Geology and Mineralogy

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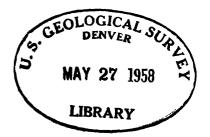
GEOLOGICAL SURVEY

MINERALOGY OF THE URANIUM DEPOSIT AT THE HAPPY JACK MINE,

WHITE CANYON DISTRICT, SAN JUAN COUNTY, UTAH*

By

A. F. Trites, Jr., R. T. Chew, III, and T. G. Lovering

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Trace Elements Investigations Report 514

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By A. F. Trites, Jr., R. T. Chew, III, and T. G. Lovering

ABSTRACT

The large uranium deposit at the Happy Jack mine occurs in beds of the Triassic Shinarump conglomerate that fill a channel cut into the underlying Moenkopi formation. The deposit has been divided on the basis of mineralogy into a sulfide zone, a transition zone, and an oxidized zone. Three types of ore are recognized in all these zones: replacements of "trash" accumulations, replacements of larger carbonized wood fragments, and bedded ores.

Ores of the sulfide zone consist of uraninite associated with pyrite, chalcopyrite, sphalerite, bornite, and galena. These primary sulfide ores appear to have been localized in the more permeable sandstone beds containing some siltstone and concentrations of carbonized vegetal material. Uranium and copper show evidence of secondary enrichment in the sulfide zone and the inner part of the transition zone.

Ores of the transition zone contain relict concentrations of uraninite and sulfide minerals and large amounts of goethite and jarosite. The ores of the oxidized zone contain abundant iron oxides but no sulfide minerals. Some uranium, copper, and iron have been retained during the weathering process, but most of the manganese, zinc, and lead are believed to have been removed by oxidation.

INTRODUCTION

The Happy Jack is the largest uranium mine in the White Canyon district, San Juan County, Utah. It is about 75 miles west of Blanding, Utah, in a deep reentrant in the southwest rim above White Canyon.

Uranium ore was first shipped from the mine in 1948, and constant production has been maintained since 1951. The property is owned by Joe Cooper of Monticello, Utah, and Fletcher and Grant Bronson of Blanding, Utah.

The U. S. Geological Survey began a detailed study of the mine in 1952. This study was to determine the mode of occurrence of the uranium minerals, to find structural and lithologic features that may be used as ore guides, and to obtain information on the geochemistry of the emplacement and oxidation of the ore deposit.

The walls of approximately 900 feet of drifts in the northeast part of the mine have been mapped on a scale of 1 inch equals 5 feet. About 750 feet of these drifts were mapped by Trites and Chew between August 7 and October 2, 1952; the remainder was mapped by Trites, assisted by E. J. Ostling, on August 19 and 20, 1954. The mineralogical study was made by Trites who examined about 30 polished sections and 50 thin sections of rock specimens from the mine. X-ray identification of some of the minerals were made by W. F. Outerbridge of the Geological Survey. Statistical analyses of assays from 103 chip samples from the mine have been made by Lovering and Chew.

Four main adits, connected by crosscuts, have been driven into the Shinarump conglomerate. The main workings were all on one level and consisted of slightly more than 3,000 feet of drifts and crosscuts when the study was made.

The writers wish to thank W. P. Walker of the Photographic Laboratory of the Geological Survey for his careful preparation of the photo-micrographs used in this paper.

GENERAL GEOLOGY

The rocks exposed in the area are sedimentary beds of continental origin that range in age from Permian to Jurassic. They have a total thickness of more than 4,000 feet and are predominantly sandstone and siltstone. The nearest exposures of igneous rocks are in the Henry Mountains about 17 miles west of the Happy Jack mine.

The uranium deposit at the Happy Jack mine is in the Shinarump conglomerate of late Triassic age. The formation is from 16 to 40 feet thick at the Happy Jack mine; it pinches out half a mile north-west and 1-1/4 miles southeast of the mine. The lower part of the formation fills a discontinuous channel cut into siltstone and sandstone of the underlying Moenkopi formation of early and middle(?) Triassic age. The channel trends about due east and is more than 750 feet wide and 10 feet deep in the area of the mine workings. Diamond drilling by the U. S. Atomic Energy Commission has suggested that the channel bends rather abruptly toward the southwest near the southwestern limit of the mine workings.

The Shinarump conglomerate is overlain conformably by the Chinle formation of late Triassic age. This younger formation is composed principally of beds of siltstone and sandstone and is gradational with the Shinarump conglomerate. The Moss Back sandstone member of the Chinle formation is about 175 feet above the top of the Shinarump, from which it is separated by siltstone and small lenses of sandstone.

The Shinarump conglomerate is composed of about 80 percent coarse-to fine-grained sandstone, 15 percent conglomerate, 8 percent siltstone, and 2 percent claystone. Gradation is common between beds of coarse-grained sandstone and conglomerate and between beds of fine-grained sandstone and siltstone. The sandstone beds are lenticular in shape and range from 1 to 100 feet in length and from a few inches to 4 feet in thickness. Cross-stratification is common in the sandstone beds; the cross-strata dip from less than 10° to more than 20° toward the northwest. Planar cross-stratification (McKee and Weir, 1953) is common in fine-grained sandstone and in coarse-grained conglomeratic sandstone containing abundant interstitial clay and silt. Small-scale slump features and current lineation also have been noted in the Shinarump conglomerate.

The sandstone is composed predominantly of colorless, angular to subangular, quartz grains; it also contains from a trace to 5 percent of microcline, and a trace of tourmaline and zircon(?). Authigenic quartz overgrowths have been added to many of the quartz grains before the deposition of the metallic minerals. Granules and pebbles of quartz, quartzite, siltstone, and claystone comprise from 1 to more than 10

percent of many of the sandstone beds; siltstone and claystone pebbles are especially abundant in the lower parts of the sandstone beds. In general, conglomerate beds grade laterally into beds of coarse-grained sandstone.

Siltstone and claystone are present throughout the Shinarump conglomerate at the Happy Jack mine. They occur in beds ranging from 10 to 100 feet in length and from 1 to 4 feet in thickness; they also occur in thin layers ranging from 1 to 6 feet in length and from one-eighth to one-half inch in thickness.

Most of the beds contain carbonaceous matter which ranges in size from finely comminuted material to logs as much as 3 feet long and 6 inches in diameter. Accumulations of smaller fragments have been termed "trash deposits" (Trites and Chew, 1955), a term that is in general use on the Colorado Plateau. These trash accumulations are commonly present near the bottom of the sandstone beds and at the contacts between sandstone beds.

STRUCTURE

The White Canyon district is on the west flank of the Monument upwarp, a broad south-plunging anticline that extends northward from 30 miles south of the San Juan River to Elk Ridge, 30 miles north of the river (Gregory, 1938, p. 85-88). The Monument upwarp has a steeply dipping east flank in which dips exceed 50°; and a gently dipping west flank in which dips range from half a degree to 3°.

The rocks in the White Canyon district strike regionally from north to northwest and dip 2^O to 3° west to southwest. Small folds occur locally and their axes are generally parallel to subparallel to the axis of the Monument upwarp. Normal faults with displacements as much as 100 feet cut the beds in the northwestern and southwestern part of the area.

The rocks at the Happy Jack mine strike about N. 20° W. and dip 3° SW. These rocks have been cut by four sets of steeply dipping fractures that have the following strikes listed in order of decreasing prominence: N. 65° W., N. 60° E., N. 85° E., and due north. Only one small fault was noted in the mine, about 30 feet from the portal. This fault strikes N. 69° W., dips almost vertically, and has had horizontal movement of less than 2 feet but no vertical movement. Minor bedding-plane movement is suggested by clay seams that have been thickened by movement along lithologic contacts.

Although uraninite and sulfide minerals have filled local micro-scopic fractures in the rocks, no relationship could be found between the uranium deposits and the larger fractures that were mapped.

MINERALOGY

The minerals listed below have been observed at the Happy Jack mine by Gruner, Lynn Gardiner, and D. K. Smith, Jr.(written communication), who reported them officially to the Atomic Energy Commission. They have not been observed by the present writers and are not discussed in this paper.

Cyanotrichite	$Cu_4Al_2(SO_4)(OH)_{12} \cdot 2H_2O$
Gersdorffite	$NiAsS$
Sabugalite (Al-autunite)	$HAl(UO_2)_4(PO_4) \cdot 16H_2O$
Schoepite	$UO_3 \cdot 2H_2O$ (approximately)
Siderotil	$FeSO_4 \cdot 5H_2O$ (?)
Sulfur	S
Not described before	$(Co,Fe)SO_4 \cdot 4H_2O$
Not described before	$MgSO_4 \cdot 6H_2O$
Bright yellow	Unknown uranium mineral
Waxy yellow	Unknown uranium mineral
Yellow	Unknown uranium mineral

The alphabetical list of minerals given below includes those observed by the senior author at the Happy Jack mine; many of these minerals are discussed in this paper. The formulas are from Dana's textbook of mineralogy (1932) unless otherwise stated.

Allophane (silicate)	$Al_2SiO_5 \cdot nH_2O$
Antlerite (sulfate)	$Cu_3(SO_4)(OH)_4$ [1]
Azurite (carbonate)	$Cu_3(OH)_2(CO_3)_2$ [1]
Barite (sulfate)	$BaSO_4$ [1]
Bornite (sulfide)	Cu_5FeS_4 [2]
Brochantite (sulfate)	$Cu_4(SO_4)(OH)_6$ [1]
Chalcanthite (sulfate)	$CuSO_4 \cdot 5H_2O$ [1]
Chalcedony (oxide)	SiO_2 [2]
Chalcocite (sulfide)	Cu_2S [2]

Chalcopyrite (sulfide)	$CuFeS_2$ [2/]
Covellite (sulfide)	CuS [2/]
Erythrite (arsenate)	$(Co,Ni)_3(AsO_4)_2 \cdot 8H_2O$ [1/]
Galena (sulfide)	PbS [2/]
Goethite (oxide)	$HFeO_2$ [2/]
Gypsum (sulfate)	$CaSO_4 \cdot 2H_2O$ [1/]
Hematite (oxide)	Fe_2O_3 [2/]
Hydrous mica (silicate)	$K_2O \ 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$
Ilsemannite (sulfate)?	$MoO_3 \cdot SO_3 \ 5H_2O$ [1/]
Jarosite (sulfate)	$KFe_3(SO_4)_2(OH)_6$ [1/]
Johannite (sulfate)	$Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$ [3/]
Magnetite (oxide)	$FeFe_2O_4$ [2/]
Malachite (carbonate)	$Cu_2(OH)_2(CO_3)$ [1/]
Marcasite (sulfide)	FeS_2 [2/]
Metatorbernite (phosphate)	$Cu(UO_2)_2(PO_4)_2 \cdot nH_2O$ n = 4 to 8 [3/]
Metazeunerite (arsenate)	$Cu(UO_2)_2(AsO_4)_2 \ 8H_2O$ [3/]
Microcline (silicate)	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$
Psilomelane(?) (oxide)	$BaMn^2Mn^4{}_8O_{16}(OH)_4$ [2/]
Pyrite (sulfide)	FeS_2 [2/]
Quartz (oxide)	SiO_2 [2/]
Sepiolite (silicate)	$2MgO \cdot 3SiO_2 \cdot 2H_2O$
Sphalerite (sulfide)	ZnS [2/]
Tourmaline	$H_9Al_3(B \cdot OH)_2Si_4O_{19}$
Uraninite	Ideally UO_2 [3/]
Uranopilite (sulfate)	$(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$ [3/]

Uranophane (silicate) $Ca(UO_2)_2(SiO_3)_2(OH)_2 \; 5H_2O$ [3]

Zippeitelike mineral $(UO_2)_2(SO_4)(OH)_2 \cdot 4H_2O$ [4]

[1] (Palache, and others, 1951)

[2] (Palache, and others, 1944)

[3] (Frondel and Fleischer, 1955)

[4] (Weeks and Thompson, 1954)

Note: Pitchblende has been omitted from the above list since according to present usage it is an inexact term akin to "limonite." The X-ray pattern of most pitchblende shows the presence of uraninite. However, the term "sooty pitchblende" is retained as a generic term.

ORE DEPOSIT

The ore deposit at the Happy Jack mine may be divided on the basis of mineralogy into a sulfide zone, a transition zone, and an oxidized zone. The sulfide zone is exposed in those parts of the mine farthest from the surface; the outer edge of this zone is about 200 feet horizontally from the outcrop of the Shinarump conglomerate and is roughly parallel to the outcrop. The transition zone extends from the sulfide zone to within 10 to 60 feet of the Shinarump rim in the part of the mine studied. The oxidized zone extends outward from the transition zone and includes the leached outcrop. The contacts between these zones are gradational.

The sulfide zone contains uraninite and sulfide minerals with no appreciable amounts of goethite. The transition zone contains abundant goethite and jarosite and locally it contains relict concentrations of uraninite and sulfide minerals. The oxidized zone contains abundant goethite, little jarosite, and insignificant amounts of sulfides.

Ores of the sulfide zone

About 15 percent (approximately 325 feet) of the mine workings in the sulfide zone were mapped and studied in detail in 1952. Most of the workings examined extend in a line across the Shinarump channel. The farthest part of the mine studied is about 475 feet from the rim.

The uranium ore in the sulfide zone occurs mainly in sandstone and conglomerate. Three types of ores are recognized: replacements of "trash" accumulations, bedded deposits, and replacements of larger wood fragments.

Replacements of "trash" accumulations constitute most of the high-grade uranium deposits and, although the rock has not been mined selectively, are believed to have yielded the greatest tonnages of ore from this zone. Ore bodies of this type are widely distributed in the mine in sandstone beds containing carbonaceous material. They range from 50 to 150 feet in length, from 25 to 50 feet in width, and from a fraction of an inch to 3 feet in thickness in the part of the mine studied.

Bedded ore bodies contain less carbonaceous material, are much smaller, and of slightly lower grade than the ores resulting from the replacements of "trash" accumulations; they have supplied less than 10 percent of the ore produced from the sulfide zone. Bedded ore bodies range from 1 to 25 feet in length, from 6 inches to 10 feet in width, and from a knife-edge to slightly more than 1 foot in thickness. They are localized at contacts between two sandstone beds and commonly replace thin layers of siltstone at the contacts.

Large carbonized wood fragments, sparsely disseminated in the mine, are commonly replaced by ore minerals in or near the two other types of uraniferous ores. These replacement ores are extremely variable in grade and contribute only a small part of the ore.

Local concentrations of uraninite, pyrite, chalcopyrite, sphalerite, and galena have been noted, but no definite zoning of these minerals has been found in the sulfide zone. Most of the uraninite apparently has been localized by sedimentary features; localization by faults and fractures has not been shown. The most highly mineralized beds appear to be semipermeable sandstone and conglomerate in the lower part of the Shinarump conglomerate, which commonly overlie siltstone. They contain 1 to 5 percent carbonized wood, 5 to 25 percent siltstone or claystone seams, and 10 to 20 percent siltstone or claystone cement.

A microscopic study was made of 13 polished sections from the sulfide zone. The modes of occurrence of the uraninite and the primary sulfide minerals are discussed below; the sulfides are given in descending order of abundance.

Uraninite

Uraninite (ideally UO_2) is the principal uranium mineral in the sulfide zone. Coffinite, the newly discovered uranous silicate (Stieff, Stern, and Sherwood, 1955), which has been identified in more than 15 uranium mines in the Colorado Plateau, has not been found at the Happy Jack mine.

The uraninite replaces carbonized wood, is disseminated in sandstone where it replaces quartz grains and microcline grains along cleavage planes, and fills microscopic veinlets cutting sandstone adjacent to fossil wood fragments. The suites of sulfide minerals with which the uraninite is associated, appear to vary with the mode of occurrence of the uraninite. In carbonized wood and other organic matter the uraninite is most commonly associated with pyrite, chalcopyrite, sphalerite, bornite, and galena; in sandstone containing no appreciable amounts of organic debris, uraninite is associated mainly with pyrite and sphalerite. Uraninite is also commonly associated with the supergene sulfide minerals marcasite and covellite in the wood.

The uraninite is of two distinct colors in polished section: most of the uraninite is gray, but some of that which occurs with chalcopyrite and covellite in carbonized wood is brownish gray. The reason for this color difference is not known. The variation in color may reflect a difference in age of the uraninite or may be caused by wood or by admixed copper minerals. Uraninite with crystal outlines has not been observed except where the uraninite is intergrown with pyrite by replacement of organic material.

Many carbonized wood fragments have been replaced by chalcopyrite and uraninite; a few have been replaced by uraninite and sphalerite. In general, the uraninite has replaced the cell walls and chalcopyrite has either replaced or filled the cell cores (fig. 1). Even in wood containing little or no chalcopyrite the uraninite shows a preference toward cell wall replacement as shown in figure 1. Nearly complete replacement of wood by uraninite is not uncommon, but sufficient unreplaced cell core material commonly remains to preserve the woody structure.
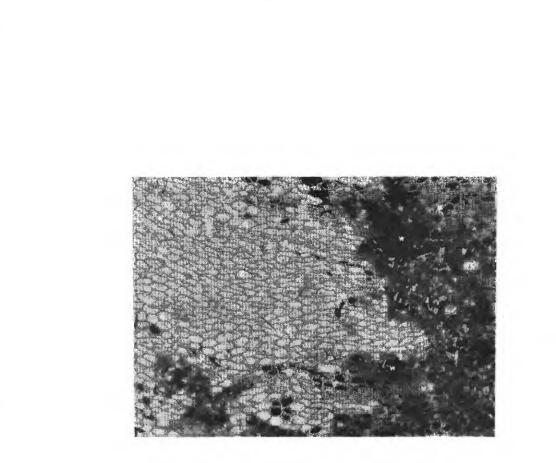
Figure 1. Photomicrograph of a cross section of a
carbonized wood fragment partly replaced by uran-
inite and chalcopyrite. Uraninite has replaced
the cell walls and chalcopyrite has filled or re-
placed part of the cell cores. u, uraninite;
c, chalcopyrite; w, unreplaced wood. X 145.

Uraninite is more concentrated in the centers of the carbonized wood fragments and is commonly surrounded by chalcopyrite which has in part replaced the edge of the wood and in part nearly completely impregnated the sandstone adjacent to the wood. Uraninite extends outward into the sandstone surrounding the wood fragments, partly filling interstices between the grains of the sandstone, coating some of the quartz grains, and filling cavities in chalcopyrite. The uraninite seems to be especially abundant in the sandstone at the ends of wood fragments, suggesting a "streaming out" of the uraninite from the wood which was the locus of deposition. Further study of the relative amounts of uraninite deposited in the sandstone at each of the ends of pieces of uraninite-replaced wood may suggest a direction of flow of the uranium-bearing solutions.

Some of the uraninite in the sandstone near carbonized wood seems to have a cell structure suggesting that smaller bits of organic matter have been replaced. Three specimens of sandstone containing uraninite without recognizable organic material were studied. In each of these specimens the uraninite was gray in color and was associated either with pyrite or with pyrite and sphalerite. Uraninite has embayed and replaced quartz grains, has replaced feldspar grains along the cleavages, has formed a thin rim around many grains of quartz, and has lined cavities. Some of the uraninite appears to be intergrown with the pyrite, and has crystal outlines (fig. 2). The uraninite is believed to be younger than the pyrite and to have replaced either organic material or a gangue mineral which was not completely replaced by the pyrite.
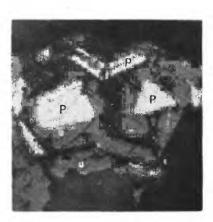
Locally uraninite has partly filled microscopic veinlets cutting individual quartz grains in the sandstone (fig. 3).

Pyrite

Pyrite is a widespread mineral at the Happy Jack mine; it is the most abundant sulfide mineral in the sulfide zone although it was subordinate to chalcopyrite in the polished sections studied. It occurs as a partial to nearly complete carbonized wood replacement, as a replacement of finely divided organic material, as disseminations in sandstone, and as partial fillings in fractures cutting the quartz grains in the sandstone. The pyrite is commonly associated with chalcopyrite, uraninite, sphalerite, marcasite, galena, and bornite in many places in the sulfide zone.

A few pieces of carbonized wood have been replaced mainly by pyrite with subordinate sphalerite or chalcopyrite. In the pieces of wood replaced by pyrite and sphalerite, the pyrite has replaced both the cell cores and walls, retaining a large part of the cell structure. Stringers of sphalerite grains cut the pyrite-replaced wood (fig. 4) and replace the pyrite. In pieces of wood replaced by pyrite and chalcopyrite the cell structure has been destroyed and the pyrite is in the form of irregular masses that have been embayed and replaced by chalcopyrite.

Pyrite replaces carbonized wood which apparently acted as a nucleus of deposition. Both individual cells, and entire fragments of wood as much as 5 inches long and 3 inches wide have been replaced. Pyrite

Figure 2. Photomicrograph of uraninite intergrown
with pyrite, replacing fine-grained organic mate-
rial in sandstone. u, uraninite; p, pyrite. X 710.
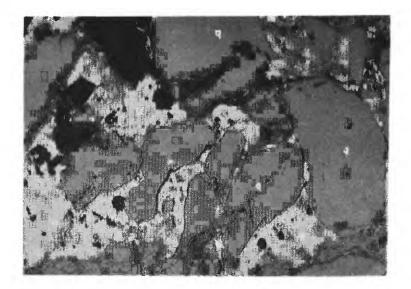

Figure 3. Photomicrograph of uraninite partly filling
the spaces between quartz grains and filling frac-
tures cutting the grains. u, uraninite, q, quartz
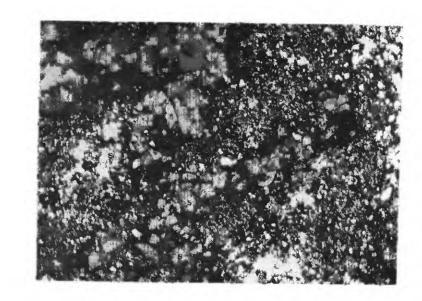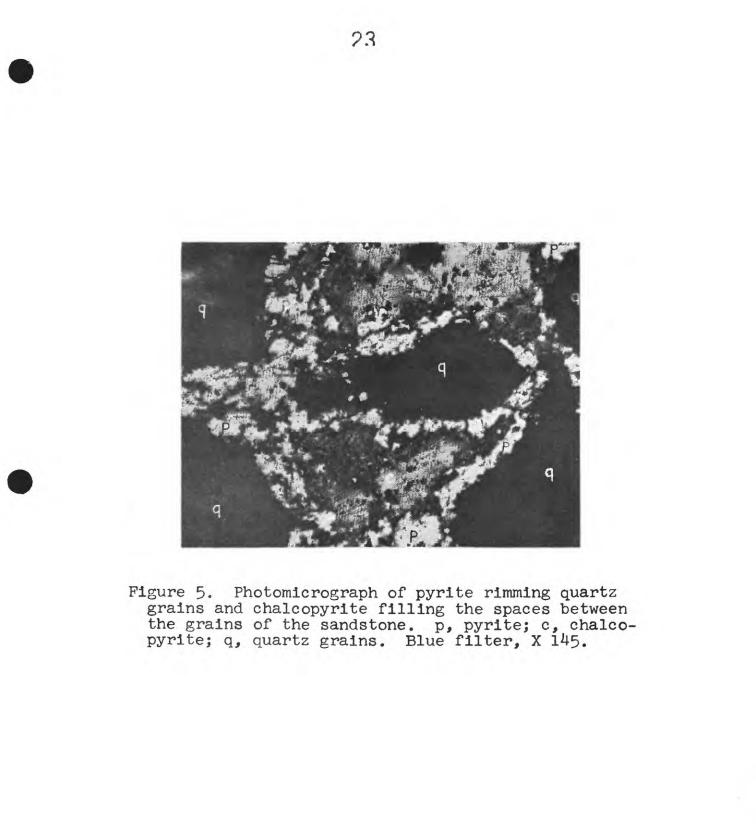grains. X 145.

Figure 4. Photomicrograph of sphalerite grains in
  veins cutting pyrite that has replaced carbonized
  wood fragments in sandstone. s, sphalerite; p,
  pyrite; w, unreplaced wood; q, quartz grains.
  X 145.

that has been deposited in larger areas in the wood commonly occupies the centers of cells whose walls remain unmineralized or have been replaced by pyrite or uraninite. Most of the pyrite in the center of the cells is separated from the pyrite or uraninite in the cell walls by unreplaced organic material.

Some of the pyrite in the sandstone has replaced small bits of disseminated organic material. Study of this occurrence of pyrite under high magnification and oil immersion has shown that the pyrite has surrounded the organic material in thin crenulated subround bands and has formed small blebs within the organic mass.

Pyrite has been deposited between the grains of the sandstone, especially near pieces of carbonized wood that contain abundant pyrite. Some of the pyrite has been concentrated along the edges of the quartz grains, incompletely filling the interstices between the grains (fig. 5) and embaying and replacing the edges of the grains.

A small amount of the pyrite is in microscopic crystals; both cubes and pyritohedrons have been observed under the microscope. Four different types of pyrite crystals have been observed: simple homo-geneous crystals; crystals with a core of unreplaced wood; crystals with a core of pyrite separated from a rim of pyrite by a layer of unreplaced wood or uraninite; and zoned crystals of alternating pink and yellow layers.

The simple homogeneous pyrite crystals are the most widespread and abundant. These simple crystals have been deposited in the sand-stone as well as in the wood and have mainly cubic forms.

Figure 5. Photomicrograph of pyrite rimming quartz
grains and chalcopyrite filling the spaces between
the grains of the sandstone. p, pyrite; c, chalco-
pyrite; q, quartz grains. Blue filter, X 145.

Some pyrite crystals that have grown around plant cells have a core of organic material. The skeletal crystal of pyrite in figure 6 is believed to have been formed in this manner. A more complex type of selective replacement of the cell by pyrite has produced the crystals with cores and rims of pyrite separated by unreplaced organic material. Later replacement of the unaffected part of the cell by uraninite has produced zonal crystals made up of pyrite and uraninite (fig. 2). Both cubic and pyritohedral forms are found in pyrite crystals of these types.

The zoned pyrite crystals are of many types. The most simple type of zoned pyrite crystal is that of normal yellow pyritohedral pyrite crystals having pinkish cores. More complex zoned crystals have many alternating zones as shown in figure 6. Square, pentagonal, and triangular outlines have been noted on these crystals, suggesting that the crystals have cubic and pyritohedral forms. In general, the inner zones have crystal forms similar to the outer boundaries of the pyrite crystals. Many of the inner zones are rotated with respect to the outer faces of the crystals so that the edges of the inner zones are not parallel to the outer edges of the crystals.

The reason for the pyrite zoning has not been determined, but the difference in color may be differences in the trace amounts of cobalt, nickel, or selenium in the layers.
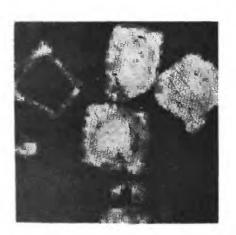
Figure 6. Photomicrograph of complex zoned pyrite crystals and a skeletal pyrite crystal. X 710.

Chalcopyrite

Although chalcopyrite is overwhelmingly the most abundant sulfide in specimens studied from the sulfide zone, the gross aspects of the deposit suggest that it is about one-tenth as abundant as pyrite. The chalcopyrite has formed disseminations in the sandstone, conglomerate, and siltstone; it has replaced fragments of carbonized wood and stringers of carbonaceous siltstone; and it has filled small fractures cutting the sandstone. In most places the chalcopyrite is associated with pyrite and locally it is associated with uraninite, sphalerite, bornite, and galena in the sulfide zone.

The amount of chalcopyrite in the beds varies from a few scattered masses to complete fillings between grains. Chalcopyrite is more abundant in sandstone and conglomerate that contain coalified wood. Rims of concentrated chalcopyrite as much as one centimeter wide surround many wood fragments that have been replaced by uraninite and sulfide minerals. The concentrated chalcopyrite grades outward from the rims into more widely scattered masses in the sandstone. The chalcopyrite has embayed and apparently has replaced many of the quartz grains; complete replacement of quartz grains is uncommon in specimens studied from the mine. Most of the chalcopyrite in the sandstone is massive, although many small crystals have been observed.

Many fragments of coalified wood have been partly replaced by chalcopyrite. The amount of chalcopyrite in these wood fragments ranges from an occasional "eye" or lens of chalcopyrite in the center of the cells (fig. 1) to nearly complete replacement of both cell cores and walls.

The initial deposition of chalcopyrite in the wood seems to have been a filling or replacement of the core of the cells. Subsequent replacement of the cell walls took place only where there was a superabundance of chalcopyrite. In its preference to fill cavities, the chalcopyrite is similar to that in the porphyry copper deposit at Ajo, Ariz. (Gilluly, 1946, p. 87).

Small subround masses of chalcopyrite in the sandstone have a pattern that suggests the replacement of seeds, pollen, or finely divided organic material with a very small cell structure. Chalcopyrite in carbonaceous siltstone has also been concentrated in fragments of wood and in finely divided organic matter.

Megascopic veins and fracture fillings of chalcopyrite have been observed at several places in the Happy Jack mine. Veinlets of chalcopyrite, less than 6 inches long and one-fourth inch across, cut siltstone lenses southwest of the part of the mine mapped, and small concentrations of chalcopyrite were observed in the sandstone adjacent to a vertical fracture in the eastern part of the mine workings.

<center>Other sulfide minerals</center>

Sphalerite is the third most abundant sulfide mineral in the sulfide zone; it is about one-tenth as abundant as chalcopyrite. Most of the sphalerite occurs as minute fracture fillings and linings of cavities; as replacements in carbonized wood that was previously replaced by pyrite, chalcopyrite, and uraninite (fig. 4); and as disseminations in sandstone. The sphalerite is light gray in polished section and nearly free of iron; it forms crystals and anhedral masses that display yellow internal reflections.

Bornite is found in trace quantities replacing wood and chalco-
pyrite in the sulfide and transition zones. Some of the bornite
forms a eutectic intergrowth with rods of chalcopyrite. Bornite has
also been deposited as rims between chalcopyrite and grains of sphalerite;
locally the bornite has been deposited in veinlets cutting chalcopyrite.
All of the bornite is of microscopic size and most patches of it are
less than 0.05 mm across.

Galena occurs in trace quantities as microscopic crystals and
irregular masses that have been deposited locally in the carbonized
wood and sandstone. The galena is surrounded and veined by chalcopyrite
and covellite (fig. 7).

Covellite and chalcocite are present in the sulfide zone and the
inner part of the transition zone. Covellite occurs as bladed crystals
cutting chalcopyrite and chalcocite and as rims surrounding many grains
of chalcopyrite, pyrite, and galena; the covellite is the youngest of
the sulfide minerals. The chalcocite occurs as feathery masses along
fractures cutting chalcopyrite and as replacement rims around grains
of chalcopyrite and bornite. The covellite and chalcocite are believed
to be of supergene origin because they appear to be localized near the
boundary between the sulfide and transition zones.

Marcasite is present locally in microscopic veinlets cutting and
replacing the uraninite and most of the sulfide minerals (fig. 8) in
fragments of replaced carbonized wood. Most of the woody texture has
been destroyed by the marcasite, although a few wood cells apparently
have been replaced by marcasite which has retained a cellular structure.

Figure 7. Photomicrograph of galena veined and re-
placed by chalcopyrite and partly rimmed by covel-
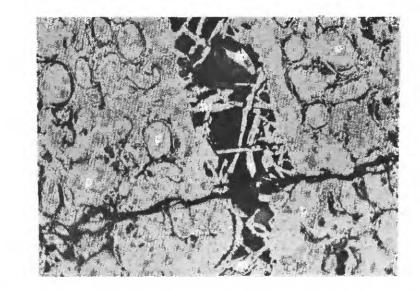lite. g, galena; c, chalcopyrite; cv, covellite.
Blue filter, X 145.

Figure 8. Photomicrograph of marcasite rimming a cavity
in wood that has been replaced by pyrite. m, marcas-
ite; p, pyrite. X 145.

The marcasite is associated with uraninite in all but one of the specimens examined. Marcasite is generally considered to be deposited from cold acid solutions in the oxide or supergene alteration zones of ore bodies (Webber, 1929, p. 305).

Nonmetallic gangue minerals

The nonmetallic gangue minerals in the sulfide zone are mainly quartz, microcline, and clay minerals (mostly hydrous mica and kaolinite) typical of the Shinarump conglomerate. Quartz is present as grains and locally as authigenic overgrowths on quartz grains. The most abundant quartz overgrowths appear to be in areas surrounding abundant uraninite and sulfide minerals; although microscopically, a few overgrowths occur with the uraninite and sulfides and have been embayed by these minerals. The association of minor amounts of quartz overgrowths with uraninite and sulfide minerals and the embayment of the authigenic quartz by these minerals suggests that silica was leached from the quartz grains of the sandstone by the mineralizing solutions and redeposited in the beds nearby. Silica was thereby moved, as a front, ahead of the ore-bearing solution; and as deposition of sulfide minerals advanced, the authigenic quartz previously deposited was moved further outward from the deposit. The more intense silicification that Waters and Granger (1953, p. 15) observed surrounding ore bodies on the Colorado Plateau could possibly be explained by this process.

Barite has been introduced locally into the sulfide zone and is particularly associated with sphalerite. The barite rims cavities that are filled with sphalerite and is believed to be older than the sphalerite. Its age, relative to the other sulfide minerals, has not been determined.

Jarosite, apparently one of the earliest secondary minerals formed by the oxidation of sulfide minerals in the mine, is common throughout the part of the sulfide zone studied.

Statistical interpretation of assay data

Preliminary studies suggest an approximately log-normal distribution of certain elements in the samples (figs. 9 and 10). No histogram is shown for the oxidized zone because of the low number of samples. A statistical study based on the assumption of log-normal distribution of these elements in the deposit was made of chemical analyses of 68 samples from the sulfide zone, 22 samples from the transition zone, and 10 samples from the oxidized zone. The results of this study are shown in tables 1 and 2. The geometric means (M) and the geometric deviations (GD) of samples from each of the three zones are shown in table 1; the correlation coefficients of copper, manganese, iron, and calcium carbon-ate─/ with respect to uranium in each of the three zones are shown in table 2.

─/ This refers to the determination as made for metallurgical purposes. Although this is an empirical method that measures calcium taken into solution by an acetic acid leach, it generally gives a good approximation of the calcium carbonate actually present in most sandstone-type ores. The weakness of this method is that it measures any acetic acid soluble calcium salt including some, but not necessarily all, of calcium carbonate. All the calcium found in the leach is expressed as calcium carbonate.

FIGURE 9. FREQUENCY DISTRIBUTION HISTOGRAMS OF URANIUM, COPPER, MANGANESE, IRON, AND CALCIUM CARBONATE, SULFIDE ZONE, HAPPY JACK MINE, WHITE CANYON DISTRICT, SAN JUAN COUNTY, UTAH (LOGARITHMIC CLASS INTERVAL, 68 SAMPLES).
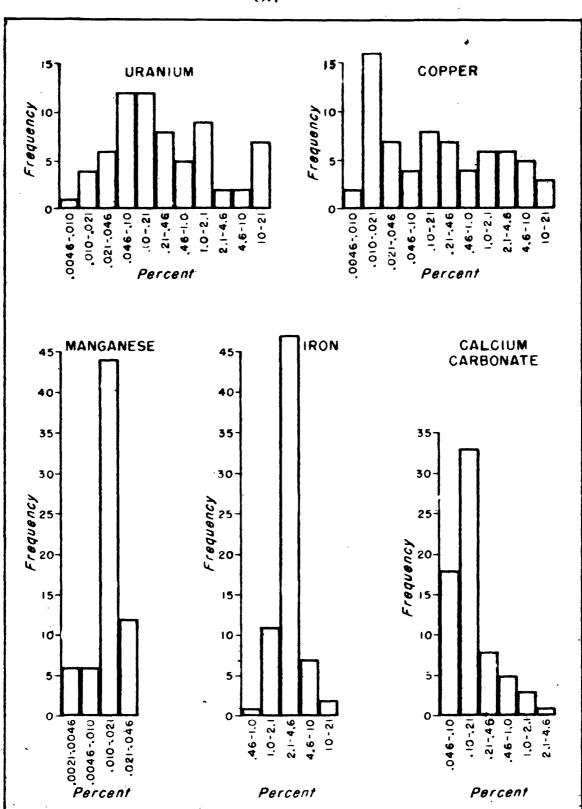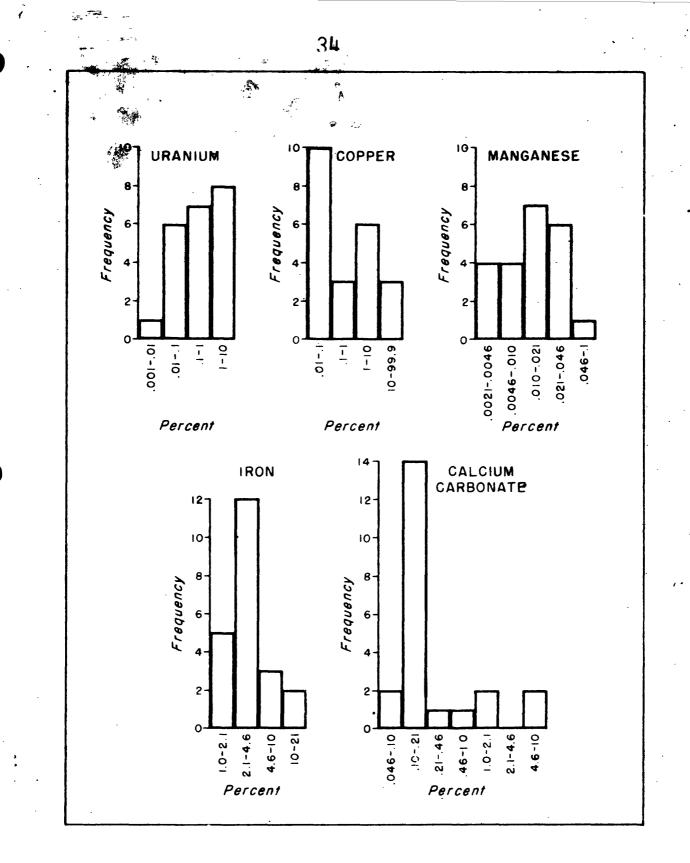
FIGURE 10. FREQUENCY DISTRIBUTION HISTOGRAMS OF URANIUM, COPPER, MANGANESE, IRON, AND CALCIUM CARBONATE, TRANSITION ZONE, HAPPY JACK MINE, WHITE CANYON DISTRICT, SAN JUAN COUNTY, UTAH (LOGARITHMIC CLASS INTERVAL, 22 SAMPLES).

Table 1.—Geometric means and geometric deviations of various elements
and calcium carbonate at the Happy Jack mine,
White Canyon district, San Juan County, Utah.

Element	Geometric mean (M) in percent; Geometric deviation (GD)	Zones		
		Sulfide (68 samples)	Transition (22 samples)	Oxidized (10 samples)
Uranium	M	$0.31 \overset{\times}{\div} 1.43$	$0.28 \overset{\times}{\pm} 2.42$	$0.021 \overset{\times}{\div} 2.72$
	GD	7.62	7.10	3.85
Copper	M	$0.20 \overset{\times}{\div} 1.76$	$0.39 \overset{\times}{\div} 5.35$	$0.54 \overset{\times}{\pm} 4.38$
	GD	10.02	41.12	7.30
Manganese	M	$0.014 \overset{\times}{\div} 1.16$	$0.013 \overset{\times}{\pm} 1.50$	$0.0018 \overset{\times}{\div} 3.95$
	GD	1.83	2.47	6.35
Iron	M	$3.09 \overset{\times}{\div} 1.15$	$3.39 \overset{\times}{\pm} 1.35$	$2.51 \overset{\times}{\div} 1.60$
	GD	1.67	1.95	1.88
Calcium carbonate	M	$0.17 \overset{\times}{\div} 1.22$	$0.26 \overset{\times}{\pm} 1.82$	$0.16 \overset{\times}{\div} 2.72$
	GD	2.25	3.79	3.84

Table 2.--Correlation coefficients between uranium and various other
elements and calcium carbonate at the Happy Jack mine,
White Canyon district, San Juan County, Utah.

Elements correlated with uranium	Correlation coefficient	Zones		
		Sulfide (68 samples) $r_s = 0.23$_/	Transition (22 samples) $r_s = 0.42$_/	Oxidized (10 samples) $r_s = 0.63$_/
Copper	r	+0.12	+0.25	+0.45
Manganese	r	-0.07	-0.12	+0.52
Iron	r	+0.59	+0.22	+0.44
Calcium carbonate	r	+0.09	-0.38	+0.11

_/ r_s = significant value of correlation coefficient, i.e., that value, which if exceeded, yields a 95 percent probability that the two variables being correlated are not independent.

The geometric deviations (GD) suggest that copper (GD = 10.02) and uranium (GD = 7.62) have the greatest deviation, and therefore, the greatest dispersion in the sulfide zone. Dispersion means the amount of scatter of the values about a mean. This high dispersion of uranium and copper assays is in accordance with the observed non-uniform high-grade concentrations of uraninite and chalcopyrite in the mine. The dispersion of calcium carbonate (GD = 2.25), manganese (GD = 1.83) and iron (GD = 1.67) is lower than that of copper and uranium suggesting that distribution of these elements is more uniform in the part of the sulfide zone studied.

The arithmetic mean of iron was calculated to be 3.43 percent in the sulfide zone. This indicates that considerably more iron is present than that which is chemically combined with copper (arithmetic mean Cu 1.51 percent) in chalcopyrite. Ideally, chalcopyrite contains 34.5 percent copper, 30.5 percent iron, and 35.0 percent sulfur. Nearly all the copper occurs as chalcopyrite in the primary sulfide zone; the small amount of bornite present has been disregarded. The arithmetic mean of 1.51 percent copper is equivalent to $\frac{30.5}{34.5}$ x 1.51 or 1.32 percent iron in this zone. Since the arithmetic mean of iron is 3.43 percent in the sulfide zone and if 1.32 percent iron is combined in chalcopyrite, a total of 3.43 minus 1.51 or 1.92 percent iron is present in other compounds. In other words, about 1.5 times the amount of iron contained in chalcopyrite is present in other compounds; most of this iron is believed to be contained in pyrite, suggesting that pyrite is more abundant in the samples analyzed than in the polished sections studied.

Part of this apparent discrepancy is believed to be explained by the
fact that specimens examined microscopically were principally of
sandstone containing radioactive material, whereas pyrite is also
abundant in the barren claystone, sandstone, and conglomerate.

The uranium appears to correlate significantly with iron, but
does not show significant correlation with copper, manganese, or
calcium carbonate in the sulfide zone (table 2). The relatively high
correlation of uranium with respect to iron suggests that sites which
favored the deposition of pyrite also favored the deposition of
uraninite. Since the principal mode of occurrence of both uraninite
and pyrite is the replacement of coalified wood, it is believed that
these sites of deposition consisted of wood and other organic matter
in sandstone, conglomerate, and siltstone. The pyrite was both earlier
and more abundant than the uraninite, consequently its distribution is
more uniform than the uraninite.

Paragenesis and origin

The general paragenetic sequence of the formation of the uraninite
and sulfide minerals in the sulfide zone is shown in figure 11. Secon-
dary silica was added to the sandstones prior to the deposition of these
metallic minerals which have embayed and replaced the authigenic quartz.
Significant wall rock alteration apparently did not accompany the depo-
sition of the metallic minerals. The solutions which deposited the
minerals in the sulfide zones are believed to have contained large
amounts of iron and abnormal amounts of zinc, lead, and other metallic
ions.

FIGURE 11. CHART SHOWING PARAGENESIS OF URANINITE AND SULFIDE MINERALS, HAPPY JACK MINE, WHITE CANYON DISTRICT, SAN JUAN COUNTY, UTAH.

Lovering (1949, p. 56) believed that the abundance of barite and the absence of alunite suggested precipitation from bicarbonate solution in late barren stage alteration of East Tintic, Utah. Iron and zinc are known to be soluble in a bicarbonate solution under pressure (Lovering, T. S., oral communication, 1955). With a release of pressure and in the presence of available hydrogen sulfide the sulfides of iron and zinc are precipitated. Copper and lead are considerably less soluble than iron or zinc in bicarbonate solution and may not have been carried in such a solution. Both iron sulfide and zinc sulfide will be reacted on by such solutions as that of lead chloride to precipitate lead sulfide, the iron and zinc ions returning to solution during the process. Such processes as these may have taken place during the deposition of the uranium deposits. Pyrite was apparently the earliest of the sulfide minerals formed and could have been derived from iron carried in bicarbonate solution under pressure and precipitated in the presence of hydrogen sulfide, extracted perhaps from organic matter. If solutions carrying copper and lead passed over the pyrite, the sulfur could have been removed from combination with the iron to recombine with these cations. Sulfur could unite with the lead to form the galena, and sulfur and iron could combine with the copper to form chalcopyrite and bornite. The role of uranium and zinc in this sequence of reactions is not known. Uranium apparently has a greater affinity for oxygen than for sulfur and has been deposited as the oxide instead of the sulfide. Sphalerite was apparently deposited later than the pyrite, galena, and uraninite; its replacement of pyrite

suggests that it may have been deposited similarly to the manner
suggested for the galena, by solution of the pyrite and combining of
the zinc with sulfur. Much of the pyrite has been etched by the later
sulfide minerals, suggesting that solution of the pyrite took place as
these minerals were being deposited.

The average ratio of equivalent uranium to uranium (eU percent/ U
percent) is less than 1.0 in samples from the sulfide zone, greater than
1.0 in samples from the transition zone, and considerably greater than
1.0 in samples from the oxidized zone. Dodd (1950) has previously
described these differences between radiometric count and percent uranium
and attributed them to leaching. These data suggest that uranium has
been leached from the oxidized and transition zones and some of it rede-
posited in the sulfide zone. Uranium is thus apparently being second-
arily enriched in the sulfide zone.

Ores of the transition zone

The transition zone has been defined as a zone containing abundant
goethite and relicit concentrations of primary sulfide minerals. The
three types of uranium ores (replacements of "trash" accumulations,
bedded ores, and replacements of large wood fragments) found in the
sulfide zone are also recognized in the transition zone. In general,
the grade of ores of each type is lower in the transition zone than in
the sulfide zone. The relict concentrations of uraninite and sulfide
minerals are believed to remain in the transition zone because the
oxidizing solutions did not penetrate the rock everywhere and local
concentrations of carbonaceous matter may have retained reducing conditions.

Mineralogy

The uranium ore in the transition zone consists of relict uraninite
and primary sulfide minerals, secondary uranium and copper minerals, and
possibly uraniferous iron oxides. Secondary uranium minerals include
the oxide sooty pitchblende (Kerr, 1951, p. 91-92), the sulfates
uranopilite and a zippeitelike mineral, and the silicate uranophane.
The secondary copper minerals are the sulfates chalcanthite, brochantite,
and antlerite(?) and the carbonates malachite and azurite. Secondary
uranium-copper minerals include the sulfate johannite; the phosphate
metatorbernite; and the arsenate metazeunerite. Most of these secondary
minerals have formed disseminations in the sandstone, conglomerate, and
siltstone, and are associated with gypsum, goethite, and hematite as
fracture coatings. Some of the sulfates, especially the zippeitelike
mineral, johannite, uranopilite, and chalcanthite, have formed
efflorescent coatings on the walls in moist parts of the mine.

Goethite, hematite, jarosite, and gypsum are abundant in the
transition zone. The goethite has impregnated sandstone and conglomerate,
coated fractures, and replaced pieces of wood that were formerly replaced
by sulfide minerals. Locally the goethite appears to be an alteration
product of hematite and jarosite, and some of the goethite is colored
red by hematite.

Jarosite is believed to be the first product formed during the
oxidation of the deposit. It is present in greatest amounts in the
inner part of the transition zone and in the sulfide zone. Only small
amounts of the mineral are found in the oxide zone and in the outer part
of the transition zone. Oxidation in arid rather than humid climate is
believed to favor the deposition of jarosite (Locke, 1926, p. 107).

Gypsum is common throughout the transition zone. It has formed disseminations in the sandstone and conglomerate and has coated the surfaces of fractures.

Statistical interpretation of assay data

A statistical study was made of 22 samples from the transition zone. The results (table 1) suggest that the only statistical values which are significantly different from the values of the sulfide zone are the geometric deviations of copper, manganese, and calcium carbonate. The geometric deviation of copper (GD = 41.12) in the transition zone is much higher than that of copper (GD = 10.42) in the sulfide zone. Large amounts of secondary copper minerals, mainly the sulfates, have formed local concentrations in the transition zone and probably account for the greater dispersion of copper assays. Secondary copper minerals are present in local concentrations similar to those found in zones of secondary enrichment in many porphyry copper deposits and vein copper deposits elsewhere. Chalcocite and covellite have been deposited in some of the relict sulfide bodies in the transition zone where they commonly replace chalcopyrite and bornite.

Manganese is present in about the same amount in the transition zone (M = 0.013) as in the sulfide zone (M = 0.014), although the manganese assays show a greater dispersion in the transition zone (GD = 2.47). Some of the manganese apparently has been moved about in the transition zone, but apparently no significant amounts have been removed from or added to the zone.

The distribution of calcium carbonate is also more variable in the transition zone (GD = 3.79) than in the sulfide zone (GD = 2.76). The calcium carbonate may be more variable in the transition zone because it is being removed near the oxidizing sulfides. Calcium carbonate is present in such extremely small amounts that it cannot be recognized in the mine.

Uranium shows no significant correlation with copper, iron, manganese, or calcium carbonate in the transition zone.

Ores of the oxidized zone

The uranium ores in the oxidized zone are similar in type to those in the transition zone but the average grade of the deposits in the oxidized zone is only about one-tenth of those in the transition zone. Copper, however, shows a slight increase in the oxidized zone over the transition zone. All of the uraninite has been leached from the oxidized zone and nearly all of the sulfide minerals have been removed by oxidation. In general, the secondary uranium and copper minerals are similar to those in the transition zone, although efflorescent deposits of secondary uranium minerals are not common on the mine walls and jarosite is sparse in the oxidized zone.

Statistical interpretation of assay data

A statistical analysis was made on 10 samples from the oxidized zone (table 1). The number of samples is admittedly small and may be insufficient for the drawing of valid conclusions. The data suggest, however, that the amount of uranium is significantly less in the oxidized zone (M = 0.021) than in the transition zone (M = 0.28) or the sulfide zone (M = 0.34), although its distribution is more uniform in the oxidized zone (GD = 3.85) than in the transition (GD = 7.10) and sulfide zones (GD = 8.40). Complete oxidation of concentrations of uraninite with the formation of dispersed secondary minerals probably accounts for the greater uniformity of uranium distribution.

The amount of manganese is considerably smaller and the assay values show more dispersion in the oxidized zone (M = 0.0018; GD = 6.35) relative to both the transition (M = 0.013; GD = 2.47) and the sulfide zones (M = 0.014; GD = 1.80). Manganese has apparently been leached from the deposit near the outcrop and a large part of it is believed to have migrated along fractures. The deposition of manganese oxide along many of the fractures is believed to account for part of its variability in the oxidized zones.

The correlation of uranium with copper, manganese, iron, and calcium carbonate is not significant in the oxidized zone.

SUMMARY

The uranium deposits at the Happy Jack mine are in beds of the Shinarump conglomerate which have filled a channel cut into the under-lying Moenkopi formation. The deposits are believed to have been localized principally in the more permeable beds containing large amounts of carbonized wood and claystone or siltstone seams. Secondary silica was added to the quartz grains prior to the deposition of the uraninite and sulfide minerals. Iron, copper, uranium, zinc, lead, barium, manganese, and other metallic elements apparently were deposited by solutions which removed a large part of the secondary quartz. The acidity of the solution is not known, but it is believed that bicarbonate solution could have removed part of the quartz and deposited some of the metallic minerals. Pyrite, galena, chalcopyrite, bornite, uraninite, and sphalerite were deposited from the solution by replacement of carbon-ized wood and of portions of sandstone and deposition in the pores of the sandstone.

Oxidation of the sulfide ore body by oxygen-bearing acid sulfate waters has penetrated to about 200 feet behind the cliff face. With oxidation of the sulfide ore body, movement of metallic ions has been both outward to be lost to surface waters, and inward to increase the concentration of elements. Although large amounts of copper and uranium have been lost by oxidation and removed at the surface, small amounts of uranium and significant amounts of copper have migrated inward from the rim and have been redeposited as supergene minerals. The uranium apparently has migrated farther than the copper to form sooty pitchblende in the outer part of the primary sulfide zone. Copper has been enriched

as chalcocite and covellite principally in the transition zone and as

sulfates in the transition and oxidized zones. Some of the iron has

been redeposited as marcasite and jarosite in the transition zones and

the outer part of the sulfide zone; a large part of the iron has been

deposited as goethite and hematite in the transition and oxidized zones.

Most of the manganese, zinc, and lead, are believed to have been removed

by oxidation. In general, the oxidation and supergene enrichment has

tended to decrease the size of the ore body, although slightly enriching

it.

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