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Mining District File Summary Sheet

DISTRICT	Tonopah
DIST_NO	4840
COUNTY If different from written on document	Nye
TITLE If not obvious	~~See cover~~ 'The Geology of the Producing Part of The Tonopah Mining District'
AUTHOR	Burgess, J
DATE OF DOC(S)	1909
MULTI_DIST Y / (N?) Additional Dist_Nos:	
QUAD_NAME	Tonopah 7½'
P_M_C_NAME (mine, claim & company names)	Montana Tonopah; North Star; Tonopah Extension; MacNamara; West End; Corkill; Rhyolite; Fraction No. 1; Fraction No. 2; Wandering Boy; Stone Cabin; Silver Top; Desert Queen; Midway; Mizpah.
COMMODITY If not obvious	Gold
NOTES	Geologic article; geology; reprint; geologic map; Economic Geology vol IV, no8 p 681-717, December 8, 1909 cross sections; geochemistry; photographs. Coats donation 37p.

Keep docs at about 250 pages if no oversized maps attached (for every 1 oversized page (>11x17) with text reduce the amount of pages by ~25)

SS: DD (Initials) 12/12/08 (Date)

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Revised: 1/22/08

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THE GEOLOGY OF THE PRODUCING PART OF THE TONOPAH MINING DISTRICT

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J. A. BURGESS

Economic Geology Publishing Company

[Reprinted from Economic Geology, Vol. IV., No. 8, December, 1909.]

THE GEOLOGY OF THE PRODUCING PART OF THE TONOPAH MINING DISTRICT

J. A. Burgess.

CONTENTS.

INTRODUCTION.

It is the purpose of this paper to present an interpretation of the structure of the Tonopah mining district, differing materially from that heretofore entertained. The "Geology of the Tonopah Mining District," by Mr. J. E. Spurr,[1] formed as complete a description of the district as could be compiled at that time; but in 1905 sufficient mine work had not been done to afford the basis for a confident determination of the relations between the earlier andesite and the underlying rocks. At the present time it is thought that mine workings have been sufficiently extended to

[1] U. S. G. S., Professional Paper, 42, 1905.

supply this deficiency; and to justify the construction of the accompanying geologic sections and the formulation of a hypothesis based upon them.[1]

The solution of the geological problem here offered is that the district is built up of a series of successive lava flows and tuffs. This differs from Spurr's hypothesis, which proposed that the earlier andesite was the oldest of the rocks exposed and that it was intruded by the rocks here designated as the upper and lower rhyolites. The present departure from the theory of the intrusive nature of these rocks is suggested by the comparative uniformity of depth and area within which the upper rhyolite has been found, and from this it is easy to take the next step of regarding all the rocks as surface-formed sheets. It has been found that this conception of them is well supported by the evidence at hand.

MAPS AND SECTIONS.

The accompanying map, Fig. 80, has been copied, with some alterations, from Spurr's report. It illustrates the surface distribution of the rocks shown in the sections. The area crossed by the sections lies almost wholly within the productive part of the district, but does not cover all the producing mines, especially those in the western part of the camp. The writer has a fair degree of familiarity with the mines not represented, and has seen nothing in them that is inconsistent with the scheme here outlined.[2] Development in the outlying, non-producing mines has seldom penetrated below the horizon of the earlier and later andesites, and consequently gives little positive information as to the position and character of the underlying rocks. The

[1] The writer wishes to acknowledge his indebtedness to Professor A. C. Lawson for numerous helpful suggestions regarding this work. Thanks are also due to Mr. E. D. North for furnishing the sections of the Montana Tonopah Mine, to Mr. E. S. Larsen for microscopic work on the lower rhyolite, and to Professor G. J. Young for chemical analyses.

[2] The information in this paper concerning the workings from the Desert Queen shaft was obtained while the writer was connected with that mine. It does not represent the development of the past two years, excepting the drift reaching out towards the Belmont shaft.

best information regarding the rocks in these mines is to be found in Mr. Spurr's paper. The writer has had little opportunity for inspecting them, owing to the cessation of work in them before

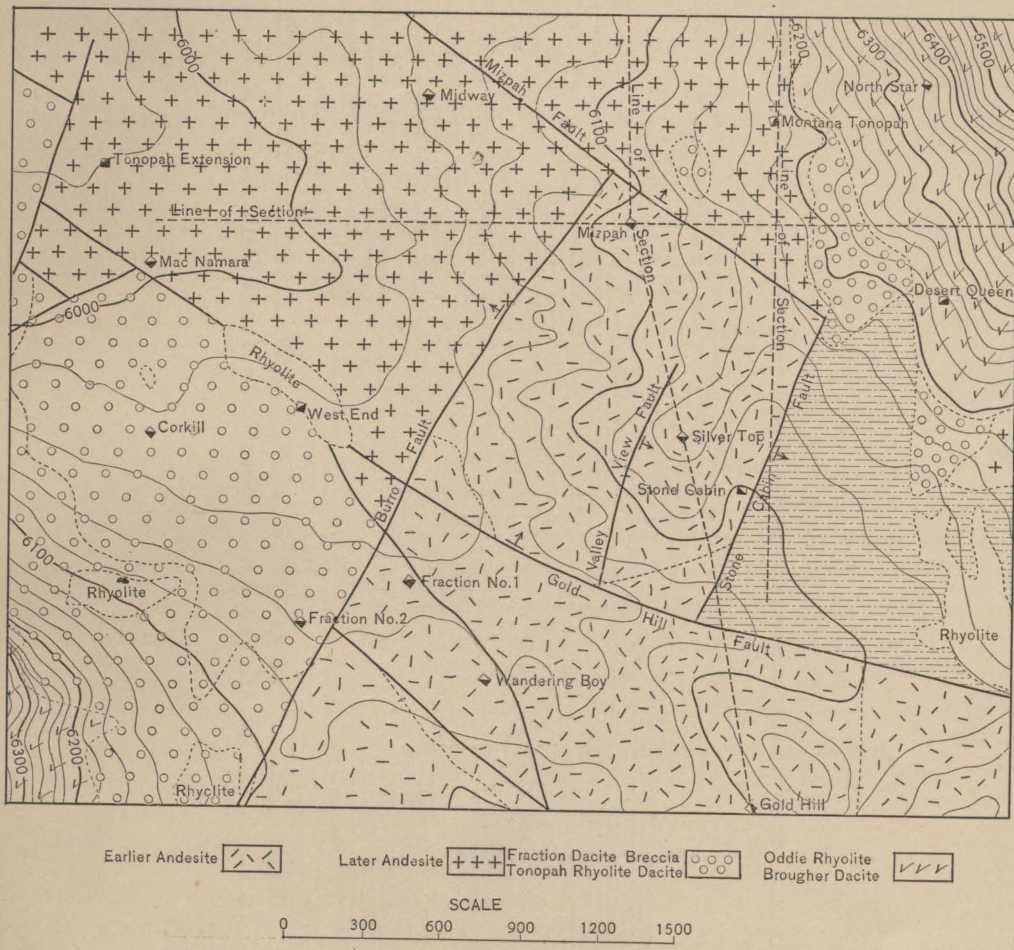

FIG. 80. Geologic surface map of the producing area of Tonopah.

or shortly after his arrival in the district in 1906, and therefore no attempt has been made, in the sections, to indicate the geology beyond the limits of present accessible workings; and the discussion which follows will be confined mainly to these limits.

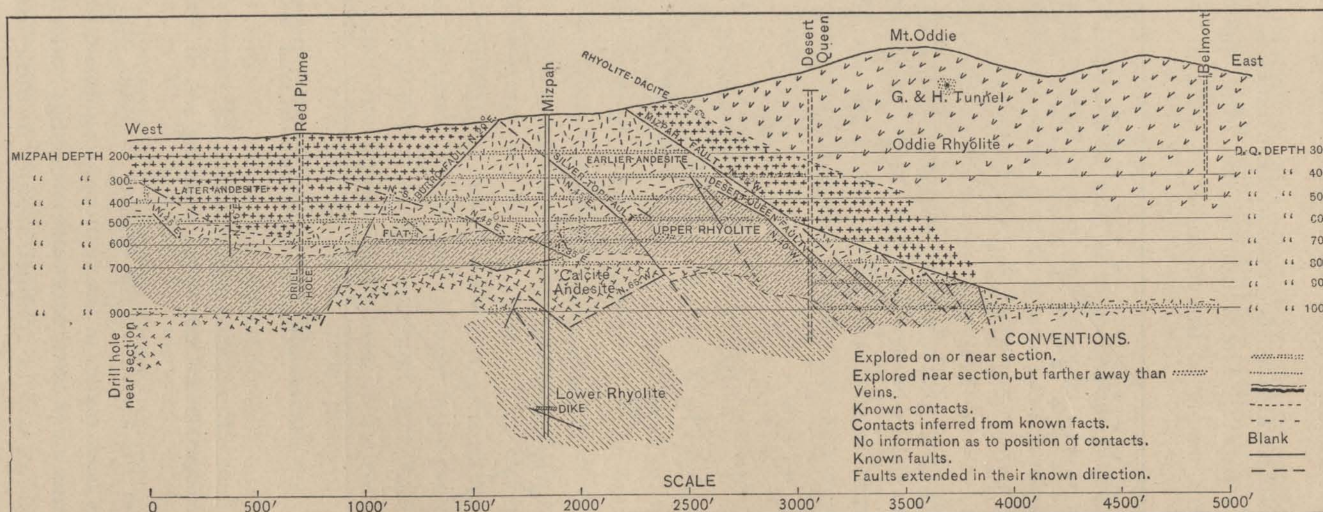

FIG. 81. East-West Section through Mizpah Shaft.

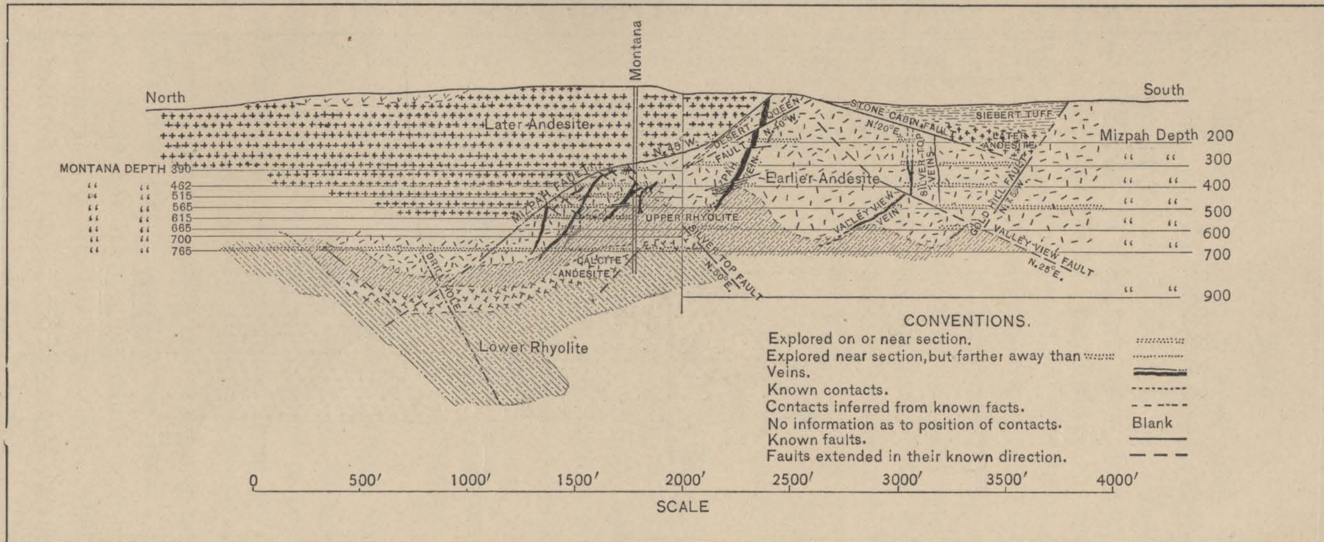

FIG. 82. North-South Section through the Montana Tonopah Shaft.

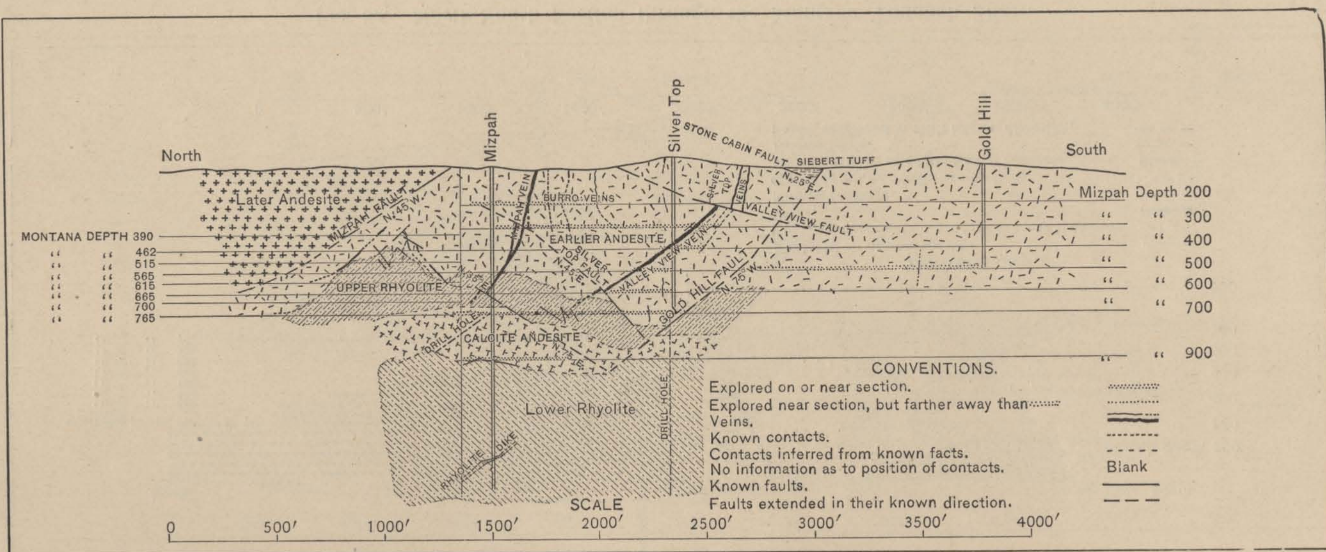

Fig. 83. Section on Line of Mizpah and Silver Top Shafts.

LOWER RHYOLITE.

The lower rhyolite is the oldest of these rocks. It has been found wherever mine workings have penetrated below the calcite andesite. This has been accomplished in the following places: in the Mizpah shaft, in the Montana shaft, in a cross-cut east and drill-hole north from the Mizpah shaft on the 700 foot level, in a drill-hole from the Silver Top shaft, in a drill-hole from the Montana workings, and probably in the Desert Queen shaft. All these exposures are shown in the accompanying sections.

In the Mizpah shaft the rock presents a fairly uniform appearance. It is a light-colored, greenish-gray, hard, compact rock. It contains numerous small grains of quartz and feldspar, and occasional small angular fragments of foreign rocks, such as granite, andesite, carbonaceous shale, rhyolite. At a depth of 1,365 feet a dike three feet in thickness was encountered, which will be described elsewhere.

In the Silver Top drill-hole, the rock is not as uniform in character as in the Mizpah shaft. After passing through 86 feet of normal rhyolite, the hole encounters a 36-foot body of white altered rock, containing sparsely scattered crystals of white feldspar, and for twenty feet below this stratum the rock consists of interbedded layers of indurated tuff and breccia. The contacts between tuff and breccia are distinct and are plane and parallel and usually dip at an angle of 60°. A photograph of this part of the core is shown in Fig. 84.

Where exposed in the cross-cut on the Mizpah 700-foot level, 500 feet east of the shaft (shown in Fig. 81, at a depth of 750 feet by projection), the lower rhyolite consists of perfectly stratified tuff and breccia, tilted to an angle of about 45°. The separate layers are composed of well assorted material, which varies in different layers from fine ash to coarse breccia, and which are from one eighth of an inch to eight inches thick. The material composing the strata has been indurated to a rock of soft or medium hard consistency. It has a clay odor when dampened. The contacts between the layers are plane and parallel, and form distinct parting planes when the rock is broken. There has been no internal movement in the rock or between the strata since its deposition, although it has been tilted and faulted in large blocks. A photograph of a specimen of this rock, marked 407, is shown in Fig. 84.

In the drill-hole from the Montana workings and in the one from the Mizpah 700-foot level, the lower rhyolite possesses the same general characteristics as in the places just described, but in places partakes more of the nature of a flow than of a consoli-

FIG. 84. Indurated stratified tuff from the lower rhyolite. Specimen No. 407 mentioned in the text. Core from Silver Top drill-hole. Size of large specimen 9 x 7 inches.

dated tuff. It has not been examined in thin section. As shown in the Montana drill-hole, there are layers within the rhyolite of what are probably latite or andesite, but which are much altered and have not been analyzed or examined microscopically. The writer has not been to the bottom of the Montana shaft, but has good authority for the statement that the rock there is a rhyolite similar to that just described.

The rock at the bottom of the Desert Queen shaft is a rhyolite, and although the writer has not seen it for two years, he would classify it from memory with the rock at the bottom of the Mizpah shaft. This has been the opinion of all who have seen both rocks. If this is correct, it means that the calcite andesite is not represented at this place, and that it wedges out between the Mizpah and Desert Queen shafts as shown in Fig. 81, and this explanation seems probable. The present hesitation to be positive of this is due to the recognition of the possibility that the rhyolite, at the bottom of the Desert Queen shaft, is a lower phase of the upper rhyolite.

Specimens and thin sections of the lower rhyolite from the Mizpah shaft and Silver Top drill-hole were sent to Mr. E. S. Larsen, of the Carnegie Institute, for examination and were reported on by him as follows:

The specimens, with the possible exception of No. 90 (the white altered rock found in the Silver Top drill-hole) are all tuffs. Some of them might be flow-breccias but I do not think it at all likely. Many of the specimens are made up of angular fragments of different rhyolitic rocks which are imbedded in a fine matrix, which shows no evidence of being a flow, but has broken fragments of quartz and feldspar in a fine dust-like base. Alteration is usually extensive. Some of the specimens show fragments of a quartzite.

The other specimens have no fragments of rock, but are similar to the matrix of those above. They consist of a varying amount of fragments of quartz and feldspar in a fine paste which is typically tuffaceous. Specimens No. 407 (four sections and specimens from the strata on the 700-feet level of the Mizpah) are well-bedded tuffs and are similar to the other rocks though made up of a little finer material.

The rocks are made up of quartz, orthoclase, plagioclase and altered biotite, and are rhyolites or quartz latites. I feel no hesitation in calling them tuffs. The abundant fragments of rock of different kinds, the fragmental character of the quartz and feldspar, and the character of the enclosing paste, all point in that direction as well as the fact that No. 407 is surely a tuff. I have not described the specimens separately as one description practically fits them all.

ANALYSIS OF THE LOWER RHYOLITE.[1]

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
75.17	15.83	0.90	0.46	0.39	2.08	3.18	0.61	0.17	2.16	100.95

From the foregoing description of the rock, together with its silica content of 75.17 per cent., the lower rhyolite may be regarded as a complex of rhyolitic tuffs, breccias and flows, with possible interbedding of latite. It cannot be intrusive. As indicated by the apparent unconformity between the overlying andesite and the tuff beds, the rock was tilted and suffered erosion before the outflow of the calcite andesite.

In sinking the Mizpah shaft through this rock a permanent flow of water was encountered at a depth of 1,230 feet. The water has a temperature of 94° F. and is slightly alkaline. The rate of flow is 60 gallons per minute.

RHYOLITE DIKE.

The dike at the 1,365-foot point in the Mizpah shaft is about three feet thick. It strikes east-west and dips about 45° north. It is rhyolite with exceptionally well developed porphyritic structure. It contains numerous quartz phenocrysts and well-developed crystals of orthoclase and plagioclase, with a lesser amount of altered ferro-magnesian mineral. The accessory minerals are apatite and magnetite. The quartz phenocrysts have been subjected to much corrosion by the groundmass, and are roughly of spherical form. The embayments have taken the shape of irregular tubes through the quartz, and are so numerous that they give the specimen the appearance of a section through the coarser variety of sponge. The material in the embayments or tubes has been replaced in some phenocrysts almost entirely by quartz and to a less extent by calcite. In some tubes the quartz has formed in interlocking grains of varying orientation; in others it has grown in crystallographic continuity with the quartz of the phenocrysts. The quartz in the tubes is readily distinguished from the original quartz of the phenocryst by the numerous dusty

[1] The rock analyses in this paper were made by Professor G. J. Young of the University of Nevada.

inclusions in the former. Some of the tubes contain sericite and various other alteration products of the glass, instead of quartz. The original quartz is irregularly cracked, and contains swarms of fluid inclusions. Many of the cavities are not completely filled with the fluid, but contain minute bubbles, some of which are moving rapidly within the liquid. The quartz encloses accessory apatite and magnetite. Some of the feldspars look pink and fresh in the hand specimen, but many of them are much altered. Some of them are altered to a fine grained mica. Of those that are not completely altered, some prove to be orthoclase and some plagioclase, and intergrowths of the two are common. The orthoclase crystals are the largest and freshest, and some of them attain a length of three fourths of an inch. The plagioclase shows small extinction angles of 5°. The ferro-magnesian mineral has altered to green chlorite which shows faint pleochroism. Judging from the outlines of some of the individuals, they consisted of biotite and hornblende. The groundmass is devitrified and consists mostly of finely mottled patches of quartz sometimes interlocking. It contains some veinlets of sericite and patches of calcite. The border facies of the rock is of finer grain than the middle, and the contacts are typically those of an intrusive.

CALCITE ANDESITE.

The calcite andesite, the name by which this rock is commonly known, is a shortened form of Spurr's term, "the calcite phase of the earlier andesite." The rock was originally a hornblende andesite of structure and composition similar to the earlier andesites. It owes its color chiefly to chlorite, which is present as an alteration product of the original ferro-magnesian minerals. In thin section, calcite, chlorite, quartz, sericite, pyrite and probably kaolin, are seen to be the most prominent among the alteration products composing the rock; while in fresher portions striated feldspars, only partly decomposed, may be found. By the Michael Levy process their extinction angles prove them to be andesine-oligoclase. The rock seems to have been originally a

ANALYSIS OF THE CALCITE ANDESITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
56.40	20.12	5.87	3.55	1.99	4.87	2.56	2.59	0.09	2.41	100.45

continuous sheet of varying thickness, throughout the greater part of the district. It is not found in the Desert Queen shaft, but west of there it has been found under the upper rhyolite wherever mine workings have extended below that rock. In the Mizpah shaft it occurs at a depth of 700 feet, and allowing for faulting and folding, it lies at a fairly uniform depth wherever found. Its thickness is known to be over 280 feet in the western part of the camp.

It was probably deposited on an uneven surface of erosion; and if its deposition were also followed by erosion, this would account for its varying thickness, and its entire absence in the Desert Queen shaft.

UPPER RHYOLITE.

The upper rhyolite, popularly known as the "dacite intrusion," is the body of rock that overlies the calcite andesite. It is mostly of a uniform type, but the sheet is a complex of several flows. The normal facies, that met with most commonly, is a dense rock of fine texture with a pale greenish-gray color. Porphyritic structure is not developed. The rock has an argillaceous odor when wet, which indicates the presence of much kaolinic substance. The joint surfaces are usually talcy.

The rock is much altered. Under the microscope, by ordinary light, the section looks murky with alteration products. Between crossed nicols the mass of the rock is seen to be composed principally of colorless mica, kaolinic substance and secondary quartz. The mica is in minute flakes showing high interference colors and is probably sericite. It is evenly distributed and covers about half the area of the section, but owing to its flaky nature it is doubtless of less quantitative importance than this observation would indicate. In parts of the section the mica is gathered into wavy non-persistent lines, having an imperfect parallelism and giving the section between crossed nicols a silky sheen, a feature which is characteristic of all the sections of this rock examined. Primary quartz is represented by small angular fragmental particles, of which there is seldom more than one grain in a section. Secondary quartz, as an alteration product, forms the bulk of the rock. It is usually evenly distributed through the groundmass, where it is recognized in microscopic areas by its transparency and its low birefringence. It also forms veins varying from minute veinlets to veins of considerable size. Pyrite, with pseudomorphs of iron oxide, or occasionally of yellow epidote after pyrite, is found in it. Originally the rock was probably a quite glassy lava of the nature of obsidian, which has been affected by devitrification.

ANALYSIS OF UPPER RHYOLITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
73.20	14.59	1.92	0.47	1.24	0.12	4.32	0.32		2.98	99.16

From its mineralogical characteristics and its chemical analysis showing 73.20 per cent. silica, the rock is here classed as rhyolite. The specimen analyzed was taken from as fresh a portion of the rock as could be found, but was altered. Stratigraphically it is classed as a flow sheet.

There are several exposures of rhyolite at this horizon which are continuous with the rhyolite just described, but which differ from it in appearance. In the MacNamara mine the upper parts of the rhyolite have the usual characteristics, but the lower part is crowded with fragments of a dense white rhyolite. The paste in which the fragments are imbedded looks more siliceous than the normal rhyolite, but otherwise resembles it. This phase seems to be part of the main flow. It is thought that the fragments were formed by the crushing of a part of the rock soon after hardening, and that they were picked up by a part of the magma that was still molten. This phenomenon was observed by Spurr and was termed "autobrecciation" by him. In the normal facies occasional included fragments are found, altered to a characterless chalky substance.

In the northern part of the Tonopah Mining Company's property there are two exposures of an altered rhyolite showing crowded, ropy flow lines. The rock is of a light gray color. The flow laminations are wavy and are as frequent as fifty to the inch. They are composed of light gray impure quartz, alternating with bands of white decomposition products. In thin section the quartz forming the bands is seen to be composed of interlocking grains. This indicates that it is of secondary origin, and is an alteration product which has preserved the structure of the original rock. The material between the quartz bands is finely flaked sericite. Small pyrite grains are enclosed by both quartz and sericite, and were probably formed at the time of the alteration of the rock. A large number of dusty inclusions in the quartz are fine pyrite and iron oxide. White secondary quartz is sometimes developed in small lenses and veinlets, which sometimes interfere with the continuity of the flow lines, and sometimes crowd them apart.

In the eastern part of the Tonopah Mining Company's property is found a rock somewhat similar to that just described. In this rock the flow lines are wavy and well marked, but the color varies from gray to a decided pink. In thin section it is seen to be murky with decomposition products. No evidence of phenocrysts is seen in the single section made of this rock. In the hand specimen there are a few imperfectly rectangular casts filled with a whitish substance which is specked with hematite. These are suggestive of former phenocrysts, but there are many holes in the section, and if there were any of these casts in the specimen they were lost in preparing the section. The flow laminæ are closely spaced and are alternately secondary quartz and a white opaque substance. Minute flakes of sericite are sparingly disseminated over the slide. Numerous specks of red hematite show that the red color of the rock is due to that mineral.

These rocks showing flow structure have not been analyzed, but from their general characteristics are thought to be rhyolites, and are considered stratigraphically as a part of the upper rhyolite flow. They are probably flows which preceded the main body.

The upper rhyolite is well exposed in the Midway mine. In this locality the upper parts of the sheet are light green rhyolite of the normal type, but the lower parts as found north of the shaft vary from a dense white rhyolite to a rhyolite breccia, composed of angular rhyolite fragments with sharp borders, set in a paste of white rhyolite or impure quartz. This rock is quite different from what has been described as the normal type of rhyolite. It seems to be much more siliceous. The exposures of this rock on the 835-foot level of the Midway mine show that it overlies the calcite andesite, and it is therefore mapped with the upper rhyolite. Much depends upon the correct explanation of the history of the upper rhyolite. In view of the fact that it was classed by Spurr as intrusive, it occupies an important position with respect to the present argument, and the evidence concerning its origin will be reviewed at length.

The upper rhyolite was either poured out in a liquid state from a volcanic vent upon an older surface formed mostly of the calcite andesite, and then covered with the earlier andesite; or it was forced in a molten state, under tremendous pressure, into a body of andesite older than itself, splitting it into two comparatively horizontal sheets, as represented by the calcite andesite and the earlier andesite. The latter idea, that the upper rhyolite is intrusive into an "earlier andesite," is the one commonly held, and it will be discussed first.

Intrusives of this character, known as sills, are common where sedimentary rocks are penetrated by igneous intrusives. In such occurrences the igneous rock is forced in the molten state, under great pressure, along the bedding planes between the horizontal sedimentary strata; and it is simply a case of a fluid under pressure escaping along the direction of least resistance. Likewise there are sheeted intrusions along fault-planes, and also dikes in either sedimentary or igneous rocks. But in either of these cases, where the thickness of the intrusive body is great, the disturbance of the enclosing rocks by the intrusion results in the formation of cracks, into which the intrusive rock is forced, thus forming the tongues which are characteristic of intrusives. The adherents of the intrusive theory may argue that the intrusive could have followed a horizontal fault plane. To this it may be answered that a horizontal fault of this extent is not consistent with the complex volcanic structure of the Tonopah district, and that it is unlikely that an intrusive 300 feet thick in places could follow such a fault without rupturing the overlying rock and forming unmistakable tongues or apophyses. Such tongues are not in evidence. Features which are sometimes mistaken for them may be accounted for by faulting. If the upper rhyolite were intrusive it should show a better developed porphyritic structure than it does. On the contrary its lack of crystallization is more characteristic of a thin surface flow than of an intrusive. Thus far it has been shown that the upper rhyolite fails to possess the usual characteristics of intrusives. The ways in which it resembles a surface flow will be taken up next.

In reviewing the positive evidence in favor of this rhyolite being a surface flow, the strongest support is found in its shape and position, as shown in the sections. It is there shown as a tabular body of rock of fairly uniform thickness, underlying the earlier andesite. Its irregularities may be accounted for in a great degree by the folding and faulting that has affected the region since its outflow. The boundary of its upper surface has been fairly well ascertained; and although less is known of its lower surface, it is thought that there is sufficient evidence to warrant the belief that its shape is approximately as shown in the sections. However, as indicated on the drawings, a distinction has been maintained between known boundaries and those that are inferred. This is true of all the contacts shown. As far as the writer knows, this sheet of rock is coextensive with the earlier andesite throughout the producing area of the camp. Wherever mine workings within these limits are known to have penetrated below the earlier andesite the underlying rock has proved to be the upper rhyolite. Judging from the criterion of position and shape alone it seems that the most natural explanation of this rock is that it was laid down as a flow-sheet.

The contact phenomena, where visible, are also in favor of this view. Original contacts in such cases are usually decisive as to the relation of the rocks; but here, in by far the greater number of exposures, they are so obscured by alteration or by faulting that they give no information as to their original character.

There are, however, some indications of considerable importance. In a number of places a pyroclastic breccia several feet thick, consisting of sharply angular, firmly cemented fragments, has been observed lying between the upper rhyolite and the earlier andesite. If this breccia had been formed as a contact breccia on the borders of an intrusive mass the fragments should consist solely of pieces of the older rock incorporated in the borders of the intrusive. On the contrary, the fragments in the breccia are of various kinds of rock; some of them are andesite, though different from the earlier andesite, and others are of various rhyolitic rocks, different from the upper rhyolite. Some of them show well marked flow-structure and some contain numerous quartz phenocrysts. Both fragments and cement are altered. There is an excellent example of this in the MacNamara mine. The breccia is there found lying on top of rhyolite, which is undoubted upper rhyolite. The contact of this breccia with the rhyolite is usually distinct, but in several places in the Tonopah Mining Company's property the breccia has been found merging gradually into the earlier andesite. Breccia of this character is not found everywhere on this contact, but it has never been found in any other position than at the contact. It seems impossible to explain it in a way that is consistent with the idea that the rhyolite is intrusive; but it can readily be explained as an accumulation of fragments that lay upon the surface of rhyolite at the beginning of the andesite flow, and which were cemented into the lower surface of the andesite; or it may be explained as a thin breccia flow immediately preceding the andesite. It may be that the breccia had its origin in explosions that initiated the andesite eruption. A photograph of a specimen of this breccia is shown in Fig. 85.

Spurr correlated the upper rhyolite with the extensive surface flow of "rhyolite dacite," and also with the rock below the 900-foot level of the Mizpah shaft. In the light of evidence now available it does not seem that this relation can exist. The rhyolite-dacite on the surface is a rock of different appearance from the upper rhyolite, and lies above the later andesite, which is undoubtedly of later origin than the main veins. In many places these veins extend downward into the upper rhyolite, and where this rhyolite forms one or both walls of the veins angular fragments of rhyolite are found included in the vein. These facts show that the upper rhyolite is older than the veins, and that the surface rhyolite-dacite is younger than the veins. As

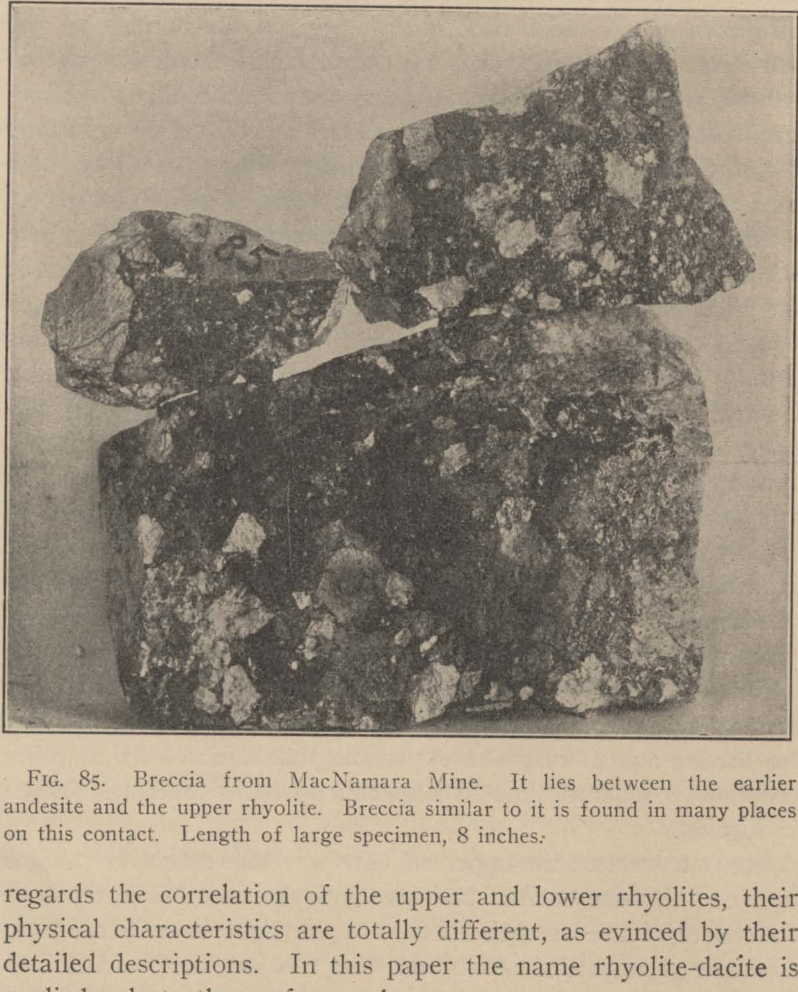

FIG. 85. Breccia from MacNamara Mine. It lies between the earlier andesite and the upper rhyolite. Breccia similar to it is found in many places on this contact. Length of large specimen, 8 inches.

regards the correlation of the upper and lower rhyolites, their physical characteristics are totally different, as evinced by their detailed descriptions. In this paper the name rhyolite-dacite is applied only to the surface rock.

Briefly, the chief evidence showing that the upper rhyolite is a flow sheet is as follows:

1. The horizontal tabular form of the body.

2. The absence of apophyses.

3. The petrological character of the normal rock. Its probable original glassy structure is a surface type.

4. The presence of various distinct types of rock within the sheet.

5. The character of the breccia between the upper rhyolite and the earlier andesite.

6. The failure to correlate the rock with the surface flow of rhyolite-dacite, or with the lower rhyolite.

EARLIER ANDESITE.

The earlier andesite, frequently called the lode-porphyry, is by far the most important of these rocks with respect to ore-formation. It outcrops at the surface on the Tonopah Mining Company's property and on Gold Hill. Elsewhere it is covered by the capping of later andesite. Its petrological characteristics have been well described by Spurr and will not be enlarged upon here. It will be sufficient to say that it is an altered hornblende andesite. Where not covered by the later andesite the earlier

ANALYSIS OF THE EARLIER ANESITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
64.50	16.82		1.08	1.76	3.00	3.80	1.77	5.70	1.63	100.04

andesite has usually a yellow or pink tinge, or is sometimes white or light gray. The light shade of the rock is due to the leaching out of the greater part of its iron content, and the colors are due to the ferric condition of most of the remaining iron. Where it is covered by capping the earlier andesite has a green appearance due to the presence of such alteration products as chlorite and others minerals containing iron in the ferrous condition. In some places, even where covered by capping, the earlier andesite is leached and oxidized, suggesting that this action had taken place to some extent prior to the later andesite flow. This coincides with the supposition that the surface of earlier andesite suffered erosion before being covered by the succeeding flow; a belief that is supported by the sharp termination of some of the veins of the earlier andesite at the lower surface of the capping. In composition the earlier andesite closely resembles the calcite andesite, and specimens from some parts of the earlier andesite are very much like the calcite andesite; but the ordinary type of earlier andesite is marked by phenocrysts somewhat larger than those of the usual type of the calcite andesite. However, the distinction between the two on this basis would be uncertain, and the only trustworthy distinction is in their position with respect to the upper rhyolite. Calcite can be found to some extent in any of the rocks of this district.

The earlier andesite extends with no other known interruption than faulting throughout the entire ore-producing region; and it undoubtedly extends to much wider limits than where it is now known. The difficulty in distinguishing it from the later andesite may account for its not being recognized in some of the outlying mines, although probably many of them have not attained sufficient depth to reach it. It seems that in the search for the ore-bearing formation, the earlier andesite, in these mines; the best means for determining it would have been by diamond drill holes driven to ascertain the kind of underlying rock. While this might not give conclusive evidence in all cases, it would undoubtedly be a help; for example, if andesite resembling the earlier variety were in doubt, and a drill-hole encountered rhyolite below it resembling the upper rhyolite, the rock immediately above the rhyolite might reasonably be thought to be earlier andesite. It is not to be thought, however, that the succession of rocks as found in the producing district is necessarily the same over an extensive area, since lava flows are characteristically irregular.

The marked variation in thickness of the earlier andesite is doubtless due chiefly to erosion. It is noteworthy that the thicker portions are those of greater silicification and vein formation, and consequent greater resistance to erosion. The irregular outline of the sections of the andesite, especially noticeable in Figs. 82 and 83, does not seem to be fully accounted for by faulting, and it seems that both folding and faulting have been involved in its deformation. The Mizpah fault-contact, as shown in Fig. 81, best expresses this idea. It seems to be a monoclinal fold faulted at the bend, although, as a matter of fact, the movement is more complex than this statement indicates. As seen in Fig. 80, the strike of the fault does not form a right angle with any of the sections. The movement is not directly downward on the dip of the fault, but as shown by striations on the slickensides and the lag of the adjacent fault-blocks, the horizontal component of the movement to the right, looking east, is nearly as great as the component downward on the dip. This kind of movement is characteristic of most of the faults east of the Mizpah shaft, many of which are not shown in the sections. They undoubtedly represent the slipping planes of fault-blocks that were dragged short distances by the motion of the Mizpah fault. It should be kept in mind in viewing the sections that the faults represented are seldom normal to the section, and that the blocks above the faults have seldom moved directly downward on the dip. This helps to account, in some cases, for the apparent inconsistence in the thickness of the same rock on different sides of a fault. In Fig. 80 the thinness of the earlier andesite, west of the Burro fault, is explained by the probable presence of an erosional trough. The downthrow of the Burro fault at this place, the amount of which is established by the displacement of the lower surface of the earlier andesite, is not sufficient to account for the presence of the great thickness of later andesite west of the fault, and it is probable that when the later andesite flow began there was a hollow at this place. The Burro fault then occurred in part along the eastern side of this hollow; or perhaps there was movement on the fault both before and after the later flow. At a point further west, in the MacNamara mine, the earlier andesite at the top of the anticline is not over twenty feet in thickness.

PRODUCTIVE VEINS.

As before intimated, the importance of the earlier andesite lies in the association of the ore-bodies with it. It is not intended to give here a full description of the ore deposits of Tonopah, but this article would not be complete without an outline of their general character. It is thought that the following statement is not too comprehensive; that all the known productive veins of Tonopah lie in one of these positions:

1. With both walls of earlier andesite.

2. With hanging wall of later andesite and foot wall of earlier andesite.

3. With hanging wall of earlier andesite and foot wall of upper rhyolite.

4. With both walls of upper rhyolite, usually having descended successively through positions 1 and 3.

These are more specifically described as follows:

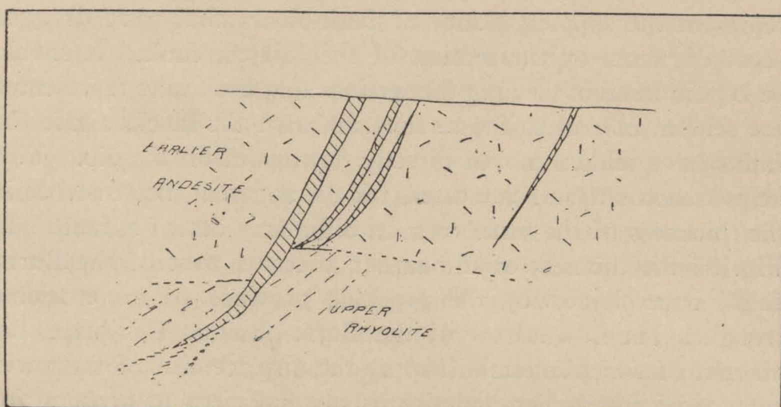

FIG. 86. Diagrammatic representation of a typical vein system.

1. The larger veins of the camp in their upper parts and many of the smaller veins through their entire extent.

2. A deposition of ore on the Mizpah fault contact, sometimes sufficiently continuous to be called a vein; and in other places bunchy or of lense-like form. This ore is apparently later than the main veins.

3 and 4. As shown diagrammatically in Fig. 86, most of the large veins descend without change of character through the following positions: first with earlier andesite on both walls, next with earlier andesite on the hanging wall and upper rhyolite on the foot wall, then with upper rhyolite on both walls. In this last position the vein may continue of good value for a consid-

erable distance into the rhyolite, but it usually deteriorates in both strength and value as it gets further into the rhyolite; and the quartz disappears, not so much by pinching out, as by merging in a frayed-out manner into the wall-rock. Frequently a quartzose zone can be traced for a considerable distance into the rhyolite. The vein often flattens as it enters the rhyolite. In some places the vein ends abruptly on the contact, but in most of such cases there are signs that there has been movement on the contact, and that the veins are faulted. The writer has not seen a single instance of a vein having been cut off at an intrusive contact. Spurr gives a map of the 800-foot level of the Desert Queen shaft, showing a vein all in rhyolite. The rock in which this vein lies is really earlier andesite. There is a block of andesite over 300 feet thick under the Mizpah fault at this place, as shown in Fig. 81. The section passes along the vein shown in Spurr's map. The vein has been opened up continuously through the andesite and has been shown to be the extension of the Mizpah vein. There are some barren veins entirely in the upper rhyolite which seem to have no connection with the ore-producing veins. The West End-MacNamara vein lies almost entirely on the rhyolite-andesite contact. The veins are undoubtedly replacement veins, the replacement occurring mostly in the foot wall and in the fragments of the crushed zone. They carry silver and gold uniformly in the proportion of 90 to 1 by weight. The gangue is mostly quartz.

LATER ANDESITE AND OTHER LATER FORMATIONS.

The later andesite immediately overlies the earlier andesite. It is similar to the earlier andesite, but was originally of slightly more basic composition. In some places it can be found almost perfectly fresh, but it is usually intensely altered. Its appearance underground is that of a dark green, altered, porphyritic rock; which in places is indistinguishable from the green variety of earlier andesite. It is known to be several hundred feet in thickness within the territory under discussion, and it is doubtless of much greater thickness outside of this district. It forms a surface flow of large extent and is found for a radius of several miles surrounding Tonopah. It is covered by later lavas and tuffs in many places. It is not known to contain ore, although poorly defined and non-continuous stringers and bunches of quartz, assaying a few dollars per ton in silver and gold, have occasionally been found in it. On the surface the earlier and later andesites are easily distinguished, but in many places underground alteration has rendered them so much alike that sometimes the most trustworthy basis of distinguishing them is by the presence or absence of ore in veins or small stringers.

The rocks lying above the later andesite are not of economic importance within the ore zone, but inasmuch as they consistently carry out the scheme of the upbuilding of the terrane by lava flows and tuffs, they will be briefly mentioned.

The later andesite was followed by a series of surface flows of rhyolites and breccias, which Spurr has segregated into the Heller dacite, Fraction dacite breccia and the Tonopah rhyolite-dacite, with accompanying tuffaceous material. These were followed by the formation of the Siebert Lake and the accompanying deposition of the Siebert tuff-beds. After the disappearance of the lake there was a period of erosion. The tuffs were then covered, in some places, with a thin flow of basalt. Then followed the outburst of rhyolitic lavas which formed the mountains, Butler, Siebert, Oddie, Golden and Ararat. Spurr was of the opinion that these mountains were the necks of volcanoes which did not overflow. There has been considerable doubt in the writer's mind regarding this, and the question arose as to whether the mountains could not be considered as the remnants of a rhyolite capped plateau. This conception of their origin is strongly suggested by several mesa-like features of the landscape and certain evidence from underground workings. On the other hand, unquestionable evidence of intrusive contacts can be found on the eastern side of Mt. Butler, on the southwestern side of Mt. Brougher, along the western flank of the Mt. Golden range and on the northern side of Mt. Oddie; and also the rock of Mt. Oddie differs in appearance and slightly in composition from that of Mt. Butler and Mt. Brougher. The conclusion finally reached is that these mountains are remnants of a plateau and that

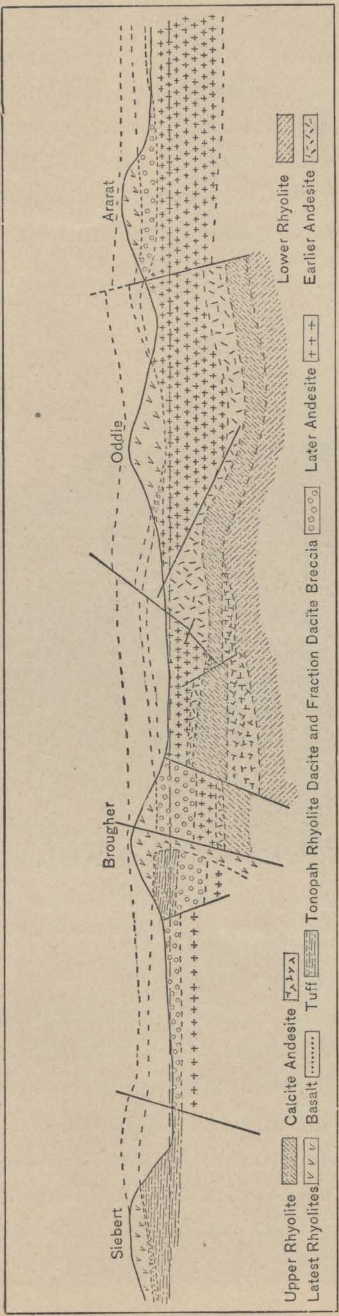

FIG. 87. Idealized section of the Tonopah District, looking North. Illustrating conditions at the close of the volcanic period. The contacts underground are not intended to be accurate.

some, if not all of them, lie over the vents from which the lava that formed the plateau flowed. A section illustrating the writer's conception of the original situation of this plateau is shown in Fig. 87. The evidence bearing upon it is as follows:

1. The surface of Mt. Ararat, part of Mt. Siebert and the small mountain west of Mt. Siebert are of mesa-like form, as shown in the photographs in Figs. 88 and 89.

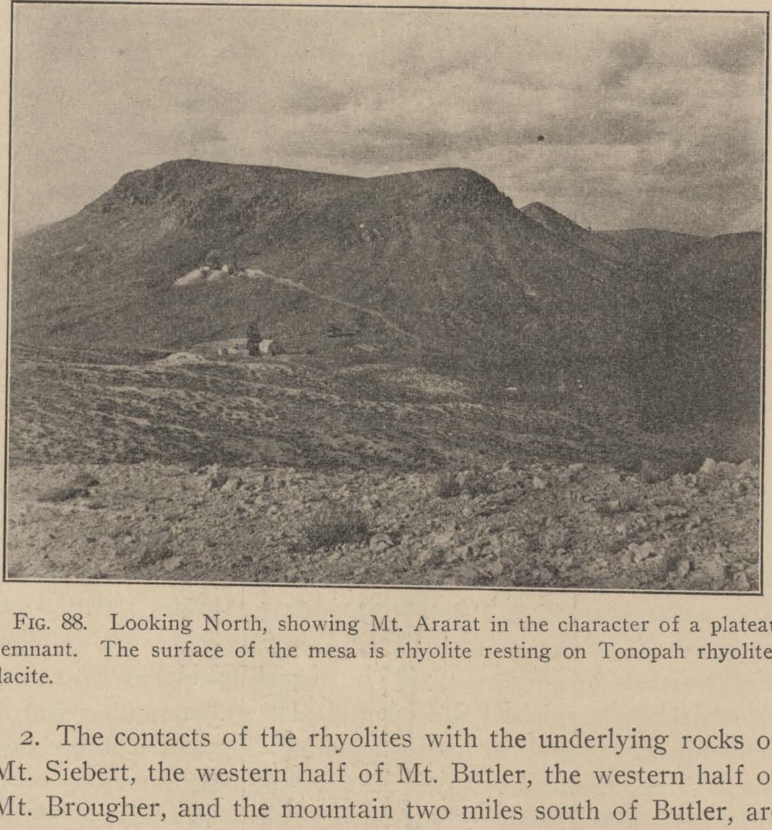

FIG. 88. Looking North, showing Mt. Ararat in the character of a plateau remnant. The surface of the mesa is rhyolite resting on Tonopah rhyolite-dacite.

2. The contacts of the rhyolites with the underlying rocks of Mt. Siebert, the western half of Mt. Butler, the western half of Mt. Brougher, and the mountain two miles south of Butler, are approximately plane surfaces, nearly horizontal, and usually follow the contours, or cross them at a uniform angle, except where they are faulted (see Figs. 89 and 90). This can be well seen in Spurr's geologic map of the district, and also in the photographs accompanying his report.

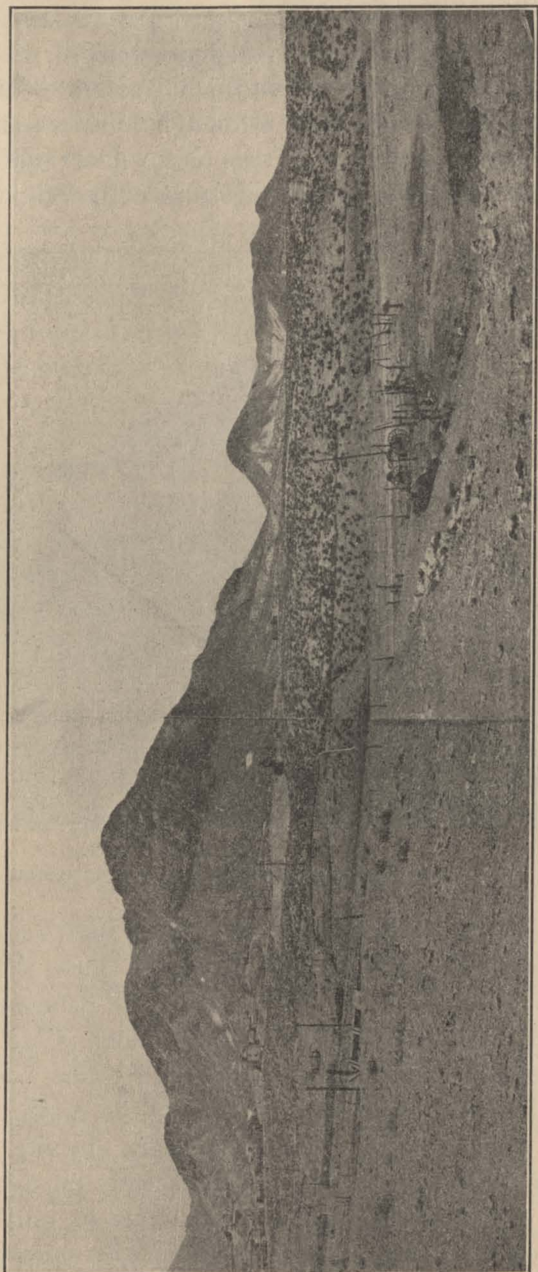

FIG. 89. Looking South. Mt. Brougher on the left, Mt. Siebert on the right, in the character of plateau remnants. The dark upper rock is rhyolite. The Siebert tuff shows white on Mt. Siebert. On Mt. Brougher it is mostly covered with detritus, but the tunnel at the white dump is in horizontally bedded tuff.

3. Flow laminæ, parallel to the supposed plateau surface, are found where the mesa-like form is most pronounced, as on the western side of Mt. Brougher and on the hills north of Mt. Siebert; and a horizontal stratification, as though due to a succession of flows of the rhyolite lava, can be seen on the north side of Mt. Brougher. This appears in the photograph of Fig. 89.

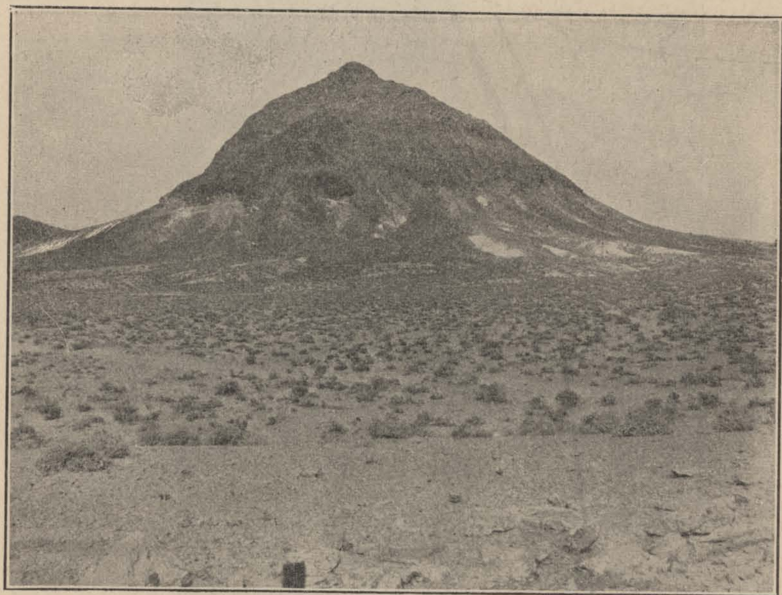

FIG. 90. Looking East at Mt. Brougher, showing the rhyolite resting on tuff.

4. On the 1,000 feet level of the Desert Queen shaft a cross-cut has been driven from a point between the desert Queen shaft and the North Star shaft to a point directly under the Belmont shaft, and although it passes under the southern shoulder of Mt. Oddie it has encountered no rhyolite like that of Mt. Oddie, and none at all except the upper rhyolite. Farther to the north, on the 800 feet level of the Mizpah Extension shaft, rhyolite closely resembling that of Mt. Oddie is found apparently intrusive into andesite, and with contacts dipping to the east or north east. Also the contacts of a small rhyolite intrusion with similar dip is

found at the mouth of the North Star tunnel on the north side of Mt. Oddie. It is thought for these reasons that the vents from which the Oddie rhyolite issued are at the north and east sides of the mountain, and are not vertical, but incline downward to the north or northeast.

Although the Siebert tuffs were covered with lava flows wherever they have come under the writer's observation, that is, for a radius of several miles about Tonopah, the capping was not always rhyolite. Three miles east of Tonopah there is a broad mesa, the surface of which is a sheet of olivine basalt of considerable thickness. It lies upon Siebert tuff and does not seem to have been covered with rhyolite. Two miles south of Golden Mountain a similar basalt forms the summit of the range. West and north of Mt. Siebert the rhyolite is now a thin sheet and probably was never as thick as it is on the higher mountains. It would seem then that the viscosity of the rhyolite, at the time of its effusion, was too great for it to spread to any great extent, probably not over a mile or two from its vents.

FAULTING AND FOLDING.

The faulting of the region is intense. Only the more important faults are shown in the sections, or mentioned here. They are most numerous in the earlier and later andesites and decrease progressively as depth is attained. This is due to the softer, altered condition of the higher rocks.

The Mizpah fault has already been described. For a distance of several hundred feet from it the faults in the earlier andesite are subject to its influence, and although usually steeper their strike is approximately parallel to it. The greater steepness of the minor faults is the natural result of the two-fold nature of the Mizpah fault and is caused by the downward pressure due to the bending. The significance of this bending is brought out by the reappearance of the later andesite at the surface east of Mt. Oddie and Rushton Hill, and although the position of the andesites under the rhyolite just east of the Belmont shaft has not yet been revealed, the situation as known suggests that Mt. Oddie lies in a depression and that the Mizpah fault is the distorted original contact between the earlier and later andesites. The depth of the depression is doubtless accentuated by faulting.

The displacement of the faults is usually not great. The greatest measured movement is on the Stone Cabin fault, which has a downthrow of about 800 feet, as measured by the displacement of the upper surface of the upper rhyolite; a fact which shows that before the faulting the Siebert tuff lay about 400 feet above the collar of the Silver Top shaft. The majority of the faults have a displacement of from one to fifty feet. The hindrance to mining offered by the faults is due chiefly to the uncertainty of their movement and to the complication introduced by cross faults. An instance of this is seen in Fig. 81, which shows that the Burro Fault fails to cut the 500 feet level where its presence is indicated by its position on the upper levels. It is equally common and surprising to find a large fault where none is expected. The wavy character of the upper surface of the upper rhyolite, as shown in Fig. 83, may be explained in part by a warping of the region. The warping is also revealed by other evidence than the position of the rock. The low dip angles of the faults must be explained otherwise than by assuming them to be simple gravity faults. Some of them, especially those at the upper contact of the upper rhyolite, or in the earlier andesite not far above it, are flat or nearly so. These faults would be the natural result of the folding of a region built up of thin sheets. It would correspond to the slipping of playing cards upon each other if the deck is held in the hands and bent. The comparison is not strictly accurate, since the rock sheets have not the tenacity of paper, and would often fracture at even a moderate bend; but this very fact is thought to account for the notched upper surface of the rhyolite at the bends.

A striking instance of folding is found in the West End-MacNamara vein, which lies mostly on the contact between the earlier andesite and the upper rhyolite. The contact here forms a pronounced anticlinal fold with its axis running about S 60° E and pitching downward at a small angle to the east. It does not show on the sections. The hanging wall of the vein bends with hardly a break over the axis of the fold and dips irregularly at an angle of from 20° to 40° on either side. Other evidence of warping and twisting is found in the striations on most of the faults, which run at angles as great as 60° from the dip, and show a large lateral movement.

SUMMARY OF GEOLOGICAL HISTORY.

Summarizing, the district is composed of a faulted and eroded series of flow sheets and tuffs, with periods of erosion between some of them. If the sequence and manner of deposition is correctly interpreted here, the surface immediately after the outflow of the Oddie rhyolite and the Brougher "dacite" consisted of a broad and probably slightly domed plateau, and the rhyolite forming the surface near Tonopah was thickest in the vicinity of the present higher mountains. Faulting played a part in the degradation of the region. As Spurr has stated, the region was much faulted at the close of the Siebert Lake period. There is also a series of faults that occurred after the completion of the volcanic period and intersected the rhyolite capping. The greater part of the erosional deformation of the plateau was probably accomplished during a period of heavier precipitation than the present, and once erosion had cut channels through the rhyolite it made rapid progress by wearing away the soft, faulted, underlying rocks and undermining the capping. At the present time erosion is proceeding in the slower manner characteristic of arid regions.

Geologic Column.

The following tabulation shows the sequence of the volcanic formations in descending order:

Rhyolites.
    Oddie rhyolite, Brougher dacite, etc.
Basalt.
Siebert tuff beds.
Rhyolites and rhyolite-breccias.
    Heller dacite, Fraction dacite-breccia, Tonopah rhyolite-dacite.
Later andesite.
Earlier andesite.
Upper rhyolite.
Calcite andesite.
Lower rhyolite.

If it can be considered established that the Tonopah terrane is built up of a series of superimposed tuff-beds and lavas as here proposed, the structure of the district then harmonizes well with the general geologic structure of this portion of Nevada; and it is of interest to compare the succession of rocks in the Tonopah District with that reported by Sidney H. Ball for southwestern Nevada.[1] The occurrence of Siebert Tuffs in both columns forms the basis for the correlation shown in the following table. The considerable thickness of the lower rhyolite of Tonopah suggests its correlation with the second rhyolite in Ball's column, which he describes as the rhyolite flow of greatest volume. The other Tonopah lavas then fall naturally in the places assigned them. Although the adaptation of the Tonopah rocks to Ball's column seems satisfactory, the fact is recognized that there is too little evidence for an assured correlation, and this comparison is offered only as a suggestion of a possibie agreement in the succession of flows.

TABLE.

S. H. Ball's column for Southwestern Nevada.			Tentative correlation with the Tonopah Rocks.
Tertiary	Pliocene	Rhyolite	Oddie Rhyolite Brougher Dacite
Tertiary	Pliocene	Siebert Tuffs	Siebert Tuffs
Tertiary	Pliocene	Rhyolite	Rhyolite Dacite Fraction Dacite
Tertiary	Miocene	Basic Andesite	Earlier and Later Andesite Upper Rhyolite and Calcite Andesite
Tertiary	Miocene	Second Rhyolite	Lower Rhyolite
Tertiary	Eocene	Monzonite Porphyry and Acid Andesite	Fragments of andesite and rhyolite in the Lower Rhyolite
Tertiary	Eocene	First Rhyolite	

[1] U. S. G. S. Bull., 308. 1907.