Geology of the Happy Jack Mine White Canyon Area San Juan County, Utah

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A CONTRIBUTION TO THE GEOLOGY OF URANIUM

GEOLOGY OF THE HAPPY JACK MINE, WHITE CANYON AREA, SAN JUAN COUNTY, UTAH

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ABSTRACT

The Happy Jack mine is in the White Canyon area, San Juan County, Utah. Production is from high-grade uranium deposits in the Shinarump conglomerate of Triassic age. The Shinarump strata range from 16½ to 40 feet in thickness and the lower part of these beds fills an eastward-trending channel that is more than 750 feet wide and 10 feet deep.

The Shinarump conglomerate consists of beds of coarse- to fine-grained quartzose sandstone, conglomerate, siltstone, and claystone. Carbonized wood is abundant in these beds, and in the field it was classified as mineral charcoal and coal.

Channels within the Shinarump, cross-stratification, current lineation, and slumping and compaction structures have been recognized in the mine. Steeply dipping fractures have dominant trends in four directions, N. 65° W., N. 60° E., N. 85° E., and due north.

Uranium occurs as bedded deposits, as replacement bodies in accumulations of "trash," and as replacements of larger fragments of wood. An "ore shoot" is formed where the three types of uranium deposits occur together; these ore shoots appear to be elongate masses with sharp boundaries.

Uranium minerals include uraninite, sooty pitchblende(?), and the sulfates—betazippeite, johannite, and uranopilite. Associated with the uraninite are the sulfide minerals covellite, bornite, chalcopyrite, and pyrite. Galena and sphalerite have been found in close association with uranium minerals.

The gangue minerals include limonite and hematite (present in most of the sandstone beds throughout the deposit), jarosite that impregnates much of the sandstone in the outer parts of the mine workings, gypsum that fills many of the fractures, and barite that impregnates the sandstone in at least one part of the mine. Secondary copper minerals, mainly copper sulfates, occur throughout the mine, but are most abundant in the outermost 30 feet of the workings. The bulk of the country rock consists of quartz and feldspar, and clay minerals.

The amount of uranium minerals deposited in a sandstone bed is believed to have been determined by the position of the bed in the channel, the permeability of the sandstone in the bed, and the amount of carbonized wood and plant remains within the bed. Not all of these features can be demonstrated in the Happy Jack mine itself. The beds considered most favorable for uranium deposition contain an abundance of claystone and siltstone both as matrix filling and as fragments.

Suggested exploration guides for uranium ore bodies include interbedded silt-

stone lenses, claystone and siltstone cement and pebbles, concentrations of "trash," covellite and bornite, chalcopyrite, and carbonized wood.

INTRODUCTION

SCOPE AND PURPOSE

The Happy Jack mine contains the largest known uranium deposit in the White Canyon area, San Juan County, Utah (fig. 38). A detailed study was started by the U. S. Geological Survey to determine the mode of occurrence of the uranium minerals, and the structural and lithologic features useful as ore guides at the Happy Jack mine and elsewhere in the White Canyon area.

This report gives preliminary results of detailed mapping done during the 1952 field season, summarizes habits of the uranium deposits, and presents guides that may be useful in exploring for additional deposits. A map of the Happy Jack mine is shown in figure 39. The large-scale map (pls. 8, 9) of part of the mine was prepared by Trites and Renzetti from June 15 to July 4. Between August 7 and October 2 Trites and Chew mapped the walls of about 750 feet of drifts in the northeast part of the mine on a scale of 1 inch = 5 feet. The fracture map (pl. 8) was prepared from the information on the wall maps by projecting all fractures to a waist-high datum plane.

The work described in this report was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

LOCATION

The Happy Jack mine is on the southwest rim above White Canyon in the western part of the White Canyon area, San Juan County, Utah. The mine is about 15 miles by road east of Hite, Utah, and 75 miles west of Blanding, Utah (fig. 38); it is reached either from Hite or Blanding by Utah Highway 95, a graded dirt road that connects Blanding with Hanksville, Utah.

PREVIOUS WORK

A report on the Happy Jack mine and the contiguous area has been written by Benson, Trites, Beroni, and Feeger (1952). Unpublished information concerning the mine and surrounding area has been furnished by the following geologists: R. P. Fischer and R. U. King (1948), S. K. Smyth (1949), P. H. Dodd (1950), H. C. Granger and E. P. Beroni (1950), J. W. Gruner and Lynn Gardiner (1950), and L. J. Miller (1952).

MINE WORKINGS

Mine workings consist of slightly more than 3,000 feet of drifts and crosscuts. Four main adits have been driven into the hillside and

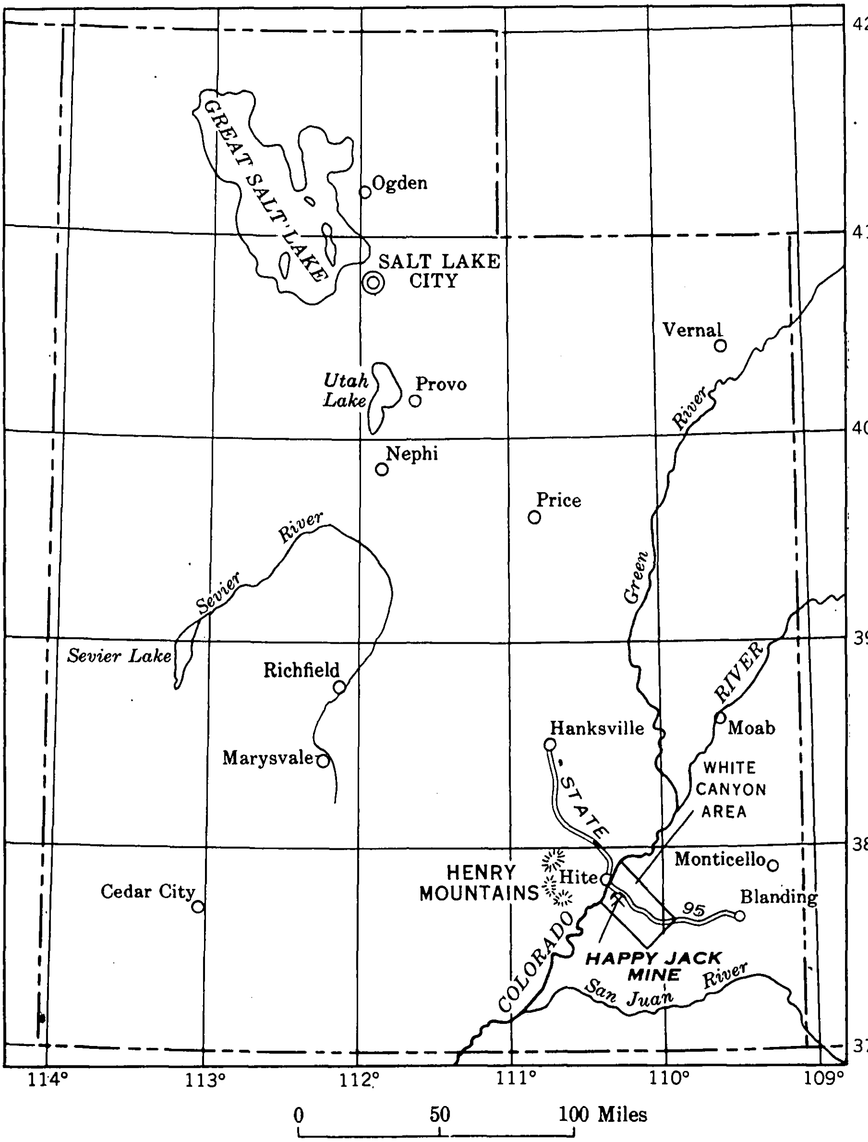

FIGURE 38.—Index map showing location of the Happy Jack mine, San Juan County, Utah.

have been connected by crosscuts. About one-quarter of the mine has been mapped and is discussed in this paper.

GENERAL GEOLOGY

Rocks cropping out near the Happy Jack mine range from the Cutler formation of Permian age to the Kayenta formation of Jurassic(?) age and total more than 2,700 feet thick (see generalized section below). These beds are on the west flank of the Monument upwarp

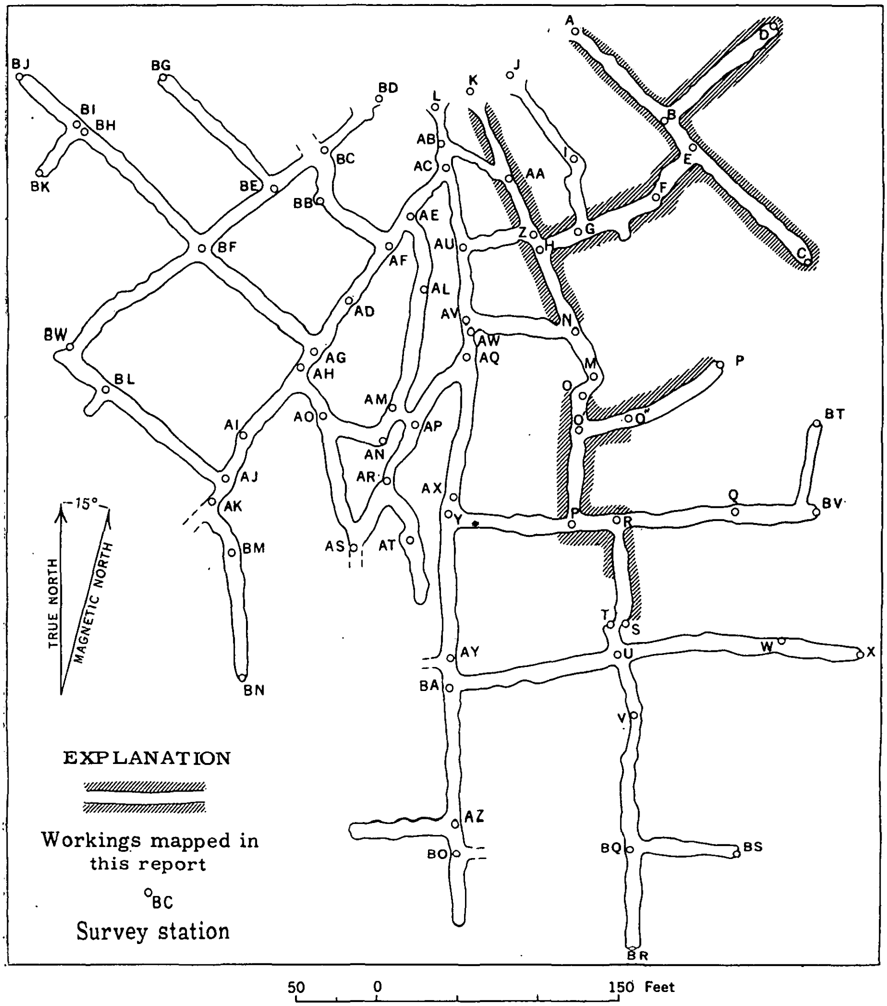

FIGURE 39.—Map of the Happy Jack mine showing the workings, July 1952.

that extends from northeastern Arizona to Elk Ridge in southeastern Utah near the northeastern corner of the White Canyon area. The beds near the Happy Jack mine have a regional dip of 2°–3° SW. The nearest exposures of igneous rocks are about 17 miles west of the Happy Jack mine in the Henry Mountains.

Only the uppermost Moenkopi strata, the Shinarump conglomerate, and the lowermost beds of the Chinle formation are described in detail in this report because only these three formations are present in the immediate vicinity of the Happy Jack mine.

Generalized section of the rock formations near the Happy Jack mine, San Juan County, Utah

Age	Formation or member	Thickness (feet)	Description
Jurassic(?)	Kayenta formation	200±	Sandstone, dark-red, thin-bedded.
Triassic(Late Triassic).	Wingate sandstone	300±	Sandstone, reddish-brown, massive, crossbedded.
	Chinle formation:		
	Upper member	107	Sandstone, reddish-brown, thin-bedded, calcareous; siltstone and mudstone.
	Middle member	304	Mudstone and siltstone, variegated, calcareous and bentonitic.
	Lower member	224	Claystone, gray and purple; sandstone and conglomerate, gray to brown, lenticular.
	Shinarump conglomerate	0–40	Sandstone, yellow to gray coarse- to fine-grained; conglomerate, orange; laminated siltstone and clay; lenticular.
	Unconformity		
Triassic (Early and Middle Triassic).	Moenkopi formation	195	Siltstone, dark reddish-brown to pale red, laminated; shale, brown; sandstone, brown, fine-grained; and conglomerate.
	Unconformity		
Permian	Cutler formation:		
	Organ Rock Tongue	306	Siltstone, reddish-brown, micaceous; and very fine-grained sandstone.
	Cedar Mesa sandstone member.	1,000 (estimated).	Sandstone, cream-colored, crossbedded; shale, red, local, near top.

MOENKOPI FORMATION

In the White Canyon area the Moenkopi formation of early Triassic age is 195 feet thick and consists of interlayered beds of brown siltstone, fine-grained sandstone, and shale; locally, it has a bed of conglomerate at the base. The Moenkopi strata just beneath the Shinarump conglomerate consist of brown micaceous sandy siltstone that has been bleached to grayish green. This siltstone is laminated, the laminae averaging 3 mm thick.

The contact of the Moenkopi formation with the overlying Shinarump conglomerate is an erosional unconformity produced by the flowing water that deposited the sediments of the Shinarump conglomerate.

SHINARUMP CONGLOMERATE

In the White Canyon area the Shinarump conglomerate is discontinuous, occurring in lenticular beds that have exposures ranging from a few hundreds of feet to more than 5 miles in length. A section of the Shinarump as much as 40 feet thick may pinch out within a distance of 2,000 feet.

The Shinarump strata at the Happy Jack mine are about 16 feet thick at the outcrop and thicken to 40 feet behind the rim. The outcrop of the Shinarump strata forms a ledge that extends ½ mile northwest and 1¼ miles southeast of the mine. Beyond these points the Shinarump pinches out.

The lower beds of the Shinarump conglomerate fill a channel more than 750 feet wide and 10 feet deep cut into the upper part of the Moenkopi formation. Diamond drilling by the U. S. Atomic Energy Commission indicates that the channel trends about due west but that the channel apparently bends rather abruptly beyond the southwestern limit of the underground workings and continues southwest. Diamond drilling further indicates that the channel is not well-defined, and that the bottom is marked by numerous scours.

Channels in the Shinarump are common within the mine and range from a few inches to 10 feet in width. This channeling is indicated by the presence of pinched-out beds and of abrupt lithologic changes both laterally and vertically. Three channels have been mapped in the Shinarump rocks (pl. 8).

The Shinarump conglomerate is comprised of beds of coarse- to fine-grained quartzose sandstone, conglomerate, siltstone, and claystone. Many of the conglomerate beds grade laterally into coarse-grained sandstone; gradation also has been noted between beds of fine-grained sandstone and siltstone.

The sandstone beds range from 1 to 100 feet in length and from a few inches to 4 feet in thickness. A large number of these beds have poorly developed internal stratification, the clarity of this stratification depending upon the type of cross bedding and the angle at which the unit has been transected by the mine working. Most of the stratified units are lenticular, although some tabular units are present. Nearly all of the units have erosional lower surfaces as described by McKee and Weir (1953).

Structural features within the beds include cross-stratification and contortion of the strata. Cross-stratification is very common in the sandstone beds; most of the sets of cross-strata have planar surfaces of erosion as their lower bounding surfaces. These planar sets have resulted from beveling of the underlying beds and subsequent deposition. Nearly all of the cross-stratification sets are lenticular, that is, are bounded by converging surfaces, the lower of which are commonly curved. Most of the cross-strata arch downward and may be described as concave upward. The cross-strata in the part of the mine mapped dip from less than 10° to more than 20°; the general direction of dip is about N. 65° W. The dip of the cross-strata suggests that the flow of streams here was from the southeast. Most of the cross-strata are termed high angle because the average maximum inclination is greater than 20° (McKee and Weir, 1953). Both medium-scale and small-scale cross-stratification are present, but the medium-scale cross-strata, 1 to 10 feet in length, is more abundant.

Horizontal bedding is common only in sandstone beds and conglomeratic sandstone beds that immediately overlie siltstone beds in the lower part of the Shinarump conglomerate. These conglomeratic sandstone beds contain abundant interstitial clay and silt.

Many beds have been contorted by slumping that has resulted from the collapse of steep channel sides shortly after consolidation. Such slump features are especially common in fine-grained sandstone and siltstone beds where units as much as 1 foot thick have been distorted. A fault with reverse movement near station R. (pl. 9) has a displacement of 2 feet and is believed to have been caused by rupture and movement at the time the sediments were deposited. Current lineation was observed in the siltstone in the channel crossing the drift near station O.

The sandstones are poorly sorted and consist predominantly of grains of quartz, from a trace to 5 percent microcline, and a trace of mafic accessory minerals. Mica seems to be absent in most of the sandstones although it is conspicuous in the sandstone of the Shinarump in most of the White Canyon area. The quartz grains range from angular to subangular, the degree of angularity depending largely upon the amount of authigenic quartz surrounding the original grains. The microcline grains are pale yellow to red, and are commonly subangular. The sandstone is cemented by clay, iron oxides, and jarosite.

Larger granules and pebbles of quartz, quartzite, siltstone, and claystone comprise from 1 to more than 10 percent of many of the sandstone beds. The pebbles of quartz and quartzite are as much as 1 inch in diameter and are commonly well-rounded. The siltstone and claystone pebbles are most abundant in the lower parts of the sandstone beds and are as much as 4 inches across.

Siltstone occurs in beds ranging from 1 to 4 feet thick and from 10 to 100 feet in length; it is also in small stringers from one-eighth to one-half inch thick and from 1 to 6 feet long. The siltstones are gray, greenish-gray, yellow, pink, or combinations of these colors. Most of the siltstones are sandy, and many grade laterally into sandstones. Horizontal contacts, however, are very sharp and vertical gradations through large ranges in grain size have not been found.

The conglomerate occurs in poorly defined units that are lateral gradations of coarse-grained sandstone. The conglomerate consists largely of pebbles of siltstone and claystone with few pebbles of quartz and quartzite.

Carbonized wood is abundant in the Shinarump conglomerate. Two forms of carbonized woody material have been recognized, a soft black mineral charcoal and a vitreous coal. The wood occurs both as logs and as accumulations of smaller fragments which have been called "trash deposits." These trash accumulations tend to be near the bottom of the sandstone beds, and commonly the contact between two cross-stratified beds will be marked by a thin trash deposit from less than 1 inch to 6 inches thick. Carbonized vegetal material is abundant as partings and fragments in many of the siltstone beds. The largest logs mapped are 2 to 3 feet long and 4 to 6 inches in diameter. Many of the logs have been replaced by sulfide minerals, pitchblende, hematite, limonite, and secondary copper minerals. Many smaller pieces of carbonized wood have been replaced by pyrite.

LOWER MEMBER OF THE CHINLE FORMATION

Thinly laminated beds of gray sandy claystone of the lower member of the Chinle formation overlie the Shinarump conglomerate at the Happy Jack mine. This member is about 225 feet thick, and contains several lenticular beds of sandstone. It is capped by a bed of resistant sandstone and conglomerate about 20 feet thick.

STRUCTURAL FEATURES

The rocks at the Happy Jack mine dip 2°–3° SW and have been cut by four sets of steeply dipping fractures. These fractures strike N. 65° W., N. 60° E., N. 85° E., and due north (pl. 9), listed in order of decreasing prominence. Besides the reverse fault noted above, only one other fault, about 30 feet south of Station A, (pl. 9) has been mapped. This fault strikes N. 69° W., dips almost vertically, and has had the north side apparently moved 1.7 feet westward relative to the south side. No vertical movement is apparent.

Some clay seams occurring at lithologic contacts are apparently abnormally thickened over very short distances and may have rolled up into thicker masses as a result of bedding-plane movement. Elsewhere along many of these contacts a finely divided clayey material, similar to fault gouge, has been observed. These features could be the result of penecontemporaneous deformation similar to that described by Fairbridge (1946).

Many of the quartz and quartzite pebbles of the more conglomeratic sandstones are fractured and are easily broken along the fracture planes. This fracturing is not believed to have resulted entirely from blasting in the mine because the shattering is very uniform and general in distribution, and pebbles in the outcrop of the Shinarump have also been fractured.

The relation of the fracturing to the ore deposits has not been determined, but the fracturing is believed to have occurred after ore deposition. The ore trends seem to have no relation to the fractures.

No fractures are filled with ore material although many fractures contain secondary sulfates and limonite, especially near the surface.

Early studies by the U. S. Geological Survey in the White Canyon area during 1951 suggested that fractures may have played a dominant role in the emplacement of many of the uranium deposits (Benson, Trites, Beroni, and Feeger, 1952, p. 6 and 8). The present study shows no such structural control of the ore deposits in the Happy Jack mine.

URANIUM DEPOSITS

MODE OF OCCURRENCE

The uranium in the Happy Jack mine occurs as bedded deposits, as replacements of "trash" accumulations, and as replacements of larger wood fragments.

The bedded deposits occur in siltstone beds and along the contacts between sandstone beds and between beds of sandstone and siltstone. Uranium minerals extend upward into the crossbeds of some of the sandstone above these deposits. The bedded deposits range from a knife-edge to more than 1 foot in thickness.

Replacement of "trash" accumulations is one of the most widespread occurrences of uranium in the mine; about 40 to 50 percent of the trash has been replaced by uranium and copper minerals in the part of the mine studied. The replaced material appears to have been small wood fragments, other plant remains, and organic material consisting of fragments too small to identify. Deposits of this type range from a fraction of an inch to 3 feet thick. Some of these areas also contain coal seams, but replacement of the coal appears to have been negligible.

Wood fragments are replaced by uranium and copper minerals near uraniferous areas. The largest replaced wood fragment found so far is about 3½ feet long and 3 inches in diameter. Wood more than 2 or 3 feet from uraniferous areas is replaced by iron oxides or altered to charcoal.

MINERALOGY

The principal uranium mineral at the Happy Jack mine is pitchblende. Some of the pitchblende is of such high specific gravity (9.1) and such purity (greater than 90 percent UO_2) that, according to A. D. Weeks (written communication, 1952) it should be called uraninite. This uraninite has replaced plant remains, larger fragments of wood, and seams and pebbles of claystone and siltstone. In places the uraninite partly fills the interstices between quartz grains and fills microscopic fractures cutting the grains.

A soft black material believed to be sooty pitchblende is contained in many of the bodies of uraninite. Also closely associated with the uraninite, and commonly deposited on the mine walls, are the uraniferous sulfates betazippeite, johannite, and uranopilite (Weeks and Thompson, 1954).

Sulfide minerals are closely associated with the uraninite. Pods of the most radioactive material commonly contain abundant covellite and minor bornite. Chalcopyrite, pyrite, bornite, and covellite have replaced wood fragments and impregnated sandstone beds adjacent to uraniferous material. Many fragments of charcoal and seams of carbonaceous claystone and siltstone that have been replaced by uraninite are rimmed by concentrated impregnations of chalcopyrite in the sandstone. Chalcopyrite also occurs in stringers and small masses and blebs in siltstone above or below uraniferous sandstone.

Galena has been found in the southeastern part of the mine workings where it has impregnated sandstone containing abundant uraninite replacements of plant fragments. Sphalerite has also impregnated the sandstone in the same area, but is associated with charcoal that has not been replaced by uraninite.

Secondary quartz has been added as overgrowths on the detrital quartz grains of many of the more coarse-grained sandstones. This authigenic quartz forms crystal faces on many of the grains.

In addition to the quartz, clay minerals, and feldspar contained in the ore-bearing sandstone, the principal gangue minerals are chalcedony, limonite, hematite, gypsum, jarosite, and minor barite.

Limonite occurs in many of the sandstone beds, especially in the more oxidized parts of the mine. Zones of limonite, such as are found in the eastern part of the mine workings, surround zones of sulfide minerals and may indicate the boundary of the ore body. The limonite, much of which has been identified as goethite by T. G. Lovering (oral communication, 1953), occurs as impregnations in sandstone, as replacements of plant remains and larger pieces of wood, as impregnations and replacements of claystone and siltstone seams and fragments, and as fillings of many of the fractures. Limonite impregnations in sandstone beds range from sparsely distributed spots, 0.2 to 2 mm across, to strongly concentrated impregnations from less than 1 inch to 1 foot thick. Strongly concentrated limonite impregnation zones occur around many of the plant remains, larger pieces of wood, and claystone and siltstone seams that have been replaced by uraninite and sulfide minerals. Some of the more heavily concentrated limonite impregnating sandstone is abnormally radioactive; much of this radioactivity is believed to be due to disintegration products from the radioactive decay of uranium.

In the oxidized part of the mine hematite has replaced some of the larger wood fragments where it is associated with limonite and secondary copper minerals.

Locally chalcedony has cemented the quartz and feldspar grains of some of the sandstone beds. Some of the chalcedony is in fibers that are in parallel orientation over areas as much as 2 inches across.

Some of the fractures cutting Moenkopi and Shinarump strata are filled with gypsum which is believed to have impregnated the sandstone adacent to sulfide bodies in the more oxidized parts of the mine.

Locally jarosite has impregnated the sandstone beds in the mine and seems to be associated with carbonaceous material.

Barite is rare in the Happy Jack mine, but in the southeastern part of the mine white tabular crystals, 1 mm long, have been found associated with sphalerite that has replaced carbonized wood.

Secondary copper minerals, mostly the hydrous copper sulfates, occur mainly in the outer 30 feet of the mine, but have been found as much as 250 feet behind the portals. A small amount of malachite has been found near the surface. These minerals have impregnated the sandstone beds, siltstone and claystone seams and pebbles, and replaced larger wood fragments.

LOCALIZATION

Apparently most of the uraninite has been localized by sedimentary features. Localization by megascopic structural features cannot be shown, although uraninite locally has filled fractures in quartz grains; bedding-plane movement, by fracturing the rocks and increasing their permeability, is a possible structural control but the existence of such movement has not been proved.

The amount of uranium contained in a sandstone bed is believed to depend mainly upon the position of the bed in the channel, the permeability of the sandstone, and the amount of carbonized wood and plant remains within the bed.

Most of the uranium deposits in the White Canyon area, as at the Happy Jack mine, are in the lower sandstone or conglomerate beds of the Shinarump conglomerate. Most of these ore-bearing sandstone and conglomerate beds immediately overlie impermeable siltstone beds of either the Moenkopi formation or the Shinarump conglomerate. This circumstance is believed to be the most important factor in the localization of the uranium ore deposits. These ore-bearing sandstone beds are believed to have been rather flat tabular conduits through which subsurface solutions migrated. Whether solution movements along these conduits took place above or below the water table has not been determined, but if the uranium deposition was of early Tertiary age, several thousands of feet of overlying sediments of Jurassic and Cretaceous ages may have been present when the minerals were deposited. The solution flow seems to have been similar to groundwater movement but the reduced state of the iron as the sulfide suggests that reducing conditions were present instead of oxidizing conditions that are prevalent in most ground-water circuits. The amount of carbonaceous material in these beds is believed to be insufficient to maintain a reducing environment for the great volume of solutions that must have migrated and deposited the sulfide minerals, and it is believed that the solutions themselves must have been reducing in nature. Solution movement is known to be possible below the water table (Tolman, 1937, p. 305–307). Water flowage below the water table has occurred in many mines, and deep wells have brought forth artesian flow from aquifers far below the present water table. Flow of this type might well explain the unoxidized condition of the ore deposits. The underlying impermeable beds would suggest a perched subsurface flow, and siltstone beds locally overlying the ore-bearing sandstone may have acted further to confine the solutions to the sandstone.

The grade of the uranium deposits seems to be independent of the thickness of the sandstone bed containing them. In the White Canyon area, the thickness of sandstone beds containing more than 0.20 percent U_3O_8 is a few inches to 4 feet. Zones as much as 7 feet thick have been mined, but most of these are believed to be composed of two or more beds of ore-bearing sandstone. Deposits of this type have been found at the Happy Jack mine.

The permeability of the sandstone is believed to be the second important factor in determining the amount of uranium contained in a sandstone. Permeability conditions within the Shinarump strata are believed to range between extremely wide limits; siltstone beds probably are nearly impermeable, sandstone and conglomerate beds containing significant amounts of clay and silt cement may be moderately permeable, and sandstone beds with little cement are probably highly permeable. Most of the uranium deposits in the Happy Jack mine occur in beds having the intermediate permeability; these beds contain abundant seams and pebbles of claystone and siltstone and abundant claystone or siltstone cement. The amount of claystone and siltstone in a sandstone bed is also dependent upon the lithology of the underlying bed; sandstone beds immediately overlying siltstone beds contain a greater abundance of clay and silt particles than sandstone beds overlying other sandstone beds. Perhaps the more permeable sandstone beds have had the uraniferous solutions pass through them too rapidly to permit precipitation within them, whereas the silty and clayey sandstones had a much slower solution movement allowing sufficient time for the deposition of uranium. Control of the ore deposits by the permeability of the beds is suggested in many of the deposits in the White Canyon area, but is not clearly seen at the Happy Jack mine.

Carbonized wood and plant remains are believed to be less important than position or permeability in determining the total amount of uranium deposited in a sandstone bed, but are believed to localize the uranium within the bed. Sandstone beds containing significant amounts of carbonized vegetal material also tend to contain abundant claystone and siltstone cement and fragments. Carbonized wood is replaced in areas of abundant uraninite, and trash accumulations form the center of most uranium mineral concentrations that grade out into and impregnate the host rock. In beds containing relatively small amounts of uranium minerals, the trash lenses contain most of the uranium, and the host rock is apparently barren. The carbonaceous material near the base of some sandstone beds has associated sulfide and uranium minerals, whereas similar material higher in the bed is barren of such minerals.

Locally the three types of deposits—bedded, trash replacement, and wood replacement—occurring in close proximity form definite areas or "ore shoots" of high-grade uranium ore. These ore shoots in many places have sharp borders, and appear to be elongated. The best evidence for this is in the drift between stations A and C (pl. 8). A narrow band of sulfide and limonite concentration can be traced along the walls for most of the distance between E and C. The face at C contains an irregular lenticular area, about 6 feet wide and 4 feet thick, of concentrated sulfide minerals. The area is highly radioactive. The drift is believed to have been driven along an ore shoot that trends approximately parallel to the drift. This belief is supported by the rapid decrease in radioactivity in drifts B–D and E–F.

ORE GUIDES

Guides believed to be useful for exploration for uranium ore bodies in the Happy Jack mine area, in order of importance, are as follows:

1. Interbedded siltstone lenses. Uranium ore is apparently concentrated in the lower parts of sandstone beds overlying this type of lens. The Shinarump conglomerate contains several of these lenses, one above the other, separated by sandstone. At least three of these lenses have been exposed in the mine workings. Drifts floored in the Moenkopi formation should be driven with the idea in mind that ore can occur anywhere, vertically, in the lower part of the Shinarump conglomerate. The back of the drift should be explored at intervals close enough together to determine the presence or absence of siltstone lenses overhead.

2. Presence of claystone and siltstone as cement, seams, and pebbles. This type of lithology is favorable for uranium occurrence in sandstones immediately overlying lenses of siltstone.

3. Presence of concentrations of carbonaceous trash in sandstone.

4. Presence of covellite, either massive or disseminated, in the

sandstone. A similar occurrence of bornite is favorable, but covellite is believed to be a better guide.

5. Presence of chalcopyrite. Chalcopyrite occurs everywhere in the ore zones but also occurs in high concentrations as much as 40 feet from high-grade ore.

6. Presence of carbonized wood. Carbonized wood indicates favorable lithology, but in mineralized zones it is replaced by copper and uranium minerals.

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