UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geochemical Exploration Studies in the Dillon, Montana-Idaho, 1° x 2° quadrangle: Applications of Exploration Geochemistry in Regional Resource Studies

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Abstract

Regional resource studies are becoming an increasingly important mechanism for collecting data pertinent to national land-use planning and minerals policy decisions. Exploration geochemistry is a frequently used tool in these multidisciplinary studies, but is commonly not employed to fullest advantage.

Stream sediment and rock geochemical studies in southwestern Montana serve to illustrate types of information that can be obtained. At the smallest map scale, when trace element suites are considered instead of single element plots, areas of porphyry-type mineralization may be distinguished from other sources of trace metals. For example, the Mo-Sn-W-REE suite is associated with sodic granitic complexes whereas copper-dominant hydrothermal systems are associated with potassic granites. By examining the areas of anomalous metal suites at a larger map scale, the multielement suites are amenable to modeling. For the sodic granite association, Mo-Sn-Nb forms a core area around which is zoned Cu-Pb-Zn. As-Sb-Cd-Ba commonly form a peripheral zone, and these elements characterize vein-type mineral deposits satellite to the focus of the porphyry-type system. As a whole, these zones serve to integrate complex components of the mineral system such that the boundaries of the system are defined, and the most probable target areas for selected types of deposits may be delineated. The third type of information is based on background trace element content of the stratigraphic units in the region. These data aid in geologic mapping as well as in helping to define areas of anomalous metal content.

Introduction

Mineral resource studies are being undertaken in the Dillon, Montana-Idaho, 1° x 2° quadrangle (Fig. 1) as part of the Conterminous United States Mineral Assessment Program (CUSMAP) of the U.S. Geological Survey. A broad spectrum of coordinated geological, geochemical, and geophysical data is being systematically collected for the purposes of disseminating and interpreting mineral-resource information for land-use planning and resource management. The synthesis of regional geological information is an integral part of the program and it can be used to increase the understanding of crustal evolution and the controls on the distribution of mineral deposits.

The overall objectives of the geochemical exploration investigations in the Dillon project area are to: (1) define the broad, regional distribution of chemical elements; (2) geochemically characterize the different types of known mineral deposits; (3) undertake research to develop and(or) evaluate regional geochemical exploration techniques; (4) research the genesis of geochemical dispersion patterns germane to gaining and understanding of regional metallogenesis and the geological controls of mineral occurrences; and (5) to provide supportive data to the consanguineous geologic and geophysical studies.

The purpose of this report is to illustrate the ways that exploration geochemistry is being applied to multidisciplinary investigations of the mineral resource potential of a large region in southwestern Montana. The Dillon, Montana-Idaho, 1° x 2° quadrangle encompasses a large number of historically productive mineral deposits including the southern parts of the Butte mining district and the highly productive Alder Creek gold placers. However, the regional geologic setting for the mining districts is not well established, and a comprehensive multidisciplinary attempt to understand the genesis of known districts and apply this knowledge to establishing the resource potential of the region is currently underway.

The problems inherent in evaluating such large regions in a limited time frame require the collection and interpretation of large and diverse data sets. The geochemical studies described here serve to illustrate how geochemical information can be of considerable value to concurrent geologic and geophysical studies in terms of planning and emphasis as well as to the final resource assessment.

Sampling and analytical procedures

Rock samples were collected during this study from selected mines and prospects in all of the major mining districts in the Dillon 1° x 2° quadrangle. The samples were chosen whenever possible to represent ore, altered host rock, and unaltered host rock. Composite stream sediment samples were collected from all first-order drainages in the Pioneer Mountains (Berger and others, 1979). These samples were dry-sieved to minus 200 mesh and pulverized prior to chemical analyses. All of the rock and stream sediment samples were analyzed for 31 elements using a six-step semiquantitative emission spectrographic technique (Grimes and Marranzino, 1968), and for three elements (zinc, arsenic, and antimony) using wet-chemical techniques. In addition, the rock samples were analyzed for tin and tungsten using wet-chemical techniques. Colorimetric techniques were used to analyze for arsenic (Almond, 1953) and tungsten (Quin and Brooks, 1972). Atomic absorption spectrophotometric techniques were used to analyze for zinc (Ward and others, 1969), antimony (Welsch and Chao, 1975), and tin (Welsch and Chao, 1976).

Stream sediment data for the Dillon 1° x 2° quadrangle, with the exception of the Pioneer Mountains, were obtained from Broxton (1979). This study analyzed minus 100 mesh stream sediments for 44 elements from 1721 sample locations as part of the Department of Energy's Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Program.

Evaluation of regional geochemical trends

The plan of an exploration geochemical survey is dependent upon the objectives and overall approach to the resource appraisal. The selection of sample media, sampling density, and analytical procedure, with built-in tests to determine the sources of variance in the derived data, depend to a great extent on the size of the area being evaluated and the types of mineral deposits that one assumes may occur within the context of the geologic framework being evaluated. Therefore, a set of working hypotheses about what types of mineral deposits to expect is recommended prior to the sampling as well as an idea of what these mineralization systems might look like in terms of the relationship between trace element zoning and alteration patterns for each deposit type.

The most common application of exploration geochemical data for large regions is to look at single-element, cartographic plots (Fig. 2) and then to do follow-up ground examinations in those areas showing "anomalous" values for that element of elements. The limitations of this method are (1) only those areas where the single element of interest is detected are studied further; (2) there is no rapid way to interpret the source of the anomalous trace element concentration with respect to the type of mineral deposit; (3) the focus and extent of the mineralization is difficult to discern due to irregular distribution patterns; and (4) there is no simple way to discriminate the various components of a complex multi-deposit mineral system or partially overlapping but independent hydrothermal systems. Figure 2 shows the spatial distribution of the upper ten percent of the copper population in stream sediments. The data define an apparent northeasterly-trending belt of copper occurrences, with a major cluster of anomalous samples in the northern

Highland Mountains and smaller clusters along Fleecer Ridge north of Divide, Montana, and in the central part of the Pioneer Mountains. Most of the anomalous samples shown in Figure 2 occur in areas underlain by batholithic rocks or Precambrian quartzites. Because there are important mining districts in Paleozoic carbonate rocks that do contain copper, yet are not readily detected in the stream sediments, the attempt to evaluate the copper mineralization potential by looking at copper by itself has significant limitations. In the montane environment of southwestern Montana the copper carbonates are relatively soluble and therefore dispersed by the active stream networks. In most of the mining districts of the region malachite and azurite are the predominant copper minerals in supergene altered gossans.

In the Dillon 1° x 2° quadrangle geochemical program, multielement models for several different types of mineral deposits are being used to evaluate the regional data base (Table 1). The models are derived through a combination of the data collected from mines and prospects throughout the quadrangle and the data reported in the literature for relevant types of deposits. Additionally, topical studies are being conducted to test and improve upon the models using known mineral systems in and around the quadrangle (e.g., Siems, Berger, and Welsch, 1979). The characteristic element assemblages in Table 1 are imposed on the regional data base to help define the locations and types of hydrothermal systems in the quadrangle, and to determine the total extent of each hydrothermal system. The imposition is effected by assigning the value of any given anomalous metal to the entire drainage basin that might have provided sediment to that sample site. Areas that contain an element suite appropriate to a given deposit model are then identified as areas of mineral potential. Not all drainages within the identified area will contain every element in the model suite, but most of the elements occur in a cluster of conterminous drainages.

Table 1.--Characteristic trace element suites of selected metallic mineral deposits

Type of deposit	Trace element suite
Complex Veins	Sb-As-Ag-Cd-Zn-Pb-Cu-Bi-Mo-Au
Stratiform Deposits	As-Ba-Ab-Zn-Pb-Cu-Co
Skarn Deposits	Zn-Pb-Cu-W-Mo
Stockwork Molybdenum Deposits	Ba-F-Zm-Pb-Ag-Cu-W-Sn-U-Mo
Porphyry Copper	As-Zn-Pb-Cu-Au-Mo

The trace element assemblages are developed by studying known mineral deposits and determining the trace elements associated with different attributes of the deposits, for example, the interrelationship of alteration zones and trace element zones. Since all mineral deposits are unique in detail, generalized models must be used and suites of elements employed to describe any complete system or parts of that total system (e.g. Lowell and Guilbert, 1970). The ultimate goal of any geochemical model is to predict the focus of any mineral system. Siems, Berger, and Welsch (1979) defined a series of trace element zones associated with a stockwork molybdenum hydrothermal system which includes peripheral vein deposits in the Bannack, Montana area, in an attempt to construct a model. The sequential zones are shown schematically in Figure 3. The zones overlap substantially, a fact which makes the study useful as a model for stockwork deposits elsewhere in the quadrangle. However, scrutiny of the data bank for the whole quadrangle (Broxton, 1979; Berger and others, 1979) indicates that uranium and lithium are frequently associated with molybdenum, and therefore these elements are shown as part of the general model in Table 2.

Table 2.--Model of stockwork molybdenum deposit showing sequential trace-element zones from innermost zone to peripheral zone.

Mo-Sn-U-Li-Nb-Te-Fe-Mg-Mn(low)-Ca(low)

La-Y

Cu-Ag-Pb-Zn ± Mo

As-Sb-Ba

Mn-Ca

In using multielement models, the first procedure in interpreting the regional stream sediment data base is to put the data into some manageable form. For the purposes of this study, the data have been grouped as follows: (1) 0 to 74th percentile of the frequency distribution; (2) 75th to 89th percentile; (3) 90th to 97th percentile; and (4) 98th to 100th percentile. For any given sample location, the given percentile value is assigned to the entire portion of the drainage basin below other sample sites or natural drainage divides that might have supplied sediment to the sample location (Fig. 4). By considering associations of elements in the various models, the spatial relationships of the elements can be discerned and the appropriate mineral deposit model chosen.

For the purposes of illustration Figure 5 shows the distribution of those areas displaying favorable geochemical suites for stockwork-molybdenum and porphyry-copper type deposits. This map immediately establishes focal points for economic geology studies, exploration targets, and alerts the geologist to the types of alteration features that might be present. The apparent northeastern trend evident in Figure 2 is still apparent, but the number and regional distribution of anomalies are better defined and there is less influence by the bedrock geology on the geochemical behavior of any individual member of the elemental assemblage. An additional change from Figure 2 is that the strong influence of a single region or mining district is not apparent.

Additional information obtained from the broad, regional geochemical patterns shown in Figure 5 is shown in Figure 6. This is the recognition of the spatial association of the trace element suite Mo-U-Sn-W-F with the "sodic" granite series of the Boulder batholith defined by Tilling (1973) in the northeastern part of the Dillon 1° x 2° quadrangle. Essentially Tilling found that plutons appearing more leucocratic than the Butte Quartz Monzonite (BQM) were also chemically distinctive in that, for any given SiO_2 content, the ratio of K_2O to $K_2O + Na_2O$ was less than for the BQM and older more mafic plutons (Fig. 7). The sodic series rocks are also the youngest plutons in the batholith (Tilling, Klepper, and Obradovich, 1968). Doe and others (1968) found the sodic series plutons to have different lead isotopic compositions than the main series intrusions (lower Pb^{208}/Pb^{204} and Pb^{207}/Pb^{204} in sodic series). However, all of the plutons in the batholith generally contain leads derived from uranium. These factors are common in the Rocky Mountain region where Precambrian rocks form the exposed basement.

Modelling of regional scale anomalies

By examining the previously described areas of anomalous trace-element suites from stream sediments at a larger scale, the multielement suites frequently display spatial distributions of the elements that reflect primary zoning patterns (Fig. 3). For example, in the eastern Pioneer Mountains in the vicinity of Pear Lake at the head of Birch Creek a definite, non-random, zonal pattern can be discerned which suggests the presence of a large, concentrically zoned hydrothermal system. A large molybdenum zone is partially circumscribed by a lead-zinc halo (Fig. 8). Copper (Fig. 9), silver, and arsenic also ring the molybdenum zone, and in conjunction with the lead-zinc zone serve to define the focus of the mineral system as well as the total spatial influence of the hydrothermal system. The stream-sediment anomalies closely mimic the primary distribution patterns because the finer fractions of the stream sediments (minus 200 mesh) contain relatively more heavy minerals than coarser fractions. The anomalies are due to minerals in the heavy fraction, and in the stream systems in the Pioneer Mountains, the mineralogy of the heavy fraction is not well homogenized along a stream profile (B. R. Berger, unpublished data), thereby reflecting the bedrock geology near the sample site.

The value of being able to rapidly _/ discern large hydrothermal systems is

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_/ The total time to complete the study, including chemical analyses, was about two to three weeks.

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again illustrated by the study of the Bannack and Blue Wing mining districts by Siems, Berger, and Welsch (1979). Using a slightly higher sampling density than for the Pear Lake area, they found that the heavy mineral fraction of the stream sediments resulted in a zoning pattern that related precious-metal, base-metal sulfide veins to a common source. In the context of the total system, peripheral precious metal silica-replacement deposits in carbonate rocks are zoned outside of tin-tungsten-bearing base- and precious-metal veins. All of these are around the propylitic alteration zone surrounding the locus of hydrothermal activity, which in this case is a Mo-Sn-W-F porphyry-type of deposit. Where there are carbonaceous, thin-bedded carbonate rocks in the vicinity of this type of hydrothermal activity, disseminated arsenical gold deposits may form in the peripheral parts of the system. An example of this relationship is found north of the Bannack-Blue Wing study area in the Ermont mining district [possibly related to the mineralization at Argenta (Berger and others, 1979)], where the regional geology is consistent with the same type of mineralization as found in the Blue Wing study area.

The degree to which the observed trace-element patterns approach the idealized model depends on the level of erosion of the hydrothermal system and the specifics of the local geological framework. For example, the geochemical anomaly in the Pear Lake area is in a generally homogeneous igneous pluton. The northeast-trending jointing plays an important role in the geochemical dispersion patterns. Pervasive alteration is generally not observed because the main source of the hydrothermal fluids is not exposed; therefore the anomaly cannot be directly correlated with alteration patterns as in the Bannack-Blue Wing study area. Nevertheless, the distribution of sulfide minerals occurring in the quartz veins along the joints as shown in Figure 10 do closely fit the zoning pattern (Willis, 1978; B. R. Berger, unpublished data).

Exploration geochemistry as a tool for geologic mapping

Geologic mapping for the purposes of resource assessment requires not only the proper identification of the stratigraphic sequence but also the need to recognize areas of anomalous metal content within the stratigraphic units in the region. Recognition of anomalous metal concentrations is particularly important in areas where there is potential for sedimentary stratiform deposits or Mississippi Valley-type deposits.

In portions of the Dillon 1° x 2° quadrangle there are quartzites of various ages that are difficult to distinguish due to a complex structural setting and similar appearance. Examples are the Cambrian(?) Black Lion Formation (Zen and others, 1979) and parts of the Precambrian Belt Supergroup; and the Cambrian Flathead Quartzite and Precambrian(?) quartzites in the Argenta area (B. Myers, Feb. 1979, personal commun.). Data obtained from the detailed geochemical sampling of the stratigraphic sequence in these areas are of considerable value in correlating the rock units. Figure 11 shows the calcium and magnesium concentrations in Beltian quartzites and in the Flathead Quartzite. The populations are distinctly different and this fact can be directly applied to solving mapping problems. In order to use geochemistry in geologic mapping, samples must be collected from known stratigraphic sequences in sufficient quantity to provide statistically-valid trace-element populations. Likewise, the samples collected during mapping must be adequate in number and size to approximate the average chemical composition of the unknown formation.

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Figure 1.

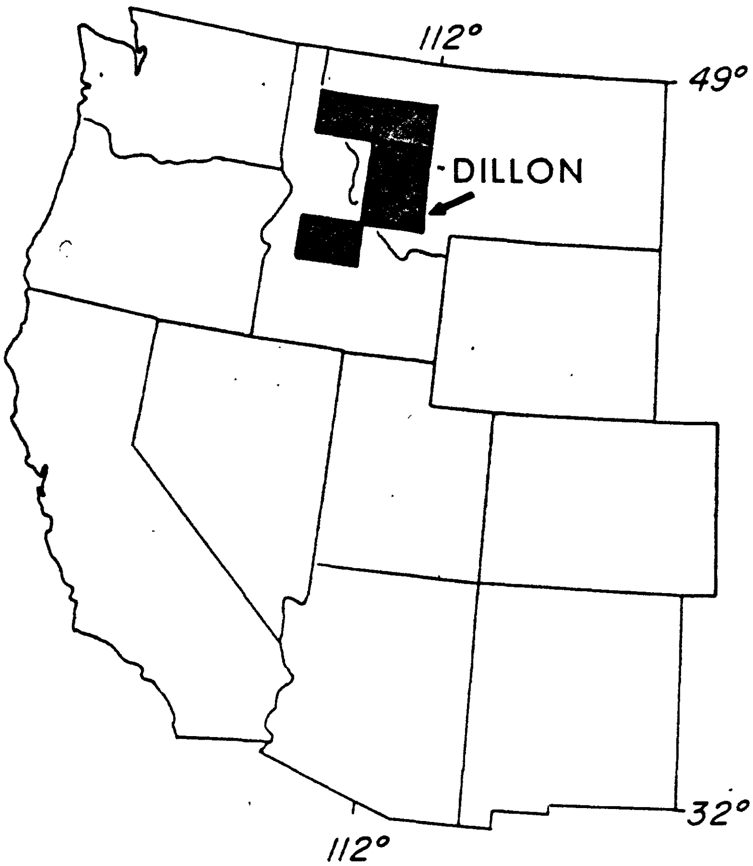

FIG. 1.--LOCATION OF REGIONAL RESOURCE ASSESSMENT AREAS IN IDAHO AND MONTANA UNDER THE "CONTERMINOUS STATES" PROGRAM, U. S. G. S.

Figure 2.

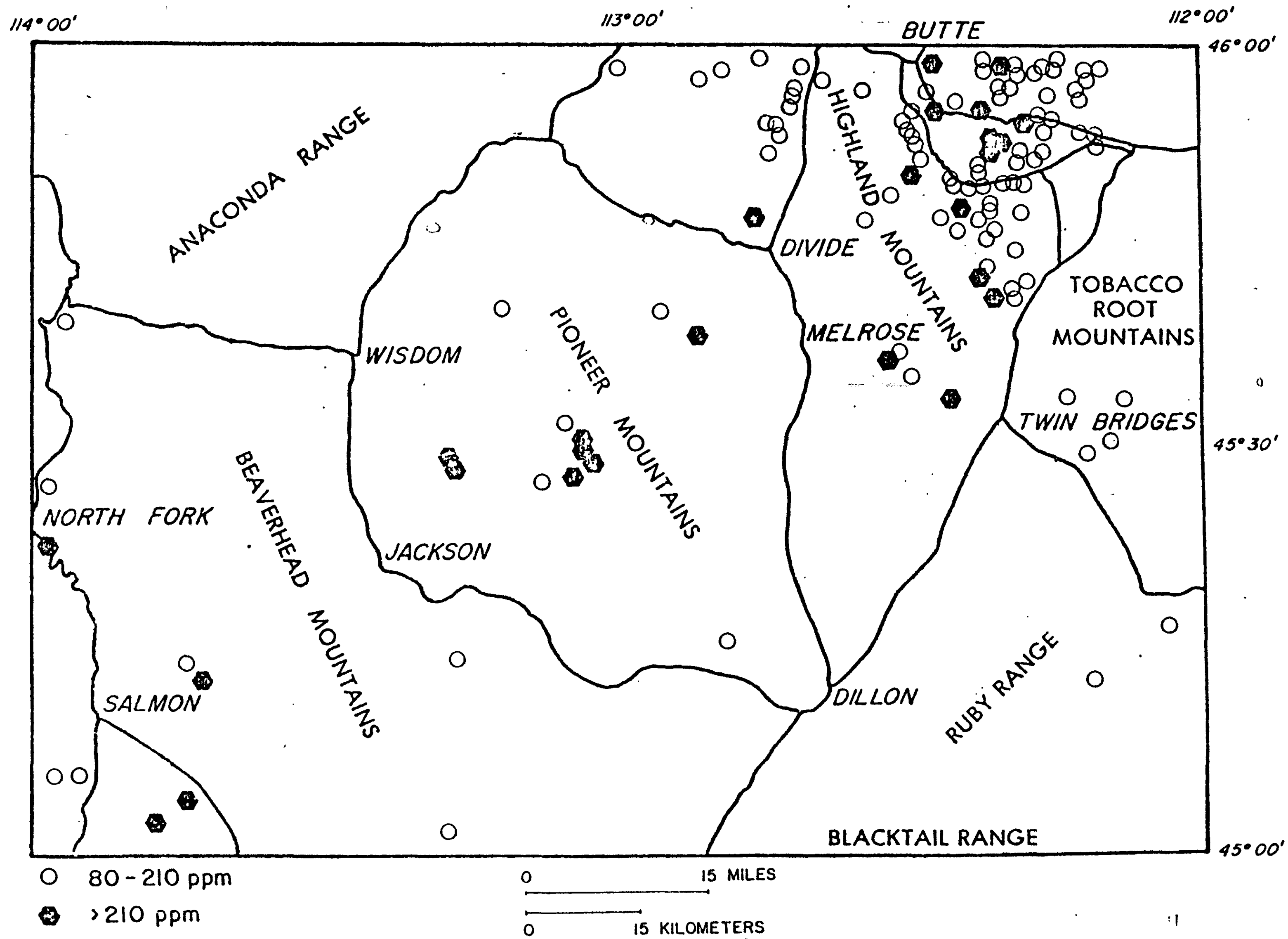

FIG. 2.--DISTRIBUTION OF ANOMALOUS COPPER VALUES IN -100 MESH STREAM SEDIMENTS IN THE DILLON, MONTANA—IDAHO, 1° X 2° QUADRANGLE (RAW DATA FROM BROXTON, 1979)

Figure 3.

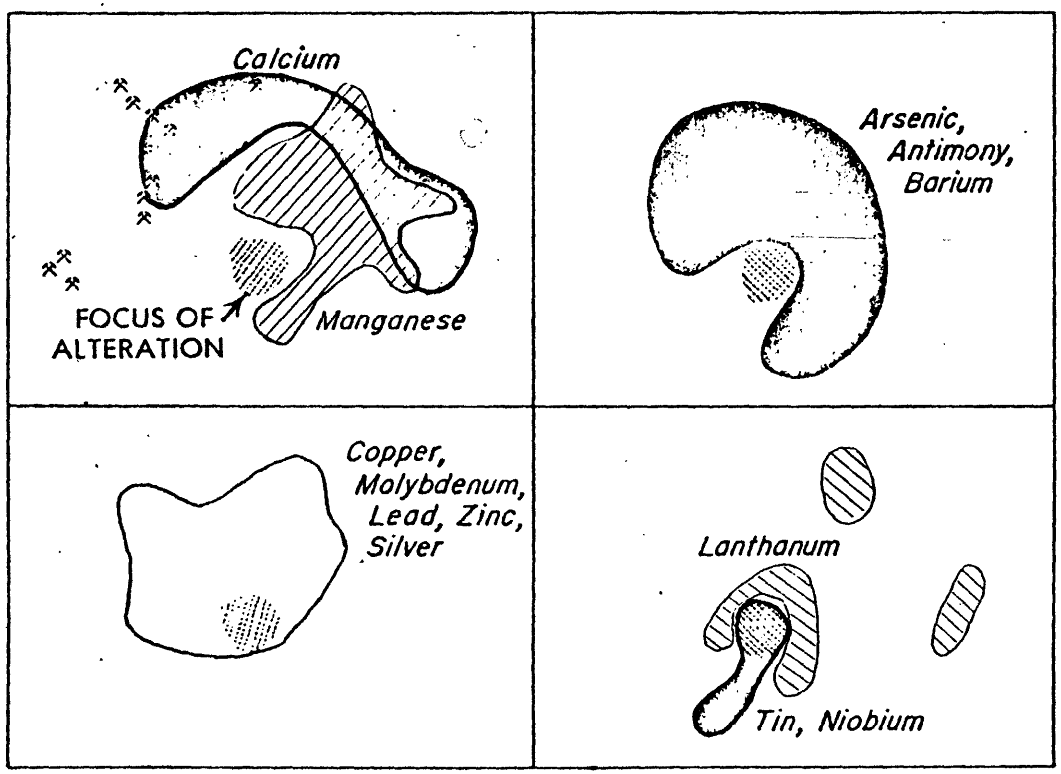

FIG. 3.--TRACE-ELEMENT DISPERSION MODEL FOR STOCKWORK MOLYBDENUM DEPOSIT IN THE BANNACK AND BLUE WING MINING DISTRICTS, BEAVERHEAD COUNTY, MONTANA (FROM SIEMS AND OTHERS, 1979)

Figure 4.

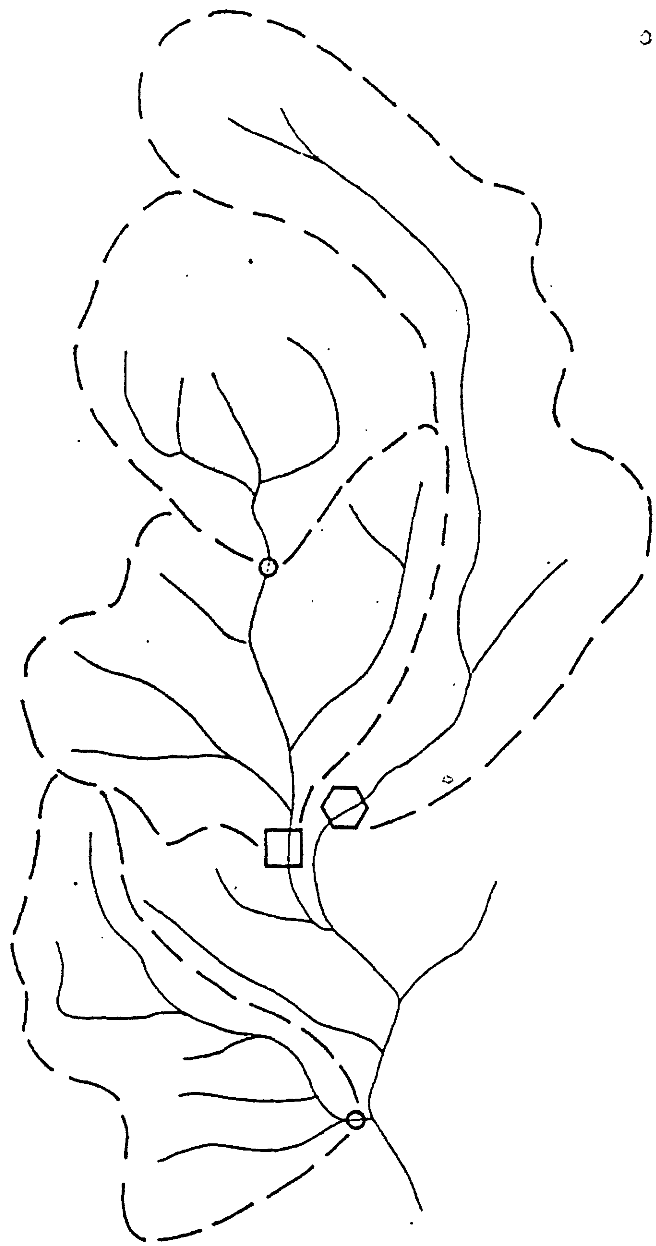

FIG. 4.--Hypothetical example of how stream-sediment data are apportioned to drainage basin. Shape of symbol represents different percentile of sample population.

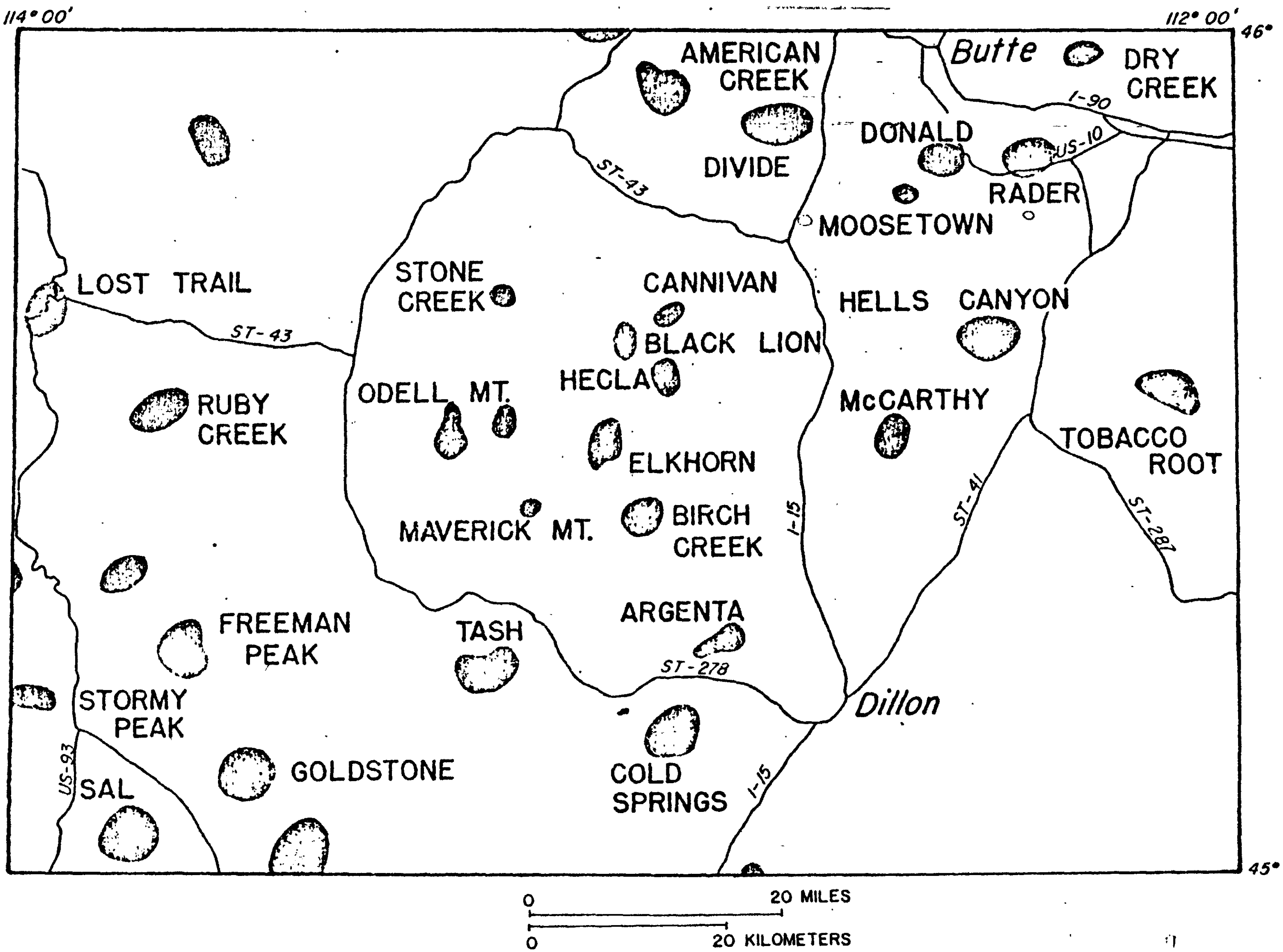

FIG. 5.--AREAS SHOWING GEOCHEMICAL SUITES CHARACTERISTIC OF PORPHYRY—TYPE MINERAL DEPOSTS IN THE DILLON, MONTANA—IDAHO, 1° X 2° QUADRANGLE

Figure 6.

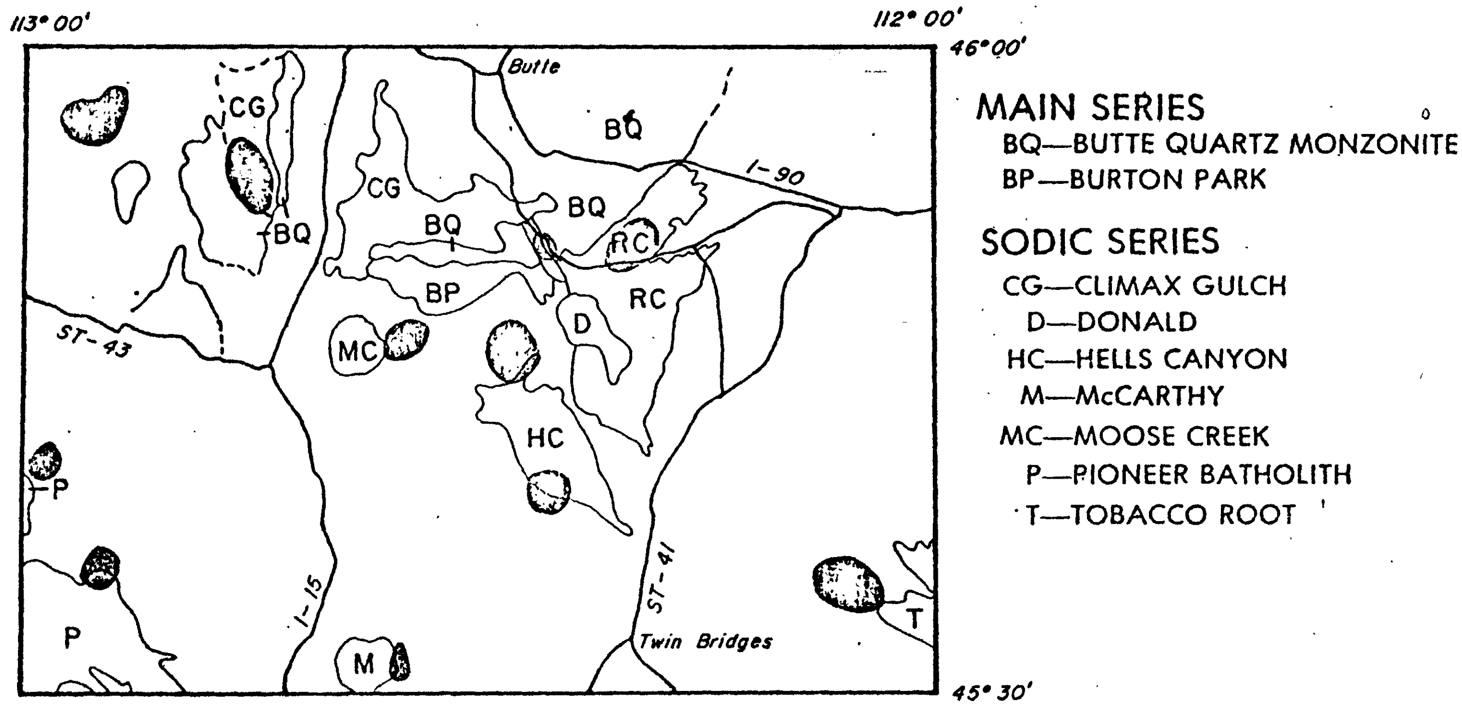

FIG. 6.--SPATIAL RELATIONSHIP OF Mo-Sn-W-U-Li TRACE-ELEMENT SUITE WITH SODIC SERIES IGNEOUS ROCKS AS DEFINED BY TILLING (1973) IN THE NE 1/4 DILLON, MONTANA—IDAHO 1° X 2° QUADRANGLE

Figure 7.

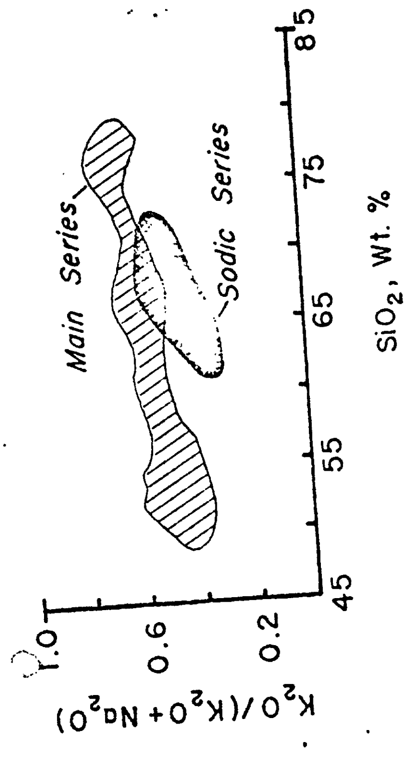

FIG. 7.--TWO-MAGMA SERIES MODEL FOR THE BOULDER BATHOLITH (FROM TILLING, 1973)

Figure 8.

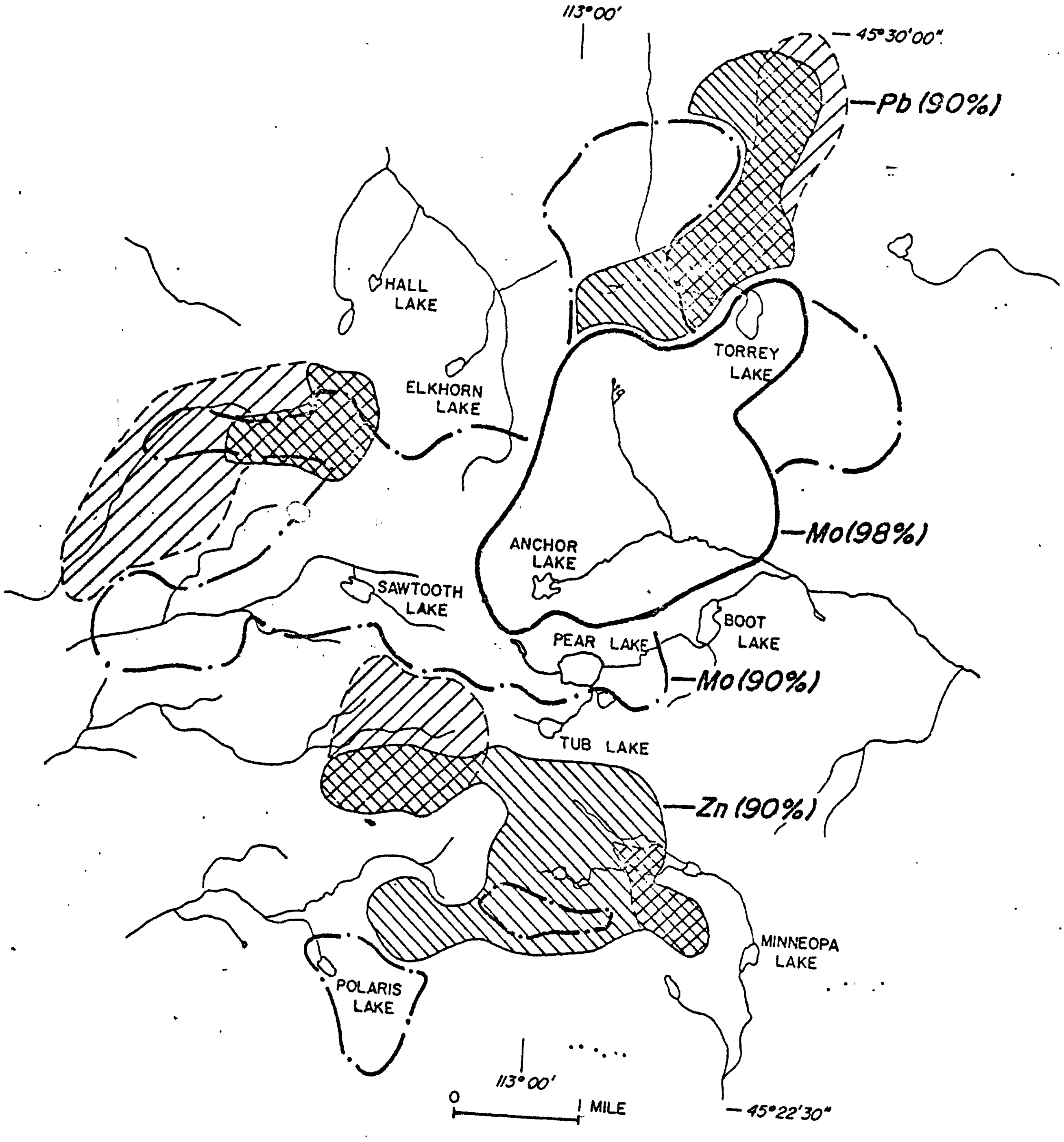

FIG. 8. Outline of areas in Pear Lake area containing higher concentrations of molybdenum, lead, and zinc. The arrows point to the patterns that represent the various elements; the numbers in parentheses show the percentile of the sample population above which the elemental concentrations fell.

Figure 9.

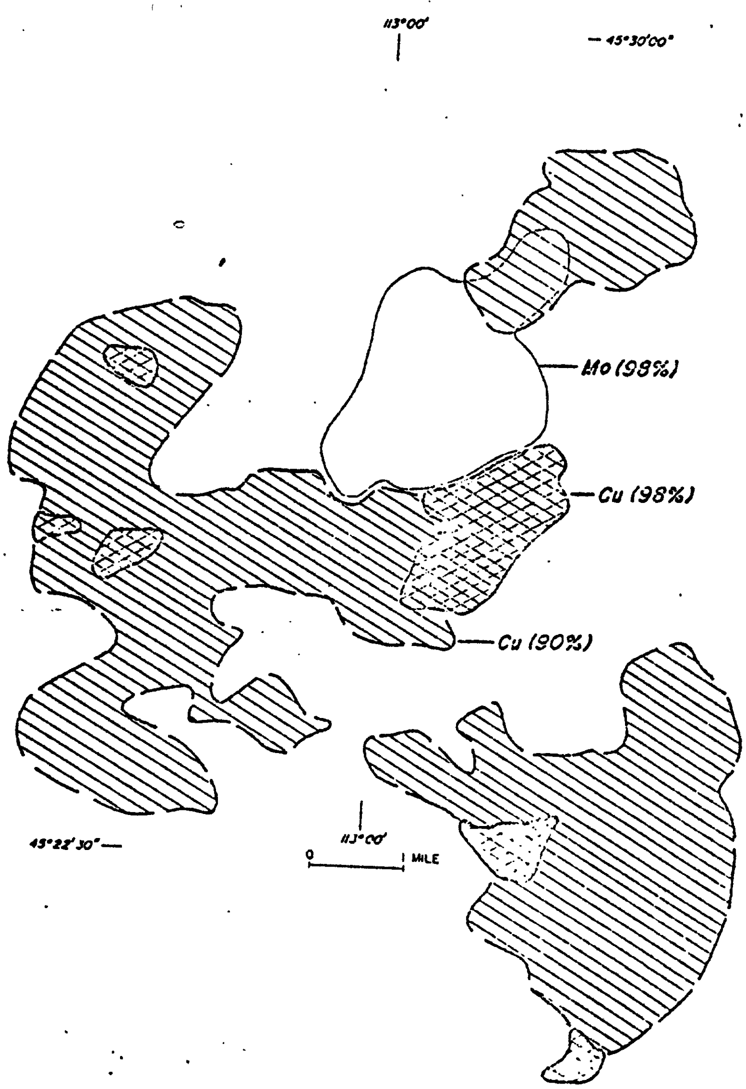

FIG. 9.--Outline of areas in Pear Lake area containing higher concentrations of copper. The zone of highest molybdenum from Figure 8 is shown for reference. The arrows point to the patterns that represent the percentile of the sample population above which the elemental concentrations fell.

Figure 10.

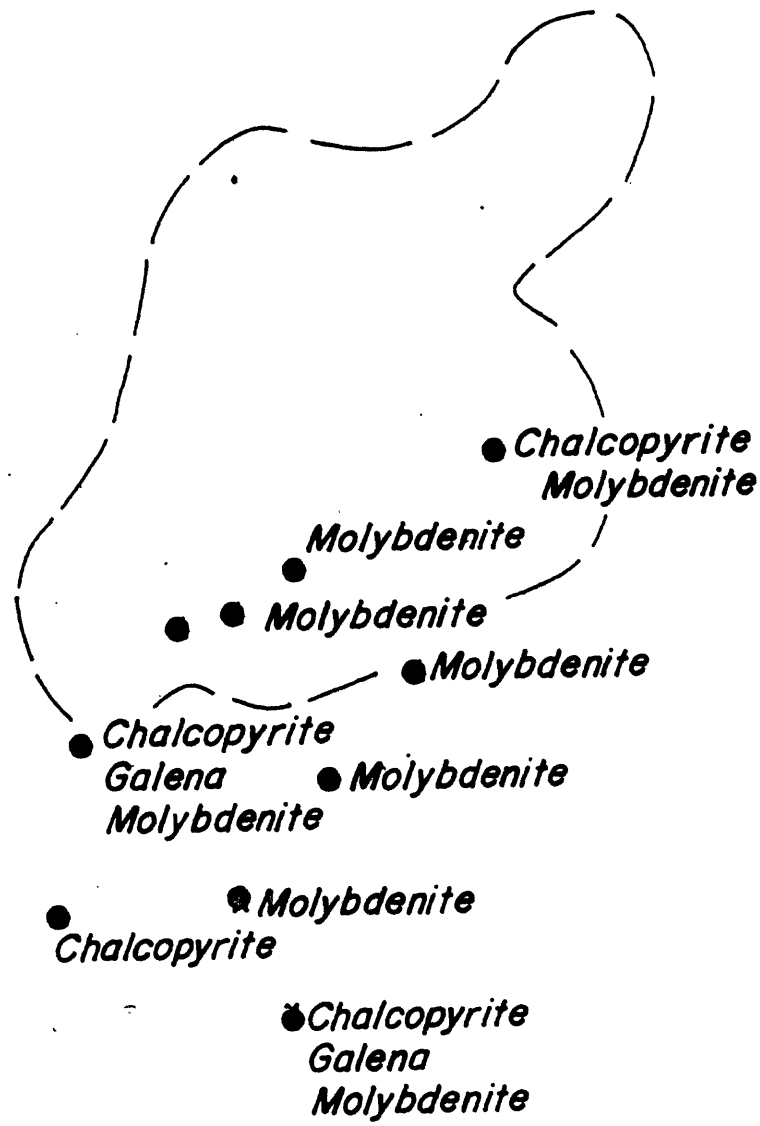

FIG. 10.--Outline of upper 2 percent of sample population of stream-sediment molybdenum concentration from Figure 8, and ore mineralogy of vein samples from locations shown.

Figure 11.

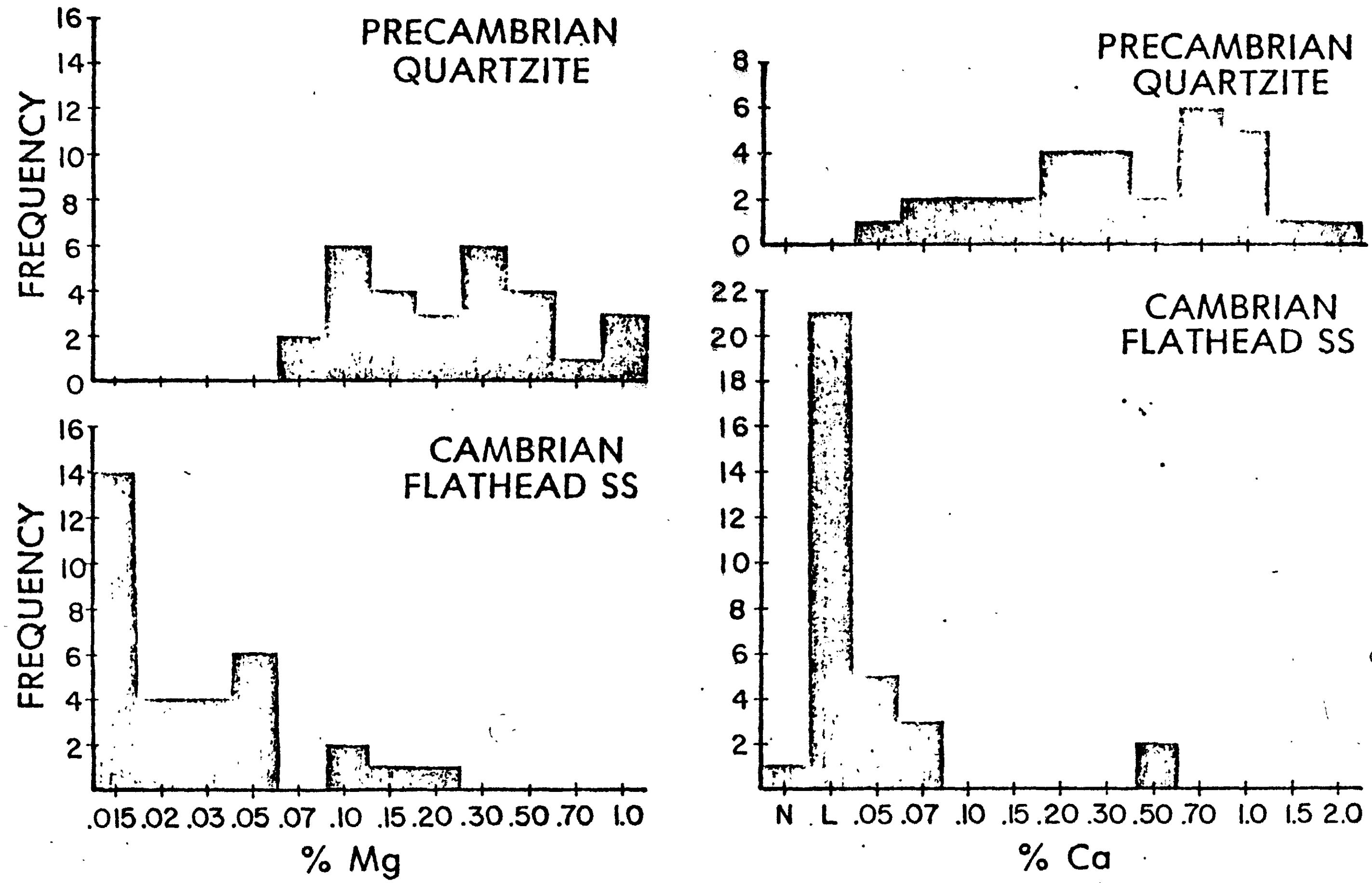

FIG. 11.--COMPARISON OF Mg AND Ca CONTENTS OF PRECAMBRIAN AND CAMBRIAN QUARTZITES IN THE DILLON, MONTANA-IDAHO, 1° X 2° QUADRANGLE