THE TERTIARY IGNEOUS TERRAIN IN THE VICINITY OF THE KING TONOPAH MINE, TONOPAH, NEVADA: AN EXPLORATION CASE STUDY

by

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Professor of Geosciences

7th April 1986
Date

DEDICATION

To my mother, Sybil M. Barker, for instilling a passion for language and learning, without which this study might not have been conducted.

ACKNOWLEDGEMENTS

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ABSTRACT

Uneconomic epithermal precious metal mineralization and associated alteration occur in the Tonopah Property, and are similar in style, although much less intense, to the deposits of the Tonopah camp two miles south. Mineralization is localized within a set of northwest-trending faults within the Tonopah, Mizpah, and King Tonopah Member of the Fraction Tuff formations, and is associated with widespread propylitic and sparse fracture-localized potassic and argillic alteration. A younger set of Mn-calcite veins, anomalous in manganese, mercury, arsenic, and antimony, occurs in northeast-trending faults cutting older formations as well as the younger Tonopah Summit Member of the Fraction Tuff. This mineralization is possibly associated with silicification, zeolitization, and clay-alteration of the Fraction Tuff.

The Tonopah Summit Member of the Fraction Tuff is reinterpreted as younger than the King Tonopah Member. Mega-breccia and basin morphology in the northeast may indicate an eruptive vent in this area.

CHAPTER 1

INTRODUCTION

General

In 1983, the author was employed as site geologist for a silver exploration project located in the state of Nevada, conducted by Silver Strike Resources Ltd., of Vancouver, B.C., Canada. The claims of interest, henceforth refered to as 'the field area', or 'the Tonopah Property', are located approximately midway between Reno and Las Vegas, north of and adjacent to the town of Tonopah, Nye County, Nevada (Figure 1). The field area is situated near the southern border of the San Antonio Mountains at an average elevation of about 6,300 feet.

The climate, as is characteristic of much of the state of Nevada, is arid, with Tonopah receiving an average annual rainfall of approximately five inches (Bonham and Garside, 1979a). The meager precipitation supports a sparse plant community composed of small sagebrush (Artemisia tridentata) and smaller desert shrubs (Figure 2). Where groundwater approaches the surface, as along one major fault in the field area, rabbit brush (Chrysothamnus grareolens) and greasewood (Sarcobatus vermiculatus) occur. Consequently, vegetation poses no obstacle to field mapping.

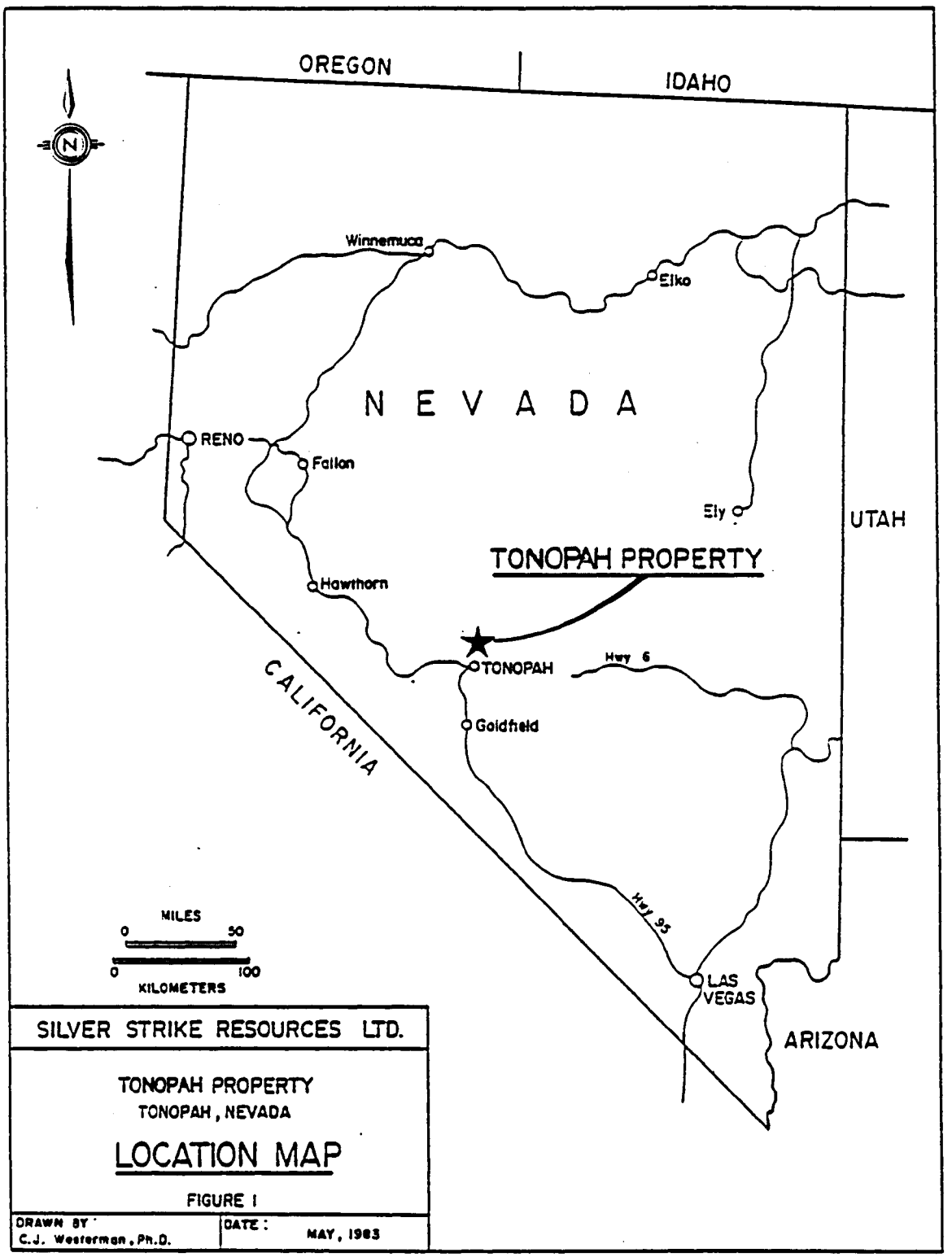


Figure 1: Location map (after C. H. Westerman).

Figure 2: Tonopah Property, looking northwest from Mt. Ararat.

The history of the Tonopah area, excluding Indian prehistory and the transitory activities of early trappers such as Jedediah Smith, commenced with Jim Butler's discovery of supergene silver ore on a ledge within the present town site, in May of 1900 (Bonham and Garside, 1979a). Mining activities were rapidly pursued, and the heyday of Tonopah's production lasted until the Great Depression. Bonham and Garside (1979a, p. 5) reported that the total production amounted to approximately 1,861,200 ounces of gold and 174,152,628 ounces of silver.

Previous Investigations

The majority of the geological investigations of the Tonopah district were conducted during the boom years of the mining camp, and were concerned primarily with the nature and stratigraphy of the district's Tertiary rocks (Spurr, 1904, 1905, 1915; Burgess, 1909, 1911; Bastin and Laney, 1918). Nolan's reports (1930, 1935) dealt with the underground workings of Tonopah while they remained accessible, during which time Campbell (1931) investigated the petrography of the district. Later work included Broderick's (1949) study of the area immediately north of Tonopah, initiating interest and subsequent exploration of terrain centered on the field area of the author's research. More recently, Core (1959) studied the hydrothermal alteration of the district; Taylor (1973) investigated the stable isotopes

of oxygen and hydrogen in relation to the alteration and mineralization; Silberman et al (1978) generated radiometric dates for the Tertiary volcanics; and Fahley (1981) studied fluid inclusions from vein material within the district. Of greatest value to this study were two Nevada Bureau of Mines and Geology reports by Bonham and Garside; the first (1979a) provided comprehensive stratigraphic and petrographic information on the region, and the latter (1981) presented detailed geochemical data of exploration import over the same region. Much of the following discussion and stratigraphic nomenclature draws extensively from these reports.

Thesis Problem

The thesis problem was, owing to the nature of the author's employment by the aforementioned company, first and foremost a preliminary exploration project. The methodologies used to attempt to solve the problem, i.e. the discovery of an economic concentration of ore, were the strategies available to the company and deemed worth the risk to the company's stock-holders. Finally, the entire exploration program needed to be shoe-horned into the allotted budget of both time and money.

In the case of the Tonopah Project, a block of claims comprising approximately 3.5 square miles, centered about several patented claims and the King Tonopah Mine, and

located one mile north of Tonopah, were made available in 1983 for exploration lease. Since the King Tonopah Mine had produced an undisclosed amount of high-grade silver ore of essentially the same alteration and vein mineralogy as the bonanza lodes from the main camp, and since previous workers (e.g., Broderick, 1949; Bonham and Garside, 1979a, 1981) believed the area to the north of Tonopah to be a reasonable exploration target for reasons of alteration patterns and structure, Silver Strike Resources Ltd. decided a preliminary exploration program was worth the risk. To this end, the company hired a consulting geologist in May of 1983 to examine the property and outline an exploration strategy. In July, the author was hired as project geologist with the responsibility of reconnaissance and detail mapping, surface sampling for geochemical analyses, and for subsequent drilling supervision and drill core logging.

The preliminary exploration strategy was as follows: First, a 1:4800 reconnaissance map of the geology of the Tonopah Property was to be constructed (Figure 22). To this end, a grid system of N-S and E-W lines were laid out with pickets at 400 foot intervals, with the origin at the King Tonopah Mine. Mapping was then conducted via the pace and compass method. Concurrent with mapping, the author was responsible for what the company considered to be the site geologist's prime function: prospecting. This consisted of

collecting grab samples of all varieties of vein material and altered rocks for geochemical analyses (Chapter 5). During the initial mapping and "prospecting" stage of exploration, a geophysical subcontractor was to conduct a ground-based electromagnetic survey of the field area. The purpose of the survey would be to delineate water-saturated clay alteration halos possibly enveloping mineralized faults. Reconnaissance mapping and sampling was to be completed in time to allow for two or three weeks of detailed (1:1200) mapping of critical areas. Upon the completion of mapping, geochemical sampling, the geophysical survey, and concluding reports, the final stage of the preliminary exploration, that of diamond drilling, would commence. The total time allotment for the preliminary exploration project was six months, concluding by the end of 1983.

In addition to the prime objective of ore search, the author pursued two further objectives in order to integrate the geology of the field area with that of the Tonopah district, and in so doing, to further elucidate the Tertiary igneous history of the region: The first goal was to decipher the general stratigraphy and structure of the field area, while the second was to describe the various styles of alteration and to compare and contrast these to alteration in the main camp in Tonopah.

CHAPTER 2

GEOLOGIC UNITS AND STRATIGRAPHY

General

The Tonopah Property is situated near the southern end of the north-trending San Antonio Mountains of west-central Nevada (Figure 3). The mountain range is delimited by normal faults and adjacent alluvial valleys typical of the Basin and Range province. Tertiary igneous rocks crop out for miles to the north and south of Tonopah, while Paleozoic and Mesozoic sedimentary rocks and Mesozoic intrusives are exposed further to the north and south. The Tertiary rocks are predominantly volcanics of Miocene age, composed of successions of intermediate lavas and ashflows and associated post-ignimbrite rhyolites, succeeded by a final eruptive stage of late-Miocene and possibly early Pliocene intermediate lavas. Broderick's (1949) Ph.D. thesis: Geology of the Southern Part of the San Antonio Mountains, presents a thorough discussion of the geology of the region.

Geologic Units and Field Area Stratigraphy

Within the field area five rock units are represented. The oldest is not exposed at the surface, but was intercepted in drill core, while the other four units crop

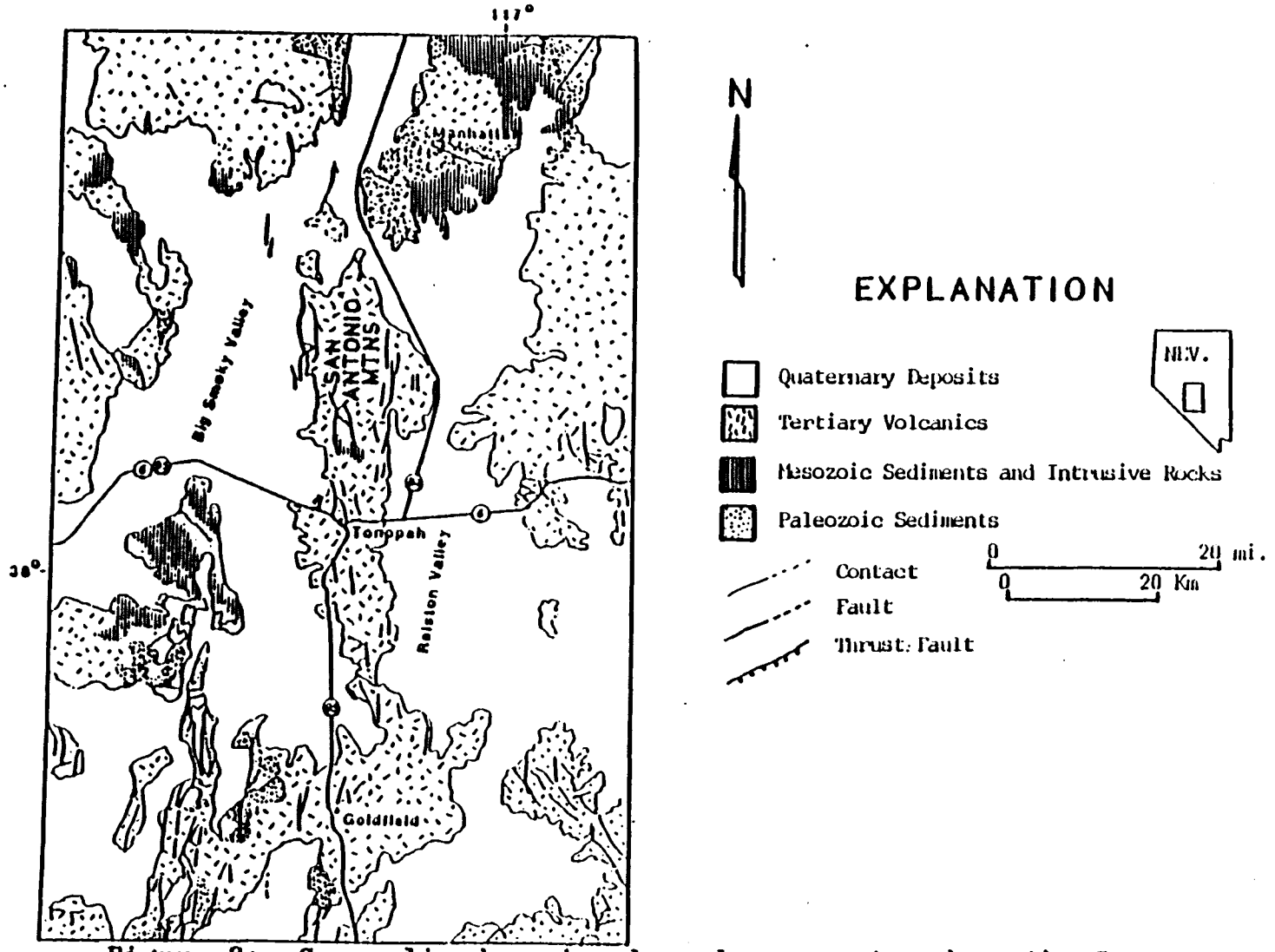


Figure 3: Generalized regional geology, centered on the San Antonio Mountains and Tonopah (after Fahley, 1981).

out. The stratigraphic relations of the units are shown in Figure 4. A generalized geologic map of the Tonopah district is presented in Figure 5 and a 1:4800 scale geologic map of the field area, with cross-sections, is presented in Figure 22.

Pre-Tertiary Units

Pre-Tertiary rocks are included as infrequent xenoliths in younger rock units. These rock fragments are composed of shale, sandstone, limestone, and chert of Paleozoic and Mesozoic age, and of granite and diabase of Mesozoic and possibly Cenozoic age. That fragments of these rocks occur in the Tertiary rocks of the field area implies, of course, that they compose the basement beneath the younger rocks.

Tertiary Units

Tonopah Formation. Bonham and Garside (1979a) have divided the Tonopah Formation into two informal units. The basal unit consists primarily of vitric and vitric-lithic, welded ashflow tuff with abundant pumice and 10 to 15% lithic fragments. Phenocrysts include potassium feldspar, plagioclase (An_{25-40}), quartz, and biotite. Zircon, apatite, and Fe-Ti oxides are accessory phases. The upper unit consists of flow-banded rhyolite, which is in part intrusive into the lower unit.

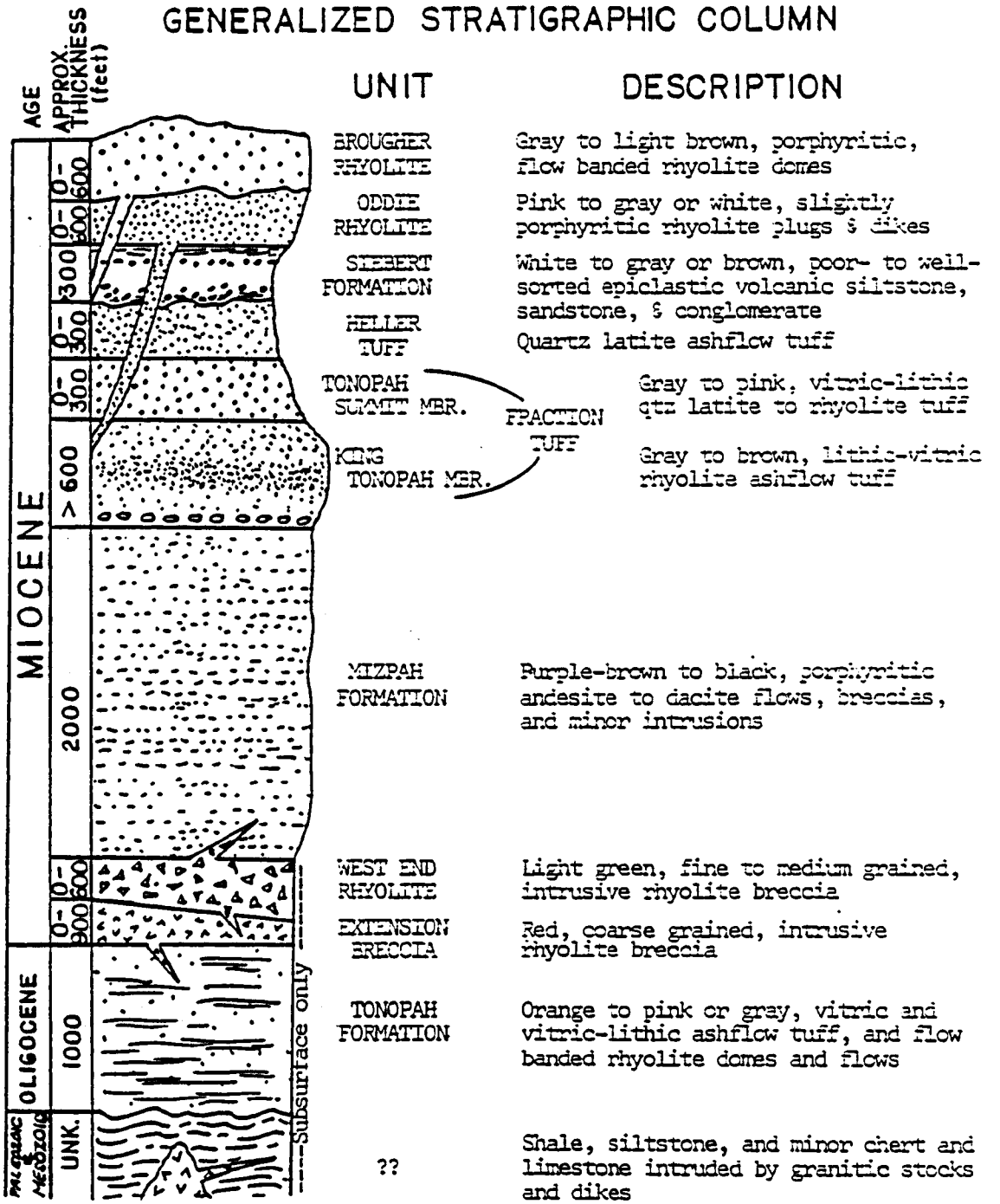


Figure 4: Generalized stratigraphic column of the Tonopah district (after Fahley, 1981).

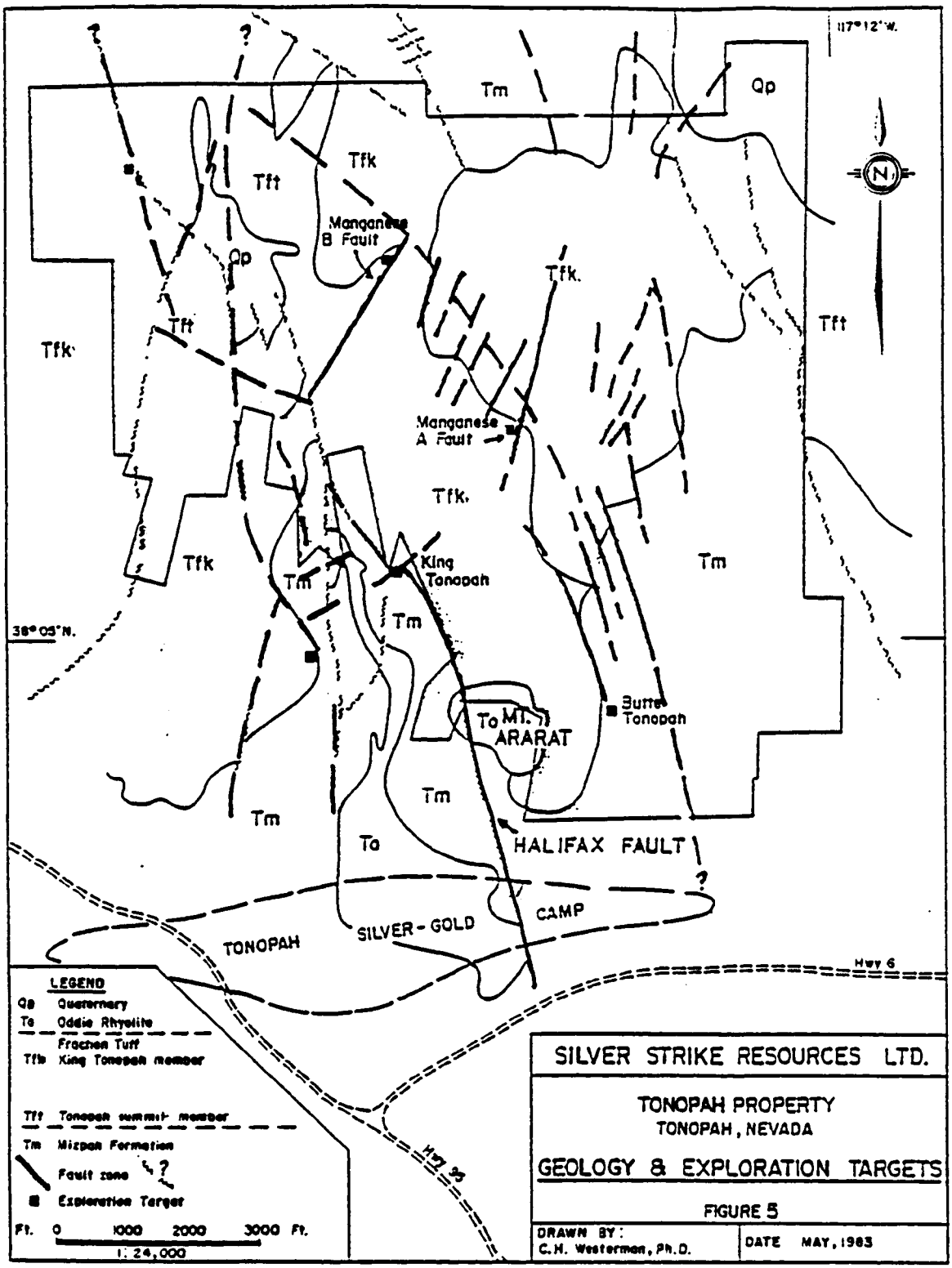


Figure 5: Generalized geologic map of the Tonopah district (after C. H. Westerman)

The Tonopah Formation, the oldest of the five rock units studied in the field area, was intercepted during the drilling phase of the exploration project, and as stated above, does not crop out at the surface in the field area, or elsewhere in the Tonopah district. It is only known to be exposed at the surface near Red Mountain, approximately six miles north of Tonopah, and in the Tonopah mine where it unconformably overlies Paleozoic or Mesozoic rocks. Nolan (1935) estimated the average thickness of the Tonopah Formation to be 1000 feet. The lower and upper units yielded fission-track ages of 34±4.2 m.y. and 24.3±2.8 m.y., respectively (Bonham and Garside, 1979a, p. 22). The age difference between the two units seems untenable, but Bonham and Garside neither offered an explanation for the time span or commented on the analyses.

The Tonopah Formation intercepted in drilling in this study is highly altered and will be described later in this report (Chapter 4).

Mizpah Formation. The Mizpah Formation consists of dark gray to gray-brown to purple-gray intermediate volcanics, ranging in composition from andesite to dacite (Bonham and Garside, 1979a). The essential phenocryst minerals are, in order of abundance, plagioclase, biotite, hornblende and augite, with or without quartz. Pleochroic apatite up to several millimeters in length is a conspicuous

accessory mineral. Lava flows within the Tonopah Property consist predominantly of porphyry, typically exhibiting some degree of flow-alignment in the orientation of plagioclase phenocrysts. Minor flow-top breccias are exposed near contacts. All flows examined showed pilotaxitic feldspar microlite texture in a fine-grained to glassy groundmass. Plagioclase occasionally displays oscillatory zoning, and exhibits a range in composition from andesine to labradorite. The common mafic minerals, biotite and hornblende, are usually partly oxidized, and quartz, where present, is embayed. The clinopyroxene noted was invariably pale green to medium green, indicating diopsidic augite.

The Mizpah Formation unconformably overlies the Tonopah Formation and is the oldest exposed rock unit in the Tonopah district. The Mizpah Formation has been estimated to be at least 2000 feet thick in the Tonopah district (Nolan, 1935), and one drill hole spudded in the southeast corner of the field area remained within the unit to the bottom of the hole, 857 feet beneath the surface. Bonham and Garside (1979a, p. 21) have dated the Mizpah Formation at approximately 20.5 m.y.

Fraction Tuff Formation. The Fraction Tuff overlies the Mizpah Formation, and has been subdivided into two informal members by Bonham and Garside (1974; 1979a). Both members are exposed in the field area. Bonham and Garside

proposed that the subdivisions be formalized and named the Tonopah Summit Member and the King Tonopah Member.

King Tonopah Member. The King Tonopah Member is a light gray to tan to brown, high-silica (,75.5%: Bonham and Garside, 1979a, p. 53), generally moderately to densely welded, vitric-lithic tuff. It has a prominent basal black hydrated vitrophyre, and immediately subjacent basal non- to poorly-welded tuff and tuff-breccia base. The bulk of the ashflow exhibits eutaxitic fabric and variable degrees of devitrification. Devitrified rock displays spherulitic and axiolitic textures. Phenocrysts are typically fragmental; the most common are plagioclase and sanidine (usually somewhat corroded), minor hornblende and rare diopsidic augite, generally largely oxidized, and occasional embayed quartz. Plagioclase commonly exhibits oscillatory zoning, and ranges in anorthite content from oligoclase to andesine. Lithic fragments commonly make up to 25% of the rock.

The King Tonopah Member of the Fraction Tuff appears to overlie the Mizpah Formation conformably in several surface exposures in the field area, particularly in the eastern half where the well developed basal vitrophyre crops out. Bonham and Garside (1979a, p. 22) provided two potassium-argon dates for the King Tonopah Member: 18.7±0.6 m.y. and 20.4±0.6 m.y., for what they consider to be upper and lower ashflow units, respectively. Further discussion

of these purportedly distinct ashflow units will follow in the section on map relations at the end of the chapter. Bonham and Garside (1979a) estimated the thickness of the King Tonopah Member to be at least 600 feet.

Tonopah Summit Member. The Tonopah Summit Member is a non- to poorly-welded vitric, lithic, tuff of quartz latite to rhyolite composition. It is highly altered everywhere within the field area and throughout the district. The tuff ranges in color from light gray to pale pink to orange-gray within the field area where it is hydrothermally altered and zeolitized. The essential phenocrysts of relatively unaltered Tonopah Summit ashflow are quartz, alkali feldspar and plagioclase of 35% to 45% anorthite content, usually exhibiting oscillatory zoning. The ashflow is lithic-rich and typically contains 50% or more lithic fragments.

Based upon the author's mapping, where exposed in the field area the Tonopah Summit Member unconformably overlies the King Tonopah Member. The evidence for this is presented and discussed at the end of the chapter in the section on map relations.

Bonham and Garside (1979a) reported a thickness in excess of 1200 feet in one shaft in the Divide district, several miles to the south of Tonopah. In the largest exposure in the field area, however, the Tonopah Summit

Member is probably less than 200 feet thick. In this particular outcrop, one drill hole penetrated the bottom of the unit at approximately 110 feet.

Bonham and Garside reported three potassium-argon dates and two fission-track dates for the Tonopah Summit Member (1979a, p. 22). The potassium-argon dates appear too recent and have probably been affected by alteration phenomena, but the fission-track dates are probably fairly reliable, since alteration temperatures should not have been so high (>300° C.)as to have annealed tracks. The fission-track dates reported are 17.0±1.3 m.y. and 18.4±3.1 m.y., from zircon and apatite, respectively.

Oddie Rhyolite. The Oddie Rhyolite is a pinkish-gray, phenocryst-poor, intrusive rock, dated by Bonham and Garside (1979a, p. 21) in two potassium-argon analyses at 16.4±0.5 m.y. and 16.9±0.5 m.y. The rock is composed of 10 to 20% phenocrysts of quartz, alkali feldspar, plagioclase, and rare biotite, in a cryptocrystalline matrix of quartz and feldspar.

The Oddie Rhyolite is the one hypabyssal intrusive within the field area, and intrudes into and uplifts rocks of the Fraction Tuff and the Mizpah Formation. The rhyolite is exposed as plugs that form prominent hills in the Tonopah district, hence no thickness estimates are given in the literature.

Remnants of one minor extrusive flow of Oddie Rhyolite are also exposed in the field area. The exposures are generally 100 to 200 feet in diameter and are widely scattered in the south-central sector, south and southwest of the King Tonopah Mine. The outcrops are bleached white, and the major exposure which occurs just south of the field area shows small-scale (2 to 4 inch wide) columnar jointing.

Siebert Formation. Bonham and Garside (1979a) reported that the Siebert Formation consists of a variety of sedimentary and pyroclastic rocks, the bulk of which are fluvatile and lacustrine epiclastic volcanic conglomerate, sandstone, and siltstone. The Siebert Formation exposed in the map area is composed of two facies found in fault and/or depositional contact with each other. One is a fluvatile conglomerate and gravels, and the other a bedded volcanic sandstone. The conglomerate and gravel facies contains clasts of all the volcanic rocks previously described, as well as pre-Tertiary materials. The author discovered one large silicified portion of a tree trunk in this facies, and was informed by an elderly Tonopah resident that the area had once been covered with silicified wood which had long ago been hauled off by collectors.

The Siebert Formation was deposited unconformably on the units described above, particularly the Fraction Tuff and the Mizpah Formation. In the field area, small remnants

are found overlying the Tonopah Summit Member of the Fraction Tuff.

Two apparently reliable potassium-argon dates are provided for the Siebert Formation (Bonham and Garside, 1979a, p. 21): 15.5±1.6 m.y. and 16.2±0.6 m.y., from biotite and whole rock, respectively.

Map Relations

General

So that the 1:4800 scale field reconnaissance map (Figure 22) may be better understood, a few general remarks are in order. First, bedrock outcrop makes up only a few percent of the field area. The bulk of the surface area is made up of a variable thickness of angular, gravel- to pebble-sized alluvium. For this reason, outcrop is designated by heavy coloring on the map, and areas where alluvium conceals bedrock are shown in corresponding lighter tints. Mapping such features as lithologic contacts, and mineralized veins and faults within talus and alluvium that has moved downslope to variable degrees proved difficult, and the features so mapped are but approximately located. In addition, many features must be so obscured that they remain unmapped, particularly the rugged topography of the eastern half of the field area, in which only certain major features of the structure have been recognized and located

with confidence. Nonetheless, overall map relations appear to be logically integrated into a coherent whole, after taking into account the author's stratigraphic revisions, discussed below in the section on the stratigraphy of the Fraction Tuff.

Perhaps the single most useful stratigraphic marker in the field area was the basal black vitrophyre of the King Tonopah Member of the Fraction Tuff. Where present as bedrock it indicated the general bedding attitude and ruled out fault juxtaposition of King Tonopah Member ashflow with subjacent Mizpah Formation, and where present as broadly scattered float over alluvium and outcroping Mizpah Formation, the vitrophyre indicated that erosion had just barely removed the superjacent tuff to expose the top of the older unit. Exposures of this distinctive vitrophyre also helped to resolve stratigraphic problems regarding the King Tonopah Member, as discussed below.

Another feature of the reconnaissance map which deserves some discussion is a rhyolite of unknown age and origin which is exposed as xenoliths up to ten meters across within the King Tonopah Member (Figures 6 and 7). The boulders are largely aligned in linear trends that generally bear north to northeast, and virtually all of the xenoliths occur in the topographically high northeastern sector of the field area. Petrographically, the author could not

Figure 6: "Megabreccia" xenolith of Mizpah Formation dacite included in King Tonopah tuff: northeast sector of property.

Figure 7: Several "megabreccia" xenoliths of rhyolite within King Tonopah tuff: northeast sector of property.

distinguish this rhyolite from the Oddie Rhyolite described above, aside from the fact that it is brecciated (although the xenoliths cannot be Oddie Rhyolite). This feature will be discussed in further detail in Chapters 3 and 7.

In addition to being a geologic map, the 1:4800 sheet is also an alteration map, in which major alteration types are contrasted with unaltered or relatively unaltered rocks of the same lithologies by their own map colors. Vein material and jasperoidal float are indicated by cross-hatches, and iron-oxide-stained breccia zones are colored in red.

Stratigraphy of The Fraction Tuff

The author concurs with the validity of the subdivision of the Fraction Tuff into the King Tonopah Member and the Tonopah Summit Member on petrographic and genetic grounds. But the author disagrees with the stratigraphic order that Bonham and Garside (1979a) have proposed for the two subdivisions for two reasons: first, their stratigraphic ordering is refuted by field evidence gathered by the author; and second, by the implications of new information regarding the differentiation of compositionally layered ashflows, to be discussed in Chapter 6. Hence, the author has determined that the King Tonopah Member is the older of the two sub-divisions, and the Tonopah Summit Member the more recent.

Bonham and Garside (1979a) placed the King Tonopah Member of the Fraction Tuff stratigraphically above the Tonopah Summit Member, but not without reservations. Both the King Tonopah Member and the Tonopah Summit Member overlie the Mizpah Formation at various exposures in the district, and as Bonham and Garside (1979a, p. 49) reported: "...there has been no unanimity as to the stratigraphic boundaries of the Fraction.", further stating that "The problem of the stratigraphic relationship between the lower ash-flow tuff of the King Tonopah Member and the tuff of the Tonopah Summit Member was not fully resolved in this study." (ibid, p. 55).

The age dates, although supportive of the author's contentions, do not in themselves provide conclusive evidence for the proposed stratigraphic order. There are too few radiometric analyses, their error limits overlap (in the case of the fission-track dates), and the fact that the samples were hydrothermally altered to some degree decreases the confidence one may place in the accuracy of the resultant dates. On the other hand, the stratigraphic relations found within the field area provide conclusive support for the author's interpretation.

The King Tonopah Member is moderately to strongly welded, allowing the bedding attitude to be discerned by apparent flow texture and fiamme, but the Tonopah Summit

Member is a pumice-rich froth, in which large pumice clasts show no sign of flattening or orientation. Therefore, the relationship of the two tuffs was determined by bedding attitudes of the King Tonopah Member and by contact relations.

Tonopah Summit ashflow remnants are exposed in two principal outcrops in the field area; the largest outcrop covers much of the northwest sector, and in plan view, is fault-bounded and in places 'breached' by exposed King Tonopah ashflow which is in depositional contact with the Tonopah Summit tuff. This exposure of Tonopah Summit tuff has been preserved by being down-dropped relative to the adjacent King Tonopah tuff outcrops. Evidence for this interpretation is to be found at 90E/158N (these coordinates refer to the reference grid on the 1:4800 geologic map). At this location a small shaft has been sunk through thin Tonopah Summit tuff cover into the King Tonopah tuff below, as indicated in the 'stratigraphy' of the tailings and in the subhorizontal depositional contact which occurs approximately ten feet beneath the surface.

The smaller of the two field area exposures of Tonopah Summit Member ashflow is located in the northeast sector. Here, both members of the Fraction Tuff dip towards the east or northeast. The contact between the two ashflows is irregular, ruling out faulting. Thus, gross bedding

relations indicate the superposition of the Tonopah Summit Member over the King Tonopah Member.

The second contention the author makes with Bonham and Garside's (1979a) interpretation of Fraction Tuff stratigraphy has to do with the subdivision of the King Tonopah Member. The King Tonopah Member is restricted in outcrop to within and adjacent to the field area, and the greatest part of this exposure has been assigned to the lower of two units. These units were defined by Bonham and Garside as separate ashflow sheets. The only occurrence of the so-called 'upper unit' recognized by Bonham and Garside is in the highest part of the field area, in the northeast sector (Figure 8). It is differentiated from the bulk of the King Tonopah Member tuff by color, in that the rock is gray-brown or tan, rather than light gray, and by the fact that it is pervasively brecciated (Figure 9), whereas the tuff beneath the topographic highs is usually not brecciated. Bonham and Garside provided normative analyses for one sample each of the 'upper unit' and the 'lower unit':

Figure 8: Iron oxide tinted hills of the northeast sector of the Tonopah Property, looking NNE from Mt. Ararat. Note King Tonopah mine mill foundation in far left middle-ground.

Figure 9: Brecciated King Tonopah Member tuff, from northeast sector of property.

Table I: King Tonopah Member Fraction Tuff normative analyses (Bonham and Garside, 1979a, p. 53).

	Fraction Tuff: King Tonopah Member	
	'upper unit'	'lower unit'
	normalized oxide values	
SiO_2	75.7	75.4
Al_2O_3	12.7	13.4
Fe_2O_3	1.1	0.1
FeO	0.5	1.2
MgO	0.3	0.6
CaO	1.5	0.7
Na_2O	3.3	3.1
K_2O	4.7	5.3
TiO_2	0.2	0.2
MnO	0.03	0.03
totals	100.03	99.93

The normalized oxide values of two samples are very similar, one important exception being that of the ratio of oxidized to reduced iron. Iron in the upper unit is virtually all oxidized, and the total iron content is slightly greater than that found in the 'lower unit' sample. Thin-section analyses show the groundmass of the 'upper unit' tuff to differ from that of the 'lower unit' tuff only in that the former is pervasively tinted red by cryptocrystalline iron oxides. No other petrographic differences in texture or content were discernible.

A further problem with the division of the King Tonopah Member into these two ashflow units has to do with physical considerations: that of very restricted outcrop versus thickness, as exposed in cliff faces and revealed in the degree of welding of the 'upper unit' (which is

identical with that of the 'lower unit' and suggestive of similar thickness. The actual areal extent of the so-called 'upper unit' is considerably less than that indicated on their map, but appears extensive because the iron-stained talus has moved downslope from the hilltops out onto the flanking pediments. Far up the slopes are numerous small exposures of non-iron-stained, non-brecciated, light gray colored King Tonopah Member ashflow standing out in contrast to the surrounding tan and brown colored so-called 'upper unit' alluvium. The implication would be that the 'upper unit' is but a negligible piece of an originally far more extensive ashflow sheet, other remnants of which are wholly lacking elsewhere on Bonham and Garsides'(1979a) geologic map.

Finally, the black vitrophyre found at the base of the King Tonopah Member ashflow crops out beneath the tuff where Bonham and Garside 1979a) place the contact between their 'upper unit' and the top of the Mizpah Formation, in the east-central portion of the field area, and also occurs at the base of their 'lower unit', again, immediately superjacent to the Mizpah Formation, in the southeastern sector of the field area. The exposures are of the same basal vitrophyre; they are lithologically identical, of the same approximate thickness, and their bedding attitudes are similar. The several outcrops of the basal vitrophyre have

been separated and down-dropped to the south by a series of parallel normal faults.

In order to account for the minimal petrographic differences, and the field relations of the so-called 'upper unit' and 'lower unit' of the King Tonopah Member ashflow, the author proposes an alternative interpretation: that the 'upper unit' is simply a portion of the ashflow exposed elsewhere (the 'lower unit') whose iron has been hydrothermally oxidized, and which has been brecciated, and uplifted attendant with the intrusion of hypabyssal rhyolite (Figure 22, cross-section A-A').

CHAPTER 3

STRUCTURE

Regional Structure

The Tonopah district is situated near the eastern boundary of the Walker Lane, a zone of complex structural disruption which separates the Sierra Nevada batholith to the southwest from the Basin and Range province to the northeast. The structural disruption resulted from right-lateral translation and concurrent flexure between these two tectonic provinces (Albers and Stewart, 1972). The southern San Antonio Mountains appear not to have been affected by the disruption to the west, but are delimited by north-trending normal faults typical of the Basin and Range province.

Numerous east- and southeasterly-directed low-angle thrust faults have telescoped the pre-Tertiary rocks of the San Antonio Mountains, but have not affected the Tertiary rocks (Albers and Stewart, 1972). One of these is the Roberts Mountains thrust, activated during the Antler orogeny of the late Devonian and early Mississippian. The eastern boundary of the Roberts Mountains thrust is tentatively drawn through the Tonopah District (Stewart, 1980). More recent faulting of regional extent has affected

Tertiary rocks and is the result of Basin and Range extension. The San Antonio Mountains are bounded east and west by major normal faults activated during this latter tectonic regime (Stewart, 1980).

Local Structure

To date, the best study of the structural features of the Tonopah district is that of Nolan (1935), who mapped and interpreted the underground workings of the main camp. He classified the normal faults encountered in the Tertiary igneous succession into four groups, here listed in order of decreasing age:

Group 1: N-S trending, shallow east-dipping, pre-(Tonopah) mineralization.

Group 2: E-NE trending, pre-mineralization and ore stage, localizing most of the district's ore shoots.

Group 3: NE-NW trending, variable dip, post-mineralization, displacing pre-Siebert Formation rocks and ore shoots.

Group 4: N-S trending, post-mineralization, Basin and Range related and reactivated Group 1 faults.

The author's field area includes faults from three of Nolan's groups, but none of group 2. The faults of group 2, collectively known as the Tonopah fault zone, are of

rather unusual geometry and are probably confined to the immediate area of the Tonopah camp, which appears to be localized on the northern perimeter of a caldera structure (Bonham and Garside, 1979a, p. 105). This will be discussed further in Chapter 7.

Given the nature of the field area, in which most structures have been inferentially mapped by the somewhat diffuse trace of altered or mineralized rocks in alluvium, the separation of discrete episodes of faulting is next to impossible. The criteria used by Nolan (1930, 1935) to differentiate pre-mineralization from post-mineralization faulting in Tonopah are only of use in the author's field area where structures can be related to the Halifax Fault zone (Figure 5). Faults within the field area that do not disrupt the Halifax Fault, or those parallel faults to the northeast that are assumed to be coeval, cannot be so differentiated.

The major faults of the Tonopah Property are presented in Figure 5 in relation to the generalized geology.

Group 1 Faults

Of the group 1 faults, the most important recognized by Nolan (1935) is the Halifax Fault zone. This prominent structure, which has been mapped along strike for more than five miles (Bonham and Garside, 1979a), is the only

structure known to occur both in the the main camp of Tonopah and in the author's field area. The fault zone is intersected by several underground workings at the east margin of the main camp, and trends through the center of the field area, curving to the northwest. The King Tonopah workings, situated near the center of the field area, were developed in a hanging-wall split above the Halifax Fault. The fault dips approximately 35 degrees to the east, and Nolan (1935) has estimated the pre-mineralization movement to be 2000 feet. In addition, post-mineralization movement has occurred.

The Halifax Fault zone may be one of a set of parallel, evenly-spaced faults. Parallelling the Halifax Fault and approximately 2800 feet to the northeast, is a probable fault zone defined by iron stained and slickensided float and abundant jasper within the King Tonopah Member, and by a swath of hydrothermally altered, green rock within the Mizpah Formation andesite. Approximately another 2800 feet to the northeast of this linear zone is the suggestion of yet another parallel trend. This is indicated by a cleft in the hills in which narrow exposures of Mizpah Formation occur, and alteration of portions of both King Tonopah Member tuff and of Mizpah Formation along the trend. Whether or not this fabric of parallel faults exists to the west of

the Halifax Fault zone is not known owing to the admixture of several source lithologies in alluvium covering the area.

Group 3 Faults

One northeast-trending fault offsets the Halifax Fault zone approximately 800 feet northwest of the King Tonopah Mine shaft. The fault trace is composed of brecciated, slickensided, and iron stained King Tonopah Member float, but there is no silicification or other evidence of hydrothermal mineralization. The Halifax Fault dips northeast and is displaced west to the north of the younger fault, which must therefore dip northwest. This assumes normal faulting without lateral translation, which is in keeping with known Tertiary tectonics. Hence, the non-mineralized northeast trending fault may belong to Nolan's post-mineralization faults of group 3. It is parallelled, about 2400 feet to the north, by a prominent fault which bounds the Tonopah Summit Member ashflow. Since the tuff is approximately 17 to 18.5 m.y. old (Bonham and Garside, 1979a, p. 22) the bounding fault must also be post (Tonopah)-mineralization in age. As younger rock is in fault contact with older rock to the southeast, again assuming normal faulting, stratigraphic sense requires that this latter fault dip to the northwest. The assumption that both of the northeast-trending faults are of normal displacement and dip to the northwest is in keeping with the

topographic expression and bedding attitudes of the area (Figure 22, cross-section B-B').

Group 4 Faults

Reactivated Group 1 Faults. The Halifax Fault is the only positively identified reactivated group 1 fault in the Tonopah Property. Whether or not parallelling structures (to the east) were formed when the Halifax Fault was, and later reactivated, cannot be ascertained.

The time of the reactivation, or at least one major reactivation, of the Halifax Fault zone and possibly those parallelling it to the northeast, can be bracketed stratigraphically. Remnants of Oddie Rhyolite lava crop out in the south-central part of the field area, atop the Mizpah Formation. Fault reactivation and relative uplift of normal movement of hundreds of feet on the Halifax Fault were required to entirely erode the King Tonopah Member ashflow in order to expose the subjacent Mizpah Formation. This must have occurred after the deposition of the King Tonopah Member ashflow but before the extrusion of the Oddie Rhyolite, bracketing the re-activation between 19.5 m.y. and 16.5 m.y.

Post (Tonopah)-Mineralization Faults. Post-mineralization faults of north-south trend can be distinguished only in the northwest section of the field area.

The longest of these faults bisects the Tonopah Summit Member tuff along the 80E grid line and continues northward beyond the field area. As this fault juxtaposes Mizpah Formation to the east with King Tonopah Member tuff to the west, it is presumed to dip to the west.

To the west of the above fault, in the extreme northwest corner of the field area, are two, and possibly more, parallel north-south faults that delimit Siebert Formation sediments and bring them into fault contact with Tonopah Summit tuff. These faults also appear, for stratigraphic reasons, to dip to the west.

Other Faults

Traces of many other faults have been mapped in the field area. Most of them are isolated features with no known relation to the classification discussed above.

A set of several faults located east of the Halifax fault and north of Mt. Ararat, have offset King Tonopah Member basal black vitrophyre. These faults parallel the Halifax Fault suggesting they were formed at the same time as the latter, but they appear to have been formed in response to the presumed intrusive uplift of the King Tonopah Member tuff to the northeast. Permissive evidence for intrusive uplift will be presented in Chapter 4, under the heading: "Massive Manganese-Calcite-bearing Mineralization."

There remains one other group of faults that deserve some consideration: All of these faults displace King Tonopah Member ashflow, trend NNE, and are restricted to the hills and ridges of the high northeast sector of the field area. Owing to the complex nature of the elevated terrain--the numerous approximately linear ridges and associated ravines, coupled with the steep topography and minimal outcrop--it seems reasonable to assume that many more faults exist than have been mapped. The dip of these faults is generally unknown, except where they have been mineralized and subsequently investigated by exploratory pits and shafts. The two major mineralized faults occur within approximately 600 feet of each other and have steep opposing dips that would converge at depth, assuming the faults are planar. The vein mineralogy of the faults is of bladed calcite and massive manganese wad, and will be discussed further in Chapters 4 and 5.

The age relationship of this set of faults to others in the field area is unknown, as none of these faults shows a cross-cutting relation with the Halifax Fault or presumed related faults.

Basin Structure Defined by the King Tonopah Member Outcrop

The dip of the King Tonopah Member ashflow, determined from flow lineation and fiamme, is generally to the

northeast in the eastern portion of the field area, except at the northwest and southeast extremities of the elevated northeast sector of the Tonopah Property, where the King Tonopah Member nears the contact with outcropping Mizpah Formation rock. At either end, the vitrophyre and superjacent welded tuff dip slightly to moderately inward, toward the center of the elevated terrain, defining a basin-like structure (Figure 22, cross-section A-A').

Fault-Related Features

Proximity to an ashflow vent is supported by the presence of linear trends of xenoliths up to approximately ten meters across. The majority of the inclusions are rhyolitic, and the remainder are composed of Mizpah Formation rock. Bonham and Garside (1979a, p.57) apparently did not recognize the rhyolite xenoliths, but did note Mizpah Formation mega-breccia immediately to the north of the northeast portion of the field area, and concluded: "The large blocks of dacite of the Mizpah Formation in the tuff of the King Tonopah Member could well represent landslide blocks from a caldera margin."

The distribution of rhyolite xenoliths of the King Tonopah Member tuff may also be fault-related, and this has important bearing on the nature and origin of the structures in the northeast sector of the field area.

The xenoliths are well rounded, as evidenced in the figures, have randomly-oriented flow foliations, and appear to have been included into the ashflow while the latter remained hot and plastic--i.e., during eruption--as evidenced in the flattening of pumice clasts about the xenoliths and by the concentric, closely-spaced cooling fractures adjacent to the contact with the inclusions (Figure 8). The lines of xenoliths all appear aligned with mapped faults which disrupt the King Tonopah Member tuff in the northeastern region of the field area. Thus it seems reasonable to assume the boulders were exposed by the faulting (Figure 10). None of the trends of inclusions occurs along faults, nor are the xenoliths typically brecciated. Therefore, the author has concluded that the xenoliths were removed from rhyolitic country rock below, and incorporated and rounded by attrition and/or partial assimilation, in the enveloping ashflow during its eruption.

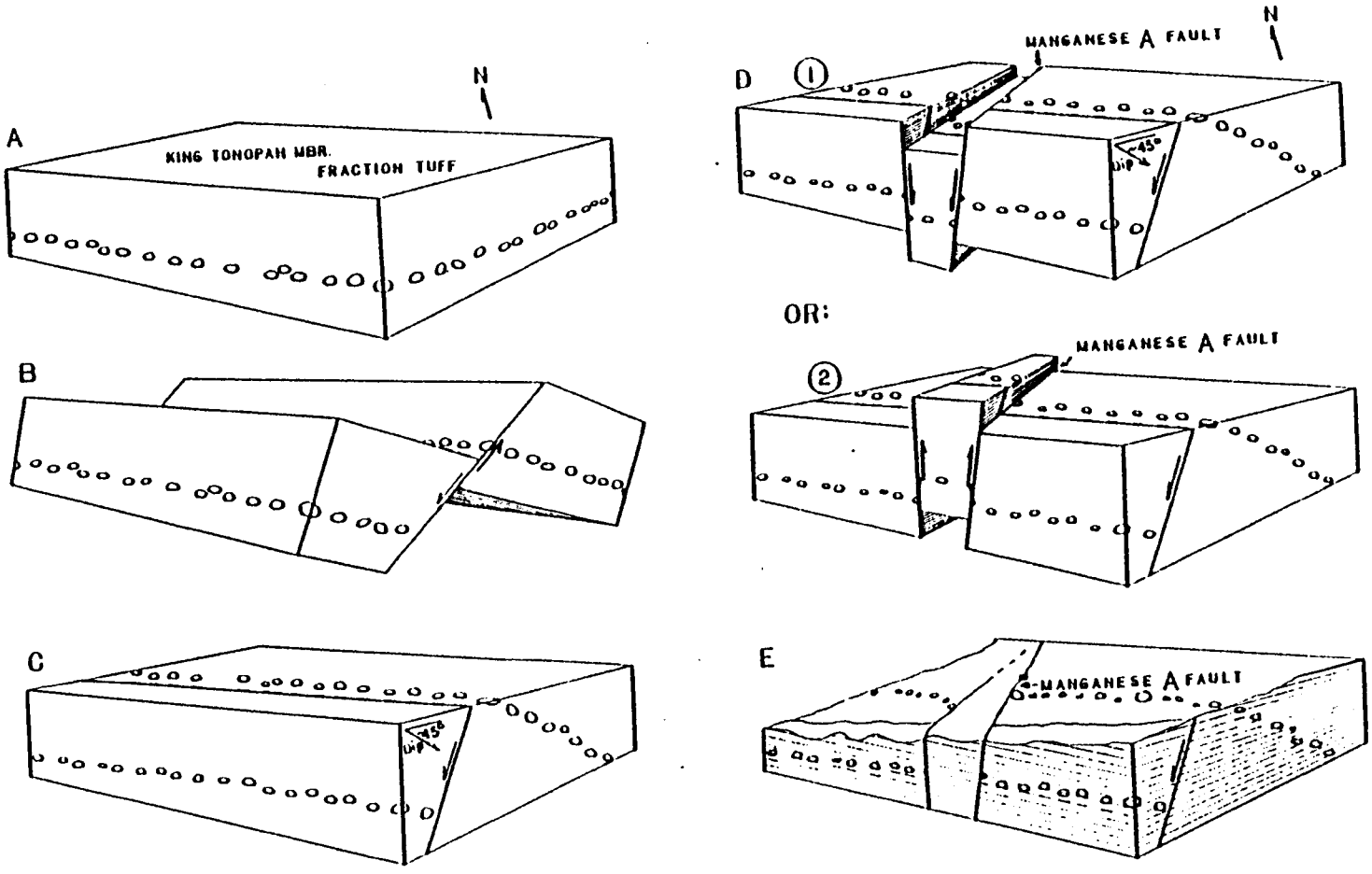


Figure 10: Block diagrams illustrating possible faulting sequences culminating in present xenolith trends.

CHAPTER 4

HYDROTHERMAL ALTERATION AND MINERALIZATION

Alteration

General

In the Tonopah district most of the Tertiary rocks have been hydrothermally altered. The extent and the style of alteration vary with lithology, stratigraphic location and depth from the surface during hydrothermal activity, and proximity to faults that acted as channels to migrating fluids. Some alteration may be regionally pervasive, as in the widespread albitization of the Mizpah Formation andesite of the Tonopah district, but other styles are localized in envelopes about mineralized fractures. This study will be concerned primarily with the latter, vein-controlled, styles of alteration.

The following discussion will be divided into two parts, the first describing the kinds of alteration encountered throughout the district, and the second treating the vein-localized alteration of the main camp and the Tonopah Property.

Regional Alteration as Represented in the Tonopah Property

Regional alteration styles occurring in the volcanics of the Tonopah District are well represented in the Tonopah Property. In particular, the styles of alteration occurring in the Fraction Tuff within the author's field area are absent in the main camp where the pyroclastic units are almost entirely removed, or were never deposited.

Mizpah Formation

The Mizpah Formation has been regionally albitized to varying degrees (Nolan, 1935). The albitization is so widespread in the propylitically altered rocks in the district that Campbell (1931) believed albite was a primary phase of the volcanic unit. In the Tonopah Property, within the distinctive green-colored outcrops of propylitized Mizpah Formation rock, albitization is partial to complete (see Table II (A)). Where apparently complete, the secondary albite has largely been replaced by calcite and montmorillonite. The process of albitization occurs with the liberation of calcium which reacts with CO_2 (possibly liberated from a subjacent magma body) to form calcite. The alteration of albite to montmorillonite involves the addition of hydrogen ion and silica, and the liberation of sodium, as represented in the following reaction (Meyer and Hemley, 1967):

Table II: Alteration zonation of the Mizpah Formation compared and contrasted between the Main Camp and the Tonopah Property.

A ALTERATION ZONATION in MIZPAH FORMATION in MAIN CAMP

ZONE	VEIN	POTASSIUM-SILICATE	ARGILLIC I	ARGILLIC II	PROPYLITIC I	PROPYLITIC II	PROPYLITIC III	PROPYLITIC IV
Characteristic Minerals	Table III	Quartz, Sericite, Adularia, Pyrite (dissem.)	Kaolinite, Halloysite, minor Quartz & Sericite	Montmorillonite, minor Kaolinite & Sericite				
Minerals Altered: Plagioclase:					Complete Albitization; Partial alteration to Sericite, Quartz, & Calcite		Partial to Complete Albitization--Montmorillonite & Calcite	Partial Alt'n. of some Plagioclase to Calcite
Ferromagnesian Minerals:					Alteration to Chlorite & Fe-Ti oxides* (Biotite: ± Rutile Hornblende: + Calcite)		Alt'n. to Chlorite & Fe-Ti oxides* (Hornbld: Calcite ± Mont.	Hornbld: Partial Alt'n. to Calcite, Mt., & Amorphous Clays Biotite: Unalt'd
Groundmass:					Alteration to Albite, Chlorite, K-feldspar, & Calcite + Pyrite (diss.)		Abundant Zeolitization (mostly Mordenite)	Unaltered ± minor Zeolitization

* "Fe-Ti oxides": Rytuba & Gaskill's ('79a) determination

B ALTERATION ZONATION in MIZPAH FORMATION in TONOPAH PROPERTY

ZONE	VEIN	POTASSIUM-SILICATE	ARGILLIC	PROPYLITIC I	PROPYLITIC II	PROPYLITIC III
Characteristic Minerals	Table III	Quartz, Sericite, ± Pyrite (Adularia ?)	Kaolinite & minor Sericite (± Amorphous Clays?)			
Minerals Altered: Plagioclase:				Partial Alteration to Albite in some Plagioclase, --Montmorillonite & Calcite (Alt'n. more intense in Zone I)		Partial Alteration of some Plagioclase to Calcite (most Plagioclase Unaltered)
Ferromagnesian Minerals:				Ferromagnesian Minerals rimmed or wholly replaced with Oxides, leucoxene (Alteration more intense in Zones I & II)		
Groundmass:				Zeolitization of Groundmass to Mordenite + Montmorillonite (More intense Zeolitization in Zone I)		Mostly Unaltered (minor Montmorillonite)

$$1.17\ NaAlSi_3O_8 + H^+ + 3SiO_2 = 0.5Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 1.67SiO_2 + Na^+$$

Other cations may substitute for sodium.

Deer, Howie and Zussman (1966, p. 269) reported that montmorillonite may be a weathering product in conditions of poor drainage when magnesium is [or other cations are] not removed. "Other factors which favor the formation of smectites are an alkaline environment, availability of calcium, and paucity of potassium." (ibid). All of these factors are met in the weathering environment of exposed Mizpah Formation; hence the montmorillonite may have formed in response to weathering rather than by hydrothermal alteration.

As shown in Table II, the ferromagnesian minerals have been partially or wholly replaced by oxides in the albitized Mizpah Formation rock.

In relatively unaltered, non-propylitized rock, the plagioclase appears fresh and ranges from andesine to labradorite in composition.

King Tonopah Member, Fraction Tuff

In the far northwest corner of the Tonopah Property, the outcrop has been pervasively altered, bleached, and silicified. The phenocrysts and lithic fragments within the King Tonopah Member tuff were altered to clays and subsequently dissolved out. Druses of minute euhedral quartz

crystals later lined the cavities, and finally, a small percentage of the cavities were filled with sericite and clays (Figure 11). At some period during this alteration sequence the devitrified groundmass was zeolitized with the development of spherulitic masses of mordenite, as shown in Figure 12. Hairline fractures filled with iron oxides occur in the thin-section 33. These to some degree follow the flow laminae of the welded tuff.

Tonopah Summit Member, Fraction Tuff

The Tonopah Summit Member is generally non-welded and porous, and hence highly permeable. Consequently, the unit has been pervasively zeolitized (primarily to mordenite) and clay-altered (primarily to montmorillonite). Of the protolith only scarce quartz phenocrysts remain unaltered. X-ray diffraction analyses of the pink material replacing pumice and the gray matrix identify a large fraction of montmorillonite in both, and possibly mordenite in the latter (Appendix A, Number 1).

In the northwestern corner of the property, the Tonopah Summit Member has been intensely silicified. Subhorizontal bodies of red and green jasperoid are exposed in exploration pits, and jasperoid float is scattered about broadly, rather than confined to trends that would suggest fault-controlled vein filling.

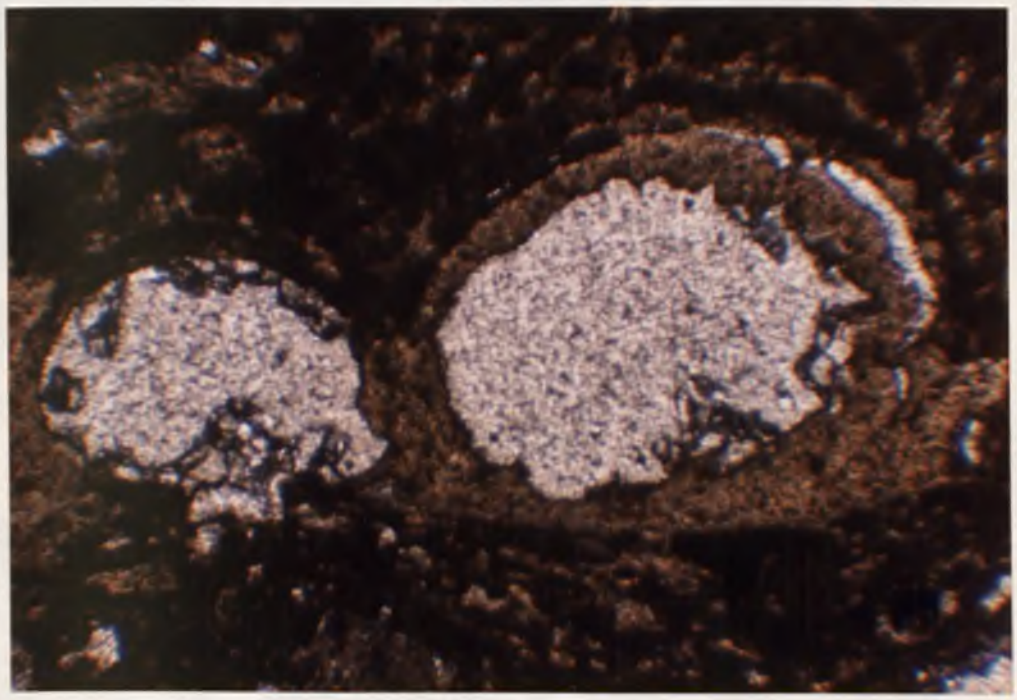


Figure 11: Photomicrograph of cavities in King Tonopah tuff lined with euhedral quartz crystals and filled with sericite and clays (Thin section no. 32: approx. 25x magnification, PPL (plane-polarized light)).

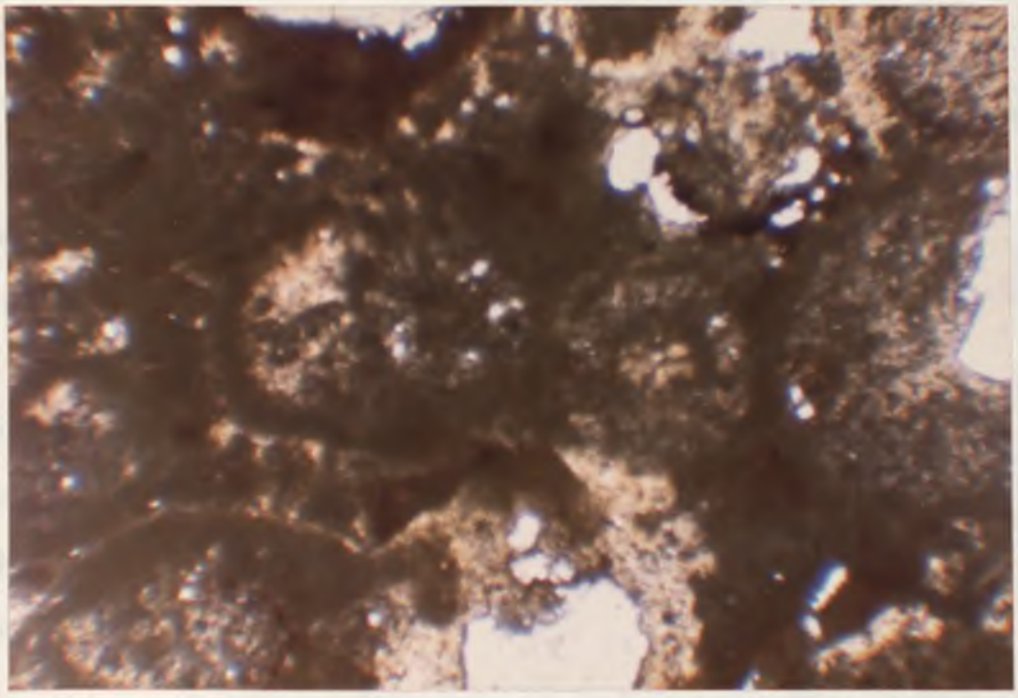


Figure 12: Photomicrograph of zeolitized (mordenite) groundmass of King Tonopah tuff (Thin section no. 32: approx. 25x magnification, PPL).

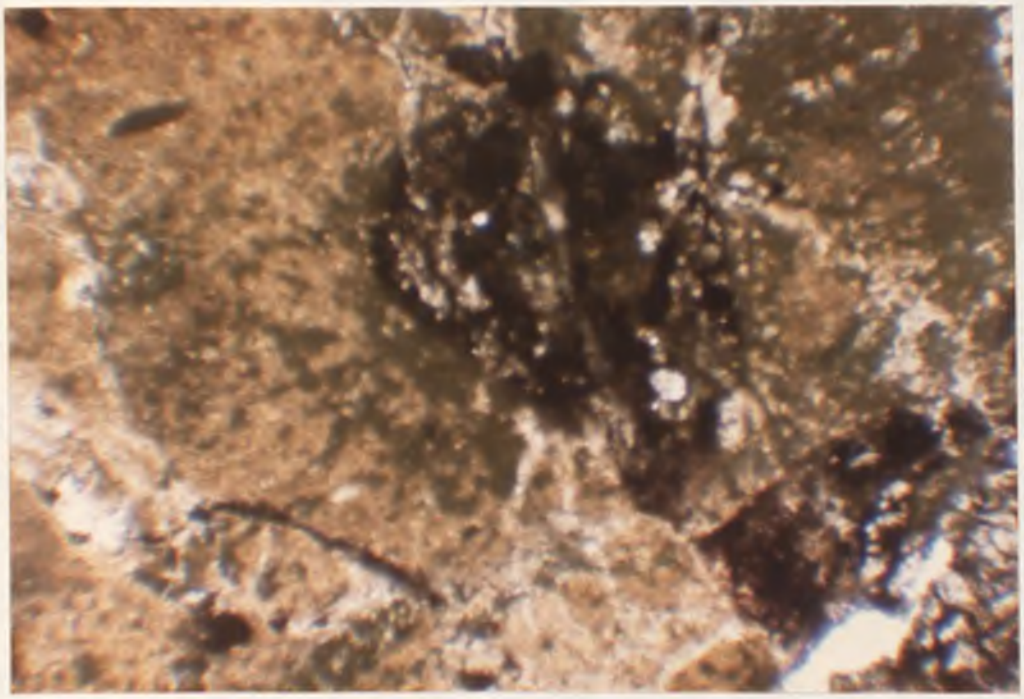


Figure 13: Photomicrograph of propylitized King Tonopah tuff containing green montmorillonite (medmandite?) in groundmass (Thin section no. 38: approx. 25x magnification, PPL).

Oddie Rhyolite

The siliceous Oddie Rhyolite is essentially unaltered throughout the field area, with the exception of the flow remnants that crop out west of the Halifax Fault zone. These vestiges of a rhyolite flow are all bleached, and most of the outcrops display argillic alteration and subsequent cavitation of the feldspar phenocrysts. The alteration product of the feldspars was identified by X-ray diffraction analysis to be predominantly kaolinite, with minor quartz (Appendix A, Number 2).

Origins of Pervasive Alteration

Mizpah Formation. The propylitization of the Mizpah Formation lavas was overprinted by the destructive potassic-silicic and argillic alteration associated with main camp mineralization, and must therefore pre-date the latter event. Whether the propylitization occurred as an early stage of the ore-forming process or was actually an earlier and distinct event was not resolved in this study. Support for early propylitization is provided by Burbank and Luedke's (1968, p. 715) work in the Silverton and Lake City calderas of the Tertiary San Juan Depression: "The post-volcanic evolution of large quantities of gases [from a subjacent magma body], chiefly carbon dioxide and water, propylitically altered the rocks in and around the volcanic depression prior to the younger period of ore deposition."

Fraction Tuff. Widespread silicification, zeolitization, and clay alteration in the Fraction Tuff is apparently restricted to the northwest sector of the Tonopah Property. Since both the King Tonopah Member and the Tonopah Summit Member have been altered it is possible that both were altered simultaneously. The Tonopah Summit tuff post-dates main camp mineralization by two or three million years (Bonham and Garside, 1979a, p. 20 and 21) thus requiring the alteration to have occurred after the main camp mineralizing event. Speculation as to why the pervasive alteration of the Fraction Tuff is restricted to the northwest part of the field area is deferred until Chapter 6.

Within the Tonopah Summit tuff, the anastomosing, sinuous, and discontinuous morphology of the widespread sub-horizontal jasperoid suggests a replacement origin, perhaps controlled by the level of a paleo-water table within the porous, saturated tuff. Note the similarity in the Pb, Zn, Ag, Mn, and Au concentrations of the tuff and a sample of red jasper (Table V, TS, A and B).

Vein-Controlled Alteration

Numerous studies have been made on the types of hydrothermal alteration that occur in the Tonopah district. These reflect the evolution of theories of epithermal ore genesis as related to the mineralizing events in the region

(Spurr, 1905; Campbell, 1931; Nolan, 1935; Broderick, 1949; Core, 1959). These studies and trends in interpretations have been succinctly summarized by Bonham and Garside (1979a) and will not be reviewed in this report. In the following discussion of the alteration of the Tonopah mining district, the author relies primarily on Bonham and Garside's synthesis.

The principal host rock for the silver mineralization and associated alteration in the district is the Mizpah Formation. Although the King Tonopah Member tuff is pre-(Tonopah) mineralization (see Chapters 2 and 3), it was not apparently mineralized or significantly altered during the ore-forming hydrothermal event. Thus the following discussion of vein-centered alteration will be primarily restricted to that of the Mizpah Formation.

Alteration Zonation: Main Camp

The various types of alteration found in the main camp, in contrast to that discussed above, are all vein-centered and zonally distributed about the veins. Table II (A) presents the vein-related alteration zonation within the main camp (as categorized by Bonham and Garside, 1979a), and contrasts it with the alteration from the Tonopah Property (Table II (B)). This table encapsulates essentially all that Bonham and Garside have to say about the alteration zonation of the main camp.

Alteration Zonation: Tonopah Property

Potassium-Silicate and Argillic Alteration. Exposed in a few places within the field area, and always associated with propylitization, are small outcrops of either indurated, silicified, green rock, or friable, argillized, pale brown and white rock, both of which contain sericite. In the former variety of altered Mizpah Formation rock, disseminated pyrite occurs in cubes up to approximately 1 millimeter. This style of alteration appears to be that of the potassium-silicate zone of Bonham and Garside. In the latter variety, the sericite is associated with kaolinite and replaces plagioclase phenocrysts, indicative of the argillic alteration zone. These isolated outcrops of more intensely altered Mizpah Formation occur in the largely alluvium-obscured and very poorly understood area located approximately 1000 feet west and northwest of the King Tonopah Mine. It is of interest to note that the only patented claims in the field area cover the King Tonopah Mine and a swath of land to the west, including the area of these exposures.

Propylitic Alteration. The propylitic alteration which surrounds the potassic-silicic and argillic envelopes is also less intensely developed on the Tonopah Property, the most intense form apparently corresponding to zone III of the main camp. The propylitization of the Mizpah Forma-

tion on the Tonopah Property is characterized by partial albitization of plagioclase, but little development of chlorite or potassium feldspar. Ferromagnesian minerals are partly oxidized and replaced and the groundmass has been variably altered to clays. Hence, the most intense propylitization of the Mizpah Formation within the Tonopah Property is but a weak and distal style of the propylitization characteristic of the Tonopah district.

Within approximately ninety percent of the propylitized Mizpah Formation the plagioclase phenocrysts, where fracture-intercepted and highly comminuted, generally appear very little altered. The relatively diffuse boundary contrast of albite-twin laminae may evidence minor alteration; otherwise the phenocrysts appear fresh.

Alteration of Mizpah Formation with Depth. During the preliminary drilling phase of the Tonopah Property exploration program, two drill holes were cut into the trend of green-altered rock in the southeast portion of the field area (Figure 17). Alteration to a depth of approximately 450 feet is rather monotonous, consisting of alternating zones of incompetent green to gray clay-altered rock and indurated, iron stained rock. In the former, generally all but original quartz phenocrysts of the Mizpah Formation protolith were altered to montmorillonite and other clays. In the latter, the competence and original texture of the

iron oxide flooded rock was retained, while the plagioclase phenocrysts had, for the most part, been altered to white clay. Soft and greasy-feeling green and white mineralization was developed along fractures within the first couple of hundred feet beneath the surface, tentatively identified (by the author and Silver Strike Resources Ltd. consulting geologist C. H. Westerman, Ph.D., via visual core inspection) as celadonite, serpentine, and talc. This mineralization may represent surficial weathering and/or supergene alteration of primary sulfide phases present below two hundred feet (pyrite and chalcopyrite). The vein mineralogy encountered in drilling will be discussed below in the section on mineralization.

Main Camp and Tonopah Property Alteration Contrasted

As can be seen in Table II, the vein-controlled alteration within the Mizpah Formation generally corresponds with that of the main camp. Within both areas, alteration adjacent to the vein is most intense with destruction of original host rock and replacement by a potassium-silicate assemblage, and outward, by argillic phases. Further from the vein, beyond the overprinting envelope of strong acid leaching, silicification, and potassium metasomatism, the various sub-zones of propylitic alteration occur.

There are, however, major differences between the main camp and the Tonopah Property that are not evident in

Table II. Alteration assemblages are much less intensely developed on the Tonopah Property than in the main camp where the veins are closely spaced and potassic and argillic envelopes coalesce. On the Tonopah Property, rare spots of potassic and argillic alteration are all but hidden within the pervasive propylitic alteration.

King Tonopah Member, Fraction Tuff

Fault-controlled alteration of the King Tonopah Member tuff is very minor and affects far less than one percent of the outcrop. Aside from the iron oxide metasomatism associated with the brecciated exposures in the northeast sector of the field area, fault-localized alteration is largely restricted to segments of faults that elsewhere correspond with propylitically altered Mizpah Formation outcrop (e.g., the fault parallel to and east of the Halifax Fault).

Several small outcrops of weakly propylitized tuff occur along the two fault trends which parallel the Halifax Fault zone. The rock is faint green, due to the development of green montmorillonite (copper-bearing medmandite?) in the groundmass (Figure 13). The presence of Cu is suggested by the occurrance of chrysocolla in the Mizpah Formation rock exposed elsewhere along these fault trends. Rarely, chlorite has replaced pumice fragments (Figure 14).

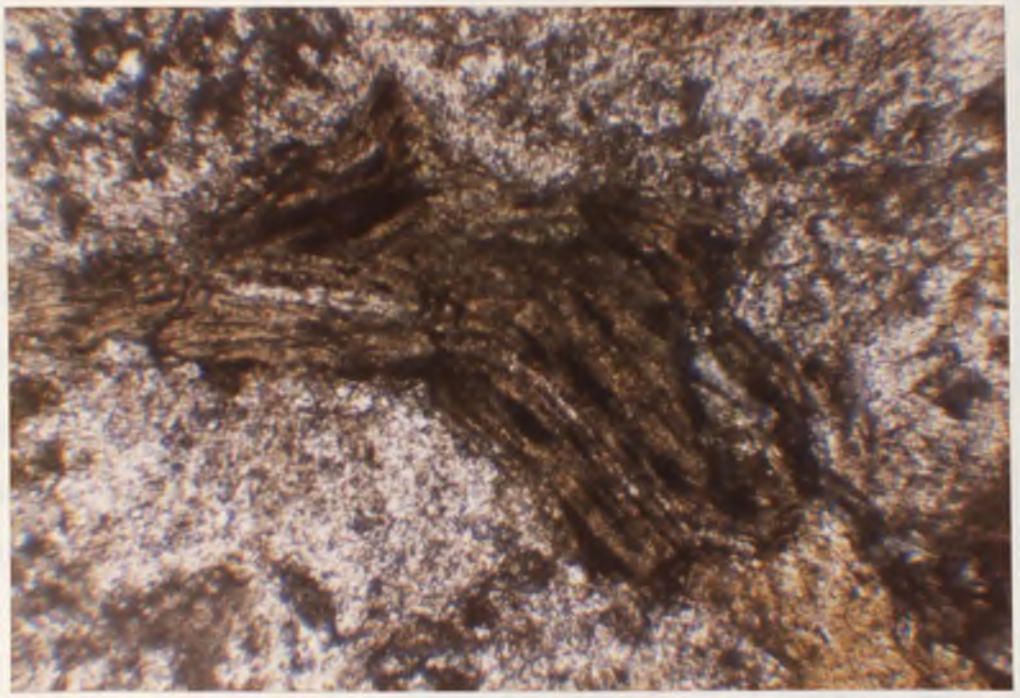


Figure 14: Photomicrograph of pumice fragment replaced by chlorite in King Tonopah tuff (Thin section no. 34: approx. 80x magnification, PPL).

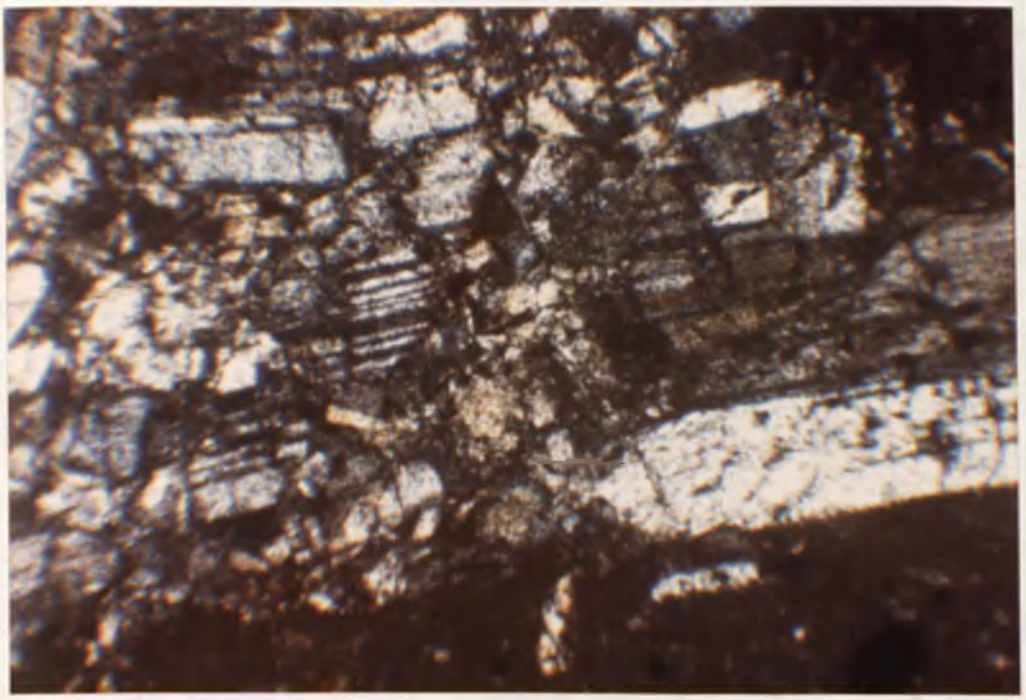


Figure 15: Photomicrograph of shattered plagioclase in Mizpah Formation dacite (Thin section no. 40: approx. 25x magnification, PPL).

Discussion

The contrasting styles and intensities of alteration zonation appear to be attributable to one prime factor: that of proximity to the center of the main camp hydrothermal system. With distance from the most intensely altered and mineralized region of the main camp, changes in the temperature and composition of the hydrothermal fluids are reflected in changes in wall-rock alteration and fracture fillings.

Mineralization

Vein Mineralization in the Main Camp

Vein Morphology. In the main camp, at the center of the hydrothermal system (Nolan, 1935; Taylor, 1973), the veins are typically of irregular shape and thickness, and horsetails and splits are common. The Tonopah Fault system veins, occupying faults of group 2 (Nolan, 1935) are of cymoidal geometry, curved and convex upward, and resemble shell halves that are closely spaced and imbricate along an east-west trend. Most of the ore in the district was taken from stopes within these veins and associated hanging wall splits. Some of the veins were over 50 feet thick (Nolan, 1935).

Three major stages of mineral deposition have been recognized in the veins of the district (Fahley, 1981):

1) Early Barren Stage

2) Ore Deposition Stage

3) Late Barren Stage

The mineral assemblages and paragenetic relations are presented in Table III, and are contrasted with those of the Tonopah Property.

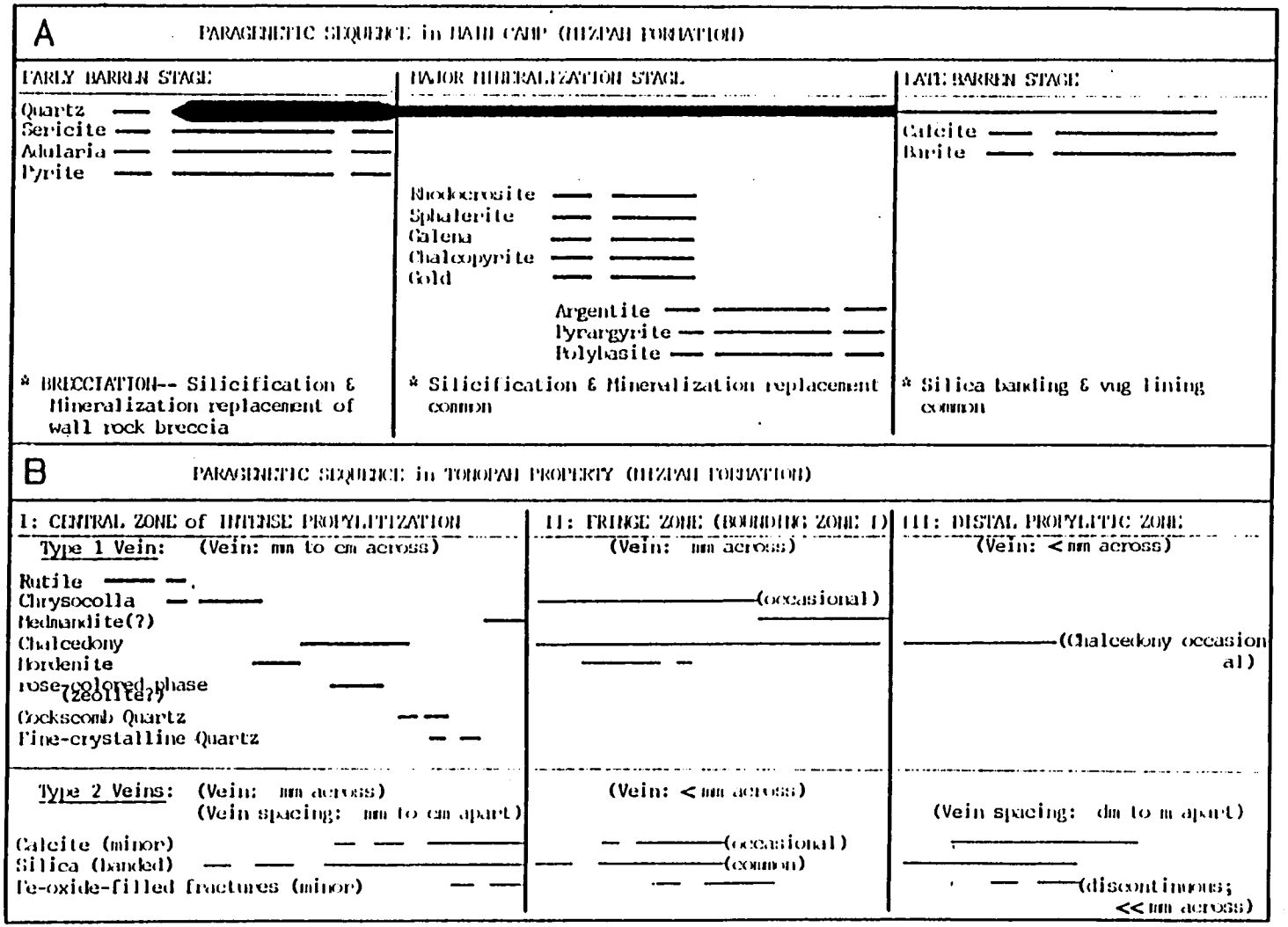
In the early barren stage, the host rock was brecciated and replaced by fine- to coarse-grained quartz and minor quantities of phases resulting from hydrogen, potas- potassium, and sulfide metasomatism (sericite, adularia, and pyrite).

Ore stage mineralization resulted in replacement of wall rock and wall rock breccia, and in the filling of open spaces within faults and fractures. Quartz, gangue minerals, simple sulfides and gold were deposited early, to be followed by silver-bearing sulfides and sulfosalts and additional quartz.

Late barren stage mineralization was predominantly quartz, which was deposited in the centers of veins, and local occurrences of minor amounts of coarsely-crystalline calcite and euhedral barite fracture and vug coatings. Fahley (1981) states that banding features and crystal vug encrustations are common during this stage.

The epithermal ore deposits were later altered by supergene processes, which are most readily apparent in the

Table III: Paragenetic sequence of mineralization of the Mizpah Formation compared and contrasted between the Main Camp and the Tonopah Property.



iron oxide and manganese wad coatings of fractures, faults, and open space fillings at the surface and higher levels of the ore bodies. Supergene ore minerals include silver halides, acanthite, polybasite, covellite, pyrargyrite, and native gold and silver (Fahley, 1981).

Discussion. The vein mineralization that occurs at the surface in the Tonopah Property is characterized by silica banding, vug lining, and minor development of comb structures. In contrast, Fahley (1981) reported that evidence in the main camp for open space filling, such as silica banding, comb structures, and vug lining, is rare. Stanton (1972, p. 218) stated that banded, spherical, and botryoidal vein fillings are indicative of low-energy solution crystallization, which lends support to the belief (Nolan, 1935; Taylor, 1973) that the hydrothermal event was centered on the main camp and that related mineralization in the Tonopah Property was largely a product of distal, lower-energy fluid migration.

Vein Mineralization in the Tonopah Property

Tonopah Formation

Although the Tonopah Formation does not crop out in the field area, it was intercepted during the drilling project in one diamond drill hole. The drill hole was spudded north of the King Tonopah Mine at 99.65E/113.85N,

bearing S 65 E at a dip of 60 degrees. At a depth of 418 feet the Tonopah Formation was intercepted. The unit is gray, wholly silicified, and extensively veined with white chalcedonic quartz. Pyrite is disseminated throughout the intercept, along with finely disseminated rutile, occasional barite crystals within quartz and calcite veins, and trace amounts of chalcopyrite (Appendix D, (I)).

Fire assays of core splits revealed anomalous silver and gold values which ran as high as 1.24 and .01 ounces per ton, respectively. Trace amounts of tennantite were associated with the ten or fifteen feet of high precious metals values, and may be the primary source of the silver.

The nature of the mineralization within the Tonopah Formation is similar to that within the Mizpah Formation, and is therefore most likely due to the same hydrothermal event.

Mizpah Formation

Mineralogy. The vein-filling mineralization and its apparent paragenetic sequence within the Mizpah Formation in the Tonopah Property are presented in Table III, where they are contrasted with the mineralization in the main camp.

Type 1 Veins. The polyphase type 1 veins (Table III (B)) are millimeters to centimeters wide and are associated with the green-colored fault zones including and paralleling the Halifax Fault. These veins contain sulfides at depth,

and weathering and/or supergene alteration products at and near the surface, as shown in Figure 17.

Within the thin sections examined, filled fractures account for approximately 10% of the total volume of the rock. Groundmass and phenocrysts, particularly the plagioclase, are shattered and displaced into the fractures, and many plagioclase phenocrysts not intercepted by visible fractures have been shattered, though not dispersed (Figure 15).

An illustration of a representative polyphase vein (Thin-section 23) is presented in Figure 16.

Rutile laths are developed within the host rock along fractures that may or may not contain vein matter (depending upon the width of the fissure). The crystals are typically sub-perpendicular to the fracture surface. Rutile is the only phase developed in and about the smallest fractures.

The first and most pervasive vein filling, extending into the smallest hairline fractures, is a yellow-green to grass-green, non-pleochroic cryptocrystalline phase tentatively identified as chrysocolla. In some cases the green phase is overlaid towards the center of the vein by an unidentified pale yellow material which is finely peppered with minute rutile crystals. Within the larger veins (>1

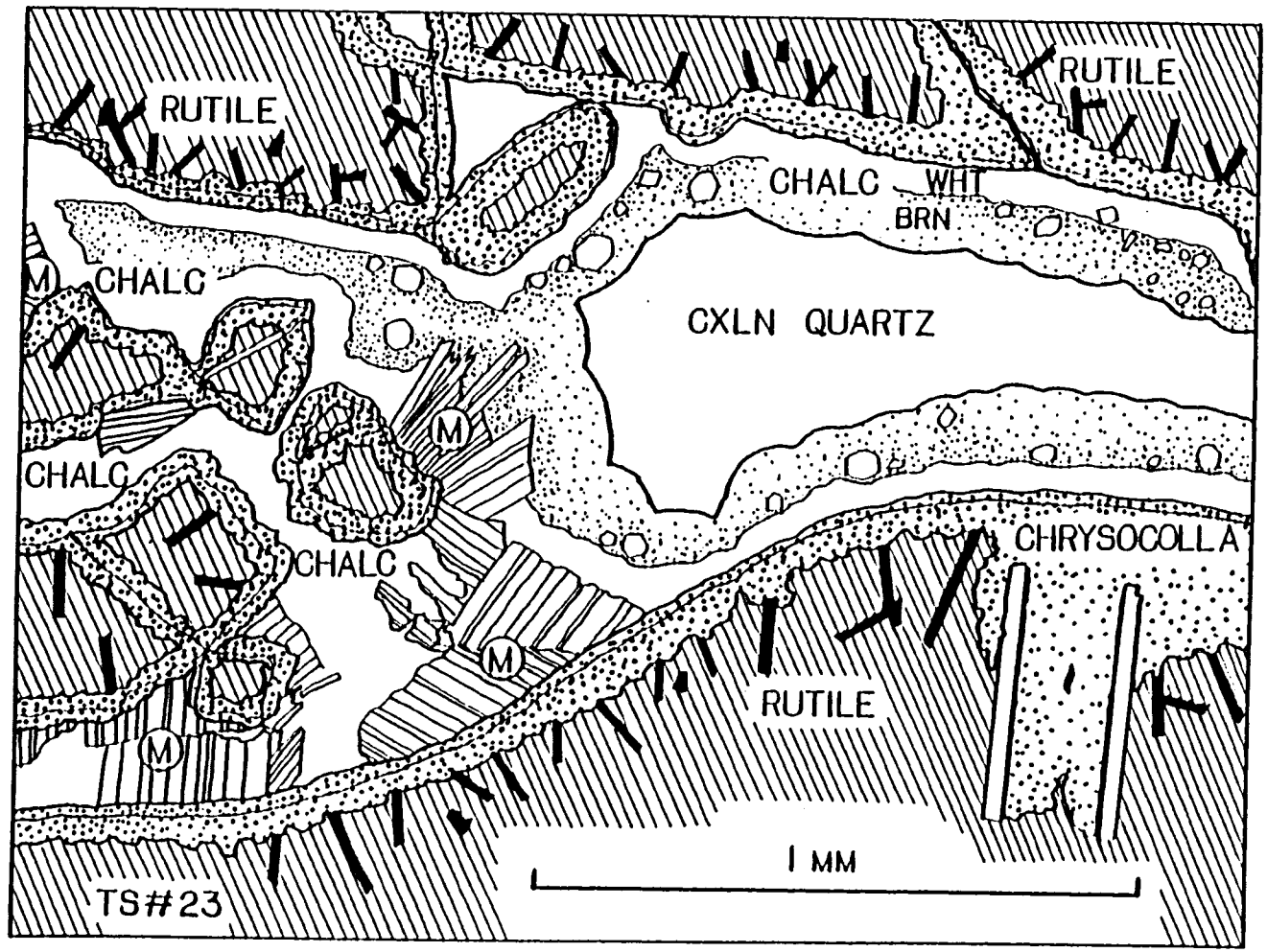


Figure 16: Drawing of a representative polyphase vein (type 1) in Mizpah Formation dacite (Thin section no. 23).

mm) the green phase may be succeeded inward by cream colored botryoidal chalcedony.

Infrequently, another phase was deposited on, and apparently after the chrysocolla, and subsequently encased in the precipitation of the chalcedony. This mineral is of platy, trapezoidal habit, appearing somewhat fibrous, of higher relief than the chalcedony, and is orthorhombic (determined by crystallographic properties) and commonly carlsbad twinned, indicating the zeolite mordenite. Minute, pale pink to rose colored crystallites, which may be zeolites, were commonly developed within the chalcedony, near the outside boundary, and may have been deposited with the first chalcedony.

In the largest fracture fillings, the chalcedony may be lined with cockscomb quartz, with fine-grained quartz filling the remaining space in the fracture centers.

In portions of the larger veins the chrysocolla appears to have been altered to the Cu-montmorillonite, medmandite (Dr. John Guilbert, University of Arizona, oral communication, 1985). Brindley (1951) reported the formula for medmandite as follows:

$0.18\ Al_2O_3.\ 0.43\ CuO.SiO_2.\ 1.91\ H_2O$

This phase may also be distributed throughout much of the

groundmass of the propylitized Mizpah Formation, although in quantities too minute to allow positive identification.

Mineralization with Depth. Diamond drill holes into the most highly altered, fault-displaced Mizpah Formation rock outcropping in the southeast sector of the field area revealed minor changes in alteration and mineralization (Figure 17). The predominant vein filling is calcite, occasionally associated with euhedral barite crystals. In the upper portion of the drill hole are considerable quantities of manganese wad, associated with the highest silver values intercepted. Below the level of manganese mineralization, disseminated pyrite is common, containing rare chalcopyrite, while at a greater depth, pyrite and rare chalcopyrite were deposited along the borders of veins which were subsequently filled with coarse crystalline quartz and calcite. Below approximately five hundred feet, pyrite occurs only as sparse disseminations.

Type 2 Veins. The simple type 2 veins (Table III (B)) are usually less than one millimeter wide, and are composed of either banded silica, or less commonly, calcite. Smaller fractures may be partly or completely filled with iron oxides. These veins are of limited length and generally occur in the major fracture sets developed within the host rock.

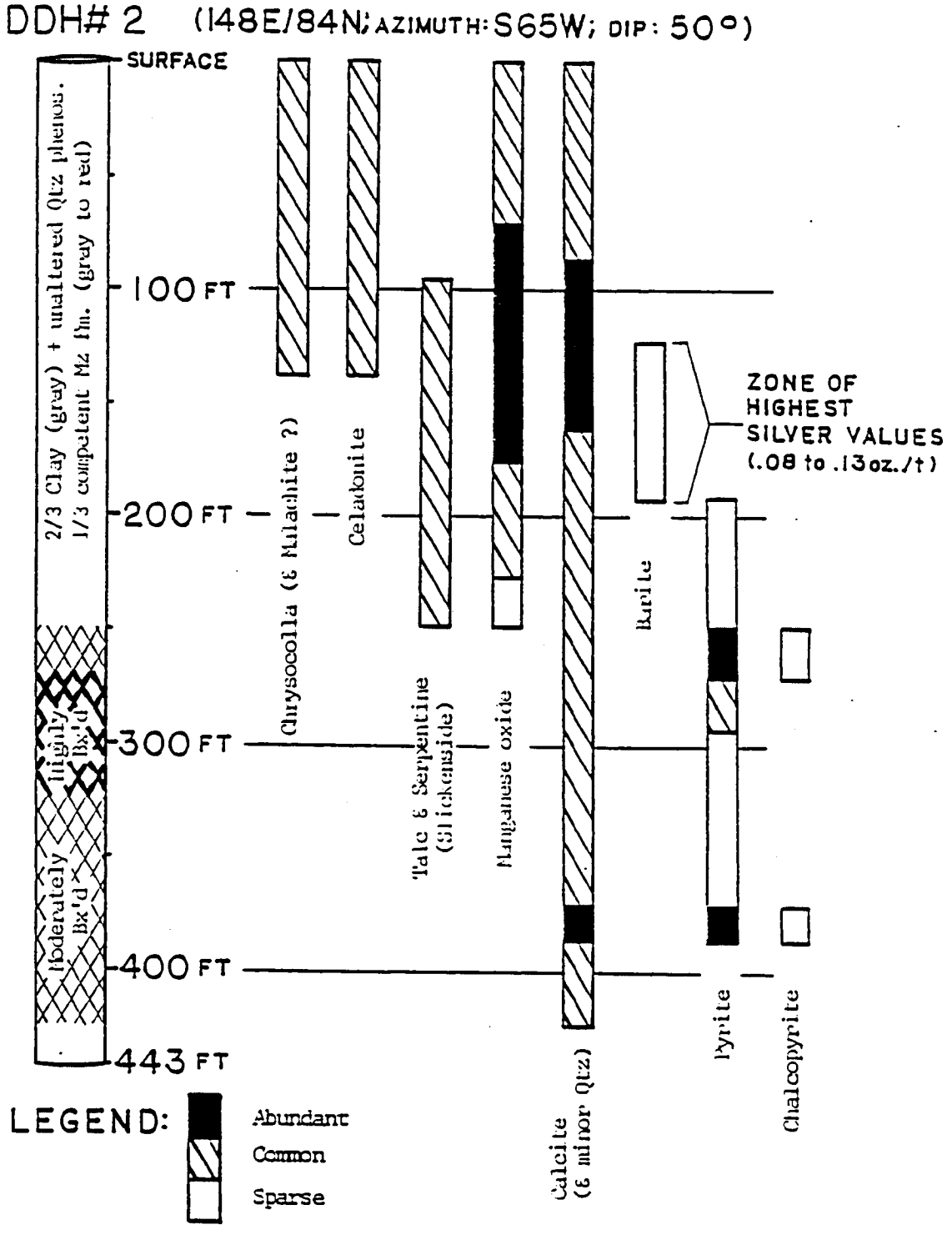


Figure 17: Mineralization with depth in the Mizpah Formation (Drill hole no. 2: loc.: 84N/148E).

Discussion. In a thesis concerned primarily with hypogene malachite and azurite mineralization distal to porphyry copper deposits, Beane (1968) reported a case of veinlets and coatings of chrysocolla, hematite, and calcite associated with andesitic dikes. Via field relations and thermodynamic formulae, Beane showed that the copper silicates and carbonates could form under hypogene conditions (e.g., chrysocolla and hematite can coexist at log $f(O_2) \leq$ 10 units and over a broad range of log $f(S_2)$ and log $f(CO_2)$).

The presence of chrysocolla, suspected Cu-montmorillonite, and possibly other copper-bearing phases, give mineralogical expression to the regional copper anomaly defined by Bonham and Garside (1982) in their geochemical survey of the district. Copper-bearing minerals associated with ore in the main camp include azurite, malachite, pseudomalachite, turquoise and tetrahedrite (Bonham and Garside, 1979a, p. 114).

As discussed above, propylitization of the intermediate volcanic rocks by deuteric alteration may have occurred prior to ore-deposit mineralization. It is possible that the copper bearing phases found within the altered Mizpah Formation on the Tonopah Property could have been deposited at this time.

In contrast to the above hypothesis, the presence of pyrite and chalcopyrite beneath chrysocolla (Figure 17) argue in favor of a supergene replacement origin for the latter. Mn oxides, calcite, and barite which occur with chrysocolla in drill hole number 2 (Figure 17) are considered to be of supergene origin by Bastin and Laney (1918) and Bonham and Garside (1979a, p. 116).

Fraction Tuff

Chalcedonic float ranging in color from cream to beige to white is scattered about almost everywhere in the northwest portion of the Tonopah Property, and occurs in both Members of the Fraction Tuff. Much of the chalcedony float defines linear trends, and is taken to indicate faults buried beneath the alluvium.

Aside from the chalcedonic float, no vein mineralization analogous to that discovered in the Mizpah Formation (Table III, B (type 1 vein)) was found in the Fraction Tuff.

Massive Manganese-Calcite-Bearing Mineralization

At many locations in the field area a distinctive class of veins is exposed whose mineralization is characterized by massive manganese wad and calcite, with or without iron oxides. First, bladed calcite was deposited; then Mn-wad in the interstices. Most of the manganese-calcite veins occur in NNE-trending faults situated in the uplifted

King Tonopah Member tuff in the northeast sector of the field area, but others are found throughout the Tonopah Property.

In many of the veins, the calcite was subsequently removed and replaced by white silica (Figures 18 and 19). Silica replacement of calcite occured in most of the manganese-bearing veins outcropping in the western half of the field area, but is largely absent in the northeast sector.

The geochemistry of the manganese-calcite veins will be discussed in Chapter 5.

One major Mn-calcite vein occurs at the contact of the Oddie Rhyolite of Mt. Ararat with Mizpah Formation dacite, along the Halifax Fault trend. Because of this contact relationship, all of the veins of this class are considered to be of post-Oddie Rhyolite age, and may have formed in response to the intrusion of the rhyolite.

Alteration-Mineralization Relationships

The alteration most likely related to the hydrothermal event which deposited the ore of the main camp and of the King Tonopah Mine, i.e., the fault-controlled alteration of the Mizpah Formation, is almost exclusively evidenced by varying degrees of propylitization (Table II (B)). The limited extent and the nature of the propylitic alteration suggests that the rock so altered is probably far removed, laterally and/or vertically, from any possible precious

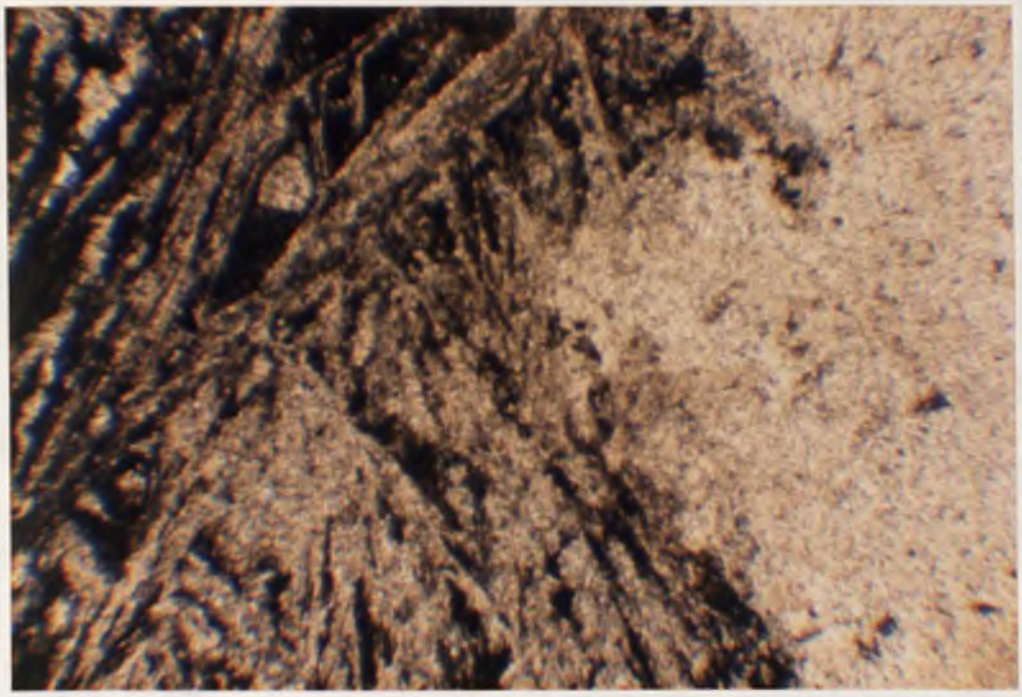


Figure 18: Photomicrograph of Mn-calcite vein matter (Thin section no. 10: approx. 25x magnification, PPL).

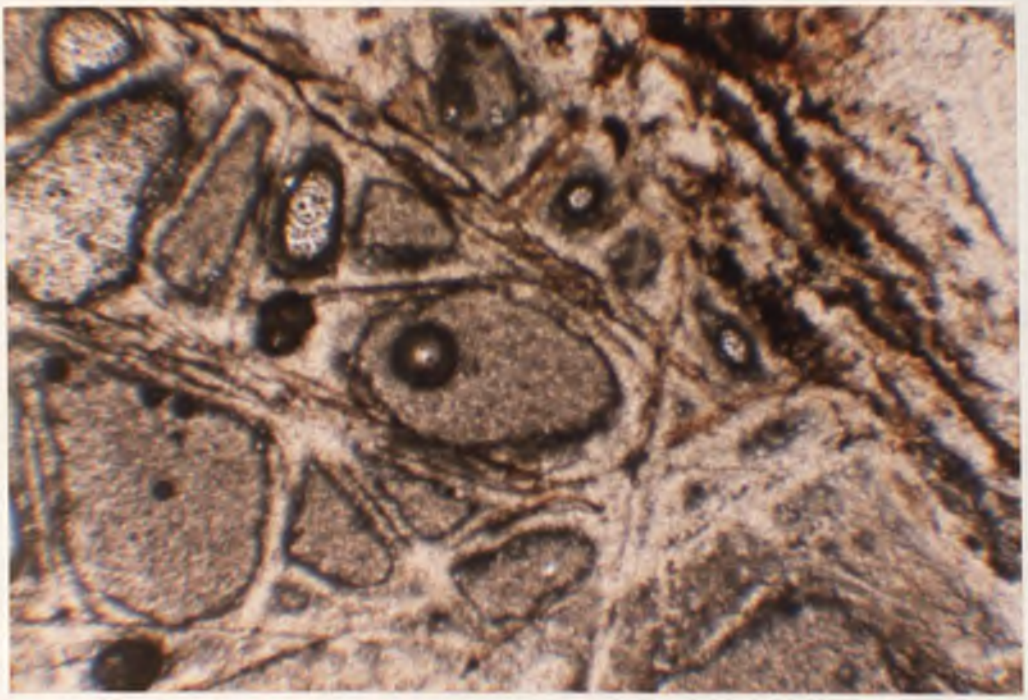


Figure 19: Photomicrograph of Mn-calcite vein matter (Thin section no. 12: approx. 25x magnification, PPL).

metal mineralization. An exception to this may exist near the King Tonopah Mine, where traces of argillic alteration occur, but the scarcity of outcrop in the area precludes any meaningful evaluation of the degree and extent of the alteration.

The fracture- or contact-controlled manganese-carbonate mineralization post-dating the intrusion of the Oddie Rhyolite, is yet another distinct event. This intrusion-mineralization event may also have coincided with the regional alteration of the tuffs in the northwest sector of the field area.

Ultimately, the scarcity of outcrop in the field area severely limits the degree to which these various styles of hydrothermal alteration can be understood.

CHAPTER 5

GEOCHEMISTRY

Introduction

Purpose. The purpose of the geochemical sampling of the Tonopah Property was to attempt to deliniate surface anomalies of selected elements indicative of mineralization at depth.

Type of Samples. Sampling conducted by Silver Strike Resources Ltd. involved the collection of 58 grab samples from veins, fault gouge, and altered host rocks. In addition, 25 analyses of grab samples collected from the Tonopah Property by Bonham and Garside (1982) were included to expand the data base. The sample locations are shown on the author's 1:4800 scale map (Figure 23), along with the elements analyzed and their concentrations.

Elements Analyzed. The elements analyzed by Chemex Labs Ltd. for Silver Strike Resources Ltd. included Pb, Zn, Ag, Mn, As, Au, Hg, and Sb, and for nine samples collected by the company's consulting geologist, Ba. Bonham and Garside analyzed their samples for the above elements and in addition for Mo, W, Cu, and Bi. This information is included for easier reference in Appendix B, and information regarding the laboratories that conducted the analyses, the

methods used, and precision and accuracy parameters are included in Appendix C.

Of negligible import to this study are the drill core assay data, which are included in Appendix D. These data include fire assays for silver and gold. The only shows of anomalous silver and gold occurred in the portion of core which intercepted the altered Tonopah Formation, previously discussed in Chapter 4 in the section on Tonopah Formation alteration. The locations of the six diamond drill holes are shown on the geochemical sample map (Figure 23).

The discussion of the geochemical variations will be brief and the reader is encouraged to examine the geochemical map carefully.

Bonham and Garside's Study

Bonham and Garside (1982) conducted a geochemical reconnaissance of several quadrangles centered on the Tonopah mining district and including several adjacent mining districts. The reconnaissance was intended to aid in the planning of future, more detailed or specialized, surveys.

In sampling on or above known ore bodies in the Tonopah district, Bonham and Garside found consistent elemental patterns. In the vicinity of mineralized vein outcrop, the samples were found to be strongly anomalous in

silver, gold, and antimony, and weakly to moderately anomalous in arsenic, copper, barium, and lead. Vein samples are not anomalous in mercury. Above blind ore bodies (known underground workings), samples are moderately to strongly anomalous in manganese and weakly anomalous in zinc and barium, and may be anomalous, but not necessarily, in arsenic and mercury. The most intensely and consistently developed anomaly over blind ore bodies is that of manganese. Bonham and Garside concluded (1982, p. 29) that:

> The results of our program suggest that in the Tonopah district and vicinity coincident manganese, zinc, and barium anomalies could indicate the existence of blind silver-gold ore bodies of the type mined at Tonopah. Anomalous mercury and arsenic may also be significant, but they do not appear to be as diagnostic as manganese, zinc, and barium. Anomalous tungsten, copper, lead, and bismuth do not appear to form definable anomalies above blind ore zones, and gold and silver are not anomalous above these blind ore zones.

Threshold values for the thirteen elements in Bonham and Garside's study are presented in Table IV. These data should be compared to the data of the Tonopah Property presented in Figure 20 and Tables V, VI, and VII.

Table IV: Concentration thresholds for analyzed elements.

All concentrations given in ppm's unless otherwise indicated (ppb) after element concentrations categorized by Bonham and Garside, 1982).

	Concentrations			
Element	very weak	weak	moderate	strong
Pb		20-100	100-500	>500
Zn	30-100	100-500	500-10,000	>10,000
Ag		0.5-2	2-10	>10
Mn		600-1000	1000-2000	>2000
As		10-40	40-100	>100
Au (ppb)		30-100	100-1000	>1000
Hg (ppb)		100-500	500-1000	>1000
Sb	1-5	5-10	10-50	>50
Ba		1200-2000	2000-4000	>4000
Mo		10-50	50-100	>100
W	1-5	5-15	15-50	>50
Cu	10-30	30-100	100-1000	>1000
Bi (ppb)		200-500	500-1000	>1000

Tonopah Property Geochemical Anomalies

Major element oxide abundances and selected metals concentrations of Tonopah Property rocks are compared with those of representative igneous rocks in Table V. Average abundances and standard deviations of the elements listed above for Tonopah Property analyses, subdivided by lithologic units, are included in Table VI. Cumulative frequency versus log concentration graphs for selected elements are presented in Figure 20, indicating anomaly thresholds obtained from Tonopah Property data. Owing to the limited number of analyses, these evaluations were of limited

Table V: Major element oxide abundances and selected metals concentrations of Tonopah Property rocks compared with those of representative igneous rocks.

	DACITE		DACITIC & RHYOLITIC ACID FLOW				RHYOLITE	
			Early		Late			
WT. %	Dacite from Tauhara[1] (Ewart & Stipp, '68)	Unaltered[2] Mizpah Bn. (Bonham & Garside, '79a)	Carpenter[3] Ridge (early) (Lipman, '75)	King Tonopah Mbr. (Bonham & Garside, '79a)	Carpenter[3] Ridge (late) (Lipman, '75)	Tonopah[4] Summit Mb. (Bonham & Garside, '79a)	"Average[1] rhyolite" (Ewart & Stipp, '68)	Oddie[5] Rhyolite (Bonham & Garside, '79a)
SiO_2	67.2	60.3	73	75.7	66.2	64.2	74.2	79.2
Al_2O_3	15.1	17.5	14.1	12.7	17	18.9	13.3	12.7
Fe_2O_3	3.3	4.8	Total Fe 1.35	1.1	Total Fe 3.3	2.4	0.9	0.2
FeO	0.5	1.2		0.5		1.5	0.9	0.4
MgO	2	1.9	0.5	0.3	0.9	1	0.3	0.3
CaO	4.3	5.5	1.5	1.5	3.5	4.6	1.6	0.7
Na_2O	3.6	3.5	3.9	3.3	3.7	2.4	4.2	1.1
K_2O	2.2	4.3	5.3	4.7	4.4	4.4	3.2	5.3
TiO_2	0.3	0.9	0.3	0.2	0.4	0.5	0.3	0.2
MnO	0.09	0.05	--[8]	0.03	--	0.05	0.05	0.1
PPM	DACITE (Taylor,[6] '69)	Mizpah Bn., Tonopah P.		King T. Mb. Tonopah P.		Tonopah S. Mbr. (T.P.)	RHYOLITE Taylor,[6] '69)	Oddie[7] Rhyolite
Pb	5.2	8.3	--	2.5	--	10	18	26.5
Zn	--	60.7	--	16.1	--	20	--	9.5
Mn	580	506.7	550	423.5	1100	190	400	71.5
Ba	520	1370	680	290	4900	400	870	698
Cu	6	6.5	8	3	13	--	6	15

Data: 1) referenced in Carmichael, Turner, & Verhoogan, 1974, p. 554; 2) Bonham & Garside, 1979a, p. 47; 3) referenced in Hildreth, 1981, p. 10156; 4) Bonham & Garside, 1979a, p. 53; 5) Bonham & Garside, 1979a, p. 70 (high SiO_2 and low Na_2O may reflect hydrothermal addition and subtraction, respectively); 6) Taylor, 1969, pp. 43-58; 7) Bonham & Garside, 1982, p. 52 (sample T305g), and Tonopah Property, sample no. 53;
8) -- = no data

Table VI: Average elemental abundances of Tonopah Property rocks, subdivided by lithologic units.

	MIZPAH FORMATION		FRACTION TUFF			OXIDE RHYOLITE
			King Tonopah Mbr.	Tonopah Summit Mbr.		
Elements	Bonham & Garside[1] (Samples T230g, T34g, T302g, GC39 GC 135, GC 137)	Tonopah Property (Samples 52, 64, 84N/148E; for Cu analyses, GC 60, GC 137)	Tonopah Property (Samples 60, GC64, 66, 68, 69, 73, 74, 76, 77, 80)	Tonopah Property (Sample 153N/84E, no standard deviation given) (A) Tuff	Tonopah Property (Sample 160N/84E no standard deviation given) (B) Jasperoid	Tonopah Property (Samples T305g, 53; for Ba, Mo, W, Cu, Bi, one analysis (T305g), no stdrd. dev.)
Pb (ppm)	$\bar{X}$ = 6.17 σ = 2.64	$\bar{X}$ = 8.3 σ = o.r.[2]	$\bar{X}$ = 2.5 σ = 2.8	10	8	$\bar{X}$ = 26.5 σ = 0.71
Zn (ppm)	$\bar{X}$ = 24.5 σ = 17.19	$\bar{X}$ = 60.67 σ = o.r.	$\bar{X}$ = 16.1 σ = 10.24	20	13	$\bar{X}$ = 9.5 σ = 4.95
Ag (ppm)	$\bar{X}$ = 0.15 σ = 0.17	$\bar{X}$ = 0.33 σ = o.r.	$\bar{X}$ = 0.095 σ = o.r.	0.5	0.4	$\bar{X}$ = 3.9 σ = 4.1
Mn (ppm)	$\bar{X}$ = 598 σ = 529	$\bar{X}$ = 506.7 σ = 429.1	$\bar{X}$ = 423.5 σ = 883.3	140	165	$\bar{X}$ = 71.5 σ = 20.5
As (ppm)	$\bar{X}$ = 5.03 σ = 6.9	$\bar{X}$ = 12.7 σ = 10.6	$\bar{X}$ = 7.1 σ = o.r.	4	36	$\bar{X}$ = 4.9 σ = 0.1
Au (ppb)	$\bar{X}$ = 1.53 σ = 1.48	$\bar{X}$ = 5 (one sample)	$\bar{X}$ = 3 (one sample)	5	5	$\bar{X}$ = 6 (one sample)
Hg (ppb)	$\bar{X}$ = 93.83 σ = 54.4	$\bar{X}$ = 163.3 σ = 123.4	$\bar{X}$ = 114.5 σ = 208.8	70	130	$\bar{X}$ = 51.5 σ = 2.1
Sb (ppm)	$\bar{X}$ = 0.19 σ = 0.17	$\bar{X}$ = 3.3 σ = o.r.	$\bar{X}$ = 0.85 σ = 0.77	2	30	$\bar{X}$ = 0.705 σ = 0.15
Ba (ppm)	$\bar{X}$ = 1209 σ = 185	$\bar{X}$ = 1370 (one sample)	290	400	120	698
Mo (ppm)	$\bar{X}$ = 2.0 σ = 0.0	--[3]	2	--	--	< 1
W (ppm)	$\bar{X}$ = 1.47 σ = 0.8	--	2.2	--	--	0
Cu (ppm)	$\bar{X}$ = 7.33 σ = 3.1	$\bar{X}$ = 6.5 σ = 2.1	3	--	--	15
Bi (ppb)	$\bar{X}$ = 68 σ = 33.1	--	69	--	--	430

Data: 1) Bonham & Garside, 1982, p. 5;
2) o.r. = out of range;
3) -- = no data

σ = standard deviation

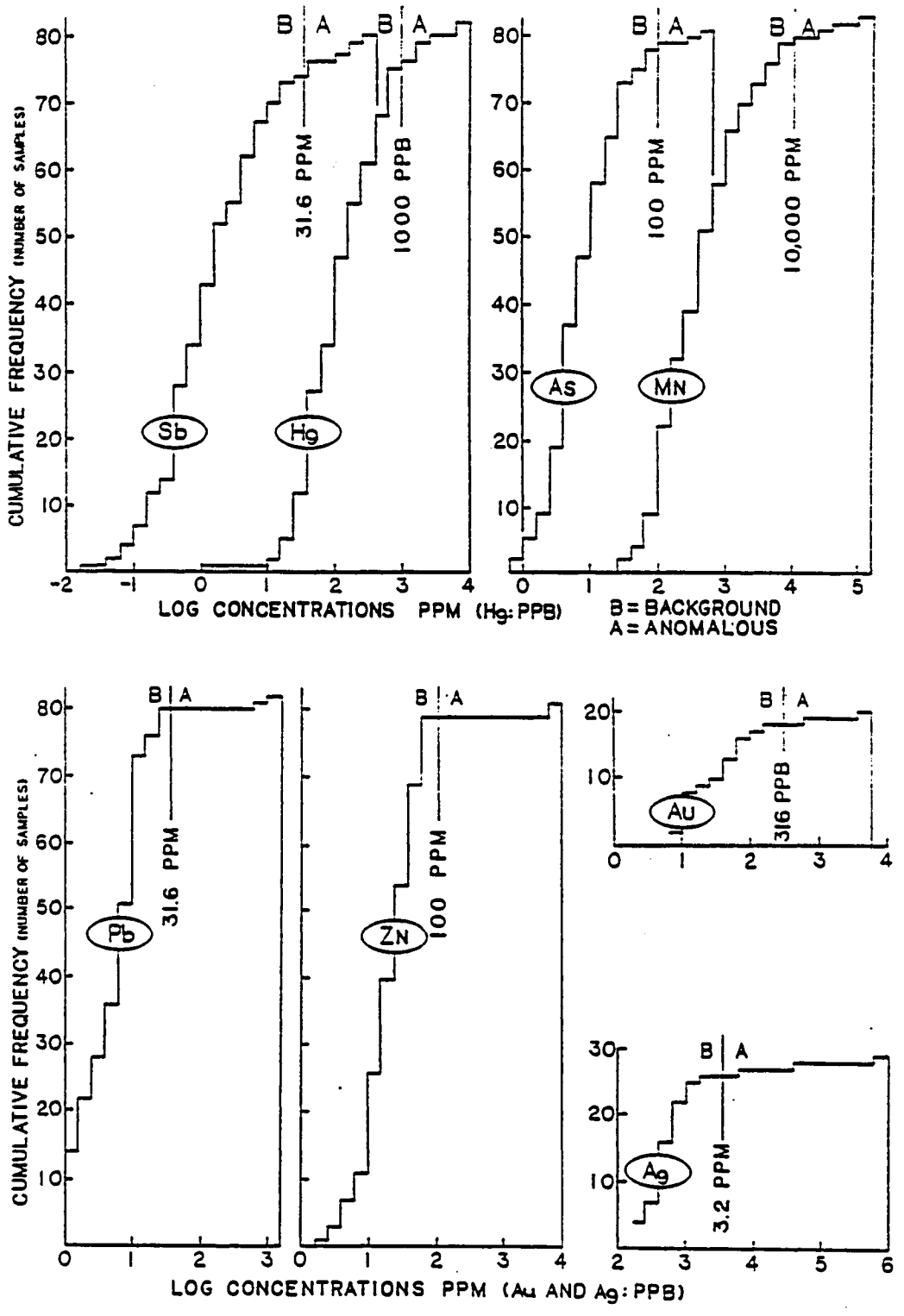


Figure 20: Cumulative frequency-$\log_{10}$ concentration diagrams.

exploration value, hence the reader is cautioned against divining much more from the data than is summarized below.

Background and Anomalous Elemental Abundances

Tonopah Property Rocks Contrasted with "Typical" Igneous Rocks. In upper portion of Table V, major element oxide abundances of the Tonopah Property igneous rocks are compared with those of "average" or "representative" lithologic equivalents. It can been seen that Mizpah Formation dacite and both early and late phases of the Fraction Tuff (King Tonopah Member and Tonopah Summit Member, respectively) are representative within their lithologic categories. The Oddie Rhyolite is of higher SiO_2 and K_2O, and lesser total FeO, MgO, CaO, and Na_2O than "average" rhyolite, indicating a greater degree of differentiation prior to eruption.

The lower portion of Table V provides partial data for concentrations of Pb, Zn, Mn, Ba, and Cu. Correspondence is generally close, although late-phase Tonopah Summit tuff contains an order of magnitude less Mn and Ba than does the late-phase Carpenter Ridge tuff (Nevada). This relative deficiency may indicate that the Tonopah Summit tuff was leached of these elements subsequent to eruption, or that these concentrations are original and that the Carpenter Ridge tuff is anomalously enriched in Mn and Ba. Owing to the pervasive alteration of the Tonopah Summit tuff and the

mobility of Mn and Ba, the author suspects that the former possibility is more likely.

These meager cation concentration data suggest that the Tonopah Property rocks are overall somewhat enriched in Pb, and deficient in Mn and Ba (although the Mizpah Formation is enriched two-fold over the Tauhara dacite in Ba).

Tonopah Property Background and Anomalous Values. In Table VI, the average background concentrations (including standard deviations) of the elements analyzed at the Tonopah Property are presented. As is readily apparent, the majority of the abundances are not even weakly anomalous in relation to the more broadly based anomaly categories derived from the regional data of Bonham and Garside's (Table IV). The few anomalous values are barely greater than background and only one value, that of Ag concentration in the Oddie Rhyolite, fits within the "moderate" category.

Cumulative frequency versus $\log_{10}$ concentration graphs of eight elements are presented in Figure 20. The graphs provide inflection point values which distinguish background from anomalous element concentrations. These data indicate few anomalies within the Tonopah Property.

Pb, Zn, and Au concentrations are anomalous only in the King Tonopah mine dump samples (T86ga and T86gb).

Ag is anomalous in the mine dump samples and in one sample taken from a remnant of extrusive Oddie Rhyolite (Number 53).

Sb is anomalous in one mine dump sample (T86ga), one Mn-"B" fault sample (WR07), one Mn-"A" fault sample (WR02), and in several samples of the Fraction Tuff from the northwest sector of the Tonopah Property (T232g, 140N/78E, and Number 57).

Hg, As, and Mn are anomalous in the Mn-calcite faults (GC81, WR02, WR07, and T85g) and in several widely scattered samples of Fraction Tuff from the western sector of the Tonopah Property (Numbers 57, 61, 71, and 88, 140N/78E, and T229g), but are not anomalous in the King Tonopah mine samples.

Tonopah Property Background Values Contrasted with Bonham and Garside's Data. Concentrations of the elements analyzed from Bonham and Garside's regional reconnaïssance of the Mizpah Formation (Table VI, far left column), compared with those of the Mizpah Formation within the Tonopah Property (adjacent column), show that, with the exceptions of Mn and Cu, base metal concentrations are higher in the Tonopah Property samples. This relation may indicate that the Mizpah Formation rock of the Tonopah Property is less depleted in metals than is the Mizpah Formation rock of the main camp, from which the majority of Bonham and Garside's

samples were collected. As described in Chapter 4 and shown in Table II, the more intense and pervasive propylitization of the dacite of the main camp may indicate greater depledepletion of original cations with perhaps a concurrent minor enrichment of mobile Mn.

Geochemistry of Fault Materials

Average concentrations of elements associated with various faults within the Tonopah Property are presented in Table VII. The elemental concentrations of selected faults are compared by means of bar graphs constructed between the fault data of interest.

Fault Classes. Faults of a given type have a characteristic geochemical signature. The degree of similarity between classes of faults is illustrated in the comparative bar graphs.

These chemical data indicate that two major classes of faults occur on the Tonopah Property: The older set includes the Halifax Fault and at least one paralleling fault to the east, of pre- and post-main camp mineralization; and the younger set comprises the Mn-bearing faults of the northeast sector of the Tonopah Property and of the Tonopah Summit tuff to the west. There is a fair degree of correspondence between the Halifax Fault (Table VII, B) and the parallel fault located approximately 2800 feet to the east (Table VII, C) indicating a class of alteration and perhaps

Table VII: Average elemental abundances associated with various faults within the Tonopah Property; compared and contrasted by bar graphs.

Elements	FAULT NW of HALIFAX F. (vic. of 88E/120N) (Samples WR05, WR06) (A)	HALIFAX FAULT (Samples T230g, T307g, T308g) (B)	FAULT PARALLEL to S.E of HALIFAX F. (Group 1 Fault) (Sample GC59, no stdrd. dev. given) (C)	HARGRAVES "A" & "B" FAULTS (Samples T85g, WR07, GC81) (D)	TONOPAH SUMMIT NBR. FAULTS (Samples T229g, T228g, T85g, WR07, 140N/78E) (E)
Pb (ppm)	$\bar{X}$ = 10.5[1] o = o.r.[2]	$\bar{X}$ = 10.7 o = 3.7	10	$\bar{X}$ = 9.0 o = 5.2	$\bar{X}$ = 11.8 o = 3.6
Zn (ppm)	$\bar{X}$ = 11.5 o = 2.1	$\bar{X}$ = 64.0 o = 18.7	36	$\bar{X}$ = 31.3 o = o.r.	$\bar{X}$ = 29.8 o = o.r.
Ag (ppm)	$\bar{X}$ = 1.5 o = 0.99	$\bar{X}$ = 0.29 o = 0.20	0.08	$\bar{X}$ = 0.42 o = 0.39	$\bar{X}$ = 0.38 o = 0.31
Mn (ppm)	$\bar{X}$ = 205 o = 28.3	$\bar{X}$ = 622.3 o = 262.4	205	$\bar{X}$ = 21,100 o = o.r.	$\bar{X}$ = 28,609 o = 41,095
As (ppm)	$\bar{X}$ = 101 o = o.r.	$\bar{X}$ = 1.6 o = 0.17	1.5	$\bar{X}$ = 136.3 o = 148.4	$\bar{X}$ = 32.2 o = o.r.
Au (ppb)	$\bar{X}$ = 130 o = 89.9	$\bar{X}$ = 7.0 o = 4.2	n.d.[3]	$\bar{X}$ = 36.7 o = o.r.	$\bar{X}$ = 6.0 o = 1.7 (T85g; 99ppb)
Hg (ppb)	$\bar{X}$ = 780 o = o.r.	$\bar{X}$ = 28.0 o = 2.8	20	$\bar{X}$ = 3067 o = o.r.	$\bar{X}$ = 1067 o = o.r.
Sb (ppm)	$\bar{X}$ = 4.5 o = 2.1	$\bar{X}$ = 0.7 o = o.r.	.13	$\bar{X}$ = 41.2 o = 56.0	$\bar{X}$ = 33.2 o = 43.7
Ba (ppm)	--	$\bar{X}$ = 956 o = o.r.	--	1624 & 25,000	$\bar{X}$ = 3204 o = o.r.
Mo (ppm)	--	2.0 (one sample)	--	2 & 16	$\bar{X}$ = 20 o = 32.1
W (ppm)	--	$\bar{X}$ = 1.25 o = 0.50	--	two samples T85g, GC81: 31.8 & 662	$\bar{X}$ = 18.1 o = o.r.
Cu (ppm)	--	$\bar{X}$ = 13.0 o = 11.4	--	11 & 33	$\bar{X}$ = 8.0 o = 3.0
Bi (ppb)	--	$\bar{X}$ = 111.0 o = 82.5	--	201 & 288	$\bar{X}$ = 300.0 o = 103.8

Data: 1) o = σ
2) o.r. = out of range;
3) n.d. = not detected

Bar graph legend:
Values (either side of bar) within 2x range
Values outside 2x range of each other
No comparison due to insufficient data

coeval origin, as proposed in Chapter 3. A better correlation is evident in the near-identical values for a majority of the elements analyzed between the Mn-"A" and Mn-"B" faults (Table VII, D) and the faults restricted to the Tonopah Summit Member of the Fraction Tuff (Table VII, E).

In contrast to the above described correspondences, it is apparent that the Halifax Fault (and the apparently related parallel fault to the east) and the Mn-calcite faults are highly dissimilar in geochemical signature. Therefore, they are unlikely to have been affected by the same mineralizing event, and may not be of the same episode of faulting.

The marked dissimilarity between the Halifax Fault and a fault trace appearing to continue along the same trend to the north, which is restricted to the Tonopah Summit tuff (Table VII, A), contradicts Bonham and Garside's (1979a) continuation of the Halifax Fault into the Tonopah Summit Member of the Fraction Tuff. This geochemical disparity is in accord with the author's inability to trace the Halifax Fault into the Tonopah Summit tuff.

Halifax Fault Class. The older set is not distinguished by any anomalous surface sample concentrations of note (Table VII, B and C). Only Mn straddles the threshhold of weak anomaly characterization (in comparison with Table IV) for the Halifax Fault. Dump samples (T86ga and T86gb)

from the King Tonopah Mine indicate that Ba may be more concentrated at the surface than at depth (1000 ppm and 840 ppm, respectively), but the surface value is not anomalous relative to district values (Table IV). Since Bonham and Garside believe Ba to be one of the most diagnostic elements in exploration for blind ore bodies, perhaps the element is anomalous only at a greater distance above such mineralization, and not generally associated with ore in anomalous quantities.

Manganese-Calcite Fault Class. As shown in Table VII, D and E, the geochemical characterization of the Mn-calcite fault zones is very different from that of the Halifax Fault class. In contrast to the non-anomalous surface sample geochemical characterization of the Halifax Fault class, the Mn-calcite faults are anomalous in Hg, As, Mn, and Sb (as indicated in Figure 20). Far less geochemical data is available for the elements not illustrated in Figure 20, but in relation to Bonham and Garside's data (Table IV), Ba concentrations are strongly to extremely anomalous, and W concentrations are moderate to strongly anomalous.

Although the Mn-bearing faults are greatly enriched in these elements, the fact that they are of a different mineralizing event than that which produced the main camp and King Tonopah Mine ore bodies obscures the significance

of the data. The affinity of amorphous Mn oxides for other cations (Boyle, 1974) may invalidate Bonham and Garside's criteria for geochemical exploration within the Mn-calcite fault class (with which they were not concerned in their study). Nevertheless, these strong surface anomalies may conceal ore bodies at depth.

A pattern of geochemical concentrations similar to that of the Mn-calcite veins is reported for a dump sample of King Tonopah tuff taken from the flank of Mt. Ararat (GC82).

Summary of Geochemistry

Overall, the geochemical sampling of the field area provided very little encouraging exploration information. As stated above, generally all of the elements within the Halifax Fault class, were of non- or marginally-anomalous concentrations (even if the data from the Mn-calcite veins is excluded from the study). These elemental distributions pin-pointed no uniquely anomalous sections of veins or altered zones, and were therefore unable to narrow the field of potential drill sites.

Concerning the alteration of the Mizpah Formation discussed in Chapter 4, and the geochemistry reviewed above, none of the most diagnostic elements (Bonham and Garside, 1982) used to predict blind ore bodies in the main camp were of use in the field area. Barium and zinc concentrations

over fault zones could not be distinguished from those apparently indicative of background levels, nor did manganese show consistent variations between fault-localized and background samples. None of these elements proved more than weakly anomalous.

Although the manganese (and associated cation) concentrations within the Mn-calcite veins are highly anomalous, this stage of mineralization is presumed to be post (Tonopah)-mineralization, and therefore the manganese concentrations may not be indicative of any precious metal mineralization at depth. Further, no uniquely enriched segments of any of these veins were discovered. At any rate, the author's exploration company decided against drilling into the Mn-calcite faults during the preliminary (and only) drilling program.

In consideration of the lack of outcrop of either bedrock or in-place vein matter, the limited geochemical data may of itself be sufficient to dissuade a greater investment in a more intensive geochemical sampling program of the area. This may have indeed been the case in previous preliminary exploration programs and concluding appraisals of these claims.

CHAPTER 6

DISCUSSION

General

Igneous terranes are the products of successive intrusions and eruptions spanning millions of years. Sequences of genetically related, often successively differentiated, igneous rocks are built up into a pile of complex stratigraphy, which none the less generally conforms in gross features to one of a number of recognizable morphologies. In the case of the Tonopah district, as well as that of much of the state of Nevada during the Cenozoic, early intermediate lavas were succeeded by the widespread eruption of voluminous ash flow tuffs, which were in turn succeeded by mafic and bimodal basaltic-rhyolitic volcanism (e.g., Stewart, 1980). The early intermediate volcanics are breached and covered by the ash flow tuffs which generally create a caldera structure during the rapid and immense eruptions of ignimbrite. In the final stages of this highly silicic igneous activity, residual, volatile-poor rhyolites intrude caldera structures and pre-existing faults, and are finally succeeded by the eruption of mafic and bimodal lavas, beyond and peripheral to the caldera structure (e.g., Hildreth, 1981).

Tonopah District Igneous Sequence

Mizpah Formation

The Mizpah Formation andesites and dacites are exposed from Tonopah to a point approximately ten miles to the north, and the unit appears to be thickest in the vicinity of the field area and Tonopah, where Bonham and Garside (1979a) reported a thickness of approximately 2000 feet. Hence, it seems likely that the unit was vented in the proximity of Tonopah. Since the hydrothermal alteration and precious metal mineralization is centered on the Tonopah district, and predominantly occurs in Mizpah Formation rocks, both the unit and the hydrothermal event appear related. As stated earlier, the average age of the Mizpah Formation is 20.5 m.y., and that of the alteration, approximately 19 m.y.(Bonham and Garside, 1979a). These data strongly suggest a magma chamber underlies the district and was responsible for both the Mizpah Formation lavas and the subsequent alteration and mineralization, as originally suggested by Nolan (1935). Taylor (1973) came to the same conclusion after studying stable isotope data.

Fraction Tuff

As discussed earlier, the author has interpreted the ash flow stratigraphy of the Fraction Tuff differently than have Bonham and Garside (1974; 1979a; 1979b). Ash flow

stratigraphic and petrologic data gathered from many regions, as well as theoretical petrologic considerations (Hildreth, 1981; Mahood, 1981; etc.), lend support to the author's interpretation, as explained below.

Gradients in Silicic Magma Chambers. The following discussion is based primarily upon a review of the nature of numerous ash flow terranes, and in particular, the theories which relate to lithospheric magmatism and gradients in silicic magma chambers as presented by Hildreth (1981).

Many carefully studied simple and composite ash flows show early- to late-eruptive stage compositional gradations. The compositional variations may occur within one ash flow, particularly if the volume of the eruption is hundreds to thousands of cubic kilometers, or within two or more ash flow sheets erupted sequentially. The reasons for such compositional variations have to do with chemical and physical differentiation within the parent magma chamber (Hildreth, 1981; Mahood, 1981; et cetera).

In the time interval required for an epizonal magma chamber to evolve preceding eruption, gravitational fractionation of crystalline phases, roofward volatile diffusion, upward and downward fractionation of chemical species, and even isotopic fractionation, transpire. "Every large eruption of nonbasaltic magma taps a magma reservoir that is thermally and compositionally zoned." (Hildreth, 1981,

p. 10153). Many such magma chambers become differentiated into two major fractions before roof failure initiates an eruption. Hildreth considered thermogravitational diffusion (Soret diffusion effects in a convecting magma column (chamber)) and volatile complexing (roofward enrichment of magma by volatiles (especially H_2O) and certain other elements with which these volatiles complex) to be the most important mechanisms for effecting the zonation of the rhyolitic magma. The upper fraction is enriched in volatiles of which water is the dominant species, helping to establish a critical thermal gradient between the fractions.

The complexities of such thermal and compositional gradients, and their establishment, will not be considered here, but the two major magma fractions that generally seem to evolve in such systems will be briefly described.

The upper, volatile-rich fraction of the magma is typically of much lesser volume than the lower fraction, and in some cases, may not develop prior to eruption. In those systems in which the upper fraction has differentiated, it is characterized by a high silica content in the range of 75 to 77.4 wt.% SiO_2, relatively low crystal content, and a distinctive chemical composition due to the pronounced effect of diffusive differentiation upon some major, and especially trace, elements, within the silica range (ibid, p. 10154-10157).

The lower, volatile-poor fraction of the magma chamber is the dominant volume, and is characterized by a silica content in the range of 63 to 71 wt.% SiO_2, and a relatively high phenocryst content (ibid, p. 10154-10157).

Of interest is the fact that ashflows rarely occur with a silica content intermediate between those of the two fractions discussed above, unless magma mixing is in evidence (e.g., as in banded or blended pumice). Perhaps the best documented example of a compositionally zoned eruption is that of the 1912 eruption in the Valley-of-Ten Thousand-Smokes, Alaska, in which magma with a 77 wt.% silica content was erupted along with a crystal-rich magma of 66 to 58 wt.% silica (Hildreth, 1980; Hildreth and Grunder, 1980).

The King Tonopah Member of the Fraction Tuff contains approximately 75.5 wt.% silica, whereas the crystal-rich Tonopah Summit Member contains approximately 64.2 wt.% silica (Bonham and Garside, 1979a, p. 53).
Thus, the early and later erupted ash flows of the Fraction Tuff conform in silica content and relative phenocryst content to the upper and lower magma fractions, respectively.

Ratios of selected elemental abundances in different silicic magmas are presented in Table VIII. A high degree of correspondence is evident in elemental enrichment and depletion trends between early erupted tuff and late erupted

Table VIII: Ratios of selected elemental abundances between early- and late-erupted volcanics of various silicic magmas, compared and contrasted by bar graphs.

ELEMENTAL ABUNDANCES in DIFFERENTIATED SILICIC MAGMAS				
Elements	EIGHT VOLCANIC CENTERS[1] Averaged Values Early / late	BISHOP TUFF[2] Early / late	TONOPAH PROPERTY BACKGROUND VALUES (Table V) FRACTION TUFF King Tonopah/ Tonopah Summit [4]	FRACTION TUFF/ODDIE RHYOLITE
Pb	--[3]	>	<	<
Zn	<	=	<	>
Ag	--	<	<	<
Mn	<	>	>	>
As	--	>	>	≥
Au	--	<	<	<
Hg	--	>	>	>
Sb	--	>	<	>
Ba	<	<	<	<
Mo	--	>	≥	>
W	--	>	>	>
Cu	<	<	<	<
Bi	--	--	<	<

Data: 1) Hildreth, 1981, p. 10156: excerpted from table.
2) Hildreth, 1981, p. 10166: excerpted from graph.
3) -- = no data
4) Background values of Mo, W, Cu, and Bi taken from following analyses of Tonopah Summit Hbr.: GC86, GC121, GC122, T3g

EXPLANATION: Correspondence (both ratios < or > 1); Non-correspondence; Partial correspondence

tuff. Bar graphs indicate the degree of correspondence between the Bishop Tuff (Hildreth, 1981) and the Fraction Tuff (left), and between the Fraction Tuff and the ratios of Fraction Tuff/Oddie Rhyolite elemental abundances.

King Tonopah Member of the Fraction Tuff. For reasons of the map relations discussed in Chapter 2, it is suggested the vent source for the King Tonopah Member tuff lies within the topographically elevated northeastern sector of the field area (Figure 21, location 1). The morphology of this eruptive center (described in Ch. 2) suggests a 'downsag' caldera (Walker, 1984), formed by the venting of the ashflow via linear fissures that may have reactivated earlier regional structures. In addition, the eruptive center for this relatively minor ash flow may be part of a larger ring fracture system, suggested by the regional topography (Figure 21, ring KT). Bonham and Garside (1979a, p. 57) lend support to this caldera hypothesis in recognizing that the megabreccia blocks of Mizpah Formation rock found in the northeast portion of the author's field area, and immediately to the north, "...could well represent landslide blocks from a caldera margin."

Tonopah Summit Member of the Fraction Tuff. As stated above in Chapter 2, the Tonopah Summit Member of the Fraction Tuff is exposed over a far greater area (in the Southern San Antonio Mountains region) than that of the King

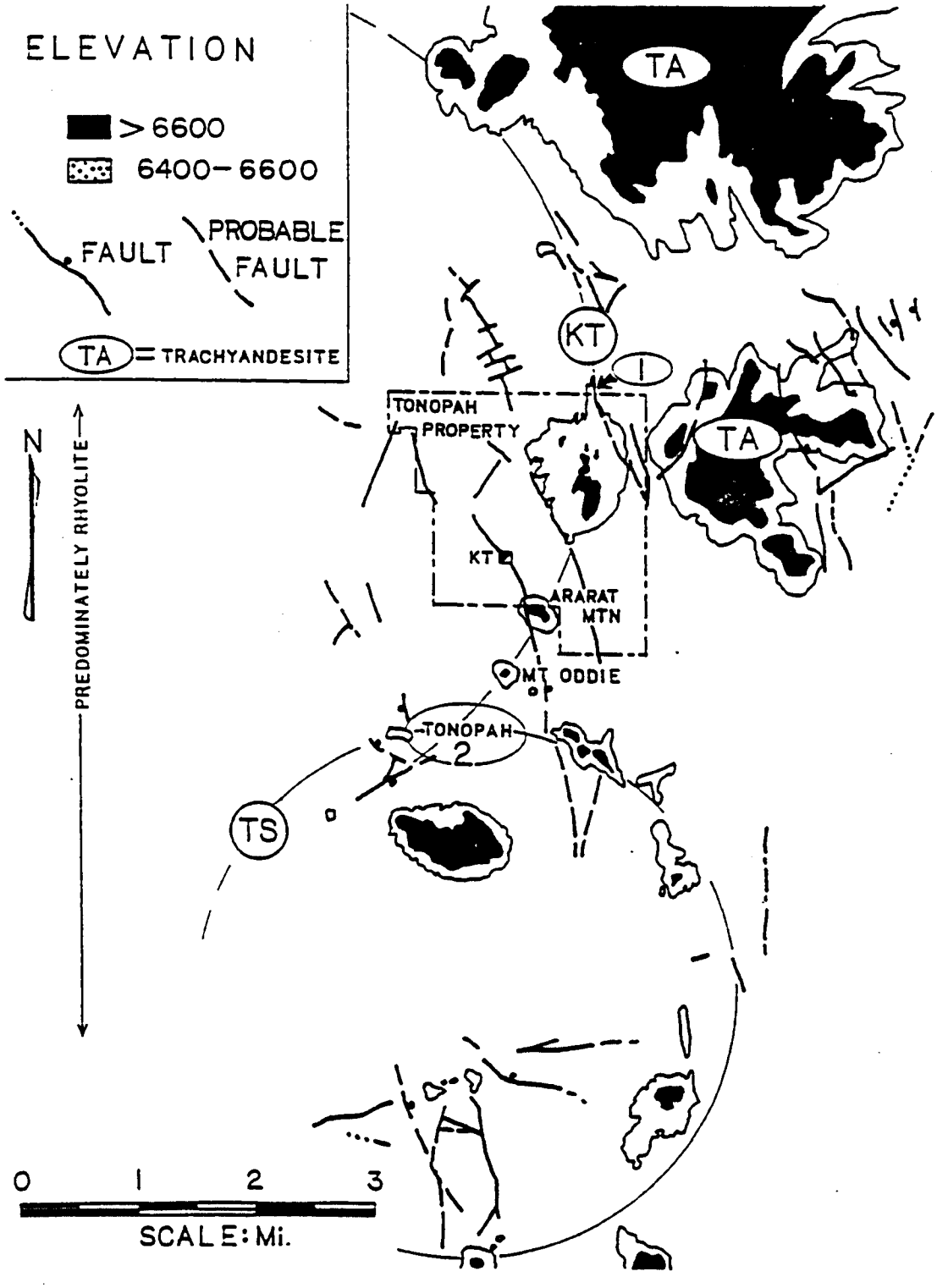


Figure 21: Topography of Tonopah district showing suggested caldera ring fractures intruded by rhyolite.

Tonopah Member. Taking into account the likely considerable portion of the Tonopah Summit Member subtracted to the west and the east as a result of Basin and Range down-faulting and burial beneath sediments, the younger of the two ash flows was probably originally an order of magnitude greater in volume than the King Tonopah Member. The existing outcrops of the Tonopah Summit Member tuff are centered on the Tonopah district, and, Bonham and Garside suggested (1979a, p. 57), upon a caldera (Figure 21, ring TS) not previously reviewed in this manuscript:

> We believe that a remnant of caldera wall related to the eruption of the Tonopah Summit Member of the Fraction Tuff may be preserved at the southern margin of the Southern Klondike Hills, where coarse breccias, which we interpret as debris flows related to caldera collapse, occur in the basal portion of the Tonopah Summit Member and are in fault contact with Paleozoic rocks and the tuffs of Antelope Springs. The northern margin of the proposed caldera would be located along the southern edge of the Tonopah district in the vicinity of Mount Butler and Brougher Mountain. The eastern and western margins of the presumed caldera are concealed beneath the Quaternary alluvium of Ralston and Montezuma Valleys.
>
> The intrusive rocks of the Oddie Rhyolite and the Divide Andesite, the domes and flows of the Brougher Rhyolite, and the intrusive rocks of the Donovan Peak vent complex define a crude arcuate pattern...in the Tonopah and Divide districts, and it is possible that they were emplaced in part along ring fractures related to the extrusion of the Fraction Tuff.

The author agrees with Bonham and Garside in believing that their 'arcuate pattern' probably delineates a caldera, but suggests that it vented only the Tonopah Summit Member of the Fraction Tuff, and that, as stated above, the

King Tonopah Member of the Fraction Tuff was erupted several miles to the north, in the author's field area. If this is the case, and if the two ashflows of the Fraction Tuff are related as the author, Bonham and Garside, and previous workers believe, and the eruption of the two related tuffs from different structures becomes a more complicated matter.

Oddie Rhyolite and Contemporaneous Rhyolites

Within about a million years of the emplacement of the Tonopah Summit Member ash flow, the Oddie Rhyolite was intruded along hypothesized caldera ring fractures and possibly other structures in the author's field area and to the south. At approximately the same time, or a few hundred thousand years thereafter, the Brougher Rhyolite was intruded about the perimeter of the hypothesized caldera described by Bonham and Garside, south of this study's field area.

Regardless of whether or not the rhyolites are genetically related to the magmatism which generated the Fraction Tuff, they utilized the hypothesized ring fractures and give regional topographic expression to the caldera-related features described by Bonham and Garside and this author.

Relation of Igneous Activity to Mineralization

The radiometric dates supplied by Bonham and Garside for the King Tonopah Member of the Fraction Tuff bracket the age date taken from vein adularia of the main camp, indicating that the eruption of the tuff and the mineralization of the district were essentially contemporaneous. Bearing this in mind, a review of Figure 21 will show that the nexus of high-grade silver ore bodies (Figure 21, location 2), associated with the Tonopah Fault zone, is situated at the intersection of ring structures, as delineated by intrusive rhyolite plugs. Perhaps the mineralization was centered upon the intersection of pre-caldera structures, or instead, upon more or less contemporaneous ring fracturing coincident with ash flow eruptions.

It is suggested that the post-Tonopah ore body mineralization event characterized by the formation of massive manganese-calcite veins, discussed at length in Chapter 4, was initiated with the emplacement of the rhyolites during the final stage of silicic magmatism within the Tonopah district.

CHAPTER 7

CONCLUSIONS

General

The final analysis of the Tonopah Property will be divided into two parts: The first will review the findings of the exploration program and make recommendations regarding any possible future investigations, while the second section is concerned with what is known of the geology of the area and how a greater understanding might best be achieved.

Precious Metals Exploration In the Tonopah Property

Structure mapping and geochemical sampling in the Tonopah Property revealed two classes of mineralized faults.

Precious metal veins. The older class, represented by the Halifax Fault (Figure 5), was mineralized by the hydrothermal event which produced the main camp ore deposits and the King Tonopah lode, depositing silver sulfosalts and base metals in a predominently quartz gangue. In the Tonopah Property this mineralization is associated with extensive propylitization and isolated exposures of argillic and potassic alteration proximal to faults. The alteration

is most pervasively developed and almost exclusively restricted to the Mizpah Formation.

Geochemical sampling of the older mineralized fault class revealed no definitive surface anomalies, and in fact elemental concentrations obtained from samples distal to recognized faults indicated that, on the whole, background elemental concentrations were comparable to respective elemental concentrations in fault matter. Diamond drill core from these faults fire-assayed for Ag and Au revealed no precious metal concentrations of interest (Appendix D).

Mn-calcite veins. The second class of mineralized faults displaces, and in one locality (the west side of Mt. Ararat) overprints the older class of faults. The younger mineralization is characterized by massive calcite and Mn oxide, sometimes associated with Fe oxides and/or quartz. Mineralized fault-localized alteration of country rock is absent, in marked contrast to the alteration envelopes associated with the older class of veins.

Geochemical anomalies of Mn, As, Sb, and Hg occurred in a number of these veins, although anomalous precious metal concentrations were typically absent. Since the Mn-calcite veins were not drilled, nothing is known of their sub-surface geochemistry.

Exploration appraisal. The author's mapping of the Tonopah Property led him to conclude that very little

information could be gained beyond a basic understanding of the gross structure and of pervasive alteration patterns. This is so primarily because of the lack of outcrop and the presence of a mixed cover of sheet-washed alluvium over those areas considered of greatest interest.

The geochemical sampling program conducted over the Tonopah Property may have been adequate, in so far as it demostrated a general lack of significant anomalies.

The author would not recommend further moneys be spent on an ore search of the Tonopah Property, given the exploration methods presently available. At the same time, the author acknowledges the likelihood of a sizeable quantity of ore-grade mineralization hidden beneath the surface of the field area, particularly in the vicinity of the King Tonopah Mine, where the mined lode was truncated by faulting. Nonetheless, without having some criteria for targeting, drilling remains a prohibitively expensive exploration method.

For those who would still consider risking capital on an exploration of the field area, the author would make one recommendation: Blanket the northwest sector, and perhaps all of the western half of the field area, with a close-interval geochemical grid surveying the elements that Bonham and Garside (1982) found useful in their regional study. If the results are ambiguous, or no more anomalous

that those obtained by the author in this study, the project should be abandoned.

Geology of the Tonopah Property

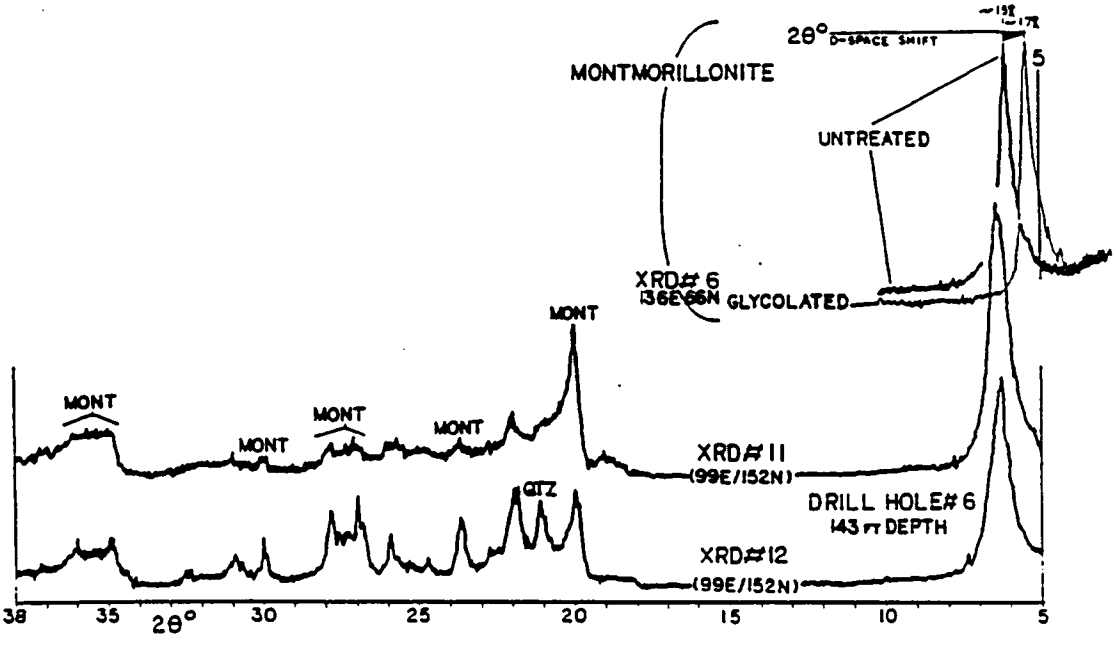
Detailed mapping of the Tonopah Property provided substantial evidence in bedding and contact relationships for re-interpreting the ash flow stratigraphy of the Fraction Tuff. Further, the author suggests that the hills in the northeast sector of the property conceal a/the vent for the eruption of the King Tonopah Member of the Fraction Tuff. Megabreccia within the tuff and the inward dipping basal vitrophyre exposed around the area support the hypothesis of a proximal vent as suggested by Bonham and Garside (1979a) and the author.

The author is of the opinion that further mapping of the field area would reveal little additional information on the geology, and would not settle the questions asked in the previous chapter regarding magma genesis and differentiation. Certain minor outcrops may have been overlooked, but after spending four months scouring approximately three and one half square miles of ground, the author believes that far more useful information could be obtained from an analysis of the trace elements and stable isotopes of the igneous rocks. Such an investigation might resolve some of the major questions put forth in the last chapter, e.g.: how are the igneous rocks of the pile related to one another?;

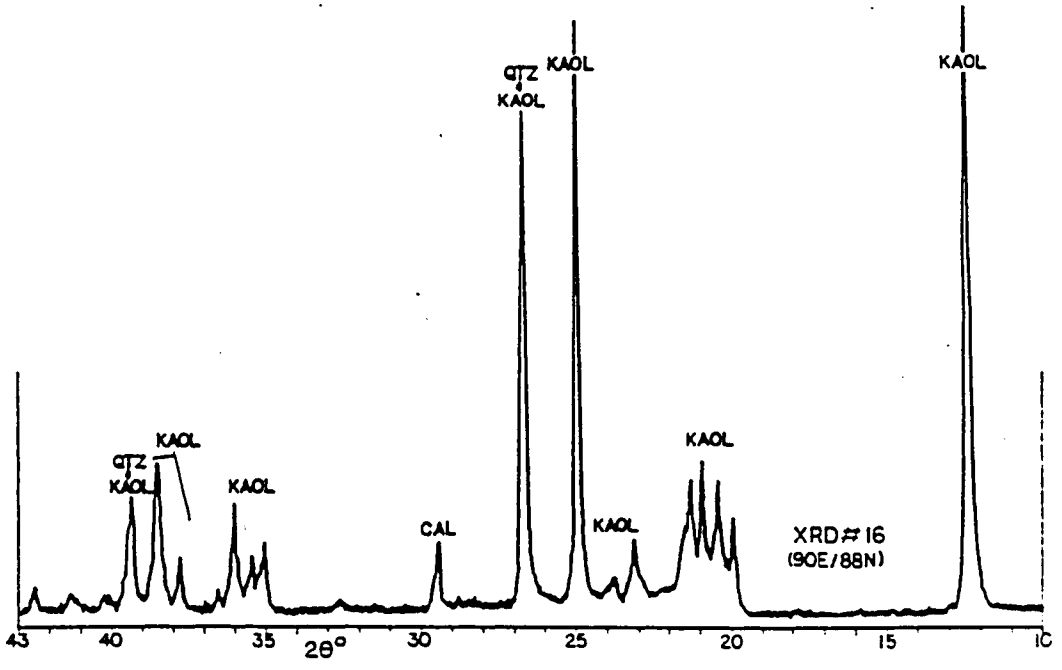
were the King Tonopah Member tuff and the Tonopah Summit Member tuff evolved from the same epizonal magma?; and are the post-ashflow intrusive rhyolites related to the previous silicic magmatism? Answering these questions of petrogenesis would allow for a fairly complete reconstruction of the Tertiary evolution of the Tonopah district.

APPENDIX A

X-RAY DIFFRACTION DATA



Number 1: Montmorillonite peaks from XRD analyses numbers 11 and 12, and montmorillonite peak shift owing to glycolation of XRD analysis number 6.



Number 2: Kaolinite, quartz, and calcite peaks from XRD analysis number 16.

APPENDIX B

SAMPLE GEOCHEMISTRY AND LOCATION DATA

Sample location coordinates refer to the location grid on Figure 23 (Geochemical Sample Map).

Pb, Zn, Ag, Mn, As, Sb, Ba, Mo, W, and Cu concentrations given in ppm; Au, Hg, and Bi concentrations given in ppb.

I. Tonopah Property exploration project data:

Sample: Location	Pb	Zn	Ag	Mn	As	Au	Hg	Sb
52: 80N/136E	6	51	.2	1000	11	<10	60	1.4
53: 92N/97E	26	6	6.8	57	5	<10	50	.6
54: 91N/108E	2	80	.2	1000	3	<10	50	.6
55: 80N/110E	1	16	.1	6800	9	<10	130	.4
56: 134N/116E	1	7	.1	610	11	<10	110	1.2
57: 134N/116E	10	79	.1	1450	620	<10	130	160.0
58: 162N/136E	1	11	.1	3500	25	<10	630	7.0
59: 163N/58E	5	27	.9	1350	50	30	240	7.6
60: 121N/139E	1	3	.1	154	6	<10	50	1.6
61: 98N/80E	1	9	.1	3900	7	10	3100	1.4
62: 128N/86E	1	10	.1	900	7	10	170	.8
63: 134N/118E	1	13	.1	510	3	<10	160	.8
64: 104N/136E	2	78	.1	300	3	<10	130	.4
65: 118N/136N	3	58	.1	9000	17	<10	400	5.0
66: 165N/112E	1	15	.1	138	4	<10	30	.2
67: 156N/119E	27	84	.1	2080	14	<10	130	3.0
68: 159N/110E	1	16	.1	140	4	<10	30	.4
69: 125.5N/135.5E	2	25	.1	312	6	<10	60	1.4
70: 107.5N/73E	2	51	.1	210	5	<10	50	.6
71: 97N/74.5E	1	15	.1	145	6	<10	1200	.4
72: 128N/134E	1	52	.1	530	11	<10	90	1.4
73: 164N/142.5E	1	7	.1	113	7	<10	40	.2
74: 165N/141E	2	26	.1	86	16	<10	40	1.2
75: 127N/76E	2	14	.1	45	4	<10	30	.1
76: 124N/101E	2	19	.1	185	10	<10	70	2.4

I. Tonopah Property Exploration Project Data (continued):

Sample: Location	Pb	Zn	Ag	Mn	As	Au	Hg	Sb
77: 132N/117E	1	3	.1	62	3	<10	20	.2
78: 83N/80E	9	49	.1	475	12	<10	40	.2
79: 83.5N/87.5E	7	41	.1	130	65	10	130	7.6
80: 106.5N/128E	4	34	.1	115	6	<10	100	.8
81: 107N/124E	3	25	.1	75	20	<10	250	1.8
84: 101N/84E	21	22	.1	1200	9	<10	40	4.8
85: 101N/84E	10	37	.1	396	6	<10	60	6.2
86: 124N/76E	4	13	.1	130	3	<10	20	5.2
87: 135N/64E	3	7	.1	730	3	<10	210	9.8
88: 124N/72E	9	21	.1	1600	11	<10	2100	12.0
89: 114N/76E	6	27	.1	560	4	<10	170	2.8
90: 184N/97E	6	71	.1	550	5	<10	100	1.4
91: 125N/80E	7	72	.8	303	12	<10	80	.6
92: 106N/87E	10	65	.8	350	11	<10	70	.6
93: 104N/89.5E	12	83	.1	460	5	<10	30	.4
94: 101N/79E	1	10	.1	830	3	<10	120	.3
95: 116N/96E	2	26	.1	480	7	<10	370	.4
WR01: 98N/101.5E	20	48	1.4	70	9	5	35	2.0
WR02: 133N/115E	6	34	.4	6500	36	20	6250	260.0
WR03: 134N/115E	8	18	.3	550	4	5	210	5.0
WR04: 91N/110E	7	14	.4	990	19	60	520	18.0
WR05: 120N/86.5E	6	10	.8	225	54	190	600	6.0
WR06: 118.5N/87E	15	13	2.2	185	148	70	960	3.0
WR07: 135N/91E	12	28	.8	4500	78	5	1750	105.0

Sample/ Location	Pb	Zn	Ag	Mn	As	Au	Hg	Sb	Ba
164N58E	14	22	1.4	440	73	95	450	2.0	620
153N84E	10	20	.5	140	4	5	70	2.0	400
160N84E	8	13	.4	165	36	5	130	30.0	120
84N148E	17	53	.7	220	24	5	300	8.0	1370
159N76E	13	22	.4	170	3	5	95	2.0	1000
140N78E	11	49	.6	26,000	10	5	1900	42.0	3980
174N32E	15	10	.3	225	5	<5	40	2.0	2170
164N32E	14	18	.4	285	2	5	500	2.0	840

II. Bonham and Garside's (1982) data (divided into two portions, A and B, owing to number of elements analyzed for):

A:

Sample: Location	Pb	Zn	Ag	Mn	As	Au
GC58: 113N/173E	8	6	.02	3970	3.2	n.d.
GC59: 105N/136.5E	10	36	.08	428	1.5	n.d.
GC60: 84N/144E	9	44	.06	1340	1.6	n.d.
GC63: 170N/142E	8	26	.03	314	2.2	n.d.
GC64: 149N/137.5E	10	13	.05	2930	9.2	3
GC81: 130.5N/121.5E	3	47	.15	46,500	305.0	6
GC82: 87N/116E	8	32	.45	2120	32.4	47
GC84: 113N/130.5E				2050		
GC135: 84N/90.5E	3	46	.05	1550	.4	2
GC136: 96N/105.5E	8	22	.07	4030	27.3	3
GC137: 78.5N/134E	10	20	.07	720	.3	2
T85g: 148N/98E	12	19	.3	12,300	25.8	99
T86ga: 100N/101.5E	836	>>1000	758	150	12.4	6080
T86gb: 100N/101.5E	1400	>>1000	40.8	150	16.7	729
T89g: 96N/86E	30	54		750	2.9	
T228g: 138.5N/80E	17	18	.05	244	7.9	n.d.
T229g: 144N/73E	7	35	.16	100,000	39.2	8
T230g: 115.5N/91E	7	43	.07	663	1.5	n.d.
T231g: 182N/190E	13	13	.1	154	9.0	45
T232g: 176N/90E	13	49	.03	158	36.3	3
T233g: 166N/64E	8	5	.12	115	18.1	5
T305g: 90.5N/99E	27	13	1.06	86	4.8	6
T306g: 84N/90.5E	15	2	1.04	35	5.0	65
T307g: 105N/99.5E	12	70	.46	342	1.8	10
T308g: 109.5N/95.5E	13	79	.34	862	1.5	4

B:

Sample:	Hg	Sb	Ba	Mo	W	Cu	Bi
GC58:	260	.02	110	2	1.9	6	47
GC59:	20	.13	1271	1	.4	6	90
GC60:	170	.14	1350	2	0.0	5	42
GC63:	55	1.7	666	1	.4	3	146
GC64:	705	.12	290	2	2.2	3	69
GC81:	7900	18.2	>25,000	16	662.0	33	288
GC82:	320	.07	1440	5	19.0	8	109
GC135:	60	.46	1069	2	.7	12	57
GC136:	285	.05	678	3	6.9	6	154
GC137:	98	n.d.	1156	2	.6	8	43
T85g:	751	.44	1624	2	31.8	11	201
T86ga:	825	160.0	840	18	1.4	181	235

B: Continued:

Sample:	Hg	Sb	Ba	Mo	W	Cu	Bi
T86gb:	488	13.3	0	10	1.3	89	103
T89g:	599	12.0	993	161	.5	19	54
T228g:	115	18.2	591	1	2.0	5	408
T229g:	723	.19	7397	57	20.6	8	291
T230g:	30	.18	1240	2	1.6	8	58
T231g:	105	.65	536	41	0.0	3	196
T232g:	685	47.0	753	5	1.4	11	2000
T233g:	145	.32	273	2	2.4	5	134
T305g:	53	.81	698	<1	0.0	15	434
T306g:	163	1.27	151	<1	.3	12	236
T307g:	<1	.83	651	0	.9		206
T308g:	26	1.08	977	0	0.0	26	69

APPENDIX C

GEOCHEMICAL ANALYSES

Geochemical analyses for the Tonopah Property were conducted by Chemex Labs Ltd., 212 Brooksbank Ave., North Vancouver, B.C., Canada V7J 2C1.

Analytical methods:

Lead, Zinc, Silver, (Manganese) ppm:

1.0 gm sample is digested with perchloric-nitric acid ($HClO_4$-HNO_3) for approximately two hours. The digested sample is cooled and made up to 25 mls with distilled water. The solution is mixed and solids are allowed to settle. Lead, zinc, silver, and manganese are determined by atomic absorption techniques. Silver and lead are corrected for background absorption.

Detection limit: Zinc - 1 ppm
Silver - 0.2 ppm
Lead - 2 ppm

Arsenic ppm:

A 1.0 gm sample is digested with a mixture of perchloric and nitric acid to strong fumes of perchloric acid. The digested solution is diluted to volume and mixed. An aliquot of the digest is acidified, reduced with KI and mixed. A portion of the reduced solution is converted to arsine with $NaBH_4$ and the arsenic content determined using flameless atomic absorption.

Detection limit: 1 ppm

Mercury ppb:

The sample is digested with nitric acid plus a small amount of hydrochloric acid. Following digestion the resulting

clear solution is transferred to a reaction flask connected to a closed system absorption cell. Stannous sulfate is rapidly added to reduce mercury to its elemental state. The mercury is then flushed out of the reaction vessel into the absorption cell where it is measured by cold vapor atomic absorption methods with a Varian Spectrophotometer. The absorbance of samples is compared with the absorbance of freshly-prepared mercury standard solutions carried through the same procedure.

Detection limit: 5 ppb

Gold FA-NAA method:

A 10 gm sample is fused in litharge, carbonate and silicious flux. The resulting lead button containing any gold in the sample is cupelled in a muffle furnace to produce a precious metals bead. Sample beads, plus standard and blank beads are irradiated in a thermal neutron flux. The gamma emissions of the irradiated beads are counted utilizing a Ge (Li) detector and quantified for gold. The detection limit for a 10 gm sample is 1 microgram/kg (ppb).

Gold (Sb) FA-AA method:

The sample fusion and cupulletion is the same as the NAA-finish method.

Beads for AA finish are digested for 1/2 hour in 1 ml HNO_3, then 3 ml HCl are added and digest for 1 hour. The samples are cooled and made to a volume of 10 mls, homogenized and run on the AA against aqueous standards.

Precision and accuracy:

As a general rule precision and accuracy is $\pm$ 10% for results that exceed the detection limit by a factor of 10 or more. For values below 10 times the detection limit the precision and accuracy get progressively worse until it reaches $\pm$ 100% at the detection limit.

APPENDIX D

DIAMOND DRILL HOLE SILVER AND GOLD ASSAYS

Fire assays by Chemex Labs Ltd. (Appendix C).

I. Diamond Drill Hole No. 1
Location: 113.85N/99.65E Azimuth: S65E
Length: 874.5 feet Dip: 60°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au(oz./t.)
90001	417.9 - 419.2	.10	<.003
90002	426.1 - 427.8	.02	"
90003	433.9 - 435.6	.01	"
90004	437.3 - 441.7	1.00	.007
90005	441 - 446.2	1.24	.010
90006	446.2 - 452	.38	.006
90007	455.1 - 456.8	.01	.003
90008	467.7 - 469.4	.06	.004
90009	483.2 - 484.9	.14	.003
90010	485 - 486.7	.06	<.003
90011	491.9 - 493.2	.07	.006
90012	498.4 - 500.1	.16	<.003
90013	502.3 - 504	.14	"
90014	510.5 - 512.2	.02	"
90015	514 - 515.7	.04	"
90016	518.3 - 520	.04	.022
90017	524.8 - 526.5	.01	.008
90018	530.9 - 532.6	.14	<.003
90019	536.1 - 537.8	.02	"
90020	543.4 - 545.1	.04	"
90021	548.2 - 549.9	.05	.010
90022	552.1 - 553.8	.06	<.003
90023	556 - 557.3	.01	"
90024	569.8 - 571.5	.01	"
90025	582.4 - 584.9	.38	.003
90026	593.2 - 594.9	.03	.010
90027	613.1 - 614.8	.01	<.003
90032	641.7 - 643.5	.01	"
90033	656.4 - 658.1	.01	"
90034	685.9 - 687.6	.08	.020
90035	709.3 - 711	.02	.042
90036	723.1 - 724.8	.03	.020
90037	752.6 - 754.3	.01	<.003

II. Diamond Drill Hole No. 2
Location: 84N/148E Azimuth: S65W
Length: 578 feet Dip: 50°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90051	39.8 - 41.4	.08	.003
90052	122.6 - 124.2	.13	.003
90053	137.1 - 138.7	.12	<.003
90054	160.5 - 162.1	.10	"
90055	190.7 - 192.3	.09	"
90056	195.3 - 196.9	.10	"
90057	211.4 - 213	.08	"
90058	237.5 - 239.1	.03	"
90059	253.6 - 255.2	.04	"
90060	265.1 - 266.7	.03	"
90061	273.5 - 275.1	.02	"
90062	288.8 - 290.4	<.01	"
90063	309.5 - 311.1	"	"
90064	323.3 - 324.9	.03	"
90065	360.8 - 362.4	.03	"
90066	377.7 - 379.3	.04	"
90067	387.6 - 389.2	<.01	"
90068	408.3 - 409.9	"	"

III. Diamond Drill Hole No. 3
Location: 85.7N/151.7E Azimuth: S65W
Length: 1046 feet Dip: 55°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90076	49.1 - 50.8	.01	<.003
90077	61.8 - 63.5	.04	"
90078	92.2 - 93.9	.01	"
90079	145.4 - 147.1	.01	"
90080	188.4 - 190.1	.01	"
90081	226.5 - 228.2	.04	.005
90082	271.1 - 272.8	.02	<.003
90083	406.3 - 408	.04	.004
90084	435 - 436.7	.02	<.003
90085	501.3 - 503	.04	"
90086	519.3 - 521	.01	"
90087	543.9 - 545.6	.01	"
90088	565.2 - 566.9	.01	"
90089	584.1 - 585.8	.04	"
90090	604.1 - 605.8	.02	"
90091	619.3 - 620.2	.02	"
90092	652 - 653.7	.01	"
90093	686.4 - 688.1	.02	"

III. Continued:

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90094	710.6 - 712.3	.04	<.003
90095	743 - 744.7	.04	"
90096	755.3 - 757	.04	"

IV. Diamond Drill Hole No. 4
Location: 120N/100E Azimuth: South
Length: 672 feet Dip: 45°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90101	40 - 41.4	.04	<.003
90102	61.5 - 62.9	.03	.008
90103	117.4 - 118.8	.03	.003
90104	128 - 129.4	.06	<.003
90105	192.3 - 193.7	.10	"
90106	233.3 - 234.7	.01	.003
90107	241.1 - 242.5	.08	.040
90108	292.7 - 294.1	.09	.006
90109	304.1 - 305.5	.06	<.003
90110	359.9 - 361.3	.02	"
90111	369.8 - 371.2	.04	"
90112	396.3 - 404.5	.06	"
90113	404.5 - 410.5	.10	"
90114	431.3 - 432.7	.04	"
90115	446.9 - 448.3	.02	"
90116	455.4 - 456.8	.08	"

V. Diamond Drill Hole No. 5
Location: 125N/93E Azimuth: South
Length: 795 feet Dip: 45°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90126	183.1 - 184.5	.12	<.003
90127	216.4 - 217.8	.08	"
90128	261.6 - 263	.08	"
90129	345.8 - 347.2	.01	"
90130	352.1 - 353.5	.08	"
90131	357.8 - 359.2	.02	"
90132	367.7 - 369.1	.04	"
90133	375.5 - 376.9	.10	"
90134	391 - 392.4	<.01	"
90135	403.1 - 404.5	"	"
90136	429.2 - 430.6	"	"

V. Continued:

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90137	441.2 - 442.6	.04	<.003
90138	470.9 - 472.3	.03	"
90139	491.4 - 492.8	.02	"
90140	498.5 - 499.9	<.01	"
90141	533.2 - 534.6	.04	.003

VI. Diamond Drill Hole No. 6
Location: 152N/99E Azimuth: East
Length: 1000 feet Dip: 45°

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90151	23.3 - 24.7	.03	<.003
90152	61.5 - 62.9	.03	"
90153	191.6 - 195	<.01	"
90154	263 - 264.4	"	"
90155	338.7 - 340.1	"	"
90156	371.2 - 372.6	"	"
90157	392.4 - 392.7	.10	"
90158	399.5 - 399.8	<.01	"
90159	410.1 - 410.4	.08	"
90160	434.2 - 435.6	.04	"
90161	473.8 - 478	.01	"
90162	486.5 - 489.3	.01	"
90163	495 - 497.1	.02	"
90164	502.8 - 505.6	.01	"
90165	519.7 - 522.6	.08	.012
90166	526.8 - 528.7	.02	<.003
90167	531.7 - 534.6	.01	"
90168	540.9 - 543.1	.02	.024
90169	546.6 - 549.4	.03	.010
90170	553 - 555.8	.04	<.003
90171	561.4 - 562.8	.04	"
90172	567.1 - 569.9	.04	"
90173	574.1 - 577	.01	"
90174	581.2 - 584.1	.08	"
90175	588.3 - 591.1	.01	"
90176	596.1 - 598.2	.01	"
90177	602.5 - 604.6	.01	"
90178	608.1 - 610.9	.01	"
90179	615.2 - 617.3	.08	"
90180	621.5 - 623.7	.12	"
90181	627.2 - 630	.18	"
90182	633.6 - 636.4	.01	"
90183	641.3 - 643.5	.28	"
90184	647 - 650.5	.01	"

VI. Continued:

Sample No.	Interval (vertical ft.)	Ag (oz./t.)	Au (oz./t.)
90185	654.1 - 657.6	.01	<.003
90186	667.5 - 671	.01	"
90187	685.2 - 688	.01	"

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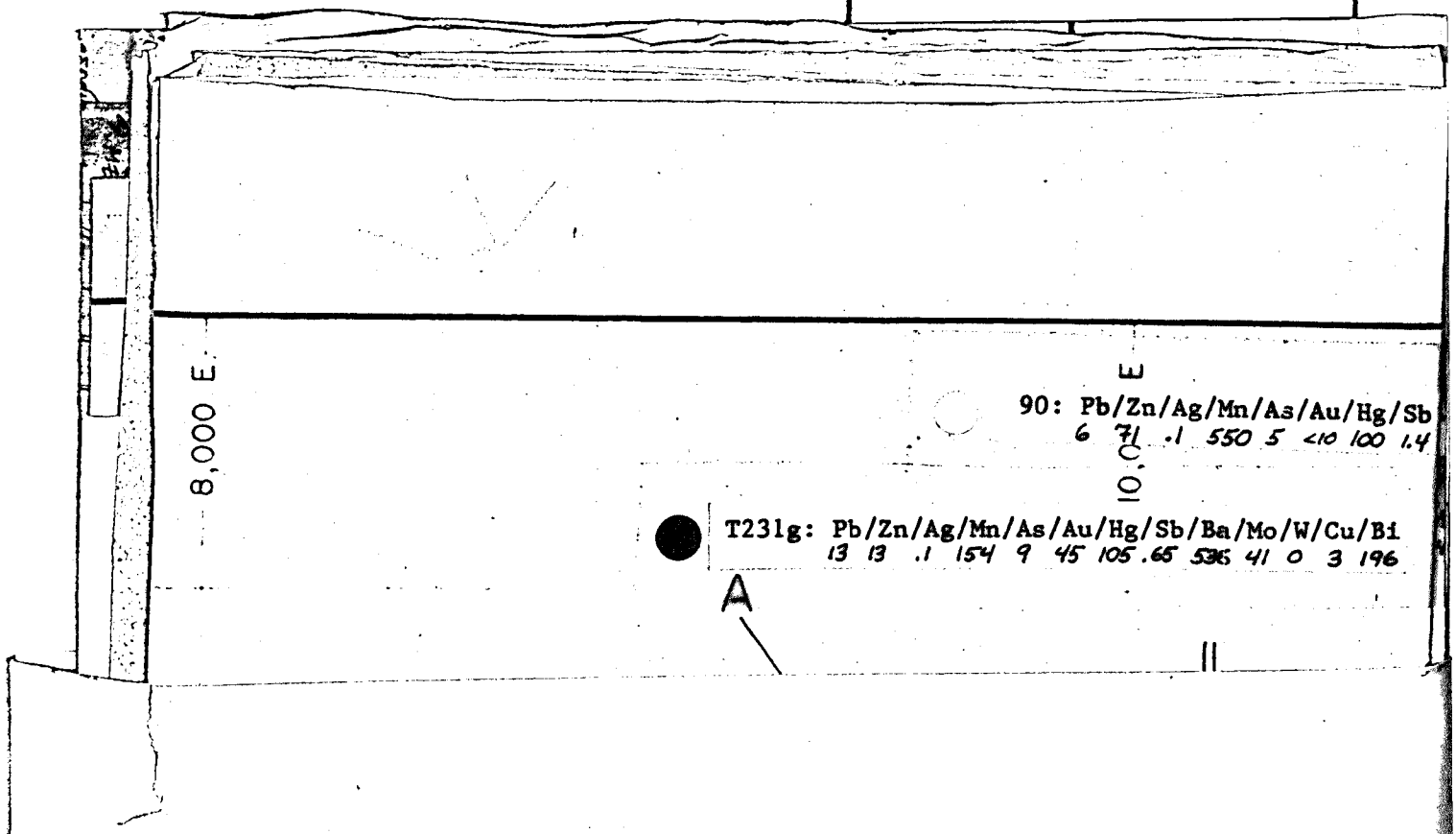

EXPLANATION

Quaternary
- Qal — Quaternary Alluvium

Tertiary (Miocene)
- Tf — Tertiary (?) Alluvial gravels
- Or — Oddie Rhyolite: predominately intrusive + other rhyolites
- S — Seibert Formation: tuffaceous sedimentary rocks
- TS — Tonopah Summit Member: ash-flow. Fraction Tuff
- KT — King Tonopah Member: ash-flow. KTg = KT gray, black vitrophyre (blk vit); KTb = KT brown, basal KT
- Mz — Miepah Formation: trachyandesite-dacite propylitic & altered Mz

outcrop · float overlying presumed outcrop · float
vein · fault · possible fault
bedding (based on pumice flattening (KT)) · shafts · adits
pit · dump & tailings · drill hole
fracture

bx: breccia	rhyo: rhyolite
qtz: quartz	vn: vein
pr: propylitic	arg: argillic
chalc: chalcedonic	silic: silicic
mod: moderately	blk: black
brn: brown	grn: green
py: pyrite	cc: calcite
mt: magnetite	hm: hematite

INTERPRETATIVE CROSS SECTIONS

Map Scale: 1:4800

No Vertical Exaggeration

Figure 22: 1:4800 scale geology map of Tonopah Property with cross-sections.

TONOPAH PROPERTY, TONOPAH, NEVADA

MAPPED BY WALTER B. BARKER
With help from Julia Brown and C. J. Westerman
Map grid provided by SILVER STRIKE RESOURCES LTD.

WALTER B. BARKER MASTER of SCIENCE
DEPARTMENT of GEOSCIENCES
UNIVERSITY of ARIZONA, 1986

Scale: 1:4800

Figure 23: 1:4800 scale geochemistry sample location map.