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URANIFEROUS MAGNETITE-HEMATITE DEPOSIT AT THE PRINCE MINE, LINCOLN COUNTY, NEW MEXICO*

By

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By George W. Walker and Frank W. Osterwald

ABSTRACT

A pyrometasomatic magnetite-hematite deposit in Permian sedimentary rocks near the margin of the Lone Mountain stock in Lincoln County, New Mexico, contains between 0.015 percent and 0.031 percent uranium. The deposit is composed mainly of magnetite with lesser amounts of hematite, hydrated iron oxides, pyrite, leuchtenbergite(?), gypsum, chalcopyrite, metatorbernite, torbernite(?), covellite, sphalerite(?), quartz, marcasite, and an unidentified uranium-bearing mineral; it is surrounded by an aureole of recrystallized limestone, gypsum, epidote, and actinolite with lesser amounts of specularite, phlogopite, fluorite, pyrite, and chalcopyrite. Autoradiographs and polished section studies suggest that most of the uranium is dispersed in the iron oxide minerals. The association of iron and uranium may be related to the melting points of the elements. The deposit probably formed at a rather low temperature by self-oxidation of a ferrous hydroxide hydrosol contained in a mildly alkaline solution.

INTRODUCTION

This paper briefly presents some data concerning an association of uranium with magnetite and hematite in a pyrometasomatic deposit in Lincoln Co., N. Mex., and briefly discusses some aspects of the genesis and the distribution of uranium in the deposit. The data were obtained through a brief examination of the deposit in February 1954, and though subsequent laboratory studies of a few representative samples collected during the examination. This report concerns work done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

The deposit, known at various times as the Carolyn O, House mine, Las Cinco Reinas, and more recently as the Prince mine, is in sec. 14, T. 6 S., R. 11 E., White Oaks district, and is about 11.5 miles N. 30° E. of Carrizozo, N. Mex. (fig. 1). It is on the north side of Lone Mountain at an altitude estimated at about 6,700 feet. The magnetite-hematite body occurs in a sequence of sedimentary rocks probably of Permian age and is assumed to be genetically related to the Lone Mountain monzonite stock. Uranium is present in the deposit in two distinct forms: 1) metatorbernite, and possibly some torbernite, as fracture coatings and pore space fillings, and 2) a finely divided, unidentified uranium-bearing mineral dispersed through magnetite and locally in primary crystalline hematite.

Minor quantities of ore containing approximately 60 percent iron (Sheridan, 1947) have been extracted from open pits; a 200-foot adit, driven on a south bearing, tested part of the ore horizon at depth. Under economic conditions existing in 1955 neither iron nor uranium is present on the property in commercially significant quantities.

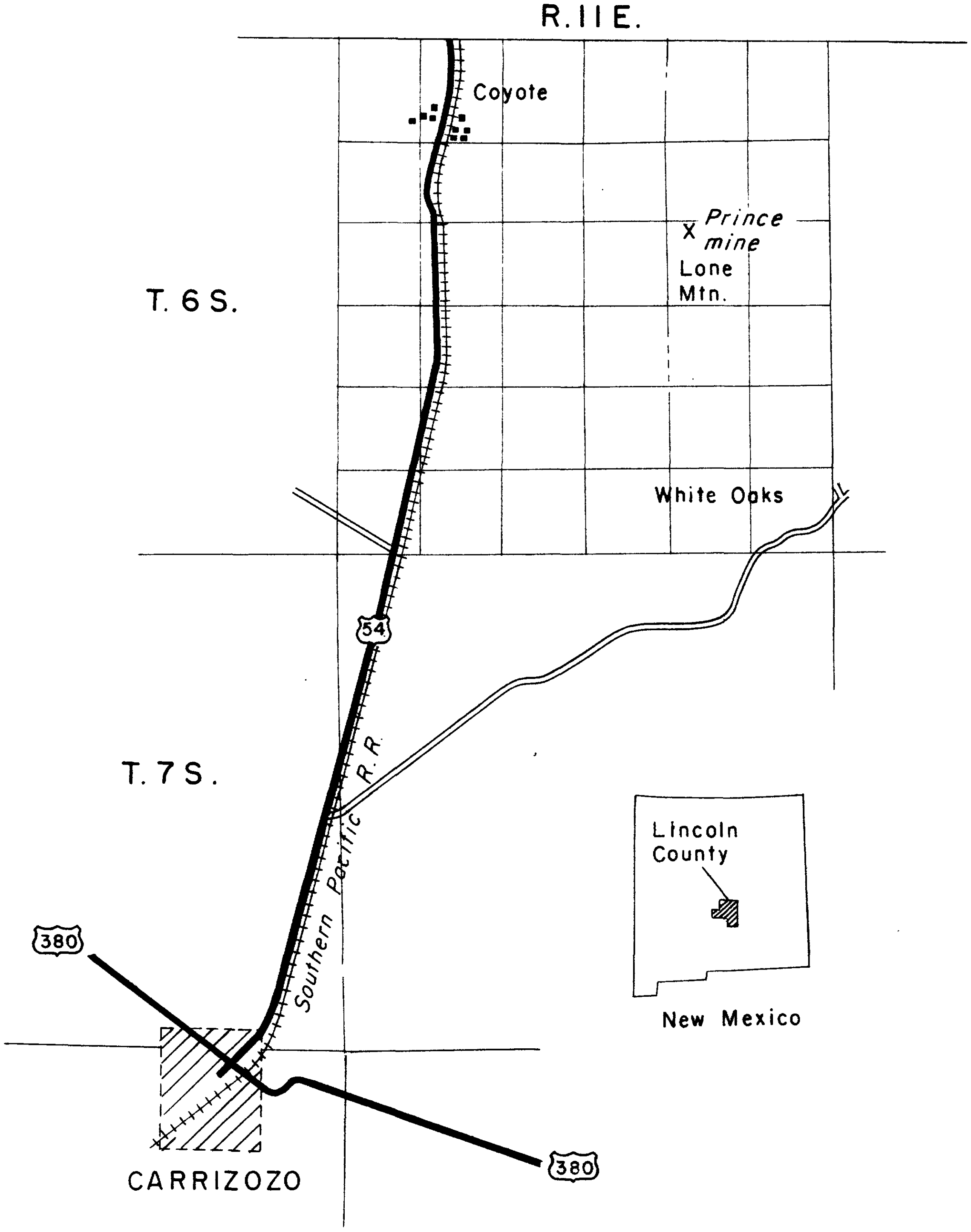

FIGURE 1-INDEX MAP SHOWING LOCATION OF PRINCE MINE LINCOLN COUNTY, NEW MEXICO.

GEOLOGIC SETTING

The Prince deposit is in a series of bedded sedimentary rocks composed of alternating gypsum, shaly limestone, quartzitic sandstone, and shale which, according to Kelley (1949, p. 157), are part of the Yeso formation of Permian age. The deposit is near the periphery of the Lone Mountain monzonite stock of Laramide age.

The sedimentary rocks, which commonly are buff, are bleached to light buff or white near the ore body, and are characterized by beds ranging from an inch to about 2 feet in thickness. Adjacent to the deposit the beds are steeply dipping and locally highly contorted; the deposit apparently is conformable to the bedding.

The Lone Mountain monzonite stock crops out less than 100 feet south of the Prince deposit. The stock and several other nearby hypabyssal intrusives in Lincoln County were emplaced during the Laramide Revolution of Late Cretaceous or early Tertiary time. Adjacent to the contact with the Yeso formation, the monzonite is a pinkish-gray, to medium- to fine-grained rock that locally is porphyritic. A thin section of the monzonite is composed of orthoclase (about 60 percent), sodic andesine (about 30 percent), hornblende, sphene, magnetite, and minor amounts of quartz, apatite, biotite, nontronite(?), and clinozoisite(?). Some of the plagioclase shows a normal, continuous zonation with rims of sodic oligoclase; many of the plagioclase and orthoclase crystals have thick overgrowths of cloudy orthoclase. Most of the hornblende crystals are ragged, highly corroded, and poikilitic and contain grains of sphene and magnetite. Sparse biotite is similarly corroded. Texturally, in thin section, the rock is dominantly hypidiomorphic-granular although protoclastic and cataclastic textures are discernable. Addording to some rock classifications this intrusive rock would be named a syenite rather than a monzonite as the alkali feldspar predominates over the calc-alkalic feldspar at a ratio of approximately 2:1 and quartz is present only in very minor amounts.

An aureole of bleached and altered material adjacent to the deposit, locally as much as 6 feet thick, is composed of recrystallized limestone, gypsum, and an assemblage of lime-silicate minerals of which the most abundant are epidote and actinolite. Also present in the aureole are minor amounts of specular hematite, phlogopite, fluorite, pyrite, and chalcopyrite. The fluorite and the sulfide minerals occur principally as ill-defined veinlets and as disseminations in the rocks of the aureole.

URANIFEROUS MAGNETITE-HEMATITE DEPOSIT

The uraniferous magnetite-hematite deposit at the Prince mine is tabular, parallel to the bedding, and is exposed in a series of pits for a strike length of nearly 100 feet; the maximum width is about 6 feet. The wall rocks adjacent to the magnetite-hematite mass show local but strong fracturing. Later and more widespread faulting has fractured the magnetite-hematite body which apparently replaced a limestone bed or lens, in a section composed largely of gypsum.

Finely granular but massive magnetite is the dominant constituent of the deposit. Present in lesser quantities are massive hematite, specular hematite, hydrated iron oxides, pyrite, a chlorite-like mineral (estimated $2V = 18^\circ$; $\beta = 1.58 \pm .05$; $n_\alpha - n_\gamma = 0.014 \pm$, which is suggestive of leuchtenbergite), gypsum, minor chalcopyrite, sparsely distributed crystals of metatorbernite (and possibly some torbernite) on fracture surfaces, covellite, an unidentified uranium-bearing mineral, sphalerite(?), quartz, marcasite, and one observed grain of questionably identified galena. Disseminated grains of pyrite and minor chalcopyrite in the iron ore commonly form a megascopically distinct reticulate pattern. Semiquantitative spectrographic analyses (table 1) of three samples of the magnetite-hematite body indicate that, in addition to iron, the only other metallic element present in amounts exceeding a fraction of a percent is magnesium, probably largely in the chlorite-like mineral but possibly in magnesite or substituting for Fe^{++} in the magnetite. Radioactive and chemical analyses for uranium of these samples gave, respectively, 0.023, 0.016, 0.044 percent equivalent uranium and 0.015, 0.012, 0.031 percent uranium.

A few veinlets of calcite, quartz, hematite, and an unidentified white chalcedonic material, suggestive of highly siliceous magnesite, cut both the wall rocks and the magnetite-hematite body.

Brief study of a few polished sections and autoradiographs of specimens of the iron ore suggests that the iron oxide minerals and the sulfide minerals were deposited separately and that the primary uranium was deposited only with the magnetite and hematite. In polished section, primary crystalline hematite is intergrown with magnetite and, less commonly, occurs as microscopic veinlets on interfaces between crystals of magnetite. Pyrite crystals occur as nearly equidimensional subhedra, as extremely irregular and embayed grains that commonly contain inclusions of magnetite, hematite, or other minerals, and as crushed crystals with some fractures filled with magnetite and hematite (fig. 2). Most of these fractures are confined to pyrite crystals and only a few extend into the bounding magnetite. The chalcopyrite in the iron deposit is present largely as inclusions in pyrite; a few irregular covellite grains are bounded by thin rims of sphalerite(?) which, in turn, is bounded either by magnetite or hematite or both. The uranium, exclusive of that in secondary uranium-bearing minerals which coat fractures and fill pore spaces, is in minute, unidentified

Table 1.--Semiquantitative spectrographic analyses of samples from the Prince mine, Lincoln Co., N. Mex. [1]

Sample[2]	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K
1	.X+	.X+	XX.	.0X-	.X-	.X	X.-	.0X	.X+
2	.X	.X	XX.	.0X-	.X-	.X+	X.-	.0X+	.X+
3	.X	.X	XX.	.0X-	.X	.X-	X.-	Tr	0

Sample	V	Ba	Be	Zn	Zr	Ce	Co	Cr	Cu
1	.00X+	.00X-	.000X-	.0X	.00X-	.X	.00X-	.00X	.0X-
2	.00X	.00X-	.000X-	.0X	Tr	.X	.00X-	.00X	.0X-
3	.00X	.000X	.000X	.0X	.00X-	.0X	.00X+	.00X	.0X-

Sample	Ga	La	Mo	Nb	Nd	Ni	Pb	Sc	Sr
1	.00X-	.X-	.00X	.00X	.0X+	.00X	Tr	.00X	.00X+
2	.00X-	.X-	.00X-	.00X	.0X+	.00X	.00X	.00X	.00X+
3	.00X-	.0X	.00X-	.00X	.0X-	.00X-	.00X	0	.00X-

Sample	Y
1	.0X-
2	.0X-
3	.00X+

Looked for but not detected: P, Ag, As, Au, B, Bi, Cd, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Os, Pd, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Th, Tl, Te, U and W.

0 = Looked for but not detected
Tr = Near threshold amount of element

[1] Analyst: R. G. Havens, U. S. Geological Survey

[2] Sample 1 - Continuous chip sample across width of magnetite-hematite body.

Sample 2 - Radioactive magnetite and hematite containing relatively abundant sulfide minerals.

Sample 3 - Magnetite-hematite specimen with metatorbernite on joint surfaces.

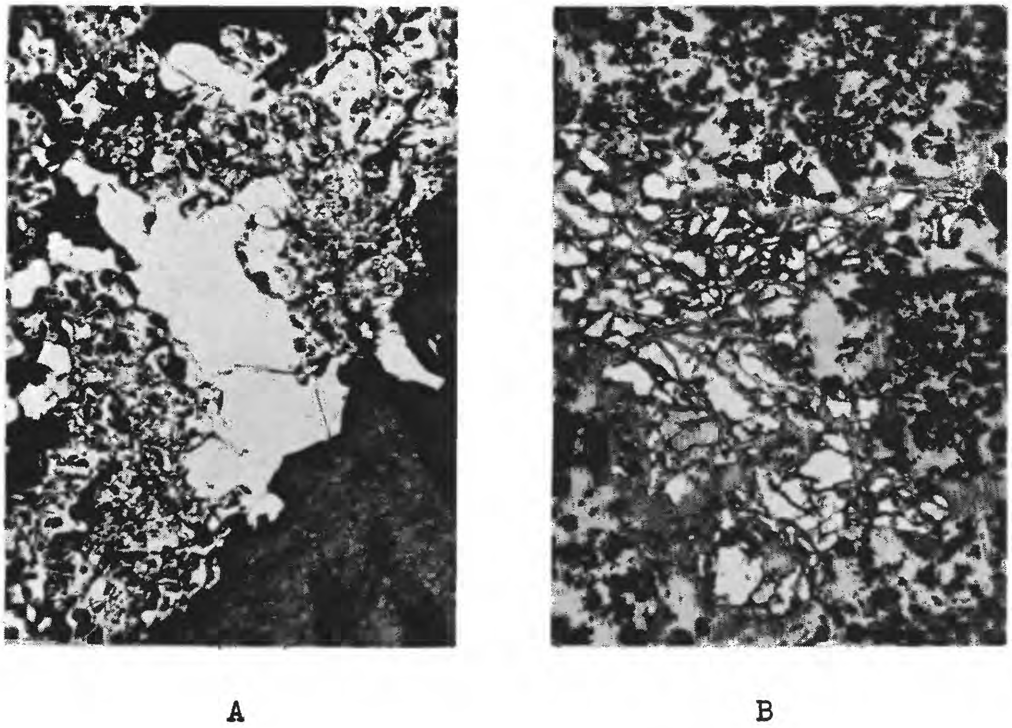

Figure 2. Polished sections of two iron ore specimens from Prince mine, Lincoln County, N. Mex.

A. Pyrite (white) embayed and replaced by magnetite and hematite. 41X

B. Fractures in pyrite (white) filled with magnetite and hematite. 94X particles rather uniformly distributed in the magnetite and, locally, in the crystalline hematite; autoradiographs show that the uranium-bearing mineral is absent in the sulfide minerals and is sparse where the magnetite is in contact with sulfide crystals (fig. 3). Some thin veinlets of supergene hematite and limonite cut most of the constituent minerals of the iron ore.

Although pyrite and minor chalcopyrite are locally distributed in the iron ore in a megascopically reticulate pattern suggesting localization in pre-existing structures in the magnetite-hematite body, study of polished sections indicates that some sulfide mineral grains are extensively replaced by magnetite and hematite, some contain inclusions of magnetite, and others are highly fractured whereas the magnetite is not. Conceivably the magnetite and sulfide minerals could be essentially contemperaneous; however, it is thought that there were two distinct periods of sulfide mineralization separated by an intervening period of iron oxide mineralization in which only sparse sulfides were deposited because of the distinctly different types of pyrite crystals. The distribution of the unidentified, uranium-bearing mineral indicates that it was deposited with the magnetite and hematite, and accordingly it is inferred that it is genetically related to the same pyrometasomatic activity that introduced the magnetite.

The sulfide minerals and fluorite in the aureole adjacent to the ore body are not appreciably radioactive although the fluorite is the deep purple variety commonly associated with uranium in other deposits.

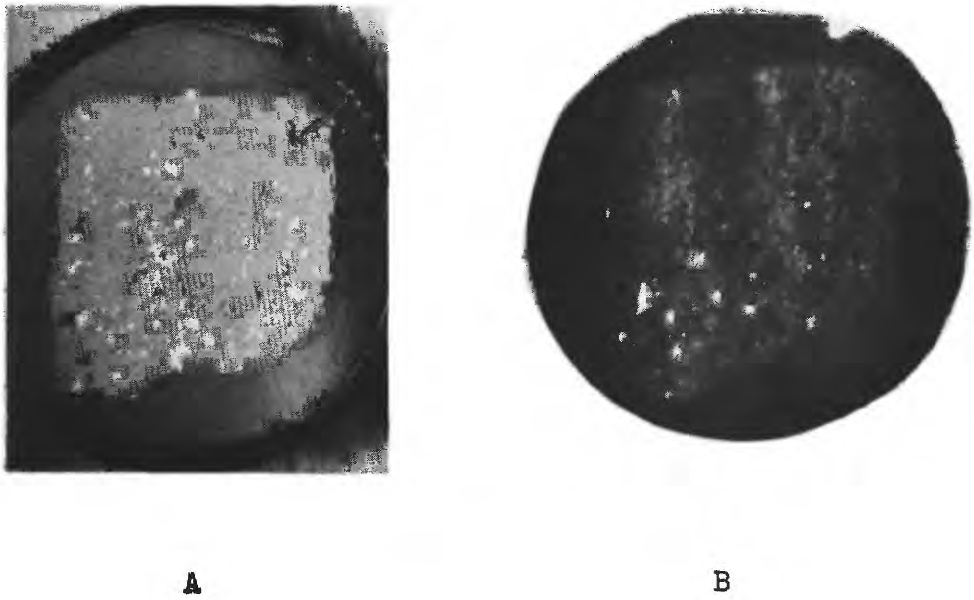

Figure 3. Polished section and autoradiograph of iron ore specimen from Prince mine, Lincoln County, N. Mex.

A. Polished section of magnetite-hematite ore with layers containing pyrite (white). Diameter of polished section mount is 1.24 inches.

B. Autoradiograph of same polished section showing distribution of uranium-bearing materials. Large white spots show location of metatorbernite and torbernite(?) crystals.

ORIGIN OF DEPOSIT

The uraniferous magnatite-hematite deposit at the Prince mine is interpreted to have formed pyrometasomatically as a replacement of sedimentary rocks adjacent to a monzonite pluton. Uranium was introduced during the oxide phase of mineralization but not during the sulfide phase.

Although all the genetic implications of this iron-uranium association are not clearly understood, these elements probably were mobilized and concentrated through energy derived from a magma now represented by the monzonite. Sullivan (1954) has suggested that similarity of melting points of elements may have a considerable significance in metallic associations in ore deposits. Because the melting points of iron and uranium are relatively close (respectively 1535° C. and 1150°C; Sullivan, 1954 table 1), the iron and uranium at the Prince mine originally may have been mobilized and concentrated more or less simultaneously. Conceivably both elements were primary constituents of the monzonite magma and were extracted at about the same time from the crystallizing melt. On the other hand, they may have been extracted from the invaded rocks, either through assimilation of wall rock or diffusion of these substances into the magma, possibly concentrated, and deposited in their present environment. Present surface exposures of the monzonite are not abnormally radioactive, although the monzonite may contain trace amounts of uranium in the relatively abundant accessory magnetite. Other uranium-bearing minerals were not observed in thin section.

Although finite temperature and pressure conditions cannot be established for the mineralizing process that introduced iron and uranium, the temperature is thought to be relatively low because:
(1) The contact-metamorphic aureole enclosing the ore body is relatively thin and (2) the aureole is composed, in part, of relatively low temperature rather than high temperature contact metamorphic minerals such as garnet and pyroxene. The physical and mineralogic character of the aureole may be more largely dependent, however, on the composition and volume of the silicating solution, the permeability of the country rock, and the relative pressure gradient at time of mineralization rather than temperature; the paucity of quartz suggests that these solutions may have contained only moderate amounts of silica. The epidote mineral in the aureole may serve as a rough indicator of the temperature at which the aureole formed. Epidote probably forms between 300° and 500° C. (Harpum, 1954, p. 1088), and the Prince ore body probably was formed within or only slightly above that range. The sulfide minerals and fluorite in the aureole, as well as some of the pyrite and chalcopyrite in the deposit, were introduced by lower temperature hydrothermal solutions which followed the higher temperature pyrometasomatism.

The field evidence suggests that the iron deposit may be a rather clear example of a process outlined by Shand (1947a) for the origin of certain magnetites and related ores. Many magnetite deposits have been ascribed to residual solutions rich in iron (Bateman, 1951, p. 410-412), but Shand (1947b, p. 191-192) believes that many such residual solutions are alkaline and do not contain dissolved iron. Such solutions from crystallizing magmas are postulated to be relatively enriched in soda and potash and, hence, have an alkaline reaction. The intrusive rocks near the Prince mine are rich in feldspar and, hence, were probably formed from a mildly alkaline magma; residual solutions were probably also alkaline. Shand (1947a) believes the solutions contain a hydrosol of ferrous hydroxide, kept in suspension by the alkalies. His belief is supported by the fact that ferrous hydroxide is insoluble in alkaline solutions (Hodgman, 1947, p. 428). With the extraction of the alkalines in the solution, the hydrosol undergoes self-oxidation, forming magnetite, water, and free hydrogen, according to the following equation:

$$3Fe(OH)_2 = Fe_3O_4 + 2H_2O + H_2\uparrow$$

The process has been observed in the corrosion of iron boilers (Shand, 1947a), and one of the authors has observed black magnetic powder, possibly magnetite, formed in marine engine boilers operated at about 300° to 400° C., at 215 pounds pressure per square inch.

The coagulation of such a hydrosol would be aided by $MgSo_4$ or $K_2Cr_2O_7$ as electrolytes in the solution (MacDougall, 1947, p. 685). Table 1 shows that the ore has an appreciable amount of Mg and a little Cr; the sulfate ion could have been extracted from the gypsum in the Yeso formation and potash could have been available from the residual magmatic solution.

This hypothesis of origin provides a good answer for two questions raised by Bateman (1951, p. 404 and 426) about the formation of late magmatic oxide ores: (1) "If concentrations of heavy ferromagnesian silicates are formed in the lower portions of intrusives then why not also similar concentrations of iron and titanium oxides?", and (2) "...why such difficultly meltable substances as magnetite and ilmenite should remain in the residuum of a basic magma and how can they remain molten to permit injection?".

The process of uranium deposition may be similar to that postulated for deposits near Schmiedeberg in the Riesengebirge by Berg (1936) and Meister (1926). Magnetite deposits in a skarn zone were affected by late stage solutions from a granitic magma which deposited copper, lead, zinc, and silver sulfides, oxidized magnetite to hematite, and deposited pitchblende around pieces of hematitized magnetite. Botryoidal pitchblende is partially replaced by sulfides. In the Schmiedeberg deposits, the Prince mine, and probably elsewhere, uranium is closely associated with iron oxide and not with sulfide minerals. As uranium at the Prince mine principally is associated only with magnetite and hematite, it is inferred that it was fixed during the oxide phase of mineralization rather than the sulfide phase; primary uranium is conspicuously absent in all of the sulfide minerals and is not associated with them, though some secondary crystals of metatorbernite do occur in open spaces in fractured pyrite.

The physico-chemical factors involved in the fixing of uranium in this type of environment are not clearly understood, although it is apparent that the iron and the uranium were introduced at essentially the same time. Probably some, and perhaps all, of the primary uranium occurs as an impurity in the interstices of the magnetite lattice; it seems likely that the cerium, lanthanum (table 1), and possibly other elements, are similarly trapped in the magnetite lattice. The uranium and rare earths also may occur as a rare earths-uranium mineral perhaps comparable to davidite. The even distribution of the uranium in the iron oxide may be the result of coprecipitation during the coagulation of the hydrosol. Most uranium compounds are slightly more soluble than the corresponding iron compounds and, according to Pierce and Haenisch (1940, p. 312), this should aid the coprecipitation of uranium with an iron hydrosol. The coagulation must have taken place at a relatively low temperature, or the iron hydroxide would have been purified, and uranium expelled. Higher temperature causes coprecipitated ions to be released and is commonly used in laboratories to purify precipitates. The association of uranium with the iron oxide phase in the ore and not with the sulfide phase may be caused by the differences in the sols of the two phases. According to MacDougall (1947, p. 686), metals and metallic sulfides form negatively charged sols in systems with water as the dispersion medium, whereas the sols of metallic hydroxides are positively charged. It may be that uranium was in the form of positively charged particles, which were coprecipitated with the oxides and not with the related sulfides in the Prince mine ore.

The exact manner in which the uranium is contained in the iron oxide minerals at the Prince mine is not known. It is unlikely that magnetite contains actual segments of the uraninite lattice, because uraninite has a face-centered cubic lattice (Palache, Berman, and Frondel, 1944, p. 611), whereas magnetite has an octahedral-tetrahedral type of structure (Bragg, 1937, p. 98-101). However, the spinal (magnetite) lattice can accomodate many different ions (Bragg, 1937, p. 98), and uranium, in six-fold coordination, could probably substitute for Zn, Cu, or Cd in the lattice, according to its ionic radius (Rankama and Sahama, 1949, p. 794-795).

CONCLUSIONS

At the Prince mine, uranium is associated with pyrometasomatic magnetite and hematite thought to be genetically related to a monzonite intruded into sedimentary rocks of Permian age. Both the iron and uranium are thought to have been mobilized and concentrated at essentially the same time by energy derived from a magma now represented by the monzonite. Both elements may have been primary constituents of the monzonitic magma or they may have been extracted from the invaded rocks. The uranium, which was fixed during the oxide phase of mineralization and not during the sulfide phase, is present in some unidentified form probably, in part, substituting for Zn, Cu, of Cd in the spinel (magnetite) lattice. It is thought that the uranium and the iron oxide were coprecipitated during the coagulation of a hydrosol of ferrous hydroxide in a mildly alkaline environment and under relatively low temperature conditions. The magnetite in the Prince deposit probably resulted from self-oxidation of a ferrous hydroxide hydrosal during extraction of alkalines from solution.

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