

Interpretation of the Regional Geochemistry
of the Tonopah $1^{\circ} \times 2^{\circ}$ Quadrangle, Nevada,
Based on Analytical Results from
Stream-Sediment and Nonmagnetic
Heavy-Mineral-Concentrate Samples

U.S. GEOLOGICAL SURVEY BULLETIN 1849



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By J. THOMAS NASH

Regional patterns in geochemical results from stream-sediment samples are described and interpreted in the context of geochemistry of mineralized rock samples, geology, and distribution of known deposits

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PLATE

[Plate is in pocket]

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 - B. Skarn-suite anomalies
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CONVERSION FACTORS

For readers who wish to convert measurements from the metric system of units to U.S. customary units, the conversion factors are listed below.

Metric unit	Multiply by	To obtain U.S. customary unit
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
kilogram (kg)	2.205	pound

Interpretation of the Regional Geochemistry of the Tonopah 1° x 2° Quadrangle, Nevada, Based on Analytical Results from Stream-Sediment and Nonmagnetic Heavy-Mineral-Concentrate Samples

By J. Thomas Nash

Abstract

Results of more than 2,400 analyses of the <0.25-millimeter fraction of stream sediments and nonmagnetic heavy-mineral concentrates from stream sediments from 1,217 sites in the Tonopah 1°x2° quadrangle demonstrate the existence of anomalous concentrations of many metals of economic interest in many areas. Single-element anomalies of As, Pb, or Sb in stream sediment provide general guides to possible mineralization, but multielement suites are more reliable for characterization of types of mineralization. Various combinations of Ag, As, Bi, Cu, Mo, Pb, Sb, and W in stream sediments and concentrates provide guides to five general types of deposits and their geologic environments. Multielement suites that recur in stream-sediment media resemble those observed in mineralized rock samples, and the distribution of the suites corresponds to the distribution of known types of deposits and to the general geology of the region.

Multielement geochemical anomalies are prominent in the Pilot Mountains, Monte Cristo Range, Paradise Range, Lone Mountain, northeastern Toiyabe Range, Cedar Mountains, and Toquima Range. The strongest multielement anomalies are associated with plutonic rocks in the western part of the quadrangle. Two base-metal suites are enriched in and around plutons: (1) Bi + W + Pb + Mo ± As, Cu, Sb, a suite that resembles base-metal enrichments in skarn deposits; and (2) Pb + Mo ± As, Cu, Sb, a suite that resembles base-metal enrichments in sulfide vein and replacement deposits, which are generally associated with intrusions. A third variety of base-metal enrichment that contains Ag and Pb is distinguished for its possible economic importance. This Ag-Pb-rich suite, which occurs both near plutons and in volcanic terrane, generally is near areas of known Ag-rich polymetallic deposits.

Many sites are characterized by modest enrichments of two to five elements in the suite As-Mo-Sb-Zn-Ag that resemble enrichments in epithermal ore deposits. Many anomalies of this type are from drainages underlain by Tertiary welded tuff, which commonly lacks alteration and mineral prospects. Some of these anomalous sites correlate with areas of known epithermal deposits or siliceous alteration of calcareous rocks; thus this suite may be a guide to precious-metal deposits if there is supporting geologic evidence.

The results from regional sampling of stream sediments, which utilized the <0.25-millimeter fraction and nonmagnetic-heavy-mineral-concentrate media, effectively outline most areas of known deposits or alteration in the Tonopah 1° x 2° quadrangle. Some clusters of anomalies that are larger than the area of known mineral prospects suggest that other deposits remain to be discovered. This regional geochemical information is most effective for exploration and resource analysis when integrated with other geologic information, especially data on rock alteration.

INTRODUCTION

Anomalous concentrations of elements of economic interest for exploration and resource assessment are widespread in the Tonopah 1° x 2° quadrangle. Elements known to be enriched in ores and altered rocks are readily detected in chemical analyses of the minus-60-mesh (<0.25-mm) fraction of stream sediments (hereafter usually termed "stream-sediment" or "sediment") or in the nonmagnetic-heavy-mineral fraction of stream sediments (hereafter termed "concentrate"); thus these media provide significant information for use in resource assessment. Interpretations of regional geochemistry made in this report are supported by information gained from companion studies of the geochemistry of mineralized

rock samples. These results and interpretations are an important step toward resource assessment.

This study is a part of geologic, geochemical, and geophysical studies of the Tonopah 1° × 2° quadrangle for the Conterminous United States Mineral Assessment Program (CUSMAP). A folio of maps, including geochemical maps (Nash and Siems, 1988), is in preparation. Analytical results reported by Fairfield and others (1985), Siems and others (1986), and Hill and others (1986) are the bases for this report. The geochemical studies were designed to aid in the resource assessment of the quadrangle through chemical characterization of known mines, prospects, and altered areas (utilizing samples of rock), as well as the description of regional geochemistry through the analysis of stream sediments. Interpretations presented here support the resource assessment made by the CUSMAP team but do not constitute an assessment because essential geologic and geophysical information is not included.

The Tonopah quadrangle has been prospected since about 1850, and many deposits have been discovered and mined. Some of the more important mines and prospects in the quadrangle are shown on figure 1. A goal of the geochemical studies in the quadrangle has been the development of geochemical methods and interpretations that are capable of recognizing the ore environments that are known in this well-prospected and geologically well exposed area. If mineralized areas can be identified and their character established, then the geologic, grade, and tonnage attributes of that type of deposit (Cox and Singer, 1986) can be utilized in exploration strategies and in resource analysis. Although every specific type of ore deposit may not be distinguishable with this interpretation of regional geochemistry, several general categories can be distinguished that are useful in identifying not only geochemical anomalies but geologic associations.

ACKNOWLEDGMENTS

Many people contributed to this geochemical study. Dave Siems coordinated the analytical work and provided thousands of reliable analyses. Randy Hill, Steve Zuker, and Jim Saunders designed and coordinated the sampling program. M.L. Marchitti coordinated the data entry for the Rock Analysis Storage System. I thank Gerry Brem, Dick Hardyman, David John, Frank Kleinhampl, Bill Keith, Dan Shawe, Jack Stewart, and Don Whitebread for their helpful advice on geology. Maurice Chaffee and Bill Miller provided thorough reviews of the manuscript. I thank these and

other people for their help; errors of omission or interpretation that remain are my responsibility.

METHODS OF STUDY

Sampling and Chemical Analysis

Samples of alluvium were collected at 1,217 localities, generally on first-order (unbranched) or second-order streams. Sites were preselected using 1:24,000- and 1:62,500-scale topographic maps to achieve a sample density of about one site per 12 km² (5 mi²) of exposed bedrock and to avoid obvious contamination from mines and dumps. Most sites were within 300 m of exposed bedrock. The sample collected was a composite of several sites or channels within a radius of about 10 m. At the site the alluvium was screened through a 2.0-mm screen and split into two portions. One part was placed in a bag for further processing as a <0.25-mm sediment sample, and the other part of about 10 kg was placed in a separate bag for processing of heavy-mineral concentrate. Because most streams were dry at the time of sampling, the concentrate sample was panned later.

The laboratory methods used to prepare the sediment and concentrate were described by Fairfield and others (1985) and by Siems and others (1986). This report is based on analytical results reported previously by Fairfield and others (1985) and Hill and others (1986) for stream-sediment samples and by Siems and others (1986) for nonmagnetic heavy-mineral-concentrate samples. All samples were analyzed for 31 elements by a semiquantitative emission spectrographic method, and stream-sediment samples were also analyzed by atomic absorption spectrometric methods for lower level concentrations of As, Bi, Cd, Sb, and Zn; these methods are explained in the reports cited above. Mineralized rock samples were analyzed by the same methods that were used for the stream sediments.

Data Processing

Analytical results for this project were entered into a computer database called RASS (Rock Analysis Storage System) that contains the analytical data as well as descriptive information for each sample. The RASS data were retrieved and converted to a different binary format for manipulation using the routines of the STATPAC system (VanTrump and Miesch, 1977). A large amount of computing was done of the Tonopah database; whether the results were considered to be reliable or unreliable, it will not be discussed much here.

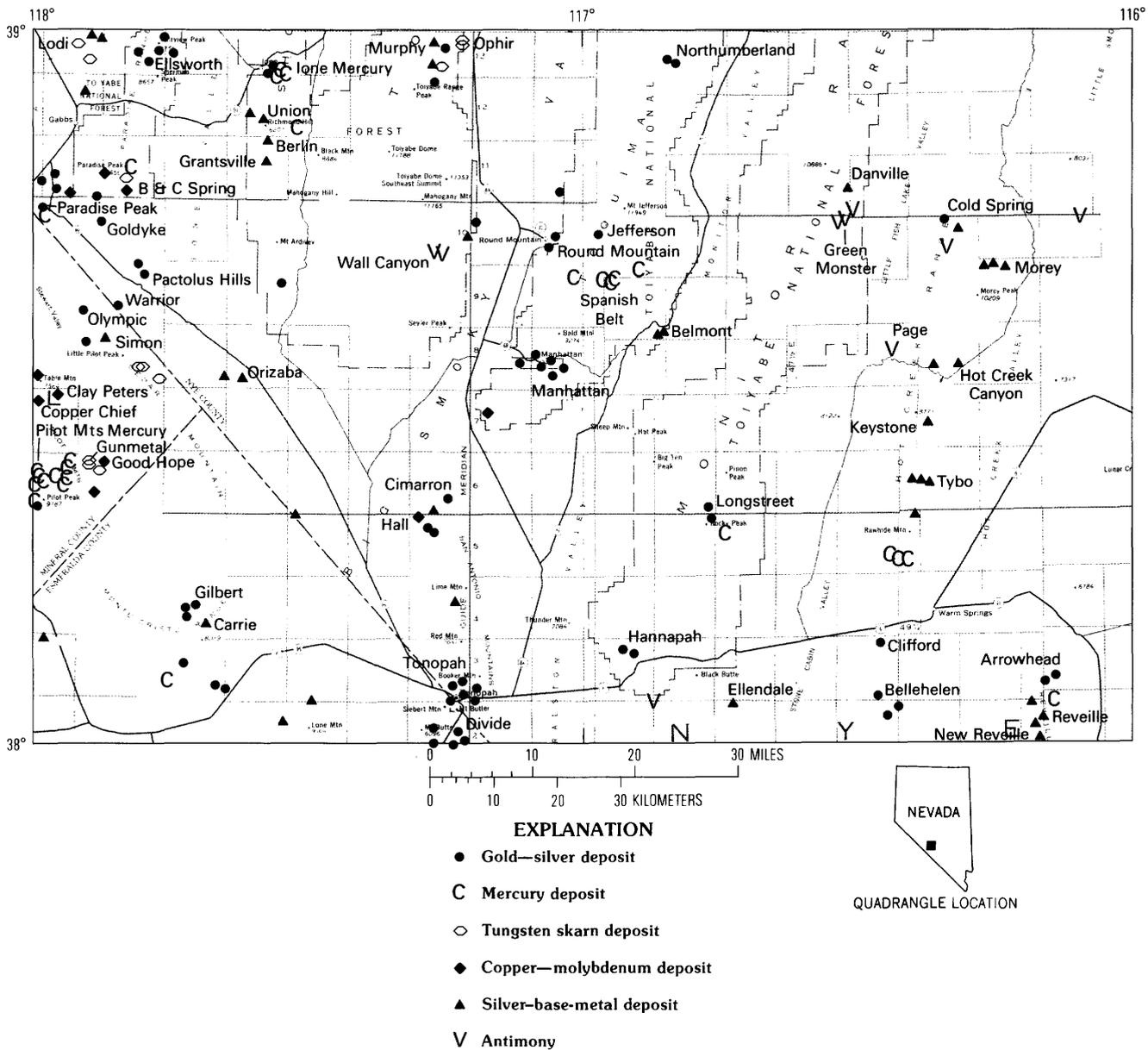


Figure 1. Location of major mines and prospects in the Tonopah 1° x 2° quadrangle. Symbols represent six different types of deposits known in the area.

Although I utilized a minicomputer extensively to handle and manipulate the data because of its size and complexity, efforts were made at all stages to use human judgment in the evaluation of computer results. An early stage of data analysis involved the computation of simple statistics, including histograms and percentiles, to evaluate the character of analytical results. The data produced by emission spectroscopy is clearly non-continuous, and for these samples, much is censored at low concentrations in cases where sample concentrations fell below the lower limit of detection (less than or not detected values reported); information for some

elements is censored at high concentrations where the upper limit of detection was exceeded (greater than values reported). Results for many elements of interest, such as Ag, Bi, Mo, and W, are highly censored and also non-normal in distribution. Attempts were made to compensate for these problems by substituting rough approximations of values for the qualified results: (1) values of N (not detected) were assigned a value that was three spectrographic steps below the limit of detection, (2) values of L (less than) were assigned a value that was one spectrographic step below the limit of detection, and (3) values of G (greater than) were assigned a value that

was one step above the upper limit of detection. The nature of steps in the emission spectrography technique and their precision are explained elsewhere (Grimes and Marranzino, 1968; Motooka and Grimes, 1976). The technique of replacing qualified values helps compensate for the noncontinuous character of the spectroscopic results, and the use of logarithmic transformations of results minimizes the effects of samples with unusually high (non-normally distributed) concentrations.

Geochemical anomalies in this report are described in relation to concentration levels defined in table 1. In this study I investigated both histograms and percentiles to define anomalies relative to background and found that the two methods produce similar results. For most elements the anomaly threshold was set at the 75th percentile, although for some elements with chiefly qualified results, the threshold had to be set higher than the 75th percentile. To provide emphasis, "highly anomalous" concentrations are defined as the 95th percentile (or the spectrographic step closest to it). Only one set of anomaly concentrations was defined for application throughout the Tonopah quadrangle. Although it is known that all rock units should not have the same background concentrations of elements, there was no way to compute different background levels according to stratigraphic or lithologic units when the computations were made in 1986. New information computed from the geology of sediment basins (Dwyer and Nash, 1987) permits refinement of geochemical backgrounds according to stratigraphic unit but, for most elements, does not change the definition of anomalies.

Multivariate statistical techniques have been utilized to search for simplifying relations between variables (elements) or between samples. The methods used, chiefly correlation, factor, and discriminant function analysis, were described by Davis (1986). Test applications of these methods to mineralized rock samples of known source in the Tonopah quadrangle have been described by Nash, Siems, and Budge (1985d) and Nash, Siems, and Hill (1985). In this study of stream-sediment samples and concentrates of relatively unconstrained source, I have used statistics for qualitative screening of results to identify elements, multielement suites, and sample localities deserving of further attention. Geochemical and geologic relations emphasized in this report have been confirmed by multiple methods of computing and by inspection of results and maps. To avoid repetition, those multiple inquiries are not elaborated in most discussions of area geochemistry.

To achieve the goal of resource assessment of areas, it is necessary to extrapolate from samples and sites to areas. For stream sediments the unit area is that of a drainage basin, which is underlain by several rock types in most cases. The basin and its geology are

represented by two samples taken at the same site. Efforts were made to ensure that the site was a good representation of the basin rather than of some local geologic feature or man-made contaminant. In this report the focus is on sites and information conveyed about areas upstream. To this end I utilize an unconventional database that is a composite of results for both sediments and concentrates. In this composite database the common entity is the site; data is included for two samples at the site. For simplicity my discussions commonly refer to the geochemistry of sites rather than the geochemistry of samples at certain sites. The ultimate objective is to discuss geochemistry and geology in terms of areas rather than of sample sites displaced from geologic areas. Advanced computing methods that simultaneously handle maps of geology and stream-sediment basins, as well as area or linear data from geophysics and remote sensing, are effective for the spatial analysis of regional geochemistry (Dwyer and others, 1987).

GEOLOGIC SETTING

The Tonopah 1° × 2° quadrangle is within the Basin and Range physiographic province, which is a region that is characterized by generally north trending, uplifted mountain ranges separated by broad valleys. The ranges with abundant rock exposure constitute roughly 50 percent of the quadrangle. Rocks range in age from latest Precambrian (Late Proterozoic) to Quaternary (Albers and Stewart, 1972; Kleinhampl and Ziony, 1985). An abundance of low- and high-angle faults combine to juxtapose rocks of many ages and lithologies in all the ranges, and multiple rock types occur within most of the drainage basins sampled in this study. Late Proterozoic and Paleozoic rocks are widespread; these units tend to be chiefly platform (miogeoclinal) carbonate rocks in the eastern part of the quadrangle and dark cherts and shales of eugeoclinal affinity in the western part. Mesozoic sedimentary and volcanic rocks are abundant only in the northwestern part of the quadrangle. Triassic to Cretaceous plutonic rocks are exposed in the central and western ranges. Tertiary ash-flow tuffs, flows, intrusions, and volcanoclastic rocks are present in all the ranges and compose the majority of rocks exposed in the eastern part of the quadrangle. Tertiary caldron complexes are found in most ranges. Quaternary basalt is present in the eastern ranges. Major orogenies in the late Paleozoic and Mesozoic produced folds and faults, whereas Cenozoic structures are chiefly normal and strike-slip faults,

Table 1. Definitions of regional geochemical anomalies in the Tonopah 1° x 2° quadrangle

[All values in parts per million. (S), determined by emission spectrography; (AA), determined by atomic absorption spectrometry; N, not detected at concentration shown; L, detected but less than value shown; G, greater than value shown; **, too few determinations, not utilized]

<0.25-mm stream sediment					
Element	Minimum	Maximum	Geometric mean	Anomalous	Highly anomalous
Ag (S)	0.5N	150	0.20	0.5L	1.0
As (AA)	5L	500	5.6	15.0	50.0
Ba (S)	20	10,000G	1025.0	5000.0	10,000.0
Bi (AA)	1N	15	0.34	0.5	1.0
Cu (S)	5N	150	12.0	30.0	50.0
Mo (S)	5N	200	2.1	100.0	500.0
Pb (S)	10L	10,000	32.0	50.0	100.0
Sb (AA)	2N	150	1.3	3.0	5.0
Sn (S)	10N	100	**	**	**
W (S)	50	700	**	**	**
Zn (AA)	5	2000	57.0	70.0	135.0
Nonmagnetic heavy-mineral concentrate					
Element	Minimum	Maximum	Geometric mean	Anomalous	Highly anomalous
Ag (S)	1N	30,000	0.49	0.5L	15
As (S)	500N	5000	260	200	300
Ba (S)	20	3380	10,000G	5000	10,000G
Bi (S)	5N	2000G	9.7	10L	20
Cu (S)	10N	3000	5.7	10	7
Mo (S)	10N	5000G	4.1	5L	30
Pb (S)	20L	50,000G	36	150	2000
Sb (S)	200N	10,000G	93	200L	500
Sn (S)	20	2000G	8.4	20	200
W (S)	100N	20,000G	47	100L	500
Zn (S)	500N	5000	178	500L	700

although low-angle detachment faults of late Tertiary age occur in the northwestern part of the Tonopah quadrangle.

Mineral deposits of many ages and types are known in the Tonopah quadrangle (Kral, 1951; Kleinhampl and Ziony, 1984). Important amounts of silver, gold,

molybdenum, mercury, tungsten, and lead have been mined, as well as minor amounts of copper, antimony, and arsenic. Among the nonmetallic ores, magnesite and barite have been mined in significant amounts. Additional information on mineral deposits is included in later discussions of areas.

GEOCHEMICAL CHARACTER OF MINERAL DEPOSITS

The geochemistry of known deposits in the Tonopah 1° × 2° quadrangle serves as a guide to elements and geochemical suites that are anticipated to occur in the regional stream-sediment chemistry. The quadrangle is well endowed with a variety of mineral deposits. Mines with small to major production are numerous in most parts of the quadrangle (fig. 1). Most of the mines or districts were examined and sampled from 1981 to 1983 to determine their geochemical signatures. Rock samples were collected from mine workings, dumps, prospect pits, drill core, and visibly altered outcrops and analyzed by the same analytical methods as used for the stream-sediment samples. Results of those studies are described in a series of reports (Nash, Siems, and Budge, 1985a, b, c, d; Nash, Siems, and Hill, 1985) and provide a framework for the interpretation of geochemical results from stream-sediment and concentrate samples.

A fundamental conclusion from my study of the chemical analyses of more than 2,000 mineralized rock samples is that there are no simple chemical distinctions between the many ore types because element concentrations generally have overlapping ranges. Multi-element suites provide a means of characterizing types of deposits but are ambiguous because of the overlapping concentration ranges. Statistical tests such as discriminant function analysis (Davis, 1986) can be used to test for significant differences between groups of analyses, providing there are an adequate number of samples and a priori basis for classifying samples into groups. Regardless of abundant chemical data and statistical tests, geologic parameters generally are required to properly characterize a geochemical anomaly or prospect.

In my studies of the geochemistry of mineralized rocks and in the present regional geochemical studies, elements that are part of the ore suite or an outer halo (the so-called "pathfinder elements") have been given emphasis because they are relatively well known by observation or theory. The elements Ag, As, Au, Ba, Bi, Cu, Mo, Pb, Sb, Sn, W, and Zn have been given the most attention. Other potential ore metals, such as Be, Co, Cr, and Ni, are given less attention because they are not expected in the known rocks of the region or have not been found in significant amounts during past prospecting. Many elements determined in the chemical analyses, such as Zr, Nb, Sc, and rare earth elements, will not be discussed because they occur chiefly in rock-forming minerals and their distribution in and around ore deposits is not well known.

The range in composition of mineralized rock samples from the Tonopah quadrangle can be described

simply in terms of two end members or chemical extremes. One extreme is a suite that contains many elements with generally high concentrations relative to background; the other extreme is a suite that contains few elements, commonly with low concentrations only slightly above background. The first extreme is a broad suite of base and chalcophile elements that includes As, Bi, Cu, Mo, Pb, Sb, W, and Zn, and commonly Ag, Au, and Sn. This group is most concentrated in mineral deposits in or near plutons but can also be developed in veins in many geologic settings. When weathered these deposits can become highly visible outcrops with abundant iron oxides if there was abundant sulfide. The other extreme is characterized by mild enrichments in base metals, the most notable generally being Sb, Zn, Mo, Hg, or Tl; the latter two elements were not determined for the stream-sediment samples and thus cannot be used in this regional assessment. This type of mineralization, which I call "epithermal" for lack of a better alternative, often is barely evident in the field other than for some silicification, argillization, or bleaching, and generally has low sulfide content (thus very little iron oxide is created on weathering). One variant of this epithermal end member is low-sulfide hot-spring-type Au deposits (Berger and Eimon, 1983). In a regional resource study of an area with many deposit types, such as the Tonopah quadrangle, recognition of epithermal systems with low sulfide relative to polymetallic base-metal sulfide systems can be difficult unless attention is given to the geologic characteristics of the former (Nash, Siems, and Hill, 1985).

The geochemical spectrum observed in mineralized-rock samples is also evident in stream-sediment and concentrate samples. The geochemical contrasts are less spectacular in the stream-sediment media because of many factors in the source region such as dilution by unaltered rocks, mixing of rock and mineral-deposit types, and weathering. As for the geochemistry of mineralized rocks, polymetallic base-metal suites, which are commonly from plutonic environments, tend to be present at high concentrations and overwhelm or obscure the more subtle signatures from epithermal systems.

Despite problems of overlapping ranges of composition, mineral deposits of the Tonopah quadrangle can be roughly classified by their chemical character (table 2). Examples of this approach and the use of multivariate statistics for classification have been discussed by Nash, Siems, and Budge, (1985d) and Nash, Siems, and Hill (1985). This empirical, nongenetic classification is based on suites of ore elements in mineralized rock samples but is similar to mineralogical classifications. A classification based on proportions of ore metals, such as Ag, Au, and Pb, was used by Ferguson (1929) and Nolan (1933) who defined two

Table 2. Generalized chemical classification of mineral deposits in the Tonopah 1° x 2° quadrangle

[Compositions identified chiefly from analyses of mineralized-rock samples, but trends also evident in stream-sediment and concentrate samples]

Type	Diagnostic elements	Associated elements	Deposit examples	Comments
1. Skarn	Bi, W	Cu, Mo, Pb, As.	Gunmetal, Ophir, and Cedar Chest.	Very strong multielement signature.
2. Base metal	Cu, Mo, Pb	Zn, As, Sb, Hg(?).	B&C Spring, Hall Moly, Clay Peters, and mercury deposits ¹ .	Strong multi- element signa- ture is varia- ble; defined as lacking Bi-W.
3. Base-precious metal.	Ag, Pb	Cu, As, Sb, Zn.	Belmont, Tybo, Simon, Mur- phy, and Reveille.	Generally very strong multi- element signa- ture that grades into types 1 and 2.
4. Epithermal	As, Sb	Mo, Zn, Ag, Au, Tl.	Titus, Green Monster, Cold Spring, Warrior, and Round Moun- tain.	Some deposits have high con- centrations of a few elements; many have low concentrations; defined as lacking high Pb and Cu.

¹Mercury deposits of Pilot Mountains, Ione, and Spanish Belt tend to have high concentrations of several base metals; compositions are closer to type 2 than type 1.

classes of precious-metal deposits: gold-silver (ores having more Au than Ag on a weight basis) and silver-gold (more Ag than Au). Ferguson (1929) also had classes for silver-lead, lead-silver, lead-zinc, and copper deposits. The four classes used in this report (table 2) are: (1) skarn type, suggested by the presence of high concentrations of Bi, W, Mo, Pb and other base metals typically found in ores and alteration zones associated with metamorphic and hydrothermal processes at the margins of plutons; (2) base-metal type, characterized by

high concentrations of Pb, Zn, Mo, Cu, or other base metals—but here defined to exclude deposits with Bi and W; (3) base- and precious-metal type, similar to type 2 but also having significant Ag as in the numerous poly-metallic deposits of the Tonopah quadrangle that have been economically important for their content of Ag; and (4) epithermal type, characterized by enrichments in As, Sb, Mo, Zn, Ag, or Au but lacking enrichment in other, base metals. Nonmetallic deposits, such as those of barium or fluorine, are not considered in this report.

GEOCHEMISTRY OF INDIVIDUAL ELEMENTS IN STREAM SEDIMENTS

Most elements in stream sediments and concentrates from the Tonopah 1°×2° quadrangle behave in predictable ways. An understanding of tendencies for elements to occur in association with certain elements or geologic settings is important for proper interpretation of geochemical results.

Silver

Silver is an important constituent in many types of ore at widespread localities in the Tonopah quadrangle and is effectively detected in both stream-sediment media. Silver was detected in 226 stream-sediment samples (18 percent) using emission spectroscopy for which the limit of detection is 0.5 ppm (parts per million) and in 223 concentrate samples for which the limit of detection is 1 ppm. Any sample with detectable amounts of Ag is considered to be anomalous, and samples of stream sediment that contain 1.0 ppm Ag or more, or concentrate with 15 ppm or more, are considered to be highly anomalous. Results for Ag in both media are useful and commonly are proportional, unlike some elements for which one media is clearly superior.

Silver anomalies in the Tonopah quadrangle occur in a variety of geologic environments from epithermal systems to high-temperature skarns near plutons, as interpreted from mineralized rock samples (Nash, Siems, and Budge, 1985d; Nash, Siems, and Hill, 1985), sediments, and concentrates. Silver in the quadrangle is associated with different metal suites but most commonly with Pb and Sb and, to a lesser extent, with Cu, Mo, or Zn. This generalization is based on statistical analyses of various subsets of regional and rock geochemical data and confirmed by inspection of tabulated results.

Arsenic

Arsenic is one of the most useful geochemical indicators of mineral deposits determined in this study. Analytical results for As in sediments are useful if the method is sensitive to about 1 ppm, as produced by the atomic absorption method used in this study. Arsenic was detected in only 6 percent of the concentrate samples, which may reflect the combined effects of the high limit of determination (500 ppm), weak dispersion of As-rich grains in alluvium (possibly caused by high solubility), or complications from a "nugget effect" of As in the form of arsenopyrite (M. Chaffee, written commun., 1987). In this study, As in concentrates reflects only the highly

anomalous sites, but As determined in sediments reflects a broader scale of source concentrations that are more easily interpreted. Stream-sediment samples are less likely to miss areas with anomalous As.

Arsenic is enriched in many types of deposits in the Tonopah 1°×2° quadrangle (for example, Nash, Siems, and Budge, 1985b, d; Nash, Siems, and Hill, 1985) and is not easily categorized. Analyses of mineralized rock samples in the quadrangle indicate that some gold deposits are characterized by As > Sb, and As is generally considered to be a guide to gold deposits (for example, Boyle, 1979). However, As is enriched in many base-metal deposits as well as precious-metal deposits of the quadrangle, thus I cannot recommend As as a guide to a specific type or environment of ore. Rather, As seems to be a useful general guide to alteration and mineral deposits. Mineral systems in sedimentary, as opposed to volcanic, rocks seem richest in As. Some of the highest concentrations of As in sediments are found in samples from the Toquima Range and Monte Cristo Range, both of which contain substantial amounts of dark pelitic rocks of marine origin that are a possible source of As.

Arsenic determinations on samples collected during the NURE (National Uranium Resource Evaluation) hydrogeochemical survey of the Tonopah 1°×2° quadrangle (Qualheim, 1979) are the most generally useful results from that survey. In that study As was determined by instrumental neutron activation analysis and the results seem to be reliable. The distribution of As based on results of the NURE study is very similar to that indicated by our study (Nash and Siems, 1988).

Gold

The sampling and analytical methods used in this study were not tailored to meet the needs of reliably detecting Au. The well-known problems of sampling Au in the field and of handling it in the laboratory that are caused by the density and particulate nature of gold require special methods that were deemed too costly for this regional study. Gold was detected in 20 concentrate samples; most of these determinations probably could not be reproduced by replicate analyses or sampling, thus no great significance is given to those sites having detectable Au. As expected, no samples of sediment contained detectable amounts of Au by our emission spectroscopy method for which the limit of detection is 10 ppm. Analyses of <0.25-mm sediment samples by a method sensitive to about 10 parts per billion probably would have been very useful for describing gold geochemistry and assessment of epithermal mineral resources (W.R. Miller, written commun., 1987).

Indirect geochemical guides or pathfinder elements among the geochemical results from this study must be utilized to evaluate areas for Au.

Barium

Barium is a constituent in some metallic ore and associated alteration assemblages in the Tonopah quadrangle and elsewhere, as well as in bedded barite at many localities in the quadrangle. Barium in sediment samples is probably chiefly in clay minerals and feldspars, whereas in concentrates it is in the form of barite (BaSO_4). Very high Ba concentrations ($>10,000$ ppm) are widespread in concentrate samples across the quadrangle (Nash and Siems, 1988), especially in areas underlain chiefly by Tertiary volcanic rocks. The distribution of Ba in concentrates does not correlate with the known occurrences of bedded barite or the rare mineral deposits that might contain barite; it is so ubiquitous that it may indicate an alteration process of regional extent. Barium in sediments and concentrates from the quadrangle cannot be related spatially to known deposits and is not known to be abundant in any important ore type in the quadrangle; thus Ba is not deemed to be diagnostic of ore-forming processes in the area and is not included in geochemical suites.

Bismuth

Bismuth is one of the most useful and diagnostic elements in this geochemical survey. Results for both mineralized rocks and concentrates indicate that Bi is enriched in two environments in the Tonopah quadrangle: (1) plutons and their metasomatic (skarn) aureoles, especially in association with W, as in the Pilot Mountains; and (2) felsic volcanic or subvolcanic complexes that produce anomalies in Sn and Ag, as in the Hot Creek Range.

Stream-sediment samples rarely contain detectable amounts of Bi; only 5 percent of the sediments contain 1 ppm or more Bi, which was the limit of detection of the atomic absorption method used in this study. Bismuth was detected in 18 percent of the concentrate samples and is considered to be anomalous when detected. Most of the concentrate samples that are anomalous in Bi are in clusters that are near plutons. Bismuth is generally associated with W and somewhat less so with Mo and Pb, particularly in samples from the western half of the Tonopah quadrangle. Some scattered samples from the eastern part of the quadrangle have Bi or Bi and Sn as the only anomalous elements; this behavior seems to characterize volcanic environments, some of which are favorable for Ag deposits.

Bismuth is a good indicator of pluton margins that are geologically and geochemically favorable for W skarn deposits. Examples of this relationship can be found at numerous sites in the Cedar and Pilot Mountains and the Toiyabe and Toiyabe Ranges. Some samples with high concentrations of Bi and W but low Pb-Mo-Cu, as within the Lone Mountain and Round Mountain plutons, seem to characterize plutonic rocks that by themselves are not favorable for W skarn deposits.

Copper

Anomalous concentrations of Cu are widespread in the Tonopah quadrangle and show no simple geologic associations. The emission spectrographic method provides results appropriate for this survey—Cu was detected in 99 percent of sediment samples and in 33 percent of concentrates. The threshold value for Cu is 30 and 10 ppm for sediments and concentrates, respectively, and concentrations deemed highly anomalous are 50 and 70 ppm, respectively. Copper in sediments commonly does not correspond to that in the concentrate sample from the same site because the two media contain Cu in different residences. Copper in sediments commonly correlates with elements such as Be, Co, or Cr, a suite that seems to be in rock-forming minerals and thus is not of much interest in this survey. Copper in concentrates probably is present in a sulfide mineral or oxidized derivative, and therefore is most pertinent for assessment of deposits. Copper in concentrates tends to increase or decrease with other chalcophile elements such as Mo, Pb, or Zn.

Copper is present in most mineral deposits in the Tonopah quadrangle. Most of the highest Cu concentrations in mineralized rocks or stream sediments are from samples collected near plutons in the western part of the quadrangle. In these areas Cu is generally associated with Mo and Pb, which might be considered permissive evidence for the existence of porphyry-type Cu-Mo deposits. However, I believe more diagnostic evidence from geology, alteration, and rock chemistry is needed to define areas with realistic potential for porphyry copper deposits. Volcanic terranes tend to produce lower concentrations of Cu and, where Cu is anomalous, it tends to correlate with Zn and Sb; this tendency is suggestive of epithermal, vein-type deposits.

Molybdenum

The distribution of Mo resembles that of Cu. Molybdenum was detected in 27 percent of the sediment samples and 12 percent of concentrates. Concentrations of Mo have a smaller range than many ore metals, but

some concentrate samples contain as much as 5,000 ppm Mo. The residence of Mo in concentrates is believed to be molybdenite, although this was not confirmed by optical or X-ray studies; if so, there may be a nugget effect during laboratory processing of this soft, platy mineral that might produce some of the extremely high values. Molybdenum is enriched in many geologic environments according to my studies of mineralized rock samples (for example, Nash, Siems, and Budge, 1985b, d), thus Mo cannot be considered diagnostic of any single deposit type. High Mo concentrations are observed in rock, stream-sediment, and concentrate samples associated with skarn, base-metal, and epithermal mineral deposits. In the epithermal deposits the enrichment of Mo is spotty and often combined with Zn, Sb, or Ag. In the regional survey, Mo results from concentrates are most useful, despite a high percentage of qualified (less than) values. In some areas of the Tonopah quadrangle high Mo concentrations in sediments appear to be produced by black shale; the identification of such lithologies is not a goal of this survey.

Lead

Lead concentrations determined for samples of sediment and concentrate ranged widely from 10 to more than 50,000 ppm. Lead was detected in 100 percent of the sediment samples and 55 percent of the concentrates. Threshold values are 50 and 150 ppm in sediments and concentrates, respectively, and values of 100 and 2,000 ppm, respectively, are deemed highly anomalous. Results for Pb in sediments correlate fairly well with results for the concentrate from the same site, despite the fact that the residence of Pb is different in the two media. Because the results from sediments show relatively little contrast relative to background they are not as useful as those from concentrates.

Lead is commonly associated with elements of the skarn suite (Bi-Mo-W) or with Ag \pm Sb in base-metal systems that have been important for their Ag rather than Pb. The widespread distribution of Pb anomalies and association with several geologic environments suggests that results for Pb (especially in concentrates) can be a useful general guide to mineralization in the Tonopah quadrangle. As for Cu, additional geologic information is needed to evaluate the type of resource. In general, Pb concentrations tend to be low in volcanic terrane but obviously can be high in some districts such as Reveille, Tybo, or Morey.

Antimony

The geochemistry of Sb seems to be more subtle than that of many ore-forming elements in the Tonopah quadrangle. The spread in values is small, and the choice

of threshold is not clear-cut. For the sediment medium the background for Sb is 1–2 ppm, the threshold is 3 ppm, and values of 5 or more are highly anomalous. Only 12 percent of concentrate samples contained detectable amounts of Sb, which probably reflects the high (200 ppm) limit of detection and the destruction of Sb phases in weathering. Although concentrations of Sb generally do not correspond in sediment and concentrate from the same site, presumably because of different mineral residences, both results are useful for locating areas of alteration or mineral deposits.

Antimony is enriched in many geologic environments in the Tonopah quadrangle according to this survey and also the study of mineralized rocks. Although Sb is generally thought to be a "volatile" element characteristic of shallow, low-temperature epithermal systems, it has been found in samples from deeper settings in association with plutons. The Pilot Mountains have numerous highly anomalous samples, which is possibly consistent with the many Hg deposits that contain large amounts of Sb (Nash, Siems, and Budge, 1985d). However, samples from the eastern and northern flanks of the Pilot Mountains that are distant from known Hg deposits and close to known W-skarn deposits contain highly anomalous amounts of Sb. Further study is required to understand the apparent association of Sb with W-Mo-Pb-Cu-Bi in this area because preliminary analyses of core samples from the W skarns do not indicate the presence of significant Sb in the ore zone (J.T. Nash and D.F. Siems, unpublished data, 1985). This apparent contradiction might be explained if the Sb determined in stream sediments comes from a halo around the skarns or a later stage of mineralization.

A distinctly different environment of Sb enrichment is in silicified carbonate rocks (jasperoids) at many localities in the Tonopah quadrangle. This association is well shown in mineralized rock samples (for example, Nash, Siems, and Hill, 1985) and is generally evident in stream-sediment samples from these areas. A poorly understood occurrence of high Sb values is in several areas of weakly altered volcanic rocks of the Toiyabe and Toquima Ranges. In these areas Sb is associated with numerous but scattered anomalies of Zn, As, or Mo, which seems to be an epithermal signature. In most of these drainages there are no known prospects and little evidence for veining or alteration in surface outcrops. This enigmatic occurrence may reflect a widespread, non-ore-forming process such as devitrification (G. Brem and J.T. Nash, unpublished data, 1986).

Tungsten

Tungsten causes analytical problems and is not easily determined by routine methods, but W is reported

as one of the 31 elements by the emission spectrographic method. The relatively high limit of detection (50 ppm for rocks and sediments, 100 ppm for concentrates) means that many samples with geochemically interesting amounts of W are not detected. Tungsten was detected in 176 concentrate samples and no sediment samples. The W in concentrates probably is present as scheelite; because partly magnetic W minerals, such as wolframite, should not be in the nonmagnetic fraction of concentrates, that variety of ore mineral would escape detection in this medium. If the sample media used do not detect W minerals other than scheelite, this bias as well as the high limit of detection may explain why no samples from volcanic terrane contain detectable amounts of W. However, results for W in concentrates are very useful for areas in the western part of the quadrangle that yield high W values in association with plutonic rocks and their metasomatic aureoles. The distribution of concentrate samples with detectable amounts of W and Bi provides a crude outline of intrusive rocks. The highly anomalous concentrations of W in concentrate samples from the Pilot and Cedar Mountains and from the Paradise and Toiyabe Ranges are consistent with the distribution of known W-skarn deposits and prospects. Several adjacent W anomalies in the southern Monitor Range, which are far distant from any other W anomalies, reflect a zone of complex structure and unusual pre-Tertiary rocks along a caldera wall. Thus, the distribution of W in concentrates has useful applications to geologic mapping as well as to identification of possible areas of W skarn.

GEOCHEMICAL SUITES

Recurring associations of elements are evident at many localities in the Tonopah 1°×2° quadrangle. Most of the associations or geochemical suites are logical and predictable from geochemical theory and ore mineralogy. In this section the element suites will be outlined, and they will be applied to the interpretation of areas in later sections.

Three methods have been used to identify geochemical suites in the Tonopah quadrangle: (1) multivariate analysis, chiefly correlation and factor analysis, of results for sediments and concentrates; (2) inspection of tabulated data; and (3) application of suites identified in mineralized rock samples of known source and deposit type (Nash, Siems, and Budge, 1985a, b, c, d; Nash, Siems, and Hill, 1985). To facilitate this work and the interpretation of subareas, the composite data set for both sediments and concentrates was utilized for some investigations rather than going through the analysis twice; results of analyses on the composite data set are

the same as for the same analyses made on data for only sediments and only concentrates.

Five general multielement suites occur consistently in stream-sediment samples across the quadrangle. In some subareas other suites are evident and will be mentioned in descriptions of the 13 subareas. The five suites are:

- (1) Skarn: Bi, Mo, Pb, W, ± As, Cu, Zn, ± Sb in concentrates; ± Ag, ± Pb, ± Mo in sediments.
- (2) Base metal: Pb, Zn, ± Cu, ± Mo, ± As, ± Sb, chiefly in concentrates (defined as lacking Bi-W).
- (3) Base-precious metal: Ag, Pb, ± Zn, ± Cu, ± As, ± Sb in concentrates; ± Ag, ± Pb, ± As in sediments.
- (4) Epithermal—two varieties: (a) Sb, Zn, ± Mo, ± As, ± Cu in concentrates. (b) Sb, As, ± Zn in sediments.
- (5) Mafic—two varieties: (a) Co, Cr, Ni in concentrates. (b) Co, Cr, Ni, ± Zn, ± V in sediments.

The skarn suite, which is best characterized by anomalous Bi-W-Mo-Pb in concentrates, is observed at many sites near plutons in the western part of the quadrangle. This suite is prominent in the Pilot Mountains, Paradise Range, Cedar Mountains, and Toiyabe Range. The chief variation in this suite is in the concentrations of Cu, Mo, and Zn, and there also is substantial variation in the concentrations of the related elements Bi-As-Sb (group Vb of the periodic table of the elements from area to area).

The base-metal suite is a group of chalcophile elements and, by my definition, does not include Bi and W. There is considerable variation in the concentration of several base metals, which may or may not be significant and deserving of subdivision. This suite is present at many localities across the quadrangle and commonly occurs in general proximity to plutons. In most volcanic terranes this suite is absent or weakly developed but can be present at high concentrations at some localities as in the Hot Creek Range. Concentrations of As and Sb are highly variable, with As high and in excess of Sb in some areas such as the Hot Creek Range or Sb in excess of As in other areas such as the Pilot Mountains.

The presence of anomalous concentrations of Ag along with the base metals is highlighted by my definition of the base-precious metal suite as a guide to sulfide deposits that have been mined at many places for their Ag. This suite is similar to the base-metal suite in its character and distribution. According to production records (Kleinhampl and Ziony, 1984) and analyses of mineralized rocks (Nash, Siems, and Hill, 1985) this suite may also be a guide to deposits with good potential for

Au. However, it is evident from production records that most base-metal deposits mined chiefly for Ag (for example, Belmont and Tybo) contained very little Au.

The suite termed "epithermal" resembles the elements commonly found in epithermal deposits, some of which are considered to be volatile (Ewers and Keays, 1977). In the stream-sediment media these elements tend to be present in relatively low concentrations and anomalous values tend to be only slightly higher than background. Another complicating aspect is that many samples are anomalous in only one or two of the elements in this suite. Also, localities that produce anomalies in the sediment media commonly do not exhibit anomalies in the concentrate, and vice versa. The epithermal-type anomalies tend to occur in adjacent localities and show systematic distribution within subareas, as discussed below; thus the anomalies seem to be valid, but they are not as distinct as nonepithermal types. The epithermal suite is typically found in volcanic terrane such as the Toiyabe and Monitor Ranges. This suite is probably best considered to represent pathfinder elements enriched near a mineral deposit rather than a guide to deposits of Zn or Mo that may be in the suite.

The mafic suite is present at many localities in the quadrangle (Nash and Siems, 1988) and may be a guide to mafic volcanic or metavolcanic rocks and to broad alteration such as chlorite-pyrite. Although there are a few prospects with Co-Cr-Ni minerals (Kleinhampl and Ziony, 1984), the geology of mafic rocks in the quadrangle does not appear to be favorable for the development of significant deposits of these metals; thus no attempt has been made to interpret the occurrence of this suite, and it will not be mentioned further.

MAPS OF GEOCHEMICAL SUITES

The distribution of sites characterized by anomalous levels of five geochemical suites is shown on map A of plate 1. This map has obvious similarities to other geochemical maps of single or multiple elements (Nash and Siems, 1988) but was produced in a somewhat different manner. Map A of plate 1 was produced by visual inspection of data for individual elements in sediment and concentrate samples at 1,152 sites. The "manual" method benefited from experience with dozens of prior maps that were generated by multivariate methods and computerized mapping of scores, but here I applied the criteria described in this section and made sample-by-sample judgments as to whether or not it was anomalous, and if so which of the five suites seemed to be present. Many samples with highly anomalous concentrations of many elements can be considered to be anomalous in more than one suite, but for this map I made a judgment as to which suite was more

characteristic of the site. Subjective choices had to be made for many sites that did not have the ideal attributes of the multielement suites, but the decision, which was made consciously, included some consideration of the character of nearby sites. All computer-generated maps are based on some subjective choices on the handling of analytical results, averaging of results from neighboring sites, and so forth; map A of plate 1 may reflect erroneous assumptions or judgments, but the choices were made during hundreds of hours of inspection of data from both stream-sediment and concentrate samples as well as from some knowledge of the geochemistry of mineralized rocks from the areas.

Maps B-D of plate 1 provide additional information that was used in the creation of map A but in a different format. Maps B-D show the distribution of multielement suites as represented by nonparametric scores or ranks rather than factor analysis scores, which can be cryptic (Goldfarb and others, 1983). Each analytical result was ranked from 1 (lowest) to 1,152 (highest). The chief advantage of this technique is to minimize the effect of non-normal distributions of values and to create a common basis for all elements. A second step involved computing the sums of the ranked element scores according to the definition of the geochemical suite. For example, the formula for the skarn suite used for map B was: skarn score = $2(Bi + W) + Pb + Mo$, where the values added are the rank scores for analytical results on concentrates; in this case the scores for Bi and W were doubled for emphasis, but the results are not much different from a score computed by adding $Bi + W + Pb + Mo$. The map of the base-metal suite (map C) was produced by adding the scores for $Pb + Cu + Zn$ in concentrates to the scores for $Pb + As + Sb$ in sediments. Sites characterized by detectable amounts of Bi and W in concentrate, thus meeting the definition of skarn suite, were eliminated by assignment of a base-metal ranking of zero prior to plotting. The epithermal suite, shown on map D, was ranked by adding the scores for $As + Sb + Zn$ based on atomic absorption analyses of sediments to the scores of $Mo + Ag$ in concentrates. Geochemical trends and associations with geology and known deposits will be discussed and interpreted in the next section, using information from maps A-D.

Broad-scale regional trends in geochemistry are evident in many aspects of the results for the Tonopah quadrangle and well illustrated by the multielement suites plotted as interpolated surfaces (figs. 2-4). The regional trend of high values for the skarn suite (fig. 2) in the western part of the quadrangle is clearly evident in the smoothed plot of the information used in map B of plate 1, and a similar trend is shown for the base-metal suite (fig. 3), although that suite also is enriched in scattered parts of the eastern half of the quadrangle. The epithermal suite (fig. 4) is enriched at more scattered

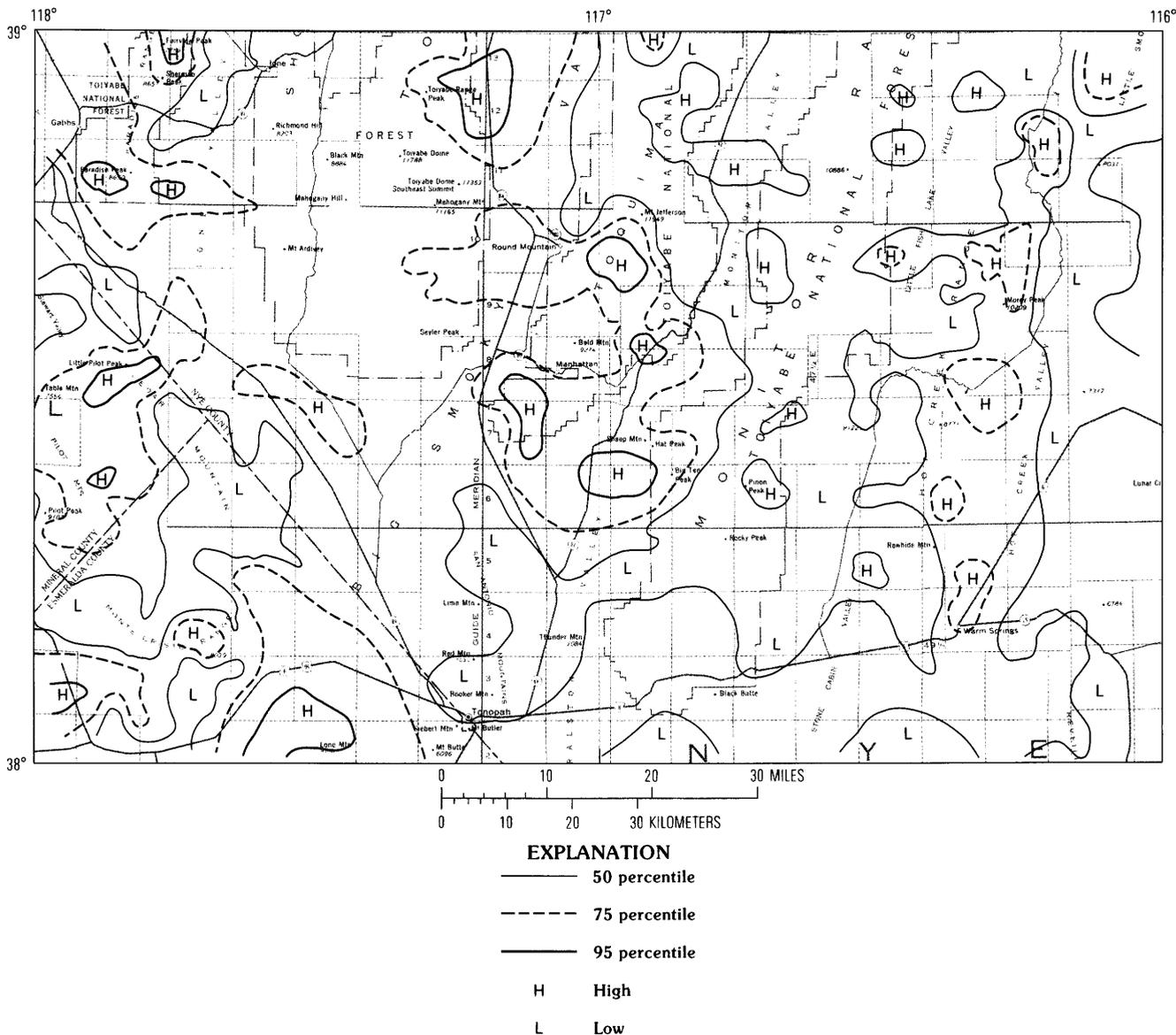


Figure 2. Regional trends of skarn-type geochemical anomalies. Harmonic surface is computed from information shown on map B of plate 2. Contours are 50, 75, and 95 percentiles.

locations than the other two suites but is notably high in the Pilot Mountains to Monte Cristo Range, Toiyabe Range, southern Monitor Range, and Hot Creek Range. The validity of the interpolation technique used to create the harmonic surfaces shown in figures 2-4 is open to question, especially as the data are smoothed without regard for geologic boundaries such as the major Quaternary basins, but for the purpose of illustrating broad trends the surfaces are instructive for considerations of regional geochemistry. I prefer to search for more specific spatial relations in the geochem-

ical results, and that is best done for individual and adjacent drainages, as will be discussed next.

GEOCHEMISTRY OF REGIONS

Geochemistry of the Tonopah 1° × 2° quadrangle is best described and interpreted in the context of smaller geologic and physiographic regions that are essentially individual mountain ranges. For this discussion the study area was divided into 13 regions (fig. 5), and these will be discussed in order from east to west. For each region a

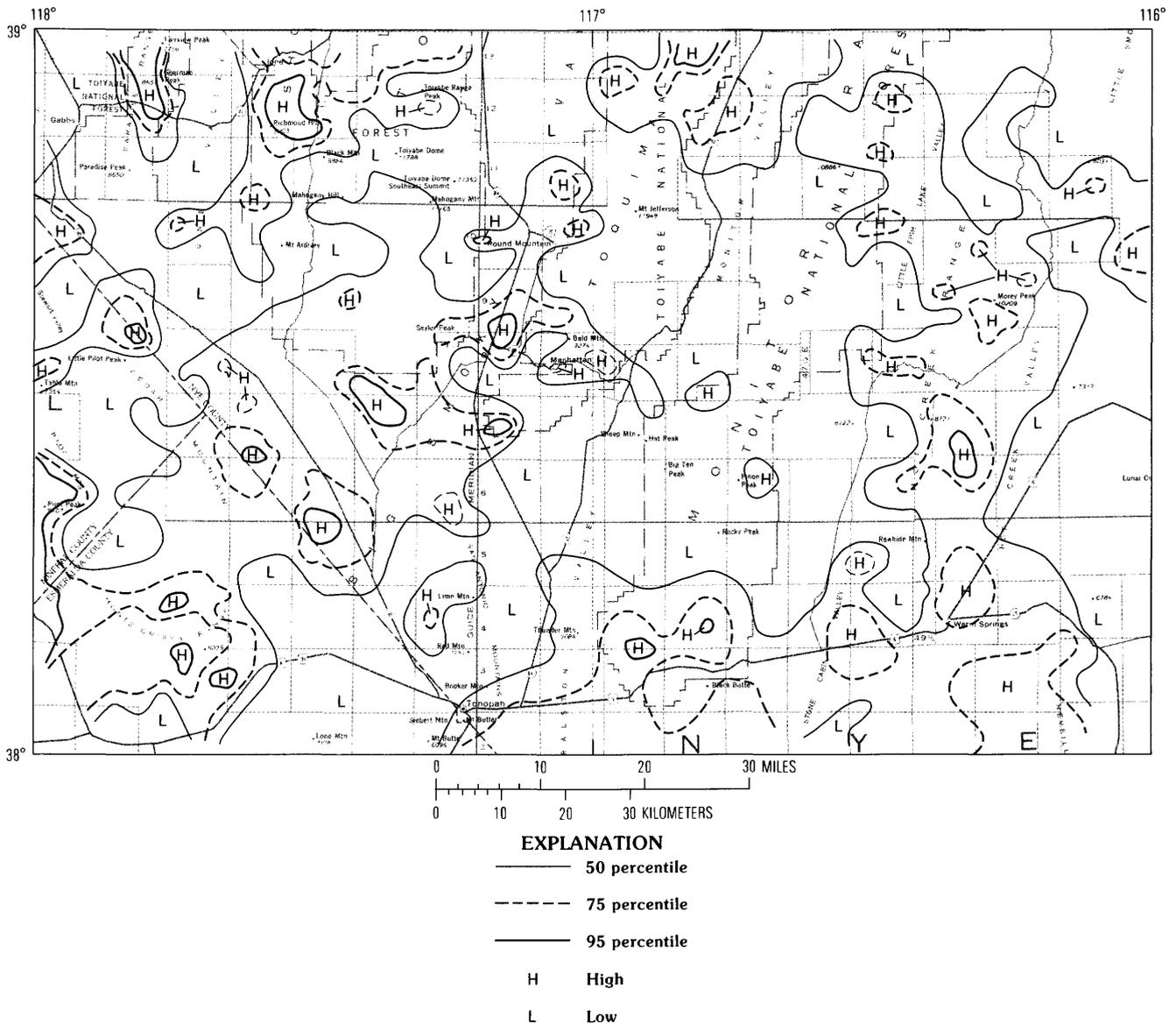


Figure 3. Regional trends of base-metal-type geochemical anomalies. Harmonic surface is computed from information shown on map C of plate 2; data for sites anomalous in Bi and W are not included. Contours are 50, 75, and 95 percentiles.

brief introduction to the geology and known mineral deposits will be given; most of the information for these summaries comes from reports by Kleinhampl and Ziony (1984, 1985), Ross (1961), and Albers and Stewart (1972).

Pancake Range

Tertiary and Quaternary volcanic rocks underlie the Pancake Range west of long 116° W. (Kleinhampl and Ziony, 1984) in the southeastern part of the Tonopah

1° x 2° quadrangle (fig. 5). A caldera, inferred to underlie the northern part of the area, is covered by younger volcanic rocks. These rocks are of intermediate composition, are cut by only a few faults, and are generally unaltered. No mines or prospects are known in the area considered here, but skarn- and hot-springs-type prospects occur about 12 km to the east (Kleinhampl and Ziony, 1984).

The Pancake Range contains no significant stream-sediment or concentrate anomalies. Some Zn concentrations in excess of 200 ppm are observed in stream sediments, but there are no corresponding enrichments in concentrates from the same sites and no

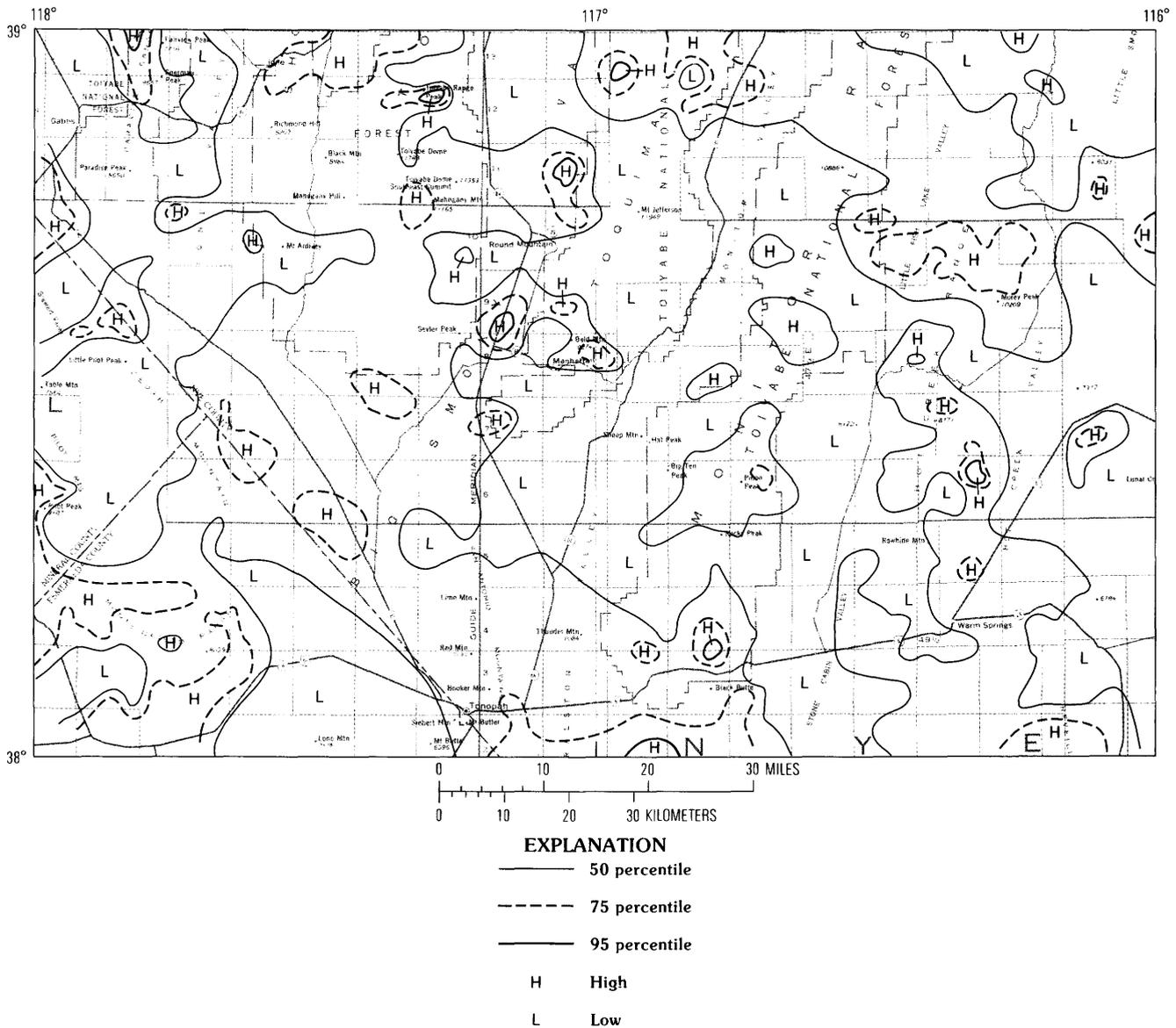


Figure 4. Regional trends of epithermal-type geochemical anomalies. Harmonic surface is computed from information shown on map D of plate 2; data for sites anomalous in Bi and W are not included. Contours are 50, 75, and 95 percentiles.

noteworthy enrichments in other metals. Thus, the Zn seems to occur in silicate minerals and is not deemed geologically significant as a guide to mineral resources.

Squaw Hills-Park Range-Antelope Range

This area in the northeastern part of the Tonopah quadrangle (fig. 5) is composed chiefly of Tertiary welded tuffs that are mostly thick outflow deposits. A caldron margin curves under the Squaw Hills. Small windows of Paleozoic rocks are scattered through the area; these are generally highly silicified carbonate rocks. No significant mines are in the area, but there are a few

prospects. The Titus antimony prospect occurs in silicified carbonate rocks near a caldron margin in the Squaw Hills (Kleinhampl and Ziony, 1984).

This area contains some single-element anomalies and a few multielement anomalies, but overall it has a weak geochemical signature. There are an unusual number of sites characterized by anomalous amounts of Bi in either sediment or concentrate samples; some of these samples also contain anomalous amounts of Ag. Bismuth and Ag together may indicate subvolcanic deposits of the type at Morey, Nev. (Nash and others, 1986), or in Bolivia (Chace, 1947; Sillitoe and others, 1975). However, the single-element Bi anomalies, although unusual for the Tonopah 1°×2° quadrangle,

oxidized Pb-Zn sulfide veins that are rich in Ag in the oxidized zone. At Arrowhead veins with Ag-sulfide minerals occur in Tertiary rocks as well as in Paleozoic strata, and some veins are locally rich in stibnite. All the deposits are probably of mid-Tertiary age.

Ten sites in the Reville Range (map A of pl. 1) have anomalous concentrations of one or more of the suite Ag-Pb-Cu-Sb-As. A site near New Reville contained one of the highest anomalies in Ag and Pb in concentrates for the entire study as well as very highly anomalous concentrations of As and Sb. The polymetallic suite highlighted by Ag and Pb was found in samples of mineralized rock from mines and dumps in the area (J.T. Nash and D.F. Siems, unpublished data, 1985), and also was identified in a factor analysis as the group Ag-Pb-As-Cd-Sb in sediments and Ag-Cu-Pb-Sb in concentrates. Seven sites are classified as base-metal or base-precious-metal types and three sites as epithermal type by the presence of anomalous Sb in concentrates. The stream-sediment and concentrate suites are consistent with the known mineralization in the area, and some of the very strong anomalies probably reflect contamination from dumps and mine workings. Two anomalous sites northwest of the Arrowhead camp suggest the possibility of more widespread mineralization in that direction.

Hot Creek Range

The Hot Creek Range (fig. 5) is underlain by a thick sequence of Paleozoic rocks, most of which are thick-bedded miogeoclinal carbonates (Kleinhampl and Ziony, 1985). The Paleozoic rocks are juxtaposed by numerous thrust faults, folded, and displaced by many high-angle faults. A thick section of Tertiary welded tuffs from several nested cauldron complexes overlaps the pre-Tertiary rocks. Rhyolitic intrusive rocks are scattered through the range. Silver-rich polymetallic sulfide deposits have been mined at several localities (Ferguson, 1933), including Tybo, Keystone, Hot Creek Canyon, and Morey (fig. 1). Mercury was mined from several deposits in the southern part of the range, and stibnite was mined from a deposit in Hot Creek Canyon. Most of the veins are in Tertiary tuff or dikes, although at places such as Tybo reactive carbonate rocks are meters away from ore localized in dikes. The ores are of Tertiary age. A newly recognized area of highly fractured and silicified Paleozoic rocks near Cold Spring (fig. 5) has the geologic setting and geochemical signature of Carlin-type (Radtke and others, 1980) sediment-hosted Au deposits (Nash and others, 1986).

The Hot Creek Range produces many anomalies (map A of pl. 1) in the general base-metal suite (Pb-Cu-As-Sb-Zn), commonly including Ag, and many sites

are anomalous in only Ag. For purposes of data inspection and interpretation the area was split into two parts at Hot Creek Canyon. The general geochemical character is similar in both parts despite the predominance of Tertiary volcanic rocks in the northern part of the Hot Creek Range. In the southern part of the area, about half of the 42 sites are anomalous in one or more elements. The site downstream from Tybo (map A of pl. 1) is very strongly anomalous in Ag, Pb, As, and Zn in both media and most likely reflects contamination from dumps and tailings. The anomalous suite of elements is consistent with the known character of the Tybo ores. Another very strong anomaly (As, Ag, Cu) is in Old Dominion Canyon (5 km south of Hot Creek Canyon) but probably does not reflect contamination because the workings in that area are not very large. Many of the sites in the southern Hot Creek Range are anomalous in As, and some are anomalous in Mo. The anomalous sites are spread throughout the southern part of the range, far beyond the known larger mining areas but consistent with the widespread prospects. The general signature of the southern Hot Creek Range is mixed base-metal, epithermal (As, Sb), and precious-metal (Ag) types consistent with the known deposits of the area.

Roughly half of the sites in the northern Hot Creek Range are anomalous in at least one element, and some are strongly anomalous in many metals of the polymetallic suite. Single-element anomalies in Mo, Bi, or Sn in concentrates seem to be derived from volcanic rocks but are not considered to be indications of significant mineralizing processes unless there is supporting geologic evidence. Most of the Mo, Bi, or Sn anomalies are in drainages with no obvious alteration zones. Factor analysis identifies two suites that are consistent with the composition of some known deposits in this region (Nash and others, 1986): (1) Ag-Pb-As-Cu-Zn in concentrates, a suite that resembles enrichments in mineralized rocks from the Morey mining area; and (2) Sb-As in sediments and Sb in concentrates, a suite that resembles mineralized samples from the Page antimony mine. In addition to the Sb-As-rich sites near the Page mine, at the northwestern end of Hot Creek Canyon (map A of pl. 1), there are several other sites with similar Sb-As enrichments that seem to reflect a north-trending zone of silicification in carbonate and volcanic rocks north of the eastern end of Hot Creek Canyon (Nash and others, 1986). Most of the other strong anomalies in the northern Hot Creek Range are of the base-metal type (Pb, \pm Mo, \pm Zn, \pm Sb) with or without Ag, as found in stream-sediment samples from drainages in the Morey area and in Hobble Canyon, 6 km south of Morey (map A of pl. 1). The highly silicified Paleozoic rocks near Cold Spring that are enriched in As, Sb, Hg, Mo, and Tl, and which appear favorable for Carlin-type sediment-hosted

gold deposits (Nash and others, 1986), are reflected at one site with a strong base-metal suite signature, but no notable As-Sb "epithermal-type" signature is produced in stream-sediment samples as it is in the altered rocks. Several scattered sites in the northern part of the northern Hot Creek Range have epithermal or base-metal signatures, but there are no nearby known prospects or alteration zones to aid in the evaluation of their significance.

Kawich Range

A thick sequence of Tertiary welded tuffs underlies the Kawich Range (Kleinhampl and Ziony, 1985). A series of northwest-trending high-angle faults, which possibly reflect the margin of a caldera, cut the tuffs and control a series of vein deposits in the Bellehelen district (fig. 1). The veins, which contain variable proportions of Ag and Au, were mined from the zone of oxidation. A similar Ag-Au deposit in quartz-pyrite veins occurs 8 km to the northwest at the Clifford mine (Ferguson, 1917).

The geochemical signature of the Kawich Range is subdued, and only 4 of 21 sites are anomalous. Silver is weakly anomalous along with Pb at one site. The other three sites, west of the Ben Hur mine in the Bellehelen district, are anomalous in As or in As and Sb. The subdued anomalies of a few elements, and very low base-metal concentrations, are consistent with analyses of mineralized rock samples from the Bellehelen deposits. These deposits have relatively little iron oxide where weathered and seem to be of the type of precious-metal veins that have low pyrite and low base-metal content (Berger and Eimon, 1983). The stream-sediment geochemistry seems to be consistent with the findings of prospectors who could locate good prospects only in the northwest-trending structural zone near Bellehelen.

Monitor Range

Tertiary volcanic rocks are dominant in the Monitor range (Kleinhampl and Ziony, 1985). At least one probable caldera is present in the vicinity of Big Ten Peak, partly inferred from large blocks of pre-Tertiary rocks engulfed in tuff in what may be a megabreccia along a caldera margin (W.J. Keith, oral commun., 1986). In the southern part of the range, south of U.S. Highway 6, complexly thrust faulted and folded Paleozoic rocks crop out. A window of Paleozoic rocks, chiefly miogeoclinal carbonates with subordinate western facies shale and chert, is present in the northern part of the Monitor Range.

Thrust faults of regional extent juxtapose western facies rocks with those of the eastern platform. No plutonic rocks are known, except in exotic blocks near

Big Ten Peak. Mineral deposits in the range are more abundant in Paleozoic than in Tertiary rocks. Base-metal deposits, some with significant Ag, occur in Paleozoic rocks in the Ellendale, Danville, and Green Monster Canyon areas. The thick tuff sequences generally are little altered, but there are some scattered areas of alteration and Ag-Au vein deposits such as at Hannapah, Longstreet, and near Big Ten Peak (fig. 1).

Results of geochemical analyses for stream-sediment samples from the Monitor Range show that sites are generally low in Cu, W, and Bi, but some sites are enriched in one or more of Ag, Pb, As, Sb, Mo, or Zn. Most sites are anomalous in only one or two elements, although a few are anomalous in as many as five. This subdued geochemical signature, especially the low base-metal content, is similar to that observed in other parts of the Tonopah quadrangle that likewise are underlain by Tertiary volcanic rocks. In the northern part of the range several strong anomalies are downstream from known mines or prospects including those of the Longstreet, Green Monster Canyon, and Danville mining areas; these sites are strongly to extremely anomalous in Sb, as expected of the mineralogy of the deposits, as well as Pb for Danville and Ag-Mo-As in both sediment and concentrates from Longstreet. These anomalies possibly reflect contamination from dumps or could reflect broader parts of these mineral systems. Scattered across the rest of the northern Monitor Range are many sites with anomalous Ag or Ag-Pb, As, Sb, Mo, or Zn. Most of these sites are anomalous in only one or two elements in concentrates. These anomalies seem consistent with scattered epithermal deposits in volcanic rocks, although more detailed geologic and geochemical follow-up studies are needed to properly assess the source of these anomalies.

Concentrate samples from four sites on the flanks of Big Ten Peak have high contents of Bi, W, Pb, and Mo, which is an unusual assemblage for the eastern part of the Tonopah quadrangle, but one that is common for sites near plutons in the western part of the area. Three of the sites are on adjacent drainages on the southwestern flank of Big Ten Peak, and at one site the high content of Bi and W is confirmed in a replicate sample. The anomalies are consistent with the unusual geology of the area (W.J. Keith, oral commun., 1986). The southwestern and northwestern flanks of Big Ten Peak are underlain by a complex zone of faults and large megabreccia blocks of granitic rocks and altered Paleozoic sedimentary rocks including limestone. The megabreccia blocks are believed to be in the margin of a caldera. The megabreccia blocks, which are mineralized, have been mined at one locality. According to the style of mineralization and a radiometric age, these ores seem to represent pre-Tertiary mineralization that has been rafted upward in the volcanic complex. The geochemical

signature in stream sediments and concentrates suggests skarn-type mineralization, which is consistent with the geology of the megabreccia blocks in the drainages.

Despite the more complex geology of the southern part of the Monitor Range (south of lat 38°15' N.), the geochemical signature there is similar to that of the northern part. Anomalies involve chiefly Ag alone, Ag-Pb, or single-element anomalies in Pb, Mo, or Sb. The Hannapah district is not evident in the results because no sample was taken in that area due to poor stream development. A sample from 2 km north of Hannapah is anomalous in Ag-Mo, similar to what might be expected from Hannapah. North of Hannapah is a group of three sites that are strongly anomalous in Pb in concentrates; one site also is anomalous in As. The source and nature of these anomalies is not known. Three sites south of U.S. Highway 6 are anomalous in Ag; silicified tuffs crop out in this area and may be the source of the anomalies. Another group of three sites south of U.S. Highway 6 in the Tertiary volcanic and Paleozoic rocks of the Ellendale area is characterized by Pb-Ag-Sb, possibly reflecting Ag-bearing base-metal mineralization that is known in the area.

Toquima Range

This geologically complex range comprises Paleozoic sedimentary rocks, Cretaceous plutonic rocks, and three Tertiary volcanic complexes (Kleinhampl and Ziony, 1985; Shawe, 1985). Thrust faults of several ages bring together silicic western facies sedimentary rocks with Cambrian to Pennsylvanian miogeoclinal carbonate rocks. Large Cretaceous plutons occur in the southern part of the range, and a small Jurassic pluton occurs in the northern part. Calderon complexes are postulated to occur near Manhattan, east of Round Mountain, and near the northern boundary of the Tonopah quadrangle at Northumberland. Pre-Tertiary rocks are highly faulted and folded.

There are many mines and prospects in the Toquima Range (fig. 1). Several types of Au-Ag deposits were mined at Manhattan (Ferguson, 1924), Ag-rich polymetallic deposits were mined at Belmont, Hg and polymetallic deposits were mined at Spanish Belt, Ag-Au deposits were mined at Round Mountain, W (ferberite) deposits were mined at Jefferson Canyon, and bedded barite and Carlin-type sediment-hosted Au deposits were mined at Northumberland.

Geochemical results for 124 sites in the Toquima Range show a wide range of concentrations that generally reflect the different geologic terranes in the range. One feature of the results for this region is the large number of stream sediments and concentrates that are anomalous in Mo, Bi, and W. In addition, samples

from the northern part of the range are unusually rich in As, Sb, and Zn compared with other parts of the quadrangle. There seem to be three types of multielement geochemical signatures in the Toquima Range: (1) skarn-type signatures indicate strong enrichments in Bi-W-Mo-Pb and commonly Ag and Cu. (2) Base-metal-type signatures are similar to the skarn type but lack Bi-W and tend to have lower concentrations of Pb-Sb-Zn. Some signatures of this type indicate Ag enrichment, and that variety is given emphasis for its possible indications of precious metals in polymetallic deposits. (3) Epithermal-type signatures indicate generally lower concentrations of a more limited suite of elements that includes chiefly Sb and Zn but in places also includes Ag, Mo, As, or Cu.

Many samples from the central and southern parts of the Toquima Range have anomalous to strongly anomalous contents of Bi and W and, in some samples, Mo or Pb and other elements in the skarn suite. The sites that show only two or three enriched elements (from the group Bi-W-Mo) are unusual for the Tonopah quadrangle, because these elements most commonly are accompanied by other base metals. The two clusters of skarn-type signatures correspond to known areas of Cretaceous granitic rocks which produce local skarns (John, 1987). The strongest polymetallic base-metal signatures seem to be from areas underlain by plutonic and metamorphic rocks, whereas the smaller suite (Bi, W, \pm Mo) seems to come from basins underlain by predominantly plutonic source rocks, which are not geologically favorable for skarns that occur in metamorphic wallrocks. The small body of Jurassic granitic rocks in the Northumberland area in the northern part of the Toquima Range does not produce a skarn-type geochemical signature in the stream-sediment samples, although small skarn zones are known to occur next to it.

Many of the anomalous samples in the Toquima Range cannot be related unequivocally to a single geologic source, which is not surprising considering that the complex geology must lead to mixed sources for stream sediments in these drainages. Base-metal and base-precious-metal anomalies are widespread in the Toquima Range and are associated with both Paleozoic sedimentary rocks and Tertiary volcanic rocks as in the complex north of Manhattan. Arsenic is notably rich in several samples from the Northumberland area (map A of pl. 1) and is possibly related to western-facies Paleozoic rocks in that area. The suite Sb, Zn, \pm Ag, Mo, As, Cu is commonly only weakly anomalous and is associated with Tertiary volcanic rocks such as the complex at Mt. Jefferson in the central part of the Toquima Range; commonly only a few elements of the suite are present. These anomalies also are difficult to interpret because they are dwarfed by multielement signatures from plutonic terranes.

Some of the highest metal concentrations of all the samples in the Tonopah quadrangle occur at three sites in streams that drain the Jefferson Canyon area; these sites were chosen to avoid contamination from the old mine dumps at Jefferson. This is an area of known precious-metal deposits, but the geochemical signature is not that expected of epithermal Ag-Au deposits. These samples have extremely high concentrations of As, Bi, Cu, Mo, Pb, Sn, and W. The margin of the Jefferson caldron cuts across these drainage basins, and a Cretaceous pluton occurs south of two of the sites. Some of the metals, such as Bi, Mo, and W, may come from a source in the granitic rocks, and others may be due to mineralization in Tertiary rocks.

San Antonio Range

Paleozoic sedimentary rocks, Jurassic and Cretaceous plutonic rocks, and Tertiary volcanic rocks underlie the San Antonio Range (Bonham and Garside, 1979; Kleinhampl and Ziony, 1985), which is here defined as including the Tonopah and Divide mining districts. Pre-Tertiary rocks are complexly deformed and metamorphosed. The Ag-Pb and Mo-Cu deposits in the Hall mine area are associated with a small felsic stock of Cretaceous age. Tertiary volcanic complexes are dominant at the northern and southern ends of the range. Silver-gold veins that occur in the volcanic complexes were important producers in the Tonopah and Divide districts (fig. 1).

Several geochemical suites are evident in results from the San Antonio Range, but these are not very distinct because the samples are anomalous in only two to four elements. Concentrations of As, Bi, Cu, and Zn are generally low, but a few scattered samples are anomalous in W and Mo. A cluster of sites that are anomalous in Ag-Pb-Cu occurs in the northern part of the range (map A of pl. 1). The largest mineral system in the range, the Hall Cu-Mo deposit, is not directly reflected in this survey because no samples were collected from drainages in that westernmost part of the range. However, Hall is in an extension of a cluster of Ag-Pb-Cu anomalies, and one site to the south of the deposit also is anomalous in W. Several samples from streams that drain the Cimmaron Au-Ag mining area at the northern end of the range are anomalous in Ag-Pb-Cu. In the central part of the range several sites that are anomalous in Pb, Mo, or W possibly show a weakly developed skarn-type signature; this might reflect mineralization in Paleozoic rocks and associated Mesozoic plutons. Three of four sites in the southern part of the range near Tonopah are weakly anomalous in one or more of the group Ag-As-Mo-Pb-Zn, which is probably an epithermal signature. Drainages in the Divide and

Tonopah mining area are not well developed and were not sampled; thus these districts do not show up in the geochemistry.

Stream-sediment geochemistry of the San Antonio Range suggests that the area should contain scattered mineralization of epithermal or base-precious-metal type but does not by itself give an indication of the large deposits known to be present. The absence of a geochemical anomaly is partly caused by the location and density of our samples. This example is a warning that large deposits cannot be presumed to create large geochemical anomalies in regional geochemical surveys. Many factors, such as lack of deposit exposure, sample density, and analytical methods, can contribute to a failure to detect a deposit and should be anticipated in a reconnaissance geochemical survey. Although geochemical anomalies are permissive evidence for the existence of mineral deposits, the absence of anomalies should not be equated to an absence of deposits.

Toiyabe Range

A thick sequence of Tertiary welded tuffs dominates the Toiyabe Range (Kleinhampl and Ziony, 1985). Cambrian to Permian sedimentary rocks occur in three fault blocks along the eastern and southern margins of the range, where they are intruded by Jurassic to Tertiary stocks. The pre-Tertiary rocks are highly deformed, and the Tertiary rocks are tilted westward.

The most significant deposits and prospects are scattered along the eastern part of the range. Noteworthy are the Sb deposit in Permian greenstone near Cretaceous dikes at Wall Canyon, several W-skarn bodies adjacent to a granitic stock in Ophir Canyon, and the Ag-rich oxidized polymetallic sulfide vein deposits at Murphy (Ophir). Small polymetallic veins and Au prospects are scattered through the southern part of the range.

Strong geochemical anomalies are widespread in the Toiyabe Range. Some of the strongest multielement anomalies of the entire Tonopah quadrangle occur in this area, and more than 80 percent of the sample sites are anomalous in one or more elements. Elemental associations suggest four groups or types of signatures: (1) generally strongly anomalous concentrations of elements in the group $Pb + Mo \pm Cu \pm Zn + Bi + W + As + Sb + Ag$, which are interpreted to reflect skarn-type mineralization associated with plutons; (2) a base-metal group, which is similar to group 1 but lacks metals such as Bi, W, and Mo and generally shows lower concentrations than group 1, consists of $Pb \pm Cu \pm Zn \pm As \pm Sb$; (3) a similar base-metal group that has Ag as well but commonly only three or four metals of the group $Ag, \pm Pb, \pm Mo, \pm As, \pm Sb$ (Ag-rich basemetal group);

and (4) weakly developed, one- to three-element anomalies of the elements Zn, Sb, and Mo. Factor analyses of the data for 208 samples from the Toiyabe Range show similar elemental associations and no strong distinction between groups 1 and 2. In multivariate tests Sn in concentrates tends to behave independently of other variables, which is perhaps explained by the physical properties of cassiterite, the presumed residence of Sn, that cause Sn to become highly concentrated in some concentrate samples. The behavior of Zn, Sb, and Mo, here grouped together for convenience in group 4, is not well understood; these elements are enriched at many sites downstream from seemingly fresh volcanic rocks with no known alteration, prospects, or deposits (G. Brem and J.T. Nash, unpublished data, 1986).

A cluster of 17 sites north and south of Ophir Canyon (map A of pl. 1) is one of the strongest multielement anomalies in the quadrangle. This cluster is clearly related in space and geochemical character to the Ophir pluton. Several substantial ore deposits occur adjacent to the Ophir pluton, including W skarns and Ag-rich polymetallic veins of the Murphy camp. The broad distribution of W-rich concentrate samples with the skarn-type metal assemblage suggests the possibility of more skarn deposits than presently identified at the surface. Samples from the western part of this strongly anomalous area, which includes the area of the Murphy vein, are rich in base metals but not Bi-Mo-W. The compositions of stream-sediment and concentrate samples, combined with the distribution of mines and prospects and with ore-zoning theory, are compatible with a spatial or temporal zonation in the Ophir area in which the Ag-rich base-metal deposits formed outward from, or later than, the skarn deposits adjacent to the plutons. This is supported by field observations (D. John, oral commun., 1986; John, 1987) that the Ophir pluton is a composite stock composed of an earlier, foliated phase and a younger, undeformed phase.

Some single sites on the southeastern flank of the Toiyabe Range are strongly enriched in base metals, some with Bi-W, which suggests possible pluton-associated mineralization similar to that of the Ophir area. Some of these sites are also associated with Permian greenstones and large felsic dikes. The Wall and Pablo Canyon areas, which are underlain in part by dikes and greenstone, have very strong base-metal anomalies. The Wall Canyon mine, which contains base metals as well as very abundant Sb (stibnite was the mineral mined), seems to be in a mesothermal pluton-associated deposit, not an epithermal vein.

The western and southwestern part of the Toiyabe Range, which is underlain by Tertiary welded tuff, is characterized by numerous anomalies of Zn, Sb, \pm Cu, \pm As, \pm Ag, \pm Sn. These sites generally have one to three of these metals in anomalous concentrations, commonly

in both media. Only a few scattered small prospects occur in this area, and the tuffs are generally unaltered except for devitrification (G. Brem, written commun., 1985), thus the source of these anomalies is not known. Other areas of widespread, largely unaltered tuff, such as those in the Shoshone, Toquima, and Monitor Ranges, produce similar geochemical signatures that I term "epithermal." These anomalies are thought to be produced by widespread geothermal processes rather than focused hydrothermal ore-forming systems.

Lone Mountain

In the Lone Mountain area Precambrian(?) to Paleozoic sedimentary rocks, which are chiefly quartzite and carbonate rocks (Albers and Stewart, 1972; Bonham and Garside, 1979), are intruded by a Cretaceous granite pluton as well as by numerous Tertiary dikes. The sedimentary units are complexly thrust, folded, and metamorphosed. A major fault on the western side of the range has moved as recently as during the Holocene. There has not been much mining activity in this area, but there are numerous prospects on the northeastern and western sides of the mountain adjacent to the pluton. The deposit at the Alpine mine and other similar deposits of Ag-rich galena, which are pervasively oxidized near the surface, occur as replacement bodies in carbonate rocks. Although these and most other deposits occur near the pluton, the presence of numerous Tertiary dikes and age data for altered rocks led Bonham and Garside (1979) to suggest that the deposits might be of Tertiary age.

The 13 sites in this area are characterized by a very strong and consistent geochemical signature that stands out at regional scale. Most of the samples are anomalous to strongly anomalous in the skarn suite, which in this area is consistently rich in Bi and Pb, and to a lesser extent W, in concentrates. Copper and Mo are not notably abundant with Bi-Pb-W. Silver is anomalous to strongly anomalous in four concentrate samples, which are all very rich in Bi and Pb. Stream-sediment samples are not anomalous, except for two weakly anomalous values of Ag; the corresponding concentrate samples from these sites are strongly anomalous in Ag. The skarn suite is logically related to the plutonic rocks and their metamorphic aureoles in the Lone Mountain area as it is elsewhere in the Tonopah quadrangle. However, the significance of these Bi-Pb-W anomalies is not clear; contact metamorphism adjacent to the pluton at Lone Mountain is not well developed and does not include skarn-type calc-silicate minerals such as garnet that

normally are developed in skarn deposits (John, 1987). Although epithermal vein deposits are known in this area, there is no geochemical indication of them.

Monte Cristo Range

The oldest rocks in this area are lower to middle Paleozoic dark chert, shale, and siltstone with some local carbonate strata (Albers and Stewart, 1972; J.H. Stewart, written commun., 1986). Small Mesozoic intrusions with porphyritic texture intrude the sedimentary rocks at several places in the range. Oligocene to Holocene flows, tuffs, and lacustrine volcanoclastics, and domes unconformably overlie the pre-Tertiary rocks. Precious metals have been mined at several places in the range, chiefly in the Gilbert district, from Ag-Au veins in pre-Tertiary and Tertiary rocks (Ferguson, 1928). Other Tertiary deposits, which are scattered through the range, include the deposit at the Castle Rock mercury mine in the southern part of the range. An older period of mineralization is best illustrated by the base-metal deposits of the Carrie mine; these are oxidized Ag-rich Pb-Zn sulfide replacements of carbonate rocks adjacent to a Mesozoic stock.

This area, along with the Pilot Mountains, exhibits the most numerous anomalies in the Tonopah quadrangle (map A of pl. 1). More than 80 percent of the sites are anomalous, generally in several elements and in both media. Concentrations reach very high levels near some mines, as in the Gilbert District, where contamination from dumps contributes to the anomalies. More subtle, but easily detected, anomalies occur over wide areas on the flanks of the range beyond major mining. Perhaps the most distinctive features of this area are the numerous sites that are anomalous in Mo, Pb, and Sb in both stream-sediment and concentrate media. Silver commonly is anomalous also. The concentration of Mo, Pb, and Sb in these samples is not as high as in many samples associated with skarn and plutons, but many sediment samples consistently contain 7–50 ppm Mo, 70–200 ppm Pb, and 4–7 ppm Sb. Geochemical thresholds for many elements probably are higher in this area, but for this quadrangle-wide assessment only the regional values have been used. The widespread Mo-Pb-Sb \pm Ag anomalies on the flanks of the range cannot be related to a specific lithology. Anomalies in the western part of the range are associated with mixed pre-Tertiary pelitic rocks and Tertiary volcanoclastic rocks, whereas the anomalies in the eastern part are associated with Tertiary flows and intrusive rocks. Numerous precious-metal prospects occur throughout the range and probably represent widespread Tertiary

hydrothermal processes that also are responsible for the geochemical anomalies.

The Gilbert district exhibits strong geochemical anomalies that in part probably reflect contamination from dumps. The Carrie mine produces a very large anomaly in Pb-Sb-W-Ag \pm Cu-Mo-Zn that is detected in five samples as far as 4 km west of the deposit (Zucker, 1986). This skarn-type geochemical expression is consistent with the mineralogy, rock geochemistry, and setting of the Carrie deposit which is adjacent to a Mesozoic stock (Nash, Siems, and Budge, 1985c). A few other sites have a similar geochemical signature that is consistent with locations near other small Mesozoic stocks in the range, but a strong skarn-type signature rich in W and Bi from a locality on the far western side of the range is not expected because no stock is known in that area (about 3–5 km east of U.S. Highway 95). The more typical epithermal vein Ag-Au deposits of the Gilbert district produce a clear Ag-Mo-Pb \pm Cu \pm As \pm Sb signature (base-precious metal) that is consistent with the composition of mineralized rocks from these deposits (Nash, Siems, and Budge, 1985c).

Royston Hills

The oldest rocks in this area are Triassic metavolcanic rocks, chert, siltstone, and limestone (Albers and Stewart, 1972; Kleinhampl and Ziony, 1985). These rocks are intruded by several small Mesozoic plutons of diorite to granodiorite composition. Tertiary welded tuffs and volcanoclastic rocks unconformably overlie the pre-Tertiary rocks. Numerous deposits of turquoise have been mined from highly altered Paleozoic and Mesozoic rocks, and Ag-Pb replacement deposits in Triassic limestone were mined at the Orizaba mine. In the 1960's and 1970's the plutonic rocks were explored for possible porphyry-type Cu-Mo deposits, but no significant mineralization was discovered.

Two chief geochemical associations occur in the Royston Hills: (1) sites characterized by base metals, especially Pb and Mo with or without Cu and W; and (2) anomalous sites characterized by an epithermal signature of chiefly Ag, Sb, and (or) Mo. A cluster of base-metal anomalies, including Ag, are in the northwestern part of the Royston Hills near the Orizaba mine, and other base-metal-enriched sites are scattered through the area. If these anomalies are related to plutonic rocks, as many seem to be elsewhere in the Tonopah quadrangle, then there would seem to be considerably more potential for pluton-associated mineralization than the relatively small amount of exposed plutonic rock would suggest.

Numerous other scattered sites exhibit Ag-Sb or Ag-Mo enrichment; the geologic association of these anomalies is not evident.

Cedar Mountains

The Cedar Mountains are adjacent to the Royston Hills (fig. 5), and for this discussion the part of the Gabbs Valley Range that is within the Tonopah quadrangle is included. The oldest unit in this area is Triassic siltstone, which is overlain by limestone and shale of the Triassic Luning Formation (Ross, 1961). Several stocks of intermediate composition, probably of Cretaceous age, intrude the Luning Formation (John, 1987). Tertiary volcanic rocks, including flows, welded tuffs, and lacustrine volcanoclastic rocks, unconformably overlie the pre-Tertiary rocks. The Triassic rocks are gently folded, and major faults along the western flank of the range cut and rotate Tertiary rocks. Mining and prospecting has focused on precious metals and W. The richest deposits, which were at Simon, consisted of oxidized Ag-rich Pb-Zn deposits in pipelike replacements of limestone and felsic Tertiary dikes. Silver-gold vein deposits in tuff were locally rich at the Olympic and Warrior mines. An older period of mineralization associated with the stocks and their metasomatic aureole in limestone strata produced W-skarn deposits at several places near Cedar Summit. The geology is similar at the southern end of the Gabbs Valley Range where many small prospects and the Copper Chief and Clay Peters mines occur. These deposits, which apparently contain precious metals, Cu and W, were evaluated as porphyry Cu-Mo targets in the 1970's.

This area has many strong geochemical anomalies. More than 80 percent of the sites have anomalous concentrations of one or more elements, and many have strong multielement anomalies in both media. Many stream sediments are rich in Cu, Mo, Pb, Sb, and W, and scattered samples are rich in As and Bi. Three geochemical suites are represented: (1) The skarn suite, here notably rich in Pb and W in the concentrate medium. Sites characterized by this suite are downstream from known skarn mines or prospects and granitic plutons, although a few sites are distant from known skarn deposits. (2) The base-metal suite, with or without Ag. These anomalies are scattered and probably are related to plutonic rocks and their aureoles. (3) The epithermal suite, chiefly As or Sb, is anomalous in stream-sediment samples. These anomalies may be related to Tertiary precious-metal deposits; the known Tertiary deposits at the Warrior and Omco mines are not reflected in the geochemistry because samples were not collected near them due to poor drainage development. These three suites were recognized in a geochemical study of

mineralized rock samples from the Cedar Mountains (Nash, Siems, and Hill, 1985). Although Tertiary epithermal precious-metal mineralization occurs at many places in this area it is not evident in the geochemical signature, possibly because those deposits contain lower concentrations of diagnostic elements than do the pluton-associated deposits (Nash, Siems, and Hill, 1985).

Shoshone Range

The Shoshone Range, like the Toiyabe Range which adjoins it on the east, is underlain chiefly by thick sequences of Tertiary welded tuff (Kleinhampl and Ziony, 1985). Permian to Triassic metavolcanic, clastic, and carbonate rocks occur chiefly on the northwestern flank of the range between Grantsville and Ione. A few small Cretaceous stocks are known, and others are inferred to exist in the subsurface. The pre-Tertiary rocks are cut by a complex set of low- and high-angle faults, and the Tertiary rocks are tilted and cut by some high-angle faults.

Prospecting in the Shoshone Range has led to the discovery of many types of ores. The first discovery was Au in large quartz veins in metavolcanic rocks of the Union district. Later Hg was discovered in pre-Tertiary and Tertiary rocks, and a large amount of Hg was produced from the mines near Ione. Polymetallic sulfide replacement deposits in limestone at Grantsville were very rich in Ag in the oxidized zone (and also contained W at the deepest level). Small deposits of fluorite and barite have been mined at several places, and placer gold was mined from several paleostream channels, most notably near Ione.

The geochemistry of the Shoshone Range is quite variable: some parts have strong and distinct multielement anomalies, and other parts have subdued enrichments in only a few elements at scattered sites. The geochemical associations in the Shoshone Range seem to be different from those in other parts of the Tonopah quadrangle. Among the base metals, Pb and Sb are most prominent, whereas Cu, W, and Bi are rarely anomalous. Zinc is anomalous in both sediments and concentrates at many sites but generally does not occur with Pb. With the exception of one very strong base-metal anomaly from Knickerbocker Wash, 4 km south of Ione, that is anomalous to highly anomalous in 11 elements in both media, other sites are anomalous in only a few base metals in either sediment or concentrate to make what I term a weakly developed signature. Silver is anomalous at about half of the anomalous sites, detected in either one or both media. Some of the high Ag values are from concentrate samples that contain native gold.

Three types of geochemical anomalies are present in the Shoshone Range. A base-metal type, rich in Pb-Sb \pm Ag, is best developed in the northwestern part between Ione and Berlin and occurs at some scattered sites to the south. The strongest single site anomaly, at Knickerbocker Wash, contains anomalous Bi and W and thus was flagged as a skarn-type anomaly, but it seems to fit in with adjacent base-metal anomalies. Base-metal deposits, with W and especially Ag, are known at Grantsville, but those deposits were not detected in this survey, probably because our sample localities were east of the deposits. The base-metal anomalies of the Ione-Union area may be related to greenstones in that area, although there are numerous possible sources in this complex area, including the Tertiary Hg deposits. The second type of anomaly in this region is highlighted by Ag, accompanied by one or two of the elements Pb, Mo, Sb, or Au. No clear or simple geologic association of these Ag-rich sites is evident, but they do confirm the known precious-metal potential of the area. The third type of anomaly is highlighted by Zn in sediment or concentrate samples, generally with no other associated metal enrichments except Sb. This type of anomaly is associated with areas of Tertiary welded tuff and seems to be like the other subtle anomalies that developed in areas of tuff elsewhere in the Tonopah quadrangle.

Paradise Range

Lower Paleozoic(?) sedimentary rocks and Permian to Triassic clastic, volcanoclastic, and intrusive rocks in the Paradise Range were overthrust by upper Paleozoic to Jurassic clastic, volcanic, and carbonate rocks, including the Luning Formation which is host to many ore deposits in this area. Numerous plutons of diorite to granite composition intruded these rocks from the Jurassic(?) through Late Cretaceous (John, 1987). Oligocene and Miocene ash-flow tuffs and intermediate lavas crop out on the southern, eastern, and northern flanks of the range and may have once covered the entire area. Mesozoic-age thrust faults juxtapose complexly folded pre-Tertiary strata, and high-angle and low-angle (detachment) faulting continued through the Tertiary.

A variety of mineral deposit types occur in the Paradise Range (Kleinhampl and Ziony, 1984), including the following: (1) Au veins in Mesozoic or Paleozoic(?) metavolcanic rocks; (2) Fe- and W-skarn deposits and base-precious-metal vein deposits associated with plutons at the northern end of the range and in the Lodi Hills; (3) several porphyry-type Mo-Cu deposits associated with Cretaceous stocks at the southern end of the range, including one unusual variety in calc-silicate-altered limestone near B and C Spring; (4) Ag-Au vein deposits in Tertiary volcanic rocks at several places at the

northern and southern ends of the range (Ellsworth and Goldyke districts); (5) the newly discovered Paradise Peak Ag-Au deposit at the southern end of the range; (6) several Hg mines and prospects in pre-Tertiary and Tertiary rocks; and (7) magnesite ($MgCO_3$) deposits in contact-metamorphosed Luning Formation east of Gabbs.

Numerous geochemical anomalies occur in the Paradise Range with notable enrichments in W, Pb, and Ag in concentrate samples and scattered enrichments in Bi, Cu, Mo, and Zn in sediments. As and Sb anomalies are relatively rare. A common association in this area is W-Pb-Ag, generally without Cu, Mo, or Bi, thus the geochemistry of W-Pb in concentrate samples in this area differs from many other areas in the quadrangle. The W-Pb-Ag association seems to be related to skarn-type mineralization based on the proximity of anomalous samples to several known skarn deposits in the Lodi Hills and northern Paradise Range (John, 1987). The Bi content of concentrate samples that contain very high W concentrations ($>5,000$ ppm) is only 30–700 ppm, and concentrates with less W contain little or no Bi; in other areas most concentrate samples with high W concentrations have similar amounts of Bi. The distribution of W-Pb-Ag-rich concentrates is more widespread than expected from the distribution of known W-skarn deposits and prospects. Although many intrusive bodies are known in the Paradise Range, most do not create skarn alteration zones in contact-metamorphosed wallrocks (D. John, oral commun., 1986). Thus, in this area the high W concentrations and their wide distribution do not meet all the requirements for postulating the presence of W-skarn deposits. Sites characterized by anomalous Ag and base metals occur at the northern end of the range, which is consistent with the known Ag-Au deposits that are associated with plutonic rocks in the western part of the Ellsworth district.

The epithermal suite, especially As and Sb, is poorly developed in the Paradise Range. Although epithermal precious-metal deposits are known at both ends of the range, they are not evident in this survey. One reason for the absence of this suite is the paucity of samples from areas underlain by Tertiary volcanic rocks which tend to have poorly developed drainage. No sample was collected near the newly discovered Paradise Peak Ag-Au deposit, and there are only a few sample sites in the low relief area of Goldyke and the Pactolus Hills, which are sites of former Ag-Au mines.

Base-metal anomalies associated with plutons in the Paradise Range dominate over subtle signatures in volcanic terrane. This recurring theme has been mentioned in the discussion of several other areas in the Tonopah quadrangle. In this geochemical interpretation

I may be underestimating the significance of element concentrations in volcanic terrane by applying quadrangle-wide geochemical thresholds to all rock types.

Pilot Mountains

Geology of the Pilot Mountains (Ross, 1961) is generally similar to that of the Cedar Mountains and Paradise Range previously described. The oldest rocks are Permian to Jurassic clastic, volcanoclastic, and carbonate rocks. Several small Jurassic and Cretaceous stocks of diorite to granite composition intrude the sedimentary rocks (Ross, 1961). Scattered remnants of Tertiary volcanic rocks cap the pre-Tertiary rocks. The Pilot Mountains have had a complex structural history that included several periods of Mesozoic thrust faulting, folding, and high-angle faulting, as well as major late Cenozoic strike-slip faulting related to the Walker Lane.

Mining in the area has yielded chiefly Hg and W. Many Hg mines at the crest of the range occur in association with thrust faults in pre-Tertiary rocks and to a lesser extent in Tertiary volcanic rocks. Tungsten and Cu prospects have been prospected and mined at many places near stocks on the east flank of the range, chiefly at the Gunmetal and nearby Good Hope mines (Grabher, 1984). Several large deposits of scheelite (W) in garnetiferous skarn have been drilled out along limestone-granite contacts near the former Gunmetal mine. The southeastern flank of the range was explored for porphyry-type Cu-Mo deposits in the 1970's, and several turquoise mines and prospects occur in altered siltstone in this area as well. The geochemistry of mineralized rock samples from the Pilot Mountains was described by Nash, Siems, and Budge (1985d).

This area produces the strongest and most abundant multielement anomalies in the Tonopah 1° × 2° quadrangle. Element concentrations in both media are very high. Most of the samples are anomalous in several metals, and virtually the entire area can be considered to be highly anomalous. The sample density in this area is higher than normal because of the research conducted by J.S. Zuker of the U.S. Geological Survey and Colorado School of Mines (Zuker, 1986). Most sites are characterized by anomalous concentrations of 4–10 elements in both media—which cannot be said for other parts of the quadrangle. Other exceptional features of the geochemical results are the generally high concentrations of As, Bi, Cu, Mo, Pb, Sb, W, and Zn. Tungsten and Sb are anomalous at more than 50 percent of the sites. Two major types of associations are evident in the results: (1) skarn type, with most of the following elements—W, Bi, Pb, Mo, Zn, Cu, Ag, As, and Sb; and (2) base-metal type, here especially rich in Sb, but also containing Pb, Zn, ±

As, ± Cu, ± W, ± Ag. Silver is notably present in both suites, as are both W and Sb. The high concentrations of Sb in stream-sediment samples collected near known W-skarn deposits, and also the presence of W in concentrate samples from areas of Hg mineralization, are not expected because these elements are not anomalous in mineralized rock samples from the deposits (Nash, Siems, and Budge, 1985d). Very high concentrations of Bi are found in concentrate samples from sites near the Gunmetal W-skarn deposits on the eastern side of the range, and Bi is less anomalous in the numerous W-rich concentrate samples from the northern and western parts of the range. These geochemical associations are only partly consistent with the geochemistry of mineralized rock samples from the Pilot Mountains (Nash, Siems, and Budge, 1985d; J.T. Nash and D.F. Siems, unpublished data, 1985). Rock samples from the Hg deposits are rich in base metals, including Cu, Sb, and Zn, and rock samples from some skarn prospects contain high concentrations of many elements, including Ag, As, Bi, Cu, Mo, W, and Zn. Drill core samples from the Gunmetal deposit are not anomalous in As and Sb (J.T. Nash and D.F. Siems, unpublished data, 1985), although many of the stream-sediment and concentrate samples collected near W skarns that have high W concentrations also contain high Sb and As concentrations in both media. The specific sources of As and Sb in the W-rich stream-sediment samples are not known, but the W and Sb could possibly be derived from different ages or zones of mineralization.

DISCUSSION

Spectrographic and chemical analyses of the two sample media utilized in this regional geochemical survey, the <0.25-mm fraction and the nonmagnetic heavy-mineral concentrate from stream sediment, are effective for defining geochemically anomalous areas that are consistent with the distribution of known deposits, prospects, and hydrothermal alteration. Although some anomalous sites probably reflect contamination from mines or mills, most anomalies found in this survey that are near known deposits are from sites that were selected to avoid man-made contamination and that appear to reflect dispersion from natural sources. Many clusters of geochemical anomalies include sites from drainages that extend beyond known deposits, which suggests the possibility of new deposits or extensions of deposits within districts. Detailed follow-up geochemical and geological studies should be made to substantiate those areas inferred to be favorable for undiscovered deposits.

Geochemical anomalies are greater in magnitude and abundance in the western half of the Tonopah

quadrangle (figs. 2-4), which is consistent with the abundance of known deposits in that area. However, some of the differences in number and intensity of anomalies in the two parts of the quadrangle may reflect the greater abundance of plutonic and eugeoclinal sedimentary rocks in the western part that probably are more enriched in base metals than are the volcanic rocks and miogeoclinal sedimentary rocks that dominate the eastern part of the quadrangle. Although one might question whether anomalous elements in stream sediments reflect regionally high concentrations in some rock types rather than contributions from mineralized rocks, either source of the elements detected in stream sediments can be considered as evidence for a greater likelihood of mineral deposits occurring in the western half of the quadrangle.

The concentrate medium produces stronger anomalies with higher contrast relative to background as compared to the <0.25-mm fraction of stream sediments. This situation, which also has been found in other regional surveys (Overstreet and Marsh, 1981), is a reason for selecting the concentrate medium. This medium seems to be particularly good for detecting W, which occurs as scheelite, and Sn, which occurs as cassiterite, as well as many chalcophile elements such as Pb, Cu, and Zn. Most of the anomalies suggested by the concentrate medium are plausible because they correspond in space to geologic features and known deposits. However, caution is suggested in the application of results from concentrates to mineral exploration because the alluvial and laboratory processes that upgrade the original detritus about 1,000- to 10,000-fold can produce geochemical accumulations from mineral grains scattered in rocks that have not been subjected to ore-forming processes. I suspect that most of the high values for Sn in concentrate reflect alluvial concentration of refractory cassiterite that cannot be traced back to mineral deposits. Likewise, some determinations of Au in concentrate probably reflect local alluvial concentrations rather than significant mineral deposits upstream, and it is just as likely that our samples failed to detect Au deposits because of the nugget effect of Au in alluvium and in laboratory processing.

This survey and interpretation may underestimate the likelihood of epithermal deposits in volcanic terrane. My experience with mineralized rock samples from the Tonopah quadrangle suggests that low-sulfide systems, such as Au-quartz systems with low pyrite content of the quartz-adularia and hot-springs type (Berger and Eimon, 1983), produce only weak geochemical enrichments compared with sulfide-rich ore systems. In addition, the use of one set of anomaly thresholds for all rock types throughout the entire quadrangle may contribute to the problem of identifying geochemical anomalies in volcanic

terrane that have low contrast relative to background. However, recalculation (J.L. Dwyer and J.T. Nash, 1987; unpublished data) of background and thresholds for samples from drainages that are underlain predominantly by volcanic rocks amplifies anomalies only a small amount and does not change the spatial trends shown on plate 1. Other sample media or analytical techniques for rare elements (such as Au) at concentrations below 1 ppm might better detect epithermal-type anomalies. Spatial analysis of multivariate geochemical, geologic, and remotely sensed alteration data (Dwyer and others, 1987) may permit realistic interpretation of geochemical anomalies with low contrast.

Finally, these geochemical results and interpretations should be combined with geology for the most effective use of the data. Most of the drainage basins in the Tonopah quadrangle are underlain by several rock types, each of which contributes alluvium with a different geochemistry; alteration or other chemical evidence for ore-forming processes may or may not be present or could be so diluted by barren rock as to preclude detection. Many sites reported as anomalous on plate 1 cannot be reconciled with the character of rocks observed in the basins. The most common examples are the lack of evidence for calc-silicate contact metamorphism in basins that produce strong skarn-type geochemical signatures and the lack of evidence for structure, veins, and alteration to explain anomalies of As-Sb-Mo-Zn in basins underlain by welded tuff. Spatial analysis of geochemical maps with alteration maps would substantially improve resource assessment.

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