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ITEM 112

REPORT ON THE GEOLOGY

OF THE PROPERTY OF THE

TONOPAH MINING COMPANY

TONOPAH, NEVADA

SPURR & COX Inc.
165 Broadway, New York

(254)
ITEM 112

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REPORT ON THE GEOLOGY
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TONOPAH MINING COMPANY
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SPURR & COX
INCORPORATED
CONSULTING SPECIALISTS IN MINING
165 BROADWAY, NEW YORK
CABLE: SPURCOX CODE: BEDFORD McNEILL

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 sulfides.

All 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.

LIST OF MAPS IN ACCOMPANYING ATLAS*

Sheet 1	Composite map of mine levels				
2	Geologic	plan 100 ft. level			
3	"	" 200 ft.	"		
4	"	" 300 ft.	"		
5	"	" 400 ft.	"		
6	"	" 500 ft.	"		
7	"	" 600 ft.	"		
8	"	" 700 ft.	"		
9	"	" 900 ft.	"		
10	"	" 1000 ft.	"	Tonopah Extension	
11	"	Section A-A'			
12	"	" B-B'			
13	"	" C-C'			
14	"	" D-D'			
15	"	" E-E'			
16	"	" F-F'			
17	"	" G-G'			
18	"	" H-H'			
19	"	" I-I'			

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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 "later 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 groundmass, 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 xxxxxxxx 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 and 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 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 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 this 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".

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

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

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 reviewal 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 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 geological 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.

YSIS FOR TONOPAH ROCKS

ASCENDING SILICA CONTENTS

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
68.68	68.86	69.13	71.14	71.71	71.79	72.27	72.31	72.50	72.98	73.00	73.20	73.50	75.17	75.44	75.45	75.56	75.66	76.25	76.57	77.02	77.30
	16.35	16.51	15.24	14.00	15.24	16.38	13.79		14.60		14.59	14.13	15.83	13.77				12.84		13.81	13.79
3.06	2.21	1.50	1.77	1.06	2.00	1.96	1.54	0.89	1.01			1.51	*0.17	0.87	0.78			0.54		0.97	0.01
	0.38	0.82	0.26	0.51	0.10	0.19	0.26		0.16		1.92	0.26	0.90	0.05				0.33		0.09	0.14
	1.30	0.36	0.09	2.25	Trace	Trace	1.08		0.18	1.55	0.47	0.12	0.46	Trace		1.16	0.47	0.16		Trace	0.10
	0.68	0.51	0.16	0.43	0.08	0.49	0.56		0.33		1.24	0.21	0.39	Trace				0.56		0.15	0.09
0.21	1.76	2.80	0.24	3.21	1.21	0.22	2.56	0.25	0.00	3.50	0.12	0.24	2.08	0.27	1.12	4.20	1.70	0.12	0.96	0.31	0.22
5.17	5.00	4.74	6.31	4.41	5.51	3.71	4.66	4.90	6.03	4.71	4.32	5.11	3.18	6.39	5.74	4.50	4.94	3.20	5.81	5.12	4.22
97.12	96.52	96.37	95.21	97.58	95.93	95.22	96.76	78.54	95.35	82.76	95.86	95.08	98.18	96.72	83.09	85.42	82.77	94.00	83.34	97.47	96.63
	4.57	3.19	2.28	4.25	2.18	2.64	3.44		1.66		3.63	2.10	2.92	0.85				1.57		1.21	1.16

	ANALYZED BY	COLLECTION NO.
t	George Steiger U.S.G.S.	219 U.S.G.S.
Collar	Dr. W.F. Hillebrand U.S.G.S.	331 "
	Booth Garrett & Blair Phila. Pa.	233 T.M.Co.
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lBasalt	Dr. E.T. Allen U.S.G.S.	168 U.S.G.S.
	Booth Garrett & Blair	255 T.M.Co.
Collar	George Steiger	408 U.S.G.S.
"	Dr. W.F. Hillebrand	349 " " " "
er Shaft	Prof. G.J. Young, Univ. of Nev. Reno, Nev.	435 Old T.M.Co.
00	Booth, Garrett & Blair	41 M
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nCollar	George Steiger	225 U.S.G.S.
	Booth Garrett & Blair	223 T.M.Co.
590	" " "	51 M
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	George Steiger	53 U.S.G.S.
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265	Booth Garrett & Blair	87 B
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Shaft	George Steiger	661 U.S.G.S.
el	Booth Garrett & Blair	227 T.M.Co.
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	Dr. E.T. Allen	368 " " " "
	Prof. G.J. Young	12 Old T.M.Co.
	George Steiger	590 U.S.G.S.
	Prof. G.J. Young	91 Old T.M.Co.
ns Shaft	Booth Garrett & Blair	236 T.M.Co.
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	Dr. E.T. Allen	368 U.S.G.S.
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	George Steiger	143 " " " "
	Dr. E.T. Allen	337 " " " "
	Booth Garrett & Blair	234 T.M.Co.
D609	" " "	226 " " "

	1	2	3	4	5	32	33	34	35	36	37	38	39	40	41	42
SiO_2	13.00	51.64	53.57	53.84	55.90	73.20	73.50	75.17	75.44	75.45	75.56	75.66	76.25	76.57	77.02	77.30
Al_2O_3	16.49	15.58		18.92		14.59	14.13	15.83	13.77				12.84		13.81	13.79
Fe_2O_3	2.86	0.16	6.67	2.37			1.51	*0.17	0.80	} 0.78			0.54		0.97	0.87
FeO	6.51	0.58		3.24		1.92	0.26	0.90	0.05				0.33		0.09	0.14
CaO	5.69	6.25		6.04	7.55	0.47	0.12	0.46	Trace		1.16	0.47	0.16		Trace	0.10
MgO	6.19	2.79		3.28		1.24	0.21	0.39	Trace				0.56		0.15	0.05
Na_2O	0.12	0.27	2.75	1.02	3.60	0.12	0.24	2.08	0.27	1.12	4.20	1.70	0.12	0.96	0.31	0.22
K_2O	0.84	2.46	5.63	1.72	2.01	4.32	5.11	3.18	6.39	5.74	4.50	4.94	3.20	5.81	5.12	4.22
Total	81.50	89.73	68.62	90.40	67.76	95.86	95.08	98.18	96.72	83.09	85.42	82.77	94.00	83.34	97.47	96.69
Fe_2O_3, FeO, CaO, MgO	21.05	9.78		14.90		3.63	2.10	2.92	0.85				1.57		1.21	1.16

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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_2	66.15	66.77	67.18	69.13
Al_2O_3		18.01	18.50	16.81
Fe_2O_3	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_2O	2.38	2.99	1.82	2.80
K_2O	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 groundmass, 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 groundmass 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_2	67.69
Al_2O_3	17.67
Fe_2O_3	2.43
FeO	0.80
CaO	0.45
MgO	0.38
Na_2O	2.54
K_2O	5.11
	97.67

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. +

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* J. E. Spurr, Prof. Paper No. 63, p. 25, 122, 132.
\+ " " " " " " p. 134.

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 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 frequent flow-structure, 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

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* 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 solutions which deposited the Cripple Creek ores probably had a similar composition (see Prof.Paper No. 63, U.S.G.S. p. 127, 155.)

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 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 5th 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 intrusions. 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 it 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, unequalled 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

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

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 sulfides or even of metal (in the case of gold) along the walls, while the centre 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 three hundred 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 wide-spread distribution in the underground workings, having been studied by the writer in the Montana, Belmont, Mizpah (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 independentmasses 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 MacNamara 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 furthest 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%) and potash (4.3 - 4.9%) 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 trachyticmagma. 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 solutions 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 dikelets 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% to 73.50%, and the latter (including both fresh and altered samples) from 45.% to 61.6%. 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 6% or over; in the trachyte these constituents are usually around 2 or 3 percent.

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

The combined lime, magnesia, ferrous and ferric oxides varies from 21.17 to 10.05%, for the andesite; and from 7.86 to 1.86% 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%; and of +2.64 to -4.37% 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% or less; and the trachyte ("Lode porphyry") from 66.15 to 73.50% or more; that the excess of lime, magnesia, iron (oxide) and soda over potash varies from +7.35 to +14.38% or more for the andesite; and from +2.64 to -4.37% 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 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 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

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

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,

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

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 rhyoliticlavas, varying from siliceous rhyolite (Oddie rhyolite) to a daciticrhyolite (Brougher 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 <u>intrusive</u> Tonopah rhyolite-dacite (Tonopah rhyolite) in the northern

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* Prof. Paper No. 42, U.S.G.S. pp. 44, 49.
\+ " " " " U.S.G.S. p. 47.

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*. 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 Brougher 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

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* Prof. Paper No. 42, Pl XI

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 Mispah 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 slightly 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 "Mispah 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 groundmass 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

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

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 foot 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 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 probable 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 sulfides, 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 sulfides, principally polybasite, stephanite, and argentite, with occasional pyrite (less abundant in the veins than in the wall rock) chalcopyrite, galena, and blende. Silver selenide 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-Brougher, 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.

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

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.

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*;

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

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 north-east 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 sulfides 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 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 sulfides 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 ~~xxixx~~ 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

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

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.

Second Period "D" Veins

These are east-west veins filling fissures 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 sulfides, and by a pinkish manganese-bearing gangue material which is probably a mixed carbonate of various earthy bases. The primary sulfides comprise stephanite and polybasite, as is the case in the veins of the First Period. The sulfides 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 unusually 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") shoot, and contains a large amount of colorless, usually translucent quartz, with occasionally sulfides in considerable amount. This is a nearly flat vein, approximately parallel to the near-by contact. The content in precious metals is trifling, and the sulfides consist of galena, blende, pyrite, and chalcopyrite. An assay of a picked sample of sulfide-bearing quartz, taken by the writer gave gold, trace; silver, 2.30 oz; copper 0.98%; zinc 5.82%; lead 5.98%. 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

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* 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.)

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

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* Prof. Paper No. 42, p. 195.

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 re-openings of veins of the earlier periods.

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 Mispah 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, argentiferous tetrahedrite and tennantite, polybasite, stephanite, and argentite; 6, the zone of earthy gangues, barren of valuable metals.

It was pointed out in this published paper that on account of changes of temperature in a certain rock zone,

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

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

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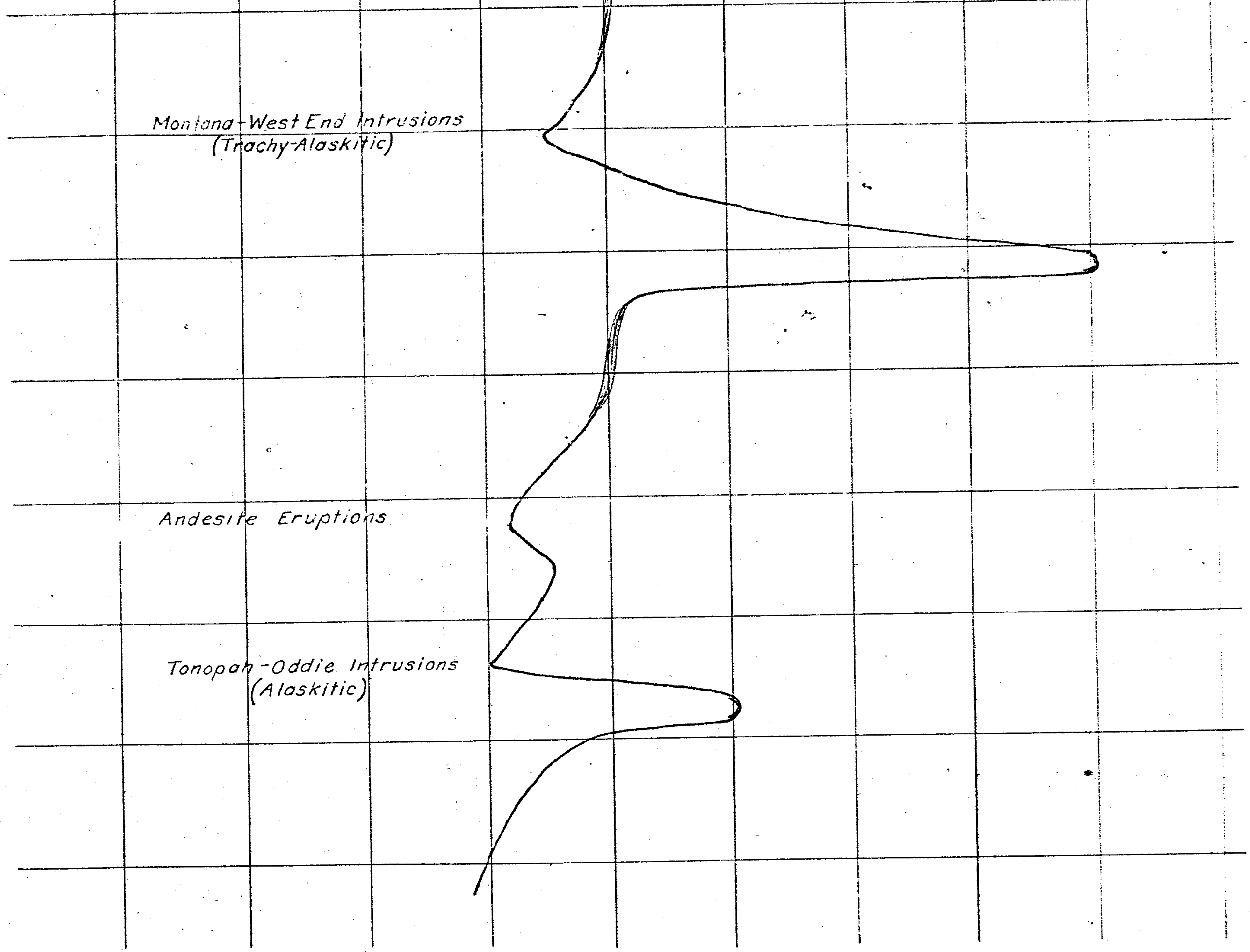
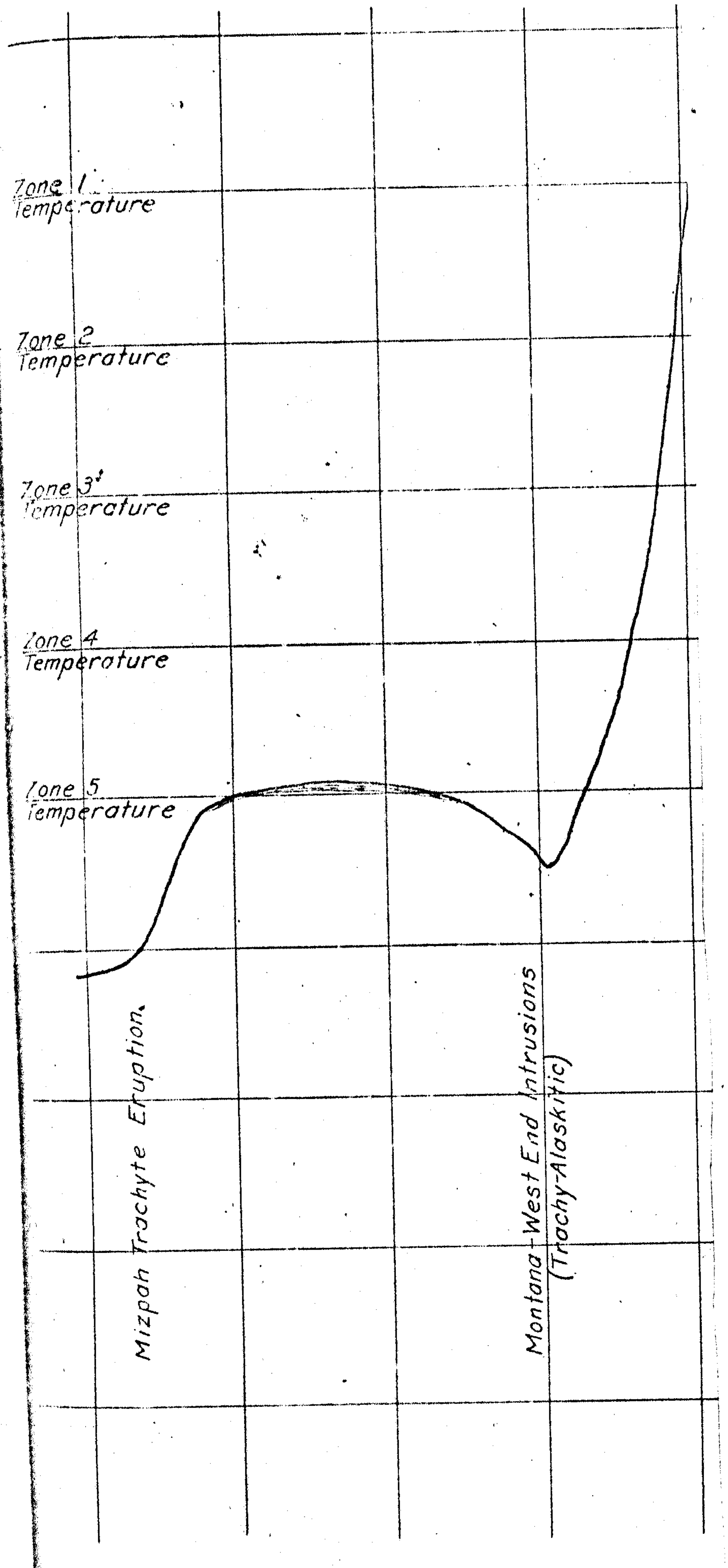
* Economic Geology, June 1909, Vol. IV, pp. 301 - 320.

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.


Montana-West End Intrusions
(Trachy-Alaskitic)
Andesite Eruptions
Tonopah-Oddie Intrusions
(Alaskitic)



Zone 1 Temperature
Zone 2 Temperature
Zone 3 Temperature
Zone 4 Temperature
Zone 5 Temperature
Mizpah Trachyte Eruption.
Montana-West End Intrusions (Trachy-Alaskitic)

The veins of the Third Period, which followed the intrusion of the Tonopah rhyolite contain very little sulfides, 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.

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 red line is a temperature curve and the blue lines represent sulfide 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°F have been encountered in the deep drill-hole at the bottom of the Mizpah shaft.

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

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

* See page 50. this report.

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 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 <u>Second Period A</u> (see p. 53), 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 Mispah andesite or the Tonopah rhyolite.

The study of the Mispah 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 Mispah, Stone Cabin and Belmont fault-zones evidently belong to this period; as for example, the principal movement along the "Desert Queen fault" in the Mispah 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 <u>after</u> their intrusion and solidification.* This is in accord with the present investigation, which shows that this movement 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 described by the writer on the 700-foot level Mizpah.# It has recently been found,

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* Prof. Paper No. 42, U.S.G.S. pp. 47, 68, 80.
\+ See p. 41. this report.
\# Prof. Paper No. 42, U.S.G.S. p.116.

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 Cabinand 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 Mispah 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 whith the microscope shows the fine interlacing nearly parallel lines of pressure-movement which has granulated the rock, marked by lines of sericite.

P A R T II

SPECIAL NOTES ON TONOPAH MINING COMPANY'S PROPERTY

Contents

NOTES ON MAPS

100-FOOT LEVEL:

This level is all in the Mizpah trachyte, and shows the Valley View vein and several of the nearly vertical Stone Cabin veins. The effect of the important Valley View Cross-wall (a more accurate term than the Valley View Fault) is here well shown. This so-called fault terminates the Valley View vein on the east throughout the mine; and on the other side are found the nearly vertical Stone Cabin veins. A strong fault was therefore originally inferred; but as explained in the preceding general part of this report, this line of apparent faulting is really essentially one of those important northeast fractures which were formed before the ore-deposition, and which played an important part in limiting and deflecting the course of the mineralizing solutions. The Valley View vein-fissure, though wide and sufficiently persistent to have formed a large and valuable vein, does not belong to the class of strong and persistent veins illustrated by the Mizpah vein. This Valley View vein branches, dwindles and essentially dies out before reaching the surface, and in depth it dwindles and dies out in the Mizpah trachyte, in most cases before reaching the West End rhyolite intrusion. Similarly on the west it dwindles and disappears in the Mizpah trachyte, as shown on the 500-foot level. It was therefore a fissure or rift formed without much attendant faulting, and therefore not persistent; and on the east side, the transverse

Valley View Cross-wall zone was sufficient to prevent the original Valley View Vein fissure from penetrating farther. As shown on the 500-foot level map, moreover, the Valley View vein on this level did not have the strength to get as far east as the Valley View Cross-wall, but died out in the Mizpah trachyte before reaching it. The Valley View vein, then, offers the unusual example of an important vein whose top, bottom, and sides are evident. The strike and dip dimensions of the vein are shown to be about a thousand feet along the dip, and perhaps 1500 feet along the strike. As the vein has a dip of only about 40°, the actual vertical zone traversed by it amounts to only about 500 feet. On the east side of the Valley View cross-wall are encountered the veins of the Stone Cabin system, with distinctly different strike, dip, and average width as compared with the Valley View vein. There are several of these veins; and it has been found that after crossing the Valley View cross-wall from the Valley View vein on any given level, the nearest Stone Cabin vein is apt to be the most important. At any rate it is clear that these Stone Cabin veins increase in importance as they approach the Valley View veins, and from this it is clear that the solutions which filled the Valley View fissure-zone traversed also to a considerable extent the cross-wall and filled the nearest fissure-zones of the Stone-Cabin system.

These Stone Cabin vein-fissures were in a sense stronger than the Valley View fissure-zone, in that they cross the Valley View Cross-wall. A good example of this is shown on the 100-foot level map, but here it will be observed that the cross-wall has still acted as a deflector of solutions, and that the vein on the west side is without value.

The Pyramid fault on this level is a slight fault, with probably considerable effect as a cross-wall".

200-FOOT LEVEL:

An interesting feature on this level is the Alpha fault, an obscure right-handed fault containing Second Period A quartz, which has faulted the Valley View vein (First Period Quartz).

The Stone Cabin and Mizpah fault systems are well exhibited on this level, particularly the former. The Mizpah-Fault vein, which has cemented the first openings formed by movement along the Mizpah fault, is well-developed, and has yielded some ore. A later movement, (the Desert Queen fault) parallel to and a part of the Mizpah fault system, has brought about a considerable right-handed offset of the Mizpah vein, and smaller faults offset it in the same direction, so that it appears probable that the main Mizpah fault is also right-handed in respect to the Mizpah vein. Striations on several of the faults of this system indicate that the horizontal component of faulting was greater than the vertical--perhaps twice as much.

The initial representative of the Stone Cabin fault, of the same age as the Mizpah-Fault vein and called by the writer the Stone Cabin-Fault vein, is well shown on the map of this level. These two fault-veins trend nearly at right angles to one another, yet at the point of junction neither seems to proceed to any extent past the other, but the main quartz turns a corner at the junction, constituting in a sense a single vein, formed at the same period. It is probable indeed that very little of the movement (normal downthrust on the east) of the Stone Cabin fault persists past its intersection with the Mizpah. The Mizpah fault still persists to the east, past the Stone Cabin, passing into Belmont ground; but its downthrust (normal) movement on the northeast side has been largely offset, east of the Stone Cabin fault, by the drop of the Stone Cabin, so that the importance of the Mizpah fault itself is very much lessened. Section C-C shows that the Stone Cabin Fault, with a dip of 40°, has a movement of as much as 1000 feet along the fault-plane, this movement being measured on a vertical section; which means a vertical component of drop of around 600 feet. As the Mizpah fault, extended past the Stone Cabin-fault, is still a strong normal fault, its maximum displacement (drop), as seen in the Mizpah hill fault-block west of the Stone Cabin fault, must be considerably greater than the figure named. Observations in the Belmont mine, where the remaining portion of the Mizpah fault movement appears to have been completely neutralized by a second fault, parallel to the Stone Cabin--the Belmont fault,--indicate that this surviving movement of the Mizpah fault amounts to several hundred feet, so that say a thousand feet may be taken as a guess-estimate of the vertical component of movement of the Mizpah fault along the Mizpah hill fault-block--and this at an average angle of dip of 30° for the fault would mean a movement of 2000 feet along the plane of the vein, as measured along the dip. But as striae do not indicate a fault-movement along the dip, but a left-handed downward movement at angles of 35° or so from the horizontal; and as the neutralisation of the Mizpah fault by the

Stone Cabin and Belmont faults, each with dips of 35 - 40°, accords with this interpretation of the fault movement, the maximum total displacement of the Mizpah fault in the Mizpah hill fault-block (separation of point from point), may be roughly estimated at between 3000 and 4000 feet. The amount of movement, both of this and the Stone Cabin faults, is varied enormously from point to point, by block faulting, not only of the Mizpah hill block, but of minor blocks within that block, and by numerous important small blocks lying on the upper side of the Mizpah-Stone Cabin fault junction, in the Belmont mine.

According to this reasoning, the actual movement of the Stone Cabin fault was probably also oblique to the horizon, and was a right-handed downward movement at an angle of 30° or so from the horizontal. Therefore the total displacement of the Stone Cabin-fault would be over 1000 feet.

The Mizpah-Fault vein is broken and for long distances cut out by more recent movements in the Mizpah Fault-zone. It normally occurs with both walls in Mizpah trachyte. The bringing in of the Midway andesite at this level was the work of later Mizpah-Fault movements; indeed, at the period of the formation of the Mizpah-Fault vein, (Second Period vein) the Midway andesite eruption had not yet occurred; but the faulting was continued after the eruption of the andesite, and the greater part of the fault-movement took place at this later period. The same observation is true of the history of the Stone Cabin fault.

On the west the veins are cut off on this level by the Burro Fault-contact, which has a quite different history from that of the other two faults described. There are no quartz-cemented auxiliary faults back of the main contact to indicate any history earlier than the main Midway andesite eruption. As a matter of fact, it is probable that this contact is essentially an erosion contact, and represents the side of an ancient valley which was eroded in the Mizpah trachyte, and which was filled by the Midway andesite flow.

Subsequently a certain amount of movement took place along this erosion contact, splitting into various strong slips in the Midway andesite above. Thus the old erosion-contact assumes the appearance and nature of a fault-contact.

An actual fault which displaces the formations, and which is nearly parallel to the Burro fault-contact, but below and to the west of it, is called by the writer the Buried fault. It appears to be older than the Midway andesite eruption. Previously the Buried fault has been confused with the Burro fault-contact, but it is evident that the two are entirely distinct phenomena, both in point of age and of nature.

The explanation of the Burro fault-contact, which appears without doubt the true one, signifies a period of extensive erosion just previous to the eruption of Midway andesite ("later andesite") which now covers so much of the surface in the Tonopah district, and which in its character of a barren capping, has presented the principal difficulty to prospecting outside of the known and developed area.

The period of erosion thus indicated, which produced rugged hills and valleys, certainly is responsible for many of the other inequalities which were overflowed by the andesite eruption; and since at the time of the powerful post-andesite faulting, considerable movement almost invariably took place along these steep or irregular erosion contacts, it is in most cases difficult or impossible, where faults, especially flatly dipping faults, separate the older rocks from the overlying later andesite, to separate the inequalities due to erosion from those due to faulting. There was, for example, very likely erosion along the Mizpah and Stone Cabin faults, previous to the andesite eruption. The above estimates of the displacement of these two faults, however, was not based on the position of the andesite, but on the displacement of the older rocks.

300-FOOT LEVEL:

About the same features are shown as on the 200. Within the Mizpah hill fault-block (bounded by the Mizpah, Stone Cabin, and Burro faults), the formation is entirely Mizpah trachyte, and in this the veins lie. The Alpha fault is shown, and on this level the eastern stump of the Valley View vein-fissure has extended itself westward across the fault, and contains quartz and ore elsewhere characterized* as representing mainly the second period C and D vein-material. On the level this younger extension of the vein is barren, but above the level it yields pay-ore, and has been stoped. There appears to be no corresponding prolongation of the west stump eastward across the fault, as some little development work done at the writer's request on the 200-foot level seems to indicate.

The Stone Cabin and especially the Mizpah fault-zones show the same complex and interesting nature as on the 200-foot level. The curving of the Mizpah-Fault vein to join

* See p. 56-57 General report.

the Stone Cabin-Fault Vein is again shown. The Desert Queen fault (auxiliary to the Mizpah fault) is shown, with a horizontal offset of the Mizpah vein of about 150 feet, measured along the fault. The main most recent portion of the Mizpah fault, separating the trachyte from the Midway andesite, takes a sudden and unexpected curve on passing into Montana ground.

The Stone-Cabin fault on this level is marked by a broad zone of ground-up andesite and trachyte, granulated and laminated so as to resemble tuffs--a condition which is also shown on the 400-foot level.

The Burro Fault-contact has a number of auxiliary slips, showing that there is a very considerable amount of actual faulting along this fault contact.

<u>400-FOOT LEVEL:</u>

At the eastern end of the workings on the Mizpah vein on this level, the Montana-West End rhyolites come in beneath the Mizpah trachyte. As shown on section F, the south branch of the vein is cut off by these intrusions, but the main north branch continues downward, with rhyolite in the footwall and trachyte in the hanging, till it reaches rhyolite, in the hanging, where it cuts out. This is probably the effect of faulting along the vein subsequent to its being cut off by the rhyolite intrusion, as illustrated in the section; the fault zone being occupied by post-rhyolite quartz (colored orange on the section). This rhyolite is dropped down below the level by one of the older auxiliary faults of the Mizpah system; and as shown on section E, the displacement of this fault is great. The curving and uniting junction of the Mizpah-Fault Vein and the Stone Cabin-Fault Vein is well shown. On this level Mizpah trachyte appears on the east side of the Stone Cabin fault*, beneath the Midway andesite (see section B).

To the west, just beyond the Burro fault-contact, the trachyte is crushed and laminated, so as to have a fine fragmental appearance.

The 400-foot level Red Plume is entirely in Midway andesite of unusually siliceous character (see analysis, General Report p.11).

500-FOOT LEVEL:

On this level, along the Mizpah vein, the West End rhyolite comes in at the east end. The vein becomes poor on entering the rhyolite, and the quartz is of the Second Period character, showing that these portions represent later (post-rhyolite) extensions of the original (pre-rhyolite) vein-fissure. Ordinarily the vein is entirely lost a short distance after passing into the rhyolite.

The main Stone Cabin fault on this level, appears to swerve to the northwest, so as nearly to coincide with the Desert Queen fault, with whose important movement its movement is joined; continuing past this fault, it joins the Mizpah. The faulted fragments of the Mizpah vein, therefore, now occur east of the Stone Cabin fault, between this fault and the Mizpah fault. The Mizpah-Fault Vein also now appears east of the Stone Cabin fault. East of the Stone Cabin fault, also, in Silver Top ground, a narrow vein having the characteristics of the Stone Cabin vein system has been developed in the trachyte. The same or similar veins are found further east, in the Belmont mine.

Along the Mizpah vein, just east of the Mizpah shaft, the Montana Breccia occurs in close proximity to the West End rhyolite; the contacts indicate that the latter is intrusive into the former. Some distance west of the shaft a northeast-trending, flatly southeast-dipping fault, (the Beta fault) cemented by quartz of the Second Period, offsets in right-handed fashion the Mizpah vein. This same fault also crosses the path of the Valley View vein, but this vein dies out just before reaching the fault, so that there is no continuation on the other side. It also crosses the path of what is probably the MacNamara vein, faulting the formations, and apparently acting to some extent as a deflecting cross-wall to this vein. Southeast of this fault, no ore has been found, and the quartz along the contact dwindles and disappears.

Going west beyond the Beta fault, the Mizpah vein pinches down very small. It barely reaches the contact of the overlying Midway andesite, whose contact is here unaccompanied by faulting, and is indeed barely recognizable. Analyses, however, (see p.11 General Report), show this overlying rock to be fairly typical Midway andesite, not so siliceous as the andesite of the 400 Red Plume, immediately above.

The MacNamara vein, as it is identified in the southwestern portion of the Mizpah workings, appears to be downthrown by the Buried fault on the west side, to its position in the West End workings. The Buried fault does not extend as far north as the Mizpah vein on this level, and is probably cut out by a combination movement with the Siebert fault. Immediately below, on the 600-foot level, it does cut the Mizpah vein with an important (about 150 feet) downthrow on the west side, similar to the movement shown by it on the 500-foot level, southwest corner, just described, where it displaces the MacNamara vein. The Siebert fault intervenes between the 500 and 600-foot levels, cutting out the Buried Fault so that it does not extend up to the 500-foot level (Section B).

The MacNamara vein also dips down from the MacNamara mine into Red Plume ground on this level, in its usual position at the upper contact of the West End rhyolite, but is badly broken by faulting and contains very little ore--a condition characteristic of most of this vein, in all mines.

A portion of the Tonopah Extension vein also comes into Red Plume ground, but is cut off on the east by a fault believed to be closely connected with the Siebert fault. It is regarded as a possible though unproved hypothesis that the Extension Vein and the MacDonald Vein of the Midway and Montana mines, (a fragment of which passes into Red Plume ground) may be the same vein, spearated by this faulting.

<u>600-FOOT LEVEL</u>:

On this level the West End rhyolite --Montana breccia intrusions have come in under the Mizpah vein, east of the Mizpah shaft, cutting it out entirely. West of the Beta Fault, a block of the Mizpah vein occurs with West End rhyolite on the foot, and trachyte on the hanging wall, the difference in the walls being evidently due to faulting, as already explained in a similar case. Where the vein-fissure, both laterally and in a winze sunk below the level, passes into the rhyolite on both sides, the pay-ore ceases abruptly, only narrow barren veins of Second Period quartz (including hübnerite-bearing quartz, Second Period B) passing into the rhyolite. Further west the vein disappears in a complication of faulting; and an important fault--the Central Fault--occurs, on the west side of which "glassy trachyte" comes in, and with some Montana Breccia and Midway andesite ("calcitic andesite" shoot) occupies the drifts as far as the Buried fault. This "glassy trachyte" shows large amounts of barren quartz of the Second Period, in ill-defined veins, but no ore.

The drop of the Buried fault brings in a block of the Mizpah vein on the west side, with Mizpah trachyte on both walls. This vein is cut off on the west, not far from the Red Plume shaft, by a barren vein of the Second Period, (Midway-Fault vein), which is probably connected with the MacNamara vein. Above, this vein-block is cut off by a flat, more recent (unsilicified) fault, evidently of considerable extent, which is regarded as probably the Siebert fault.

The West End rhyolite at and west of the Red Plume shaft on this level adjoins the Mizpah trachyte which lies on the north, with a very evident east-west striking, north-dipping ancient normal fault contact (Red Plume fault), now occupied by an immense Second Period Vein (Red Plume Vein) of the MacNamara type. This fault and vein are well shown in Section I, where is also shown the probable connection and contemporaneity with the

MacNamara vein. This Red Plume vein, like all others of this type is mainly barren, although locally it contains some high-grade ore. The data on this vein, combined with that on the Midway 530-foot level (only a few feet above the Red Plume 600) shows that the Midway fault-vein cuts off and probably terminates on the east the Red Plume vein; and that both are cut off above by the Siebert fault. The Midway fault and fault-vein represent an important northeast-striking, flat (30 - 35°) southeast-dipping zone of displacement, having as seen on horizontal plan (in the Midway) a strong left-handed displacement. This fault is older than the Montana fault, which it does not displace (in the Midway), and also older than the Siebert fault, which belongs, like the Montana, to a relatively recent period. As the Montana fault is probably, like the Burro fault-contact, probably mainly a normal contact affected by subsequent faulting, the Midway fault and fault vein is also older than the Midway andesite, which confirms the designation of the vein as belonging to the Second Period.

A north cross-cut is now exploring the Mizpah trachyte lying north of the Red Plume shaft on this level.

The Valley View vein on this level is near its normal bottom, even where it has not reached the West End rhyolite--and it pinches out to little or nothing at both ends. Some probable faulting along this vein, subsequent to the intrusion of the West End rhyolite, is indicated by the relations at the east end of this vein, the movement having been a drop of the hanging wall, as in the case of the Mizpah vein.

700-FOOT LEVEL:

On this level neither the Valley View nor the Mispah veins occur. The Mizpah shaft is in the intrusive Midway andesite ("calcitic andesite") sheet, and a small patch of Tonopah rhyolite ("lower rhyolite") is exposed near the Silver Top fault. This rock is mainly dense, white, and well banded, and is discussed on p.46 General Report).

South from the shaft, the Midway andesite is separated from the overlying West End rhyolite by the Siebert fault, as named in the writer's earlier report. This shows a regular layer of a few feet of compact breccia, with a hardened clay gouge seam limiting the breccia. This fault, well shown also north of here in the Montana, belongs evidently to the more recent series of post-andesite movements. There are on this level, as shown in the main cross-cut, a number of strong, north to northeast, barren veins (Veins of the Second Period) in the West End rhyolite, which do not extend into the Midway ("calcitic") andesite, showing that the Veins of the Second Period are older than the advent of the andesite.

In the Red Plume 700-foot level, the Red Plume vein has been followed down from the 600, and has a Glassy trachyte foot, and a West End rhyolite hanging wall. On this level, however, it is mostly barren, so far as developed to date. Some blocks of Mizpah trachyte appear on this level, and should be explored.

The Red Plume shaft on this level is in fine-grained Mizpah trachyte, lying beneath the West End rhyolite in the shaft above, and showing transition into the Glassy trachyte. The south cross-cut from the shaft passes from the Glassy trachyte into the Midway ("calcitic") andesite, overlain by the Glassy trachyte. This andesite is associated with banded rhyolitic rocks, and rhyolitic breccias referred after much study, with considerable confidence, to the Tonopah rhyolite ("lower rhyolite") Numerous small dikelets of this rhyolite breccia definitely intrude the andesite, showing partly the same dark glassy phases described on a former page (p. 49 General Report) and partly the typical rhyolite breccia. A band of this breccia a few feet thick lies between the Midway andesite and the overlying Glassy trachyte, and is regarded as a dike. The white banded rocks, with occasional quartz phenocrysts, represent the same phase of the Tonopah rhyolite as is exhibited on the 700 and 900-foot levels of the Mizpah (see p. 46 General Report).

The drill-hole record in the bottom of the Red Plume shaft, below this level, indicates that this Midway andesite sheet is comparatively thin, and that below it the Glassy trachyte again comes in (Section I).

NOTES ON SECTIONS

Section A shows especially the Stone Cabin fault; the parallelism of the Valley View cross-wall to this fault; the Silver Top and Alpha faults, and their relation; the Buried fault and the Burro Fault-contact, and their relation; the Siebert fault; the MacNamara vein; and the wedging of the West End rhyolite intrusion from west to east.

Section B shows especially the Stone Cabin fault;

the Valley View cross-wall, with the relation of the Valley View and Stone Cabin veins on its two sides; the Silver Top fault; the Buried fault and Burro fault-contact, and their relations; the valley of erosion filled by Midway andesite and bounded on one side by the Burro fault-contact; the Red Plume vein; and the Red Plume shaft section.

Section C is designed to show especially the Stone Cabin-Fault Vein and Stone Cabin fault; the junction of the Stone Cabin fault and the Mizpah fault; the Siebert fault; the intrusion of the Glassy trachyte by the Midway("calcitic") andesite in the Midway mine; the wedging out and disappearance of the andesite to the east; and the large block of Glassy trachyte around the Desert Queen shaft. The Siebert fault as here depicted indicates a westerly movement on the under side, which may possibly amount to as much as 1500 feet. Viewed in this light, it is a possible hypothesis that the Midway and Beta faults are one and the same fault, separated by the Siebert fault. Both the Midway and the Beta are northeast-striking, flat southeast-dipping faults, with normal moderate downthrow on the southeast; both are marked locally by large amounts of barren Second Period A quartz, and both are evidently older than the Siebert fault. The distance between the faults, which would measure the Siebert fault movement if their identity should be true, is 1000 to 1100 feet, as measured on the 600-foot level map, and on section C.

Section D is designed especially to show the Mizpah and Valley View veins; the pinching out of the Valley View vein in Mizpah trachyte, in depth; the effect of the Alpha fault on the Valley View vein, and the extension of one of the broken stumps, after the faulting.

Section E is designed especially to show the complex structure and history of the Mizpah Fault-zone; and also affords a good section of the Valley View Vein.

Section F shows good sections of the Mizpah and Valley View veins; the behavior of the Mizpah vein on reaching the West End rhyolite; the Valley View cross-wall, and the relation of the Valley View and Stone Cabin veins, on the two sides of this cross-wall; and the course of the Mizpah fault on passing from Mizpah into Montana workings. It also shows the identity of the "Desert Queen" fault with the "106 Fault" of the Montana.

Section G, taken approximately through the two main shafts and drill-holes, shows impressively the immense mass of Tonopah rhyolite ("lower rhyolite"); with excellent cross-sections of the Valley View and Mizpah veins; the pinching out of the Valley View vein in depth, before reaching the West End rhyolite; the relation of the Valley View and Stone Cabin veins, on the two sides of the Valley View cross-wall; the passage of some of the Stone Cabin veins through the Valley View cross-wall, though with abrupt change of volume; the decided tendency of the Mizpah vein to pinch in depth along this section, even before reaching the West End rhyolite; the Siebert fault; the Desert vein (Third Period); a rhyolite porphyry dike in the Tonopah rhyolite; and the masses of andesitic rock included in the Tonopah rhyolite.

Section H shows excellent cross-sections of the Mizpah and Valley View veins; shows the effect of the Alpha fault on the original Valley View vein, and the subsequent prolongation of the original fissures past the fault, which new fissures have been cemented by later, smaller, usually low-grade or barren veins; illustrates the dying out of the Valley View vein in the Mizpah trachyte in depth; shows the dying out in depth, in the Mizpah trachyte, of one of the Burro veins; illustrates the displacement of the Mizpah vein by the Beta Fault-vein; and the cutting out of the still strong Mizpah vein in depth by the West End rhyolite.

Section I shows especially the MacNamara and Red Plume veins, and their relation; the cutting off of the Mizpah Vein (First Period) by the extension of the MacNamara vein (Second Period); and the flat fault (Siebert fault?)--cutting off the Mizpah Vein above.

SALIENT POINTS BROUGHT OUT BY MAPS AND SECTIONS

The maps and sections show that the Valley View vein has been developed to its termination--in the Mizpah trachyte--on top, bottom and sides; and that no further extensions of it in any direction are likely to be found. The stronger Mizpah vein mainly continued downward in full strength till it was cut off by the Montana-West End rhyolite intrusions. The subsequent Mizpah andesite and Tonopah rhyolite intrusions obliterated all the older rocks, and the thickness of the latter intrusion appears to be so immense that there is very little further hope of encountering veins of this First Period type in depth in this mine. The extension of the Mizpah vein on the east passes into the Belmont.

Some development work may still be done on the

Veins of the Second Period--especially the Red Plume vein--in the Red Plume ground. The Mizpah trachyte in the northwestern part of the Company's property should be thoroughly explored for new veins.

ANALYSIS OF WARM WATER

Following is the analyses made by the United States Geological Survey of warm water from the deep vertical drill-hole in the Mizpah shaft:

Report of Analysis No. 2496.
Material received from J. E. Spurr,
Hot water, Tonopah, Nevada.

Parts per million

SiO_2	64.8
Al	0.7
Fe	0.7
Ca	68.8
Mg	6.3
Zn	tr
Na	148.8
K	3.4
SO_4	327.2
Cl	35.6
NO_3	tr
CO_3	10.6
HCO_3	157.2
Br, I	none

Total solids 824.1

Equivalents (exclusive of SiO_2) (Molecular ratio)

Al	.10	SO_4	6.82
Fe	.00	Cl	1.00
Ca	3.44	CO_3	.35
Mg	.52	HCO_3	2.58
Na	6.46		
K	.08		
	10.60		10.75

Examined by R.C. Wells
and reported Oct. 14, 1910

F. W. Clarke,
Chief Chemist

RECOMMENDATIONS FOR DEVELOPMENT WORK

900	No work recommended.
700 RED PLUME	From extreme Western portion of workings (D 706) drive straight exploration drift in Mizpah Trachyte ("Earlier Andesite") cross-cutting at intervals south to explore quartz on trachyte-rhyolite contact, and at greater intervals north as plain exploration work.
700 SILVER TOP	Drive E.N.E. on vein about 20' N. of S. T. Shaft, until W. E. Rhyolite is encountered. From this drift, at a suitable distance in, cross-cut Mizpah trachyte ("E. A.") to W. E. rhyolite contact, both North and South.
	From breast of drift 798, cross-cut M. T. ("E.A.") formation, in a S.S.W. direction, to W. E. rhyolite contact.
600 LEVEL	Along line about 170 East of Desert Queen Shaft, arrange for North-South Cross-cut between north boundary line of property and Glassy trachyte or other barren formation on South, thereby cross-cutting whole Mizpah trachyte ("lode porphyry") formation at this point.
	On same level explore veins on North of Desert Queen shaft from workings, especially fragment of Mizpah vein about 150 ft. N. of Shaft, raising up on vein.
	From this vein just West of property line, cross-cut M. trachyte ("lode porphyry") in a direction a little West of North.
600 SILVER TOP	From point on Valley View drift about coordinate 1700 W. Cross-cut M. trachyte ("E. A.") to North to W. E. rhyolite contact.
	From S. T. Shaft Cross-cut M. trachyte South to W. E. rhyolite contact on property line.
RED PLUME	Continue cross-cut No. 630 South, keeping on West side of Buried Fault, so long as it remains in Mizpah trachyte ("E. A.") If contact of trachyte ("E. A.") and rhyolite (W.E.Rhy.) is encountered, explore this contact if it shows favorable indications.
	At point about 3560 W. 2235 N. cross-cut North through M. T. to property line
	Continue cross-cut 628 North to property line, so long as in M...

500 LEVEL

Drive 515 East to line, following vein if possible. From near end cross-cut South to line and North to Mizpah fault.

Drive 517 West.

Drive cross-cut South from Valley View Shaft property line, or until the W. E. rhyolite is reached.

Connect up 525 S. T. and 563 Mizpah cross-cuts.

Continue cross-cut 536 Mizpah south in Mizpah trachyte ("E. A.") to Wandering Boy line. If Buried fault is encountered, with one of the formations designated in the report as unworthy of much prospecting beneath it, work may be stopped.

Continue 519 cross-cut north to property line from Mizpah near co-ordinate 1900.

On cross-cut 514 Mizpah at point 2435, drift east and west on vein.

Continue cross-cut 544 due south 100 feet.

400 LEVEL

Continue cross-cut 403 about S. 30 E. to explore Mizpah trachyte ("E. A.")

Turn cross-cut 457 to a N. 45 degree E. course, and continue to Mizpah fault or property line.

Continue cross-cut 439 south to drift on Stone Cabin vein.

From about co-ordinate 1400 or Stone Cabin vein, cross-cut southeast to property line.

Continue 409 cross-cut south-southwest, keeping on west side of Valley View cross-wall.

Continue 458 south to property line.

Continue 425 cross-cut S.S.W. keeping on west side of Silver Top fault. Either 406 or 425 cross-cuts should be continued to Valley View vein.

Cross-cut north from 440 cross-cut Silver Top to connect with 402 drift Mizpah.

Continue cross-cut 410 Northeast to line keeping east of Burro fault-contact.

[illegible] LEVEL

Continue [illegible] cross-cut south, keeping west of [illegible] cross-cut.

From [illegible] drift [illegible], cross-cut due south west to [illegible] line.

Continue cross-cut [illegible] north to line.

200 LEVEL

From east end drift 219 on Stone Cabin fault vein, drive north along vein, following quartz.

Continue cross-cut 201 to line.

Continue cross-cut 240 further south.

Connect cross-cuts 205 Mispah and 234 drift Silver Top.

SANDGRASS

Analyze andesite to determine if capping. If so put down several vertical drill holes from surface to determine formation. This will give information as to how to proceed.

Respectfully submitted:

SPURR & COX (INC.)

[illegible]

by

Tonopah, Nev., Oct. 31, 1910

Montana Section a~a'
Scale 1in = 80ft.
Spurr & Cox, Inc.
October 1910.

These maps apparently are part of the Spurr & Cox 1910 report — the text was xeroxed at Univ. of Wyoming
MONTANA - TONOPAH Rpt.