THE UNDERGROUND GEOLOGY OF THE WESTERN PART OF THE TONOPAH MINING DISTRICT, NEVADA

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PREPARED AND PUBLISHED BY THE NEVADA STATE BUREAU OF MINES IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY
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INTRODUCTION

Early in 1929 the Nevada State Legislature appropriated $10,000 to be expended on geologic and topographic work in cooperation with the United States Geological Survey during the biennium 1929–1930. The Nevada Mine Operators Association recommended that one of the projects undertaken under this fund be a geologic resurvey of the Tonopah mining district, in Nye and Esmeralda Counties. The writer was assigned to this project and carried on field work from July 11 to October 25, 1929. During this period the readily accessible workings of the following mines in the western half of the district were examined: Tonopah Extension Mines, Inc. (Victor, Cash Boy, McKane, Extension No. 1, and Extension No. 2 shafts); West End Mining Co. and the associated West End Extension Co. and Tonopah 76 Co. (West End and Ohio shafts); MacNamara Mining Co. (MacNamara shaft); Tonopah Midway Mining Co. (New Midway and Old Midway shafts); Jim Butler Mining Co. (Wandering Boy, Fraction No. 1, and Fraction No. 2 shafts); Tonopah Mining Co. of Nevada (Sand Grass, Red Plume, and the country west of the Mizpah and Silver Top shafts); and Keystone Mining Co. shaft.

The present report is based upon this examination and summarizes the preliminary conclusions reached. These conclusions are subject to revision after the workings in the eastern half of the district are examined—a task which it is hoped will be accomplished during the field season of 1930. It is planned that the final report on the district, which will include the geologic maps, will be published as a professional paper of the United States Geological Survey.

The writer desires to acknowledge his appreciation of the whole-hearted cooperation shown by the officials of all the companies and his indebtedness to them for the details of the geology in workings not now accessible. He also wishes to acknowledge the able assistance of Ian Campbell and J. W. Vanderwilt, and the helpful suggestions and criticisms made by H. G. Ferguson, G. F. Loughlin, and W. C. Mendenhall during their several brief visits to the district. Mr. Campbell has also provided for this report the results of his microscopic study of the rock specimens collected.

1Published by permission of the Director, U. S. Geological Survey.
PREVIOUS GEOLOGIC WORK

By far the greater part of the geologic work in Tonopah represented by published reports has been done by J. E. Spurr. His first work there was done in 1902 and 1903, and is covered by Professional Paper 42 of the U. S. Geological Survey, published in 1905. He also visited the district in 1908 to examine the West End and MacNamara mines professionally, and returned in 1910 to study the Belmont, Montana, Midway, and Tonopah Mining Co. properties. He was made an officer of the Tonopah Mining Co. in 1912 and remained in Tonopah for more than three years. Two publications represent the investigations made during the two later visits. The following extract from the second of these papers summarizes his final conception of the geology:

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 trachyte extrusion produced horizontal fissuring near the zone of transition between the main body of trachyte and its glassy lower portion; and along here an andesite (Sandgrass andesite) intrusion penetrated. After renewed fissuring along the same zone, a glassy trachy-alaskitic intrusion (Montana brecia), very full of inclusions, took place, usually following along immediately above the andesite. Subsequent movement reopened this line of weakness, and a second trachy-alaskitic intrusion came in—the West End rhyolite sheet—which penetrated along a fissure usually lying immediately above the Montana brecia. At a subsequent epoch came an eruption of andesite (Midway andesite) as a surface flow; 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 Sandgrass andesite-Montana brecia-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, 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 carrying occasional lead, zinc and copper sulphides.

All these veins formed at shallow depths, and the different types are held to 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 probably represent an abnormally intense shortly sustained temperature, following the trachy-alaskitic intrusion; the second-period D veins a 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 disturbances.

Somewhat earlier, Burgess reached a radically different conclusion from that formed by Spurr as to the nature of the several formations disclosed by the mining operations. He considered that the sequence shown by the formations is that in which they were formed—in other words, that the different formations originated as surface flows or accumulations of volcanic material—thus questioning Spurr's conclusion that many of these rock masses are intrusive. Burgess also notes that many of the productive veins continue downward into the West End rhyolite, and he implies, although he does not so state, that the mineralization in the two portions is contemporaneous.

The district has also been briefly discussed by Locke, who in general agrees with Burgess that the formations are present in their proper stratigraphic sequence. Locke also questions the validity of Spurr's statement that the mineralization occurred at a number of epochs, and notes that "There is no mineralogical distinction whatever to be made between many veins which, according to the hypothesis [Spurr's] should belong to different periods."

The most recent contribution to the geology of the district has been made by Bastin and Laney. These authors confined their attention chiefly to a study of the ores, and did not concern themselves with either the stratigraphic sequence or the geologic structure of the district. With regard to the ores, however, they note that "Mineralogic differences between veins of supposed different ages are commonly no greater than may be observed in different parts of one continuous vein. * * * Upon the sole basis of the mineral composition and texture of the primary ore there would be little reason for the impartial geologic observer to regard the principal productive veins as of more than one age."

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1Burgess, J. A. The geology of the producing part of the Tonopah mining district: Econ. Geology, vol. 4, pp. 861-712, 1909.
3Idem, p. 104.
5Idem, p. 8.
The results of the previous work may perhaps be very briefly summarized as follows: The district is underlain by a series of volcanic rocks, which are considered by Spurr to be in large part intrusive sills and by Burgess and Locke to be entirely of surficial accumulation. All these observers imply that these formations are relatively flat-lying and that their essentially horizontal continuity is disturbed only by faulting, the cause of which is attributed by Spurr to volcanic activity and is considered by Burgess to be in part a reflection of the irregularities in original distribution of the formations. Spurr postulates a number of different periods of ore formation, a view which is directly challenged by Locke, indirectly questioned by Burgess, and not supported by the work of Bastin and Laney.

Spurr, Burgess, and Locke all appear to agree in the fact that the “Midway andesite” is later than the period of ore formation and acts as a capping to the ore.

SUMMARY STATEMENT OF RESULTS OF PRESENT INVESTIGATION

During the 15 years or more that has intervened since the last work by Spurr, Burgess, and Locke there has been a considerable amount of development work done in the western half of the district, which has reached to much greater depths than in the older, central portion. This new work has disclosed a number of features of the geology that are not readily apparent elsewhere, and as a result, the writer’s conception of the geologic setting at Tonopah is in part rather widely at variance with the views expressed by earlier writers. The points of difference may be divided into three groups—those relating to the stratigraphy, the structure, and the ore deposits.

The sequence of formations in the western part of the district is as follows: The oldest unit is that called by Burgess the “Lower rhyolite” and by Spurr, in his 1915 paper, the Tonopah rhyolite; for this unit the writer proposes the name Tonopah formation. It consists of interbedded rhyolitic flows, tuffs, breccias, and well-laminated silt composed largely of volcanic material, and is locally cut by dikes and small intrusive masses of similar composition. Interbedded with the Tonopah formation at two or more horizons are dark lavas, for the most part keratophyric, which are identical with rocks mapped by Spurr as the Sandgrass or “calcite” andesite. Similar rock exposed in the lower portions of Sand Grass and Extension No. 1 shafts may perhaps be an intrusive plug into the Tonopah formation. The next younger formation is the Mizpah trachyte, which might be termed more accurately a keratophyre. This formation probably overlies the Tonopah formation conformably, but in most places the contact between them has been a site for the intrusion of the irregular sill-like mass long known as the West End rhyolite. Earlier than the West End rhyolite but younger than the other formations is an intrusive mass of breccia, here named the Extension breccia, which appears to have been intruded along an old fault. Only two other formations, both of which appear younger than the ore, have been recognized in the underground work. The earlier is the Fraction breccia, elsewhere considered to be the basal part of the Esmeralda (“Siebert”) formation. This, as well as the other formations, is cut by intrusive dikes of rhyolite porphyry, which are presumably similar to the Oddie rhyolite or Brougher dacite defined by Spurr. The writer was unable to distinguish the “Midway andesite,” generally supposed to be later than the ore, in any of the underground exposures examined by him.

The extension of mining westward has brought to light a great deal of information concerning the geologic structure of the district. In this regard, particularly, some of the conclusions here reached must be considered as preliminary in nature and dependent for confirmation upon the detailed mapping of the eastern half of the district. In general, the formations have been tilted to form a westward-dipping monocline, the observed dips in which reach 60° or more in some localities. The dip on the whole decreases toward the east, and there is a suggestion, based upon observations in the deeper workings from the Midway and Mizpah shafts, that after passing through the horizontal it reverses, and the beds dip to the east. The tilted formations are cut by a remarkable compound fault, whose appearance in cross section is that of a recumbent crescent, convex upward. This fault may most conveniently be considered a transverse fault along which the rocks on the upper side have moved eastward for a total distance of about 1,500 feet. There are in addition a number of other faults, of considerable throw, that cut the crescent-shaped fault and represent several successive movements.

The occurrence of ore is intimately associated with the unusual fault mentioned in the preceding paragraph, in that almost all the ore bodies that have thus far been mined appear to be localized either in the fault itself, in faults that are hanging wall splits from its limbs, or in faults, many of them of almost insignificant throw, that roughly radiate from its crest. The factors that have governed this localization of ore shoots are probably...
several in number, and their relative importance is not known. The writer's present view is that at least three factors must have been operative during the formation of ore in any of the fractures above mentioned—(1) the fracture must have been situated above a certain isotherm (line of equal temperature) existing at the time of ore deposition; (2) it must have been open to the passage of solutions at that time; and (3) the wall rocks of the fracture must have been permeable to the solutions. Specific applications of these factors are discussed on a later page. The presence of quartz appears to have little or no bearing upon the localization of ore, and the writer believes that the bulk of the silver is of distinctly later introduction.

In addition to the ore deposits in fractures related to the major fault, ore has been found in three faults of later age. In each of these three, however, the strike of the productive part is close to the general strike of the other productive fissures—nearly east-west.

THE FORMATIONS

Tonopah formation—The name Tonopah formation is proposed for what has been previously called the "Lower rhyolite." The formation has also been called the "Tonopah rhyolite" or "Tonopah rhyolite-dacite," and correlated with rhyolite exposed on the surface north of the mining district. These exposures have not yet been studied by the writer, but from the descriptions of their lithology and relations they do not appear to be in any way related to the beds here discussed. The formation as here defined includes rocks that have been mapped previously as "Glassy trachyte" and "Montana breccia," but it does not include all the exposures that have been so assigned by Spurr, Burgess, and others.

The best exposures of the formation are found in the westerly workings of the Tonopah Extension mine, notably on the 1,200-foot, 1,540-foot, and 1,880-foot levels. Less extensive but equally significant exposures are present in the 1,050-foot level from the Extension No. 1 shaft, the 1,000-foot and 1,140-foot levels of the Sand Grass, the 700-foot level of the Mizpah, and the 800-foot level of the West End. The formation may also be seen in many of the workings of all the other mines studied, but in these extensive alteration has generally served to mask its true nature.

The outstanding feature of the formation is that it is composed of an interbedded sequence of volcanic breccias, massive tuffs of varying grain size, porphyritic flows, banded flows, and water-laid deposits of several kinds, the most striking of which is probably the well-laminated material that closely resembles much of the Esmeralda formation.

The rocks described by Burgess as bedded pyroclastic material belong in this formation, and the exposures in the Tonopah Extension workings add abundant proof of the nonintrusive character of the great bulk of these rocks. Bedding planes are apparent in many places, and in numerous specimens there is an obvious gradation from coarse-grained material at the bottom of a bed to fine-grained material at the top. On one bedding surface well-developed ripple marks were noted. In addition, the fact that these rocks are interbedded with amygdaloidal flows of Sandgrass andesite renders it almost certain that the great bulk of the formation is a surface accumulation.

Some intrusive rocks are, however, included within the formation, as may well be expected in such an accumulation of dominantly volcanic débris. One of the clearest examples of such an intrusive is the strikingly porphyritic dike that is exposed on the 1,140-foot level of the Sand Grass, in the shaft crosscut, about 200 feet in the footwall of the vein. Other small intrusive dikes and masses of porphyry and breccia may be found at several localities. Those of breccia are probably related to the intrusive mass of Extension breccia, but it has not been practicable in all places to correlate them certainly with that body.

Strongly flow-banded rhyolites are interbedded with the other members of the formation in almost all exposures. This rock has been distinguished by some of the geologists who have visited the district as "Glassy trachyte." The writer, however, found it impossible to separate this rock satisfactorily because of its intimate interbedding in many places with tuff and breccia. Contortion of the flow banding is locally marked.

Mr. Ian Campbell has studied a number of specimens of this formation under the microscope and has submitted the following notes concerning them:

In thin sections of the flow-banded rock phenocrysts are not common. Crystals of albite are found occasionally, and altered biotite more rarely. The matrix is everywhere much altered, either to quartz or sericite or both, and its original character is therefore uncertain. None of the rock in the sections studied is now glassy, although originally it


may have been partly to wholly glassy in a few places. The writer believes that for the most part it was originally holocrystalline. The altered matrix consists of extremely fine to medium-grained feldspathic material, sericitized and in part silicified to greater or lesser extent. Flow structure is common, and in a few sections there is suggestion of a trachytic texture. Apatite and zircon occur as very scant accessories.

Quartz veinlets are the most striking feature of most sections. These appear to have been formed by replacement along the more permeable zones of the flow. Adularia occurs in these veinlets, but is by no means common. Sericite is generally present, especially along the middle of the veinlets. Another set of quartz veinlets, mostly mere threads, are found roughly at right angles to the main banding. These seem to follow cracks along which there has been a slight offsetting of the main bands. Pyritization of these rocks has been very common.

The elastic character of the breccias and tuffs is unmistakable in most thin sections. These rocks consist typically of angular fragments of quartz, orthoclase (both sanidine and adularia), albite, and very rarely microcline and microcline microperthite in a fine-grained groundmass which appears to consist mostly of feldspathic material. Quartz is much the most abundant of the larger fragments. Apatite (colorless) and zircon occur sparingly.

In some of the finer-grained tuffs the peculiar concave trilobate structure known as “eutaxitic texture” is well developed, indicating that the fragments were originally glass. They have since been altered to secondary quartz.

Alteration has affected these rocks in much the same heterogeneous fashion as it has the other formations of the district. Carbonatization and chloritization were perhaps the commonest types; but sericitization, silicification, and adularization have also occurred. Pyrite is widespread but not particularly abundant, and much of it is partly altered to siderite.

The bottom of the formation has not yet been exposed by the mining operations. In all but a few places its top is marked by the intrusive West End rhyolite, which separates it from the Mizpah trachyte. On the 1,330-foot level of the Midway mine, however, the intrusive is absent, and a normal contact between the Tonopah formation and the Mizpah trachyte is exposed. The beds are steeply tilted at this place, and the mine workings show that the two formations interfinger with each other, beds of tuff or breccia alternating with relatively thin layers of typical Mizpah trachyte.

As the base of the formation is nowhere exposed, its total thickness is not known. Approximately 1,000 feet is present in the western part of the Tonopah Extension mine, exclusive of the interbedded Sandgrass andesite.

The age of the formation is not definitely known. It is unconformable beneath the Esmeralda formation, of upper Miocene age, and contains fragments of black slate that presumably belong to the Cambrian or Ordovician, inasmuch as lithologically similar rocks in adjacent areas are known to be of lower Paleozoic age.1 The greater portions of the Sandgrass andesite and Mizpah trachyte, both of which are of essentially the same geologic age as the Tonopah formation, are rich in albite and are similar to rocks at three other localities in Nevada that Knopf2 has described as Keratophyres.3 Almost all these rocks are of Mesozoic age but one occurrence at Cedar Mountain4 is considered to be Tertiary. If similarity in composition may be used as a basis of correlation, the formation may be either of Mesozoic or Tertiary age. H. G. Ferguson has studied the Mesozoic rocks in the Tonopah and Hawthorne quadrangles and has also seen the exposures of the Tonopah formation underground, and he informs the writer5 that the two are not at all similar in appearance. It would appear most probable, therefore, that the Tonopah formation is of Tertiary age (older than upper Miocene).

Sandgrass andesite—In Spurr’s earliest examination of the district, rocks belonging to the Sandgrass andesite were considered to be an altered phase of the Mizpah trachyte and were called by him the “calcitic phase of the earlier andesite.” When the formation was recognized as distinct from the Mizpah trachyte, the name was shortened by those working in the district to “calcite andesite.”6 In his final publication Spurr proposed the name Sandgrass andesite7 for the formation, and this name is retained in the present report, although microscopic study has shown that the formation contains relatively little andesite, most of the rock being keratophyric.

The formation is exposed in all the mines that were examined during this survey, but its character and relations are best

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3Almost all these rocks are of Mesozoic age but one occurrence at Cedar Mountain is considered to be Tertiary.
4The term keratophyre in recent years has been applied to essentially unaltered rocks which are similar to trachytes but which have a sodic plagioclase, albite or albite-oligoclase, in place of potash feldspar as the characteristic feldspathic mineral. This usage is retained in this report, although the term was originally applied to altered rocks in which the soda-rich feldspar was developed subsequently.
5Knopf, Adolph, op. cit. p. 368.
6Personal communication.
observed in the 960-foot level of the West End, the 1,540-foot and 1,880-foot levels of the Tonopah Extension, and the 1,000-foot and 1,140-foot levels of the Sand Grass.

Previous writers are not in agreement as to the true nature of this formation. Spurr considers it to be an intrusive sill-like mass, and Burgess implies that it is a flow, a view that is accepted by Locke. So far as the present examination went, the bulk of the formation as exposed underground is definitely extrusive. This is very clearly shown by the West End and Tonopah Extension occurrences cited in the preceding paragraph. At these localities the formation is composed of a series of flows of different composition and texture, some of which are strikingly amygdaloidal, and is divided into two separate bodies by an intervening strip of the Tonopah formation. The mass exposed in the workings from the Sand Grass shaft, however, is rather uniform in composition and texture and may be intrusive, though, on the other hand, the uniformity may be due to the fact that the workings that cut the formation are nearly parallel to the general strike, and thus expose only a single flow. The relation of this mass to the other formations is in large part masked by the presence of the intrusive Extension breccia.

In the Red Plume mine and in many of the workings from the old Midway shaft the Sandgrass andesite is also exposed. In these localities there is in general rather pronounced crushing and alteration, which has tended to mask the nature and relations of the formation. The boundaries of the formation in this region are somewhat irregular, but it appears most probable that this is due to a combination of an interfingering contact and folding than to intrusion. The interfingering of the andesite with the Tonopah formation may be observed on a small scale on the 530-foot level of the West End, and the fact that folding has affected these intertonguing formations is apparent from the dips of the Tonopah formation. The boundaries of the formation in this region are somewhat irregular, but their outlines suggest that they were originally hornblende and very probably biotite. These are now completely altered to elongate prismatic forms outlined with a heavy "fuzzy" border of black iron oxides, the inner portion of which consists of chlorite and quartz, with locally a little carbonate or sericite. The groundmass seems to have suffered less alteration than the phenocrysts. Outlines of small lathlike to tabular feldspar phenocrysts in subparallel arrangement can be distinguished. These seem to be albite chiefly; though there may be a little orthoclase and quartz. Among them can be found all the alteration products mentioned above, with chlorite and calcite the most abundant. Apatite is fairly common throughout the rock, and all of it is the ordinary colorless variety. Zircon was not noted. Pyrite occurs sparingly in rather irregular aggregates.

The total thickness of the formation is not definitely known. On the 1,540-foot level of the Tonopah Extension approximately 500 feet are exposed, and a portion of a somewhat lower belt is present but its lower limit is concealed by faulting. The formation must be of the same age as the Tonopah formation, with which it is interbedded.

Mizpah trachyte—The rock of andesitic appearance first described by Spurr under the name "Earlier andesite," as originally defined, also included the Sandgrass andesite, and therefore, in 1915, he renamed the formation the Mizpah trachyte. This name is retained in the present report, although microscopic work has shown that albite is the only feldspar

Mr. Campbell has provided the following notes upon the microscopic features of the formation:

In the amygdaloidal facies of the formation altered feldspars appear in a groundmass of chlorite. The feldspar phenocrysts are of small to medium size and, though mostly altered to calcite, appear to have been albite originally. Ferromagnesian phenocrysts were evidently rather rare. The amygdules show concentric filling by chlorite, calcite, and quartz. Pyrite is found as swarms of small cubes, but is only rarely present in the amygdules.

The basaltic rock consists of about 30 per cent of small tabular fresh crystals of calcic andesine in a typical basaltic texture. The groundmass material is made up of exceedingly small lathlike feldspars, the interstices between which are filled with a fine-grained aggregate of chlorite and calcite. Magnetite in small subhedral grains is abundant, but apatite is relatively rare. Pyrite and zircon are absent.

Specimens from the vicinity of the Sand Grass shaft show a seriate porphyritic texture of altered feldspar phenocrysts in a rather fine-grained, altered groundmass. The feldspars are almost completely altered to epidote, zoisite, sericite, chlorite, and calcite, but a few remnants indicate that their composition is that of albite. Other phenocrysts are also abundant and their outlines suggest that they were originally hornblende and very probably biotite. These are now completely altered to elongate prismatic forms outlined with a heavy "fuzzy" border of black iron oxides, the inner portion of which consists of chlorite and quartz, with locally a little carbonate or sericite. The groundmass seems to have suffered less alteration than the phenocrysts. Outlines of small lathlike to tabular feldspar phenocrysts in subparallel arrangement can be distinguished. These seem to be albite chiefly; though there may be a little orthoclase and quartz. Among them can be found all the alteration products mentioned above, with chlorite and calcite the most abundant. Apatite is fairly common throughout the rock, and all of it is the ordinary colorless variety. Zircon was not noted. Pyrite occurs sparingly in rather irregular aggregates.

present, and the rock is in reality a keratophyre or albite trachyte, a distinction first made by Winchell in an unpublished report to the Tonopah Extension Mining Co. On the lower levels of the Tonopah Extension mine this formation has been called the Victor andesite.

In several of the mine workings there are exposures of the rock that have been mapped by other geologists as "Midway andesite" or "later andesite," and described by them as lying unconformably above the Mizpah trachyte and forming a "cap-rock" to the veins. So far as the writer’s observations in the mines of the western part of the district show, the rocks assigned to the "Midway andesite" cannot be separated from the Mizpah trachyte by reason of any original differences in composition or texture, nor has he seen any examples of this rock capping any of the veins, or found in the literature reference to any specific example of it. In many places, it is true, extensive chloritization has affected these rocks and changed their appearance, but within such altered bodies less altered facies are found to be of the same keratophyric nature as the unquestionable Mizpah trachyte.

The least altered rock of the formation is normally a porphyritic rock of grayish-green or brownish-green aspect. The phenocrysts of feldspar are almost invariably somewhat dulled by partial alteration, are somewhat variable in size and number, and are set in a dense matrix locally flecked with chlorite. Pyritization has been rather widespread. Two other types of rock are found in the formation in a number of places. One of these is a flow-banded rock which is particularly abundant in the Wandering Boy workings, and is recognized less commonly in the other mines. The other is a fragmental rock, commonly a breccia, but locally tuffaceous, which is generally well-bedded. This variety was recognized in several places, particularly in the region between the Red Plume and new Midway shafts and in the Jim Butler and West End workings in the hanging wall of the West End vein.

Mr. Campbell writes:

In thin section the Mizpah trachyte shows rather numerous and prominent albite phenocrysts, set in a fine-grained, somewhat orthophyric groundmass composed principally of albite and orthoclase. A little quartz in the groundmass may be primary, but it is difficult to distinguish from secondary quartz. In the interstices of the feldspars in the groundmass are scattered small shreds of chlorite and sericite. Ferromagnesian phenocrysts are very rare. Biotite may be inferred from its pseudomorphs, which are generally either sericite or chlorite. Apatite, much of which is pleochroic, is relatively abundant, and zircon rather scant. Magnetite or ilmenite may have been sparingly present, but if so, it is now entirely altered to rutile.

Albite, as noted above, is the chief feldspar. Its average composition is Ab94An6. The phenocrysts are tabular and usually show the typical polysynthetic twinning, except where this has been obscured by alteration. Neither pericline nor carlsbad twinning is particularly common. Zonal growths are almost unknown. All these phenocrysts are altered to a greater or lesser extent. Sericitization of the albite phenocrysts was the most widespread type of alteration. Locally, adularization occurred and there has also been replacement by quartz, calcite, and chlorite. Any two or even three alteration products may be found on a single crystal. Alteration of the groundmass is more difficult to estimate with accuracy. It seems to have proceeded more rapidly than that of the phenocrysts, but along the same general lines except that much altered specimens are found in which the phenocrysts have gone entirely to sericite, but the groundmass has become a mass of intergrown quartz and sericite, with quartz the more abundant. Even in specimens that appear to be but little altered it is common to find veinlets and nests of quartz or quartz and adularia.

A thickness of at least 2,000 feet of the Mizpah trachyte is indicated by the hanging-wall exposures in the Sand Grass and Tonopah Extension mines. The top of the formation is not known, except where it is unconformably overlain by the Fraction breccia. The Mizpah trachyte conformably overlies the Tonopah formation and must therefore be slightly younger.

Extension breccia—The name Extension breccia has been locally used in the district for an intrusive mass of breccia whose relations are best exposed in the Tonopah Extension mine; and as it is desirable to distinguish this mass, the name is retained here. It is probable that in some of the previous geologic mapping this formation has been included either with the Tonopah formation or with the "Montana breccia."

On the lower levels of the Tonopah Extension mine the breccia is found in the footwall of the Murray and Merger veins. The exposure continues up to the 600-foot level, but the area of breccia present on each level steadily decreases upward, because of the fact that the dip of the breccia mass is somewhat steeper than that of the vein. The Extension breccia is also found on the hanging wall of the combined Murray and Merger veins in the lower levels of the Sand Grass and Merger mines, but is by no means adequately outlined there because of the relative scarcity of mine workings.

The intrusive nature of the mass is clearly shown in only a few places, such as the 1,880-foot, 1,760-foot, 1,680-foot, and 950-foot levels of the Tonopah Extension and the 1,000-foot
level of the Sand Grass, the relations in other localities being more or less masked by alteration near the veins. The intrusion appears to have been localized along an earlier fault, striking nearly east and dipping north, within the Tonopah formation. On the 1,140-foot level of the Sand Grass, for example, east of the main body of the intrusive, a narrow dike of the breccia is found in this fault zone, which here separates breccias and tuffs of the Tonopah formation from Sandgrass andesite. Still farther east on the 1,060-foot level from the Extension No. 1 shaft, however, the formation is absent from the fault zone. The actual contact of the intrusion is in many places difficult to locate exactly. Rock typical of the breccia passes gradually through a variety in which fragments of the invaded rock predominate, then to one in which they are exclusively present, and finally to shattered wall rock cemented by thin veinlets of the Extension breccia matrix.

The greater part of the intrusion is remarkably homogeneous in appearance, consisting of fragments of various rock types set in a characteristically reddish matrix containing rounded dark phenocrysts of quartz. The rock fragments included are largely of the Tonopah formation and less abundantly of the Sandgrass andesite and Mizpah trachyte. Not uncommonly small fragments of black shale are also found. Locally it is difficult to distinguish the formation from the breccias of the Tonopah formation, for in the vicinity of veins alteration has masked its relations and obliterated its distinctive characters.

Mr. Campbell's observations on the thin sections of this formation are as follows:

Under the microscope most of the inclusions are banded rocks, trachytic rocks, eutaxitic-textured rocks, and tuffaceous rocks, and can be recognized as belonging to the Tonopah formation. The matrix is not usually easy to separate from the rest of the rock. It seems to consist almost entirely of fine-grained quartz, much of which is probably secondary. Large quartz grains are embedded in this matrix and are much corroded and resorbed. Throughout the matrix there is distributed a faint reddish-brown dust, undoubtedly an iron oxide, which must account for the red color observed in hand specimen.

The Extension breccia shows the same kinds of alteration, with sericitization and silicification predominating, that the other formations have.

The maximum strike length of the Extension breccia mass was observed on the 1,380-foot level of the West End mine, where it amounted to nearly 1,500 feet. The maximum thickness (at right angles to the strike length) is not known because of the interruptions to the mass by faulting, but it is probably in the neighborhood of 1,000 feet.

The formation is later than the Mizpah trachyte, for it includes fragments of that rock, but it is older than the West End rhyolite, which intrudes it. It was probably formed in the same general period of volcanic activity as the Tonopah formation and its associated flows.

West End rhyolite—At the time of Spurr's earlier report the West End formation had been exposed in only a few shafts and was considered to be a part of what is called in this report the Tonopah formation. More extensive exposures, however, proved it to be a distinct rock, and it became known as the "Upper rhyolite," being described by Burgess\(^1\) under that name, although he appears to have included in it rocks that have since been assigned to the Tonopah formation. The formation was redefined in 1915 by Spurr and named the West End rhyolite,\(^2\) a name that is retained here.

Burgess describes the mass as being a series of flows, in contrast to Spurr's contention that it is an intrusive sill-like body, but the newer mine workings have exposed abundant evidence showing that Spurr's view is correct. Burgess's interpretation was in part due to the fact that he included in the West End rhyolite rocks that are now known to belong to the Tonopah formation.

The formation is best exposed in the West End mine workings, where it is found as a westward-dipping mass separating the Tonopah formation and the Mizpah trachyte. By reason of faulting, this same mass is also found in the more easterly mines, where, however, its thickness is considerably less. On the 1,330-foot level of the Midway it is entirely absent, and a normal contact between the Mizpah trachyte and the Tonopah formation is exposed. After allowing for the extensive subsequent faulting it appears that the intrusive originally decreased in thickness northward and upward. A second smaller mass of the West End rhyolite is exposed in the extreme westerly workings of the district, a short distance in the footwall of the main body.

The intrusive nature of the formation is shown by several features. Perhaps the most convincing is the fact that it cuts through the Extension breccia, which is itself intrusive. At several places in the Tonopah Extension and West End mines the formation sends apophyses into the stratigraphically overlying Mizpah trachyte, and in some localities inclusions of that rock may be found within the rhyolite. The largest of these is the

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long, narrow wedge in the footwall of the West End vein on the 500-foot level of the West End mine. In addition to these larger features, the details to be observed at individual contacts exposed in the mine workings can be explained only by considering that the West End rhyolite is an intrusive mass.

The rock most characteristic of the formation has a dense greenish matrix in which are set abundant angular fragments of white chalky rock. The number and size of the fragments vary greatly. Normally they form about a third of the rock and have an average diameter between a quarter and half an inch. Locally, particularly toward the east, they are tiny and in places almost completely lacking. Near contacts, on the other hand, the rock in many places is a coarse breccia, with inclusions as much as a foot in diameter, representing rocks of all the older formations, particularly those of the Tonopah formation. In the MacNamara mine, on the 400-foot level, similar coarse breccias may also be observed as bands within the formation: Wherever these variations in the number and size of inclusions are found in contact, it was observed that there is no sharp contact between the two phases, but rather a gradual blending over a distance of several feet. At the contacts of the formation the matrix shows chilling phenomena and is darker in color and glassy in appearance. A faint flow banding may be observed in several places, not only near contacts but within the mass of the formation.

Mr. Campbell writes as follows concerning the microscopic features of the formation:

In thin section the rock is seen to be a very fine-grained but generally holocrystalline rhyolite. Sparse phenocrysts of quartz, albite, and orthoclase are found in a matrix of feldspar (probably orthoclase) and quartz (much of which may be secondary).

The white inclusions so prominent in hand specimens are distinguishable with difficulty under the microscope. The “Glassy trachyte” and associated rocks appear to have furnished the material for the inclusions, because textures seen in a few of the sections are entirely similar to those characteristic of parts of the Tonopah formation.

The alteration of the rock was chiefly sericitization, with an indeterminable amount of silicification. Pyrite is widespread and abundant in this formation, and many of the pyrite cubes are bordered by quartz or sericite. Quartz veinlets in the rock are of widespread occurrence, and in many of these adularia is a rather abundant accessory. Sericite occurs in such veinlets more rarely.

The maximum thickness of the formation appears to be exposed in the West End Extension and Tonopah 76 workings, where the main intrusion appears to be at least 600 feet thick. On the 1,330-foot level of the Midway, however, this has decreased to the vanishing point.

The West End rhyolite intrudes all the formations previously described but is, like them, unconformably overlain by the Fraction breccia.

Fraction breccia—For the formation which was first described by Spurr as the Fraction dacite breccia and whose southern continuation in the Divide district was renamed by Knopf as the Fraction rhyolite breccia, the writer proposes the simplified name Fraction breccia, because at Tonopah the basal portion of the formation contains locally very large amounts of andesitic-appearing débris, with the result that there has at times been considerable confusion as to the proper correlation of the beds. They have, for example, been considered to represent the “Midway andesite”; indeed, all examples of “Midway andesite” cappings of veins that were seen by the writer proved to be this basal portion of the Fraction breccia.

The formation is exposed in the workings of the Jim Butler, MacNamara, West End, West End Extension, Monarch Pittsburg, and Tonopah 76 mines as a generally southward-dipping mass that unconformably overlies the older formations and the veins. In detail the lower contact of the beds is very irregular, showing that the surface upon which they were deposited had moderate relief. In many places the major faults that affect the veins appear to have exerted a control upon this old surface, for the breccia extends deeper where such faults formerly reached the surface. In addition, relatively slight renewed movement along many of the faults has resulted in shearing of the breccia.

The formation as exposed underground is almost everywhere a massive rock without any indication of bedding, although in a few places interlaminated fine-grained material may be observed. Near its contact with the older rocks it is generally sheared, presumably as a result of the later earth movements that imposed upon the formation its general southward dip. The basal beds are commonly made up almost exclusively of rock fragments that are andesitic in appearance, although most of them are undoubtedly keratophyres derived from the Mizpah trachyte. The proportion of matrix in this variety is in many places relatively small, and for the most part the matrix has the same dark color as the fragments. Higher up in the formation the

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rock is lighter colored and has a lower ratio of fragments to matrix. Of this portion Mr. Campbell writes:

The matrix is light colored, exceedingly fine-grained, and under the microscope appears holocrystalline to hypocrystalline. Fluidal texture has been observed. The aggregate index is lower than Canada balsam and higher than gamma of sanidine. Phenoocrysts of quartz and sanidine are abundant, and there are a few of albite and biotite. The sanidine is generally much altered to calcite, the albite somewhat altered to sericite, the biotite also to sericite. There has been some silicification throughout the rock and heavy kaolization locally. Pyrite, partly altered to limonite, occurs sparingly.

Only a small part of the formation is exposed in the underground workings so far examined, and the determination of the total thickness must wait until the surface exposures have been adequately studied.

The Fraction breccia is considered by Ferguson to be the basal member of the Esmeralda ("Siebert") formation and is therefore of upper Miocene age.

Rhyolite dikes—Dikes of rhyolite were observed in two of the mines examined. On the 1,680-foot, 1,760-foot, and 1,880-foot levels of the Tonopah Extension mine in the vicinity of the Cash Boy shaft, there is a thin dike which in one place at least cuts cleanly across the veins. Larger masses of similar lithology are exposed on the 800-foot level of the West End and West End Extension mines, cutting both the Fraction breccia and the older formations.

In both occurrences the rock is a light-colored, rather fine-grained rock with abundant quartz phenocrysts. Mr. Campbell has examined these rocks under the microscope and reports as follows:

In thin section the quartz phenocrysts stand out prominently. They are generally rounded but locally are embayed as a result of resorption, are slightly fractured, and are rather free from inclusions. Pheno- crysts of sanidine are common, and in one specimen these show partial alteration to calcite. More rarely albite occurs. An occasional small flake of biotite, now altered to sericite, was noted. The groundmass has been much silicified, as is well shown in one specimen where the secondary silicification has produced "enlargements" of quartz pheno- crysts, similar to the well-known quartz enlargements that occur typically in quartzites. If we discount this alteration it seems likely that this groundmass was holocrystalline and composed of quartz and orthoclase. There has been in places a slight sericitization, and locally small patches of calcite occur. Some pyrite was also noted.

No attempt has been made to correlate these rocks with the several types of rhyolite and rhyolite-dacite described by Spurr from surface exposures.

FOLDING AND FAULTING

Previous publications on the Tonopah district have described the several formations as being essentially horizontal and have implied that the bulk of the major faulting was later than the deposition of ore. The more extensive exposures available during the present examination indicate that these earlier conclusions are in error, for the formations are considerably tilted, and faulting appears to have been far more pronounced before mineralization than afterward. The apparent horizontal attitude of the formations in the older central portion of the district is in large part the result of premineral faults.

The block diagram included as Plate I of this report (in pocket) presents all the principal structural features of the western part of the district. This method of illustration was chosen because in no other way could the relations between dominantly eastward-striking veins and northward-striking formations be adequately shown. There are, of course, some objections to the method, one of the most important being that all the mine workings cannot be shown, but it is thought that these are outweighed by the numerous advantages. For several areas where there are no mine workings the writer has projected geologic features seen in surrounding areas. In a district where faulting is so widespread this is rather a dangerous procedure, and the doubt that is attached to such projections is indicated by question marks.

Many of the formations as already noted show either flow banding or sedimentary bedding planes, and these features are sufficiently abundant to provide adequate information as to the attitude of the rocks in most of the workings examined and to permit correlation of unfaulted contacts from level to level. They show that in the western part of the district there is a regional westward dip that averages close to 45°. The dips appear to decrease toward the east, and on the 700-foot and 800-foot levels of the Red Plume mine low northerly and easterly dips may be observed. On the 700-foot level of the Mizpah mine low easterly dips predominate, thus indicating that the beds are folded into

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a northward-plunging anticline. On the 630-foot level of the Midway mine in the vicinity of the old shaft there is apparently a moderate amount of minor folding on or near the crest of the anticline, to judge from the divergent dips observed there and also from the irregularity of the contact between the Tonopah formation and the Sandgrass andesite.

Faulting appears to have been much more effective in the premineral deformation of the district than folding. It clearly occurred at several stages, to judge from the relations of the faults to one another, but practically all of the faulting must have occurred during the interval between the intrusion of the West End rhyolite and the deposition of the Fraction breccia. The only earlier fault that could be distinguished is the nearly east-west fault that localized the intrusive mass of Extension breccia.

The first major fault formed after the intrusion of the West End rhyolite was a unique compound fault, here termed the Tonopah fault, whose appearance in cross section approaches that of a recumbent crescent, convex upward, and whose crest trends nearly east and plunges to the east. (See fig. 1.) The fault is economically the most important single structural feature in the district, for it not only has played a dominant part in determining the present distribution of the formations but has been the chief factor in the localization of the ore bodies, in that, together with its subsidiary fractures, it has provided the courses along which mineralization took place. Ore bodies along different parts of the fault have received different names, some of which are shown on the figure.

Figure 1 shows the extent to which the fault has been exposed by mine workings—for considerably more than 1,400 feet vertically on its north limb and for nearly 700 feet vertically on its south limb. The junction of the lower branch with the upper branch on the north is well exposed on the 500-foot level of the Tonopah Extension mine. This locality is not shown on Plate I. The diagram, however, does show the junction in cross section between the 600-foot and 660-foot levels of the Tonopah Extension mine, about 500 feet southwest of the Sand Grass shaft. The upper branch is apparently unmineralized at this point. The comparable junction to the south has not yet been found, but the dips of the two branches indicate that it very probably exists.

The crests of these two “anticlinal” branches both plunge to the east at low angles, ranging from 5° to 20°. The present rather inadequate exposures of the crest of the lower branch suggests that it plunges at a lower angle than the upper.
The appearance of the cross section of the fault suggests at once that it is simply a folded fault that originally had a uniform dip. This view is not tenable, however, because there is no similar folding in the formations adjacent to the fault—in fact, as noted above, the axis of the major folding in the wall rocks is at right angles to the axis of the crest of the fault. The throw along the fault may best be measured by the displacement of the nearly northward-trending contacts between formations on both sides of the essentially eastward-trending fault, as is well shown by the contact between the West End rhyolite and Mizpah trachyte on the 1,540-foot level of the Tonopah Extension mine.

The determination of the displacement along the fault, however, is somewhat complicated on the upper levels because of the presence there of a number of subsidiary, related faults that branch from its flanks and radiate from its crest, and because the dip of many of the contacts between formations there decreases rapidly eastward as the axis of the anticlinal fold is approached. On the lower levels the total horizontal shift of an individual contact by the fault and its splits is about 1,500 feet. Less trustworthy information on the upper levels also gives a figure close to this, but here the displacement is divided almost equally between the two major branches that form the crest of the fault.

The subsidiary related faults are most abundant on the upper levels. The only large one found at depth on the north limb of the main fault is mineralized and is locally known as the Merger vein. Its line of junction with the main fault plunges steeply to the east, and the two diverge from each other to the west. West of the point of junction the displacement along the main fault decreases by about one-half, the remainder being along the branch fault. No comparable branch or split has yet been observed along the south limb of the Tonopah fault.

The radiating faults along the crest of the fault differ from those on the flanks in that their lines of intersection with the main fault are nearly horizontal and their divergence is in a vertical rather than a lateral horizontal direction. Several of these fractures have been developed in the property of the Tonopah Mining Co., although most of them have only a very slight throw. The principal one is that occupied by the Mizpah vein and by its probable extension to the west as the Red Plume-Extension North vein. The latter has a maximum vertical displacement of several hundred feet, which, however, as in almost all the others of these faults that are sufficiently well developed, decreases rapidly, both upward and westward. This feature is particularly well shown along the Mizpah vein in the workings from the Mizpah shaft, the Extension North vein in the Extension mine, and the Egyptian vein in the Extension and West End mines. As the throw decreases the fracture generally steepens in dip, and in many places splits into two or more branches. This is particularly well exhibited along the Valley View vein and Mizpah vein.

The method by which the Tonopah fault was formed is not clearly understood. It must have developed in essentially its present form, for the wall rocks fail to show any comparable deformation, and hence it is obvious that the movement along it was essentially horizontal. It also appears probable that its origin is closely connected with that of the northward-trending anticlinal fold, although the anticline is clearly earlier, its axial plane being also offset by the fault. However, it is not known whether the fault was formed as a result of differential pressure continuing after the folding and is therefore in the nature of a transverse fault or flaw, or whether it represents a slump, following too great a piling up of volcanic material near the surface as a result of the folding, or whether it was formed in some other way. The apparent absence of drag effects near the fault perhaps favors the second view.

There are, in the western part of the district, some other pre-mineral faults of sufficiently great economic importance to warrant special mention in this preliminary report. These may be assigned to four groups of different ages, each group characterized by certain strikes and dips. There are many other faults that displace the veins, but they have not caused any confusion in mining operations.

The oldest group of faults that cut the Tonopah fault trend northwest to west-northwest and dip at a moderately low angle to the northeast. Two faults have been placed in this group, both with rather large throws. The more westerly has been considerably developed in West End Extension and Tonopah 76 ground and in the Tonopah Extension, as it has been mineralized and contains an ore shoot that is known in the Extension mine as the Merton vein. The horizontal shift of the contact between West End rhyolite and Mizpah trachyte along this fault amounts to more than 1,000 feet on the 1,540-foot level of the Tonopah Extension mine, and as the contact dips about 45° in that place, the vertical movement along the fault must have been the same. In the workings along this vein on the 1,540-foot level, southwest of the McKane shaft, it is clear that the fault is compound, in that there are two major branches, which in places must be
200 feet apart. To the west, however, they appear to join. The workings on the 800-foot level of the West End Extension and Tonopah 76 mines do not show a similar branching, unless the two masses of quartz found in the workings south of the main crosscut, or "Long Shot," represent the western junction of the branches.

The second of the two faults in this group may be called the Monarch-Pittsburg fault, as it has been rather extensively explored in the mine of that name, where it appears to have been mineralized. It has also been exposed on the 800-foot and 950-foot levels of the West End mine, where it cuts off the Ohio vein, and in the lower levels of the Tonopah Extension mine, where it offsets the Murray vein. The fault is essentially continuous between the exposures in the Extension and those in the Monarch-Pittsburg, but is cut and displaced by two large younger faults in the region between the Monarch-Pittsburg and the West End. The offset of the Murray vein in the Tonopah Extension mine indicates that the vertical movement along this fault must amount to about 1,000 feet. The Monarch-Pittsburg fault, like the parallel fault to the west, is compound, two major branches, which unite both to the southeast and to the northwest, being observed in the more westerly workings. In the Tonopah Extension mine this fault is known as the Denver fault.

Only one fault was recognized that may be placed in the second group. This fault, which is known in the Extension mine as the Rainbow fault, has a northerly to northeasterly strike and an easterly dip. It is best exposed on the 600-foot level, about midway between the Extension No. 1 and Sand Grass shafts. In most of these exposures the strike is nearly north, but southward toward the 600-foot level of the McNamara mine the fault splits, and the main branch assumes a northeasterly strike. The workings on the Ohio vein, particularly on the 555-foot level, show that this southeasterly branch is cut and offset by the Extension fault of the third group. The vertical movement along the fault is about 150 feet in the lower levels of the mine. On the upper levels the throw decreases and is divided between several branches; the movement along the main southwesterly branch was about 50 feet.

The third group of faults has a northerly strike and a deep westward dip. The throw along them is relatively small compared to that along the faults of the first group. The most thoroughly developed fault in the group is the Extension fault, which has been exposed throughout the vertical range of the Tonopah Extension workings and is also shown in parts of the MacNamara and West End mines. On the lower levels of the Extension mine the vertical movement along the fault amounted to about 125 feet, but on the upper levels it appears to have been somewhat less, in part at least because of the development upward of several branches.

The most westerly fault of this group is the 76 fault, exposed both in the Extension and in the West End Extension and Tonopah 76 mines, where it offsets the Merton vein. The vertical throw is somewhat less than 100 feet. Another fault of this group is present near the McKane shaft, where it offsets the earlier Monarch-Pittsburg fault. It may be called the McKane fault. The vertical movement along it is about 150 feet just above the 1,540-foot level but appears to decrease rapidly upward, amounting to about 50 feet in the Monarch-Pittsburg workings. These workings were not accessible, and it is not clear if this decrease in throw is the result of branching upward, as in the Extension fault.

A somewhat different behavior is exhibited by the fault to the east. This fault, which is unnamed, is about halfway between the McKane and Extension faults and is exposed in the workings from the Extension No. 2 shaft and the Extension incline. The maximum displacement along the fault in this vicinity appears to have been about at the 1,260-foot level, where the Murray vein has been dropped on the hanging-wall side about 100 feet vertically. Below this level the fault passes into a flexure, as is shown by the curving hanging wall of the Murray vein on the 1,540-foot level. Above the 1,260-foot level the throw decreases, and on the 850-foot level is comparatively insignificant. This fault appears to be represented to the south by a fault of similar strike and dip that is exposed in two places on the 800-foot level from the Ohio shaft. Here, however, the throw is considerably greater, as the offsetting of the Monarch-Pittsburg fault by it indicates a vertical drop of at least 200 feet.

The last fault of the third group that need be considered here is one found in the western part of the property of the Tonopah Mining Co., which has been called the Buried fault. This fault cuts the nose of the upper branch of the Tonopah fault and drops it to the west slightly more than 100 feet. The workings from the Wandering Boy shaft indicate that it frays out southward and upward, and as it could not be recognized in the Midway workings it must also die out northward. It is not certain that this fault is of the same age as the other faults in this group,
for it appears to offset minor faults of similar strike to those that have been placed in the fourth group.

The faults of the fourth group strike northeast to east-northeast and dip at different angles to the southeast. The most interesting fault of this group is one that has been called the MacNamara fault in the mine of that name. This fault is well exposed in the upper levels of the MacNamara and West End mines, where it displaces the upper branch of the Tonopah fault and may be correlated with a fair degree of certainty with a fault of similar strike and dip that cuts the Ohio vein on the 700-foot level of the MacNamara and 800-foot level of the West End. On the latter level the fault is clearly later than the Extension, Rainbow, and Monarch-Pittsburg faults. In this region the vertical displacement along the fault ranges from more than 200 feet on the western portion of the 800-foot level of the Ohio to less than 50 feet where it cuts the Tonopah fault on the 500-foot level of the Tonopah Mining Co. East of the latter point, however, the character of the fault appears to change completely near the hanging wall of the older Tonopah fault. The dip decreases notably, and the fault takes on a rolling habit which appears to be partly controlled by the low eastward pitch of the nose of the Tonopah fault. This is well exhibited on the most westerly workings of the 600-foot level from the Mizpah shaft and on the 530-foot level of the Midway. The displacement along this rolling portion of the fault is considerably greater than that shown by the offsetting of the Tonopah fault to the west. This feature appears to be most readily explained by considering that the excess movement along this portion of the MacNamara fault is represented elsewhere by renewed movement along the upper branch of the Tonopah fault, which roughly corresponds to it in strike and dip.

The fact that the MacNamara fault resumes its normal character upward away from the Tonopah fault is shown by the workings north of the shaft on the 500-foot level of the Red Plume mine. Another major fault in this group is the Sand Grass fault, which is well exposed only on the 600-foot level of the Sand Grass mine, where it cuts the shaft, and on the 660-foot level of the Tonopah Extension mine. It is thought that exposures of faults with similar strike and dip on the 1,050-foot and 770-foot levels from the Extension No. 1 shaft and the 1,000-foot level of the Ohio represent the same fault; and others on the 600-foot level of the Monarch-Pittsburg and the 800-foot level of the West End Extension-Tonopah 76 just west of the Monarch-Pittsburg connection are still more western extensions. To the east the Tonopah fault is dropped more than 150 feet vertically by the Sand Grass fault, but on the 660-foot level of the Extension this displacement is distributed along several branches.

Several other faults of similar strike and dip are exposed in the properties of the Tonopah Mining Co., Jim Butler, and West End, but the throws along them are relatively small. One of the best known of these is the Silver Top fault, in the ground of the Tonopah Mining Co., which offsets the Valley View vein throughout the mine.

The movement along the faults of all these four groups must have been largely accomplished before the deposition of the ore, for essentially unshattered quartz has been deposited in places along almost all of them. In some of these occurrences such quartz is continuous with the quartz of the mineralized Tonopah fault and its related fault veins. In addition ore has been stope from several of the faults, as on the Merton vein in the Tonopah Extension and West End Extension-Tonopah 76 and on the Rainbow fault in the MacNamara. There has of course been post-mineral movement along some of the faults, for in several places quartz pebbles are present in the fault gouge, but this movement appears to have been relatively slight.

THE ORE BODIES

The form and character of the silver-rich ore bodies have been thoroughly described by Spurr and Bastin and Laney. The following quotations from the latter authors rather inadequately summarize some of their conclusions regarding the ores:

As emphasized by Spurr, the ores of Tonopah are in the main replacement deposits along sheetlike zones of fracturing. They are therefore typical replacement veins. Every gradation may be traced from heavy sulphide ore into slightly replaced wall rock. Ore-cemented breccias, true crustification, comb structure, and other features characteristic of the filling of open spaces are rare or developed only on a small scale. Banding somewhat resembling true crustification, which is locally conspicuous, is possibly to be explained by diffusion during replacement. * * *

Although supergene mineralization has played an interesting part in the genesis of certain of the Tonopah ores, it appears to have been quantitatively much less important than the hypogene mineralization.

Most of the ore bodies in which it was most prominent are worked out, and the principal dependence of the mines today is upon ores that, the writers believe, are almost wholly of hypogene origin.¹

In view of the adequate description of the character of the ores given in these two publications, it seems desirable in this preliminary report to consider only the factors that are thought to have been active in the localization of the ore bodies. A complete discussion of this subject, however, is not possible, for it would require the use of physico-chemical data that are only partly known. The following paragraphs, in which the factors derived empirically from a study of the known ore bodies are considered, may nevertheless prove of some benefit in directing future exploration.

The most outstanding feature of the known ore bodies in the western part of the district is their localization in the Tonopah fault and its subsidiary fractures. There is, of course, no direct connection between the ore and the fault, because extensive faulting intervened between the formation of the Tonopah fault and the deposition of the ore, and the later faults are only locally mineralized. It would seem rather that at the time the silver mineralization occurred the nearly east-west Tonopah fault and the deposition of the ore, and the later faults are only locally mineralized. It would seem rather that at the time the silver mineralization occurred the nearly east-west Tonopah fault and its associated fractures were parallel to compressive forces existent at that time, and they therefore were capable of being open to the mineralizing solutions. Applying this conclusion to future exploration would suggest that, subject to the limitations imposed by the other factors, development work should be confined to the Tonopah fault and its branches and splits, almost all of which are found on the hanging wall, and to such other fractures or faults as have a parallel strike. The fractures that radiate from the crest of the upper branch of the main fault appear to have been rather thoroughly explored, but this cannot be said for those that radiate from the crest of the lower branch. One such fracture has been found to be ore bearing in the West End mine, and it is possible that other similar ones may be present.

Ore bodies are unfortunately not found everywhere along the Tonopah fault and its branches; and there obviously must be additional factors governing their local distribution. The writer believes that the most essential requisites for the deposition of ore along these fractures were, first, that they should be open to the flow of the ore solutions at the time the solutions were circulating, and second, that the wall rock along such open fractures should be of a nature to facilitate precipitation and accumulation of the silver minerals.

¹'Bastin, E. S., and Laney, F. B., op. cit., pp. 9–10.'
silicification has converted it into material that has afforded ample fractures for admission of the ore-depositing solutions.

The determination as to the direction of exploration based upon these two factors is a somewhat more difficult matter than that based upon the relation of ore to the Tonopah fault. It appears to the writer that the character of the wall rock is by far the more important of the two in relation to possible ore deposits, in that if this condition is satisfied along a known fracture it is probable that the fracture will be found to have been open to ore-bearing solutions at some place along its strike or dip. Prediction as to the character of the wall rock must necessarily be based upon the observed alteration. At present it is not possible to delimit areas in which favorable rock may be expected to occur, but from the work thus far accomplished it seems probable that this may be done when the field work has been completed.

The final factor—that of depth—demands recognition, but the data available are not sufficient to determine its true importance. The fact that some of the ore bodies decrease in value with depth has been noted by Bastin and Laney, and in similar occurrences seen by the writer the decreased silver content does not appear to be explained by the action of any of the three factors above set forth. In such occurrences the appearance of the vein material is not greatly changed, except that the sulphides present are almost entirely those of the base metals, silver sulphides occurring only sparingly. It is impossible to set a definite elevation at which this decrease may be expected to be operative, for the few localities at which it is thought to have occurred vary considerably among themselves; for example, the inadequate information now available appears to show that this depth may be different on either side of a premineral fault. The writer believes that these features may best be explained by considering that the depth of ore deposition was also controlled by the temperature of the ore-depositing solutions, in that above a certain temperature the precipitation of silver sulphides was impeded; and that at different localities this temperature was reached by the cooling, ascending solutions at different elevations, because of differences in the facilities for movement of the solutions along the ore channels. In general, it seems to be true that the required elevation was higher in the central part of the district than it was in the western part, but this statement is subject to many local variations.

1Bastin, E. S., and Laney, F. B., op. cit., p. 44.