resembling kaolinized adularia. This is an east-west, steeply south-dipping vein in Mizpah trachyte.

#### Second Period "C" Veins.

After the Valley View Vein (First Period) had been offset by the Alpha fault (which was later cemented by **Second Period A** quartz), resumption of stresses produced the extension of one stump of the Valley View vein past the fault, in line with the old vein. In this new extension the quartz is different from that in the main vein, being more clearly crystalline and vitreous, and marked by an abundance of adularia. This vein, in distinction from the original Valley View vein, has characters indicating that it was largely deposited in an open fissure. It is the same type as the Fraction vein, which is an east-west striking, **south-dipping** vein, and which was low grade or barren except in spots, or where subsequent silver sulphides had been deposited along crevices in the original quartz.\*

Veins and veinlets of this type of mixed crystalline quartz and adularia are common, both in the Mizpah trachyte and in the West End rhyolite. They are typically low grade or barren. They seem to represent the chief period of adularia formation, which was therefore distinctly subsequent to the main period of ore-deposition (First Period). Quantitatively, these veins are not of the first importance.

The exact age relations of the Second Period B veins to those of the Second Period C are not determined, but both are distinctly later than the Second Period A, and the relations of the Second Period A and B quartz are very close, suggesting that the B immediately followed the A, and therefore that the C succeeded the B. The C type appears probably distinctly older than the D type, to be described.

\* Prof. Paper No. 42, p. 140, 146.



### Second Period "D" Veins.

These are east-west veins filling fissure of usually small size in the earlier andesite or the West End rhyolite. They have frequently a south dip. They are marked by a frequent banded or crustified structure, by bands of black sulphides, and by a pinkish manganese-bearing gangue material which is probably a mixed carbonate of various earthy bases. The primary sulphides comprise stephantic and polybasite, as is the case in the veins of the First Period. The sulphides of the baser metals are still inconspicuous, but chalcopyrite, galena, and blende are more frequently met with. These veins are frequently high-grade, and are responsible for practically all the ore formed since the intrusion of the West End rhyolite. Veinlets of this type have intruded the false (Second Period C) extension of the Valley View vein above referred to, and have created some "stoping ore" out of this part of the vein. East-west fissures carrying ores of this period have also penetrated the large practically barren MacNamara vein (Second Period A) in the West End mine, and have created a pay-ore shoot. The ore in the MacNamara mine also appears to be due to a deposition of ores of this D period along fissure-zones in the barren A quartz. The origin of the pay-ore in the Red Plume vein and the Mizpah-Fault vein is probably similar, and due largely to a reopening of the original A quartz, and local enrichment by the D deposition. The best examples of clean veins of this period are found in the Montana and extend to a certain extent into the Midway, where a number of small but fairly high-grade veins, generally south-dipping, occur in the West End rhyolite. The relative proportions of gold and silver values appear to be about the same as in the ores of the First Period.

This "Second Period D" stage represents the second period of ore-deposition, and although insignificant as compared with the First Period has locally furnished considerable pay-ore.

The waters which formed the veins of the Second Period altered the wall-rocks, including the West End rhyolite, intensely, principally to quartz, sericite, kaolin, adularia and pyrite, with some chlorite and calcite.

### VEINS OF THE THIRD PERIOD.

The veins of the Second Period do not occur in the Midway andesite nor the Tonopah rhyolite; nor are these later rocks affected by the siliceous type of alteration which accompanied the veins of both the First and Second periods.

The veins of the Third Period are usually small, sometimes very large. They occur both in the Midway andesite and in the Tonopah rhyolite—possibly in the Oddie rhyolite. So far as observed, they are associated with the intrusive contact of the Tonopah rhyolite, and their formation seems to have followed the intrusion of this rock.

One of the most striking veins of this class occurs on the 900-foot level Mizpah, in the uppermost portion of the Tonopah rhyolite ("upper rhyolite") sheet, and contains a large amount of colorless, usually translucent quartz, with occasionally sulphides in considerable amount. The is a nearly flat vein, approximately parallel to the near-by contact. The content in precious metals is trifling, and the sulphides consist of galena, blende, pyrite, and chalcopyrite. An assay of a picked sample of sulphide-bearing quartz, taken by the writer, gave gold, trace; silver, 2.30

ozs.; copper, 0.98 per cent; zinc, 5.82 per cent; lead, 5.98 per cent. A similar and very likely the same large flat vein was cut in the upper portion of the Silver Top drill-hole, here lying in the Midway andesite ("calcitic andesite") somewhat over a hundred feet above the flat Tonopah rhyolite ("lower rhyolite") contact.

In the Desert Queen shaft of the Belmont a similar and very likely the same large flat quartz vein was encountered at a depth of 934 feet, in the uppermost portion of the Tonopah rhyolite ("lower rhyolite")\* within 12 feet of the contact. This vein showed a little pyrite and galena, but the highest of several assays showed only 0.08 ounces gold and 2.12 ounces silver with traces of arsenic and copper. This large vein of the Third Period near or close to the upper Tonopah rhyolite contact may be conveniently designated the Desert vein.

In the Mizpah Extension shaft, according to the writer's original published report,† the Tonopah rhyolite ("lower rhyolite") comes in at a depth of 430 feet, and continues to a depth of 505 feet, where andesite comes in to a depth of 620 feet, below which the shaft is in Tonopah rhyolite to the bottom (about 1000 feet at the present writing). On all three of these Tonopah rhyolite contacts (probably all intrusive), either at the contact or within a few feet of it and usually in the Tonopah rhyolite, large quartz veins occur, containing a notably large amount of pyrite, but practically barren, showing only very low assays in gold and silver.

The vein shown in the Mizpah 900-foot level and the Silver Top drill-hole (which is very likely the same as the Desert vein) was evidently formed along a powerful flat fault following very roughly the upper contact of the Tonopah rhyolite, and probably formed directly after its intrusion; just as the great flat fault which served as locus for deposition of the MacNamara vein (Second Period A) followed directly the intrusion of the West End rhyolite. Both faults were probably due to lateral strains which accompanied these nearly horizontal intrusions, and lasted even after the local solidification of the intrusives.

Along the margin of the outcropping intricately intrusive Tonopah rhyolite mass, there is much alteration of the intruded Midway ("later") andesite, which is highly pyritized and contains many quartz stringers carrying considerable pyrite, and locally showing assays in gold and silver, the gold values usually being predominant.

Except near the margin of the Tonopah rhyolite intrusion there has been very little vein-formation either in the Tonopah rhyolite or the Midway ("later") andesite. Occasional small veins in the Midway andesite, away from the contact, consist usually of clear, translucent quartz, with frequent calcite. They are invariably practically barren.

The quartz described above in the Silver Top drill-hole showed in places a decided amethystine color; and a more or less pronounced slight rose or amethyst tinge seems to be often characteristic of veins of this Third Period, whether they are encountered in the Midway andesite or Tonopah rhyolite, or in the older rocks, or cementing reopenings of veins of the earlier periods.

\* Prof. Paper No. 42, U. S. G. S., p. 193. The enclosing rock of this vein was determined at the time of this published report as Oddie rhyolite; it is now found to be part of the main mass of Tonopah rhyolite ("lower rhyolite") and to represent a phase practically indistinguishable from the Oddie rhyolite. (See discussion on p. 41-42, this report.)

† Prof. Paper 42, p. 195.



The "propylitic" alteration of the Midway andesite (to chlorite, calcite, pyrite, etc.) being most marked near the Tonopah rhyolite intrusions, is probably due to the waters attendant upon or following the Third Period of vein-formation.

#### CONDITIONS OF THREE PERIODS OF VEIN-DEPOSITION

All the evidence tends to show that the zone occupied by the present veins was probably never very deeply buried, and hence that all the veins described were formed at relatively shallow depths. While considerable of the thickness of the original Mizpah trachyte flow has doubtless been removed by erosion, yet it is probable that at the time of formation of the veins of the First Period there was no formation overlying the trachyte, and hence that the depth at which these veins were formed can be easily estimated in hundreds of feet, without having recourse to the thousands. At the time of the formation of the veins of the Second Period, the surface should have been still lower, on account of intervening erosion, and because no known surface accumulation intervened; but as the central point of deposition of the veins of the Second Period is a few hundred feet lower than that of those of the First Period, the depth at the time of deposition was perhaps roughly the same for the two Periods. Between the time of the deposition of the veins of the Second Period, and those of the Third Period, there were very considerable surface accumulations of volcanic rocks (Fraction-breccia, the surface forms of rhyolite-dacite, probably the Siebert tuffs); but there was also great erosion. As the central locus of deposition of the principal known veins of the Third Period is typically a few hundred feet lower than those of the Second period, these Third Period veins may have been formed at slightly greater depths than the first two periods; but it is probable that 2000 feet is a fair guess-estimate.

With this preliminary consideration it is interesting to consider the origin of the various metallic depositions which succeeded one another in this district, and now occupy practically the same zone, overlapping one upon the other.

In a published paper\* a few years ago, the writer advanced the theory that the principal ore-deposits were differentiation products of igneous magmas, and that the different metal-groups might be and were deposited at different temperatures from solutions having a single source. Since the terrestrial temperature normally increases with depth, the different metal groups are in the simplest combination of circumstances deposited in successive vertical zones, one below the other. A preliminary division of the vein groups into five was made, and are stated in the order in which, under the simplest circumstances, they are deposited, from the bottom up, beginning with those formed under the highest temperatures and ending with those deposited at low temperatures, near the surface: 1, the pegmatite zone, containing tin, molybdenum, tungsten, etc., with characteristic gangue minerals; 2, the free gold-auriferous pyrite zone, with coarse quartz gangue; 3, the cupriferous pyrite zone; 4, the galena-blende zone; 5, the zone of silver and also much gold, associated with antimony, bismuth, arsenic, tellurium and selenium, characterized by tellurides and selenides of silver, gold tellurides, argenterous tetrahedrite and tennantite, polybasite, stephanite, and argentite; 6, the zone of earthy gangues, barren of valuable metals.

\* A Theory of Ore-Deposition. *Economic Geology*, Vol. II., No. 8, Dec., 1907, pp. 781-795.

It was pointed out in this published paper that on account of changes of temperature in a certain rock zone, metallic depositions belonging to different groups might successively be deposited within the same zone, or even successively occupy a single periodically reopened vein-fissure, the simplest case being due to a gradual fall of temperature due to the downward progress of cooling of an igneous mass; in which case any of the above-defined groups of metals might be followed by one of the later-mentioned groups. In a later paper on Ore-Deposition at Aspen, Colorado,\* it was found that certain vein-groups corresponding to the above divisions succeeded one another, but in the reverse of the normal order named; and this was interpreted as due to a gradually rising temperature (instead of falling) during ore-deposition, due to the attendant gradual upward progress of an igneous intrusion. The consideration was also brought out in this paper that relatively long-sustained temperatures at the critical point for precipitation of a certain mineral-group were necessary for the accumulation of an important representation of this group; while on the contrary, critical temperatures that were rapidly passed resulted in slight or unrecognizable representation of the corresponding mineral-group precipitations, within a certain rock-zone; and the dependence of the relative transitoriness of these temperatures upon the quantity and behavior of intrusive igneous rocks was pointed out.

At Tonopah the veins of the First Period are typically zone No. 5, as above defined; as are also the veins of the Second Period D. This vein group is the normal one for the shallow depth, Tertiary age, and associated fine-textured or glassy volcanic rocks; and the two classes of veins, therefore, represent recurrences of the most normal stage of vein-deposition, separated by a sharply intervening period of time. The First Period was, however, long sustained, and resulted in exceptionally large and important veins; the Second Period D was sustained for a much shorter time, with correspondingly less important results.

The First Period seems to have followed with no intervening vein-phenomena, the eruption of the Mizpah trachyte; the Second Period D was subsequent to the Montana breccia-West End rhyolite intrusion, but was preceded, subsequent to this intrusion, by distinctly different vein-phenomena—Second Period, A, B and C, whose formation probably represents considerable time. Omitting for the present the A and C veins, which contain very little metallic minerals (although these are not wanting) and which are therefore not so clearly significant, the Second Period B veins contain, in proportion to their limited quantitative amount, abundant minerals of tungsten, a metal highly characteristic of the zone No. 1, as defined above; and, so far as known to the writer, not normally occurring in any other zone. This seems to indicate an enormous though only briefly-sustained temperature following the Montana breccia-West End rhyolite intrusions, and preceding the more normal temperature of formation of the No. 5 zone.

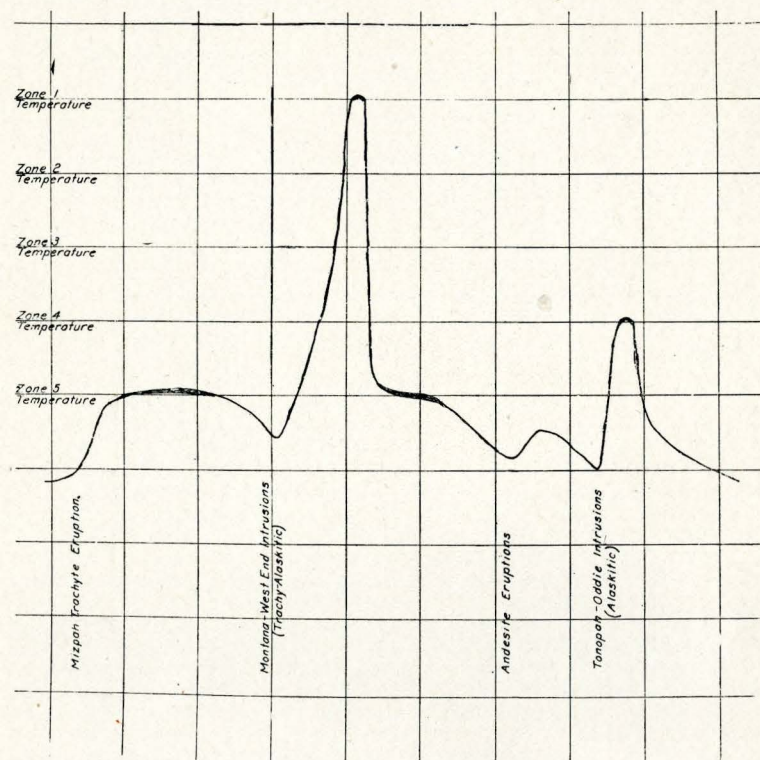
The veins of the Third Period, which followed the intrusion of the Tonopah rhyolite contain very little sulphides, though locally these are bunched and are almost massive. They consist of galena, blende, pyrite, and chalcopyrite; and represent therefore the characteristic association of the lower part of zone No. 4, as defined by the writer. This may also be taken to indicate an abnormally high, though only briefly sustained temperature, following the Tonopah rhyolite intrusion.

\* *Economic Geology*, June, 1909, Vol. IV., pp. 301-320.



The succession of apparently distinct vein groups is then: 5-1-5-4. The intervening groups are not represented, which may be taken to indicate changes of temperature so rapid as not to leave any record in vein-deposition.

As we lack definite knowledge of the critical temperatures of these zones, and the relative lapse of time between intrusions, the conditions as reasoned out and inferred can be shown only roughly in the accompanying diagram, in which the light line is a temperature curve and the heavy lines represent sulphide precipitations.



The underground temperature of the rocks of the district is still abnormally high, as pointed out by the writer in his published report,\* where it was suggested that neighboring hot waters, not yet tapped might be the source of the heat. Lately waters having a temperature up to 106-108 degrees Fahr. have been encountered in the deep drill-hole at the bottom of the Mizpah shaft.

Summarizing the history of eruption and vein-formation, it may be stated that a trachytic eruption (Mizpah trachyte) was followed by

\* Prof. Paper No. 42, U. S. G. S., p. 65.

a trachy-alaskitic eruption (Montana breccia and West End rhyolite), and this by an alaskitic eruption (Tonopah and Oddie rhyolites) and that each eruption was followed by a period of active quartz-vein formation; and that between the trachy-alaskitic and the alaskitic periods a typical andesite (Midway andesite) was erupted, which was followed by no period of vein-formation. The vein-forming magmatic residues, therefore, seem to have been closely associated with these extreme alkali-siliceous magmas.

## FAULTS

The history of faulting is revealed by this examination to be a complex one. After the eruption of the "Mizpah trachyte," with its "glassy trachyte" basal phase, the vein channels were formed by the development of a series of east-west, typically north-dipping fracture zones which may have been accompanied by slight faulting.

Nearly or quite at the same time as the development of the east-west fractures, a series of less-pronounced north-east transverse-fractures were formed. These transverse-fractures were present before the initial vein deposition, which followed the east-west fracture-channels; for the transverse ones have acted as cross-walls\* to these earliest veins; and as such are of the utmost economic importance, since the quartz and ore not only often changes abruptly on reaching a cross-wall, but sometimes ceases entirely. Sometimes these cross-planes have no displacement of the vein; again, they are marked by faulting of varying usually slight degree. The effect as cross-walls is independent of the degree of displacement, and the slight faulting is probably largely of subsequent origin, belonging to one of the later stages of movement. At the time of the first (and most important) vein-deposition (veins of the First Period) the direction of pressure in the rocks was evidently such (east-and-west) that the east-west channels were left open, the northerly striking transverse fissures were jammed shut; hence there was little or no ore-deposition along the transverse fractures, in spite of the exceedingly important role which they played.

The most important of these transverse fractures is the Valley View cross-wall in the Silver Top mine of the Tonopah Mining Company.

Subsequent to the first vein-deposition, it is probable that the first of the important long series of nearly horizontal fault-movements took place, producing a considerable differential movement following approximately the upper limit of the "Glassy Trachyte." Along this horizontal zone of disruption and movement the Montana Breccia was probably intruded. Subsequently this movement was renewed, splitting the Montana Breccia intrusion, and along the channel thus formed the West End Rhyolite was intruded. A continuation of the flat fault-movement after the West End Rhyolite intrusion produced the powerful horizontal fault which took place in part along the upper contact of the West End rhyolite, and which was afterwards filled by the MacNamara vein. Other strong flat or flatly-dipping faults were formed at the same time, some of which faulted the veins of the First Period (as the Mizpah and Valley View veins); and these are exemplified by the Alpha and Beta faults of the Mizpah mine. At the same period, some little movement took place along the earlier northeast (transverse) fractures, such as the Valley View fault, and, further east, a more important fracture of

\* See page 49, this report.



this system began to assume the proportions of an important fault (Stone Cabin fault), striking northerly, and dipping at a moderate angle to the east. The important Belmont fault developed at the same time. At the same time the veins of the First Period were affected by differential fault-movements, parallel to the walls, and one wall of the vein was typically dropped relative to the other, so that at the contact of the Mizpah trachyte veins with the West End rhyolite below, the rhyolite was frequently slid up along the extended fault so as to form for a limited vertical distance one of the walls of the vein.

All the openings thus formed were cemented by the quartz of the **Second Period A** (see p. 52), which indeed registers the age of this fault-movement.

Later than this, successive fault movements, probably all very slight, produced the typically east-west and often south-dipping fissures which were successively occupied by the veins of the Second Period B, C and D. These movements reopened some of the old east-west vein-channels, and cut across the north and northeast veins (of the Second Period A) transversely; but though not unimportant in their results as affording channels for vein-formation, they were unimportant from a dynamic standpoint.

These movements took place before the advent of either the Midway andesite or the Tonopah rhyolite.

The study of the Mizpah and Stone Cabin faults especially shows the progressive growth of faulting from the period mentioned down to a comparatively recent one. The older faults belonging to these broad zones of movement are more silicified by circulating hot waters; the younger ones, which are often found to displace the older ones, less and less so.

The intrusion of the Tonopah rhyolite, as above remarked, appears to have been followed by the development of a strong horizontal fault, later cemented by vein-material of the Third Period; and many other faults, including renewed movement along older faults, evidently took place at this time. Such later faults are often marked by considerable silicification, but the quartz, even where abundant, is quite barren.

Some of the fault-movements of the Mizpah, Stone Cabin and Belmont fault-zones evidently belong to this period; as, for example, the principal movement along the "Desert Queen fault" in the Mizpah mine, which fault is an auxiliary of the Mizpah fault, and which is continued into the Montana as the "106 Fault."

Finally a number of very strong and striking faults are entirely unsilicified, and are marked by soft gouge; hence are later than the latest stage of silicification. Such is the principal movement along the Mizpah fault, and a large share of the movement along the Stone Cabin, Belmont, and other older faults. At this stage faults like the Montana fault and the Burro fault originated; and altogether the period was one of intense movement.

In the writer's original published report, it was shown that this conspicuous faulting followed the intrusion of the latest rhyolitic-dacitic lavas, largely in the form of volcanic pipes or necks; and that the faulting was due to the collapse and sagging of the crust around the volcanic necks, which sagged after their intrusion and solidification.\* This is in accord with the present investigation, which shows that this movement

\* Prof. Paper No. 42, U. S. G. S., pp. 47, 68, 80.

originated after the intrusion of the intrusive Tonopah rhyolite, which is now shown to be intimately connected with the Oddie rhyolite, and to have immediately preceded the intrusion of the Oddie rhyolite proper.\*

The extensive horizontal faulting was also repeated at this most recent stage of movement, and is illustrated by the Siebert fault, which was early prescribed by the writer on the 700-foot level Mizpah.† It has recently been found, just north of here, as an important flat fault on the 765-foot level of the Montana, where the movement is shown to have been to the north on the under side. From these points it can be traced, with more or less certainty or probability, over a large area, often following and forming the lower boundary of the West End rhyolite sheet.

### Rock Grinding.

The faults of this last period especially are often attended by intense crushing and grinding, and often show a wide zone of movement. In places, this movement seems to spread itself out, instead of confining itself to narrow zones, and to have resulted in the fine brecciation and even in granulation of a zone often many feet in width. Such brecciated and granulated rock is often layered by the fault-movement and fault-pressure, so that it assumes all the appearance of certain varieties of surface-formed detrital tuffs. Such occurrences have been found adjacent to (or in) the Stone Cabin and Burro faults (Tonopah Mining Company) and occasioned much perplexity in the early part of the recent examination. Here these dynamoclastic rocks have developed at the expense of the Mizpah trachyte and locally, probably, of the Midway andesite. The extremely brittle "glassy trachyte" has lent itself especially to this kind of granulation and pressure-layering, as was especially observed in the Montana-Tonopah and elsewhere, producing in this case also dynamoclastic rocks having somewhat the appearance of stratified tuffs. A similar process has been observed in some of the Tonopah rhyolite, especially in specimens studied from the Tonopah Extension, in which the microscope shows the fine interlacing nearly parallel lines of pressure-movement which has granulated the rock, marked by lines of sericite.

\* See p. 41, this report.

† Prof. Paper No. 42, U. S. G. S., p. 116.



PART II.  
Special Notes on Montana-Tonopah  
Mine

---

CONTENTS

	Page
Notes on Maps.....	3
390-foot level.....	3
462 " " .....	3
515 " " .....	3
562 " " .....	4
615 " " .....	4
765 " " .....	5
Notes on Sections.....	6



## NOTES ON MAPS.

### 390-Foot Level:

This map shows the block of Mizpah trachyte bounded on the north and east sides respectively by the Montana and Mizpah faults, beyond both of which Midway andesite comes in. The "106" fault, which is identified with the "Desert Queen" fault of the Mizpah mine, and is thus shown to have a considerable displacement (offset to the southeast on the northeast side—"right-handed" fault) of at least a hundred and fifty feet, and very likely considerably more. According to this, the series of veins west of the fault are probably thrown laterally nearly or quite into Mizpah ground, where they will have a very limited extent on account of the greatly shortened distance between the 106 fault and the Mizpah fault. The downward component of movement (down in the northeast side) is also very great.

Fragments of the Mizpah fault-vein, cut out by the more recent portion of the Mizpah fault, are shown.

The MacDonald vein, considerably broken by slips auxiliary to the Montana fault, and cut out by this fault on the west, is shown. On the east the vein is cut off by the Mizpah fault.

The top of an intrusive plug of West End rhyolite is shown on this level. The east side of this rhyolite is cut off and dropped down by the "106" fault, bringing in Mizpah trachyte on this side.

### 462-Foot Level:

On this level are shown the Mizpah, the Montana, and the 106 faults. The junction of the Montana and the 106 faults is shown. The former is certainly in general the more recent, and probably cuts off the latter.

The MacDonald vein is well shown, considerably cut into by the parallel Montana fault, as on the level above. A patch of the Mizpah fault vein is shown along the Mizpah fault, but is of little consequence.

The group of branching and uniting lesser veins south of the Montana vein are shown on this as on the level above. Some of these veins are evidently of the Second Period D (Second Period of Ore-Deposition), and indeed offer the most important (economically) examples of veins of this age in the district. They have formed since the West End rhyolite intrusion, and ore occurs in them with rhyolite in both walls. Other members of the group appear to belong to the First Period (general report, p. 49). They occur in the Mizpah trachyte, but are cut off by the rhyolite. The intrusive rhyolite plug has a considerably larger horizontal section on this level than on that above.

### 515-Foot Level:

On the 515-foot level the Montana fault and the Mizpah fault are both well shown, with Midway andesite beyond them, adjoining the Mizpah trachyte block to the north and northeast. The 106 fault is also shown, limiting on the northeast the West End rhyolite plug, which here has a considerably increased cross-section over the level above.

The MacDonald vein is shown well, and is for a space cut into and perhaps wiped out by a swing of the Montana fault, and is much confused by lesser faults, attendant upon the Montana.



The vein-group lying south of the Montana is also shown on this level, with ore in the rhyolite as well as the trachyte, indicating that such veins belong to the Second Period.

On this level, as on the levels above, there appears to be small chances for future development work on any large scale. On this level a narrow band of a glassy breccia occurs in one locality, between the West End rhyolite and the Mizpah trachyte. It shows inclusions of various rhyolitic and andesitic rocks, mainly of types strange to the developed portions of the Tonopah mines, in a glassy ground-mass, often showing faint flow-structure. The veins of the Second Period cut through this breccia and offset it, as they do the West End rhyolite; and the West End rhyolite adjoins it with a clean, sharp contact. This breccia has been called the Montana Breccia; it is not shown higher up in the mine, but increases in volume rapidly in the lower levels.

#### 562-Foot Level:

The 562-foot level (intermediate) shows the 106 fault, fragments of the MacDonald vein (much broken and partly effaced by the 106 fault) and illustrates well the more southerly veins of the Second Period in the rhyolite.

On this level is also shown a northeast-trending, southeast-dipping normal fault, which is probably the Silver Top fault of the Mizpah mine. With the north-dipping veins of the T. M. Co.'s mine this fault has a right-handed offset; here with a south-dipping vein of the Second Period (in the rhyolite) it has a left-handed offset, both of which effects can be explained by a simple normal faulting, nearly with the dip of the fault. Considering the slight displacement of this fault, it is extraordinarily persistent. The Silver Top and the 106 faults appear to cross each other on this level; but there is some complication here not clearly understood.

The contact of the West End rhyolite and the Mizpah trachyte shrinks away from the 106 fault on this level, showing that it is largely independent of the fault, and suggesting that the position of the 106 fault in this mine may have been partly determined by the original (intrusive) rhyolite contact.

One of the south veins shown on this level, and called the X vein, passes into the Midway, where it dies out on the south. All of the veins of this Second Period D type (see general report, p. 56) lack persistence; and in the Montana they have contributed more ore than in any other mine; although in the MacNamara and West End enrichments of Second Period A quartz by Second Period D ore have contributed considerable ore.

#### 615-Foot Level:

On the 615-foot level the West End rhyolite has expanded so that it covers the most of the level. The Montana breccia appears as bands between the West End rhyolite and the Mizpah trachyte in two portions of the level; besides fragments of lavas, a fragment of black shale several inches in diameter is included in it in one place. The Mizpah, 106, and Silver Top faults are shown. The Silver Top shows its simple normal faulting, offsetting to the right a north-dipping rhyolite-trachyte contact. The relations of the 106 fault are obscure, as on the level above.

The MacDonald vein is well shown on this level; and north of it, the A. B. K. vein, which is of much less importance.

At the north end of the main cross-cut from the shaft there appears to be a steep-dipping, irregular contact of Mizpah trachyte and Midway andesite, under the Mizpah fault. This is interpreted as an intrusive contact.

#### 765-Foot Level:

On this level the West End rhyolite shows in two large patches, but covers considerably less area than on the 615-foot level, showing that the 765-foot level is in general below the intrusive rhyolite sheet. On the other hand, the Montana breccia, scanty on the levels above, increases on this level so that it covers most of the level. This formation has about the same relative age in regard to the various vein-periods as does the West End rhyolite. The Montana breccia is intruded, in the main north cross-cut, by dikes of West End rhyolite; and the breccia is itself younger than the glassy trachyte, of which it includes many fragments up to the size of huge blocks. The West End rhyolite on this level shows excellent intrusive contacts into the Mizpah trachyte, and these intrusive contacts, in the northwestern part of the mine, cut off sharply a vein of the First Period, which may be a fragment of the MacDonald vein.

Further east, the downward extension of what is probably the MacDonald vein occurs in the West End rhyolite as a vein of the Second Period. To the east, on leaving the rhyolite, this vein passes into probable Midway andesite, where the values are abruptly cut off, the vein becoming very small and weak and showing only scattering assays. This vein in the andesite is regarded as a vein of the Third Period. According to this, the original MacDonald vein, high-grade and important, was formed at the First Period in the Mizpah trachyte, and was cut off by the West End rhyolite. Later renewed movement along the vein-fissure extended the fissure into the West End rhyolite, and this new fissure was cemented by quartz of the Second Period—usually low-grade, but containing some pay-ore. This Second Period vein was cut off by the Midway andesite intrusion. Subsequently there was renewed movement along the vein-fissure, which was thus extended into the Midway andesite; and this last fissure was cemented by scanty quartz of the Third Period, of no economic value.

In the main cross-cut this Midway andesite shows an intrusive contact into the Montana breccia. At the contact for an inch or so the andesite is black, dense and aphanitic; further away it is fine-grained crystalline, increasing in coarseness as the distance from the contact is increased. The contact of the Montana breccia and the andesite is quite irregular.

Around the shaft, on this level, is shown the intrusive sheet of Midway andesite which extends through the Mizpah, Midway, West End, MacNamara, and Tonopah Extension mines ("calcitic andesite"). This sheet dips below the level to the north, and probably connects with the south-dipping contact of the Midway andesite further north, as shown in section A. This same intrusive sheet ("calcitic andesite") is shown in the western part of the level, where the contact swings around to the north, and comes within a few hundred feet of joining the main body of Midway andesite.

The most northwestern drift on this level follows for a long distance a nearly horizontal fault, which has Midway andesite above and Montana breccia below, and which finally dips down to the northwest below the floor of the drift. Further southeast this fault passes up into the roof



and cuts off the veins which it encounters. This is evidently the Siebert fault, encountered first, and named by the writer some eight years ago, on the 700-foot level of the Mizpah, where it separates the West End rhyolite above from the Midway ("calcitic") andesite below. This is a fault younger than the Midway andesite.

The glassy trachyte appears on this level, though it does not show on the levels above. Around the shaft fragments of it, up to the size of large blocks, are included in the Montana breccia and the intrusive Midway andesite (which also here includes blocks of the breccia); and in other parts of the level it is included, often in very large amounts, in the Montana breccia. In the main north cross-cut the Midway andesite continues to a point about 1400 feet north of the shaft, where a patch of West End rhyolite, bounded by faults, is encountered. The Mizpah fault, which occurs about 770 feet from the shaft, has Midway andesite on both sides.

About 120 feet north of the patch of West End rhyolite above referred to a larger patch of the same rock occurs, with a band of Montana breccia between it and the Midway andesite. On the north, the West End rhyolite is in contact with Tonopah rhyolite, which continues without interruption for about 1100 feet, at which point a band of Midway andesite 100 feet across is intersected. Beyond the andesite the Tonopah rhyolite continues some 140 feet further, to the breast of the cross-cut.

This mass of Tonopah rhyolite is probably the same as outcrops at the surface nearly over the end of the cross-cut, and which is encountered in depth in the Mizpah, Tonopah Extension and Belmont workings.

The southern contact of the Midway andesite band shows that the Tonopah rhyolite is intrusive into the andesite. The latter is dense and flow-banded along the exact contact and sends many irregular tongues into the andesite. The northern contact shows some slipping, but is probably nearly a normal intrusive contact.

On this level it is recommended to put in a cross-cut from the main north cross-cut, at about N 11400, E 9400, with course a trifle north of east, to explore the formations at this point.

#### NOTES ON SECTIONS.

##### Section A:

This important section goes through the Montana shaft and along the long north cross-cut. The limitation of the block of productive ground on all four sides is here well shown. Above, the block is cut off by the Mizpah fault and the Midway andesite; below, by the Siebert fault and the Midway andesite and Tonopah rhyolite intrusions, the latter being by far the most important; to the north, by the Midway andesite intrusion; and to the south, by the property line.

A drill-hole 791 feet in length, and inclined to the south, goes down from the main cross-cut, as shown in the section. At a depth of about 135 feet the hole passed from Midway andesite into West End rhyolite; below this, about 20 feet of probably Mizpah trachyte was encountered; and below this, some 15 feet of West End rhyolite again. Below this, Midway andesite continued to a depth of about 31 feet, when there was glassy trachyte to about 460 feet; then Midway andesite to about 490, and from there on to the bottom Tonopah rhyolite.

This section shows that the upper surface of Tonopah rhyolite dips down considerably at this point, but rises again to the north, so as to

form a marked trough, which is, however, a trough of intrusion and not of folding.

It is recommended that a winze be sunk to the patch of probable Mizpah trachyte developed in the drill-hole, and that this formation be then explored by cross-cutting, in the expectation that it may widen.

##### Section B:

Section B shows especially well the section of the intrusive cone-shaped West End rhyolite plug, with its steep intrusive contacts on both sides; it shows the close relation of the 106 fault to its north boundary, but yet indicates the conclusion that this boundary existed in nearly the present form previous to the faulting.

The Montana fault-contact is also well shown. Below the main mass of West End rhyolite comes the main mass of Montana breccia, and beneath this the intrusive Midway ("calcitic") andesite sheet, which is very thin at the shaft (Section A), near which point it probably wedges out entirely, but has thickened greatly to the south, as shown here.

##### Section C:

Section C shows the Montana and 106 faults, and especially the Siebert fault, which is probably here correctly depicted, whereas its exact position in Sections A and B is not certain. As shown, this fault produces a bench, at the north end of the section, indicating a movement to the north on the under side. In the Midway and Red Plume mines, however, a possible movement to the south, on the under side of this fault is indicated. From this it is suggested that the main movement may have been more in an east-west direction, and in this case the total displacement must have been great. One of the sections through the Tonopah Mining Company's property (Section C) indicates a movement to the west on the under side of the fault, which movement may possibly have amounted to as much as 1500 feet.

The fact that the bulk of the Montana breccia underlies the bulk of the West End rhyolite is illustrated in this section; and also the fact that the thickness of the underlying intrusive sheet of Midway ("calcitic") andesite is still greater than in Section B.

Respectfully submitted,

SPURR & COX (Inc.).

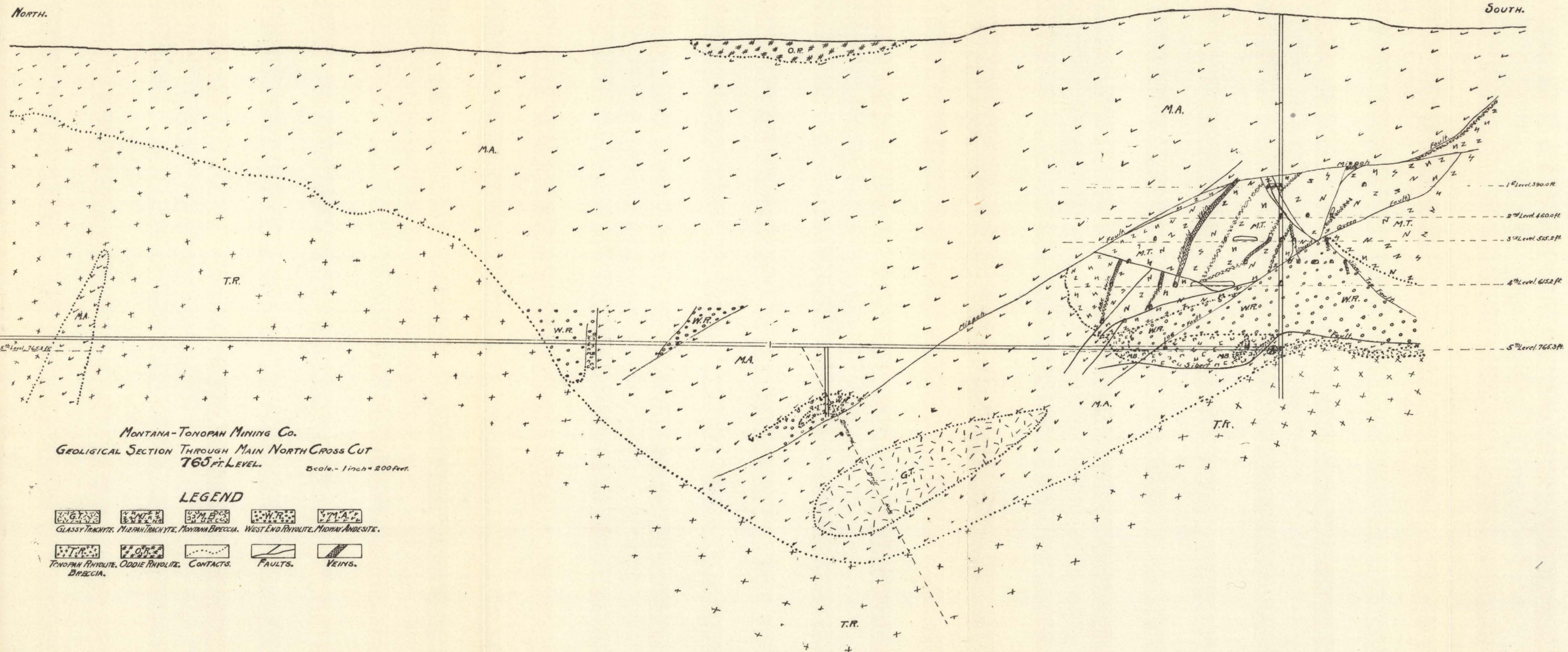
By J. E. SPURR.

Tonopah, Nev., Oct. 31, 1910.



NORTH.

SOUTH.



MONTANA-TONOPAH MINING CO.  
 GEOLOGICAL SECTION THROUGH MAIN NORTH CROSS CUT  
 765 FT. LEVEL. Scale. - 1 inch = 200 feet.

LEGEND

- |                  |                   |                    |                   |                 |
|------------------|-------------------|--------------------|-------------------|-----------------|
|                  |                   |                    |                   |                 |
| GLASSY TRACHYTE. | MONTANA ANDESITE. | WEST END RHYOLITE. | TONOPAH RHYOLITE. | ODDIE RHYOLITE. |
|                  |                   |                    |                   |                 |
| CONTACTS.        | FAULTS.           | VEINS.             | CONTACTS.         | FAULTS.         |



11/14/36

557.3 Montana-Tonopah mining  
N499m co. Report on the geology  
of the property of

SC  
Trx  
0784

557.3  
N499m

This Book is Due