THE AMERICAN MINERALOGIST, VOL. 47, JANUARY-FEBRUARY, 1962

PROPERTIES AND PARAGENESIS OF COFFINITE FROM FROM THE WOODROW MINE, NEW MEXICO[1]

ROBERT H. MOENCH, *U. S. Geological Survey, Denver Federal Center, Denver, Colorado.*

ABSTRACT

Well-crystallized coffinite found as a vug filling in the Woodrow mine, New Mexico is botryoidal with a radially fibrous internal structure. In polished surfaces the mineral is hard, gray, isotropic, and has a reflectivity of 7.5 per cent in orange light. In transmitted light it is anisotropic, shows parallel extinction, and the optic and crystallographic *c* axes parallel the fibers. It is brown and slightly pleochroic, from pale yellow brown parallel to the fibers to brown normal to the fibers. The refractive indices are near 1.74 and the birefringence is less than 0.01 and variable. Coffinite is associated with pyrite, barite, small amounts of galena, wurtzite, cobaltite, and trace amounts of chalcopyrite. Textural relations data, combined with data from other specimens of Woodrow ore, suggest that sulfide and uranium mineralization were related in time as well as in space.

INTRODUCTION

Coffinite (probably $U(SiO_4)_{1-x}(OH)_{4x}$) is nearly ubiquitous in the unoxidized sandstone-type uranium deposits of the southern San Juan Basin mineral belt (Hilpert and Moench, 1960, p. 445). In the Laguna district, in fact, it probably accounts for most of the uranium in the unoxidized ore deposits. Most of the coffinite is so finely divided and so intimately mixed with carbonaceous material, however, that it has been detected by *x*-ray methods only, and its paragenetic relations to the carbonaceous material, vanadium-bearing minerals, and sulfide minerals have remained largely unknown. Well-crystallized coffinite found in one small specimen from the Woodrow mine in the Laguna district, New Mexico, has provided an opportunity to study the mineral. This paper describes the habit of the coffinite, its properties in reflected and transmitted light, and its paragenetic relations to associated minerals, in the specimen and in the Woodrow deposit as a whole.

Stieff, Stern and Sherwood (1956) defined coffinite by indirect techniques and were unable to determine its optical properties, for the material available to them was exceedingly fine grained and impure. Subsequently, Hoekstra and Fuchs (1956) synthesized bluish-green coffinite with refractive indices of 1.83 to 1.85; this material is anhydrous (Fuchs and Gebert, 1958, p. 243). Ramdohr (1960, p. 1001; 1961, p. 313–324; and written comm., Dec. 1960) has found natural, relatively coarse-grained coffinite of different ages in several European mining districts. The youngest (Miocene or younger) is fresh, but the older coffinite (early Tertiary to Precambrian) is largely metamict or is pseudomorphously re-

---

[1] Approved for publication by the Director, U. S. Geological Survey.

placed by quartz or pitchblende. Taylor and Harrison (1958, p. 363) describe the habit of coffinite in Cornwall, England, and Strunz and Seeliger (1960, p. 706) describe the habit of coffinite from Wölsendorf, Bavaria. Coffinite occurs also in some Tertiary vein deposits of the Front Range, Colorado and in appearance and optical properties is similar to coffinite from the Woodrow mine (P. K. Sims, oral comm. 1961). The Woodrow coffinite is suitable for optical study but not for chemical analysis or specific gravity determination, because the quantity available is small and the mineral cannot be readily separated from inclusions. Because of its fine-grained spherulitic habit, single crystal *x*-ray studies will be difficult but are being undertaken by the U. S. Geological Survey.

The writer gratefully acknowledges the assistance of the Anaconda Company and of L. S. Hilpert of the U. S. Geological Survey who supplied the specimen, and R. B. Taylor and Ernest Krier of the Survey who took the photomicrographs. Quantitative and semiquantitative spectrographic analyses of mineral separates were done by Nancy M. Conklin of the Survey.

This work is one facet of a comprehensive study of the geology and uranium deposits of the Laguna district, New Mexico, which was done in behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Field work was done mainly in 1955 and 1956; subsequently, a few short trips have been made to the area.

Geology of the Woodrow Pipe

The Woodrow mine is in the central part of the Laguna uranium mining district, which constitutes the eastern end of the southern San Juan Basin mineral belt (Hilpert and Moench, 1960, Figs. 1, 2). It is about 45 miles west of Albuquerque, New Mexico, 10 miles north of the Laguna Indian Pueblo and U. S. Highway 66, and about 1 mile southeast of the Jackpile mine—one of the largest producers of uranium ore in the United States. The Woodrow mine has been inaccessible since the summer of 1956. A description of the pipe (Hilpert and Moench, 1960, p. 1656) is summarized below.

The Woodrow deposit occupies a nearly vertical sandstone pipe, or cylindrical collapse structure in the Morrison Formation of Jurassic age (Hilpert and Moench, 1960, Fig. 14). The pipe has a known height of about 230 feet and a maximum diameter of about 35 feet. It extends downward from the Jackpile sandstone (of local usage), the uppermost unit in the Morrison Formation, and well into the Brushy Basin Shale Member of the Morrison Formation. The core of the pipe is a heterogeneous, compact mixture of arkosic sandstone derived largely from the Jackpile sandstone and of montmorillonite-bearing mudstone derived largely from the Brushy Basin Member. Near the top of the pipe, sandstone predominates; near the bottom, mudstone predominates. The transition zone is about 35 feet below the base of the Jackpile sandstone of the surrounding strata. The core is bounded by a narrow zone of branching ring faults. Tops of other similar pipes in the district are well exposed and show that they are overlain by the uppermost beds of the units that contain them (Hilpert and Moench, 1960, Fig. 8).

The uranium deposit is small but exceptionally high grade, averaging more than 1 per cent U_3O_8. In contrast with ore from other deposits of the district, the vanadium content is exceedingly low, and the uranium-vanadium ratio is about 50:1. In comparison, other deposits in the district typically contain about 0.2 per cent uranium, and have a uranium-vanadium ratio of about 3:1, which is much higher than the ratio for typical deposits of the Uravan mineral belt. In addition to uranium and vanadium, trace amounts of arsenic, barium, cobalt, copper, nickel, lead, and several other elements are present in the ore.

The highest grade ore was found in the upper part of the pipe, where it forms massive bodies of sulfide and uranium minerals along the boundary ring faults. Here, the core of the pipe is barren, but high-grade ore locally extends outward from the ring faults several feet into the surrounding sandstone. In the lower part of the pipe the ore is lower grade and is distributed throughout the core.

The ore concentration along the ring fault is a replacement, not a fissure filling, and examples of vug filling are rare in the deposit. Massive sulfides commonly show relict bedding, in which the outlines of individual grains are visible. High-grade ore locally shows boxwork textures, controlled by bedding-fracture intersections.

Ore Mineralogy

Unoxidized ore is composed of coffinite and uraninite, which typically are extremely finely divided and intimately mixed with a carbonaceous substance. Pyrite and marcasite are abundant also, and small amounts of chalcopyrite, galena, wurtzite, cobaltite, barite and carbonate minerals are present. The ore is partly oxidized to a depth of about 50 feet. Owing to the low vanadium content of the deposit, the oxidized ore contains a large variety of minerals of hexa-valent uranium, including, among others, uranopilite, betazippeite and cuprosklodowskite.

The intimate mixture of coffinite, uraninite, and carbonaceous material impregnates sandstone, markedly embays the detrital silicates and quartz overgrowths, and evidently locally completely replaces interstitial clay and carbonate minerals. To a lesser extent it also embays associated pyrite and marcasite. This mixture is black, opaque, hard and has a specific gravity that ranges from slightly less than 2 to more than 3, probably depending upon its uranium content. Most specimens yield sharp coffinite lines in x-ray powder patterns, although faint, diffuse uraninite lines are commonly present also. Polished surfaces of the mixture, as seen under oil immersion at high magnification, commonly show aggregates of dull-gray blebs in a matrix of a lighter gray submetallic substance. In places the dull substance is cut by a mesh of submetallic veinlets. Presumably the submetallic substance is more uraniferous than the dull-gray material, but more work is needed to prove this assumption.

An infrared spectrogram (by I. A. Breger) of impregnating uraniferous carbonaceous material in sandstone shows a dominance of aromatic over aliphatic structures and closely resembles uraniferous and nonuraniferous coals from the Jackpile mine, suggesting that the carbonaceous material was derived from humic acid.

The small amount of vanadium in the ore is contained in a clay-like material similar to that described by Hathaway (1959, p. 133). This material is exceedingly fine grained, brown, weakly pleochroic, strongly birefringent, and locally vermicular in habit. Similar material from other deposits in the district contains about 8 per cent vanadium (determined by quantitative and semiquantitative spectrographic analysis). X-ray diffractometer analysis (by J. C. Hathaway) of vanadium-bearing clay-like material from one deposit shows that it is composed of mica, probably roscoelite, with some interstratified montmorillonite layers and subordinate amounts of chlorite.

Pyrite and marcasite are mixed and abundantly disseminated in the ore, and in places they form massive replacement deposits. These sulfides contain 0.15 to 3.0 per cent arsenic, as determined by semiquantitative spectrographic analysis.

Cobaltite is sparsely disseminated in the bodies of massive pyrite and marcasite and is associated with well-crystallized coffinite (Fig. 3). The cobaltite was identified by its appearance in reflected light, by etch tests, and by its slightly superior hardness relative to pyrite.

Wurtzite is associated with well-crystallized coffinite (Fig. 1). The identification of wurtzite is questionable, for zinc was not revealed by spectrographic analysis. However, in polished surfaces it is similar in color, reflectivity, and hardness to sphalerite; and in transmitted light it is orange brown and gives an uniaxial positive interference figure.

Locally chalcopyrite is disseminated abundantly in the uraniferous carbonaceous material and sparse, minute blebs are also present in wurtzite. Galena is sparsely disseminated in the highest grade ore, where it forms minute cubes, veinlets, and small patches (Fig. 1). Barite is abundant in the specimen that contains well-crystallized coffinite (Fig. 3) but is sparse in other parts of the deposit.

WELL-CRYSTALLIZED COFFINITE

Well-crystallized, botryoidal coffinite partly fills a small vug and is interbanded with pyrite and barite. Cobaltite, wurtzite, galena, vanadium-bearing clay-like material, and a fine grained colorless clay mineral, probably kaolinite, also occur in the specimen. The textures of all of these minerals, except that of the vanadium-bearing clay-like material, are shown in Fig. 1 to 3, which are photomicrographs of a polished thin section in reflected and transmitted light. The coffinite forms botryoidal encrustations (less than 0.1 mm. thick) on mudstone fragments that largely have been replaced by pyrite, cobaltite, and finer grained coffinite. In turn the coffinite encrustations are coated with more pyrite and some barite. The fact that these materials were deposited in open space probably accounts for the relatively coarse crystallinity of the coffinite and for the well-developed textural relations which are so rare in sandstone-type uranium deposits.

The *x*-ray powder diffraction pattern of hand-picked coffinite shows weak, diffuse uraninite lines, in addition to sharp coffinite lines, indicating that the two mineral phases are present even in these specimens. Examination of the polished surface under oil immersion at 640× discloses sparse, minute, light-gray specks, possibly uraninite, alined in trains parallel to the coffinite fibers.

The general appearance of polished surfaces of the coffinite (Fig. 1) is similar to that of botryoidal uraninite. The coffinite is hard, gray, and isotropic. Locally, the radially fibrous texture of the coffinite is seen under oil immersion by internal reflections from thin films or minute rods of pyrite that have grown parallel to the fibers. The coffinite gives a measured reflectivity of about 7.5 per cent in orange light,[1] and shows no detectable anisotropism. This is distinctly less than that of uraninite (about 13 or 14 per cent in orange light).

In transmitted plane polarized light, particularly under crossed nicols (Fig. 2), the radially fibrous texture can be seen. Many of the cracks seen in reflected light may be partings that formed by shrinkage. The coffinite is brown and shows parallel extinction. It is weakly to moderately pleochroic from pale yellow brown parallel to the fibers to medium brown normal to the length of the fibers. Most of the coffinite fibers are length-slow, but some are length-fast; both positive and negative uniaxial optic axis figures were obtained. These data are consistent with the tetragonal

---

[1] Reflectivity was measured using the Hallimond visual microphotometer, as described by Leonard (1960), p. 1306–1312.

FIG. 1. (Left) Photomicrograph showing coffinite (C), pyrite (P), clay (K), wurtzite (W), and galena (G) in reflected light; about 155×. Photograph by Richard B. Taylor.

FIG. 2. (Right) Same area as Figure 1; transmitted light, crossed nicols; about 145×. Photograph by Ernest Krier.

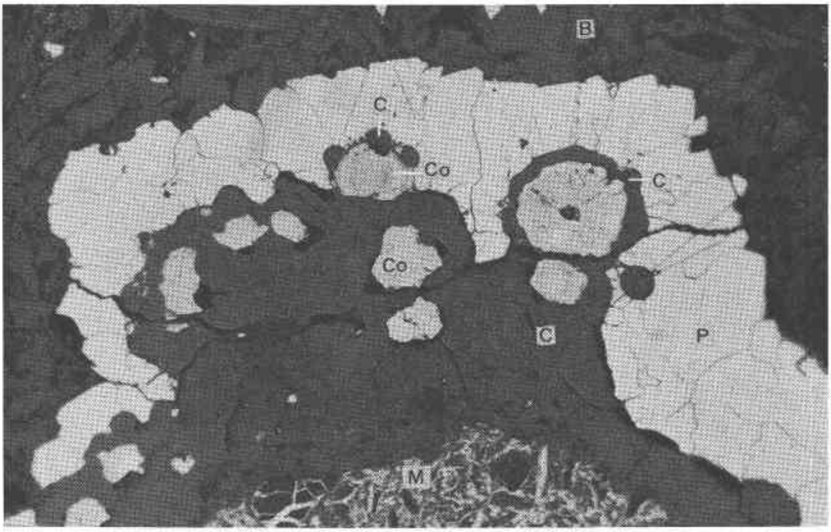

FIG. 3. Photomicrograph showing coffinite (C), pyrite (P), barite (B), cobaltite (Co), and relict mudstone fragment (M) veined by pyrite and cobaltite in reflected light; about 80×. Photograph by Richard B. Taylor.

symmetry proposed by Stieff, Stern, and Sherwood (1956). The optic and crystallographic *c* axes are parallel to the fibers.

The indices of refraction range from slightly more than 1.73 to slightly less than 1.75 and average about 1.74. As the optic sign changes from positive to negative, the omega index exceeds epsilon. Birefringence is low (less than 0.01) and variable from fiber to fiber; locally the mineral is isotropic.

The measured refractive index of about 1.74 compares with 1.83 to 1.85 for synthetic coffinite (Hoekstra and Fuchs, 1956, p. 105). Conceivably, the role of water substitution for silica may explain this difference. It is also likely that auto-oxidation, as in uraninite (Berman, 1957), in time would affect the physical and optical properties of coffinite.

PARAGENESIS

The textures shown in Figs. 1 to 3 and on other parts of the slide, combined with data obtained from other parts of the Woodrow deposit, indicate a definite order of precipitation and suggest a close temporal relation between sulfide and uranium mineralization. To elaborate on these processes is beyond the scope of this paper. The relations described here may apply to other deposits of the Laguna district, however, for these deposits are similar in composition and mineralogy to the Woodrow and differ chiefly in the relative abundance of their components.

The textures shown on Fig. 3 and on other parts of the slide indicate that a generation of coffinite and cobaltite closely followed or overlapped in time a generation of pyrite and cobaltite, and was followed by a second generation of pyrite, later barite, and still later pyrite. Figure 3 shows that a relict mudstone fragment (M) is coated by botryoidal coffinite, which in turn is encrusted with pyrite, and thence with bladed barite containing interstitial pyrite. The mudstone fragment has been partly replaced by exceedingly fine grained coffinite (not identifiable in Fig. 3) and apparently has been cut and replaced later by a mesh of pyrite-cobaltite veinlets. The pyrite and cobaltite in the veinlets probably formed contemporaneously, for they are closely intergrown, and in other parts of the slide they are minutely interbanded directly beneath the botryoidal coffinite coat. The botryoidal coffinite, in turn, contains large patches and concretions of cobaltite, and the textures shown on Fig. 3 indicate that they formed contemporaneously. The facts that cobaltite is associated with both coffinite and the early pyrite, and that pyrite-cobaltite veinlets cut some of the early, fine-grained coffinite indicate that pyrite, cobaltite, and coffinite generations overlapped in time.

The early-generation pyrite shown on Fig. 3 is thought to have formed at the same time as the massive pyrite-marcasite replacement deposits elsewhere in the pipe, for both contain cobaltite, and both formed before most of the uranium was introduced.

Other minerals probably formed nearly contemporaneously with the deposit of uranium and sulfide minerals, and some possibly formed later. Some pyrite and barite clearly followed coffinite in the order of precipitation (Figs. 1–3), but a close temporal relation between these generations of minerals cannot be demonstrated. On parts of the slide, coffinite and the pyrite that encrusts it are separated and the gap is filled with barite. If the gap formed by shrinkage of coffinite, the pyrite was introduced before shrinkage and the barite afterward. Vanadium clay commonly occupies the boundary between the post-coffinite crust of pyrite and the later barite, suggesting that vanadium was introduced after uranium and the pyrite crust, but before most of the barite. Wurtzite (Fig. 1) and chalcopyrite probably formed contemporaneously with coffinite. Judging from the amounts of lead and uranium in the sample and the maximum possible age of the deposit (Late Jurassic), all the galena (Fig. 1) may have formed by sulfidation of radiogenic lead.

In summary, the formation of massive replacement bodies of arsenic-bearing pyrite and marcasite was overlapped in time and closely followed by the introduction of uranium and small amounts of other elements. Most of the uranium became intimately associated with a carbonaceous substance, possibly humic acid, and both substances may have precipitated together. The textures of the uraniferous carbonaceous material are suggestive of a deformed emulsoid gel, but as yet are not understood. Where open space was available nearly pure coffinite crystallized. The botryoidal texture of this material also suggests colloidal precipitation.

REFERENCES

BERMAN, R. M. (1957), The role of lead and excess oxygen in uraninite. *Am. Mineral.*, **42,** 705–731.

FUCHS, L. H. AND ELIZABETH GEBERT (1958), *X*-ray studies of synthetic coffinite, thorite, and uranothorite. *Am. Mineral.*, **43,** 243–248.

HATHAWAY, J. C. (1959), Mixed-layered structures in vanadium clays. *U. S. Geol. Survey Prof. Paper* **320,** pt. II, 133–138.

HILPERT, L. S. AND R. H. MOENCH (1960), Uranium deposits of the southern part of the San Juan Basin, New Mexico. *Econ. Geol.*, **55,** 429–464.

HOEKSTRA, H. R. AND L. H. FUCHS (1956), Synthesis of coffinite-$USiO_4$. *Science*, **123,** 105.

LEONARD, B. F. (1960), Reflectivity measurements with a Hallimond visual microphotometer. *Econ. Geol.*, **55,** 1306.

RAMDOHR, PAUL (1960), Die Erzmineralien. Akademie-Verlag, Berlin.

——— (1961), Das Vorkommen von Coffinit in hydrothermalen Uranerzgängen besonders vom Co-Ni-Bi-Typ: Neues Jahr. Mineral., Abh., **95,** 313–324.

STIEFF, L. R., T. W. STERN, AND A. M. SHERWOOD (1956), Coffinite, a uranous silicate with hydroxyl substitution: a new mineral. *Am. Mineral.*, **41,** 675–688.

STRUNZ, H. UND E. SEELIGER (1960), Erzpetrographie der primären Uranmineralien von Wolsendörf: Neues Jahrb. Mineral., Abh., **94,** 681–719.

TAYLOR, K. and R. K. HARRISON (1958), Coffinite in Cornwall: *Nature*, **181,** 363.

Manuscript received March 24, 1961.