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1. Distribution of gold and other ore-related elements near ore bodies in the oxidized zone at Goldfield, Nevada, by R.P. Ashley and J.P. Albers. 210 p., including 84 p. tabular data, 13 pl., 9 figs. 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; 8102 Federal Office Bldg., Salt Lake City, Utah 84111; Library, Mackay School of Mines, University of Nevada, Reno, Nev. 89507. [Material from which copy can be made at private expense is available in the Salt Lake City and Reno offices shown.]

2. Preliminary geologic maps of the Gilroy Hot Springs quadrangle, the Gilroy quadrangle, the Mt. Sizer quadrangle, the Morgan Hill quadrangle, Santa Clara County, California, and the Mt. Madonna quadrangle, Santa Clara and Santa Cruz Counties, California, by Thomas W. Dibblee, Jr. 5 sheets plus index map, scale 1:24,000. 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; California Div. Mines and Geology Library, Ferry Bldg., San Francisco, Calif. 94111; State Office Bldg., 107 So. Broadway, Los Angeles, Calif. 90012; 118 Resources Bldg., 1416 9th St., Sacramento, Calif. 95814. [Material from which copy can be made at private expense is available in the USGS offices listed, in San Francisco, Menlo Park, and Los Angeles.]

3. Descriptions, sketch maps, and selected pictures of 87 gravity stations, reoccupied after the San Fernando earthquake of February 9, 1971, by S.L. Robbins, R.B. Grannel, R.W. Alewine, Shawn Biehler, and H.W. Oliver. 12 p., 33 figs., 30 photographs, 3 tables. [See information following No. 2, above.]

4. Possible rift origin of the Canada basin, Arctic Ocean, by Irvin L. Tailleux. 14 p., 6 figs. Brooks Bldg., College, Alaska 99701; 441 Federal Bldg., Juneau, Alaska 99801; 108 Skyline Bldg., 508 2nd Ave., Anchorage, Alaska 99501; 678 U.S. Court House Bldg., Spokane, Wash. 99201; 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; 1012 Federal Bldg., Denver, Colo. 80202; Alaska Div. of Geological and Geophysical Surveys, 509 Goldstein Bldg., Juneau, Alaska 99801; 323 E. 4th Ave., Anchorage, Alaska 99504; and University Ave., College, Alaska 99701. [Material from which copy can be made at private expense is available in the Alaskan Geol. Branch, USGS, 345 Middlefield Rd., Menlo Park, Calif. 94025.]

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5. Geologic map of the Cotuit quadrangle, Barnstable County, Massachusetts, by R. N. Oldale. Map, cross-section (1 sheet), scale 1:24,000, 9 p. expl.

6. Geologic map of the Dennis quadrangle, Barnstable County, Massachusetts, by R. N. Oldale. Map, cross-section (1 sheet), scale 1:24,000, 8 p. expl.

7. Geologic map of the Hyannis quadrangle, Barnstable County, Massachusetts, by R. N. Oldale. Map, cross-section (1 sheet), scale 1:24,000, 15 p. expl.

Distribution of gold and other ore-related
elements near ore bodies in the
oxidized zone at Goldfield, Nevada

By R. P. ASHLEY and J. P. ALBERS

GEOLOGICAL SURVEY PROFESSIONAL PAPER

*An orientation study for geochemical
prospecting in the hydrothermally
altered area at Goldfield*

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Distribution of gold and other ore-related elements
near ore bodies in the oxidized zone at Goldfield, Nevada--

A geochemical orientation study

By R. P. Ashley and J. P. Albers

Abstract

The heart of the Goldfield mining district occupies 0.6 square mile within a 15-square-mile area of hydrothermally altered Tertiary volcanic rocks. Most of the ore shoots were irregular bodies of epithermal bonanza ore within a few contiguous silicified zones enclosed within clay-bearing altered rocks. Two hundred seventy-eight samples of argillized and silicified dacite were collected from recent excavations at the Combination and January mines, which once yielded gold in commercial quantities. Semiquantitative analyses show that gold, silver, lead, bismuth, mercury, and arsenic are notably enriched in rocks of the cuts. All these elements except lead and mercury formed conspicuous ore minerals. Geochemical maps and one geochemical profile across strike show that relatively high concentrations of all these elements are restricted to silicified zones. This low-tenor metallization dispersed through silicified zones does not extend into adjacent clay-bearing rocks. During oxidation arsenic, copper, molybdenum, and zinc were more or less strongly leached from the silicified zones and the ore bodies within them, but these metals did

not form distinct supergene halos in the surrounding argillized rocks.
From the semiquantitative data available, the average amount of gold
in silicified vein material is between 2.4 and 3.8 ppm.

Geochemical sampling to detect relict hypogene dispersion patterns in the Goldfield altered area, using oxidized rock samples, is best restricted to the silicified zones. If only a few samples are collected from each silicified zone, analysis for lead, of all the elements tested besides gold, is most likely to detect significant gold metallization, even though the lead was only a minor constituent of the ores. Abundance of iron oxides is not a reliable guide to anomalous amounts of gold.

Introduction

General

This report discusses distributions of minor elements, particularly gold, in the oxidized zone in the vicinity of a mined gold-bearing vein at Goldfield, Nevada. The work described herein is part of a broader study treating the geology and geochemistry of hydrothermally altered rocks in the vicinity of Goldfield.

Most of the gold ore produced near Goldfield came from a 0.6-square-mile area immediately northeast of the town of Goldfield (fig. 1). This area is referred to in this report as the "main district."

Figure 1 near here

It lies at the western margin of the Goldfield Hills, a group of peaks with maximum relief of about 1,200 feet, nearly surrounded by desert basins. Maximum relief in the main district is only 180 feet, with elevations ranging from 5,640 to 5,820 feet. The climate is (semi)arid; vegetation, sparse. U.S. Highway 95 passes through the town of Goldfield. An all-weather gravel road skirts the western and northern sides of the main district, and several dirt roads traverse it.

Figure 1.--Map of Goldfield, Nev. and vicinity, showing the locations of major mines and the Combination-January cuts. 1. Combination mine. 2. January mine. 3. Florence mine. 4. Laguna mine. 5. Red Top mine. 6. Silver Pick mine. 7. Jumbo Extension mine. 8. Clermont mine. 9. Mohawk mine. 10. Jumbo mine. 11. Grizzly Bear mine. 12. Merger mine.

In March 1966 the Davis-Goldfield Mining Corporation completed two deep exploratory cuts in the main district. These open cuts lie just east of the Combination and January shafts, along the vein system common to these two mines (pls. 1 and 2). The open cut walls, 15 to 50 feet high, expose many tunnels and stopes developed upward from the 80-foot levels of the Combination mine, but the mine workings are almost completely inaccessible. Three months after excavation ceased, 278 samples for geochemical analysis were collected from the cut walls at 5-foot intervals. The samples were located by plane-table methods, and most of the geology was mapped at the same time, using the plane-table control. The land surface around the cuts, although much disrupted by mining operations, has topographic relief of only about 50 feet. The floors of the cuts and the exposures above the Combination Glory Hole vary in elevation, but again the total variation is only about 50 feet, with the highest elevations in the vicinity of the January shaft, and the lowest around the Combination Glory Hole. For simplicity, therefore, contours and elevations are omitted from the planimetric maps. The reader need only remember that the cut floors and the ground surface surrounding the cuts both have relatively little relief, whereas the intervening cut walls at the time of sampling and mapping were very steep, representing elevation changes between 15 and 50 feet along any given profile across the cut wall.

The 278 samples from the cuts and much smaller numbers of average-grade ore, high-grade ore, and unoxidized altered rock samples were studied to find indicator elements suitable for geochemical exploration for gold. Ideally, amounts of an indicator element should correlate well with amounts of gold; also, the range of concentrations should be detectable by a reasonably inexpensive analytical procedure, with few samples falling below the detection threshold; data should be subject to less sampling error than gold data; and, the element should form a dispersion aureole or halo larger than its associated economic gold deposit. These requirements imply that both the indicator element and gold were concentrated by means of the same processes.

The assumed exploration target is another heavy metals deposit like that mined in the Goldfield main district. The main district lies within a 15-square-mile area of hydrothermally altered volcanic rocks. Since a genetic relationship exists between hydrothermal alteration and ore deposition, this entire altered area has potential for new deposits. The Combination-January cuts expose oxidized altered and low-tenor metallized rocks, so data from them is appropriate for an orientation study, particularly if geochemical exploration of the altered area is limited to bedrock samples.

Wilson (1944) showed that silver, bismuth, and tin are positively correlated with gold in the Goldfield Consolidated main vein on the 830-foot level of the Jumbo Extension mine (2,400 feet northeast of the Combination shaft, see fig. 1 and Searls, 1948, pl. 2). Although he did not find a clear relationship between gold, silver, bismuth, and tin in and near the Clermont vein on the 225-foot level of the Clermont mine (2,000 feet northeast of the Combination shaft), or in two surface localities, including one on the Jumbo vein (Jumbo mine, fig. 1, 1,200 feet east-northeast of the Combination shaft), Wilson concluded that bismuth and silver are promising indicator elements for gold. Since his samples yielding recognizable element correlations were entirely from unoxidized rocks, his results apply most directly to underground exploration. We have presented preliminary results of this study (Ashley and Albers, 1969), but no other reports concerning indicator elements for gold at Goldfield have been published.

In the first section of this report we identify potential indicator elements for gold. These include the following metals associated with gold in the Goldfield ores: copper, zinc, arsenic, antimony, bismuth, tellurium, mercury, lead, molybdenum, tin, and probably selenium. In the second section we examine geochemical maps of the Combination-January cuts for gold and for seven of the above potential indicator elements: those for which we have adequate data. In the third section, we attempt to determine which elements owe their spatial distributions in the cuts primarily to hypogene dispersion, and which owe their distributions largely to supergene processes. We also attempt to explain various interesting features seen on the geochemical maps, and various associations between the ore-related elements. The conclusions section draws together information from the preceding sections pertinent to geochemical prospecting in the Goldfield altered area.

The cooperation and assistance of Davis-Goldfield Mining Corporation, owner of the investigated ground, made this project possible. All underground information on the Combination and January mines is from level maps compiled by Goldfield Consolidated Mines Corporation, now held by Davis-Goldfield Mining Corporation. Mr. M.

P. R. Billingsley and Augustus Locke are probably the major authors of these maps.

G. Martin was particularly helpful in providing these maps. D. H. Whitebread and L. D. Schultz assisted in geologic mapping and sampling of the cuts. The late Martin C. Duffy, owner of the Florence mine, conducted us through that mine, allowed us to map and sample the limited workings still open, and discussed with us the history of the mine. Mary E. Ashley coded the geochemical data for computer input.

Geologic setting

The geology of the Goldfield area has been described by Ransome (1909, 1910a,b), Locke (1912a,b), Searls (1948), Albers and Cornwall (1968), and Albers and Kleinhampl (1970). The main district is at the western margin of a Tertiary volcanic center composed of silicic and intermediate tuffs and volcanic breccias, and rhyolite, quartz latite, trachyandesite, and rhyodacite flows. These volcanic rocks cover Ordovician metasedimentary rocks and Mesozoic granitic rocks that crop out in many small inliers to the north and northeast of the main district. Numerous subparallel faults and fractures form a band several hundred feet to more than a mile wide which outlines a partial ellipse elongate east-west. Pervasive hydrothermal alteration is associated with this band; silicified zones (veins) are localized along the faults and fractures. East-dipping, north-northeast trending faults cut across the west side of the ellipse and successively drop the volcanic units down eastward. These features, as suggested by Albers and Cornwall (1967) and Albers and Kleinhampl (1970), indicate that the volcanic center is outlined structurally by concentric fractures possibly formed by caldera collapse. The ellipse encompasses an area with maximum dimensions 5 miles east-west by $3\frac{1}{2}$ miles north-south; the 15-square-mile Goldfield altered area includes the large tracts of altered rock associated with the ellipse, the north-northeast trending faults that traverse it, and a strong N. 80° W.-S. 80° E.-trending fracture zone tangential to the south side of the ellipse.

The ore deposits were irregular pipes and sheets within 7 or 8 vein systems composed of silicified rocks, striking north and dipping at moderate to low angles to the east. Dacite, andesite, and latite were altered to form these silicified zones and the argillized rocks which surround them.

The terms "dacite," "andesite," and "latite" are the names Ransome gave to the three volcanic units that dominate the Tertiary section in the main district. The dacite is actually a rhyodacite, the andesite includes both trachyandesite and rhyodacite flows, and the latite is a quartz latite. We retain Ransome's nomenclature, however, to make the contents of this report easily comparable with the reports of Ransome, Locke, and Searls, which provide the background for this work. The nomenclature of the volcanic units will not be changed until a complete stratigraphic revision is completed.

The Combination-January, the westernmost of the major vein systems, is shown on level maps of the Combination and January mines (pl. 1). The first level of the Combination mine was 80 feet below the shaft collar, at an elevation of 5,650 feet. Since the open cuts intersect workings that were reached from this level, a generalized geologic map of the cuts and adjacent surface has been substituted for the map of the first level. Early in the development of the properties, the workings of the Combination and January mines were joined; the Combination shaft serviced workings of the January throughout most of the history of production. Consequently, many workings of the January are accordant with those of the Combination and different maps are not required for the two mines.

Locally on the west side of the open cuts, as much as 15 feet of sedimentary breccia of the Siebert Formation unconformably covers the hydrothermally-altered volcanic rocks of the cuts (pl. 2). Mine dumps and 2 to 5 feet of alluvium cover much of the surface around the cuts. The positions of contacts shown on plates 1 and 2 are inferred where they are covered by these post-alteration materials. Dacite is the most widespread rock type in the two mines, occurring on all levels, but latite increases at the expense of dacite with increasing depth. Dacite rests directly on latite, and abuts andesite just east of the mine workings. Three miles east of the town of Goldfield, latite, andesite and dacite form a stratigraphic sequence from base to top; in the Combination-January area the dacite either intrudes the andesite, as suggested by Ransome (1909, p. 79-81) or is interlayered with the andesite, as suggested by Searls (1948, p. 11,12). Geologic mapping elsewhere in the Goldfield mining district indicates that Ransome's interpretation of the dacite as locally intrusive into the andesite and latite is correct.

The most conspicuous feature of the Combination-January vein system is the abrupt change of strike at the January shaft from N. 60°-70° W. for the southern part of the system to N. 50°-65° E. for the northern part. The acute angle thus formed persists to the second (130-foot) level, but opens progressively on the third (180-foot), fourth (230-foot), and fifth (280-foot) levels, and is not a notable feature on the sixth (380-foot) level (see pl. 1). The arcuate vein that passes through the January shaft at the surface and on the second level is nearly vertical, ^{at the shaft, but dips northwest north of the shaft and northeast south of the shaft.} The dip of the vein decreases below the second level, reaching 65° E. on the fourth level, ^{The January shaft and} ~~where the vein is~~ ^{the vein both continue to the fifth level, but these workings are not included} ~~located about 35 feet east of the January shaft. Smaller veins with~~ ^{on the Goldfield Consolidated Mines Corporation maps, so we do not know their} ~~parallel trends seen nearby in the hanging wall on the second and third~~ ^{full extent, and we have omitted them from plate 1.} ~~levels also dip steeply to the east or are vertical.~~ This western part of the vein system pinches out ^{fifth} ~~immediately~~ below the ~~fourth~~ (280-foot) level. The eastern part of the vein system ~~has generally lower dips~~ ^{steeply} ~~to the east: to the~~ ^{in the area} ~~east and south of the Combination shaft, dips are~~ ^{but} ~~65°-75° E. and~~ ^{on the inside, or eastern side, of the sharp bend, they dips} are 50°-30° E. decreasing with increasing depth. The eastern and western parts of the vein system are ^{close together near} ~~inseparable~~ at the surface, where-as separation is maximum at the fourth level. On the fifth and sixth levels all vein material belongs to the eastern part of the system, which continues to a maximum depth of 440 feet below the Combination shaft collar, corresponding to a minimum elevation of 5,290 feet. Most of the stoping was done from locations at the surface at elevations as high as 5,710 feet, to a point 330 feet below the Combination

shaft collar, at an elevation of 5,400 feet. Ransome includes the western part of the vein system in his description of the January mine (1909, p. 216-220, pl. XVI), ^{and} ~~whereas~~ he includes the eastern part of the system in his description of the Combination mine (1909, p. 209-216, pls. XVII, XVIII).

11 The ore bodies lying in the eastern part of the sharp bend had not yet been discovered at the time Ransome examined these mines. Consequently we have no detailed information for this part of the area on the distribution of silicified rock. It is likely, however, that the eastern vein extends northwestward into this ground and that it enveloped these ore bodies.

The shapes and orientations of veins belonging to the Combination-January vein system are probably controlled mainly by pre-alteration fractures. Also, on the fourth, fifth, and sixth levels, some veins conform to the shape of the dacite-latite contact. (See discussions by Ransome, 1909, p. 211-212, 217-218, and Locke, 1912b, p. 844, on form of the Combination-January vein system.)

The Combination-January open cuts closely follow outcrops of vein material, ~~glory holes~~, and caved areas related to the Combination-January vein system (pls. 1 and 2). A conspicuous structure seen in the cuts is the set of northeast-trending faults exposed 160 feet northwest of the Combination shaft. Neither this set of faults nor parallel-trending but southeast-dipping faults, such as the one at the surface 320 feet west-northwest of the Combination shaft, can definitely be identified on the second level or deeper levels. The segment of the silicified zone between these two opposing faults is apparently offset to the west, because the block between the faults is probably down-dropped. Possibly the dip of the northeast-trending, northwest-dipping fault system progressively decreases with depth; if so, it could connect with the northeast-trending, 30° northwest-dipping fault seen 250 feet northwest of the Combination shaft on the second level, before dying out at greater depth.

Much of the rock exposed in the cuts, both silicified and argillized, is moderately to intensely fractured; the fractures have diverse orientations and show slickensides at many localities. They are too small and too numerous to show on plate 2. The shear zones marked on plate 2 consist of many closely-spaced fractures, whereas fault zones consist of one or several large breaks with few subsidiary fractures. The fault zones and shear zones obviously displace the silicified zones and thus record movement that occurred after silicification developed along northwest-trending fractures. Ore minerals, particularly in high-grade ores, filled open spaces in shattered portions of the silicified zones. The shattering resulted from movement that occurred after hydrothermal alteration was well advanced but before metallization was complete; metallization accompanied the later stages of hydrothermal alteration (Ransome, 1909, p. 215-216). Some of the shear zones and fault zones have different abundances and proportions of clay minerals than do adjacent argillized rocks, suggesting that these breaks formed before hydrothermal activity ceased. Supergene alteration could also be partly or wholly responsible for these differences in clay content, but we cannot rule out the possibility that at least some, possibly all of the post-silicification fault zones and shear zones shown on plate 2 originated before hydrothermal alteration and metallization ceased, even though some of these breaks show slickensides that must postdate all alteration.

Analytical methods

Gold values¹ for samples from the Combination-January cuts were

¹The terms "value," "amount," and "concentration," as used in this report, mean quantity of an element expressed as weight per unit weight of rock. The specific units used in this report are percent and parts per million (ppm).

determined by atomic absorption spectrophotometry using hot hydrobromic acid extraction from 2-gram samples (Huffman, Mensik, and Riley, 1967). Three other groups of samples were analyzed by the cold hydrobromic acid-bromine method of Thompson and others (1968). Tellurium and zinc concentrations were also determined by atomic absorption spectrophotometry (Nakagawa and Thompson, 1968; and Ward and others, 1969, p. 20-22). Antimony concentrations were determined by a solution-colorimetric method, and arsenic concentrations by the Gutzeit-apparatus confined-spot colorimetric method (Ward, Lakin, Canney, and others, 1963, p. 38-44). Mercury concentrations were determined by the atomic absorption technique described by Vaughn and McCarthy (1964), and Vaughn (1967). All other elements, including silver, barium, beryllium, bismuth, cobalt, chromium, copper, lanthanum, manganese, molybdenum, niobium, nickel, lead, tin, strontium, vanadium, yttrium, iron, magnesium, calcium, and titanium were determined by 6-step semi-quantitative spectrographic analysis (Ward, Lakin, Canney, and others, 1963, p. 91-94, and Grimes and Marranzino, 1968).

R. L. Miller, E. E. Martinez, F. Michaels, T. A. Roemer, J. A. Thomas, J. D. Mensik, W. D. Goss, G. T. Burrow, G. D. Shipley, and C. Huffman carried out the gold analyses. The analysts for tellurium were H. D. King and E. E. Martinez; for zinc, G. W. Dounay; for antimony, H. D. King; for arsenic, A. L. Meier, Z. Stephenson, and W. Campbell; for mercury, W. W. Janes, J. James, S. Noble, J. G. Frisken, and W. Campbell. A. W. Helz, W. B. Crandell, J. L. Harris, H. W. Worthing, C. Heropoulos, H. Bastron, E. L. Mosier, J. M. Nishi, and J. L. Finley made the spectrographic analyses.

Statistical methods

Element abundances were calculated using techniques described

"Abundance," as used in this report, means average concentration or weight proportion of an element in a given specimen or body of rock. Here it is calculated essentially by averaging analyses for some number of specimens of a given rock type.

by Miesch (1967). Frequency distributions for gold, mercury, arsenic, and zinc show moderate to strong positive skewness, so the data were transformed to common logarithms of the concentration values; a better statistical estimate of abundance is possible if the frequency distribution is relatively symmetrical. All other elements were spectrographically determined, with geometric reporting intervals, making it mandatory to convert the data for these elements to common logarithms to provide statistics valid for intercomparison (see Miesch, 1967). The class intervals used for the gold, mercury, arsenic, and zinc histograms given on plates 4, 8, 9, and 12 were determined using a formula based on Sturges' rule (Sturges, 1926). For all other elements,

$C_i = \frac{MAX_i - MIN_i}{NM_i}$, where C_i is the class interval, or class size, MAX_i is the largest data value, MIN_i is the smallest data value, and NM_i is the number of classes. $NM_i = 2.5 + 1.442726 \ln(N_i)$, where N_i is the number of data values.

class intervals are equivalent to the geometric reporting interval used in 6-step spectrographic analysis: the sixth root of 10. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2,

0.15, 0.1, etc. Analytical error (one standard deviation) is approximately plus or minus one reporting interval.

In order to compare abundances of various elements in various data sets, relative abundances were calculated as follows. First, arithmetic means and standard deviations were computed for each element using all data (transformed to common logarithms) within the analytical detection limits. The antilogarithms of the means thus calculated are geometric means. Some elements have "censored" frequency distributions: here some fraction of the observations fall below the lower analytical detection limit or above the upper analytical detection limit. For these elements, geometric means are too high if the censored data falls below a minimum detection limit, or too low if the censored data falls above a maximum detection limit. Using Cohen's method (see Miesch, 1967, and Cohen, 1959, 1961), these means and their associated standard deviations were revised. Cohen's method assumes that the data outside the censor point would, if known, complete a normal (in this study, lognormal) distribution when combined with the known portion of the distribution. The revised mean and standard deviation calculated by the method are those of this ideal complete distribution. Use of Cohen's method for log-transformed data, therefore, assumes that the frequency distribution is lognormal. Many of the elements have frequency distributions that depart substantially from lognormal, but the method gives a satisfactory estimate of the geometric mean as long as the total distribution is unimodal. Where more than 50 percent of the data for an element are censored, lognormality is a tenuous assumption. Here abundance estimates are not calculated, and the true abundance is assumed to be

less than the detection threshold value (all such cases involve the lower detection limit). Where geometric means for two data sets are claimed to be significantly different statistically, the difference between them was tested for significance at the 95 percent confidence level (Hoel, 1960).

The abundance estimates derived by the above method are suitable for intercomparison, and they are used in figures accompanying the text. These estimates, however, are not the best estimates of true abundance possible, because the geometric mean generally gives values somewhat smaller than the true abundance. To obtain the best possibly estimate of true abundance, one must calculate Sichel's \underline{t} estimator, a statistical measure of central tendency for lognormal frequency distributions, designed to eliminate the negative bias inherent in the geometric mean. The \underline{t} estimator gives a value close to

The \underline{t} estimator, developed by H. S. Sichel (1952, 1966), is not to be confused with Student's \underline{t} , a frequency distribution function commonly used to calculate confidence intervals for various statistical measures.

the arithmetic mean, but is not as strongly influenced by relatively few very high values, as is the arithmetic mean. Sichel's \underline{t} estimator was calculated for each element from the geometric mean and standard deviation previously calculated with the aid of Cohen's method. These values are included in Appendixes ^K and L for the interested reader, even though they are not used for the data comparisons upon which this study relies. Approximate confidence intervals for Sichel's \underline{t} were calculated for gold using an equation given by Aitchison and Brown (1963, p. 50). These are given for gold and silver, the only potentially economic elements.

Correlation coefficients were calculated for each pair of elements by computer using the log-transformed data, although using the untransformed data would have produced the same results because we calculated Spearman's rank correlation coefficient rather than the more widely used product-moment correlation coefficient. Flanagan (1957) showed that the rank correlation coefficient is particularly suitable for semi-quantitative spectrographic data, and is the only valid method of computing a correlation coefficient between an element determined chemically and an element determined spectrographically. The Spearman rank correlation coefficient is nonparametric, and therefore does not require the assumptions that must be made when using the product moment correlation coefficient. These assumptions include a fundamentally normal distribution for each element, independence of successive data pairs, and homogeneity of variances. Since most of the elements investigated here were determined spectrographically, but several important elements were determined chemically, we have adopted Flanagan's method. Each correlation coefficient was calculated using only those observations having data within the detection limits for both elements involved. Since a different number of observations was used for nearly every correlation coefficient, the reliability of each coefficient is different. Each coefficient was subjected to a significance test, using Student's t . The correlation matrices (fig. 7) show which correlation coefficients are significant at the 99- and 95-percent confidence levels. Flanagan (1957) presents and explains the formulas for computing both the rank correlation coefficient and the

significance test, and gives references to the statistics literature that carries the derivations of these formulas. Additional explanation of rank correlation coefficients and the way in which we use results of the significance test are given later in this report (p. 66 b6a).

Potential indicator elements:

Elements associated with gold in Goldfield ores

The volcanic flows that occupied the Combination-January area were hydrothermally altered, metallized, and later oxidized to the depths now accessible. Strong fracture zones which cut the flows provided channelways for the hydrothermal solutions; the rocks in and adjacent to these fracture zones were silicified and rocks farther from the fracture zones were argillized. According to Ransome (1909, p. 158), Locke (1912a, p. 800-801), and Collins (1907, p. 398), ore was associated with silicified zones (veins), and little ore extended into surrounding argillized rocks. Changes in ore grade were often abrupt, but boundaries between ore and low-grade or barren rock were always gradational over at least a few feet (Ransome, 1909, p. 213, 218, and Collins, 1907b, p. 435). Hydrothermal wall-rock alteration was well advanced when metallization began, but some hydrothermal quartz and alunite formed contemporaneously with metal sulfides and gold (Ransome, 1909, p. 167, 169-170). Fracturing of the silicified ledges during the later stages of alteration produced local concentrations of gold and sulfides and provided relatively large open cavities in which rich ore formed. The bulk of the precious metal recovered, however, was apparently disseminated through volumes of rock within the silicified zones; most ore is therefore structurally controlled by prealteration fracturing (Ransome, 1909, p. 160-162). In the extensive barren parts of the Goldfield altered area the silicified zones show structural relationships and alteration mineral assemblages identical to those in

metallized areas, so metals were deposited during and after wallrock alteration only where they were available to the hydrothermal system, presumably entering the system at deeper levels. Elements potentially suitable for geochemical exploration must therefore be characteristic of the ores and not of silicified rocks alone. Published descriptions of the ores and comparisons between silicified rocks (13 samples), average-grade ores (16 samples), and high-grade ores (15 samples), all unoxidized, served to delineate the potential indicator elements; that is, those elements associated with gold in the ores.

Unoxidized ore typically contained pyrite (FeS_2), bismuthinite (Bi_2S_3), stibioluzonite (famatinite) ($\text{Cu}_3(\text{Sb,As})\text{S}_4$), and native gold

/Ransome (1909, p. 118-119) identified this mineral as famatinite, and presented an analysis showing the As:Sb ratio of the mineral to be nearly 1:1. Levy (1968) has shown that famatinite belongs to the tetragonal series luzonite-stibioluzonite, and has suggested that the name famatinite be dropped. Our X-ray data, when compared with Levy's data, indicate that the Goldfield famatinite is stibioluzonite.

(Ransome, 1909, p. 110-119, 165-166, 170). Collins (1907a, p. 398) reported tetrahedrite ($(\text{Cu,Fe})_{12}(\text{Sb,As})_4\text{S}_{13}$) and small quantities of chalcopyrite (CuFeS_2) and sphalerite (ZnS) from the unoxidized ores of the Combination mine. Ransome (1909, p. 216) reported telluride ore from the 280-foot level of the Combination (unoxidized ore). Tolman and Ambrose (1934, p. 264-278) reported marcasite (FeS_2), tennantite ($(\text{Cu,Fe})_{12}(\text{As,Sb})_4\text{S}_{13}$), goldfieldite ($\text{Cu}_3(\text{Te,Sb,As})\text{S}_4$), sylvanite

/Palache, Berman, and Frondel (1944) give the formula $\text{Cu}_{12}\text{Sb}_4\text{Te}_3\text{S}_{16}$. Thompson (1946), and more recently Levy (1968), consider goldfieldite a member of the tetrahedrite group. Levy gives the formula $\text{Cu}_3(\text{Te,Sb,As})\text{S}_4$.

(AgAuTe_4), hessite (Ag_2Te), and petzite ($(\text{Au,Ag})_2\text{Te}$) in ores from other mines in the vicinity. Searls (1948, p. 20) reports calaverite (AuTe_2) from a small vein developed by Newmont Mining Corporation about 0.3 mile west of the Florence mine. Ransome (1909, p. 112) described a few

occurrences of galena (PbS). Ransome's analyses of ore from the Mohawk mine show copper, tellurium, bismuth, antimony, arsenic, gold, silver, zinc, and traces of lead (1909, p. 167, 169). X-ray diffraction ^{and optical examination} analysis of 4 of the 16 average-grade ore samples confirmed

—/The ores examined contain approximately 0.1 to 2 ounces gold per ton and 0.1 to 6 ounces of silver per ton except for one sample bearing 30 ounces silver per ton. The average values for Goldfield, calculated using annual production figures for the most active period of the district, 1906 through 1918, are 1.56 ounces gold per ton and 0.35 ounces silver per ton (U.S. Geol. Survey, 1906-1918).

^{subordinate tetrahedrite - which is often enclosed in the stibioluzonite.}
stibioluzonite and ~~(minor)~~ tennantite. A small amount of polybasite (?) ^{tetrahedrite -}
 $((Ag,Cu)_{16}Sb_2S_{11})$ accompanies stibioluzonite and tennantite in one sample. Polished sections show that small amounts of bismuthinite are commonly associated with ^{tetrahedrite - tennantite} stibioluzonite. cursory examination of the 15 high-grade ores spectrographically analysed for this study revealed

—/Samples loaned by National Museum of Natural History, Smithsonian Institution.

no new major ore minerals. Searls (1948, p. 18) reports minor but notable amounts of tin in ore from some of the deeper ore bodies of the district. ^{Insert next page} The ores were thus characterized by copper, antimony, arsenic, bismuth, tellurium, gold, silver, zinc, lead, and tin, in approximate order of decreasing absolute abundance. The economically important elements were gold, silver, copper, and lead, in order of decreasing total value of production.

Insert, p. 23a

Preliminary microprobe data obtained by G. K. Gramske showed that
contains tin in variable amounts:

Tin occurs in stibio borate: [spots tens of microns in diameter
concentrations of 1 are common and
often show at least 0.5% tin, [with] a maximum of 2.7% tin was
detected
[recorded]; no separate tin-bearing phase was recognized. A polished
section for one of the average-grade ores provided this microprobe data
and some additional microprobe data referred to later in the report.

Elements associated with gold were further investigated by spectrographically analyzing unoxidized silicified rocks and ores. Sampling of unoxidized materials from the Combination-January area would have been desirable, but was not possible due to lack of access and lack of ore samples. Thirteen unoxidized silicified dacite samples for minor-element comparisons were collected from the Florence mine, 1,600 feet southeast of the Combination mine, because the Florence is the only mine currently accessible (Fig. 2). The Florence and the

Figure 2 near here

Combination are both located on the same vein system. The 16 unoxidized average-grade ore samples are from mine dumps throughout the main district (Fig. 3) and the 15 high-grade ores are from mines in several parts of the main district (Fig. 4). Only five(?) of the

Figures 3 and 4 near here

high-grade ore samples came from the area under study, and locations of these samples are poorly known. The samples are few in number and from scattered localities, but they can be used for qualitative comparisons because the same alteration mineral assemblages occur throughout the district, and ore mineral assemblages from various parts of the district have important features in common (Ransome, 1909, p. 165-169, 172-173). Data for 17 samples of unaltered dacite are included for comparison with the altered and metallized rocks. These samples were collected from scattered outcrops of unaltered dacite

east of the productive areas. The average minor element content of these samples should be similar to that of the dacite in the Combination-January area before hydrothermal alteration. Unaltered dacite samples, unoxidized silicified dacite samples, average-grade ores, and high-grade ores form a sequence of four groups whose compositions show progressively stronger effects of the ore-forming process. Before examining minor-element relationships, we will describe the four groups of samples briefly.

Figure 2.--A,B,C. Locations of unoxidized silicified dacite and hydrated sulfate samples.

Figure 3.--Locations of average-grade ore samples.

Figure 4.--Locations of high-grade ore samples.

The unaltered dacite is a porphyritic volcanic rock with plagioclase, biotite, hornblende, augite, and a few quartz phenocrysts in an aphanitic, partly glassy groundmass. A more complete description is given on p. 32. In unoxidized silicified dacite, the groundmass and phenocrysts are both replaced by quartz, alunite, and kaolinite, but the phenocrysts are richer in alunite and kaolinite than the groundmass. Pyrite partly replaces former mafic minerals and is also scattered throughout the altered groundmass. The oxidized silicified rocks described in the next section are petrographically the same as these rocks, at least with respect to minerals coarse grained enough to identify optically or abundant enough to identify by X-ray diffraction, except that hematite or goethite replaces the pyrite. Unoxidized average-grade ores ^{consist} 10 to 25 percent sulfide-bearing quartz aggregates which form veinlets that cut the silicified wallrock, or surround wallrock breccia fragments. Pyrite, stibio-luzonite, and other sulfides (see p. 23) in these veinlets and fillings form crusts or are intergrown with the quartz. Considerable alunite accompanies the quartz in many veinlets, and kaolinite fills scattered vugs remaining at the centers of the veinlets. Much of the material in the veinlets filled open fractures or open breccias, but some specimens show metasomatic effects extending several millimeters from the vein margins into the silicified wallrocks. Otherwise, wallrocks in these specimens are identical to unmetallized silicified rocks; relict textures are generally well preserved. In a few specimens stibio-luzonite is disseminated through the silicified wallrock. Here relict

textures are obliterated, indicating that more extensive metasomatism occurs locally. The high-grade samples could only be examined visually; sulfide minerals are conspicuous in all samples and abundant in some. Native gold is visible in several.

The comparisons provided by Figure 5 confirm that copper

Figure 5 near here

dominates the ores, and antimony, arsenic, bismuth, tellurium, gold, silver, zinc, lead, and tin are relatively abundant, as one would expect from available information on the ores. Data for tellurium are incomplete, but there is no reason to believe that amounts greater than 0.1 percent (1,000 ppm) reside in unaltered or silicified dacite. In addition to the above elements, mercury and cadmium are relatively abundant. Molybdenum shows modest enrichment in some ore samples, although the averages for molybdenum in the two groups of ores are not notably larger than the average for silicified dacite. These elements form a group which will subsequently be referred to as "ore-related elements." These are the elements to be investigated as geochemical indicators for the Goldfield deposits. Barely detectable amounts of palladium appeared in seven of the high-grade ore samples, and small but variable amounts of indium appeared in five of the high-grade ore samples. Detectable tungsten (200-300 ppm) appeared in two high-grade ore samples. Platinum, tantalum, and thallium were sought by spectrographic analysis, but none of the samples from any data set contained detectable amounts of these elements. The only element not tested that might be important as an indicator is selenium. Ransome (1909, p. 134, 166) notes that selenium was found in tellurium-bearing oxidation products from two mines several miles northeast of the main district. Levy (1968, p. 131-132) notes an unidentified selenium-bearing mineral found as inclusions in goldfieldite.

Figure 5.--A-I. Element abundances in unaltered dacite, unoxidized
silicified dacite, and unoxidized ores.

Regarding iron, silicified dacite samples bear pyrite, much of which replaces former mafic minerals. Since the iron of this pyrite probably came from the pre-existing mafic minerals, it is reasonable that unaltered and silicified dacite have comparable amounts of iron, even though their mineral assemblages are vastly different. Average-grade ore samples have some pyrite associated with quartz veins and open-cavity fillings, in addition to that which replaces former mafic minerals in the silicified wallrock. High-grade ore samples, on the other hand, have much stibioluzonite and other ore minerals but relatively little pyrite, so these samples contain the smallest amounts of iron. Cobalt, chromium, nickel, and vanadium change little through the groups of samples. Cobalt and nickel (Ramdohr, 1969, p. 779) probably are retained in pyrite along with iron. These two elements are not, however, notably less abundant in the high-grade ores, as is the case with iron; small amounts may have been introduced into the high-grade ores along with the abundant base and precious metals found therein. It is not clear why chromium and vanadium are not strongly depleted; we do not know which mineral phase(s) they reside in. Vanadium in the ores could reside in tetrahedrite-tennantite or stibioluzonite; substantial amounts of vanadium occur in colusite ($\text{Cu}_3(\text{Sn}, \text{V}, \text{As})\text{S}_4$), a mineral closely related to both the luzonite and tetrahedrite-tennantite mineral series (Levy, 1963, p. 129). Magnesium, calcium, and manganese each show a pronounced and progressive decrease, indicating that depletion is directly related to intensity of hydrothermal activity. The same is true of titanium,

Figure 6.--Element abundances in unaltered dacite, unoxidized
silicified dacite, and unoxidized ores. A, Cu, Sb, As, and
Bi. B, Te, Au, Ag, and Zn. C, Sn, Pb, Hg, and Mo. D, Cd.
E, Fe, Mg, Ca, and Ti. F, ²/₃ Ca. G, Co, Cr, La, and Nb.
H, Mn. I, Ni, Sr, V, and Y.

barium, and strontium, except that each of these shows little difference between unaltered and silicified dacite samples. Thin sections of the silicified dacite samples show that titanium is retained in leucoxene (fine-grained anatase, TiO_2) or in some cases rutile (TiO_2), and barium and strontium are retained in barite (BaSO_4) or celestite (SrSO_4) or both. Barite and celestite form a continuous solid solution series, but natural minerals are generally nearly pure BaSO_4 or SrSO_4 (Dear and others, 1962, p. 187-188, 197-198). The barite-celestite series mineral(s) recognized in thin section are too fine-grained to separate easily for a more exact composition determination. It is not surprising to find barite (or celestite) along with the abundant alunite ($\text{KAl}_3(\text{OH})_6(\text{SO}_4)_2$) in the silicified rocks, since all these minerals are sulfates. Alunite abundance generally decreases with increasing amounts of ore minerals, and barite (celestite) probably decreases also. Lanthanum, niobium, and yttrium apparently are depleted relative to amounts in fresh dacite, but little else can be said with the data available.

Titanium, barium, and strontium are potential negative indicators of gold metallization. These elements might be depleted, however, by particularly strong or long-enduring hydrothermal activity without metallization. Use of negative anomalies, furthermore, requires particularly careful chemical analysis, and involves greater difficulties in interpretation than use of positive anomalies, so these elements will not be considered further.

Dispersion patterns of ore-related elements in the oxidized zone

General

The previous section of this report established that copper, antimony, arsenic, bismuth, tellurium, gold, silver, zinc, cadmium, tin, lead, mercury, and molybdenum characterize metallization at Goldfield. The following discussion examines the relationships between most of these elements in oxidized rocks of the Combination and January mines. It is particularly important to see whether these elements form primary aureoles or secondary halos around the ore bodies, and how closely related such elements are in the aureoles or halos.

—/Our use of the terms "primary," "secondary," "aureole," and "halo" is the same as that of Hawkes and Webb (1962). Since the Goldfield deposits are epigenetic (and hypogenetic), our usage is also concordant with revised definitions of the terms "primary," and "secondary" proposed by James (1967).

Plate 2 is a geologic map of the open cuts at the Combination and January mines, showing rock types, structural features, and hydro-thermal alteration zones. Sample localities are shown on plate 3. Specific localities mentioned in the text are numbered separately, and these numbers are given on plate 2 and the geochemical maps, plates 4-13.

The 278 samples that provide the data for this part of the report were collected about 4 feet above the floor of the large central cut, the smaller northwesternmost cut, and the northwestern part of the cut east of the Combination shaft (see pl.2). Much of the latter cut is occupied by now-caved ~~glory hole~~ and stopes; samples here were taken about 4 feet above the top of the cave-in debris accumulated against the upper walls. The present walls are partly, perhaps largely, scarps left by blocks that broke off and slid or fell into the large caved area. Except for the caved area, the walls at the time of sampling and mapping were freshly excavated and very steep, representing elevation changes between 15 and 50 feet along any given profile across the cut wall. All rock exposed in the cuts is within the upper part of the oxidized zone. The depth of oxidation at the Combination mine is 130 to 140 feet (Ransome, 1909, p. 177, 216), and water was encountered at 210 feet when the shaft was sunk (Gollins, 1907a, p. 398). The depth of oxidation at the January mine is 180 feet and the original water level was 160 feet (Ransome, 1909, pl. XVI, p. 187, 219).

Open workings, some forming precipitous holes, intersect the cuts at 14 locations. Six of these lie within silicified rocks along the west wall of the largest cut between localities 1 and 2. Field examination indicates all of these are probably old stopes. The seventh location (loc. 3), at the southeast end of the large caved area, in argillized rocks, is probably an access drift. Three more openings are located on the wall of the largest cut, between localities 4 and 1, and connect with the large opening at 1. The last four appear in the vicinity of locality 5, and were probably originally interconnected. All the workings represented by the latter two groups of openings are tunnels that intersect the nearly vertical cut wall at various elevations; the several near locality 5 almost overlap when projected onto a horizontal plane. For simplicity, therefore, these workings are not included on the plates. To place the resulting problem of sampling bias in perspective, 12 of the existing samples (about 9 percent of

__/Samples 88, 89, 90, 91, 92, 161, 162, 185, 186, 187, 194, 195.

the silicified rock samples) came from the walls or floors of stopes, and probably contain less gold and other gold-related elements than the mined-out rock would have. Furthermore, several additional samples would have been taken in the vicinity of locality 5 if it had not been previously disrupted by mining activity.

Petrography of the oxidized samples

The January-Combination cuts expose soft clay-bearing altered rock and hard silicified rock equally well; both are the products of hydrothermal alteration of dacite and andesite. Since no samples were collected from the few small exposures of altered andesite, this section describes only the petrography of altered dacite. Thin sections from 30 of the samples from the cuts and X-ray diffractograms for 112 of the samples from the cuts provided the petrographic data which follows. Three thin sections from rocks outside the Combination-January area provided the data on unaltered dacite. The altered rocks at Goldfield have been described in detail by Harvey and Vitaliano (1964).

Unaltered dacite is characterized by porphyritic texture, with 20-25 percent plagioclase phenocrysts 0.3 to 10 mm in diameter, about 5 to 8 percent each of biotite, hornblende, and augite phenocrysts as much as 2 mm long, 0.5 to 1 percent corroded quartz phenocrysts as much as 2 mm long, and 1 percent opaque grains 0.1 to 0.3 mm in diameter. The plagioclase phenocrysts show normal oscillatory zoning, and have a bulk composition of about An_{50} . The groundmass is one-half to two-thirds microlites of sodic labradorite, a few percent minute opaque and mafic grains, and the remainder glass. The groundmass shows good pilotaxitic texture.

Soft, clay-bearing altered rocks, although considered a single group for geochemical comparisons, are described here in two subgroups: those that contain montmorillonite, and those that do not. Montmorillonite-bearing rocks, restricted to a small area northwest of the Combination shaft (pl. 2), have plagioclase phenocrysts that are partly to almost completely altered to aggregates of 1 to 10 μ -long illite and montmorillonite grains. Illite flakes and leucoxene granules replace biotite. Illite, leucoxene(?) or opaques, and in some cases minor quartz replace hornblende and augite. The groundmass is an aggregate of 1 to 5 μ -diameter quartz grains and 1 to 10 μ -long montmorillonite, illite, and in some rocks kaolinite flakes. Crystals of jarosite 2 to 10 μ in diameter are scattered through the groundmass of some specimens. These rocks have experienced the weakest hydrothermal alteration of any rocks exposed in the cuts; they were located farther from local sources of hydrothermal solutions than any other rocks described here. They belong to the montmorillonite subzone of the argillic zone described by Harvey and Vitaliano (1964, p. 568).

Clay-bearing rocks with no montmorillonite contain abundant illite and various amounts of kaolinite. In rocks with appreciable kaolinite, this mineral replaces the plagioclase phenocrysts with aggregates of crystals less than 3 μ to 50 μ in diameter. In most rocks illite also occupies the plagioclase phenocrysts; the amount varies from a few flakes parallel to former crystallographic planes to 80 percent of the crystal, intergrown with the kaolinite. Biotite is replaced by illite and leucoxene; hornblende and augite are replaced by leucoxene, hematite, and minor quartz. The groundmass is an aggregate of 10- μ quartz grains with as much as 20 percent 1 to 5- μ illite and as much as 30 percent diffuse patches of very fine-grained kaolinite. Scattered 1 to 5- μ granules of hematite, leucoxene, and in some rocks 10- μ jarosite or barite form about 10 percent of the groundmass. These clay-bearing rocks, which belong to the illite-kaolinite subzone of Harvey and Vitaliano (1964, p. 568-571), are the product of more intense hydrothermal alteration than the montmorillonite-bearing rocks.

The rocks mapped as silicified rocks constitute the second group of samples used for geochemical comparisons (pl. 2). They are microcrystalline quartz with 15 to 65 percent alunite and kaolinite. Most rocks contain alunite and kaolinite in 10:1 to 1:3 proportions, but some have no kaolinite. Typically, alunite and kaolinite form about one-third of the rock, but it is dense and hard, resembling chert, because most of the alunite and kaolinite is localized at the sites of former plagioclase phenocrysts, and sometimes former biotite phenocrysts. Samples with more than 50 percent alunite and kaolinite become relatively soft, because these minerals become important in the groundmass; these rocks are indistinguishable in the field from nonsilicified clay-bearing rocks. Twelve such samples, found locally at the margins of visibly silicified zones, are included with silicified rocks on plate 2. These alunite- and kaolinite-rich zones are always substantially thinner than the harder silicified zones adjacent to them. Former plagioclase phenocrysts in silicified rocks are randomly-oriented aggregates of 20- to 100- μ -wide alunite plates with 25 to 80 percent quartz (10^{to} 50 μ) and kaolinite (2^{to} 10 μ). The former groundmass is a 2^{to} 20 μ aggregate of quartz with 10 to 50 percent alunite or kaolinite or both, alunite generally the more abundant, and scattered granules of hematite, leucoxene or rutile, and in some rocks diaspore or jarosite. Biotite, hornblende, and augite are outlined in the groundmass by subhedral areas containing 20 to 50 percent hematite, leucoxene, or rutile, and rarely jarosite. In some rocks, however, biotite is the site of coarse platy alunite with 20 to 30 percent fine-grained leucoxene or rutile,

hematite, and minor quartz. The silicified rocks belong to the alunite-quartz zone of Harvey and Vitaliano (1964, p. 571). They form crudely tabular bodies which represent the rocks immediately adjacent to the fissures that conducted hydrothermal solutions.

All the altered rocks show moderately to well-preserved relict textures regardless of intensity of alteration. Relict quartz phenocrysts remain in all samples.

Element distribution maps

Rocks affected differently by hydrothermal activity often show pronounced differences in amounts of ore-related elements, so plate 2 is used as a base for the element-distribution maps which follow. The cuts generally parallel the vein system, but they expose one section approximately across strike immediately northwest of the Combination shaft. ^(see AA', p/s. 3-13) A geochemical profile for this section is shown for each element along with the geochemical map to help bring out relationships between the minor element distributions and various alteration and structural features, and to show the degree of contrast between metallized silicified and nonmetallized argillized rocks, which may also be expressed as "anomaly-height to background ratio," or "anomaly contrast." The histograms accompanying each geochemical map serve to show the relative amounts of each element in silicified versus argillized rocks. The histograms also show the relative numbers of samples included in each range of values represented by a different map symbol. Distribution maps are included for gold, lead, silver, bismuth, mercury, arsenic, copper, molybdenum, and zinc. Tellurium and antimony are not included because replicate analyses indicated that sample preparation and extraction problems affected the atomic absorption and colorimetric analyses for these elements. Replicate determinations resulted in values from 10 to as much as 100 times higher than the first determinations. Possibly tellurium and antimony in these rocks are very finely divided and were not quantitatively liberated from the quartz matrix with the original grinding and extraction procedure.

Unfortunately, the original splits for many samples were depleted before this problem was satisfactorily solved, so the data is not worth examining in detail. The limited data available suggests, however, that both tellurium and antimony are enriched in metallized silicified rocks relative to surrounding argillized rocks. Cadmium and tin, the two remaining potential indicator elements (ignoring selenium), were not included because only 17 of the 278 samples from the cuts had 3 ppm or more of tin, and none of the samples had as much as 50 ppm of cadmium.

Gold

All but three high gold values (greater than or equal to 3 ppm) and most intermediate gold values (1 to 2.9 ppm) are in silicified rocks (pl. 4). The three high values in argillized rocks are all from fault or shear zones adjacent to silicified zones (see locs. 4, 6, and 7, pl. 4). Of the six intermediate values in argillized rocks, two are from fault zones between argillized and silicified rocks (loc. 8 and fault at loc. 4), and two more are within 5 feet of silicified zones, but are not associated with strong structures (locs. 9 and 10). The remaining two intermediate values, at locality 11, are at least 20 to 30 feet southwest of the nearest silicified rock contact exposed in the wall of the cut or projected along the floor of the cut toward locality 9, and are not associated with structures. All remaining samples from argillized rocks have less than 1 ppm gold; many have less than 0.1 ppm. ✓

—/Note that the detection threshold for gold for samples from the cuts is 0.1 ppm, whereas it is 0.02 ppm for the unaltered dacite samples and unoxidized silicified rocks discussed in the previous section.

The histograms reflect the substantially different amounts of gold in silicified versus argillized rocks. The geometric mean for silicified rocks, 1.3 ppm, is more than 10 times that determined for argillized rocks, 0.11 ppm. The frequency distribution for silicified rocks is relatively symmetrical, with a rather broad peak between -4.00 and -3.50 log percent (between approx^{imately} 1 and 3 ppm). If ore samples had been available from the 12 locations at which old stopes intersect the walls of the cuts, the upper tail of the histogram, representing values of 10 ppm or more, would presumably be somewhat larger. A large number of values appear at the left end of each gold histogram, just above the detection threshold. Most of the readings that contribute to these large frequencies in the class interval immediately above the detection threshold are readings of "0.1 ppm." In fact, 44 of the 278 samples were read as 0.1 ppm, whereas only 17 samples were read between 0.1 and 0.2 ppm. This suggests that analytical discrimination was poor for samples near the detection threshold. Consequently, both readings of "0.1 ppm" and "less than 0.1 ppm" are given the same symbol on the map.

Silicification alone is by far the most important feature associated with relatively high gold values, but the silicified zones do not show uniformly high values. The west edge of the vein system, exposed between localities 12 and 1 and on the wall to the west and north of the January shaft, shows the lowest values. The small silicified bodies at localities 13 and 14, in the hanging wall of the main vein system, also show low values. Along the wall between localities 6 and 2, even though the gold tenor is relatively high, many adjacent samples have substantially different amounts of gold. Moving southeastward along the vein system, individual exposures seem unpredictable: relatively high values appear in the vicinity of locality 15, low values at locality 16, and high values again east of locality 10. Localities 7 and 3 are each represented by only one sample; more information would be needed to categorize these outcrops. The geochemical profile, which includes locality 15, shows nearly the maximum anomaly contrast that one would expect to see between metallized silicified rocks and argillized rocks, unless the sampling encountered ore-grade material.

The geochemical profile shows a sharp break within the large silicified zone at locality 15, produced by an isolated very low reading. Irregularities like this, but usually less pronounced, apparently must be expected. The variations between adjacent samples seen locally between localities 6 and 2 have already been mentioned. The partial profile seen between localities 1 and 4 provides another example. Geologic processes must account for most of this variation, producing "bunches" of gold at the scale of an outcrop or even within a hand specimen, but sampling error may well be a factor also. Gold

/"Sampling error" refers to variation introduced into the data by samples or analytical portions of samples that are not truly representative of the localities from which they were taken. "Analytical error," on the other hand, refers to variation introduced into the data by imprecision in the laboratory analytical procedure.

for atomic absorption analysis was extracted from only 2 grams of *an analytical portion very much smaller than the field sample,* sample, which was 2 to 3 kg. Gold was separated from approximately one-half-kilogram portions of the three samples having the highest gold values: the largest gold flake recovered was 0.07 mm in diameter.

—Data provided by William J. Keith, U.S. Geological Survey.

Applicable here is the diagram prepared by Clifton and others (1969, p. C8) relating gold particle mass (and particle diameter, for both spheres and flakes) to size of analytical portion expected to contain

20 gold particles for samples of various true grades. Their diagram

Clifton and others show that if a sample contains 20 particles of gold, it is 95 percent probable that the true gold value will be within a range of values from approximately 50 percent more to approximately 50 percent less than the value obtained by chemical analysis.

shows that sampling error is acceptable for 0.07 mm flakes only if the true grade is larger than about 10 ppm. Gold flakes not quite twice as large (0.125 mm) or gold spheres of about the same diameter (0.062 mm) would produce sampling error for rocks having a true grade less than about 30 ppm, which is nearly the same as the highest reading (29 ppm) obtained in this study. Most of the gold is probably smaller than 0.07 mm and most 2-gram analytical portions probably contain more than 20 particles of gold, but it is likely that a relatively few larger gold particles significantly affect the readings for samples with more than 3 ppm gold. Fire assay, utilizing 29.167 grams of sample, would avoid sampling error for samples with true grade above 0.5 ppm, if the largest gold grains were 0.07 mm flakes, or for samples with true grade above about 4 ppm, if the largest gold grains were 0.07 mm spheres. Since the main objective of this report is delineating indicator elements for gold, some sampling error is not objectionable, but for a precise determination of ore grade, fire-assay analyses would be necessary.

With the foregoing discussion in mind, it is of interest to estimate the grade of unmined silicified rock exposed in the cuts, using the data at hand. The geometric means calculated for various elements in the several data sets discussed in this report are suitable for comparison with one another, but they are not the best estimates of true abundances (see introduction, p. 20). For minor-element data obtained from groups of rock samples, the geometric mean is always less than the arithmetic mean, which generally gives the best estimate of true abundance. Sichel (1952, 1966) developed the \bar{t} estimator specifically for evaluating ore blocks in South African gold mines. It is essentially an estimate of true abundance derived for data showing a lognormal frequency distribution. To obtain \bar{t} , the antilog of the geometric mean is multiplied by a correction factor approximately proportional in size to the antilog of the geometric standard deviation but also partly determined by the number of samples (see discussion by Miesch, 1967, p. B7-B8). As mentioned earlier, the resulting \bar{t} value is somewhat smaller than the arithmetic mean one would calculate using untransformed data, and ^{is} not as strongly influenced by relatively few very high values, as is the arithmetic mean (Sichel, 1952, p. 265). For the silicified rocks of the cuts, \bar{t} is 30ppm. With 95 percent confidence, the true abundance should be between 2.4 and 3.8 ppm (confidence interval calculated by method of Aitchison and Brown, 1963, p. 50). One part per million gold at 35 dollars per troy ounce is approximately equivalent to an ore grade of one dollar per short ton; specifically 3 ppm is equivalent to \$3.06

per ton, and the corresponding confidence interval is \$2.45 to \$3.88 per ton. These amounts of gold, although subeconomic, are large enough to commend further exploration and evaluation of the remaining vein material.

Lead

Silicified rock samples show many high lead values (200 ppm or more) and intermediate lead values (70 to 150 ppm), whereas argillized rock samples show only 5 high values and 10 intermediate values (pl. 5). Some of the intermediate values in argillized rocks are adjacent to silicified zones, as at locality 12 and near localities 10 and 18. An intermediate value appears in a shear zone adjacent to silicified rock at locality 15, and a high value appears in a fault zone adjacent to silicified rock at locality 4. Four of the five high values for argillized rocks are grouped together north of locality 4. This group of relatively high-lead samples has no distinctive structural or alteration feature associated with it.

The anomaly contrast shown by the profile, is representative of what one might expect along any traverse across the strike of the silicified zones in the vicinity of the cuts. The anomaly contrast is as strong as that for gold itself, and in some possible profiles it might well be stronger.

Consistently high lead values appear within the silicified zones in the areas characterized by high gold values. Between localities 1 and 12, scattered high lead values accompany intermediate gold values. Other smaller silicified outcrops all show some degree of consistency between gold and lead values, but it would be difficult to predict gold tenor from lead readings. The histogram for silicified rocks (pl. 5) shows large frequencies in four class intervals above the geometric mean: 200, 300, 500, and 700 ppm, so the frequency distribution looks skewed toward the higher values, with a very small upper tail above 700 ppm. The frequency distribution for gold, by comparison, shows a long, relatively smoothly-declining upper tail above the geometric mean. Thus even though an area may show some very high gold values, along with some high and intermediate values, almost all the lead readings are between 200 and 700 ppm. Lead values from silicified rocks therefore give no idea about the highest gold values to be anticipated, but on the other hand, lead values of 200 ppm or larger indicate that gold values of at least 1 ppm will be found nearby (locality 16 is an exception). A different method of chemical analysis offering greater analytical precision for rocks with true lead values between 100 and 1,000 ppm might improve the correlation between gold and lead for individual samples, but geologic factors, rather than analytical precision, may account for the limited range of variation for lead in relatively gold-rich samples (see interpretation section, p. 71-71a). The apparent "ceiling" on lead values has an advantage for geochemical exploration, in that lead might well show broader, less ragged anomalies over potential gold ore bodies than would gold itself.

Silver

1
2 All high silver values (greater than or equal to 10 ppm) appear
3 in silicified rocks (pl. 6). Only one intermediate value (between 3
4 and 7 ppm) appears at locality 17 in argillized rocks associated with
5 a fault zone; all the other intermediate values are in silicified
6 rocks. Of the 8 low values (between 1 and 2 ppm) in argillized rocks,
7 3 are adjacent to silicified zones (localities 15, 18, and 10), and
8 one other is in a fault zone (southeast of loc. 17). Almost all the
9 argillized samples and 48 of the silicified rock samples (37 percent)
10 bear less than 1 ppm silver. Obviously, no notable silver halo exists
11 in argillized rocks. The geochemical profile shows anomaly contrast
12 typical of what might be expected many places in the cuts. Silicified
13 rocks at localities 13 and 14 and between localities 5 and 12 would
14 not be anomalous, whereas one can anticipate that profiles run north-
15 east of the January shaft might produce anomalies twice as strong as
16 those shown on the profile. The gold and silver patterns in the
17 silicified zones are grossly similar, even though larger areas within
18 the zones show relatively low silver values.

The semiquantitative spectrographic data available for silver is not precise enough to allow a good determination of silver tenor in the silicified rocks. Even an approximate estimate is not possible because the detection threshold for 26 of the silicified rock samples (20 percent) was 1 ppm, due to spectral interference, rather than the usual 0.1 ppm. In calculating the geometric mean for the silicified rocks by Cohen's method, the lower of these two detection limits, 0.1 ppm was used, possibly biasing the result toward low values. Furthermore, the histogram for silver in silicified rocks is very irregular; possibly more data with higher analytical precision would show a polymodal frequency distribution. The resulting geometric mean shown with the histogram on plate 6 has such a large standard deviation associated with it that it has little meaning. The data does suggest, however, that fire assays of samples taken northeast of the January shaft should show some silver values as high as 1 ^{ounce} ~~oz~~ troy per short ton.

One part per million by weight is equal to 0.0291667 ^{ounce} ~~oz~~ troy per short ton.

Bismuth

Only two argillized rock samples yielded detectable amounts of bismuth (5 ppm). Forty-five silicified samples show readings ranging from 5 to 200 ppm, but the majority of silicified samples (65 percent) also have less than 5 ppm bismuth. Clearly, the 5 ppm detection threshold provided by the semiquantitative spectrographic technique employed is too high to provide enough data for many conclusions about geochemical relationships. Bismuth cannot be fully evaluated as an indicator element for gold, but it obviously shows a strong preference for silicified zones, and most of the intermediate and high bismuth values appear northeast of the January mine shaft, in an area characterized by intermediate and high gold values (pl. 7).

Only three readings above the detection threshold appear along the geochemical profile line, so the profile for bismuth is not included with plate 7.

Mercury

The silicified rocks of the cuts contain more mercury than do the argillized rocks. The averages for the two data sets are not greatly different (see histograms on pl. 8) but they are significant statistically, at the 99 percent confidence level. Plate 8 bears this difference out for most of the area of the cuts: silicified rocks along the south and west sides of the largest cut, continuing into the area northeast of the January shaft, have many intermediate (0.11 to 0.30 ppm) and high (greater than 0.30 ppm) mercury values. Throughout the southeastern cut (locality 16 to locality 3), silicified and argillized rocks are similar. The silicified rock east of locality 10 has intermediate to high gold values, but it is expressed no more distinctly on the mercury map than is locality 16. On the other hand, the area northeast of the January shaft with high gold values certainly has the most mercury. The consistently intermediate to high mercury values south of locality 9 and between localities 9 and 11, furthermore, suggest that mercury halos may extend 30 to 35 feet into argillized rocks from silicified zone contacts in gold-bearing areas. The width of this possible halo, however, is small relative to the width of the adjacent silicified zone: about 90 feet at locality 9. Also, the geochemical profile reveals that the anomaly contrast is very low.

The histograms jointly show that the total range of mercury values is barely two orders of magnitude, compared to at least three, and probably four orders of magnitude for gold, so one cannot expect mercury anomalies to be very strong. Under these circumstances, relatively narrow halos extending into argillized rocks are not particularly valuable for reconnaissance sampling. They might be of minor value for a detailed sampling program in a small area.

Arsenic

The Gutzeit colorimetric method used for arsenic determination has a reporting interval that becomes larger with increasing values, but is arithmetic within certain ranges of values. Values reported for the oxidized rocks of plate 9 are: less than 10, 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, and 250 ppm. Corresponding log percent figures are: less than -3.000, -3.000, -2.699, -2.398, -2.222, -2.097, -2.000, -1.921, -1.854, -1.796, -1.744, -1.699, and -1.602. Within this range of values the interval is arithmetic except for the upper and lower ends of the range. The histograms (pl. 9) are based on the logarithms of the reported values, however, to avoid overemphasizing values of 200 ppm or more, and to make the histograms more easily comparable with those on the other plates. The resulting histograms, with class intervals determined by Sturges' rule, have null class intervals below -2.500 log percent. Other class intervals, *determined arbitrarily, will not eliminate the problem unless one reduces the number of class intervals* to three or four, and this, in turn, eliminates variations shown in the upper parts of the histograms. Such treatment also subdues the fact that a disproportionate number of values for both silicified and argillized rocks were read as 10 ppm. "10 ppm" was reported for 49 of the 129 silicified rocks (38 percent), and 74 of the 149 argillized rocks (49.7 percent), whereas "less than 10 ppm" was reported for only 7.0 percent of the silicified rocks and 12.8 percent of the argillized rocks. Analytical discrimination was apparently poor near the detection threshold for the Gutzeit colorimetric test. Readings of "less than 10 ppm" and "10 ppm" are therefore given the same symbol on plate 10. This same problem arose with gold readings near ~~the gold reading near~~ the gold detection threshold of 0.1 ppm, and was treated similarly.

The geometric means indicate that silicified rocks have about twice as much arsenic, overall, as do argillized rocks. Since the problems with reporting interval and analytical discrimination produce discontinuities among the smaller data values, as shown by the histograms, the validity of these geometric means is questionable. The percentages of samples read as "less than 10," "10," "20," and "40" ppm, however, are generally similar for the two data sets, so improved analyses would likely have similar effects on both frequency distributions and both geometric means. The upper parts of the two frequency distributions, clearly different, probably would not be substantially changed. Both geometric means would likely be decreased with better analyses, but the difference between them would probably not be changed much.

Although silicified rocks contain more arsenic than argillized rocks, as is the case for the preceding elements, the relationship between arsenic and gold is not consistent (compare pl. 9 with pl. 4). Intermediate (50 to 80 ppm) and [#]high (100 ppm or more) arsenic values accompany moderate to high gold values for most, but by no means all, samples northeast of the January shaft. Arsenic values are relatively lower than gold values for the area between localities ¹8 and ⁴12, relatively higher than gold values for the area between localities 5 and 12, relatively lower in the vicinity of locality 15, and relatively higher at locality 16. The other silicified rock outcrops show a few samples with concordant gold and arsenic values, but these are but a small percentage of the silicified rock samples.

Intermediate and high arsenic values appear at many localities in argillized rocks. Some are associated with fault zones and shear zones, but many are not. Halos around silicified zones do not exist. The geochemical profile shown is typical for argillized rock areas, but gold-bearing silicified rocks could show greater arsenic anomaly contrast in profiles taken at some other locations. With the small range of variation in the data, however, even a profile taken in the northwestern part of the cuts would show only modest anomaly contrast. For geochemical exploration, arsenic is not reliable as an indicator for gold.

Copper

The maps for copper and gold (pls. 10 and 4) are dissimilar except for a group of high-gold samples in the vicinity of locality 20 that also show high copper values. The histograms for silicified rocks and argillized rocks are much the same, and the two data sets have nearly the same range of values. The geometric means are not significantly different statistically at the 95 percent confidence level, and the geometric standard deviations are not much different. Throughout the map area fault zones and shear zones are not particularly favorable to high copper values relative to less broken ground.

Obviously copper cannot be used as an indicator element for gold in the silicified rocks. The geochemical profile (pl. 10) bears this out. The question arises whether some areas of argillized rock with intermediate and high copper values, such as those between localities 12 and 15 and between localities 16 and 17 represent a halo. One or more longer profiles across strike would be helpful in answering this question, but the low values between localities 9 and 11 and the lack of a systematic decrease in values from locality 15 to locality 19 indicate that a halo is not consistently developed.

Molybdenum

Some intermediate (7 to 10 ppm) and high (more than 10 ppm) molybdenum values are scattered throughout the high-gold area northeast of the Combination shaft (pl. 11). Most other silicified outcrops also show only a few scattered intermediate and high values with no consistent relationship to gold values. The overall tenor of molybdenum is higher in argillized rocks than it is in silicified rocks. The intermediate and high molybdenum values in argillized rocks are also scattered, but about half of these values are associated with faults and shear zones (west of locality 2, near locality 4, at locality 6, near locality 14, north of locality 18, and south of locality 16). No coherent halo is developed in argillized rocks. The geochemical profile demonstrates that molybdenum values cannot be predicted on the basis of alteration and structural criteria.

Zinc

Except for a few scattered intermediate (50 to 90 ppm) and high (100 ppm or more) values, zinc is relatively scarce in the silicified rocks (pl. 12). Intermediate zinc values appear near silicified zones between localities 12 and 19, 16 and 17, and at locality 11, suggesting that zinc may form a geochemical halo. As is the case with copper, however, other areas near gold-bearing silicified rocks, particularly between localities 15 and 19 and between localities 9 and 11 are not enriched in zinc, so again a halo is not consistently developed. The group of intermediate and high values found along the cut wall east of locality 14 and 100 feet northeast of locality 18 show no systematic relationship to faults or shear zones.

The geochemical profile for zinc is not particularly informative, so it is not included with plate 12.

Interpretation of the geochemical maps: Separating effects
of hypogene and supergene processes

General

The distribution of gold and other ore-related metals in the Combination-January cuts is the result of two processes: hydrothermal alteration culminating in metallization, and oxidation. Here metallization is a primary (and epigenetic) geochemical dispersion process. Oxidation and accompanying dissolution and redeposition of the epigenetic elements constitute a secondary geochemical dispersion process. The objective of this section is to determine to what extent the map pattern for each element is the result of secondary rather than primary dispersion processes.

The Goldfield hydrothermally-altered rocks, both silicified and argillized, have ubiquitous pyrite (Ransome, 1909, p. 113-114, and our observations). In the prevailing arid climate, surface water descends to the water table, reacting with pyrite above the water table to yield Fe^{2+} , Fe^{3+} , HSO_4^- , and $\text{SO}_4^{=}$. Usually most of the iron reacts further to form limonite minerals (hematite, Fe_2O_3 , and goethite, FeO(OH)). Where ore is exposed to meteoric waters, other sulfides and sulfosalts are also oxidized to yield metal cations and sulfate ion ($\text{SO}_4^{=}$). Studies by Baas Becking, et al. (1960) on mine waters, and by Sato (1960) on mine waters and on experimental oxidation of iron and manganese indicate that Eh values in oxidizing sulfide ore deposits may be as high as +0.6 to +0.86 volt with low accompanying pH values of 2 to 3. Any metal whose compounds (hydroxide, carbonate, chloride, and particularly sulfate) are soluble in these aqueous

FOOTNOTE NEAR HERE

solutions having relatively high Eh and low pH will be more or less mobile in this environment. Highly mobile (soluble) elements, such as copper, may be thoroughly leached, destroying their primary dispersion patterns. Metals having intermediate mobility, such as molybdenum, are transported only short distances and precipitated, some along with limonite. Some metal cations are easily reduced to the native metal and precipitated (mercury), or form stable compounds that remain essentially in situ (lead). The latter elements should reveal relict primary dispersion patterns. Copper, and silver to a lesser extent,

-Garells and Christ (1965) consider a species with an activity of $10^{-6}M$ or greater "soluble" in the framework of geologic processes.

may be redeposited below the water table to form a supergene enrichment zone. The samples from the cuts, however, lie approximately in a plane parallel to the ground surface and within the upper part of the oxidized zone, so supergene enrichment effects can be ruled out. Ransome (1909, p. 170-174), in describing oxidized ores and changes in the ores with depth, does not mention supergene enrichment at or near the water table. Leaching effects should be essentially the same in rocks of the cuts as at the ground surface.

A number of authors give relative mobilities for many of the metals being considered here. Figure 6 summarizes information given by three authors, who have in turn assembled data from other sources.

FIGURE 6 NEAR HERE

The figure shows that we may expect zinc to be highly mobile, copper and molybdenum to be moderately to highly mobile, silver and gold to be moderately mobile, arsenic to be immobile to moderately mobile, and lead, bismuth, antimony, and tellurium to be immobile. Krauskopf (1967) and Hawkes and Webb (1962) agree that Hg should show low mobility in solution, but Hawkes and Webb indicate that Hg may be very mobile in the vapor phase.

Figure 6.—Relative nobilities of various metals during oxidation.

During oxidation, groundwater passing through rocks bearing pyrite and other sulfide minerals dissolves and carries away mobile elements, accomplishing leaching. Where such groundwater encounters mine workings, it evaporates, leaving coatings and crusts of hydrated sulfates which incorporate the metals actively being leached (see for example Lovering, in Morris and Lovering, 1952). Such coatings are common on the walls of mine workings beneath oxidizing sulfide ore bodies, and hydrated iron sulfates are usually the most abundant constituents of the coatings; these hydrated iron sulfates, formed initially by the oxidation of pyrite, are intermediate products that are eventually converted to hematite and goethite (Blanchard, 1968, Chapter 9, p. 51-55). Eight samples of secondary hydrated sulfates from walls of workings in the Florence mine (table 1 and fig. 2)

TABLE 1 NEAR HERE

contain relatively large amounts of copper and zinc, lesser but notable amounts of bismuth and molybdenum, and cobalt, nickel, and manganese as well. None of the seven hydrated iron sulfate samples contain as much as one part per million silver, but the gypsum sample contains 3 ppm silver. None of the samples has as much as 7 ppm lead. The detection thresholds for gold (15 ppm), arsenic (200 ppm), antimony (100 ppm), and tellurium (1,000 ppm) are too high to allow significant amounts to be recognized, except for antimony in gypsum (700 ppm). All the sulfates sampled except gypsum are readily soluble in water, so they were separated and cleaned by hand-picking; consequently not enough material was available for extensive chemical testing.

TABLE--1

Most of the mine workings from which the sulfates came were put in between 1903 and 1905 (Ransome, 1909, p. 225-226 and plate XXIV; Martin C. Duffy, oral commun., 1966). The tunnel from which samples F-350-8B and F-350-9C came (fig. 2) is a crosscut driven about 1919 (Searles, 1948, p. 20). The workings in the Florence mine generally follow a north-trending silicified zone which forms the southern extension of the Combination vein system, as previously mentioned. The silicified zone and ore shoots within it dip steeply, and the Florence shaft passes close to the silicified zone from the surface all the way down to the 350-foot (7th) level. Silicified rock is oxidized to the 100-foot (2nd) level, but little oxidation appears on the 150-foot (3rd) level and none below it (Ransome, 1909, p. 227). A small flow of water has entered the 350-foot level since at least 1908 (Ransome, 1909, p. 230). Sample localities F-350-3 and F-350-4 are crusts from the only part of the mine that was wet at the time of sampling. The sulfates at localities F-350-8 and F-350-9 form incrustations also; this part of the mine was probably wet at some time in the past. Localities F-350-8 and F-350-1 yielded fluffy efflorescences typical of most of the mine; these apparently form in dry parts of the mine as small quantities of groundwater reach the walls and evaporate.

Sample F-250-8 lies between 50 and 100 feet beneath and to the east of the stope developed under the Sweeney lease, one of the largest single ore bodies in the district (Ransome, 1909, p. 154, 225-228; Newmont Mining Corporation, unpub. maps). Localities F-350-3 and F-350-4 lie about 120 to 200 feet from the Sweeney stope, being a few tens of feet to the south and east of a vertical projection of the stope to the 350-foot level. Another smaller stope lies approximately 60 to 100 feet above and immediately to the south of these two sample localities. A stope approximately 250 feet above the localities was entirely of oxidized ore (Ransome, 1909, p. 228). Locality F-350-1 is from the wall of a stope along a fault that may continue to the northeast into the Engineers' lease (Ransome, 1909, pl. XXXV, p. 232). Localities F-350-8 and F-350-9 lie between 120 and 230 feet below and to the west of the Sweeney stope. No ore bodies are known to have been mined from the ground immediately above these samples. Thus the sulfate coatings sampled resulted from supergene leaching of low-grade unmined silicified rock, and possibly unknown small bodies of high-grade ore, for over 60 years when the samples were taken in September 1966 (47 years for samples F-350-8B and F-350-9C).

Comparing amounts and ratios of elements shown in table 1 with amounts and ratios shown in figure 5, the potential indicator elements

~~FIGURE 5-NEAR HERE~~

for gold can be qualitatively arranged in order of decreasing mobility as follows: zinc, molybdenum, copper, bismuth, silver, lead.

Information is inadequate or lacking for gold, arsenic, and mercury. This arrangement must be approximate because geochemical information is lacking for average-grade ores taken from the Florence mine. Silver was unusually scarce in ores from the Florence (Ransome, 1909, p. 230), so silver might be more mobile than indicated.

Secondary sulfates such as those analyzed here were used by Lovering (in Morris and Lovering, 1952) to determine supergene mobilities of gold, silver, lead, copper, and zinc in the Tintic district, Utah. His results generally agree with ours, even though his samples contained larger amounts of these metals, and he considered differences in mobility related to several different wallrock environments.

Iron and manganese are included in figure 6 because they are both

FIGURE 6. NEAR HABA

easily oxidized and precipitated as hematite, goethite, and various manganese oxides and hydroxides. Several other elements, among them arsenic, copper, molybdenum, and zinc, may be precipitated with these minerals or adsorbed by them (Hawkes and Webb, 1962, p. 162-177). Since these four elements are potential indicator elements for gold, it is appropriate here to discuss the distribution of iron and manganese in the rocks of the Combination-January cuts.

Many high and very high iron values are associated with fault zones, but the majority of such values are not (see pl. 13). Iron does not seem to show consistent preferences for any lithology or structural environment. The most important thing to note is that unaltered dacite, unoxidized silicified dacite, and unoxidized average-grade ores contain 4.2, 4.7, and 6.7 percent iron (geometric means, see fig. 5), but the oxidized silicified dacite and oxidized argillized dacite of the cuts average only 1.0 and 2.2 percent iron, respectively (see histograms, pl. 13). This means that even though hematite and limonite stain many of the rocks of the cuts conspicuously, much iron has been removed. Figure 5 shows that essentially all iron is retained during hydrothermal alteration and ore deposition, except in the high-grade ores, which occurred in relatively small volumes; the iron removed from the cuts, therefore, must have been leached during oxidation. In the few unoxidized argillized rocks we have examined from the Florence mine and elsewhere in the Goldfield altered area, pyrite mostly replaces former mafic minerals, just as it does in unoxidized silicified rocks. Before oxidation, therefore, the amounts of iron in silicified and argillized rocks must have been similar, so the silicified rocks were more strongly leached than the argillized rocks. The most likely explanation for this is that numerous small post-alteration fractures remain open in the silicified rocks, whereas in argillized rocks they are squeezed shut. These small fractures have diverse orientations, and are easily visible in the silicified rocks along the cut walls. Locally they are so abundant that from a distance the rock looks

brecciated (~~apart from the breccias designated on pl. 2, which are true breccias with angular fragments in a fine-grained matrix~~). The same small fractures in argillized rocks, on the other hand, are much tighter and can only be seen readily on freshly excavated surfaces from a few feet away. The histograms show that both silicified and argillized rocks have a wide range of iron values. Probably differences in porosity, permeability, and other properties affecting movement of ground water and reactivity of ground water solutions would have to be considered to explain details of the iron distribution map. The present petrographic division of the data, in spite of the obvious differences in physical properties between silicified and argillized rocks^{2/}, is

^{2/}An exception is the advanced argillic rocks (12 samples), included with silicified rocks because of their alunite-bearing mineral assemblages. These rocks appear physically similar to argillized rocks (see p. 30).

inadequate for evaluating these factors. Clearly iron, even though it is quite immobile once it forms limonite, has undergone considerable redistribution during oxidation at Goldfield. It will be useful to compare the iron map with the maps for potential indicator elements to assess the extent of supergene dispersion of each element.

Manganese should behave in the same way iron does during oxidation (see fig. 6). Manganese, like iron, is depleted in silicified rocks (average 17 ppm) relative to argillized rocks (average 96 ppm) (see appendices ^KJ and L), but manganese, unlike iron, is strongly and progressively depleted during hydrothermal alteration and ore deposition (see fig. 5 and discussion, p. 27). It seems likely that manganese was removed from both silicified and argillized rocks of the cuts during hydrothermal alteration, and probably more was removed at that time from silicified rocks. 100 to 300 ppm manganese appears in the secondary sulfates previously described, indicating some movement during oxidation. Manganese therefore was probably removed during both hypogene and supergene alteration, so it is of little use for determining whether other elements have undergone supergene redistribution: consequently a manganese distribution map is not included, and manganese will not be considered further.

Finally, before discussing individual potential indicator elements it is convenient to introduce correlation matrices for these elements and iron (fig. 7). A correlation matrix facilitates making comparisons

FIGURE 7 NEAR HERE

between the various elements and visualizing the results. The statistical methods used to generate each matrix were discussed on p. ^{21-2/5}~~15-20~~; further discussion of the meaning of numbers given in the matrices follows. The upper triangle of each matrix gives the correlation coefficients. The lower triangle gives the number of data pairs used for calculating each coefficient; where either or both data values of a data pair were outside the detection limits, that data pair was rejected. The maximum correlation coefficient is 1.0, corresponding to ~~perfect~~ ^{perfect} correlation, in which case ranked lists of samples for each of the two elements being compared would be identical. A correlation coefficient of zero indicates complete absence of correlation, and a coefficient of -1.0 indicates perfect negative correlation, in which case ranked lists would be exactly reversed. By no means are all the positive correlation coefficients large enough to constitute significant positive correlations, or are all the negative correlation coefficients close enough to -1 to constitute significant negative correlations. As the number of data pairs increases, however, the smallest coefficient that may be considered significant at a given statistical confidence level becomes progressively

Figure 7.--Correlation diagrams for oxidized silicified and argillized
rocks from the Combination-Jaquiry area.

smaller. Coefficients statistically significant at the 99 percent confidence level, and coefficients statistically significant at the 95 percent confidence level but not at the 99 percent confidence level are each designated in the matrix. All other coefficients are taken to indicate no significant correlation. The numerical value of a given correlation coefficient is of little importance: the important thing is whether it is large enough, considering the number of data pairs used, to indicate a significant degree of positive or negative correlation. The statistical confidence levels provide arbitrary but objectively-defined cut-offs for deciding which correlation coefficients are large enough to consider geologically important. Coefficients significant at the 95 percent confidence level are taken to indicate a meaningful association or correlation in the geologic context, and coefficients significant at the 99 percent confidence level are taken to indicate a strong correlation.

In the following discussion gold is presented first, and the remaining ore-related elements are presented in order of increasingly strong supergene leaching and redistribution. We used the same order in the previous section, so that it would be easier to refer back to that section. The position of bismuth in this ordering is rather arbitrary because most of the analytical data for bismuth falls below the detection threshold.

Interpretation of data for the potential indicator elements

Gold

The pattern for gold in the Combination-January cuts (pl. 4) is mainly the result of hypogene dispersion processes little modified by supergene dispersion, and therefore is essentially a relict primary dispersion pattern. Plate 1 shows that some parts of productive silicified zones were not ore-grade, but most of the ore, whether primary or oxidized (above 130 to 180 feet depth) was from silicified zones. The fact that moderate and high gold values in the cuts are almost entirely within silicified zones indicates that the gold map pattern is essentially a hypogene dispersion pattern. The low-tenor silicified rocks of the cuts may be thought of as belonging to a hypogene gold aureole connecting and extending outward from the ore bodies, but restricted to the silicified zones. The fact that the ore bodies had assay walls (Ransome, ¹⁹⁰⁴Ap. 213, 218, and Collins, 1907b, p. 435) is consistent with this conclusion.

Some supergene movement of gold might be expected, since gold is thought to be capable of at least an intermediate degree of mobility (fig. 6). Both Ransome (1909, p. 170-174, 216) and Spurr (1905, p. 138) felt that the gold of rich oxidized ores, some of which occurred with limonite in fractures, was concentrated to some degree during oxidation, but even where notable enrichment occurred, rich sulfide ore existed previously. All the gold-bearing samples found along faults in argillized rocks (three high and two intermediate gold values) have high iron contents due to abundant hematite or hematite-goethite mixtures (see localities 4 (two samples), 6, 7, and 8, plates 4 and 13). The abundant ferric oxide and hydroxide indicate that the high Eh's (0.9 volt or more) and low pH's (less than 2 to 5) necessary to dissolve gold may well have developed at these localities (see Cloke and Kelly, 1964). These faults may have formed before hypogene activity ceased; if so, gold might have been transported to these sites by either hypogene or supergene processes, or both, since hypogene gold left along faults might be particularly susceptible to supergene mobilization. The correlation diagrams (fig. 7), however, show no significant gold-iron correlation for either silicified or argillized rocks, indicating that supergene dispersion of gold cannot be generally important, even if gold moves short distances to produce enrichment along fractures. This result agrees with Cloke and Kelly's (1964) data on gold solubility and Krauskopf's (1967) calculations and conclusion that significant migration of gold occurs only locally and for short distances. Even if gold moves as much as a few feet, the effects would not be visible at the scale of sampling of a geochemical exploration program.

Lead

The map patterns for gold and lead are very much similar (pls. 4 and 5). Lead is generally thought to be immobile during oxidation (fig. 6) because it forms a very stable sulfate (anglesite, $PbSO_4$) and carbonate (cerussite, $PbCO_3$). It is not found in supergene sulfates from the Florence mine (p. 58, 62). The lead pattern is certainly a hypogene dispersion pattern, and anglesite is likely the predominant lead-bearing mineral in the oxidized zone. Lead has a tendency to show smaller changes between adjacent samples than does gold (compare geochemical profiles, pls. 4 and 5), indicating that lead is more evenly distributed through the rocks than gold is. Since lead should be less mobile than gold during oxidation, we infer that this is mainly, if not entirely a hypogene rather than supergene feature. The correlation diagrams show that gold and lead are correlated in argillized rocks and strongly correlated in silicified rocks.

Two features shown by the histograms for lead (pl. 6) are presumably the result of hypogene processes: the negatively skewed distribution of logarithms of lead values in silicified rocks, mentioned earlier (p. ⁴⁴~~43~~), and the bimodal distribution of lead in argillized rocks. The histogram for gold in silicified rocks has a distinct upper tail which would be even better developed if mined-out ore/bodies intersected by the cuts had been sampled. With the strong correlation between lead and gold in silicified rocks and the similarity between the lead and gold maps, we would expect the histogram for lead to show a better-developed upper tail. The histogram for lead in silicified rocks shows instead a sharp drop above 700 ppm, with very few values of 1,000 ppm or more. Figure 5 shows that few values greater than 1,000 ppm occur in either average-grade or high-grade ores. Amounts of lead in these two groups of samples are similar, whereas all other ore-related elements show at least some enrichment in the high-grade ores, and most show considerable enrichment. Another manifestation of this apparent "ceiling" on lead values was the paucity of lead-bearing minerals in the ores, although some lead production is recorded (U.S. Geol. Survey, 1912-1924, U.S. Bureau of Mines, 1934-1946). Ransome (1909, p. 112) reported galena from only a few localities in the main district. No lead minerals have been reported in either oxidized or unoxidized ores of the Combination and January mines. ^{There, next page} The relative scarcity of lead thus seems to be characteristic of the Goldfield district, and most likely relates to lack of available lead at the source of the ore-bearing solutions. Ores obtained in the deeper, eastern parts of the district contained

Inert p. 71

of ~~some~~^{one} unoxidized average-grade ore samples

Preliminary microprobe examination[^] by C. G. Gomanste shows^x that neither stibiochalcocite nor tetrahedrite-tennantite contains ^{detectable} lead (detection limit 0.1 percent) [for a spot several tens of microns in diameter], but bismuthinite may contain [amounts] on the order of 0.5 percent.

considerable copper and tin (Searls, 1948, p. 17-18; Wilson, 1944), suggesting some zoning of those metals, but lack of information on lead content of the ores makes it impossible to evaluate zoning in the district with respect to lead.

Regarding the bimodal frequency distribution of lead in argillized rocks, the lower mode lies below the average amount of lead in unaltered dacite (17 ppm or -2.8 log percent) and the upper mode lies above it. The dacite represented by the lower mode was leached of lead, probably during the hydrothermal activity that produced argillization. Most of the values comprising the ~~the~~ upper mode, in the range 20 to 150 ppm, are found in fault zones or within 10 feet of silicified zones or fault zones. The 20 to 150 ppm values ^{near} silicified zones likely represent a narrow hypogene aureole extending from the silicified zones a short distance into the argillized zones. If most of the faults originated during the later stages of hydrothermal alteration, the values associated with these structures could also represent low-tenor hypogene metallization. We have no explanation for localities enriched in lead but devoid of structure, such as that north of locality 4 where four high values appear. We infer that igneous lead was leached from the dacite during the earlier stages of hydrothermal activity, and ore lead was added to the resulting argillized rocks during the later stages of hydrothermal activity. Other ore-related elements may have had a similar history in argillized rocks, but if so, ranges of values, detection limits, and supergene redistribution effects obscure the bimodal frequency distributions.

Silver

Almost all intermediate and high silver values are found in the silicified zones, with the highest values in the same general areas as those in which high gold values occur. This fact argues against much supergene movement of silver, even though silver often shows at least moderate supergene mobility (fig. 6). Supergene silver mobility is relatively low at the Florence mine, as deduced from the analyses of secondary sulfates (p. ⁵³ ~~53~~, ⁶² ~~62~~). Ransome (1909, p. 119-120, 171) reported chlorargyrite (cerargyrite, AgCl) and probable minor embolite ($\text{Ag}(\text{Cl}, \text{Br})$) in the oxidized zone at Black Butte and McMahon Ridge, three miles northeast of the main district. Much of the ore in that part of the Goldfield altered area was oxidized, and yet it generally had higher silver-to-gold ratios than did ores from the main district (Ransome, 1909, p. 246-251). Schaller (1941) reported probable minor iodyrite in oxidized ore probably from the Combination-January area. Burgess (1911) reported silver halides in the Tonopah district, 25 miles north of Goldfield. In the upper part of the oxidized zone at Tonopah, silver was not carried far from the original sulfide ore before it was precipitated as chlorargyrite, the most abundant silver halide mineral. Boyle (1968, p. 188-207) indicates that much silver should remain in the oxidized zones of sulfide ore deposits in semiarid and arid areas, with silver halides the most abundant silver minerals in the upper parts of the oxidized zones. The foregoing observations point to a relatively low supergene mobility for silver in the oxidized zone at Goldfield, and indicate that the silver map shows essentially a relict hypogene pattern.

Silver and iron are positively correlated in argillized rocks, indicating some movement of silver and redeposition with limonite. Silver must therefore be more mobile than lead. The supergene mobility of silver relative to gold is difficult to determine based on association with limonite, because gold is associated with abundant limonite minerals at several conspicuous localities, but overall, gold and iron are not correlated (see p. 69).

Although high gold and silver values occur in the same areas, silver and gold show no significant correlation in silicified rocks or argillized rocks. Wilson (1944) analyzed silicified rock samples from the Goldfield consolidated main vein (Jumbo Ex mine, 830-foot level), Clermont vein (Clermont mine, 225-foot level), and from two surface localities, one of these on the Jumbo vein (p. 6). He found a consistent relationship between gold and silver in the vein on the Jumbo Ex 830-foot level, but found no consistent relationship at the other three localities. Figure 8, designed to explore the lack of gold-silver correlation further, is a plot of gold-silver ratio against gold value for all samples from the Combination-January cuts that have detectable amounts of both gold and silver. The gold-silver ratios have a wide range (15:1 to 1:50), and the plotted points show considerable scatter, which accords with the lack of statistical correlation. Analytical error for both gold and silver certainly accounts for a good deal of the scatter, as the one-standard-deviation "boxes" accompanying figure 3 show. Sampling error may be a problem

FIGURE 3 NEAR HERE

for gold (see p. ^{41-41a}~~43-44~~), along with analytical error. Supergene redistribution of both elements, even though we consider it insignificant in terms of the geochemical maps, probably also accounts for some of the scatter, since leaching may have changed the original gold-silver ratios more or less in some samples. A significant part of the data

Figure 3.--Relationship between gold value and gold-silver ratio in
samples from the Combination-January area.

scatter may also be due to differences in the proportion of gold and silver deposited by the ore-bearing fluids, but sampling and analytical error aside, we cannot determine precisely how important supergene versus hypogene effects were in producing the wide range of gold-silver ratios without being able to compare gold-silver ratios for oxidized and unoxidized portions of individual ore bodies in the Combination-January vein system. Lack of access to the workings eliminates this approach, but we can gain some information by comparing other ore-related elements with gold and silver in silicified rocks. Bismuth, mercury, and copper all show residual highs northeast of the January shaft in spite of supergene effects, important particularly in the case of copper. These three elements correlate with both gold and silver, but gold-silver and lead-silver correlations are conspicuously missing from this tightly-knit group of undoubtedly hypogene element associations, supporting the idea that the variations in gold-silver ratio have a significant hypogene component.

Regardless of the wide range of gold-silver ratios, the ratios generally increase with increasing gold values; if a significant part of the data scatter is due to hypogene processes, this trend is probably also the result of hypogene processes. The high ratios at high gold values cannot be satisfactorily explained by supergene leaching of silver relative to gold in richer ores, because production data from Ransome (1909) and from U.S. Geological Survey statistics (1903-1918) indicate that high gold-silver ratios were characteristic of most ore-grade material from the main district whether oxidized or unoxidized, as shown in table 2. The ore-mineral paragenesis should

The reverse is true for some ores from mines in outlying areas (Ransome, 1909, p. 171-172, 250).

TABLE 2 BEAR HERE

be compatible with the observed increase in gold-silver ratios with increasing gold values. Tolman and Ambrose (1934) determined the ore mineral paragenesis as: pyrite and marcasite, followed by ~~famatinite~~ ^(stibiochalcocite) tennantite, sphalerite, followed by bismuthinite, followed by goldfieldite, followed by gold-silver tellurides and native gold, with considerable overlap between adjacent minerals in the sequence. They found at least small amounts of tennantite associated with ~~famatinite~~ ^{stibiochalcocite} in all the high-grade ore specimens they examined, but in a figure showing sequence of precipitation of the ore metals, they show both silver and gold being precipitated simultaneously at the

end of the ore paragenesis, implying that virtually all of the silver accompanied gold late in the depositional sequence. According to Goldschmidt (1954, p. 190, 194), tennantite-tetrahedrite series minerals may bear even more silver than galena. ^{Insert, next page} In the average-grade ores we examined, which all contain more silver than gold, pyrite and stibioluzonite (~~fermatite~~) are the only abundant minerals that belong to the ore-mineral sequence, but small amounts of ^{tetrahedrite} tennantite, ~~[and probably other silver-bearing minerals]~~ are associated with the stibioluzonite. Except for small amounts of bismuthinite and very small amounts of native gold, none of the other minerals characteristic of rich ores appear in the average-grade samples. We suggest that silver, mainly in ^{tetrahedrite} tennantite, was deposited early in the ore-metal sequence, accompanying copper. Copper and bismuth continue into the middle of the sequence, but overlap gold (and, by inference, lead), which are deposited late along with lesser amounts of silver. By this suggested two-stage introduction of silver, we infer that most of the silver in many of the ores was introduced early in the paragenesis, and the amount of gold introduced late in the paragenesis at any given spot was largely independent of the amount of silver introduced earlier. Bismuth, deposited in the middle of the paragenesis, and copper, deposited both early and in the middle, overlap both early silver and late gold and ^{middle-to-late} lead, producing several positive correlations between silver, bismuth, and copper, and between gold, lead, bismuth, and copper, but no correlation between gold and silver or lead and silver associated with hypogene aureoles in ore-bearing silicified rocks.

Insert, p. 25a

Preliminary microprobe analyses by G. K. Gammons suggest that tetrahedrite-tennantite is an important host mineral for silver in the Goldfield area, ^{the silver content is variable.} Concentrations of 0.5 to 1.5 percent silver ~~are~~ common in tetrahedrite-tennantite, whereas stibiochalcocite does not contain detectable silver ($< 0.1\%$), as much as 0.5 percent.

TABLE -- 2

Figure 8 shows that in argillized rocks, the gold-silver ratio is generally higher than it is for silicified rocks with comparable amounts of gold. No sulfide mineral other than pyrite has been reported from argillized rocks, nor have we observed any sulfide other than pyrite in our few observations of unoxidized argillized rocks in the Florence mine and elsewhere in the Goldfield altered area. Possibly the small amounts of lead, gold, and silver in these rocks were all introduced by ore-bearing fluids late in the paragenesis, explaining the high gold-silver ratios, but leaving unexplained the lack of correlation between gold and silver that persists in argillized rocks. In argillized rocks silver correlates with iron, indicating different behavior, and possibly greater mobility, than it shows in silicified rocks, where it probably forms silver halides nearly in situ. The strong lead-silver correlation in argillized rocks may also be due wholly or partly to oxidation. Silver may be associated with lead-bearing oxidation products such as anglesite (PbSO_4) or plumbojarosite ($\text{PbFe}_6(\text{SO}_4)_4(\text{OH})_{12}$) instead of silver halides (see Boyle, 1966, p. 192-195). Since lead moved little during oxidation, presumably the silver associated with lead did not move much either, and likely the silver distribution in argillized rocks is still dominantly a hypogene pattern.

Bismuth

Wilson (1944) noted that bismuth correlated with gold, silver, and tin in vein material from the 830-foot level of the Jumbo Ex mine, but these correlations did not exist at any of the other three localities he sampled (p. 6). Our data show that bismuth correlates with gold, lead, and silver in the Combination-January area in spite of oxidation (fig. 7). The bismuth and silver maps are similar, although more samples have undetectably small amounts of bismuth than is the case with silver. Figure 6 indicates a low mobility for bismuth. With the large number of samples having amounts of bismuth below the detection threshold, effects of oxidation are difficult to evaluate. Since there are only two argillized samples with detectable amounts of bismuth, correlation coefficients cannot be calculated for argillized rocks. Since bismuth in silicified zones correlates with gold, lead, and silver, which all show essentially relict hypogene dispersion patterns, plate 7 must also show essentially a relict hypogene pattern. According to Ransome (1909, p. 121-123, 213, 214), however, bismite (Bi_2O_3) was found in oxidized ore, in some cases partially filling prismatic cavities in quartz left by leaching of bismuthinite (Bi_2S_3). The supposed bismite was subsequently reidentified by Schaller (1941) as bismoclite (BiOCl), another secondary bismuth mineral. Ransome's observations indicate partial removal of bismuth during oxidation, and thus moderate supergene mobility is likely, as bismuth contents of the secondary sulfate samples suggest (p. ^{58, 62}~~62~~, ⁶⁵~~65~~). Better data for bismuth, therefore,

might well reveal some definite supergene effects. Analyses with a detection limit at least an order of magnitude lower than ours (at least 0.5 ppm instead of 5 ppm) would probably be necessary to provide adequate data for bismuth.

Mercury

Mercury correlates strongly with gold, lead, and silver in silicified rocks and with gold and silver in argillized rocks (fig. 7), indicating that hypogene processes were important in producing the features seen on the mercury map (pl. 8). These relationships are somewhat difficult to appreciate by visual comparison of the mercury map with the gold, lead, and silver maps, due to the rather small total range of mercury values and strongly overlapping ranges for silicified and argillized rocks (see histograms, pl. 8). Mercury also correlates with copper, as do silver and gold; much copper was leached during oxidation, but enough remains to give correlations with these three ore-related elements (see p. ⁹⁰~~91~~). Mercury thus forms a hypogene dispersion aureole extending outward from the ore bodies but restricted to silicified rocks, just as gold, lead, and silver do.

Intermediate and high mercury values between localities 9 and 11 may represent a narrow mercury halo around the silicified zone exposed in the cut wall northwest of locality 9 (see p. ⁴⁸ 51). This is the only area within the cuts showing a halo, but it is, after all, adjacent to a particularly wide segment of the Combination-January vein system (pls. 1 and 2) and the vein material to the northwest is definitely enriched in mercury. In this setting, we must consider whether the mercury between localities 9 and 11 originated in the adjacent silicified zone and moved to its present location in the gas phase, in solution, or both. Mercury probably has low mobility in the low pH, moderate to high Eh solutions that must have been involved in oxidation at Goldfield (Krauskopf, 1967, p. 516). Diffusion of mercury gas, therefore, should account for most post-hydrothermal movement of mercury away from the silicified zones at Goldfield. Migration of mercury gas could conceivably become more important than hypogene dispersion as hydrothermal activity waned, and continue to the present, regardless of when oxidation took place. Various sulfide minerals, however, probably carried most of the mercury in the ores, so that little mercury was free to disperse until the sulfides were destroyed by oxidation. Gaseous diffusion of mercury might explain the fact that differences in mercury values between adjacent samples in the cuts are mostly rather small, diffusion having evened out sharp variations. On the other hand, the lack of distinct gradients outward from silicified zones argue against extensive supergene migration of mercury gas. Explaining the narrow mercury halo between localities 9

and 11 as due solely to diffusion raises another problem: it is hard to understand how several samples at localities 4 and 6 escaped being enriched in mercury. Mercury is correlated with gold in argillized, as well as silicified rocks; this could be due either to hypogene association, or to amalgamation of gaseous mercury with native gold, or both. Mercury, however, is also strongly correlated with silver in argillized rocks. Free native silver has not been reported in any ^{Gold} ~~gold~~field ores, and silver in the oxidized zone is probably present mainly as silver halides, or, in argillized rocks, it may be associated with oxidized-zone lead-bearing minerals (p. ~~42~~⁷⁷). With amalgamation of mercury on native-silver ruled out, we do not know how silver and mercury might be associated mineralogically in the oxidized zone, silver, regardless of whether its association with lead in argillized rocks was produced by supergene processes, probably still shows a dominantly hypogene pattern, so the mercury-silver association in these rocks cannot be taken as evidence for supergene dispersion of mercury. Mercury, furthermore, shows negative correlations with copper and molybdenum in argillized rocks: both copper and molybdenum have undergone considerable supergene redistribution in argillized rocks, as will be explained later (p. ~~32~~⁸⁷⁻ ~~93, 99-100~~^{87a 93-94a}). We infer that hypogene dispersion features dominate the entire mercury map. If gaseous diffusion effects were predominant, we would expect to see fewer and weaker correlations between mercury and other metals in silicified rocks, and no significant correlations, except possibly with gold, in argillized rocks.

With the strong association between mercury and gold, lead, and silver in silicified rocks, the lack of correlation between mercury and bismuth is surprising. Published descriptions of mineral paragenesis are of no help because mercury-bearing minerals have not been reported from any part of the main district, even from high-grade ores, although mercury definitely was enriched in the ores (fig. 1, Ransome, 1909, p. 113). Relatively large amounts of mercury are known to occur in tetrahedrite-tennantite (Ramdohr, 1969, p. 554; Chan, 1969), which could explain the correlation with silver, which also occurs in tetrahedrite-tennantite, but does not explain the association with gold and lead. Without a detailed investigation of the amounts of mercury in all the various ore minerals, we cannot attempt further explanation.

The analytical data for unoxidized silicified rocks, average-grade ores, and high-grade ores (fig. 5) show much more mercury in these groups of samples than in rocks from the cuts. One might conclude that much mercury has been lost from the silicified rocks of the cuts, presumably by secondary migration. We hesitate to compare the data of figure 5, however, with that for the cuts because the low-grade ore samples, Florence mine samples, and unaltered dacite samples were prepared by a different laboratory using different procedures than samples from the cuts (the high-grade samples were hand-ground). Different sample preparation procedures can produce greatly different mercury yield from the same sample, due to loss of mercury during grinding (Crosby, 1969, p. 189-191). Relative differences between samples done by a given method tend to be retained if the samples are treated differently and rerun, even though absolute amounts of mercury obtained may be considerably different. Thus there should be no problem making comparisons between rocks from the cuts, and between the groups of samples shown on figure 5, but we cannot compare the former body of data to the latter one.

Secondary dispersion of mercury to form anomalies in soil or other overburden above ore bodies is very common and has been documented in many studies. To produce these anomalies, mercury is transported as gas, in solution, or by mechanical movement of mineral and rock fragments, the relative importance of these three mechanisms varying from place to place, depending on permeability and adsorptive capacity of the soil or overburden, climate, and topography (Koksoy and Bradshaw, 1969). Often primary dispersion aureoles exist along with the secondary halos, but not in every case, even if secondary halos in soil are well developed (see particularly Friedrich and Hawkes, 1966). The Goldfield ore bodies are in the category of deposits with limited primary dispersion of mercury, because hypogene aureoles are essentially restricted to silicified rocks, and gas-phase dispersion has not substantially modified the primary dispersion pattern. Similar relationships have been observed in several other districts: Pachuco Real del Monte, Mexico (Friedrich and Hawkes, 1966), Achisai, Kazakhstan (Fursov, 1958), Ivrendi, Turkey (Bradshaw and Koksoy, 1968), and probably Cripple Creek (Gott and others, 1967). We did not attempt a soil survey for mercury in the Combination-January area because much of the surrounding area is covered with mine dumps or otherwise disturbed. Since mercury at Goldfield probably does not move in solution during oxidation, and since relatively little has moved in the gas phase, mechanical dispersal of mercury-bearing silicified rock detritus is the only way that soil anomalies could form. Low to moderate topographic relief throughout the altered area and low

anomaly contrast between metallized silicified rocks and surrounding argillized rocks thus become two factors that limit the possibilities for developing mercury soil anomalies at Goldfield.

Arsenic

Arsenic is the first element to be discussed that shows a strong correlation with iron, indicating significant supergene redistribution. The arsenic map, however, also shows at least one definite relict hypogene feature: a group of high and intermediate arsenic values in silicified rocks northeast of the January shaft, an area with particularly high gold, lead, silver, bismuth, and mercury. This relict hypogene feature is less pronounced than it was for the foregoing elements, and a lack of correlation with gold, lead, silver, and bismuth results, although correlation with mercury persists. As noted previously (p. 50), silicified rocks in other parts of the cuts do not show a consistent relationship between gold and arsenic. Silicified rocks have enough residual arsenic so that their average arsenic content is higher than the average arsenic content of argillized rocks, as is the case with the preceding dominantly hypogene elements. More severe leaching can reduce the average amount of an element in silicified rocks to a figure below that for argillized rocks, as is the case with iron (see p. 64). We conclude that arsenic has undergone some supergene redistribution throughout the area, although the hypogene pattern has not been completely erased northeast of the January shaft.

The arsenic-copper and arsenic-molybdenum correlations in silicified rocks are of interest because both copper and molybdenum have also been partly leached during oxidation, as will be described later. The copper and arsenic in silicified rocks were both derived from stibioluzonite, Cu_3AsS_4 , which was relatively abundant even in low-grade ores.

Ransome's analysis of famatinite shows almost 50 percent Cu_3AsS_4 , the remainder of the mineral being Cu_3SbS_4 (Ransome, 1909, p. 118-119). As previously explained (p. 22), this mineral is actually stibioluzonite.

Stibioluzonite in the silicified rocks was oxidized along with pyrite, releasing iron, copper, and arsenic, and antimony as well. No molybdenum minerals have been reported in the ores, so without analyses for individual ore minerals the paragenetic relationships of molybdenum are unknown. Even though considerable iron was removed from silicified rocks during oxidation (p. ⁶⁴~~63~~), enough remained to produce the strong iron-copper-arsenic-molybdenum association, which must be due to sorption of all three elements on limonite (note the strong copper-iron and molybdenum-iron correlations in silicified rocks), and probably also to coprecipitation of hydrated iron arsenates (particularly scorodite, $\text{Fe}(\text{AsO}_4) \cdot 2\text{H}_2\text{O}$), copper and copper-iron arsenates and hydrated arsenates, and possibly hydrated iron molybdate (ferrimolybdite, $\text{Fe}(\text{MoO}_4)_3 \cdot 8\text{H}_2\text{O}$) with limonite.

Copper

Copper was the most abundant metal in both average and high-grade ores, because stibiochalcocite was either the most abundant sulfide mineral in the ores, or was second only to pyrite. Tetrahedrite-tennantite and in rich ores, goldfieldite, also account for some of the copper. Chalcopyrite occurred in the Combination mine, but in small amounts (Collins, 1907a, p. 398). Copper is relatively abundant in the unoxidized silicified rocks of the Florence mine (300 ppm average, fig. 5). Silicified rocks of the Combination-January cuts likely had at least as much copper as the Florence mine silicified rocks, and locally more. The average copper content of silicified rocks, however, is only 10.4 ppm, and is virtually the same as the average for argillized rocks, 10.1 ppm. These figures are not much above the 10 ppm copper found in unaltered dacite (fig. 5). Since the ores and their associated hypogene gold, lead, and silver aureoles were restricted to silicified rocks, the silicified rocks surely contained more copper than did argillized rocks prior to oxidation. Obviously considerable copper has been leached from silicified rocks during oxidation, more, no doubt, than for any element yet discussed. Whether the oxidized argillized rocks have also suffered overall removal of copper cannot be determined without unoxidized argillized rocks for comparison. Copper correlates strongly with iron in both silicified and argillized rocks, another indication that copper has undergone considerable supergene redistribution. Arsenic and molybdenum also correlate strongly with iron in both silicified and argillized rocks.

and copper correlates with both these elements in silicified rocks and with molybdenum in argillized rocks to form an arsenic-copper-molybdenum-iron supergene association. We have no specific explanation for the strong negative correlation between copper and mercury in argillized rocks, but presumably greater supergene movement of copper relative to mercury is the ultimate cause. Many geochemical field studies, as well as laboratory studies on the solution chemistry of copper, have shown that copper is moderately to highly mobile in oxidizing sulfide ores (fig. 6, Garrels and Christ, 1965, p. 240). Behavior of copper at Goldfield is no exception, judging from rocks of the Combination-January cuts and from the Florence mine secondary sulfates (p. ^{58 62}~~62~~, ~~63~~).

The role of limonite is clearly important in determining the distribution of copper and other elements that were mobile during oxidation. Clays might play a similar role, because clay minerals are capable of ion exchange and sorption (Grim, 1968, Chap. 7, p. 185-233; Carroll, 1959). The argillized rocks of the Combination-January area all contain kaolinite and illite in various proportions, and 22 samples from the area north of locality 18 contain montmorillonite as well (pl. 2). Most of the silicified samples contain more or less kaolinite, but a minority have no clay at all, being composed mainly of quartz and alunite (p. ³²⁻³⁶~~35-39~~). Although pH of solution, clay-mineral particle size, and metal-iron concentration in solution all affect the amount of metal sorbed by clays, capacity of the common clays to sorb copper, molybdenum, and zinc generally increases in the following order: kaolinite, illite, montmorillonite (Heydemann, 1959; Jones, 1957; Chu, 1969). Montmorillonite is particularly effective in sorbing many ore metals, mainly because of its large cation exchange capacity (Perel'man, 1967, p. 100). Cation exchange is important in the sorption of copper and zinc, whereas anion exchange is important for molybdenum and arsenic, which form molybdate (MoO_4^{-2}) and arsenate (AsO_4^{-3}) ions in solution. Molybdate and arsenate, however, readily form very insoluble compounds with ferric iron (ferrimolybdate, $\text{Fe}_2(\text{MoO}_4)_3 \cdot 8\text{H}_2\text{O}$ and scorodite, $\text{Fe}(\text{AsO}_4) \cdot 2\text{H}_2\text{O}$), so we would expect the clays to be less important than iron in determining the supergene redistribution of these two metals. In the argillized rocks kaolinite, illite, and montmorillonite

occur in various proportions; total clay contents generally are between 20 and 60 percent. Ideally, we should compare copper, molybdenum, and zinc abundances in rocks with known amounts of each clay mineral. Clay mineral percentages are difficult to estimate accurately, however, so we have merely divided the argillized rocks into three groups, as follows: montmorillonite-bearing, montmorillonite-free with illite dominant over kaolinite, and montmorillonite-free with kaolinite dominant over illite. The groups include only samples that we X-rayed in the course of our petrographic examinations.

Figure 9 gives the results. Data for iron is included for comparison:

the
FIGURE 9 NEAR HERE

the three groups of samples have similar iron contents. Arsenic, copper, molybdenum, and zinc do not show significant differences between the three data sets, with the possible exception of zinc in kaolinite-dominant rocks. Since the average for zinc in these rocks may not be much below the detection threshold at -2.60 log percent (25 ppm), we cannot say definitely that clay content has an effect on zinc. Realizing that our data sets are not as precisely defined as we would like with respect to relative amounts of the various clay minerals, we conclude that the clay content of argillized rock has little effect on supergene redistribution of the above four elements. At least, abundance of iron must be much more important than clay content.

In spite of the relatively high mobility of copper, hypogene element associations in silicified rocks have not been completely destroyed. Once again, high values appear northeast of the January shaft (pl. 10) associated with high gold, lead, silver, bismuth, mercury, and arsenic values, and correlations between copper and gold, silver, and mercury persist. As explained above, the copper-arsenic association is due to their mutual association with limonite and therefore is mainly a supergene phenomenon, but hypogene association may contribute to this correlation indirectly in that both copper and arsenic were locally released from ores together in relatively large amounts, and consequently large amounts of both elements found their way into the limonite formed at these localities. The copper remaining with gold, silver, and mercury must not be associated with limonite, because none of these three elements correlate with iron. This copper could occur as azurite ($\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$), ^{or} malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$) both reported by Ransome (1909, p. 108-109, 216) as rarely staining some oxidized and partly oxidized ores. It is unlikely that much copper resides in these two minerals, because pH values of solutions in the oxidized zone at Goldfield probably were generally too low to form them (Garrels and Christ, 1965, p. 240). We have not seen chrysocolla ($\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$) or turquoise-group minerals (particularly turquoise $\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$, and chalcociderite, $\text{CuFe}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$), and as far as we know none of these minerals have been previously reported. Of the 39 silicified rock samples we X-rayed, 30 contained kaolinite, and 9 were free of kaolinite.

Figure 9.--As, Cu, Mo, Mn, and Fe in argillized rocks with various
clay contents.

Average amounts of copper for these two data subsets are essentially the same and both are very close to the average for all 129 silicified rock samples. Copper thus is not notably associated with clay in the silicified rocks, and the form of copper in these rocks remains unexplained.

A question worth considering is what happened to the copper that was leached from the silicified rocks. Copper commonly forms zones of supergene enrichment immediately below the water table. No such zone has been reported in the mines at Goldfield, although some enrichment might have escaped notice because copper content was irrelevant in determining the values of near-surface ores. Another reasonable explanation is that not enough ore has been oxidized to produce a pronounced supergene enrichment zone; the pre-Siebert Formation and present-day erosion surfaces in the Combination-January area probably truncate the upper parts of the lodes. Perhaps part of the copper from metallized silicified rocks moved laterally into the surrounding argillized rocks during oxidation, the argillized rocks having previously experienced no hypogene addition of copper or possibly even hypogene removal of copper. Whatever the case, copper values are not consistently high in argillized rocks, being related particularly to limonite distribution. We conclude that copper does not form a distinct and coherent supergene halo around ore-bearing silicified rocks. We have no way of knowing whether a hypogene copper aureole extended into the argillized rocks, but even if it did it was destroyed during oxidation. Perhaps if the lodes were more deeply eroded we would see greater development of a supergene enrichment zone or a supergene halo, or both.

Molybdenum

Molybdenum and copper show similarities on the geochemical maps and in the correlation matrices. Some high molybdenum values occur northeast of the January shaft along with all the preceding elements (pl. 11). Molybdenum is not as strongly enriched in the ores as are many other ore-related elements (fig. 5), but during metallization molybdenum probably was somewhat enriched in silicified rocks relative to argillized rocks. The histograms show that silicified rocks now contain less molybdenum than argillized rocks, although an average was not calculated for silicified rocks because slightly less than half the silicified samples contained detectable molybdenum. The relict hypogene association shown by rocks northeast of the January shaft is so weak that molybdenum shows no correlations with gold, lead, silver, bismuth, or mercury in silicified rocks (fig. 7). This may be due to greater supergene mobility of molybdenum than any previously discussed element, or to lack of pronounced enrichment of molybdenum in the ores, or both.

The association between molybdenum and iron is as strong or stronger than the association between copper and iron; it is strong enough to be readily visible by comparing the molybdenum and iron geochemical maps and profiles (pls. 11 and 13). Possible supergene minerals producing these associations have already been discussed in the section on arsenic, the most important molybdenum mineral probably being ferrimolybdate ($\text{Fe}_2(\text{MoO}_4)_3 \cdot 8\text{H}_2\text{O}$). Jones (1957) showed that hydrous ferric oxide is highly effective in sorbing molybdate ($\text{MoO}_4=$) anions from acid solutions. Significant amounts of molybdenum in the Florence mine supergene sulfates (p. ⁵⁸~~62~~, table 1) show that water moving downward through oxidizing rocks does indeed contain molybdenum. We conclude that molybdenum, like copper, is relatively mobile in the oxidized zone, at least until solutions carrying it come in contact with limonite. The correlation matrix for argillized rocks, however, shows one important difference between the supergene behavior of copper and molybdenum: the strong lead-molybdenum correlation. This correlation could be due to formation of wulfenite (PbMoO_4), which, although not reported at Goldfield, is a common secondary mineral in oxidized ore deposits containing lead. Takahashi (1960, p. 1105-1108) and Williams (1963, p. 1121-1122) have shown, however, that wulfenite is only conditionally stable in an oxidizing environment with sulfate and carbonate present. Since we do not know the mineral forms of lead and molybdenum in either silicified or argillized rocks prior to oxidation, we cannot investigate the lead-molybdenum correlation further, nor can we determine why lead and molybdenum are correlated in

argillized rocks but definitely are not correlated in silicified rocks. Molybdenum shows no correlation with calcium in either silicified or argillized rocks (not shown on fig. 7), so powellite (CaMoO_4) must not be an important supergene molybdenum mineral at Goldfield.

The relatively high supergene mobility of molybdenum presumably produced the negative molybdenum-mercury and molybdenum-silver correlations, just as relatively high supergene mobility of copper presumably produced the strong negative copper-mercury correlation.

Zinc

The hypogene behavior of zinc must have been similar to that of the other ore-related elements (fig. 5), and consequently it must have been enriched in the silicified rocks during metallization. Sphalerite (ZnS) appeared as a minor constituent in ores of the Combination mine (Collins, 1907a, p. 398). The histograms show that zinc, rather than being abundant in the silicified rocks, is depleted in silicified rocks relative to argillized rocks. No vestiges of the strong hypogene metal concentrations northeast of the January shaft remain (pl. 12). Furthermore, zinc shows no positive correlations with any of the preceding elements, but does show negative correlations with gold in silicified rocks and lead in argillized rocks (fig. 7). Both the latter elements have experienced only minor supergene redistribution. We conclude that zinc has been strongly leached from the rocks of the cuts, and leached more strongly from the silicified rocks.

The geochemical map (pl. 12) shows that the distribution of zinc in argillized rocks near silicified zones is too erratic to form a distinct halo. Zinc may be coprecipitated with limonite (Hawkes and Webb, 1962, p. 55, 164, 377), but zinc shows no correlation with iron, so it has not been partially retained in the oxidized zone by coprecipitation with limonite or sorption by limonite, as have arsenic, copper, and molybdenum. Sorption by clays probably was not effective in retaining zinc in the oxidized zone (p. ^{88 88a}~~94-96~~).

Apparently zinc was more mobile during oxidation than any other element considered in this study. The relatively large amounts of zinc in the Florence mine supergene sulfates attest to this high mobility (p. ^{58 67}~~62~~, 65, table 1). High supergene mobility for zinc is in accordance with results of previous work summarized in figure 6.

Conclusions--discussion of indicator elements for gold

High values for gold, lead, silver, bismuth, and mercury, the elements showing dominantly relict hypogene dispersion patterns, are found mostly in silicified rocks. Even though all these elements except bismuth show at least a few intermediate and high values in argillized rocks, none of them consistently form hypogene aureoles extending a significant distance into argillized rocks. They do, however, form aureoles surrounding ore bodies within silicified rocks. The geochemical profiles constructed for gold, lead, and silver show that these elements in particular form aureoles that contrast sharply with low values found in adjacent argillized rocks. None of the elements that were notably leached and redistributed during oxidation, including arsenic, copper, molybdenum, and zinc, have moved outward from ore-bearing silicified zones into the surrounding argillized rocks to form distinct supergene halos. Hence bedrock sampling should be restricted to silicified rocks.

Gold analyses are indispensable as a guide to ore. Lead is reliable as an ore guide, and should be particularly useful for reconnaissance sampling programs, because lead is even less mobile than gold during oxidation, and its aureoles are characterized by less sample-to-sample variation than accompanying gold. Silver analyses are also worthwhile because gold-silver ratios vary considerably, and amounts of silver cannot be predicted from gold or lead values. Amounts of silver exceeded associated amounts of gold in some ores, particularly in mines away from the main district (Ransome, 1909, p. 171-172), so potential ore bodies might well be missed if silver were not determined. We consider mercury optional in a geochemical survey because its aureoles are not distinguished by outstandingly high values. Information on mercury might be more interesting in other parts of the Goldfield altered area than it is in the Combination-January area, because Ransome (1909, p. 113) reported mercury showings at an otherwise unmetallized locality about four miles northeast of the main district. Our data is inadequate to fully evaluate bismuth, so we cannot determine how useful bismuth might be in a geochemical survey. Arsenic, copper, and molybdenum are too strongly leached to detect anything but a fairly near-surface, extensive, and relatively high-grade ore occurrence such as that northeast of the January shaft: that is, an occurrence that likely would have been discovered already. Zinc is so strongly leached during oxidation that it seems useless, but we cannot rule out the possibility that arsenic, copper, molybdenum, or zinc could form well-developed supergene halos extending into argillized rocks

around ore bodies in other parts of the Goldfield altered area. From the results of this study, however, we cannot commend a sampling program utilizing bedrock samples from the argillized rocks.

Assuming that bedrock samples will be taken from silicified zones and will be analyzed for gold, lead, and silver to accomplish a geochemical survey, we should establish the minimum values to be considered anomalous. A survey should not miss any significant anomalies if gold values equal to or greater than 0.3 ppm, lead values equal to or greater than 70 ppm, and silver values equal to or greater than 1 ppm are considered anomalous. Values in the ranges of "high" values shown on plates 4, 5, and 6 (3 ppm or more for gold, 200 ppm or more for lead, and 10 ppm or more for silver) should certainly be worthy of further investigation. Treating a large number of samples from the entire Goldfield altered area to determine geochemical background and anomalous values is beyond the scope of this report, and is the subject of additional work.

If samples are selected from silicified zones, particularly for a reconnaissance survey, it is useful to know whether visible concentrations of limonite minerals are a good guide to anomalous amounts of metals. Qualitative comparison between iron content and relatively intense color of either red (hematite dominant) or yellow-red (goethite dominant) hue, determined with a G. S. A. Rock Color Chart, indicates that intense color and iron content are definitely well correlated. Unfortunately iron content is not correlated with gold, lead, silver, bismuth, or mercury content in silicified rocks (see fig. 7). Thus, although limonite-rich samples are likely to have larger amounts of arsenic, copper, or molybdenum than limonite-poor samples nearby, they will not necessarily have larger amounts of gold, lead, silver, bismuth, or mercury. We expect that a sampling program utilizing limonite-rich altered rocks or limonite scrapings from fractures, and analyzing for arsenic, copper, or molybdenum, would produce results difficult to interpret. At many localities silicified zones are so numerous that the source of anomalous arsenic, copper, or molybdenum could be hard to find, particularly if the highest values showed up in argillized rocks; detailed sampling for gold would then be required. A better approach would be to selectively sample silicified rocks rich in limonite to look for unusual amounts of arsenic, copper, and molybdenum in addition to gold, lead, and silver. Such samples should be just as likely to show anomalous gold, lead, and silver as limonite-poor silicified rocks, but on the other hand, silicified zones showing little limonite should

not be ignored. Whether the information gained over doing gold, lead, and silver alone would be worth the cost of the additional arsenic, copper, and molybdenum analyses is open to question.

We doubt that soil sampling surveys would be of much use in the Goldfield altered area, but should such a survey be undertaken in one of the more poorly exposed parts of the area, the anomaly contrast between silicified and argillized rocks shown by the geochemical profiles should be an indication of the maximum anomaly contrast that might be encountered, assuming mainly mechanical dispersal of the ore-related elements in colluvium. Lead would be the best indicator in a colluvial-soil survey. Soil-covered parts of the Goldfield altered area appear to be dominantly of colluvial origin, although residual soils that are actually soft argillized rocks appear locally.

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Note for Monthly List of Publications

Prof. Paper ____-A. Distribution of gold and other ore-related elements near ore bodies in the oxidized zone at Goldfield, Nevada, by R. P. Ashley and J. P. Albers. 19___. p. _____, pls. _____. figs. _____. Price _____.

Gold, silver, lead, bismuth, mercury, arsenic, copper, molybdenum, and zinc are evaluated as indicator elements for use in geochemical prospecting at Goldfield. Gold, silver, lead, bismuth, and mercury reveal relict hypogene aureoles in oxidized parts of veins that locally contained ore bodies. Lead is a particularly useful indicator element, but analyses for gold and silver are indispensable for geochemical exploration. Arsenic, copper, molybdenum, and zinc were leached during oxidation, largely obliterating previous hypogene dispersion patterns; these four elements do not form supergene halos large enough to aid geochemical prospecting.

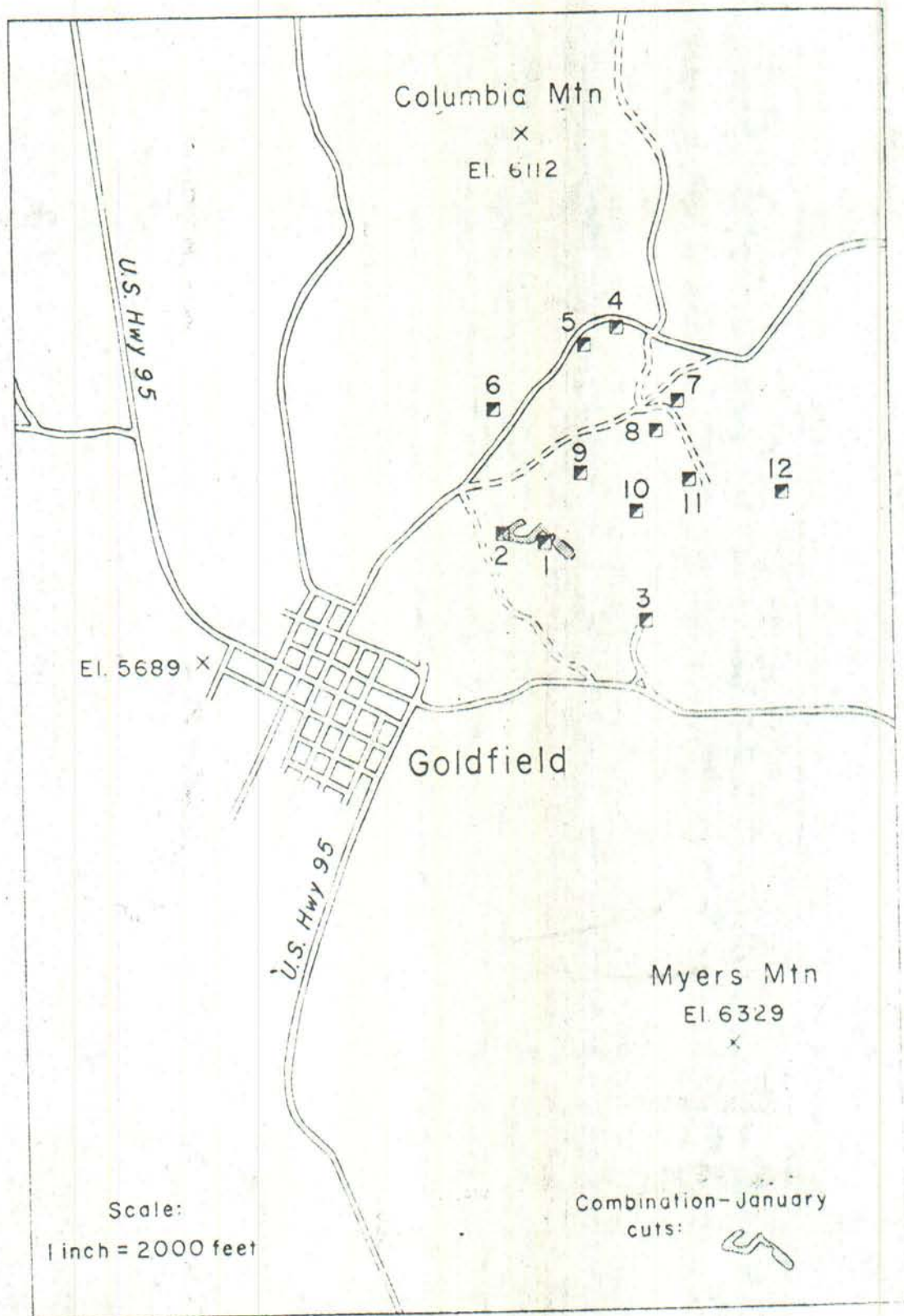


Figure 1.—Map of Goldfield, Nevada, and vicinity, showing the locations of major mines and the Combination-January cuts. 1. Combination mine. 2. January mine. 3. Florence mine. 4. Laguna mine. 5. Red Top mine. 6. Silver Pick mine. 7. Jumbo Extension mine. 8. Clermont mine. 9. Mohawk mine. 10. Jumbo mine. 11. Grizzly Bear mine. 12. Merger mine.

Plate I.—PLAN MAPS OF THE PRINCIPAL LEVELS OF THE COMBINATION MINE, GOLDFIELD, NEVADA

ASHLEY AND ALBERS
OPEN FILE REPORT
PLATE I

EXPLANATION

Miocene	Td	Tertiary
	Goldfield Dacite	
	Tma	
	Milltown Andesite	
	Tl	
	Goldfield Latite	

Contact

Dashed where approximately located, short dashes where inferred beneath Tertiary Siebert Formation sediments, alluvium, and mine dumps

Fault

Dashed where approximately located, short dashes where inferred beneath cover, arrow in direction of true dip

Open cut, top only

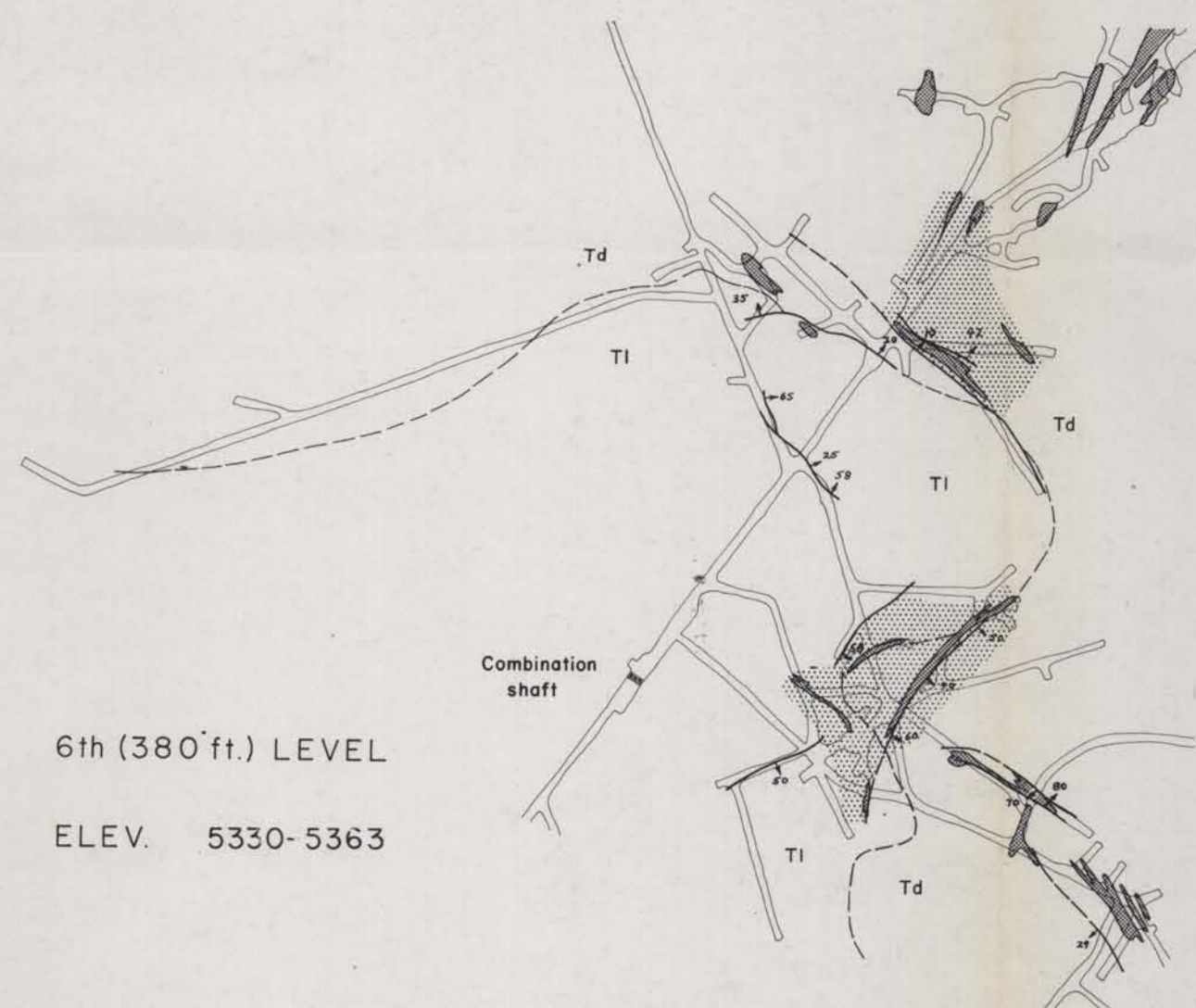
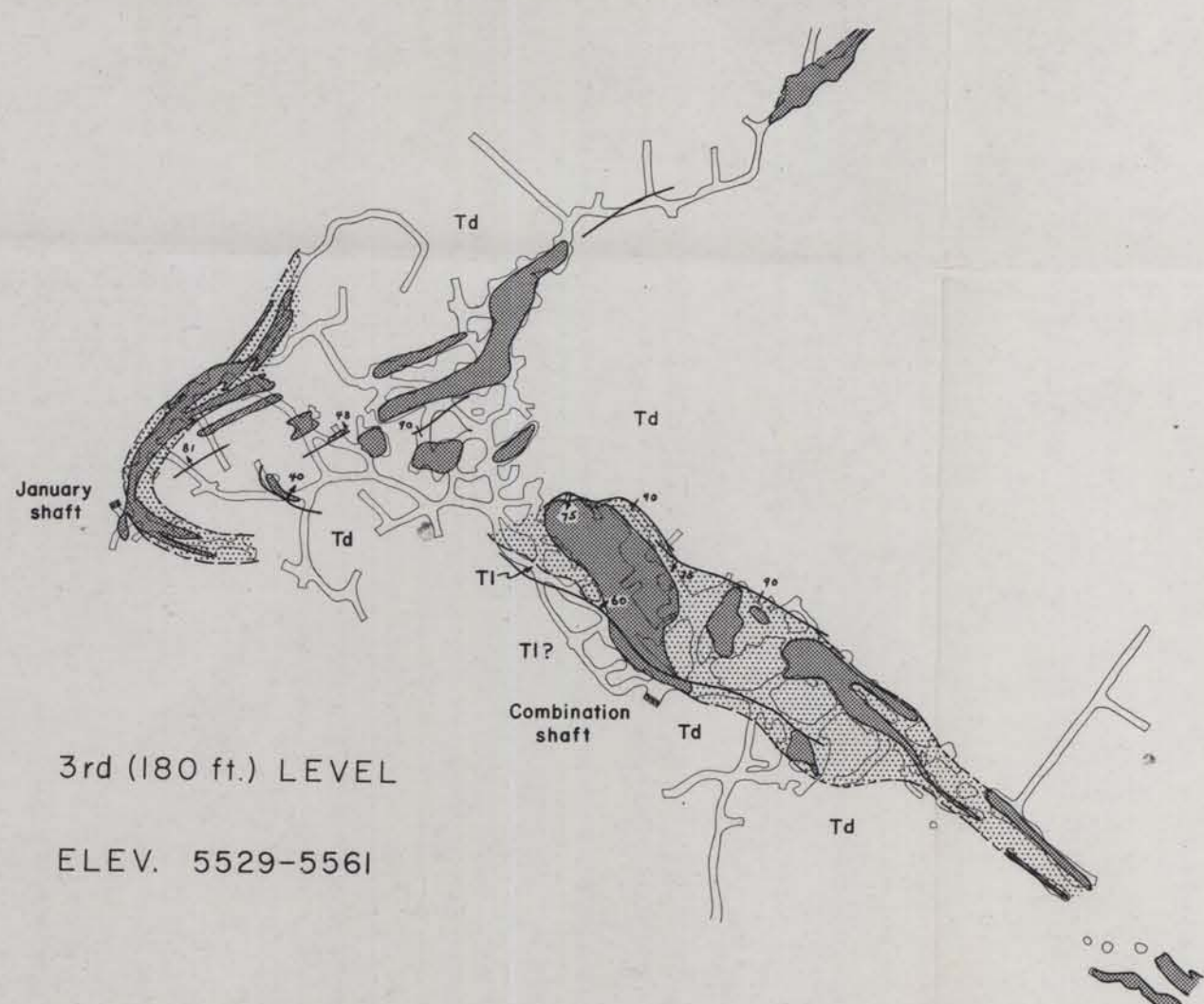
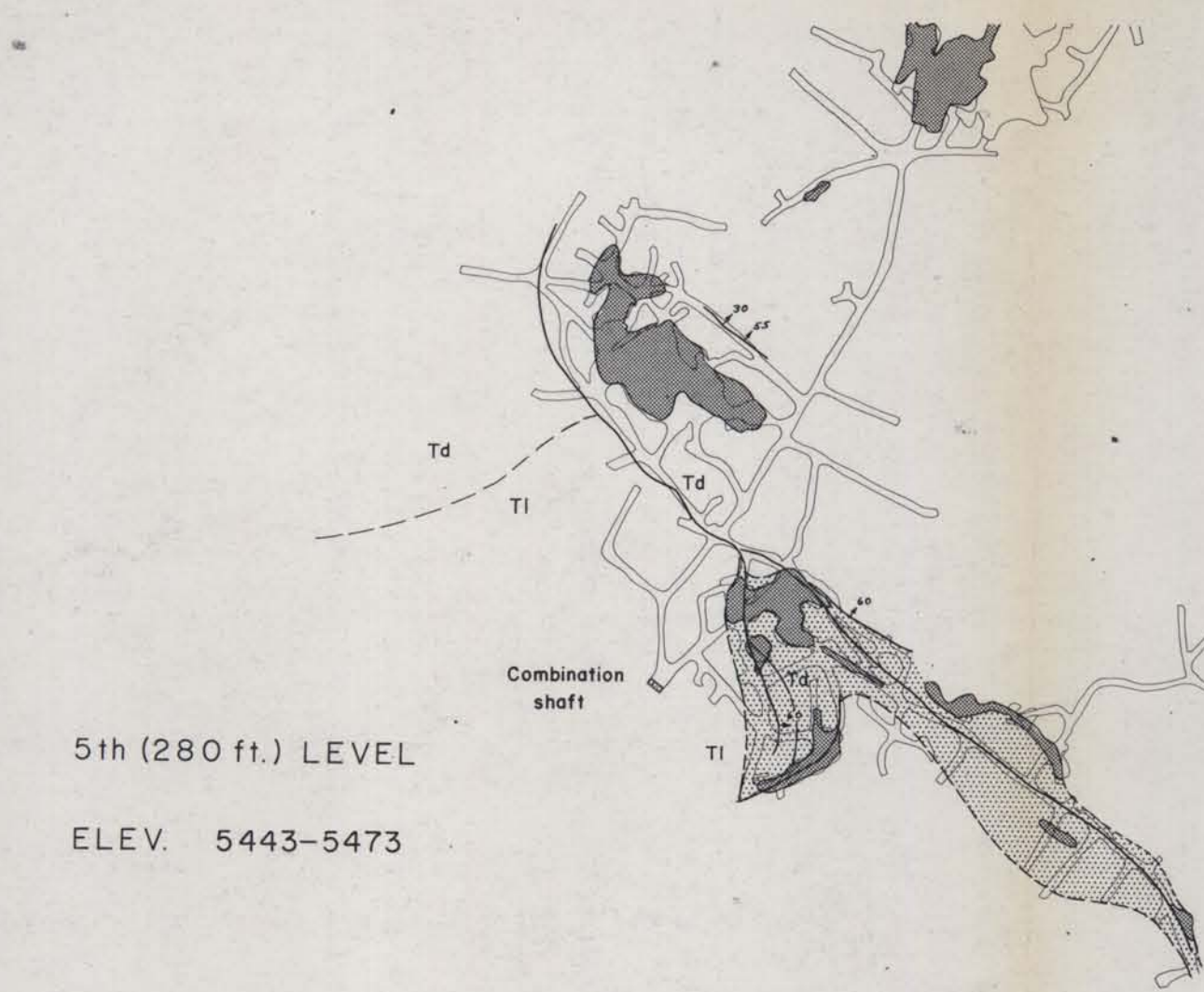
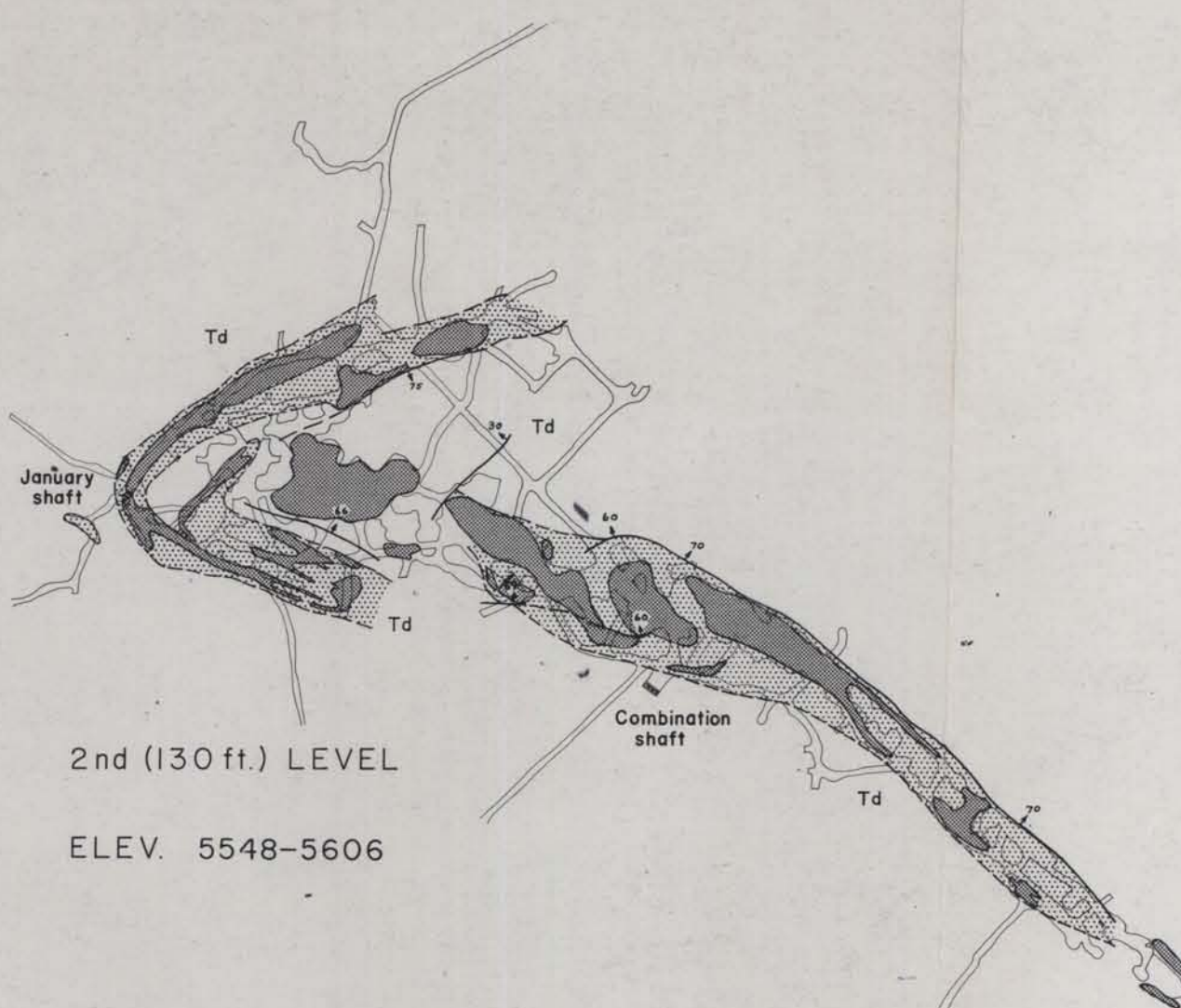
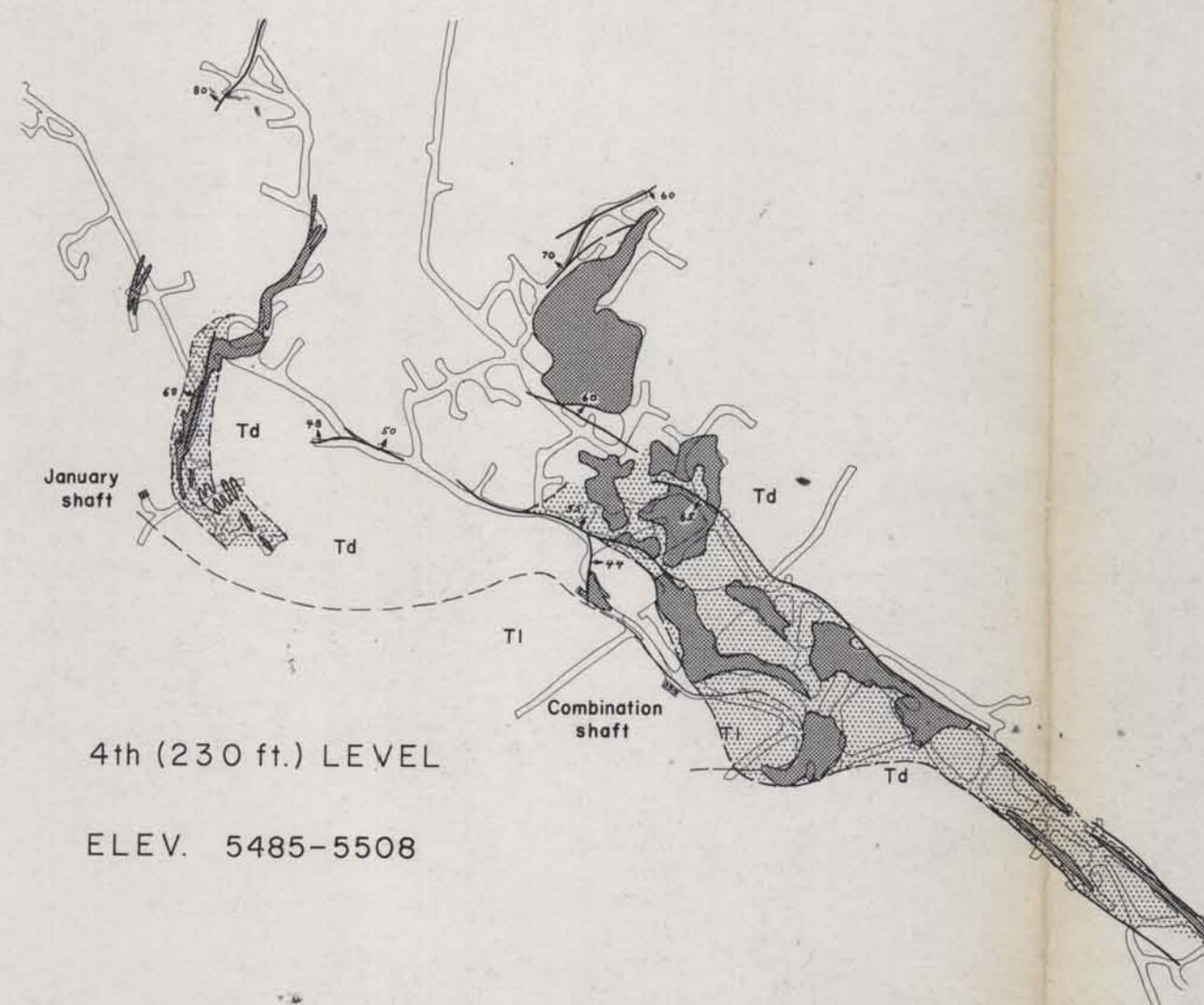
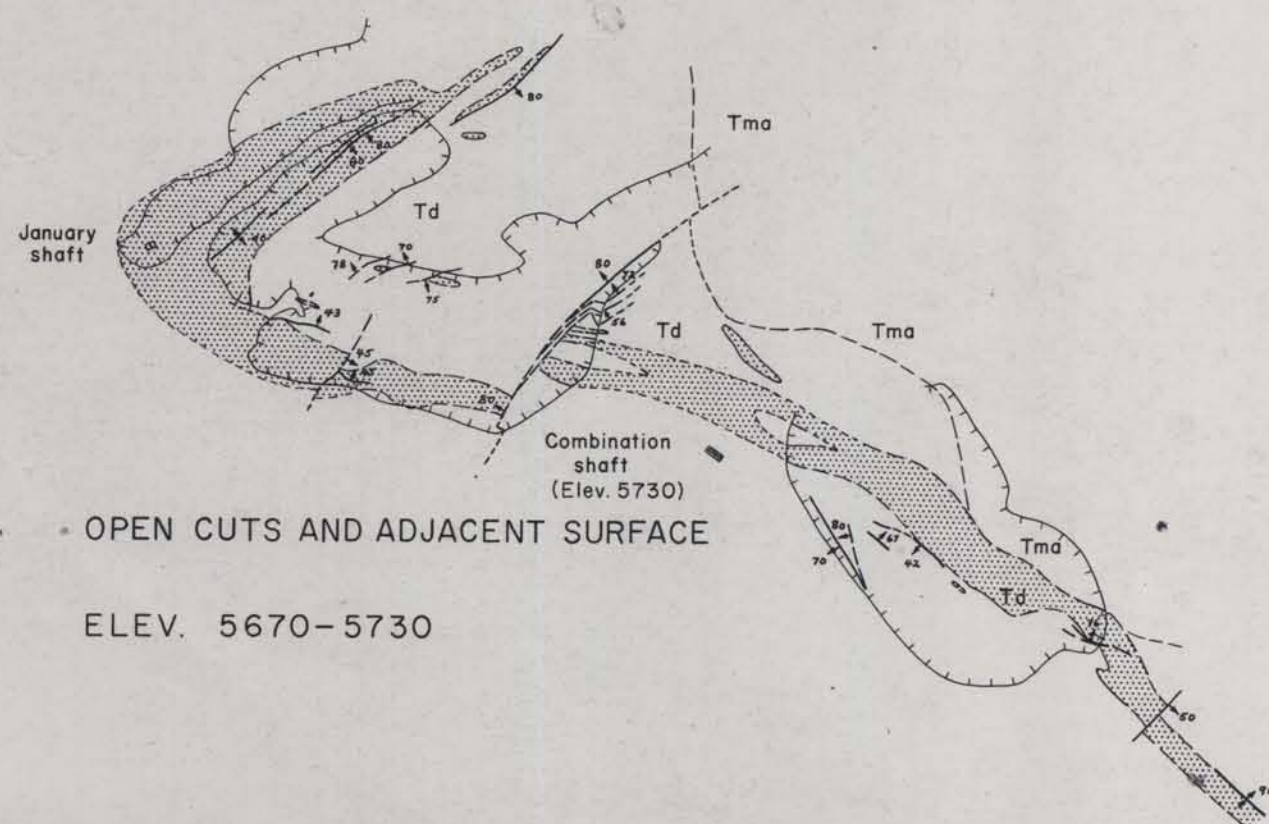
Ore bodies
(Not shown for cuts and adjacent surface)

Silicified zones (veins)
(Shown only where known or easily inferred)

Scale: 1 inch = 160 feet

Geology of open cuts and adjacent surface generalized from plate 2 and planetable map at 1 inch = 40 feet by Goldfield Consolidated Mines Corporation (unpublished data)

Workings of mine levels and locations of ore bodies modified from maps compiled at 1 inch = 40 feet by Goldfield Consolidated Mines Corporation (unpublished data, 1905-1938). Silicified zones from Ransome (1909, pls. XVI and XVIII). Lithologic contacts from both sources



U. S. Geological Survey
OPEN FILE REPORT
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PLATE 3.- SAMPLE LOCALITY MAP

ASHLEY AND ALBERS
OPEN FILE REPORT
PLATE 3

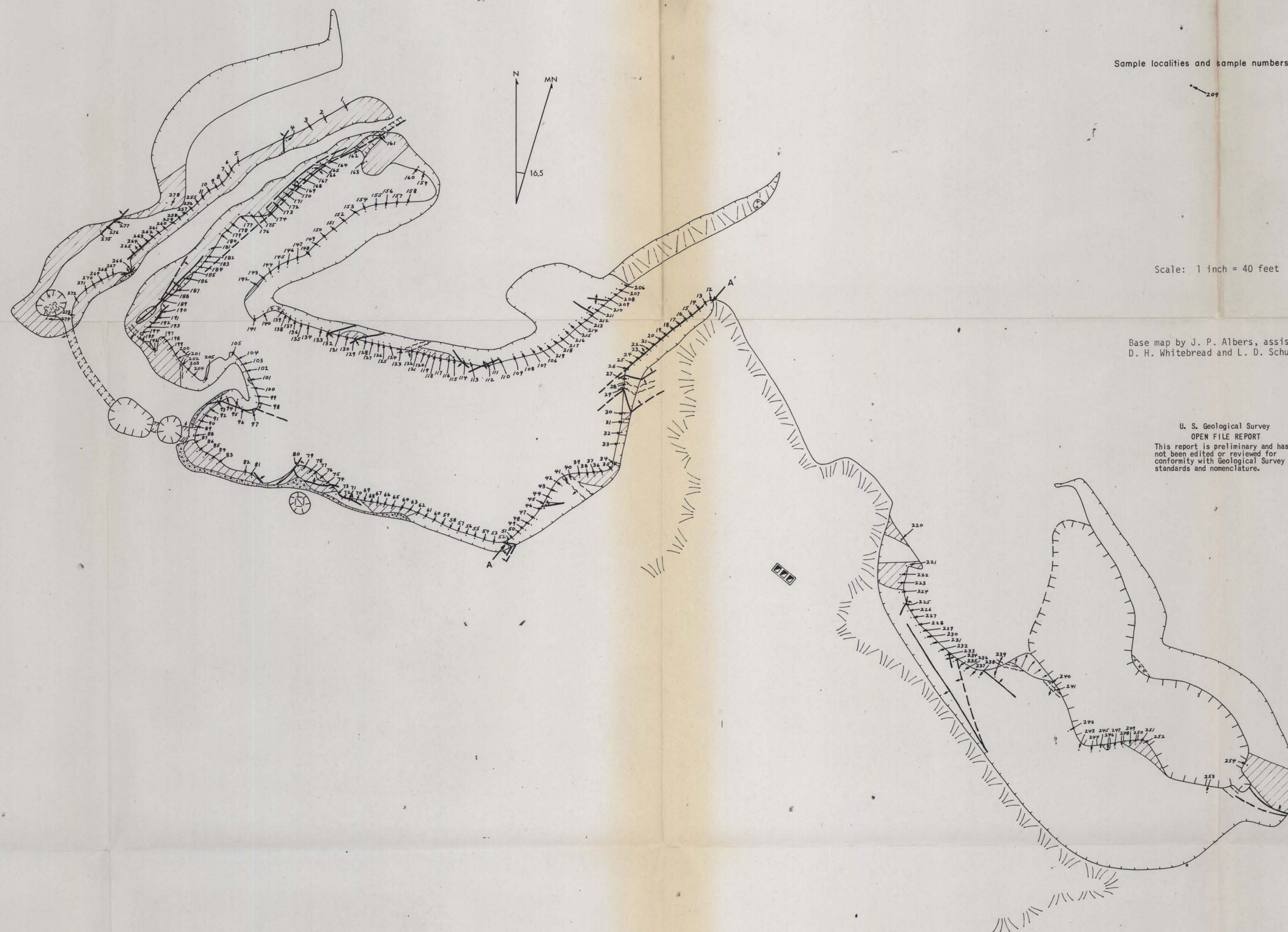
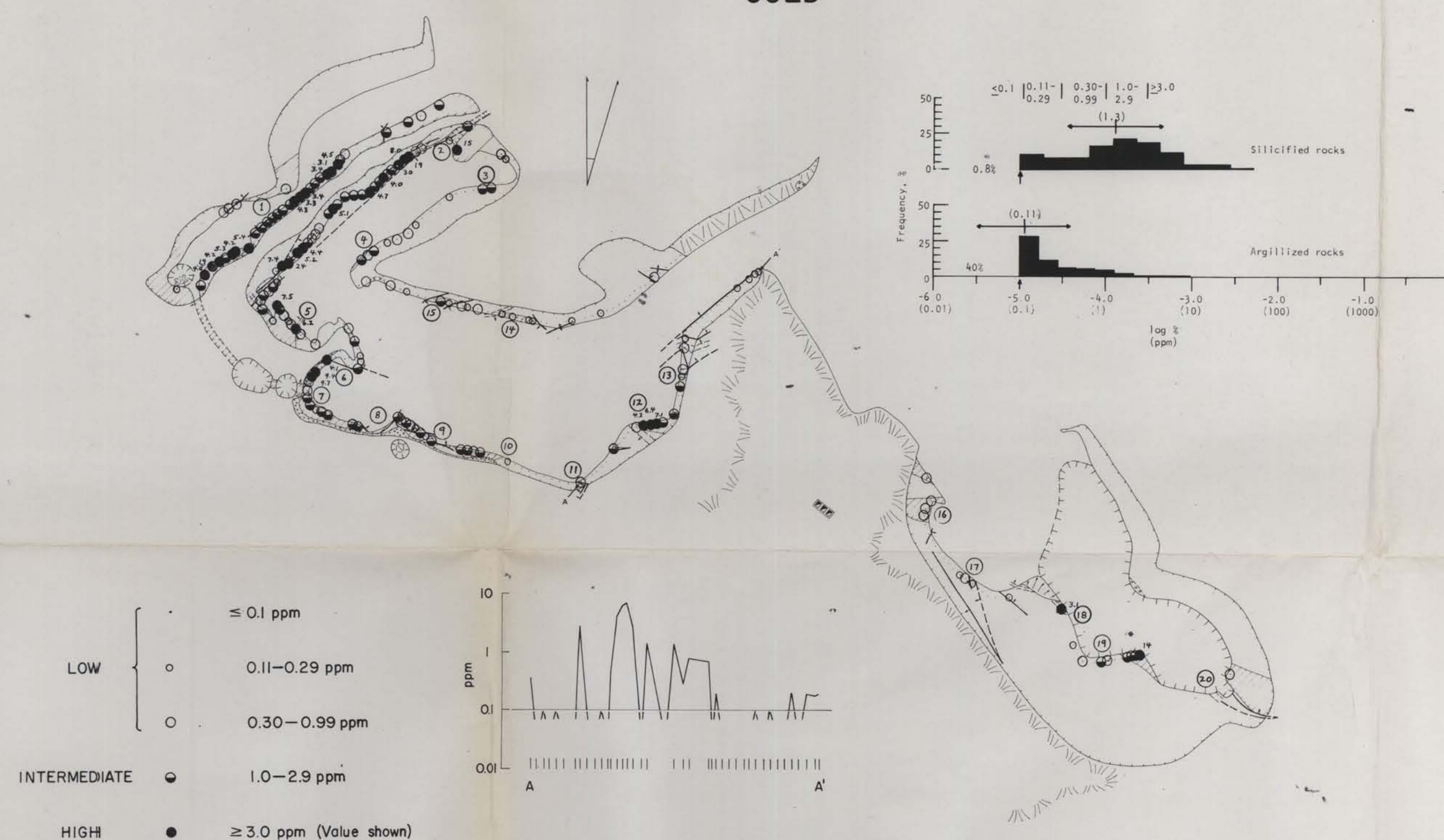


PLATE 4.- DISTRIBUTION OF GOLD, LEAD, SILVER, BISMUTH, AND MERCURY
IN THE COMBINATION-JANUARY OPEN CUTS

GOLD



EXPLANATION

Silicified zones

Localities referred to in text

Explanation of histograms

Ranges of values plotted on map, in ppm

Geometric mean, adjusted for data above or below detection limits by Cohen's method. Antilog of geometric mean, given in parts per million, in parentheses

Geometric deviation, adjusted for data above or below detection limits by Cohen's method. Range of one standard deviation on either side of mean shown by arrows

Percentage of data, if any, below lower detection limit

10%

lower detection limit

5.5%

upper detection limit

Percentage of data, if any, above upper detection limit

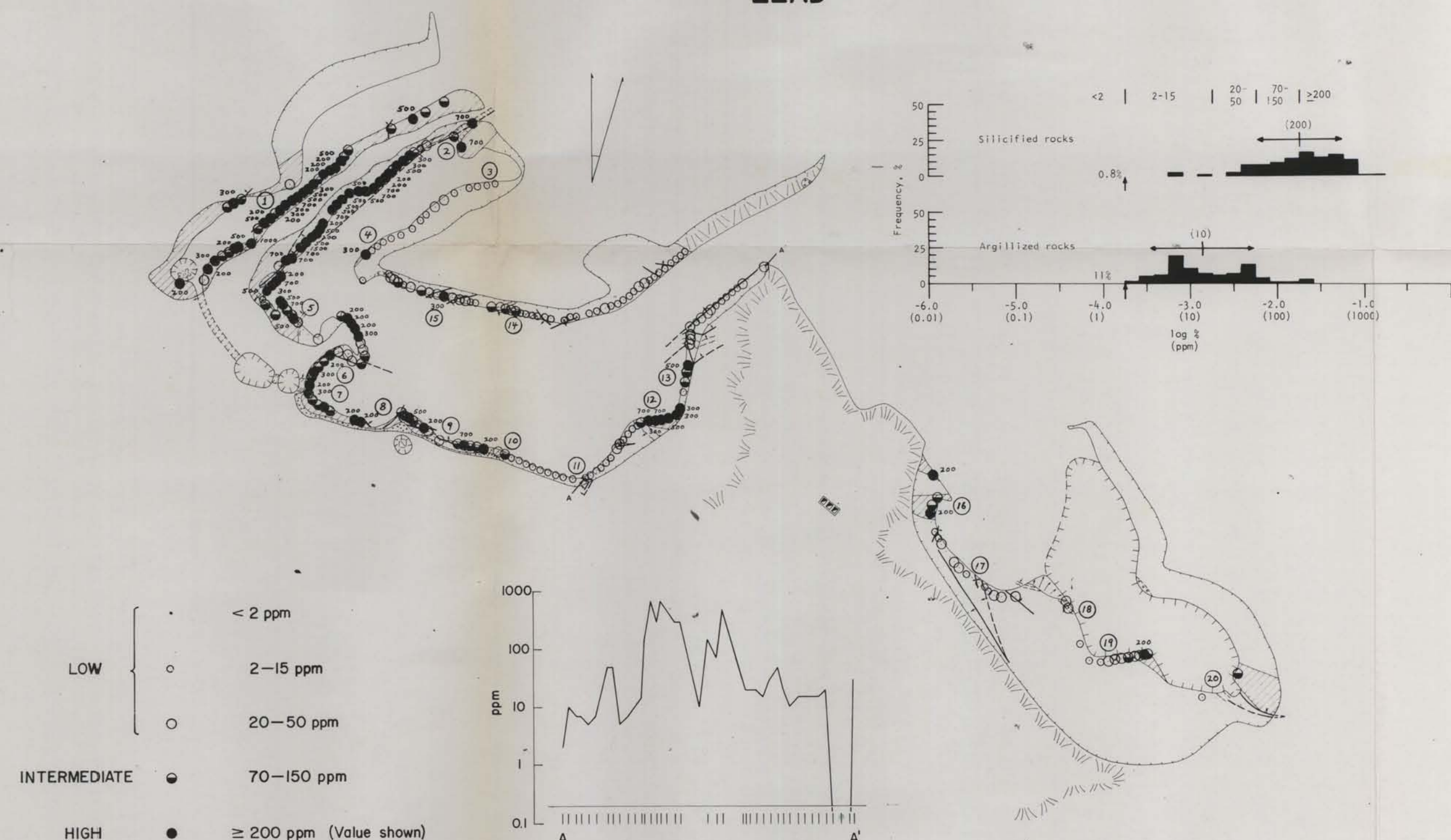
Note: Silicified rocks data set includes 129 samples, argillized rocks data set includes 149 samples

Scale: 1 inch = 80 feet

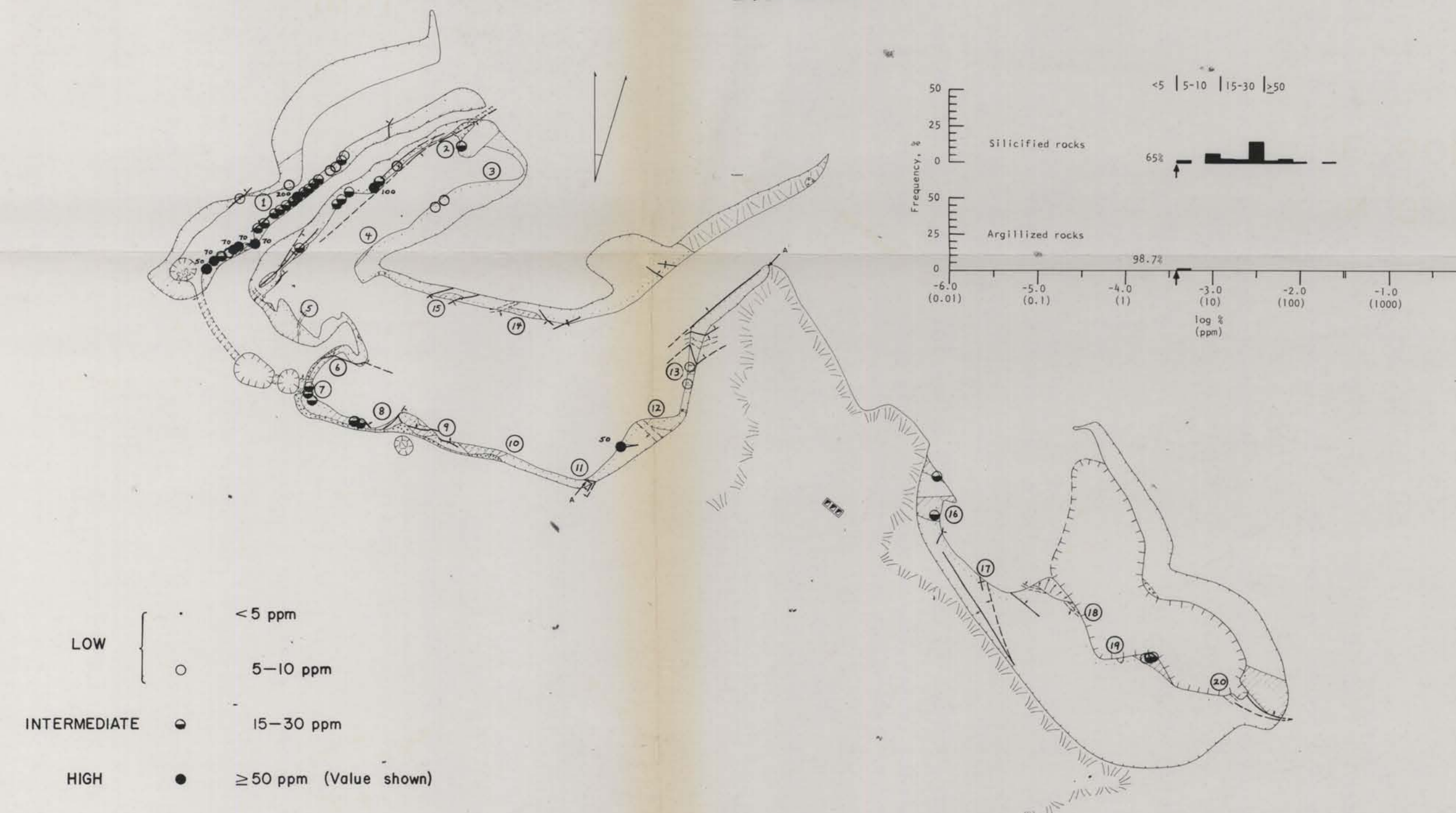
Base map by J. P. Albers, assisted by D. H. Whitebread and L. D. Schultz

1967

LEAD



BISMUTH



SILVER



MERCURY

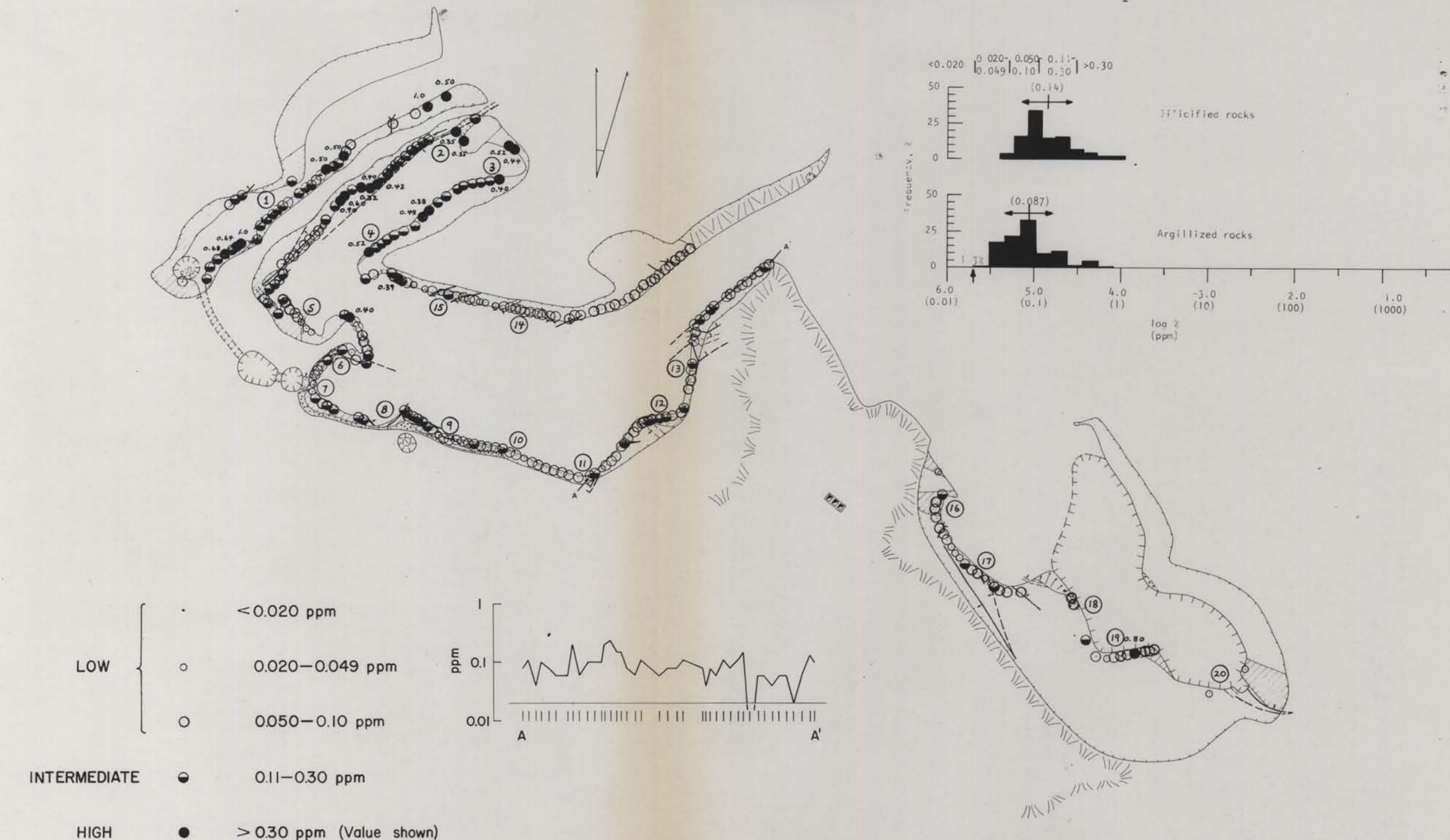


PLATE 2.- PLAN GEOLOGIC MAP OF THE COMBINATION-JANUARY OPEN CUTS, GOLDFIELD, NEVADA

S.E. CORNER SEC. 35
T.2S., R.42E.

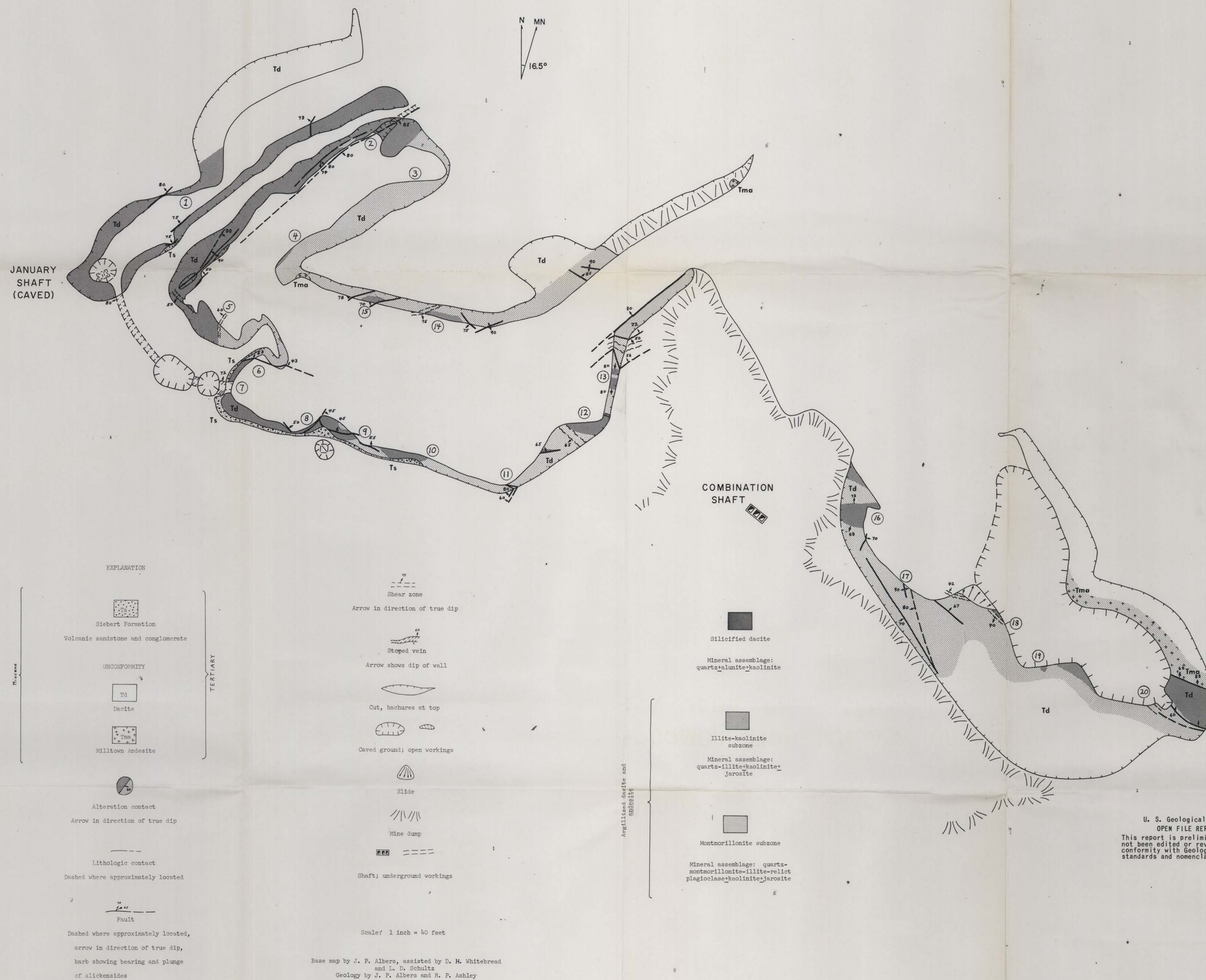
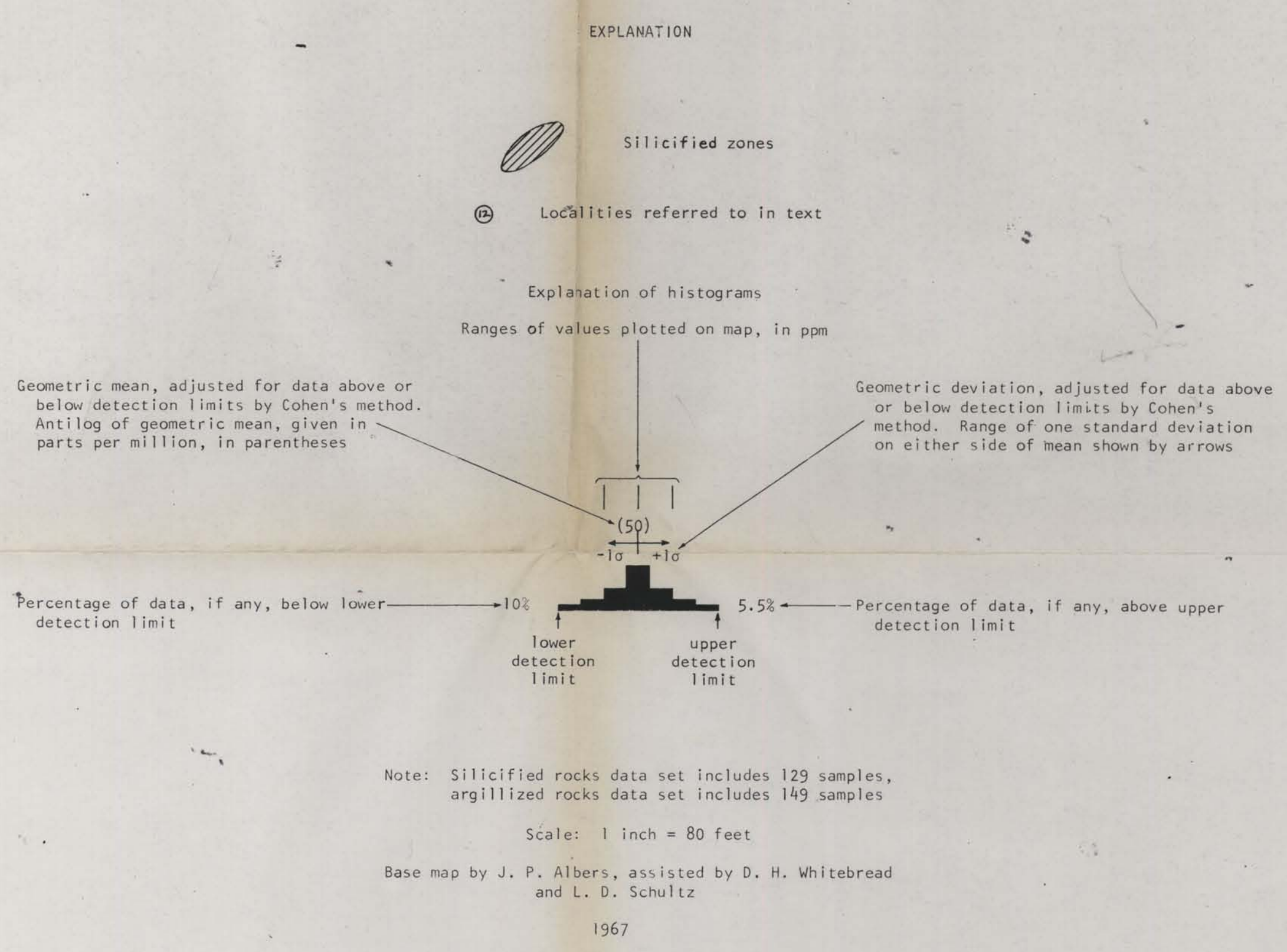
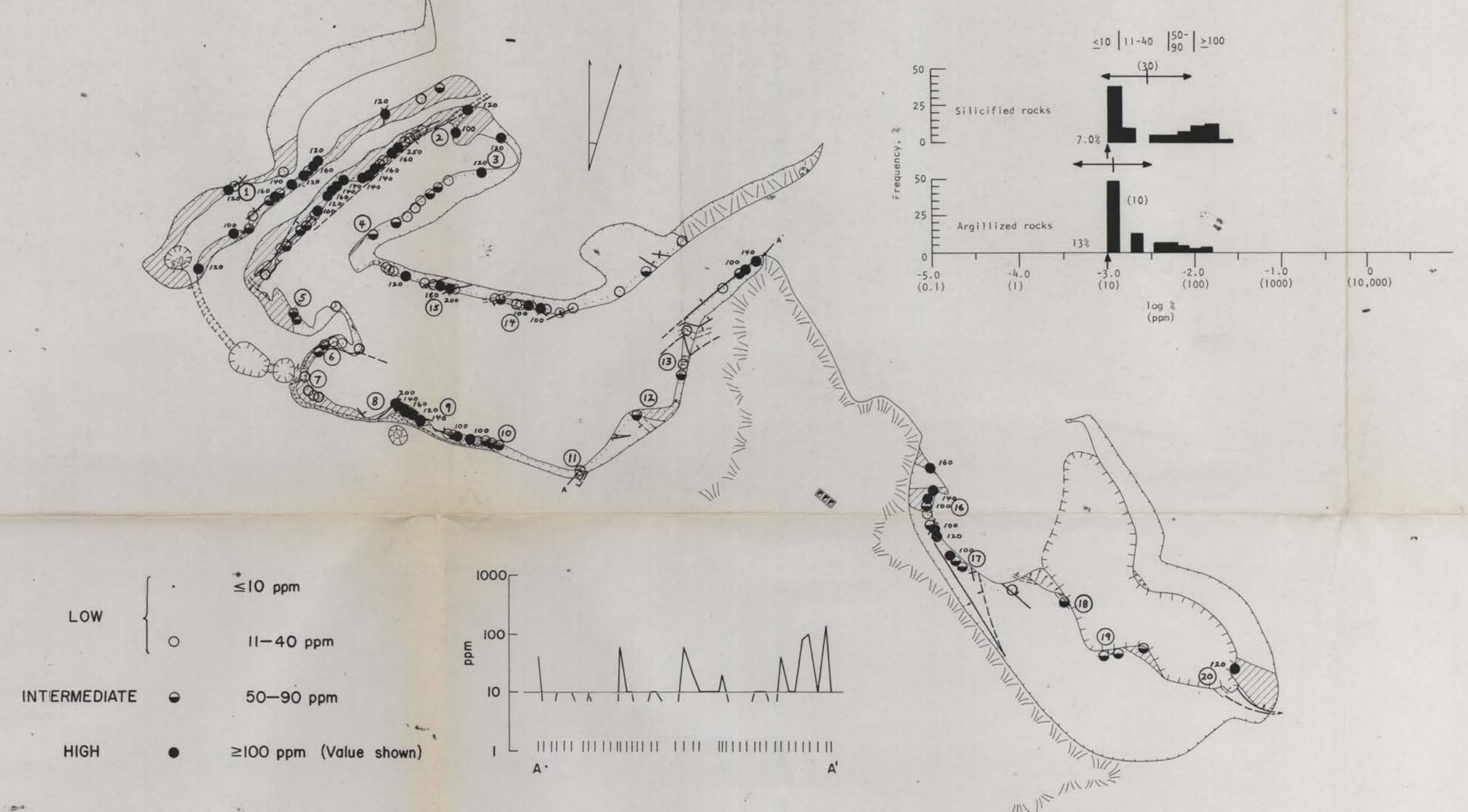
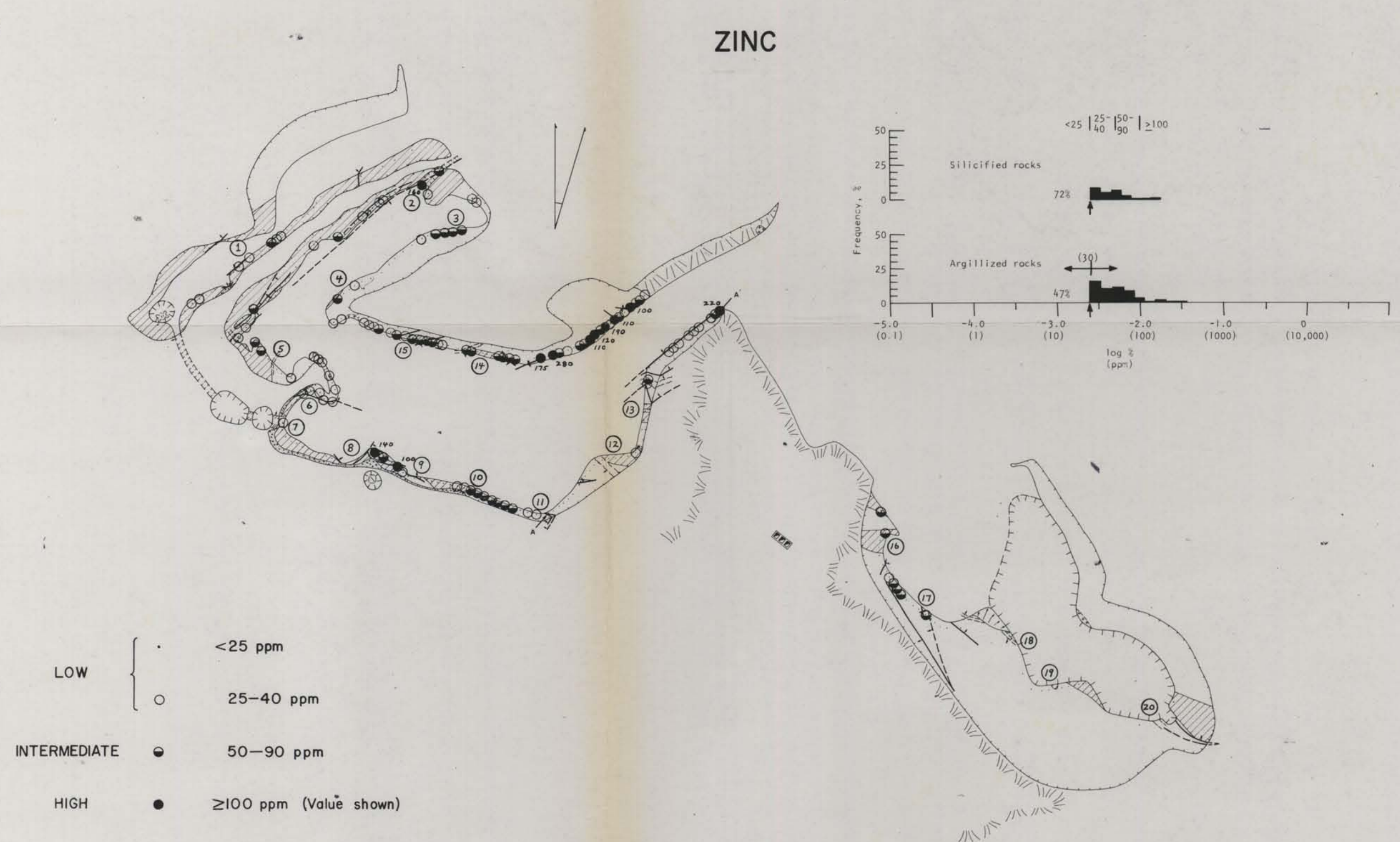
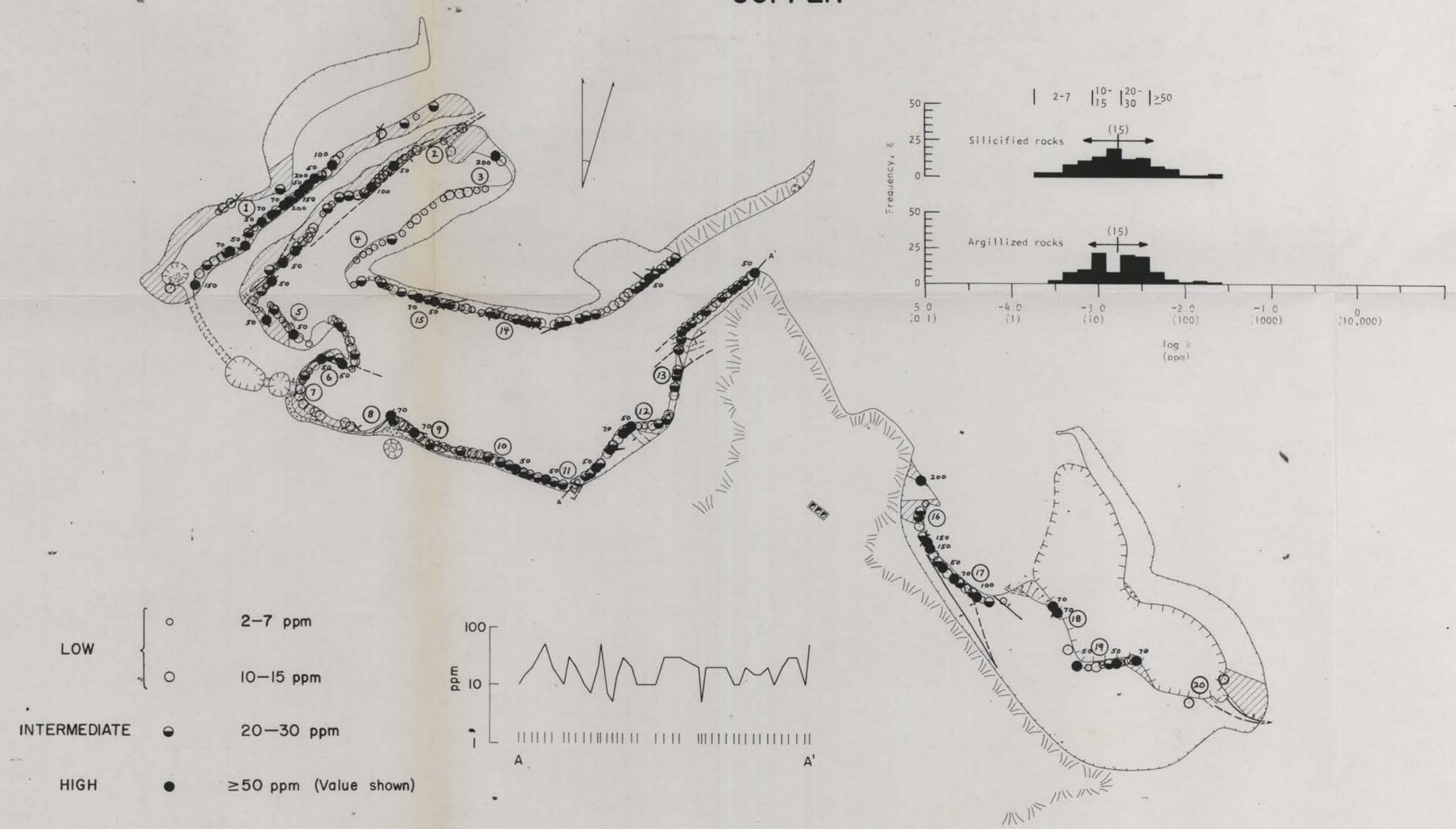


PLATE 5.-DISTRIBUTION OF ARSENIC, COPPER, MOLYBDENUM, ZINC, AND IRON
IN THE COMBINATION-JANUARY OPEN CUTS

ARSENIC



COPPER



MOLYBDENUM

