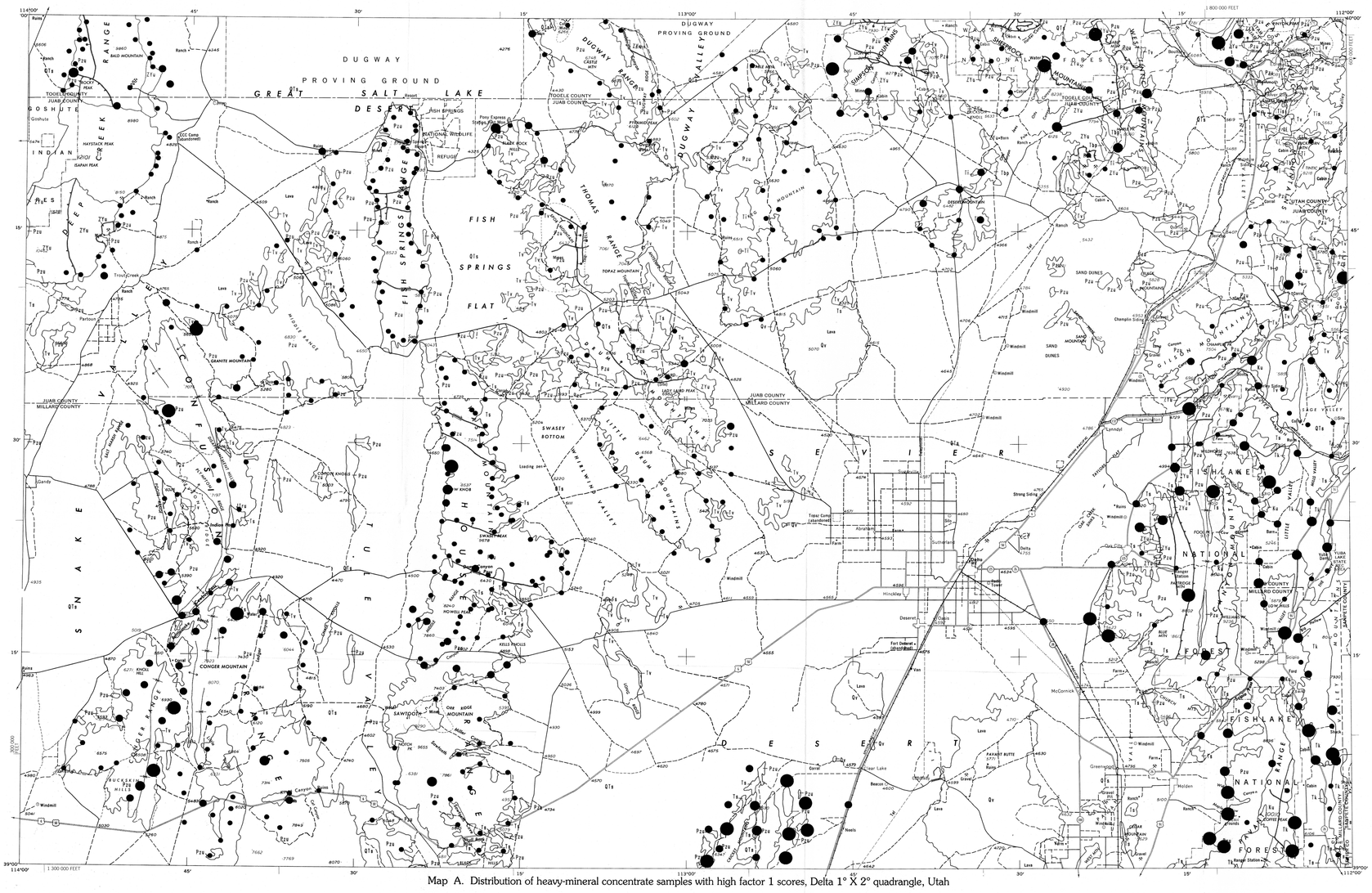
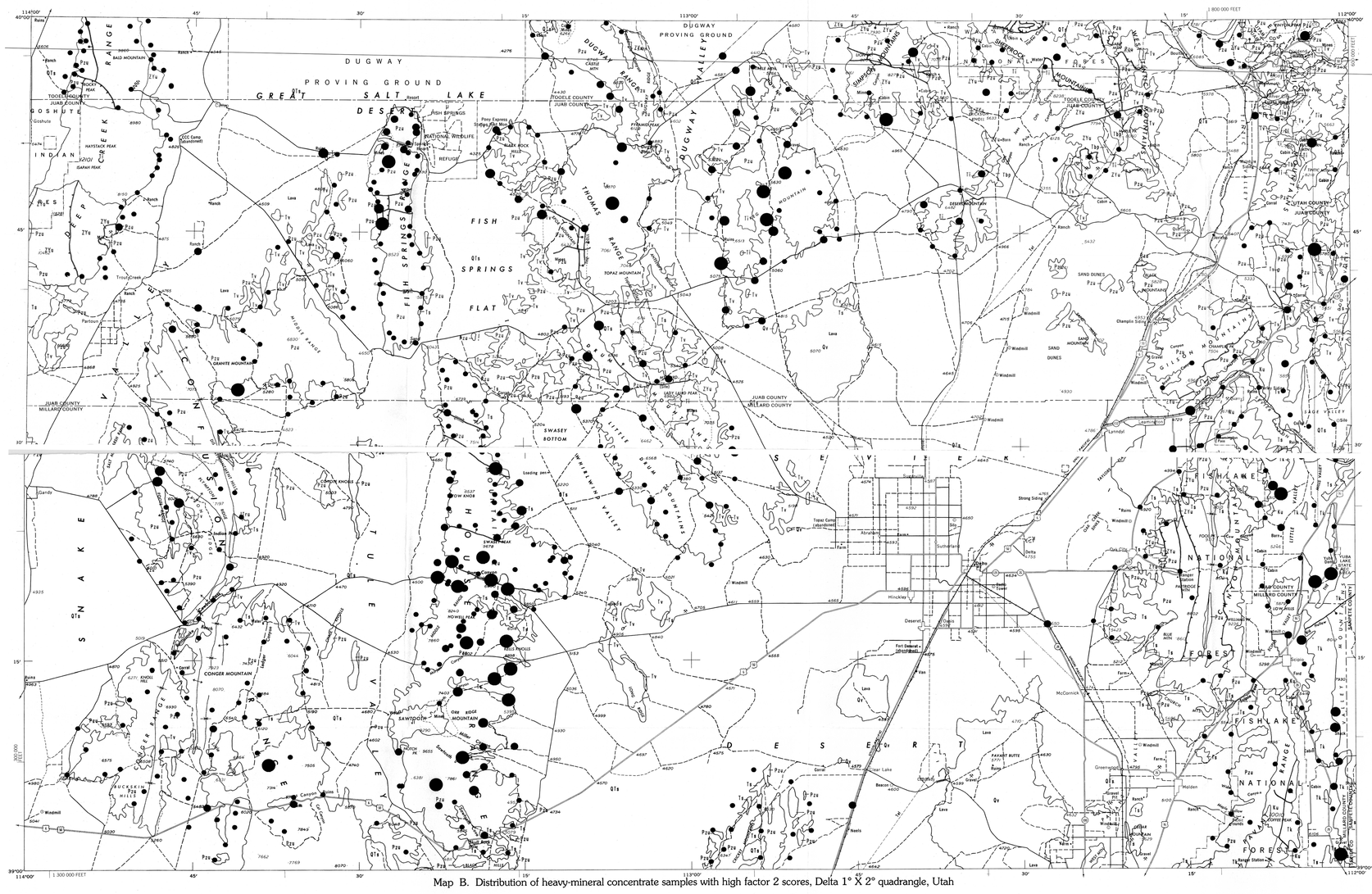
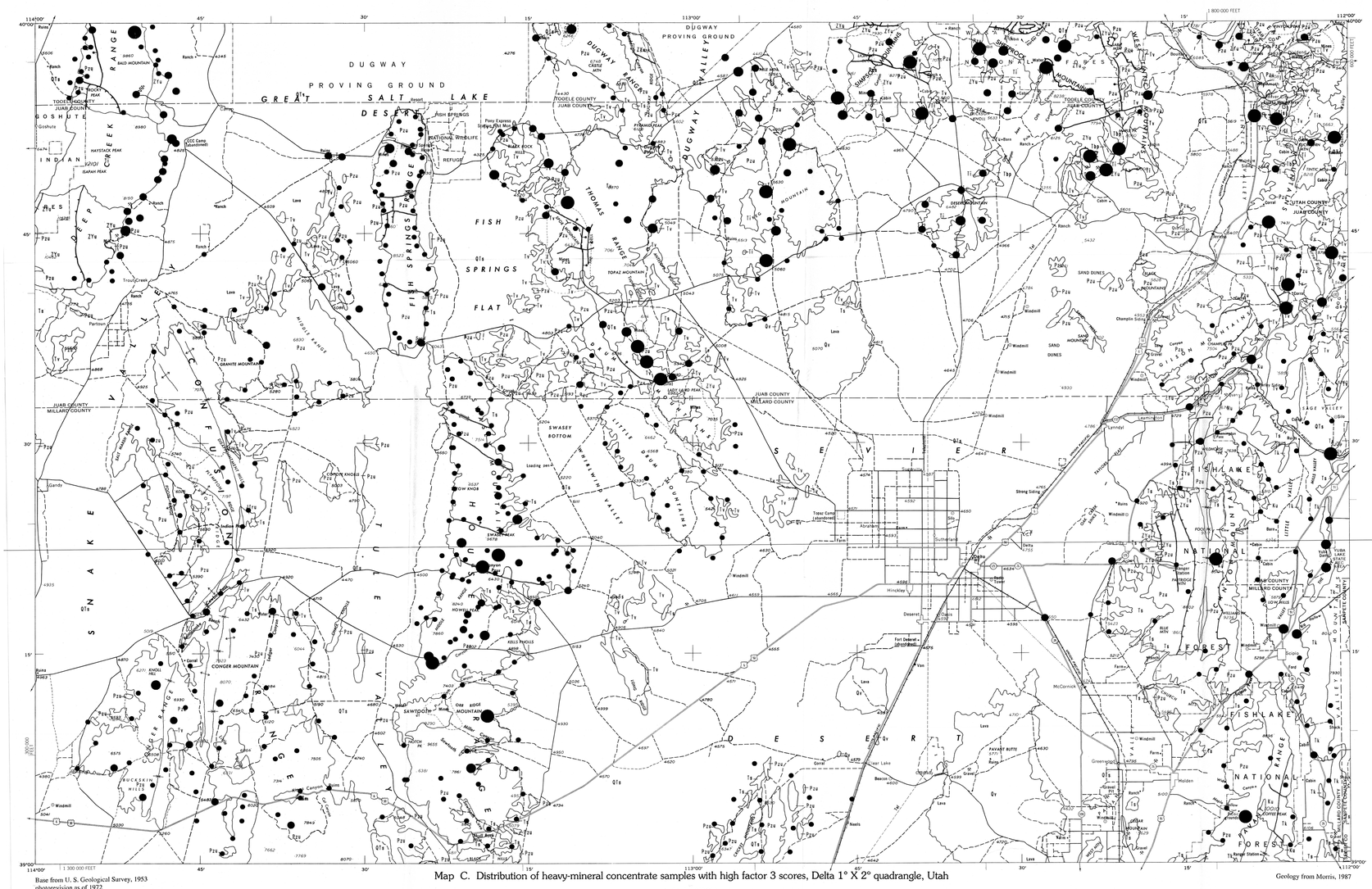


Map A. Distribution of heavy-mineral concentrate samples with high factor 1 scores, Delta 1° X 2° quadrangle, Utah



Map B. Distribution of heavy-mineral concentrate samples with high factor 2 scores, Delta 1° X 2° quadrangle, Utah



Map C. Distribution of heavy-mineral concentrate samples with high factor 3 scores, Delta 1° X 2° quadrangle, Utah

Base from U. S. Geological Survey, 1953
photorevision as of 1972

Geology from Morris, 1987

SCALE 1:250 000

EXPLANATION, FACTOR 1

Lower boundary	Upper boundary	Symbol	Approximate percentile
-3.14	0.76	•	<75
0.76	1.18	●	75–90
1.18	1.39	●	90–95
1.39	2.36	●	>95

Samples located at geometric midpoint of symbols.

INTRODUCTION

A set of heavy-mineral concentrate data for the Delta 1° x 2° quadrangle, Utah Conterminous U.S. Mineral Assessment Program (CUSMAP) project was compiled from results of analyses of samples collected during the National Uranium Resource Evaluation Program (NURE), as well as results obtained from samples collected more recently by the USGS. Data results, sampling methods, and analytical methods are provided in Arbogast and others, 1993; 1990; 1988a; 1988b). A similar report, discussing results obtained from stream-sediment samples, is presented in Zimbelman (1993a).

The Delta 1° x 2° quadrangle, Utah (figure 1) contains a variety of hydrothermal mineral deposit types, including porphyry-, vein-, replacement-, and Carlin-type deposits. These deposit types have been worked for commodities including gold, silver, beryllium, uranium, lead, zinc, copper, manganese,and cadmium (Lindsey, 1977; Morris and Mogensen, 1978; Zimbelman and others, 1990; Zimbelman and others, 1988). Heavy-mineral concentrate and stream-sediment samples derived from these hydrothermally altered rocks typically contain many geochemical anomalies (for example, see Zimbelman 1993b,c,d).

Element associations characterizing lithology and hydrothermal mineral deposits can be distinguished using R-mode factor analysis. This tool often is useful in reconnaissance-scale surveys where sample anomalies are often weak, and single-element distributions may not help to delineate targets. R-mode factor analysis can help identify geologic trends and areas most likely to contain the mineral deposits.

R-mode factor analysis was performed on a data set of results of analyses for 19 elements in 643 samples and produced a six-factor model. These six factors represent the geochemical contributions to the data set provided by lithologic and mineralization processes. The distribution of samples that contain high scores for mineralization-related factors is widespread in the Delta quadrangle. These sample sites are thought to relate to both known prospect and mineralization areas, as well as to define new areas that are geochemically favorable to contain altered or mineralized rocks.

GEOLOGIC SETTING

The geologic history of Utah is summarized by Hintze (1988) who describes eight major episodes. Primary features characterizing these episodes and their relationships to hydrothermal mineral deposits are briefly described below. The generalized geology of the study area can be found in the geologic map of the Delta 1° x 2° quadrangle (Morris, 1987). The report and map referred to above also contain many additional references to more detailed studies of individual mining districts and prospect areas.

The oldest known rocks in this area only crop out in isolated exposures and consist of a Proterozoic metamorphic basement sequence characterized by mixed island arc sedimentary-volcanic rock assemblages. These rocks are not known to be important in the formation of mineral deposits in the quadrangle. During the Late Proterozoic to Devonian, a miogeoclinal setting produced extensive shallow-water marine deposits that host many of the base- and precious-metal deposits in this area, especially in the Deep Creek-Tintic mineral belt. A thick sequence of fine-grained siliceous units was deposited in the Oquirrh basin during the Mississippian to Permian. These rocks host large ore bodies north of the study area at the Mercur gold mine and the Bingham copper-gold mine. Rocks formed in an interior basin during the Trlassic and Early Cretaceous are poorly exposed in west-central Utah. These rocks are commonly covered by thrust plates of older rocks. The Late Cretaceous Sevier orogeny consisted of compressional tectonism, eastward-directed stacked thrusting, and mountain building. One result of these processes was the development of regional-scale fluid pathways along which younger mineral deposits eventually formed. The Paleocene to Eocene were characterized by Laramide uplifts and basin formation, a record of which is not well preserved in the study area. Explosive volcanic activity produced calderas and stratovolcanoes during the Oligocene to early Miocene. Numerous ash-flow tuffs, lavas, and stocks were emplaced throughout much of the study area during this time, along with associated base- and precious-metal deposits. Basin-range tectonism, characterized by block faulting, regional uplift, and

EXPLANATION, FACTOR 2

Lower boundary	Upper boundary	Symbol	Approximate percentile
-2.48	0.53	•	<75
0.53	1.40	●	75–90
1.40	1.89	●	90–95
1.89	4.08	●	>95

Samples located at geometric midpoint of symbols.

the accompanying deposition of nonmarine sedimentary rocks, rhyolite, and basalt, prevailed during the late Miocene to Holocene. Lithophile-metal mineralization was especially prevalent during this geologic episode.

MINERAL DEPOSIT TYPES

Western Utah contains several types of metallic mineral deposits. These include a diverse suite of base- and precious-metal deposits, such as Carlin-type deposits, skarn deposits, porphyry and porphyry-related deposit types, and polymetallic vein and replacement deposits. These base- and precious-metal deposits are present throughout the Delta quadrangle, especially within the Deep Creek-Tintic mineral belt (Butler and others, 1920; Hilpert and Roberts, 1964; Stokes, 1968). In addition, various other metals have been mined in the quadrangle. Of particular note are deposits related to alkali rhyolite magmatism in the Spor Mountain area, which contains one of the largest economically recoverable beryllium resources in the world (Griffitts, 1964). Typically, these beryllium deposits are associated with fluorspar and uranium mineralization (for example, ludwig and others, 1980; Bowyer, 1963; Burt and Sheridan, 1981). A brief summary of the general features of these base-, precious-, and lithophile-metal deposit types, as they apply to the study area, is given below.

CARLIN-TYPE DEPOSITS

The characteristics of Carlin-type deposits are summarized by Bagby and Berger (1985) and Percival and others (1988). These deposits are generally found in the Basin and Range province, are hosted by carbonate-bearing sedimentary rocks with a wide range of lithologies, are closely associated with high-angle faults, and frequently include igneous rocks at a district scale. Hydrothermal alteration in Carlin-type deposits consists of decalcification, silicification (including jasperoid formation), argillization, and veining of calcite and quartz. Many deposits of this type contain both oxide and sulfide ores. The sulfide minerals commonly include disseminated pyrite and arsenian pyrite, with less common occurrences of marcasite, arsenopyrite, realgar, orpiment, and stibnite. Gold-silver ratios are high in most of these deposits. Associated trace elements include Hg, As, Sb, Tl, Ba, F and Ag; small amounts of base metals are also characteristic.

PORPHYRY-TYPE DEPOSITS

The term "porphyry-type deposit" is used in a general sense for the purposes of this report. Numerous porphyry-type deposits are present in western Utah, especially within the mineral belts (Hilpert and Roberts, 1964). Porphyry-type systems consist of porphyry stocks emplaced near the surface and associated with pervasively altered and mineralized rock that is commonly arranged in roughly concentric zones centered on the stock(s). Sillitoe (1988) described precious-metal deposits that are spatially related to porphyry systems throughout the world. This deposit type commonly includes both oxide and sulfide zones that contain complex assemblages of anomalous concentrations of trace elements, including several, but not necessarily all, of the following: Cu, Mo, Pb, Zn, Cd, Au, Ag, As, Sb, Ba, Bi, Sn, and(or) W. Gold-silver ratios can vary widely within and between different porphyry systems.

VEIN- AND REPLACEMENT-TYPE DEPOSITS

Polymetallic vein- and replacement-type deposits are present throughout a large part of western Utah. Typically, vein and replacement deposits occur within the same mineral district and can grade into each other depending on the host rock lithology (Morris, 1974). In addition, these deposits may be present in the same districts as the porphyry-type deposits, contained within several host rock lithologies within, above, or around the porphyry deposits. These deposits generally include fault- or fracture-controlled veins or replacement bodies, typically with narrow alteration selvages, and commonly possess complex geometries. These deposit types typically contain complex trace-element assemblages and a wide range of gold-silver ratios.

EXPLANATION, FACTOR 3

Lower boundary	Upper boundary	Symbol	Approximate percentile
-1.98	0.41	•	<75
0.41	1.20	●	75–90
1.20	1.93	●	90–95
1.93	6.09	●	>95

Samples located at geometric midpoint of symbols.

ALKALI RHYOLITE-RELATED DEPOSITS

Epithermal replacement deposits associated with alkali rhyolite magmatism are present throughout much of western Utah (Lindsey, 1977). These include large deposits of beryllium and smaller deposits of fluorspar and uranium. In addition to the carbonate-hosted replacement deposits at Spor Mountain and other localities, smaller vein deposits are present in much of the northern part of the Delta quadrangle (Montoya and others, 1964; Cohenour, 1963). The alkali rhyolite-related deposits contain ore-grade concentrations of Be, F, and U; the deposits also contain anomalous concentrations of Mo, Pb, Sn, W, Cs, Li, Ga, Nb, and Y (Lindsey, 1977). Many members of this same suite of elements, along with a few other incompatible lithophile elements such as Rb, Th, and Ta, are also present in anomalous concentrations in the associated alkali rhyolites (Christiansen and others, 1986).

SAMPLING AND ANALYTICAL PROCEDURES

Heavy-mineral concentrate samples that were chemically analyzed for this report were collected from 643 sites. Of these samples, 169 were collected by the USGS and 474 samples were collected during the National Uranium Resource Evaluation (NURE) program (Sharp and Aamodt, 1978).

The stream-sediment samples collected during the NURE program were a composite of three subsamples, roughly equal in size and collected within a radius of approximately 30 m of the designated site (Sharp and Aamodt, 1978). This material was sieved and a plus-40-mesh fraction was stored in a warehouse, from which it was retrieved for study.

Samples collected by the USGS consisted of active alluvium collected primarily from first-order (not branched) and second-order (below the junction of two first-order) streams, as shown on USGS 1:24,000-scale topographic maps. Each sample represents a composite derived from subsamples collected within a radius of as much as 17 m from the site plotted on the map.

ANALYTICAL PROCEDURES

The heavy-mineral-concentrate samples were analyzed for 31 elements (Ag, As, Au, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, La, Mg, Mn, Mo, Nb, Ni, Pb, Sb, Sc, Sn, Sr, Th, Ti, V, W, Y, Zn, and Zr) using a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). The results of the analyses can be found in Arbogast and others (1993; 1990; 1988a; 1988b). All values are reported within a framework of six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, or multiples of 10 of these numbers) and represent approximate geometric midpoints of the concentration ranges. The precision has been shown to be within one adjoining reporting interval on each side of the reported value 83 percent of the time, and within two adjoining intervals 96 percent of the time (Motooka and Grimes, 1976).

ANALYTICAL RESULTS

Univariate statistics, histograms, and single-element distribution plots were used to evaluate the geochemical data. Data concerning the censorship of the elements are presented in table 1. Single-element distribution maps for Ag, As, Ba, Be, Bi, Cd, Cu, Mo, Pb, Sb, Sn, W and Zn reveal complex patterns of anomalously high values for many elements (Zimbelman, 1993d). Many of these anomalies can be attributed to the presence of hydrothermally altered rock at several localities in the study area.

MULTIVARIATE ANALYSIS

Analysis of multivariate data allows one to simultaneously consider changes in several parameters. Factor analysis, one of several types of multivariate analysis used in geologic studies (for example, Davis, 1973), is a method for identifying common factors (suites of elements, in this case) in the variables of a data set. Factor analysis is useful when the number of factors is smaller than the number of elements analyzed. The method involves interpreting the structure within a variance-covariance matrix of a multivariate data set and assigning the various elements of the matrix to groups (factors) based on a common variability of these elements. A factor is a vector weighted proportionally to the amount of the total variance that it represents. R-mode factor analysis is used to investigate the interrelationships in a matrix of correlations between variables, whereas Q-mode factor analysis is used to investigate the interrelationships between samples. Thus, R-mode factor analysis can be used to identify groups of elements that have common associations, for example a group of elements that represents a certain rock type or a certain zone in a hydrothermal mineral system.

RESULTS OF R-MODE FACTOR ANALYSIS

The R-mode factor analysis, with varimax factor rotation, resulted in an six factor model. The contributions of each element onto each factor (termed factor loadings) are shown in table 2 and summarized in figure 2. Each element may have a high positive or negative loading for one or more of the factors, or the element may not have a significant loading for any of the factors (for example, for these data, Nb). Regarding base-, precious- and lithophile-metal mineral deposits, factors 2, 3, 4, and 6 are especially significant, representing mineralization or a combination of mineralization and lithologic processes. The other factors (1 and 5) are regarded as representing lithologic contributions to the geochemical data set.

The effect a factor has at a sample site is represented by a factor score. Sample scores for all of the factors were divided into four groups on the basis of percentiles as follows: more than 95th, 95-90th, 90-75th, and less than 75th. Maps A through F summarize the distribution of samples that contain factor scores represented by these percentiles for factor 1 through 6, respectively. These maps portray the areal variation of the interpreted mineralization and lithologic types.

INTERPRETATION

FACTOR ANALYSIS

Factor 1 is defined by the elements B, Ti, V, Cr, and Sc (table 2). This factor is interpreted to represent the geochemical influence of Proterozoic and Paleozoic clastic sedimentary rocks on the heavy-mineral concentrate samples.

Factor 2 is defined by the suite of elements Mn, Fe, and Co (table 2). This factor is interpreted to represent ferromagnesian-mineral-bearing rocks, including various igneous rocks, sedimentary rocks that contain detrital ferromagnesian minerals, and rocks with coatings of ferromagnesian minerals. In addition, this factor may represent hydrothermal rocks derived from contact zones between igneous rocks and carbonate-bearing sedimentary rocks (tactites).

Factor 3 is defined by high positive loadings for the elements Pb, Sn, and Cu (table 2). These elements are interpreted to represent the geochemical contribution made by hydrothermally altered rocks related to base- and precious-metal mineral systems in the study area.

High positive loadings for Ba and Sr define factor 4 (table 2). These elements can be found both in sedimentary rocks, especially carbonate-bearing ones, and in rocks associated with base- and precious-metal-bearing hydrothermal mineral systems.

Factor 5 is defined by La and Y (table 2). These elements are interpreted to represent the geochemical contribution to the data set from relatively evolved igneous rocks.

Factor 6 is defined by positive loadings for Be and negative loadings for Ca and Mg (table 2). This geochemical association is interpreted to represent the occurrence of lithophile-metal mineralization in the study area, especially carbonate-hosted lithophile-metal mineralization. In addition, this factor can be interpreted to represent the geochemical contribution of felsic igneous rocks or vein- or disseminated lithophile-metal deposits and prospects related to such rocks.

Lithologic Factors

Samples that contain high factor 1 (B-Ti-V-Cr-Sc) scores cluster in the Cricket, Canyon, and Valley Mountains, and in the Confusion and Pavant Ranges; samples that contain high factor 1 scores from widely scattered sites were collected in the Deep Creek and House Ranges, in the Simpson, Sheeprock, Tintic, and West Tintic Mountains, and in the Black Rock Hills areas (map A). Most of these samples were collected from drainages that contain outcrops of clastic sedimentary rocks and factor 1 is interpreted to represent the geochemical contributions of such rocks to the data set.

Samples that contain high factor 2 (Mn-Fe-Co) scores and that are interpreted to be related to lithologic processes were collected throughout much of the study area (map B). These sample sites cluster in areas drained by Tertiary volcanic rocks in the Keg Mountains and areas that contain Cretaceous and Tertiary clastic sedimentary rocks in the Canyon and Valley Mountains. Samples that contain high factor 2 scores and are related to mineralization processes are discussed below.

Samples that contain high factor 4 (Ba-Sr) scores were collected from the Confusion, Deep Creek, Fish Springs, and House Ranges in the western part of the study area (map D). The factor 4 element suite may reflect the presence of Paleozoic carbonate-bearing rocks in drainage basins associated with some of these samples and the suite probably reflects the presence of outcrops and buried hydrothermally altered rocks at other sample sites, as discussed below.

Samples that contain high factor 5 (La-Y) scores were collected from streams that drain outcrops of intermediate to felsic igneous rocks throughout the northern part of the quadrangle, as well as areas that contain upper Paleozoic, sedimentary rocks in the Confusion Range. Clusters of samples that contain high factor 5 scores and are related to igneous rocks were collected in the Deep Creek Range and in the Desert, Keg, and Sheeprock Mountains. Samples containing high factor 5 scores and that were collected from drainages containing clastic sedimentary rocks in the Confusion Range may indicate that some of these rocks were derived from a felsic igneous protolith.

Samples with high factor 6 (Be) scores were collected from drainages that contain outcrops of igneous rocks in the Thomas Range and in the Keg and Sheeprock Mountains (map F). This factor is interpreted to represent the location of evolved igneous rocks in these areas. Additionally, various types of lithophile-metal mineral deposits related to similar igneous rocks may be represented by some of these samples, as discussed below. Many samples from areas that contain clastic-sedimentary rocks also contain high factor 6 scores. These include samples from the Canyon and Cricket Mountains and the Pavant Range. These geochemical results suggest that these sedimentary rocks were formed from a protolith that included evolved igneous rocks.

Mineralization Factors

Samples that contain high factor 2 (Mn-Fe-Co) scores and that may represent mineralization-related rocks were collected from scattered sites throughout the study area, including clusters of samples from the House and Fish Springs Ranges (map B). These samples were collected from drainages that include fractured Paleozoic sedimentary rocks. Such rocks may contain secondary Fe- or Mn-bearing minerals that represent subtle geochemical indications of the distal parts of base- and precious-metal mineral systems. In addition, samples with high factor 2 scores from other parts of the study area may also represent subtle geochemical indicators of base- and precious-metal hydrothermal systems. These sample sites are widely scattered throughout the quadrangle (map B).

Samples with high factor 3 (Pb-Sn-Cu) scores were collected throughout the study area (map C). Areas that contain clusters of samples with high factor 3 scores include the Confusion, Deep Creek, Fish Springs, House, and Thomas Ranges, the Keg, Sheeprock, Simpson, Tintic, and West Tintic Mountains, and the Black Rock and Slow Elk Hills. In addition, scattered samples containing high factor 3 scores were sourced from the Dugway and Pavant Ranges and in the Canyon and Valley Mountains. Some of these samples may reflect the presence of buried mineralization, which would be reflected by more subtle geochemical signatures than would mineralization that outcrops. Thus, even samples with subtle, but positive, loadings for this factor may be important geochemical indicators of Carlin-type deposits and other base- and precious-metal deposits related to the distal parts of igneous-driven mineral systems.

Samples that contain high factor 4 (Ba-Sr) scores and are associated with carbonate-bearing sedimentary rocks were discussed above. Some of the high factor scores probably reflect the presence of Paleozoic carbonate-bearing rocks, as discussed above, however, some of the high scores may be due to the presence of hydrothermally altered rocks at depth and in outcrops. Carbonate-hosted replacement deposits associated with base- and precious-metal mineral systems and containing anomalous barium concentrations in the House and Fish Springs Ranges were discussed in Lindsey and others (1989a,b). Additionally, Carlin-type mineral occurrences in the Confusion Range typically contain anomalous barium concentrations, as discussed in Zimbelman and others (1990). Samples that contain even weakly positive factor 4 scores may also represent relatively subtle geochemical expressions related to the distal or buried parts of base- and precious-metal mineral systems. Samples of this type were collected in the Confusion, Deep Creek, Dugway, Fish Springs, and House Ranges, the Cricket, Desert, Gilson, and Tintic Mountains, and the Black Rock and Slow Elk Hills areas (map D).

Samples containing high factor 6 (Be) scores were collected throughout the quadrangle (map F). Geochemically, this factor is probably related to relatively evolved igneous rocks that crop out in the northern part of the study area, as discussed above. However, samples that contain high factor 6 scores from other areas may reflect the presence of lithophile-metal-bearing hydrothermally altered rocks nearby. Such samples were collected in the Deep Creek and House Ranges, and in the Dugway, Keg, Thomas, and Simpson Mountains.

CONCLUSIONS

The results of the R-mode factor analysis of 643 heavy-mineral concentrate samples collected in the Delta, Utah quadrangle are characteristic of rocks derived by various lithologic and mineralization processes. The results are somewhat limited for studying mineral deposits found in the quadrangle because geochemical data for many elements that would be useful in characterizing the mineral deposits are highly censored. These elements include Au, Ag, As, Bi, Cd, Mo, Ni, Sb, Th, W, and Zn. With this limitation in mind, the factor analysis results can be interpreted to be useful indicators of base- and precious-metal mineral occurrences, as represented by high scores in factors 2, 3, or 4. Lithophile-metal occurrences may be indicated by samples that contain high factor 6 scores.

Selected results may reflect subtle geochemical indicators of buried or distal parts of base- and precious-metal mineral occurrences. The presence of such occurrences is suggested by high scores for factors 2 and 4 in many areas throughout the study area. Some of the sample sites with positive scores for factors 2 or 4 should be investigated for other geologic indications of buried hydrothermally altered rock occurring nearby. Other uses of these results include delineating the generalized distributions of various lithologic types. The distribution of clastic sedimentary rocks in the quadrangle is broadly reflected by samples with high scores for factor 1. Thick sequences of Paleozoic carbonate rocks are broadly indicated by samples with high factor 4 scores. Many areas that contain evolved igneous rocks are indicated by samples that contain high scores for factors 5 or 6. Finally, the protolith for some clastic sedimentary rocks is indicated to have included an evolved igneous source by selected samples that contain high factor 5 and 6 scores.

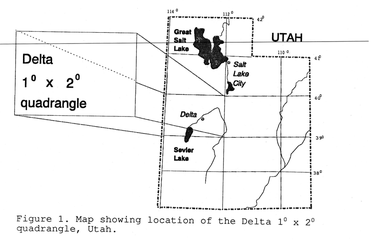


Figure 1. Map showing location of the Delta 1° x 2° quadrangle, Utah.

MAPS SHOWING INTERPETATION, USING R-MODE FACTOR ANALYSIS, OF TRACE-ELEMENT ABUNDANCES IN HEAVY-MINERAL CONCENTRATE SAMPLES, DELTA 1° X 2° QUADRANGLE, UTAH

By

David R. Zimbelman

1994

Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1994

For sale by U.S. Geological Survey Map Distribution, Box 25286, Federal Center, Denver, CO 80225