

A Paleozoic Geochemical Anomaly Near Jerome Arizona

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A PALEOZOIC GEOCHEMICAL ANOMALY NEAR JEROME, ARIZONA

By LYMAN C. HUFF

ABSTRACT

The pre-Cambrian copper deposits at Jerome, Ariz., and their enclosing metamorphic rocks are overlain unconformably by a thick sequence of Paleozoic formations. Immediately overlying the pre-Cambrian rocks and ores is a marine sandstone correlated tentatively with the Tapeats sandstone of the Grand Canyon region. Samples of this Tapeats(?) sandstone were collected and analysed for traces of copper, zinc, and lead.

The analyses reveal that the basal sandstone unit of this formation contains anomalous copper concentrations of more than 100 ppm (parts per million) near Jerome and in an area extending about 2 miles southeast from Jerome. Elsewhere the same basal unit contains about 20 ppm copper. Anomalous zinc concentrations of over 100 ppm are distributed in roughly the same area as the copper, but abnormal lead concentrations are limited to the immediate vicinity of the ore bodies. It is concluded that the abnormal copper and zinc content of the basal sandstone represents ore metal eroded from the ore deposits and incorporated in the sand during deposition.

Apparently geochemical prospecting techniques can be used to identify and trace heavy-metal anomalies like that present in the basal Tapeats(?) sandstone. The anomaly in this sandstone is much more extensive than most geochemical anomalies developed near ore in soil or alluvium. The broad extent of the basal Paleozoic anomaly probably results from the great dispersal power of wave action and shore currents in a marine environment. A search for other ancient anomalies may be helpful in prospecting large areas in which ore-bearing rocks are covered unconformably by younger sediments, whether marine or continental.

INTRODUCTION

Surficial dispersion of ore metals such as copper, lead, and zinc in water, soils, alluvium, and other sediment has been investigated in modern deposits and in those of fairly recent origin such as glacial till. However, the possibility that analogous geochemical anomalies exist in older rocks, such as basal sandstones or conglomerates, has not been investigated. If such anomalies do exist, it may be possible

to use them as drilling guides to prospect vast areas of concealed ore-bearing formations. This paper describes the investigation of such an ancient geochemical anomaly at Jerome, Ariz.

The geology and ore deposits of the Jerome area are being studied in detail by a U. S. Geological Survey party consisting of C. A. Anderson and S. C. Creasey. After the Geological Survey initiated geochemical prospecting investigations in 1946, the writer spent parts of several field seasons testing geochemical methods in the Jerome area. The initial geochemical investigations of the district concerned surface drainage, mine drainage, alluvium, and soils. The results of these studies will be incorporated in a detailed report concerning the geology and mineral resources of the area being prepared by Anderson and Creasey. The chemical investigation of the Tapeats(?) sandstone is described separately here because it is a new application of geochemical prospecting of possible economic significance.

The writer is indebted to H. E. Hawkes, C. A. Anderson, and other colleagues of the Geological Survey who suggested a chemical study of the Tapeats(?) sandstone and who encouraged and facilitated its progress. In addition the writer is indebted to Geological Survey chemists mentioned in the text for their painstaking analysis of the many samples involved. The Phelps Dodge Corporation kindly provided necessary background data and other useful information concerning the mines at Jerome.

This paper includes a brief description of the basal Paleozoic or Tapeats(?) sandstone and its relationship to the ore bodies at Jerome, an account of the sampling, analysis, and results of the geochemical study of the sandstone, and a consideration of the use of ancient geochemical anomalies as drilling guides.

GEOLOGIC SETTING OF THE BASAL PALEOZOIC SANDSTONE

The basal Paleozoic formation or Tapeats(?) sandstone overlies unconformably the pre-Cambrian rocks and ore bodies at Jerome. In general this formation consists of a well-sorted coarse red sandstone at the base, lenses of white and red sandstone above, and red or green siltstone and claystone at the top. The basal unit of this formation is commonly an arkosic sandstone which contains a few small pebbles. The red color of the basal unit apparently is caused by a ferruginous grain coating and cement. The Tapeats(?) sandstone near Jerome is similar to the Tapeats sandstone at the Grand Canyon, which has been studied in detail by Sharp (1940) and by several earlier writers. Sharp concluded that the Tapeats is a shallow-

water marine deposit derived from a residual soil which was in turn derived by thorough chemical weathering of the underlying pre-Cambrian rocks under humid conditions. These conclusions can apply equally well to the Tapeats(?) sandstone of the Jerome area.

The thickness of the Tapeats(?) sandstone near Jerome averages about 50 feet but within short distances it ranges from less than a few inches to a maximum of about 100 feet. This variation in thickness is a consequence of gentle undulations of its base. Apparently this formation filled shallow depressions in the surface of the pre-Cambrian rocks as it was deposited so that it is thickest in these old depressions and thinnest over what must have been low knolls on the pre-Cambrian surface. Locally, over what must have been the highest knolls of the pre-Cambrian surface, the Tapeats(?) sandstone is missing.

The age of the Tapeats(?) or basal Paleozoic sandstone at Jerome is in doubt. Reber (1938) and McKee (1951) correlate this basal Paleozoic sandstone near Jerome with the Tapeats sandstone of Cambrian age of the Grand Canyon area. McNair (1951), however, correlates the basal sandstone at Jerome with the Martin limestone of Devonian age. Until satisfactory index fossils are found in it the age of the basal sandstone in the Jerome area will remain doubtful. Following a suggestion by C. A. Anderson and S. C. Creasey (personal communication) the basal sandstone formation near Jerome is referred to here as the Tapeats(?) sandstone to indicate that its Cambrian age is not proven.

Near Jerome the Tapeats(?) sandstone is overlain by a thick sequence of formations in layer-cake arrangement including, from the Tapeats(?) upwards (1) 450 feet of Martin limestone (Devonian), (2) 290 feet of Redwall limestone (Mississippian), (3) about 370 feet of siltstone and shale of the Supai formation (Pennsylvanian and Permian), and (4) more than 1,000 feet of basalt (Tertiary). The Tapeats(?) and younger rocks cover much of Mingus Mountain, west of Jerome, and the broad valleys near Jerome contain extensive alluvial fill. Thus, throughout much of the area near Jerome, the pre-Cambrian rocks are concealed beneath younger sedimentary rocks (fig. 14).

Because the basal Paleozoic sandstone was derived from the underlying pre-Cambrian rocks and ores it seems probable that the chemical composition of these pre-Cambrian rocks and ores largely determined the chemical composition of the Tapeats. These pre-Cambrian rocks, formerly lumped together as the Yavapai schist (Lindgren, 1926), consist of metamorphosed lava flows, tuffs, and tuffaceous sediments which are intruded locally by quartz porphyry, diorite, diabase (Creasey and Anderson, 1948). About 15 miles south of Jerome, the pre-Cambrian Bradshaw granite underlies extensive areas.

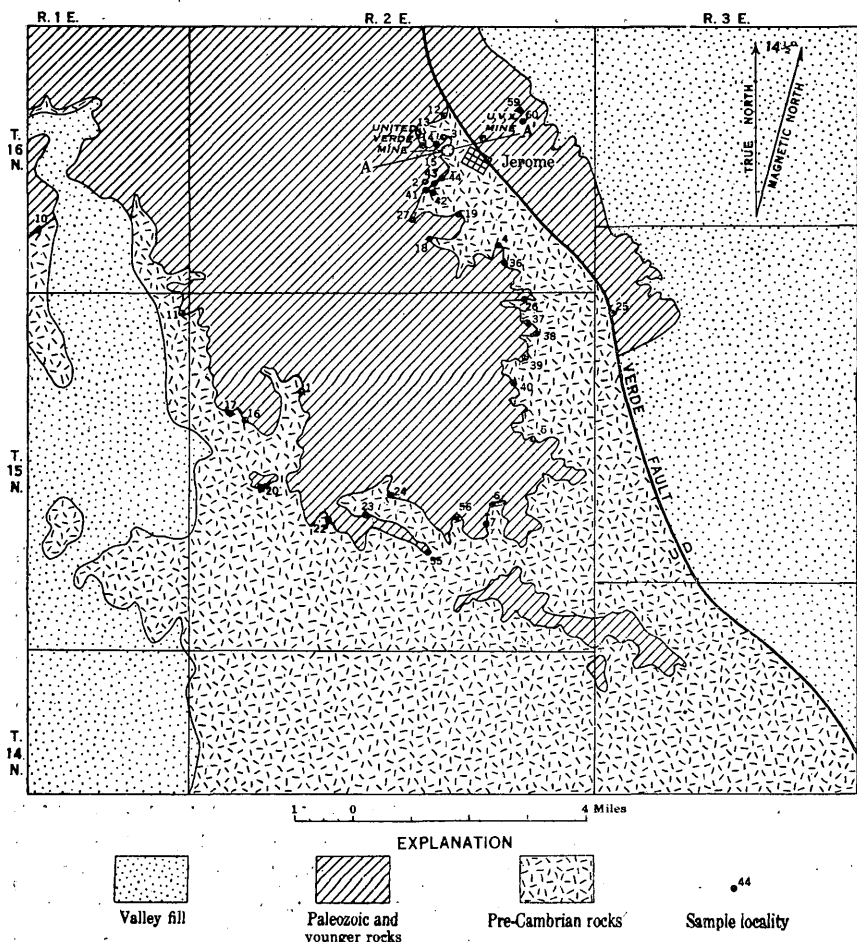


FIGURE 14.—Simplified geologic map of Jerome and vicinity, showing where samples of the basal Paleozoic sandstone were collected. Geology modified from Lindgren (1926).

The principal mines of the area are the United Verde and United Verde Extension, both of which are located at Jerome. The United Verde Extension is known locally as the U. V. X. The United Verde ore is an irregular pipelike body localized along contacts between diorite, quartz porphyry, and metamorphosed tuffaceous sediments (Reber, 1938). Chalcopyrite and sphalerite are the principal ore minerals, and tennantite and galena are minor ones. In addition to these ore minerals, the ore body contains quartz, pyrite, specularite, magnetite, dolomite, and chlorite. When first discovered by Indians and early prospectors, the ore body was covered with about 100 feet of a limonitic gossan containing oxidized copper minerals. The small amount of chalcocite beneath the gossan indicates only minor supergene enrichment of the ore.

The U. V. X. ore contains primary minerals similar to those of the United Verde, but they have been replaced largely by supergene chalcocite. A deep oxidized zone containing much malachite, chrysocolla, and azurite covers the U. V. X. ore body. This ore body and its oxidized zone are completely concealed beneath a cover of younger rocks; the story of the discovery of the U. V. X. ore body in 1914 is a dramatic chapter in the history of mining (Rickard, 1932, p. 365-379). Originally both the United Verde and U. V. X. ore bodies were completely covered by the basal Paleozoic sandstone. The relations of these ore deposits and the sandstone are shown in simplified form in figure 15.

The United Verde and U. V. X. ore bodies have been interpreted as segments of what was once a single large ore body having a thick zone of supergene enrichment (Reber, 1938). According to this interpretation the zone of supergene enrichment, which became the U. V. X. ore body, was separated from the United Verde ore pipe by movement along the Verde fault in late pre-Cambrian time and separated still farther by additional Tertiary movement along the fault. An alternative interpretation is that the United Verde and the U. V. X. have always been separate ore bodies. This problem is vital to interpreting the genesis of these ore bodies but is of only minor importance to this geochemical prospecting study. As far as the geochemical study is concerned, the important fact is that both of these ore bodies must have been undergoing weathering and erosion at the time the basal Paleozoic sandstone was deposited. Because these ore bodies are close to each other they can be considered for the purposes of this chemical investigation as a single concentration of copper, zinc, and lead.

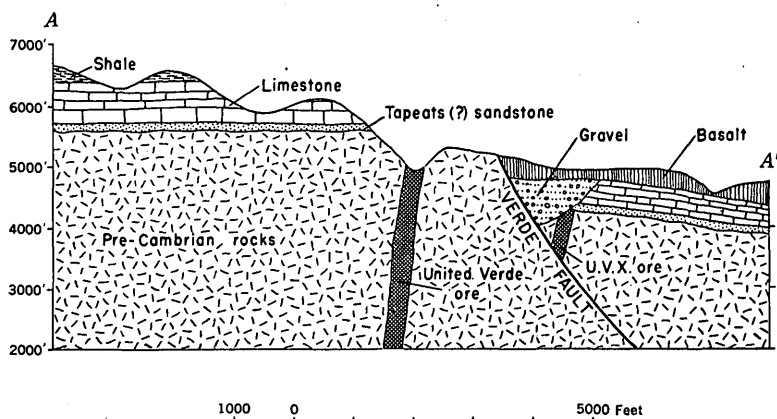


FIGURE 15.—Simplified geological cross section showing relationship of basal Paleozoic sandstone to ore deposits at Jerome. Modified from Reber (1938).

Reber (1938) states that over 99 percent of the ore production of the Jerome district has come from the United Verde and United Verde Extension mines. Other known ore bodies of the district, such as the Copper Chief and the Iron King, lie in the belt of pre-Cambrian outcrop extending southeast from Jerome along the east flank of Mingus Mountain. Some gold mines are near Cherry, about 12 miles southeast of Jerome; one copper mine, the Yaeger, is located about 7 miles southwest of Jerome on the west flank of Mingus Mountain; other small mines and prospects are distributed throughout the the outcrop area of pre-Cambrian rocks. All of these mines are smaller than the mines at Jerome. According to Reber, many of these deposits were hardly adequate to supply the stockholders with ore specimens. Thus, it seems likely that the contribution of copper and zinc from these ore bodies to the Tapeats(?) sandstone was smaller than that of the United Verde and U. V. X. ore.

GEOCHEMICAL INVESTIGATION OF THE BASAL PALEOZOIC SANDSTONE

The geochemical investigation described here was made to determine whether a detectable amount of copper derived by erosion of the Jerome ore bodies was incorporated in and deposited with the Tapeats(?) sandstone. Both the vertical and horizontal distribution of copper and zinc within the Tapeats(?) sandstone were investigated. At 18 localities each lithologic unit of the formation was sampled. Depending upon the local thickness and lithologic variation of the Tapeats(?) the number of samples collected at each site ranged from 2 to 7. Samples representing only the basal member were collected at 19 additional localities. The locations of all of the sample sites are shown in figure 14.

The sampling method consisted of knocking small chips from good exposures with a prospecting pick. Each sample consisted of 6 to 10 chips from an area about 6 feet in diameter. Pint cardboard cartons served as sample containers.

After the samples were ground to a powder on a bucking board, they were analyzed by field-type tests for total heavy-metal content (Huff, 1951) and copper (Stevens and Lakin, 1949). These field-type analyses indicated that throughout a considerable area near and south of Jerome the heavy-metal content in the basal sandstone member is higher than normal. Near Jerome the total heavy-metal content ranges from 80 to 300 ppm, whereas it averages less than 75 ppm elsewhere.

The field-type tests are not very suitable for detecting small differences in metal content. For this reason all of the samples were analysed for copper, lead, and zinc by a more accurate laboratory-

type analysis (Holmes, 1945). The laboratory analyses permit a better discrimination between high and low samples than the field-type analyses (table 1). Duplicate analyses by the laboratory method were made for some of the samples (table 1). It is evident that the errors involved in analysing these samples by the laboratory method are small in comparison with the total range of metal content among the samples.

TABLE 1.—*Metal content, in parts per million, of the basal member of the Tapeats(?) sandstone*

[Samples listed in order of increasing copper content, with duplicate determinations given where available. Analyses made by H. E. Crowe and J. P. Schuch]

Sample no.	Field test		Laboratory analysis ¹			
	Total heavy metal ²	Copper ³	Copper	Lead	Zinc	Calculated total heavy metal
6-----	75	10	4, 10	19	17	26
7-----	75	10	4, 10	25	17	27
11-----	75	10	7, 10	19	80	89
22-----	100	10	10, 13	31, 35	20, 20	34
25-----	50	10	10, 15	31	30	44
26-----	50	10	10, 15	21	24	35
10-----	75	10	15, 15	25	32	46
56-----	100	10	10, 20	9, 30	18, 20	32
20-----	50	10	15, 25	30	30	47
36-----	100	10	20, 24	12, 30	108, 110	124
38-----	50	10	25, 27	16	44	61
27-----	50	10	25, 29	13	42	59
37-----	75	10	20, 50	20	43	83
14-----	50	10	40, 44	30	54	83
3-----	100	10	54	120	210	267
5-----	75	10	54, 55	20	28	60
15-----	75	100	60, 75	40, 45	50, 60	99
41-----	250	10	70, 90	18	140	184
4-----	225	100	90, 100	30	160	214
42-----	200	50	110, 130	40	86	156
44-----	100	50	130, 130	11, 35	150, 160	226
43-----	275	100	140, 190	40	160	252
24-----	225	150	250, 300	35, 37	30, 40	184

¹ Analytical method described by Holmes (1945).

² After digestion for 1 hour in dilute nitric acid; method B of Huff (1951).

³ Determination by chromatograph (Stevens and Lakin, 1949).

Abnormal copper concentrations within the Tapeats(?) sandstone are concentrated mostly in the basal ferruginous sandstone unit (table 2). Similar data, which are not given here, show that the same generalization can be made for zinc and lead.

The laboratory-type analysis revealed, much better than the field-type analyses, the systematic distribution of copper, zinc, and lead in the basal unit of the Tapeats(?) sandstone. The normal or background copper content of the basal unit ranges from 5 to 20 ppm, but

TABLE 2.—Copper content of various units of the Tapeats(?) sandstone

[Copper determined by H. I. Crowe and J. P. Schuch using laboratory-type analytical methods. Analytical method described by Holmes (1945). Samples listed in order of increasing copper content of basal unit]

Lithologic description	Copper content, in parts per million, for indicated samples																	
	6	7	11	25	26	10	20	38	27	37	14	3	5	15	41	4	42	43
Upper green shale unit, present locally																		
Upper maroon shale unit, present locally														7				
Upper sandstone unit, commonly white sandstone, present locally			8								27			17			70	
Lower shale unit, green or maroon shale, present locally			15				22	18	7	16	90			27	14			20
White sandstone, present locally	8	7		18		27				15		24		27	92	24		72
Fine-grained red sandstone, present locally		7												37				
Coarse-grained red sandstone, present locally						32	10		25			47	7		77		140	
Coarse-grained red sandstone with ferruginous cement. Basal unit	7	7	10	12	12	15	20	26	27	35	42	54	55	70	80	100	120	160

throughout a large area near Jerome the copper content ranges from 100 to 270 ppm (fig. 16). The area of abnormal copper content is somewhat asymmetric; it extends for 2 miles south of Jerome and is very large in comparison with the cross section of the United Verde and U. V. X. ore bodies. In addition, there is one anomalous copper

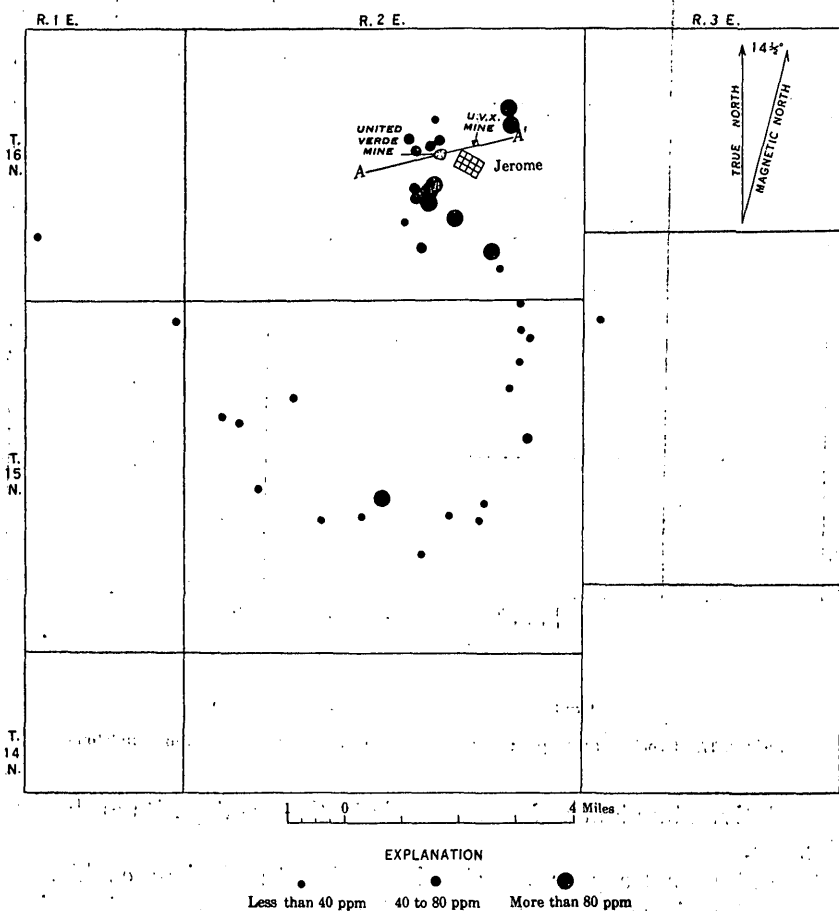


FIGURE 16.—Geochemical map showing concentration of copper in basal Paleozoic sandstone.

value of 275 ppm about 6 miles south of Jerome. Unfortunately, the writer has had no opportunity to collect additional samples at this locality.

The zinc content of the basal Paleozoic sandstone unit has a pattern somewhat similar to that of copper with a normal or background concentration of from 15 to 30 ppm and abnormally high concentrations of more than 100 ppm near Jerome (fig. 17). The small size of the lead anomaly as compared with copper and zinc is in conformity with

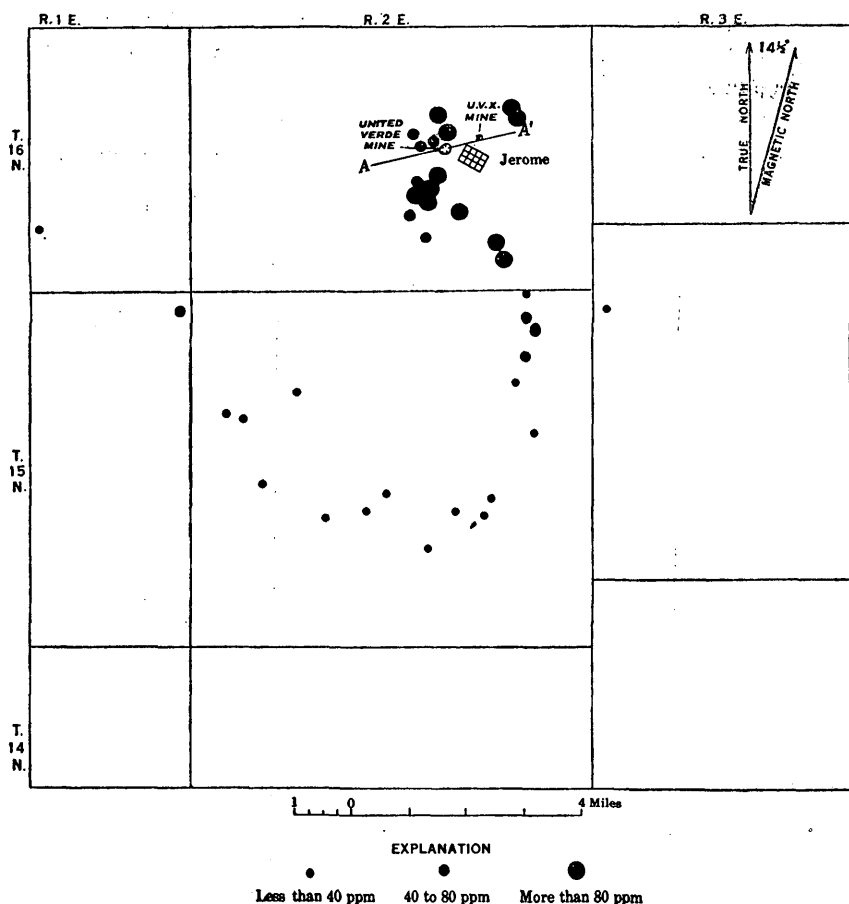


FIGURE 17.—Geochemical map showing concentration of zinc in basal Paleozoic sandstone.

the relative abundance of these metals in the ore deposits at Jerome (fig. 18).

The abnormal copper and zinc in the basal sandstone could have been derived in part from the ore bodies and in part from mineralized pre-Cambrian rock surrounding the ore. Dispersion of metals from either of these sources could explain an anomaly asymmetric with respect to the ore bodies. The asymmetry of the anomaly might be a consequence of southward movement of beach sand and eroded materials from the Jerome ore bodies during Tapeats(?) time. A zone of hydrothermal alteration extends for two or three miles southeast of Jerome. Widespread dissemination of metals in this zone is indicated by the metal content of the associated soil (unpublished Survey data). Thus, the mineralized pre-Cambrian rocks of this zone could also have contributed to the asymmetry of the anomaly.

Although the data available are inadequate to permit evaluation of the contribution of each source to the copper and zinc of the basal sandstone member, a discrimination may not be essential for geochemical prospecting.

The geochemical anomaly observed in the basal Paleozoic sandstone near Jerome is different in several respects from geochemical anomalies that have been investigated elsewhere. Most copper, lead, or zinc anomalies in residual soil have maximum concentrations ranging from 1,000 to 10,000 ppm, but extend only several hundred feet. The low maximum of the basal Paleozoic sandstone anomaly and its broad extent may be the effect of the relatively great dispersing power of marine processes. This characteristic of broad areal extent and low maximum metal content indicates that anomalies of this

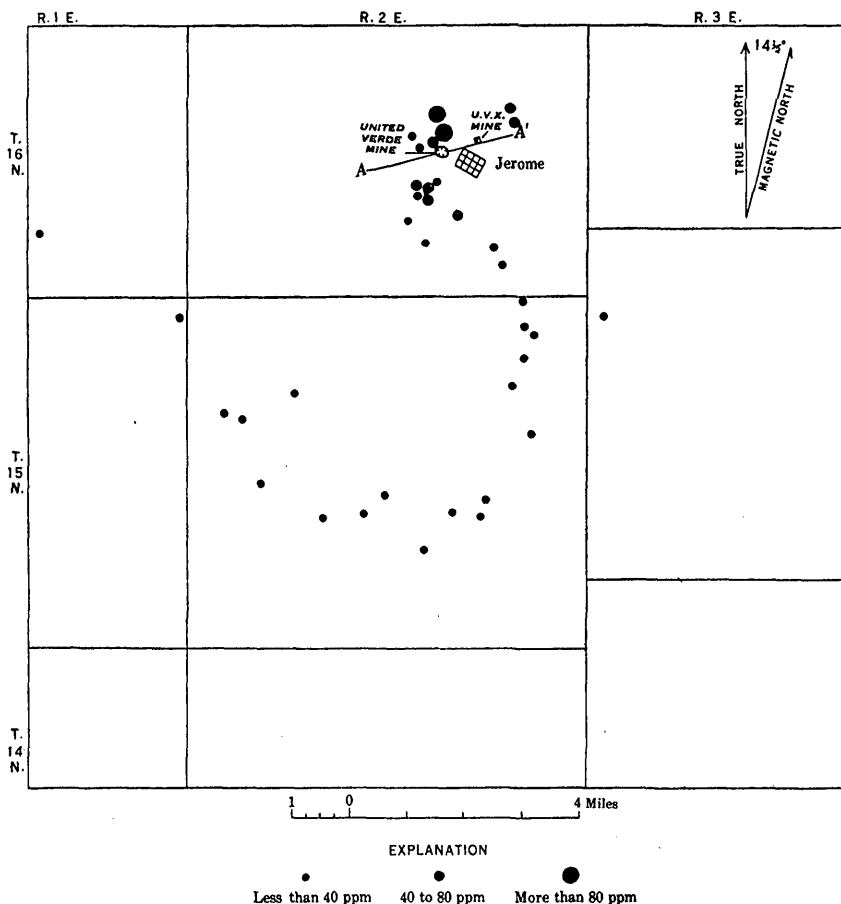


FIGURE 18.—Geochemical map showing concentration of lead in basal Paleozoic sandstone.

kind may be mapped by samples taken at comparatively broad intervals but that accurate analytical methods are required.

Geochemical anomalies have been classified as primary or secondary according to whether they were formed in the rocks surrounding the ore at the time of ore emplacement or whether they were formed much later by the weathering and erosion of the ore. According to these definitions, the geochemical anomaly in the basal Paleozoic sandstone is secondary in that it was derived by erosion of the pre-Cambrian ore bodies and rocks. On the other hand, the Paleozoic anomaly was formed long before development of the modern secondary anomalies in vegetation, soil, and alluvium that have received most attention in geochemical prospecting investigations. It is possible that geochemical anomalies of secondary origin might occur elsewhere in the geologic column; for example, a geochemical anomaly of Tertiary age might be revealed by a chemical study of the Tertiary gravels near Jerome. In fact, buried anomalies might exist anywhere that ore-bearing rocks are overlain unconformably by basal conglomerates or sandstones which postdate the ore. This type of geochemical anomaly may necessitate some revision of the simple twofold classification of primary and secondary anomalies.

ANCIENT GEOCHEMICAL ANOMALIES AS DRILLING GUIDES

The foregoing material describes the geochemical anomaly in the basal Paleozoic sandstone near Jerome and presents evidence supporting the conclusion that this anomaly was formed by weathering and erosion of the exposed ore deposits and neighboring mineralized rock at the time that the sandstone was deposited. This study will be completed by a consideration of the possible use of such ancient anomalies in prospecting near Jerome and elsewhere.

The copper deposits of the United Verde and United Verde Extension mines at Jerome provide good examples of the manner in which ore deposits can be concealed by younger rocks. The U. V. X. ore body is completely covered by younger rocks and would very probably never have been found if it had not been near the United Verde deposit. The United Verde deposit itself is less than 1,000 feet from the outcrop of the basal Paleozoic sandstone (fig. 15). An overlap of the Paleozoic formations extending 1,000 feet farther east than it does would have covered the United Verde deposit, with the result that even this deposit might never have been discovered. Thus, the discovery of both of these ore deposits can be attributed to the fortunate progress of erosion that stripped the cover from one of them. The situation leads to speculation concerning the possible existence of other covered ore deposits near Jerome. According to

Reber (1922, p. 25) the possibilities are good that additional ore deposits occur under the Paleozoic and younger rocks near Jerome.

Where ore-bearing rocks have a post-ore sedimentary cover, the customary method of prospecting is to drill through the cover of the ore-bearing rock. Such drilling, to be successful, must rely upon hitting the sought-for ore body directly with a drill hole or coming close enough to the ore that geologic evidence of mineralization in the core will encourage more detailed exploration. An average ore body and its mineralized periphery present a very small target to the exploration drill, commonly requiring a maximum spacing of holes of 100 to 200 feet.

If the drilling program were designed primarily to locate geochemical anomalies measuring at least 1 mile in diameter, only 1 hole per mile would be required. Thus, preliminary drilling at wide intervals to locate geochemical anomalies might avoid much closely spaced drilling in the search for buried ore.

The favorable results of one experiment with an ancient geochemical anomaly hardly justifies large-scale prospecting programs based upon their use. The use of such geochemical anomalies will be impractical where there have been significant epigenetic changes in the metal content of the sedimentary cover. Although the geochemical anomaly at Jerome does not appear to have experienced any epigenetic modification in metal content, without more data it is impossible to say whether the anomaly at Jerome represents the exception or the rule.

Another deterrent to the application of geochemical anomalies like that of the basal Paleozoic sandstone at Jerome is the difficulty in obtaining reliable measurements of low metal concentrations. Most geochemical prospecting investigations deal with higher metal concentrations, which are easier to measure. An accurate measurement of copper, zinc, and lead in the range of 10 to 200 ppm, as was necessary to detect the Jerome anomaly, is considerably more difficult and required a laboratory-type analytical method. It may be anticipated that working in such low ranges will require studies of errors involved in sampling and analysis to make certain that these errors are small in comparison with significant variations.

To balance these difficulties in the use of buried geochemical anomalies are the benefits which might possibly accrue through their use. Vast areas of pre-Cambrian rocks are overlain by Cambrian sandstones in the Eastern and Midwestern States. These areas could possibly be prospected by a search for buried geochemical anomalies.

The Basin and Range province offers other and perhaps better opportunities. Nolan (1950, p. 604) has made some rough estimates

of the value of ore deposits concealed by gravel-filled valleys and relatively undisturbed lavas in the Basin and Range province. He estimates that from one-half to two-thirds of the province is concealed by the young gravels or lavas and that the exposed fraction of the province has yielded a production of metals in excess of one billion dollars. If it is assumed that the amount of ore is roughly proportional to the area (as Nolan does), then it follows that the concealed area must contain at least a billion dollars worth of undiscovered ore. Part of the covered area consists of rock pediments covered by a thin layer of gravel that could be sampled by shallow drilling and therefore seems especially amenable to the search for buried geochemical anomalies.

Buried geochemical anomalies might be useful for prospecting in many other areas. However, before any extensive prospecting for them is attempted we should have more data concerning anomalies near known ore bodies. Additional investigations of ancient or buried geochemical anomalies in the vicinity of known ore will permit a better evaluation of this technique.

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