

MAP A-MAP SHOWING THE DISTRIBUTION OF SAMPLE LOCALITIES HAVING ANOMALOUS COPPER IN STREAM SEDIMENTS

This map is part of a folio of maps of the Ajo and Lukeville 1° x 2° quadrangles, Arizona, prepared under the Centenniary United States Mineral Assessment Program. Other publications in this folio include U.S. Geological Survey Miscellaneous Field Studies Map MF-1834-C, 1984, and Open-File Reports 82-419, 82-599, and 83-734. Open-File Reports 82-419 and 83-734 constitute the basic data and initial interpretation on which this discussion is predicated.

#### INTRODUCTION

The geochemical reconnaissance sampling was done during 1979 and 1980. The area covered includes all of the Ajo 1° x 2° quadrangle in the U.S., except the Parry Pass area, and the northern part of the Ajo 1° x 2° quadrangle west of the Indian Reservation and north of the Mexican border (fig. 1). A total of 971 samples were taken, 700 of which were stream sediment finer than 300 microns and 290 of which the nonmagnetic fraction of heavy-mineral concentrate from the stream sediments. Samples were collected on first-order drainage channels, generally selecting a drainage basin of less than 1 km<sup>2</sup>. Sample locations were further selected to represent the mountainous terrain of the Ajo Range, largely ignoring the 80 percent of the quadrangle underlain by a thick fill of young sediments in the basins. The average sample area was 1.2 km<sup>2</sup> and sample density per 3 km<sup>2</sup> for the mountain ranges. All samples were analyzed by optical emission spectroscopy for 31 elements. Sample preparation, analytical procedures, and data analysis are described by Theobald and Barton (1982).

The porphyry-type copper deposit of the New Cornelia mine at Ajo (Dixon, 1966) is the largest known copper deposit in the Ajo Range, and therefore, is the element of most immediate importance to the evaluation of potential mineral resources. In Theobald and Barton (1982), analytical data for copper was discussed in terms of stream sediments and in terms of the statistical relation of copper to other elements. The purpose of this report is to analize the information presented in earlier reports in terms of the geographic distribution of copper and, thereby, identify areas having potential for mineral resources.

#### COPPER DISTRIBUTION

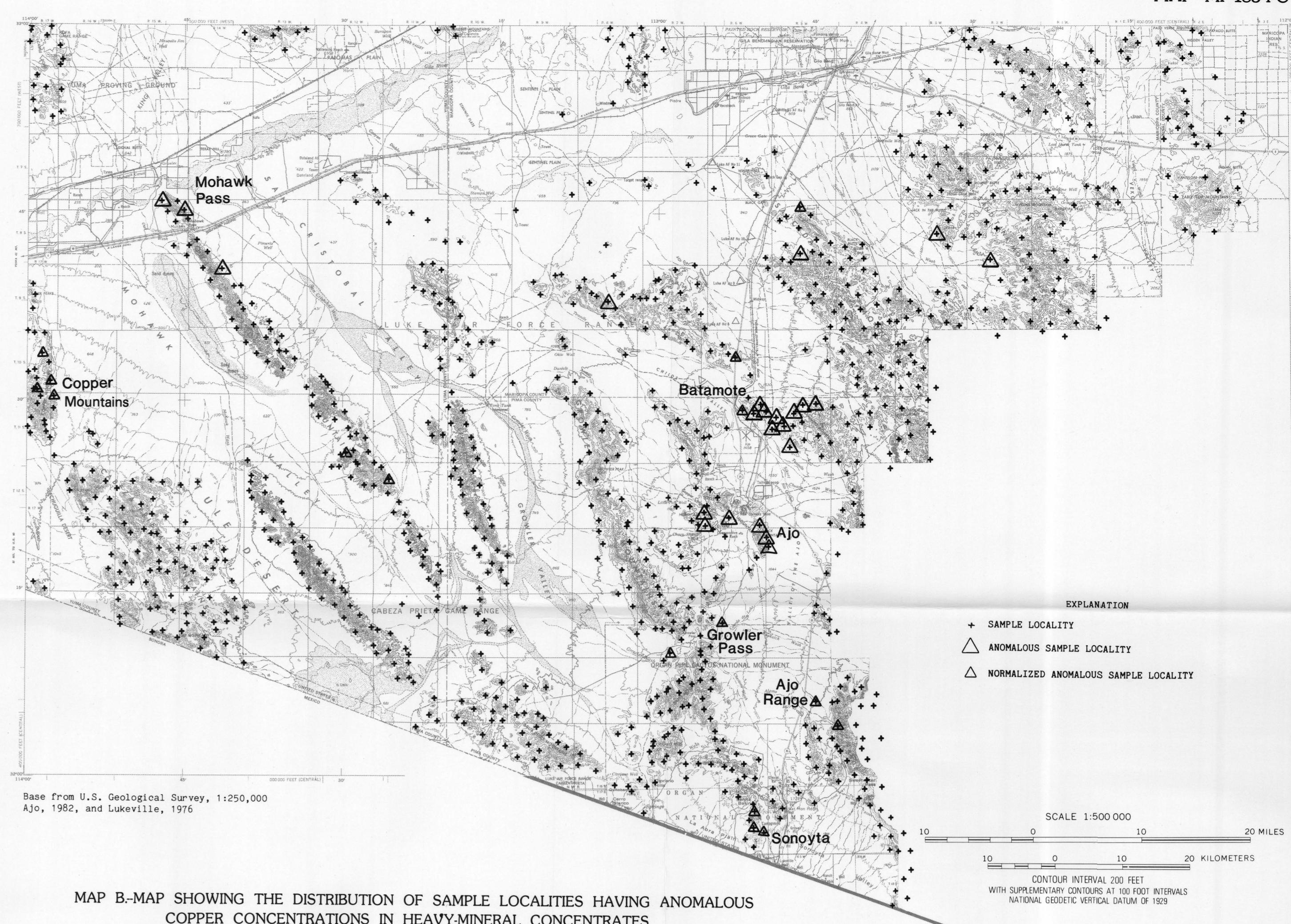
The copper content of the stream sediments ranges from less than 5 ppm (parts per million) to 700 ppm (fig. 2). The majority of the samples contain 50 ppm or less copper, and the shape of the histogram for these samples approximates a lognormal curve. The area on the histogram above 50 ppm appears to reflect a different population of samples and is defined as the anomalous population. The population suspected to directly reflect mineralization is the anomalous population.

The copper content of the heavy-mineral concentrates ranges from less than 10 ppm to 15,000 ppm (fig. 3). The part of the histogram (fig. 3) below 100 ppm is the majority of the samples and forms what appears to be a very broad (low kurtosis) essentially lognormal curve. The area on the histogram above 100 ppm reflects the anomalous population suspected of directly reflecting mineralization. Because of the low kurtosis of this histogram and the extreme range of concentration, the anomalous population is not clearly separated from the population, and the choice of the break between 300 and 500 ppm is rather arbitrary. Intuitively, we judge that the anomalous population of stream sediments is conservative, and we expect that information of resource value is also in the upper part of the histogram.

The large triangles on map A identify the 28 sample localities defined as having anomalous concentrations of copper in stream sediments. All but five of these are located in the mountainous part of the area identified as Ajo and the cluster in the area identified as Batamote. The gap between the areas identified as Ajo and Batamote is a large alluvial plain, which was not sampled. The southern part of the cluster at Ajo and the cluster in the area identified as Batamote may be directly related to this deposit because the country rock in these areas consists of volcanic rocks younger than the Ajo deposit. Four of the sample localities having anomalous concentrations of copper, in the southern Sand Tank Mountains, the Painted Rock Mountain, and the mountains near Mohawk Pass, and the Copper Mountains, are located in areas where secondary copper minerals are visible. The fifth of the isolated localities has no obvious source.

The large triangles on map B identify the 23 sample localities defined as having anomalous concentrations of copper in the heavy-mineral concentrates. All but one of these sample localities are in the areas identified as Ajo and Batamote. The two major geochemical anomalies were confirmed to be the same as the direct association of the three anomalous sample localities in the vicinity of Mohawk Pass is in the same area as one of the anomalous sample localities in the stream sediments data and, as noted above, is the locality of a copper mine. The remaining four anomalous sample localities are in the Sand Tank Mountains (two sample localities), the Sandia Mountains, and the Ajo Range (one sample locality). These correspond to anomalous sample localities in the stream sediments and only one, in the Sand Tank Mountains, is near a known copper deposit. The areas of the most intense ordnance testing and practice, the Luke Air Force Range, therefore, contamination may be possible. However, microscopic examination of these concentrates for copper minerals, including chrysocolla in a sample from the Sand Tank Mountains, as would be expected from examination of prospects in the area, and no minerals were seen in samples from this or the other three sample localities. Artificial contamination, though possible, seems unlikely.

The geographic distribution of the scores of the first four factors for copper in both sample media differs significantly. The first two factors for stream sediments and, as noted above, are the locality of a copper mine. The remaining four anomalous sample localities are in the Sand Tank Mountains (two sample localities), the Sandia Mountains, and the Ajo Range (one sample locality). These correspond to anomalous sample localities in the stream sediments and only one, in the Sand Tank Mountains, is near a known copper deposit. The areas of the most intense ordnance testing and practice, the Luke Air Force Range, therefore, contamination may be possible. However, microscopic examination of these concentrates for copper minerals, including chrysocolla in a sample from the Sand Tank Mountains, as would be expected from examination of prospects in the area, and no minerals were seen in samples from this or the other three sample localities. Artificial contamination, though possible, seems unlikely.



MAP B-MAP SHOWING THE DISTRIBUTION OF SAMPLE LOCALITIES HAVING ANOMALOUS COPPER CONCENTRATIONS IN HEAVY-MINERAL CONCENTRATES

#### INTERELEMENT RELATIONS OF COPPER

The major part of the variation in the concentrations of copper has been related to gross variations in the composition of the country rocks (Theobald and Barton, 1982). The anomalies in copper, related to mineralization in copper-poor rocks, are probably masked by the great range of copper concentrations in more copper-rich country rocks and the great range of copper content. Theoretically, this problem could be overcome by normalizing each of the copper values against the average copper content of the sample, or against the average copper content of the sample in each drainage basin. The absence of detailed information about the lithologies in each drainage basin and the normal copper content of each lithology precludes the use of either technique. However, used here, is to geometrically characterize the drainage basin in terms of the multi-element data and determine the correlation of copper to the multi-element characteristics, and, thereby, define as anomalous the samples in which copper concentrations exceed the expected levels for the composition of the sample as expressed by the factor score—the average copper content of the sample. One can then expect levels of copper for the composition of the sample as expressed by the factor score—they are the expected levels of copper for the sample to the left of this zone on figures 8 and 9 are samples that contain more copper than would be predicted from the average copper content of the sample and are relatively low loadings for the first factor and are defined here as normalized anomalous samples. Samples that contain more than 50 ppm copper in stream sediments or more than 300 ppm copper in heavy-mineral concentrates are considered to be anomalous on the basis of copper distribution alone (figs. 2 and 3). Samples that contain less than 10 ppm copper in stream sediments or less than 100 ppm copper in heavy-mineral concentrates are not considered anomalous because of analytical uncertainties at the low levels of concentration.

Data from the stream sediments allowed analysis of relations among 16 elements in stream sediments and 17 elements in heavy-mineral concentrates. The correlation coefficients of each of the other elements are expressed by the correlation coefficients in figure 4. The relation of copper to the ferric oxide factor (fig. 4) is the same as the multi-element characteristics, and, thereby, define as anomalous the samples in which copper concentrations exceed the expected levels for the composition of elements present. Thus, samples are defined as anomalous only when normalized against the expected lithologically controlled outer content.

Data from the heavy-mineral concentrates allowed analysis of relations among 16 elements in stream sediments and 17 elements in heavy-mineral concentrates. The correlation coefficients of each of the other elements are expressed by the correlation coefficients in figure 4. The relation of copper to the ferric oxide factor (fig. 4) is the same as the multi-element characteristics, and, thereby, define as anomalous the samples in which copper concentrations exceed the expected levels for the composition of elements present. Thus, samples are defined as anomalous only when normalized against the expected lithologically controlled outer content.

The correlation matrix analysis is based on the correlation matrix and yields a pattern of coefficients for copper remarkably predictable from the correlation coefficients described above (for definition of terms, see Barton, 1982). The reader is referred to the chapter on multivariate analysis by Howarth and Sinding-Larsen in Howarth, 1982. In general, the "factors" may be considered to be groups of elements that are correlated to provide a measure of the correlation of the elements with the factors, and the "community" provides a measure of the correlation of the elements with the factors. A more complete analysis of the Ajo data is provided in Theobald and Barton, 1982. Copper is most strongly associated with the first factor when models are fit as many as four factors to stream sediments and as many as 8 factors in heavy-mineral concentrates are considered. These relations are closest for the anomalous sample localities. The communities of copper with the number of factors (figs. 5 and 6) are as follows:

#### AREAS HAVING ANOMALOUS CONCENTRATIONS OF COPPER

Two major and six lesser areas are defined as having anomalous concentrations of copper. The geological and geochemical characteristics of each of these areas are unique. Only areas having clusters of anomalous sample localities are considered. However, follow-up studies aimed at finding ore should include isolated sample localities having anomalous concentrations of copper. The scale of the sampling for this compilation is such that moderate-size deposits could be indicated by only one sample locality or perhaps even missed.

The relation of copper to other elements in heavy-mineral concentrates is remarkably similar to that in stream sediments. About 40 percent of the variance is accounted for by the first factor, and another 35 percent by the ninth factor, again a unique factor for copper. About 10 percent of the variance is related to the fifth factor, and the fifth factor is a molybdenum-lead factor, which for six or more factors is a unique factor for molybdenum. The apparent association of copper with molybdenum in the stream sediments to an association of copper with molybdenum and subordinately with lead in the heavy-mineral concentrates is because of the low level of molybdenum in the stream sediments and the limits of the analytical method.

Because 40 percent of the values for molybdenum in the stream sediments is beyond the limit of measurement, this element was not included in the factor analysis. A close association of molybdenum and lead does exist in the stream sediments data in the stream sediments suggesting that if more complete data were available, the two sample media would yield similar associations. Although the unique molybdenum-lead factor is not related to the variance, the correlation coefficient between the two elements suggests a random relation. This apparent association results from the close association of copper with ferric oxide and the close association of copper to molybdenum and lead. Only when the relations of these three elements to the major, lithologically controlled factor, ferric oxide, are in relatively extractable form, presumably incorporated in secondary iron and manganese oxides, lateral leakage from the deposit at Ajo is a remote possibility, but more likely the source of the anomalous metals is not exposed.

The geographic distribution of the scores of the first four factors for copper in both sample media differs significantly. The first two factors for stream sediments and, as noted above, are the locality of a copper mine. The remaining four anomalous sample localities are in the Sand Tank Mountains (two sample localities), the Sandia Mountains, and the Ajo Range (one sample locality). These correspond to anomalous sample localities in the stream sediments and only one, in the Sand Tank Mountains, is near a known copper deposit. The areas of the most intense ordnance testing and practice, the Luke Air Force Range, therefore, contamination may be possible. However, microscopic examination of these concentrates for copper minerals, including chrysocolla in a sample from the Sand Tank Mountains, as would be expected from examination of prospects in the area, and no minerals were seen in samples from this or the other three sample localities. Artificial contamination, though possible, seems unlikely.

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The large triangles on map B identify the 23 sample localities defined as having anomalous concentrations of copper in the heavy-mineral concentrates. All but one of these sample localities are in the areas identified as Ajo and Batamote. The two major geochemical anomalies were confirmed to be the same as the direct association of the three anomalous sample localities in the vicinity of Mohawk Pass is in the same area as one of the anomalous sample localities in the stream sediments data and, as noted above, is the locality of a copper mine. The remaining four anomalous sample localities are in the Sand Tank Mountains (two sample localities), the Sandia Mountains, and the Ajo Range (one sample locality). These correspond to anomalous sample localities in the stream sediments and only one, in the Sand Tank Mountains, is near a known copper deposit. The areas of the most intense ordnance testing and practice, the Luke Air Force Range, therefore, contamination may be possible. However, microscopic examination of these concentrates for copper minerals, including chrysocolla in a sample from the Sand Tank Mountains, as would be expected from examination of prospects in the area, and no minerals were seen in samples from this or the other three sample localities. Artificial contamination, though possible, seems unlikely.

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The geographic distribution of high values for this factor coincides with the distribution of mafic rocks, which are copper-poor rocks, and with the distribution of felsic rocks. Copper, though strongly associated with this factor, has a loading less than 0.5 in contrast with the dominant elements of the factor which are loading more than 0.5. The high values of copper against the factor 1 scores (figs. 8 and 9) yield a dense cluster of points in the upper right of the plot. At low levels of copper to factor 1, there are no points. One can expect levels of copper for the composition of the sample as expressed by the factor score—the average copper content of the sample. The points to the left of this zone on figures 8 and 9 are samples that contain more copper than would be predicted from the average copper content of the sample and are relatively low loadings for the first factor and are defined here as normalized anomalous samples.

Samples that contain more than 50 ppm copper in stream sediments or more than 300 ppm copper in heavy-mineral concentrates are considered to be anomalous on the basis of copper distribution alone (figs. 2 and 3). Samples that contain less than 10 ppm copper in stream sediments or less than 100 ppm copper in heavy-mineral concentrates are not considered anomalous because of analytical uncertainties at the low levels of concentration.

The copper content of normalized anomalous samples is probably not related to major, exposed rocks, but is related to the geographic distribution of sample localities with normalized anomalous copper concentrations (the smaller triangles on maps A and B) is relatively consistent with a variety of evidence for mineralization in the Ajo Range, the Copper Mountains, Sauceda, Growler Pass, Ajo Range, and Sonoya.

Growler Pass

The copper anomaly in the vicinity of Growler Pass is reflected in normalized data for both stream sediments and heavy-mineral concentrates. Most anomalous sample localities in the vicinity have been observed for lead, molybdenum, antimony, tin, and tungsten, but strontium is found in anomalous low concentrations. The rocks in the vicinity of Growler Pass are Mesozoic sedimentary rocks. They are overlain in the west by the volcanic rocks of the Ajo Range, and in the east by the volcanic rocks of the Grangesberg massif. The rocks in the vicinity of Growler Pass are Mesozoic sedimentary rocks. They are overlain in the west by the volcanic rocks of the Ajo Range, and in the east by the volcanic rocks of the Grangesberg massif. The rocks in the vicinity of Growler Pass are Mesozoic sedimentary rocks. They are overlain in the west by the volcanic rocks of the Ajo Range, and in the east by the volcanic rocks of the Grangesberg massif.

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