Distribution of uranium in the Bisbee district, Cochise County, Arizona

By S. R. Wallace, 1919

Trace Elements Investigations Report 426

UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Geology and Mineralogy

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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By

Stewart R. Wallace

January 1956

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DISTRIBUTION OF URANIUM IN THE BISBEE DISTRICT, COCHISE COUNTY, ARIZONA

By Stewart R. Wallace

ABSTRACT

The Bisbee district has been an important source of copper for many years, and substantial amounts of lead and zinc ore and minor amounts of manganese ore have been mined during certain periods. The copper deposits occur both as low-grade disseminated ore in the Sacramento Hill stock and as massive sulfide (and secondary oxide and carbonate) replacement bodies in Paleozoic limestones that are intruded by the stock and related igneous bodies. The lead-zinc production has come almost entirely from limestone replacement bodies.

The disseminated ore exhibits no anomalous radioactivity, and samples from the Lavender pit contain from 0.002 to less than 0.001 percent equivalent uranium. The limestone replacement ores are distinctly radioactive and stoping areas can be readily distinguished from unmineralized ground on the basis of radioactivity alone. The equivalent uranium content of the copper replacement ores ranges from 0.002 to 0.014 percent and averages about 0.005 percent; the lead-zinc replacement ores average more than 0.007 percent equivalent uranium.

Most of the uranium in the copper ores of the district is retained in the smelter slag as a residual concentrate; the slag contains about 0.009 percent equivalent uranium. Uranium carried off each day by acid mine drainage is roughly equal to 1 percent of that being added to the slag dump. Although the total amount of uranium in the district is

large, no minable concentrations of ore-grade material are known; samples of relatively high-grade material represent only small fractions of tons at any one locality.

INTRODUCTION

In September and October 1954, the writer, assisted by D. C. Laub and M. S. Lindholm, spent about five weeks making a preliminary survey of the Bisbee district, Cochise County, Ariz. to determine its suitability for a detailed study of the relation between uranium and hypogene mineral zoning. The Bisbee district was selected for this reconnaissance for three reasons: (1) significant concentrations of uranium had been reported from the district (Thurlow and Towle, 1949), (2) the geographic position of different types of ore within the district suggested a zonal distribution of the ores, and (3) the total amount of metal deposited within the district was known to be large, suggesting that the quantity of uranium might be appreciable.

Various types of mineralized ground, both on the surface and in the mines were sampled and examined for radioactivity. More than 40 miles of underground workings were traversed with scintillation and Geiger counters, and samples of mine water, and various products from the copper precipitation plant, mill, and smelter were collected for analysis.

The reconnaissance and sampling program provided data on the distribution of uranium in the ores of the district, and its redistribution by mining, milling and smelting.

Location, physical features, and climate

The town of Bisbee, 7-1/2 miles north of the Mexican border, is in Cochise County in the southeastern corner of the State of Arizona (fig. 1). U. S. Highway 80 connects Bisbee with points to the east and west. The Mule Mountains, which encompass the Bisbee district, are about 25 miles long in a northwesterly direction and have a maximum width of more than 10 miles. The mountains rise abruptly 2,000 to 3,000 feet from surrounding broad alluvial valleys and have a maximum altitude of 7,400 feet. Within the mountain area, slopes are generally steep and the soil is thin and rocky. The climate is hot and dry and desert-type vegetation is common; small conifers, principally juniper, are present on the higher parts of the range.

Acknowledgments

The study of radioactivity in the Bisbee district was made possible through the complete cooperation of the Phelps Dodge Corporation. In particular the writer wishes to express his thanks to Mr. C. R. Kuzell, General Manager of the Phelps Dodge Corporation, and Mr. C. E. Mills, Mr. W. G. Hogue, and Mr. H. E. Metz, General Superintendent, Chief Engineer, and Chief Geologist, respectively, of the Copper Queen Branch of the Phelps Dodge Corporation. Mr. Hogue and Mr. Metz made many helpful suggestions and conducted the members of the party to many critical points of interest, both on the surface and underground. Thanks are extended to the many other members of the Engineering and Geology Departments who cooperated in many ways during the course of the work. D. C. Laub and M. S. Lindholm ably assisted

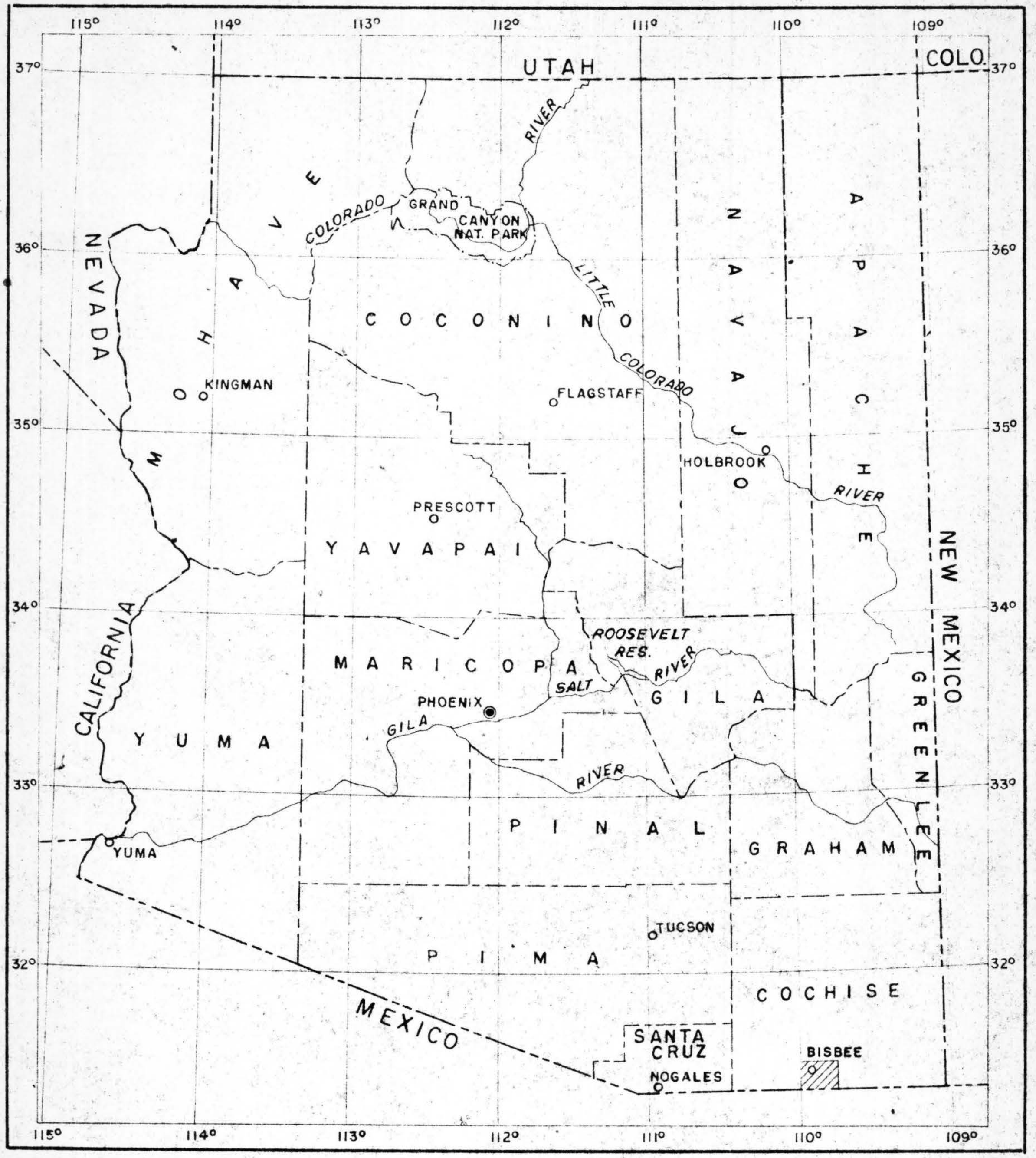

FIGURE I–INDEX MAP SHOWING LOCATION OF BISBEE QUADRANGLE, ARIZONA the writer and made many valuable contributions to the study. This study of the distribution of uranium in the Bisbee district was made by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GEOLOGIC SETTING

The rocks exposed in and near the Bisbee district range in age from Precambriam to Lower Cretaceous. The lithology and thickness of these rocks is summarized in table 1; also given is the radioactivity of some of the rocks.

The Mule Mountains block is a broad, doubly-plunging anticline of post-Early Cretaceous age whose axis trends northwestward; a generalized geologic map of the Bisbee district in the south-central part of the mountains is shown in figure 2. Rocks of Early Cretaceous age crop out on the northeast flank of the anticline and on both limbs of the structure where it plunges beneath the alluvium at the southeastern end of the mountains. The southwestern part of the mountains is underlain predominantly by rocks of Paleozoic age. These rocks are completely faulted along two systems of breaks that trend generally NNE and WNW; faults of the WNW set are generally older than those of the NNE set. The faults are especially numerous in and near the mineralized area and here form a mosaic pattern. (See fig. 2.) The strongest and one of the earliest faults in the district is the Dividend fault. This is a steep- to moderate-dipping normal fault that trends about N. 65° W. along the northern edge of the mineralized area. The maximum known

Table 1--Summary of rocks exposed in the Mule Mountains, Arizona*

Period		Formation	Thickness (feet)	Description	Radioactivity (mr/hr)
Cretaceous	Bisbee group (Comanche series)	Cintura formation	1800 +	Red and reddish purple shales, buff and red sandstones and some limestone near base; overlain by alluvium.	
		Mural limestone	650	Upper part of formation is thick-bedded; lower part is thin-bedded and arenaceous.	
		Morita formation	1800	Buff, gray and red sandstones and dark red shales.	
		Glance conglomerate	25 to 500	Coarse conglomerate; principally angular fragments of Precambrian schist and Paleozoic limestone.	
U N C O N F O R M I T Y					
Small stocks, dikes, sills and irregular bodies of quartz monzonite, rhyolite, and granite porphyry.					0.02-.07
Pennsylvanian		Naco limestone	3000 +	Light-gray, fine-grained limestone; beds of moderate thickness.	.015-.025
Mississippian		Escabrosa limestone	700	Thick-bedded, light-gray limestone	.015-.025
Devonian		Martin limestone	340	Dark-gray limestone	.01-.02

* Data mostly from Ransome (1904).

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Table 1--Summary of rocks exposed in the Mule Mountains, Arizona--Continued

Period	Formation	Thickness (feet)	Description	Radioactivity (mr/hr)
Cambrian	Abrigo limestone	700	Thin-bedded, cherty, argillaceous limestone.	0.015-.03
	Bolsa quartzite	430	Tan- to brown-weathering quartzite with thin conglomerate layer at base.	.03-.04
UNCONFORMITY				
Precambrian	Pinal schist	?	Mostly well foliated quartz-sericite schist; feldspathic and biotitic (?) in some places.	.03-.04

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displacement is approximately 5,000 feet at a point about 2-1/2 miles southeast of Bisbee; the south side is downthrown. The major dislocation along the fault was pre-Cretaceous or early Cretaceous and most of the Paleozoic sedimentary rocks were stripped from the upthrown block and deposited disconformably on the Paleozoic strata of the downthrown block as coarse angular constituents of the Glance conglomerate. On the north side of the Dividend fault the Glance is much thinner than the south and in many places rests directly on the Precambrian.

Northwestward from the vicinity of Bisbee, Precambrian Pinal schist and intrusive rocks, predominantly granite and rhyolite porphyry stocks, dikes and sills, are exposed in an irregular belt 1 to 3 miles wide along the crest of the Mule Mountains anticline. The intrusive rocks, which are also found at scattered localities on the southwest flank of the mountains, cut all Paleozoic formations and in places are overlain by Glance conglomerate containing porphyry fragments. One or two dikes of andesite cut the Glance conglomerate, but these probably belong to a later (Tertiary?) period of igneous activity.

The Sacramento Hill stock, an isolated intrusive east of Bisbee, is the principal igneous body that shows strong mineralization, and the age of this stock and the mineralization associated with it are controversial. Tenney (1932) believes that the mineralization was of Tertiary age whereas Trischka (1938) thinks that the ores were pre-Cretaceous in age. The writer feels that fragments of altered porphyry in the Glance conglomerate overlying the Sacremento Hill stock and other evidence now available in the files of the Phelps Dodge Corporation definitely indicate a pre-Cretaceous origin. An absolute age determination is in progress on a sample of Bisbee ore, but the results are not yet available. More detailed information of the geology and ore depostis of the Bisbee district is given by Ransome (1904), Schwartz and Park (1932), Tenny (1932), Trischka (1938), Hogue and Wilson (1950) and others.

ORE DEPOSITS

Types

Two types of deposits have yielded essentially all ore produced from the Bisbee district: 1) low-grade disseminated ore of the "porphyry copper" type, and 2) relatively high-grade massive sulfide replacement deposits in limestone. The disseminated ores occur in strongly fractured, pyritized, silicified, and sericitized granite or quartz monzonite porphyry of the Sacramento Hill stock. The ore consists of very sparse chalcopyrite and bornite and microscopic films and stringers of chalcocite that vein and replace the pyrite. Some copper has been produced from contact breccia zones marginal to the Sacramento Hill stock.

The limestone replacement ores are divided, on the basis of mineralogy, into two subtypes: 1) chalcopyrite-bornite-pyrite ore with generally lesser amounts of lead and zinc sulfides, and 2) sphalerite-galena ore containing essentially no copper. The limestone replacement bodies contain minor amounts of many ore minerals other than those listed above; these are discussed in more detail in the section on mineralogy. Quartz, pyrite, and carbonates are the most abundant gangue minerals, sericite, clay minerals, and chlorite are common; lime-silicate minerals are rare. The depth of supergene alteration of the ores varies greatly and ranges from about 200 feet in the northwestern part of the distrct to more than 2,500 feet along some fissure zones in the southeastern part of the district (Hogue and Wilson, 1950). In many parts of the district, copper carbonates, silicates, and oxides were important ore minerals in the shallower deposits, and the first lead ore produced was mined from a mass of cerussite. Chalcocite has been an important ore mineral in many of the copper sulfide bodies.

Concentrations of manganese oxides in limestone crop out at many places in the district, and many of these bodies were worked for manganese during the first World War (Jones and Ransome, 1919). Most of the manganese ore bodies are small and commonly bottom within 50 feet of the surface. The wad is generally regarded as a residual concentration formed by the oxidation of manganiferous carbonates and, in some places, alabandite (Hewett and Rove, 1930).

Localization of replacement ores

Replacement ore bodies occur in all Paleozoic limestones, but the Martin and Escabrosa limestone have been the most productive formations. The Abrigo limestone is a favorable formation in the southern part of the mineralized area, and some ore has been mined from the Naco limestone in the eastern part of the district. In general, the primary structural controls are the intersection of favorable beds with one or more systems of persistent joints or faults; many of the faults are zones of fractured ground from a few feet to as much as 100 feet in width. Blanket-type deposits are common especially in the Abrigo limestone, but many ore bodies in the district have a greater vertical than horizontal extent.

Except for the Sacramento Hill stock, outcrops of igneous rocks are rare in the mineralized area. Dikes, some of which were intruded along fault zones, sills and irregular bodies of porphyry are abundant, however, in some parts of the underground workings, and these are considered to indicate generally favorable ground. Some ore bodies have been found in irregular "embayments" in the porphyry.

Distribution and zoning of the ores

The mineralized area of the Bisbee district includes about 4 square miles, but most of the ore has been produced from an area about 2 miles long from northwest to southeast and about 1/2 mile wide. The northeast limit of economic mineralization coincides roughly with the Dividend fault. The Paleozoic limestones have been eroded from the area north of the fault and the limestone replacement deposits are grouped in a semicircular pattern around the south end of the Sacramento Hill stock (fig. 2). The Dividend fault passes through the stock; and, although both the porphyry and the Pinal schist are heavily pyritized to the north, all the disseminated-type ore has come from the part of the stock south of the fault.

Complete production records of zinc-lead ore are available only for the deposits in the eastern part of the district, but sufficient data are known to give a general picture of the distribution of copper and zinc-lead ores throughout the district. According to Hogue and Wilson (1950), a generalized map of the district would show both copper and zinc-lead deposits in the same mineralized zones in the central part of the area with copper predominating. Outward from this general center, the ratio of copper to zinc-lead ore decreases progressively, and as of June 1947, in the extreme eastern part of the district (the area east of the Campbell fault) 17 units of zinc and 11 units of lead were produced for every unit of copper (Hogue and Wilson, 1950).

A more detailed picture of the distribution of copper, zinc, and lead would show many separate centers of mineralization; some areas contain only copper ore, others only zinc-lead ore, and others ore of both types. Mixed ores of copper and zinc-lead are uncommon; and, where both types of ore occur in the same sulfide mass, the contact between ore types is generally sharp.

Individual ore bodies and groups of ore bodies within a mineralized area vary greatly in size, shape, and mode of occurrence, and both copper and zinc-lead ores occur as isolated bodies in various structural environments. But in many places either copper ore, zinc-lead ore, or both are found peripheral to and partly enveloping a siliceous-pyritic core. Hogue and Wilson (1950, p. 27) discussing zinc-lead deposits, state: "In this type of deposit, copper and zinc-lead sulfides occur closely associated as massive replacements, with zinc-lead minerals commonly outside of and partly around the copper bodies." Thus, some deposits duplicate, on a smaller scale, the general zoning pattern of the district as a whole. In some places disseminated specular hematite is moderately abundant in the area surrounding the sulfide masses (Schwartz and Park, 1932), and bleached carbonate rock, commonly manganiferous, is characteristic of the peripheral zone surrounding zinc-lead ore bodies (Hogue and Wilson, 1950).

RADIOACTIVITY OF THE COUNTRY ROCK

The general radioactivity of the rocks of the Bisbee district is summarized in table 1. The Pinal schist averages about 0.035 mr/hr (milliroentgens per hour), but in some places reaches as much as 0.045 mr/hr; outcrops are most radioactive where the schist is cut by generally small, but numerous, dikes of rhyolite and rhyolite porphyry, and these apparently account for the increased radioactivity. The Juniper Flats granite (not shown on fig. 2), which forms a northwest-trending elongate stock 1 to 5-1/2 miles northwest of Bisbee, shows a maximum radioactivity of about 0.07 mr/hr. Satellite granite porphyry and rhyolite porphyry dikes are equally radioactive, and a maximum reading of 0.17 mr/hr was obtained at the bottom of a 15-foot prospect shaft sunk in a dike near the west end of the mountains. The radioactivity of the fresh quartz monzonite porphyry is not known; the mineralized and highly altered and leached quartz monzonite and/or granite porphyry of the Sacramento Hill stock shows 0.02 to 0.03 mr/hr.

The Paleozoic limestones are relatively nonradioactive, and readings of 0.015 to 0.025 mr/hr are common. Underground, the radioactivity of unaltered limestone is as little as 0.007 mr/hr.

RADIOACTIVITY OF THE ORES AND DISTRIBUTION OF URANIUM

As noted previously, no anomalous radioactivity is associated with the disseminated copper ore of the Sacramento Hill stock; radioactivity of heads, tails, and concentrate tested inside the mill ranged from 0.015 to 0.025 mr/hr. A grab sample of leach ore from the Lavender Pit in the Sacramento Hill stock contained 0.002 percent equivalent uranium, and samples of both mill feed and the concentrate contained less than 0.001 percent equivalent uranium.

In contrast to the pit ore, the sulfide replacement ores in limestone of the district are quite radioactive. Readings taken at waist height in the center of underground workings with scintillation counters ranged from less than 0.01 mr/hr in unaltered limestone, to more than 1.0 mr/hr in some of the mining areas. This range in radioactivity and the large number of workings in the mining areas provided an excellent opportunity for making isoradioactivity contour maps. Radioactivity readings were taken at 10- or 20-foot intervals in all accessible workings in and adjacent to some of the stoping areas, and the results contoured. The maps showing lines of equal radiation were then compared with the corresponding stope maps to determine the correlation between ore and radioactivity. A composite map showing both the ore bodies and the results of the radioactivity traversing of the 7-stope area, 2433-level, Junction mine, is shown in figure 3, and clearly demonstrates that the limestone replacement ores are radioactive. Maps similar to that shown on figure 3 were made in many parts of the Campbell, Junction, and Cole mines with generally similar results.

Maximum radioactivity was recorded at three localities where mineralized limestone contained unusually high, but local, concentrations of uraninite. Readings of 15 mr/hr were obtained at each locality with a Geiger counter held directly on the ore. Two of these high-grade spots were in altered limestone containing zinc-lead sulfide ore; the third was in copper sulfide ore.

Equivalent uranium content of composite samples from 27 stopes and workings driven in copper sulfide ore bodies ranged from 0.002 percent to 0.014 percent and averaged about 0.005 percent; the equivalent uranium is greater than that of the pit ore which is less than 0.001 percent. The composite samples showed variations in content of gold, silver, lead, and zinc and are summarized as follows: gold, 0.02 - 0.20 ounces; silver, 0.4 - 12.74 ounces; lead, 0.01 - 0.74 percent; and zinc, 0.43 - 2.66 percent. Attempts to show a relation between copper, the various elements listed above, or groups of elements and equivalent uranium gave negative results.

Although the rather small variations in lead and zinc content of the copper ores failed to show any relation to uranium content, there is some reason for believing that there is a correlation of uranium with lead and zinc. The equivalent uranium oxide content of three mill-head samples taken from the lead-zinc mill in 1948 and 1949 is shown in table 2. The unweighted average of the equivalent uranium of the lead-zinc is 0.007 percent. This is about 50 percent more than the average equivalent uranium content of 27 copper-stope composite samples.

Table 2--Equivalent uranium oxide content of/ composite samples of lead-zinc mill heads./

Period	eU_3O_8
Year 1948	0.008
July 1949	0.01
August 1949	0.009

/ Bain (1949).

The manganese oxides samples at various localities throughout the district give readings of 0.025 to 0.22 mr/hr. Analyzed specimens contained from 0.001 to 0.016 percent equivalent uranium. In contrast to the uraninite in the sulfide ores, the uranium in the manganese probably does not form its own minerals. The writer believes the uranium is probably occluded by the manganese oxides during weathering of the original manganese carbonate or sulfide material, and that variations in equivalent content of the wad reflect similar variations in the uranium content of the unoxidized material. Semiquantitative spectrographic analyses of four samples suggest that the uranium content of the wad is lowest in areas that, so far as is known, contain no important copper-lead-zinc ores, and suggest a positive correlation of uranium and manganese. Because of the small number of samples, however, this correlation is considered highly tentative.

MINERALOGY AND PARAGENESIS

The material in this section of the report deals entirely with the mineralogy and paragenesis of three samples of relatively fresh sulfide ore that contain local concentrations of uranium oxides.

In each of these three samples, the uranium mineral uraninite, has a different form and is in a different paragenetic relationship with the associated sulfides; in one sample the uraninite is euhedral and early, in another it is colloform and intermediate in age, and in the third it is finely disseminated and late in the paragenetic sequence. The reader is referred to Ransome (1904), Schwartz and Park (1932), and Hewett and Rove (1930) for detailed descriptions of the mineralogy of the Bisbee ores.

Specimen 5-B-54 (fig. 4a) is copper ore from the 1300-level, Cole mine in the 97 crosscut opposite the intersection with the 117 crosscut. The gangue minerals, in order of sequence, are fine-grained quartz followed by moderate amounts of sericite; no residual carbonate was observed. Uraninite, identified by X-ray, is the earliest metallic mineral. It occurs as isolated euhedral crystals, generally hexagonal to circular in outline, and in groups of crystals; individual crystals average about 0.05 mm in diameter. The almost universal six-sided to circular outline of the uraninite crystals suggest the dominant form is dodecahedral. The alpha-track pattern of the uraninite shown in figure 4a is reproduced in figure 4b. The scattered tracks in the light parts of the field indicate minute amounts of uranium present in the sulfides and gangue; this may represent original distribution of the uranium by supergene waters.

The uraninite was followed by pyrite, chalcopyrite, and minor amounts of bornite, sphalerite and covellite; pyrite is the principal sulfide.

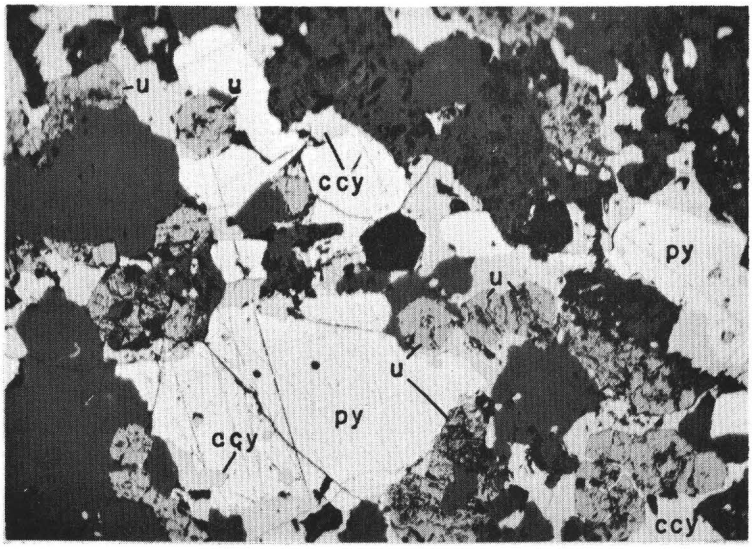

Figure 4a. Photomicrograph of copper ore from 1300-level, Cole mine; specimen 5-B-54. U, uraninite; py, pyrite; ccy, chalcopyrite; dark gray, gangue; black pentagon in center of field is pit in surface where crystal of uraninite was torn out. Plane-polarized light. X 128.

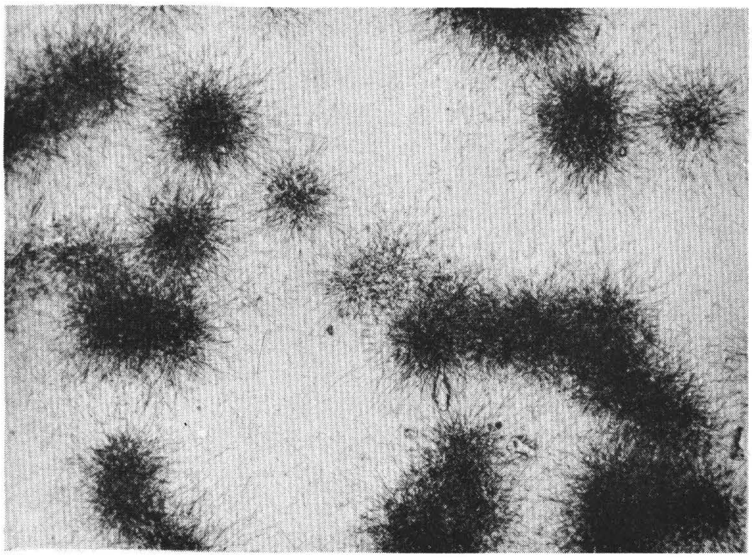

Figure 4b. Photomicrograph of nuclear emulsion film covering approximately same field as figure 4a. Scattered tracks in light parts of field indicate that trace amounts of radioactive material are present in the sulfide and gangue minerals.

Specimen 9i-B-54 is a silicified and argillized, brecciated limestone containing sparse sulfides of copper, lead and zinc. The specimen was taken from the margin of a lead-zinc stope, 2700-level, Campbell mine, at the intersection of the 96 crosscut and the 38 crosscut. This is approximately 10,000 feet N. 75° E., and 1,500 feet below sample location 5-B-54. The specimen from the 2700-level, Campbell mine, records a complex history of mineralization and fracturing (fig. 5a and 5b); the sequence is outlined below:

1. Complete replacement of the limestone by clay minerals and fine-grained quartz.
2. Development of pyrite as small cubes; minor sphalerite and galena.
3. Brecciation.
4. Deposition of bands of colloform pitchblende or uraninite on the surface of the breccia fragments.
5. Partial filling of the voids by carbonate.
6. Deposition of chalcopyrite, sphalerite (with exsolution chalcopyrite) and galena on the carbonate.
7. Complete cementation of the breccia by carbonate.
8. Fracturing, and open filling of the fractures with euhedral to subhedral quartz, garnet, and minor chalcopyrite, sphalerite, and galena.

Only the first seven stages are illustrated in figures 5a and 5b.

Specimen 24-B-54 is mineralized limestone containing lead, zinc, and copper sulfides from the 2100-level, Campbell mine, at the intersection of the 247 crosscut and the 257 crosscut. This location is 1,400 feet N. 35° E., and 600 feet above the locality of the specimen just described.

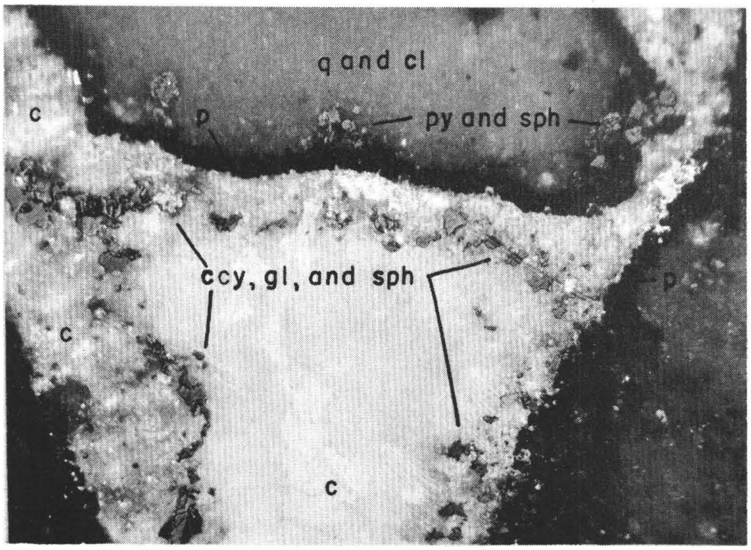

Figure 5a. Photomicrograph of altered, mineralized, and brecciated limestone from 2700-level, Campbell mine; specimen 9i-B-54. Large light-gray areas are breccia fragments composed of fine-grained quartz (q) and clay minerals (cl); dark bands coating fragments are colloform pitchblende (p); fragments cemented by carbonate (c), pyrite (py), chalcopyrite (ccy), sphalerite (sph), galena (gl). Crossed nicols. X 44.

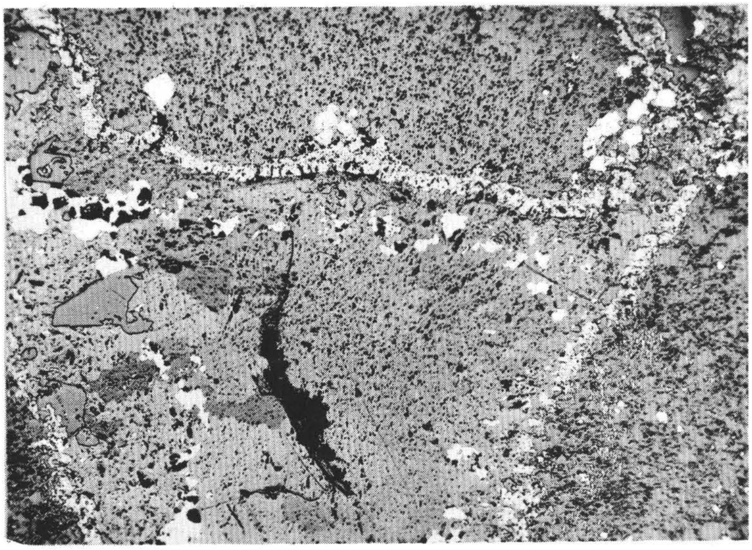

Figure 5b. Same as figure 5a, but in plane-polarized light.

Euhedral to subhedral secondary quartz grains that average about 1 mm in size constitute the bulk of the gangue; residual carbonate and clay minerals are sparingly present. The earliest sulfides are bornite (with exsolution chalcopyrite) and minor sphalerite. The predominant metallic mineral--galena--replaces the earlier sulfides. The youngest mineral is sooty pitchblende, which replaces bornite, sphalerite, galena and minor covellite. The pitchblende occurs as small disseminated grains that average about 3 microns in diameter, and as clumps and irregular chain-like stringers made up of aggregates of these grains (fig. 6). At moderate magnification, some of the pitchblende is seen as groups of roughly concentric bands, suggestive of diffusion banding.

In contrast to the hypogene uraninite and pitchblende in the first two specimens described, the textures of the pitchblende in the third specimen and the fact that the pitchblende replaces the covellite indicate that it is supergene.

REDISTRIBUTION OF URANIUM BY MINING, MILLING, AND SMELTING OF COPPER ORE

No lead-zinc ore was being mined in the Bisbee district at the time this study was made. The material in this section of the report, therefore, applies only to the redistribution of uranium from the copper ores as diagrammed in figure 7.

Most of the replacement ore is direct shipping, but some of that produced from the Abrigo limestone is sufficiently aluminous to be quite refractory, and it is treated in the concentrator. About 97 percent of the mill feed, however, is the realtively low-grade disseminated ore

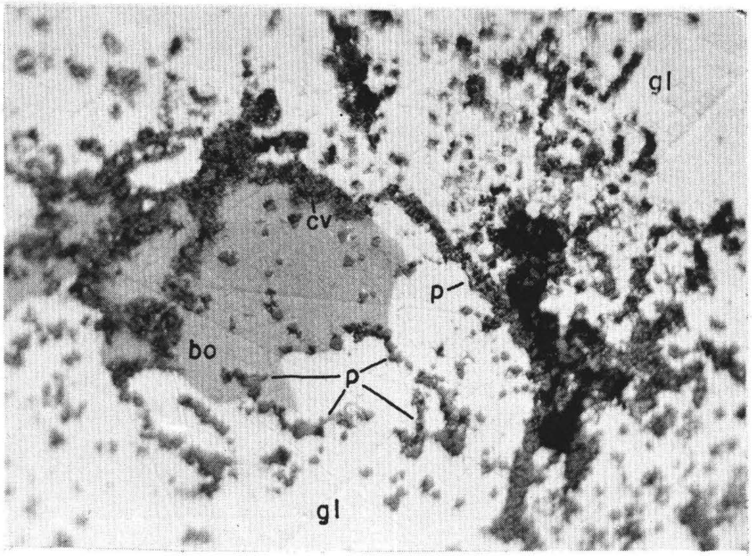

Figure 6. Photomicrograph of mineralized limestone. Specimen 24-B-54 from 2100-level, Campbell mine. Sooty pitchblende (p) replacing bornite (bo), galena (gl), and covellite (cv). Plane-polarized light. X 680.

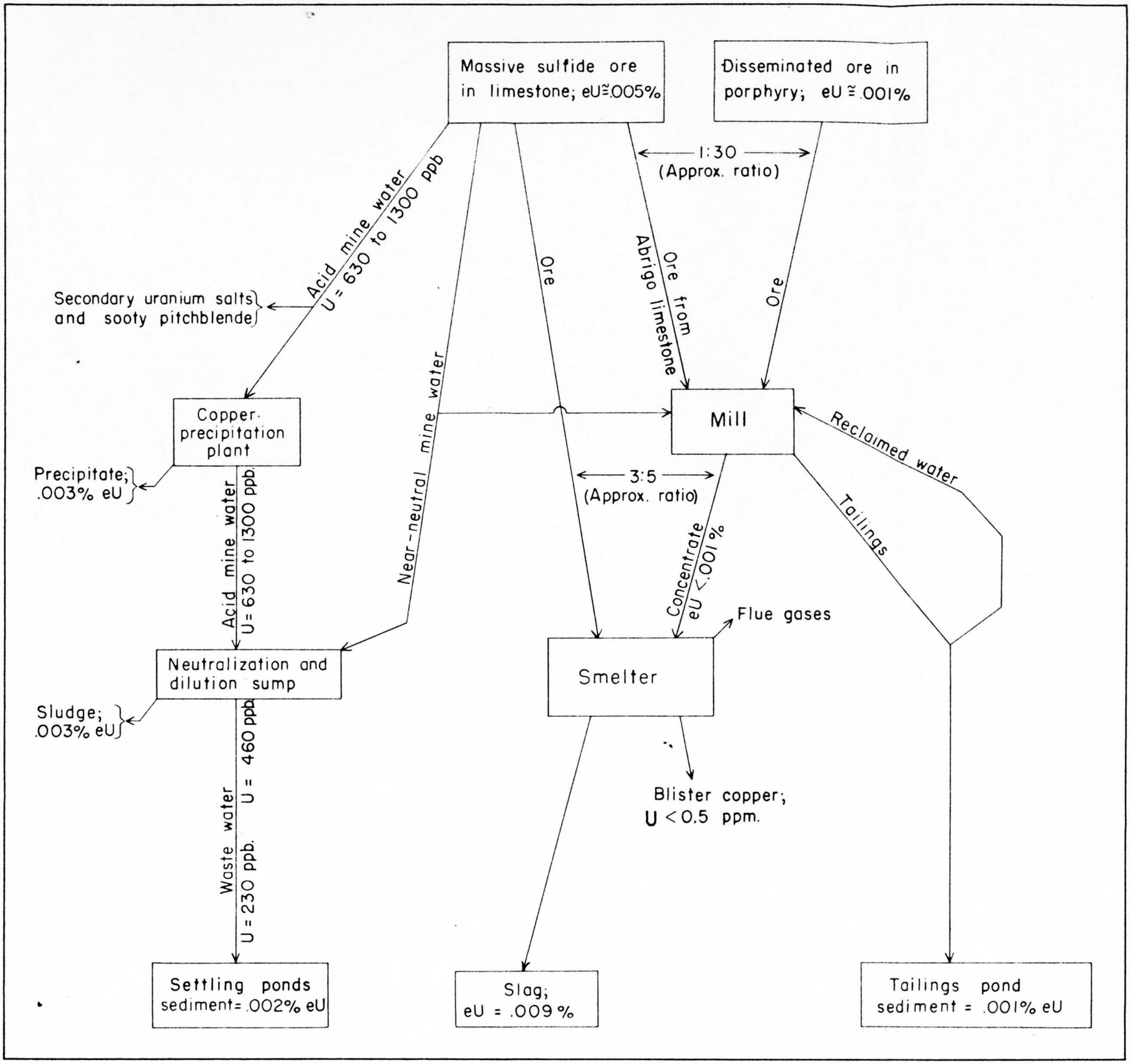

FIGURE 7.-SCHEMATIC FLOW SHEET SHOWING REDISTRIBUTION OF URANIUM BY THE MINING, MILLING, AND SMELTING OF COPPER ORE

from the Lavender Pit. Concentrate from the mill is shipped to the smelter at Douglas some 25 miles to the east, and bedded with the direct-shipping ore and silica flux. Because of the large proportion of low uranium content in copper concentrate, the material now being treated at the smelter probably does not average more than 0.003 percent equivalent uranium. The blister copper produced contains less than 0.5 ppm (parts per million) of uranium, and the flue gases, although not sampled, probably contain only trace amounts; there is nothing in the charge that would produce volatile uranium compounds. Thus, most of the uranium in the ore is retained in the slag. The extraction of the copper and the loss of sulfur and other volatile constituents during the roasting and smelting of the ore probably results in about a one-third-loss of weight of the original material. The slag is thus enriched in uranium by residual concentration.

A grab sample and a composite sample of the slag collected from different parts of the dump contained 0.008 and 0.009 percent equivalent uranium, respectively/. In view of the very large tonnage of slag and the potential source of sulfuric acid at the smelter, several tests were made to determine the possibility of extracting uranium from the slag by acid leaching. These tests, made by the U. S. Geological Survey, were preliminary and were not intended to take the place of bulk sample tests customarily made by the U. S. Bureau of Mines. The slag is a basic iron, calcium, magnesium glass, and the tests show that extraction of uranium

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/ The slag now being produced, probably contains somewhat less than this because of the relatively large percentage of low uranium concentrate from the mill.

from the slag by acid leaching is impractical. Even when ground to minus 80 mesh and treated with 1:4 sulfuric acid in a steam bath for 15 hours, the slag retains more than 50 percent of the uranium; a large part of the uranium removed was contained, not in the acid filtrate, but in a silica gel formed by reaction of the acid with the basic slag. Thus, most of the uranium in the ores of the Bisbee district eventually is tied up in the slag and cannot be recovered economically.

The abundance of secondary uranium minerals on the walls of the mine workings in the stoping areas indicated that appreciable amounts of uranium were being leached and carried by ground water, and that some of it was being deposited in sites favorable for precipitation. To determine how much uranium was being discharged in mine water (ground water and drilling water) samples were collected at various points in the mine drainage system and analyzed for uranium. The least uraniferous underground water sampled contained 10 ppb (parts per billion) of uranium and had a pH of 7. This compares with a threshold of anomaly of about 4 ppb of uranium for surface waters on the Colorado Plateau and about 5 ppb for corresponding ground waters (Fix, 1955). Acid mine waters sampled at Bisbee contained much higher concentrations of uraniun than the neutral and near-neutral waters. Some of the mine waters, made acid by passing through the sulfide ores, had a pH of less than 2, and one sample contained 5,300 ppb of uranium.

A large part of the acid water in the mines at Bisbee is directed into a single drainage ditch and then through a copper precipitation plant. This water contained from 630 to 1,300 ppb of uranium. The two values were obtained from different samples taken about three months apart. Because of seasonal rains the flow of water was much greater when the first sample was taken, and apparently the greater the flow through the system that produces this acid water, the lower the concentration of uranium. The extraction of the copper does not affect the uranium content of the water and almost all of the uranium passes through the precipitation plant. The water discharged from the precipitation plant drops to a dilution and neutralization sump and is then pumped to settling ponds. During these processes the concentration of uranium is reduced, as shown in figure 7.

In the Bisbee district, an estimated 6 percent of the total uranium removed by underground operations is carried off in acid mine water, but at the present time and under existing conditions this is not considered sufficient to be of economic interest. However, the study of acid waters at Bisbee, and at localities in New Mexico and Colorado show that water passing through sulfide-bearing material that contains only very small concentrations of uranium may carry relatively large amounts of uranium.

Although the acid mine waters at Bisbee are among the most highly uraniferous natural waters known in the United States, waters as acid as these probably can contain many many times the maximum ppb of uranium found at Bisbee. These facts suggest that there may be localities where flow and concentration are sufficient to permit the profitable extraction of uranium from acid waters--particularly as a byproduct of leaching operations.

CONCLUSIONS

There are many separate centers or source areas of mineralization in the Bisbee district, and district-wide mineral zoning is poorly developed. In general, however, lead-zinc deposits are more abundant in the peripheral parts of the mineralized area; that is, those parts of the district farthest from the Sacramento Hill stock. Some composite ore bodies locally duplicate the district zoning.

The total amount of uranium deposited with the copper and lead-zinc sulfide ores of the Bisbee district is large, but the concentration of uranium in the ores is low. The lead-zinc replacement ores are more uraniferous than the copper replacement ores, and these in turn contain a higher percentage of uranium than the low-grade disseminated copper ores of the Sacramento Hill stock; much of the uranium originally present in the pit ore has undoubtedly been leached by acid supergene waters. Material containing more than ten percent uranium as primary uranium oxides is associated with both copper and lead-zinc sulfides, but known concentrations of ore-grade uranium material are not of economic interest because of their small size.

Although no uranium ores are known in the district, the radioactivity of the limestone replacement bodies might prove a useful prospecting guide to base-metal ores in the district. The equivalent uranium content of manganese oxides sampled in various parts of the district, suggest that there is less equivalent uranium in the wad in areas that, so far as is known, exhibit only very weak copper, lead, and zinc mineralization.

Most of the uranium in the copper ores being taken from the mines remains in the slag; some uranium is leached from the ore in place by acid water and is discharged in the mine drainage. The uranium content of these waters suggests that there may be localities where concentration and flow are sufficient to encourage attempts to extract uranium from solution.

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