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PRELIMINARY REPORT ON THE WHITE CANYON AREA SAN JUAN COUNTY UTAH

By W. E. Benson, A. F. Trites, Jr., E. P. Beroni, and J. A. Feeger

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Oscar L. Chapman, Secretary

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SAN JUAN COUNTY, UTAH

ABSTRACT

The White Canyon area in San Juan County, Utah, contains known deposits of copper-uranium ore and is currently being mapped and studied by the Geological Survey. To date, approximately 75 square miles, or about 20 percent of the area, has been mapped on a scale 1 inch=1 mile.

The White Canyon area is underlain by more than 2,000 feet of sedimentary rocks, Carboniferous to Jurassic(?) in age. The area is on the flank of the Elk Ridge anticline, and the strata have a regional dip of 1° to 2° SW.

The Shinarump conglomerate of Late Triassic age is the principal ore-bearing formation. The Shinarump consists of lenticular beds of sandstone, conglomeratic sandstone, clay, and siltstone, and ranges in thickness from a feather edge to as much as 75 feet. Locally the sandstones contain silicified and carbonized wood and fragments of charcoal. These vegetal remains are especially common in channel-fill deposits.

Jointing is prominent in the western part of the area, and apparently affects all formations. Adjacent to the joints some of the redbeds in the sequence are bleached.

Deposits of copper-uranium minerals have been found in the Moenkopi, Shinarump, and Chinle formations, but the only production of ore has been from the Shinarump conglomerate. The largest concentration of these minerals is in the lower third of the Shinarump, and the deposits seem to be controlled in part by ancient channel fills and in part by fractures. Locally precipitation of the copper and uranium minerals apparently has been aided by charcoal and clays.

Visible uranium minerals include both hard and soft pitchblende and secondary hydrosulfates, phosphates, and silicates. In addition, unidentified uranium compounds are present in carbonized wood and charcoal, and in veinlets of hydrocarbons. Base-metal sulfides have been identified in all prospects that extend beyond the oxidized zone. Secondary copper minerals in the oxidized zone include the hydrous sulfates and carbonates, and possibly chrysocolla. The principal gangue minerals are quartz, clay minerals, chlorite, oxides of iron and manganese, alunite, calcite, gypsum, pyrite, allophane, gibbsite, opal, and chalcedony.

The origin of the copper-uranium ores has not been determined, but the association of many deposits with fractures, the mineralogic assemblage, and a lead-uranium age determination of 50 to 60 million years for the pitchblende in the Happy Jack mine favor the hypothesis that the ores are of hydrothermal origin and were deposited in early Tertiary time.

Criteria believed to be the most useful in prospecting for new deposits are (1) visible uranium minerals; (2) visible copper minerals; (3) alunite; (4) hydrocarbons; and (5) bleaching of the underlying Moenkopi formation.

INTRODUCTION

Location

The White Canyon area is in the central part of San Juan County, Utah (fig. 1). It is bounded on the north by Dark Canyon, on the east by Elk Ridge, on the south by Red Canyon, and on the west by the Colorado River; it is about the size of two 15-minute quadrangles.

The area is accessible from the east and west by Utah Highway 95, a graded dirt road. Blanding, Utah, is 50 miles east and Hanksville, Utah, is 65 miles west across the Colorado River. A ferry at Hite, Utah, provides the only vehicular crossing of the Colorado River in the area.

Previous work

A reconnaissance of the White Canyon area was made between 1925 and 1929 by H. E. Gregory (1938, 123 pp.).[1] Some of the uranium deposits in White Canyon were examined briefly by H. C. Granger and E. P. Beroni (1950) for the U. S. Geological Survey, and a report on the Happy Jack mine was made by P. H. Dodd (1950, 23 pp.) for the U. S. Atomic Energy Commission. Other reports on the uranium deposits of the area have been made by Fischer and King (1948), Smyth (1949), and Gruner and Gardner (1950).

Purpose of work

The principal objectives of the present investigation in the White Canyon area were (1) to map the general geology and determine the regional relationships of the uranium deposits; (2) to study the physical and mineralogic characteristics of the uranium deposits to establish ore controls and guides; and (3) to select areas favorable for exploration for concealed deposits in the Shinarump conglomerate and other Triassic formations. This work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Field work for this report was done during the summer of 1951.

[1]See literature cited.

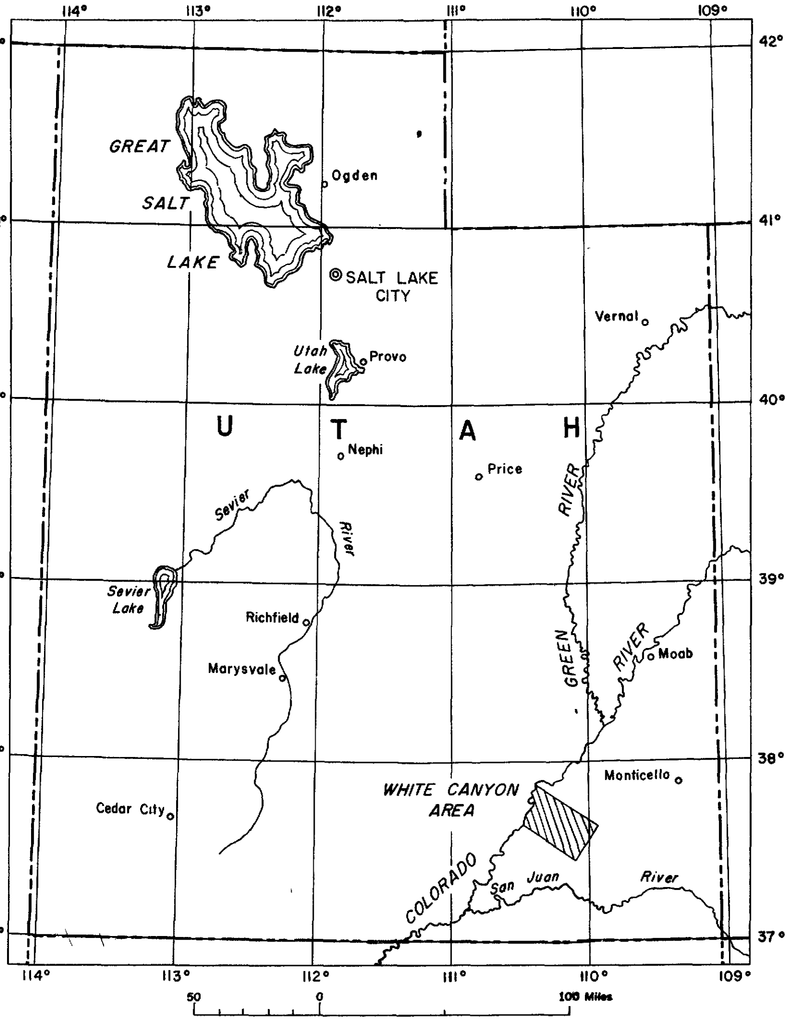

Figure 1.--Index map of Utah.

Field methods

Approximately 75 square miles have been mapped on a scale 1 inch=1 mile. The method used was an attempt to combine the advantages of a plane table with the advantages of aerial photographs. Triangulation control was established by plane table, and points on the geologic contacts were located by intersection. The contact lines were mapped on the aerial photographs and were transferred to the plane-table sheets by inspection.

Parts of the Gonway and North Point claims, a quarter of a mile east of the Happy Jack mine, were mapped by plane table on a scale 1 inch=20 feet.

GENERAL GEOLOGY

Rocks in the White Canyon area consist of sedimentary formations ranging in age from Carboniferous to Jurassic(?); the entire section is more than 2,000 feet thick. These beds are on the southwest flank of the Elk Ridge anticline and have a regional dip of 2° to 3° SW. The nearest exposures of igneous rocks are in the Henry Mountains, about 7 miles to the west.

Gregory (1938, pp. 40-56) has described most of the rocks exposed in the area. The general stratigraphic features of the formations are summarized in the table referred to on the following page, part of which is taken from Gregory.

Carboniferous rocks

Hermosa formation

The Hermosa formation of Pennsylvanian age is exposed only in Dark Canyon, and was not examined during this investigation. Gregory (1938, p. 40) described the formation as interbedded limestone, sandstone, and shale, ranging from 400 to 1,000 feet in thickness.

Permian(?) rocks

Rico formation

The Rico formation of Permian(?) age, like the Hermosa formation, is exposed only in Dark Canyon, and was not studied by the authors. Baker (1946, pp. 32-36) has described the Rico formation of the Green River Desert-Cataract Canyon region north of White Canyon as comprising approximately 575 feet of interbedded sandstone, shale, siltstone, and limestone, with sandstone predominating.

General sections of the rock formations in the White Canyon area, Utah

Age	Formation	Description	Thickness (feet)
Jurassic(?)	Glen Canyon group: Navajo sandstone.	Sandstone, cream-yellow, massive cross-bedded. (Not yet examined.)	300±
	Glen Canyon group: Kayenta formation.	Sandstone, dark-red, thin-bedded. (Not yet examined.)	200±
	Glen Canyon group: Wingate sandstone.	Sandstone, reddish-brown, massive cross-bedded.	300±
Triassic (Upper Triassic).	Chinle formation:		
	Upper member.	Sandstone, reddish-brown, thin-bedded calcareous; siltstone and mudstone.	100±
	Middle member.	Mudstone, variegated calcareous and bentonitic; and siltstone.	300-330
	Lower member.	Clays, gray to variegated; gray to brown lenticular sandstone and conglomerate.	220-245
	Shinarump conglomerate.	Sandstone, yellow to gray conglomerate; siltstone and clay.	0-75
	Unconformity.		
Triassic (Lower Triassic).	Moenkopi formation.	Siltstone, dark-brown to grayish-red thin-bedded; brown to yellow shale, and white to pink fine-grained sandstone with local clay balls.	200-350
Permian	Cutler formation:		
	White Rim sandstone member.	Sandstone, cream-colored fine-grained. (Not yet examined.)	< 10
	Organ Rock tongue.	Siltstone, reddish-brown micaceous; and very fine grained sandstone.	200-300
	Cedar Mesa sandstone member.	Sandstone, cream-colored, cross-bedded; with local red shale near the top.	1,000±
Permian(?)	Rico formation.	Sandstone, interbedded gray, red, and purple; siltstone, shale, and limestone.	575±
Carboniferous (Pennsylvanian).	Hermosa formation.	Limestone, gray cherty; with gray, buff, and red calcareous sandstone and shale.	400-1,000

Permian rocks

Cutler formation

The Cutler formation in southeast Utah consists of six units, namely, the Halgaito tongue, the Cedar Mesa sandstone member, the Organ Rock tongue, the De Chelly sandstone member, the Hoskinnini tongue, and the White Rim sandstone member. Of these, only Cedar Mesa, Organ Rock, and White Rim members are present in the White Canyon area. The upper part of the Organ Rock tongue is a cliff-forming red sandstone similar to the Hoskinnini tongue, and may be the equivalent of the Hoskinnini.

Cedar Mesa sandstone member.--The Cedar Mesa sandstone member of the Cutler formation forms the floor of White Canyon and has been trenched by streams to depths of 50 to 200 feet. It comprises thick beds of light-cream colored, cross-bedded fine-grained calcareous sandstone with local thin beds of red shale near the top. The cross bedding is eolian-type and is foreset to the southeast. In Dark Canyon the Cedar Mesa sandstone member directly overlies the Rico formation with apparent conformity.

Organ Rock tongue.--The Organ Rock tongue of the Cutler formation is composed of 200 to 300 feet of pale and dark reddish-brown micaceous siltstone and very fine grained sandstone, the upper 50 to 100 feet of which forms a cliff. Gray sandstone beds are present in the upper 50 feet of the formation near the western end of the mapped area. The upper cliff-forming sandstone may be the equivalent of the Hoskinnini tongue.

White Rim sandstone member.--The White Rim sandstone member, described by Baker (1946, pp. 44-48) and Hunt (1952?), occurs only in the lower part of White Canyon, where it is a light-colored fine-grained sandstone, less than 10 feet thick. It thins and pinches out a few miles east of the Colorado River.

Triassic rocks

Moenkopi formation

The Moenkopi formation of Early Triassic age comprises 200 to 350 feet of thin-bedded dark-brown to grayish-red siltstone, brown to yellow shale, and grayish-red to light-gray sandstone. Many of the sandstone beds contain abundant clay balls. In the western part of the mapped area the lower part of the Moenkopi contains lenticular beds of light-gray sandstone, and beds of dark-gray, petroliferous cherty conglomerate. The lowest bed of the cherty conglomerate forms the base of the formation and fills channels cut into the underlying Organ Rock tongue. The lower beds of the Moenkopi formation and upper beds of the Organ Rock tongue are crumpled locally by small folds as much as 5 feet high and 5 to 10 feet wide.

Shinarump conglomerate

The Shinarump conglomerate, the principal ore-bearing formation in the White Canyon area, rests unconformably on the Moenkopi formation and was regarded by Gregory (1938, p. 49) as the basal conglomerate of the Upper Triassic Chinle formation. The most striking feature of the formation is its extreme lenticularity. Conglomerate of the Shinarump 40 feet thick may pinch out completely in an outcrop less than 2,000 feet in length. The thicker parts of the formation resulted both from the filling of channels in the underlying Moenkopi formation and from lateral facies change to conglomerate of the overlying shales of the Chinle formation. The formation reaches a maximum thickness of 75 feet.

The Shinarump conglomerate is composed of interbedded yellowish-gray to gray, red, and brown sandstone, conglomerate sandstone, conglomerate, and gray to yellowish-gray clay and siltstone. Sandstone beds, locally conglomeratic, form the top of the formation in most exposures, and range in thickness from less than 1 foot to more than 30 feet. Sandstone constitutes the entire formation along some segments of the outcrop, especially where the Shinarump is less than 10 feet thick.

The sandstone beds of the formation consist of well-rounded to sub-angular quartz and microcline grains and a few zircon, apatite, and tourmaline grains with calcite, clay, and iron-oxide cement. In some places molds of logs remain, the wood itself having been removed. A few logs have been replaced by copper and uranium minerals and iron oxides; other logs have been silicified.

The conglomerate of the formation contains reworked siltstone fragments of the Moenkopi formation, clay balls, carbonized wood, and quartz pebbles. Where all these types of fragments are present it gives the conglomerate a "trashy" appearance. These "trashy" conglomerates are common at the base of many channel scours.

Gray clay and siltstone beds underlie the uppermost sandstone and are interbedded with it in some localities. They are most common in the channel fills, constituting the greater part of the fill in some exposures. These beds range from 2 to 30 feet in thickness. The minerals contained in the clay are principally hydromuscovite, kaolinite, and quartz. Very little montmorillonite has been identified from White Canyon. Many of the clays contain abundant fragments of charred wood, some of which has been completely carbonized to mineral charcoal. The charcoal is porous and may be pulverized easily to a black powder (Waters, A. C., personal communication). Mineral charcoal is fairly common in sedimentary formations that contain lignite coal or other carbonized plant material. In the Shinarump and Chinle formations the presence of volcanic material in the charcoal-bearing beds suggests that the charcoal was produced by falls of hot ash that partly burned the Late Triassic forests.

Chinle formation

The Chinle formation has been divided into three units: upper, middle, and lower. The lower unit of the Chinle ranges from approximately 220 to 245 feet in thickness and locally consists of variegated gray bentonitic clay, and lenticular beds of sandstone and conglomerate. A resistant sandstone and conglomerate bed, 10 to 100 feet thick, forms the top of this unit in many places. This sandstone bed, which has been confused with the Shinarump conglomerate by some geologists, has been differentiated from the rest of the lower part of the Chinle and is shown on plate 1 by the symbol ℞cs.

The middle unit of the Chinle is composed principally of variegated calcareous and bentonitic mudstone and siltstone with minor amounts of cherty conglomeratic claystone. Much of this unit may be altered tuffaceous sediments. Measured sections range from about 300 to 330 feet in thickness.

The upper unit of the Chinle comprises 100 feet of reddish-brown very fine grained calcareous sandstone, siltstone, and mudstone with some thin beds of gray and purplish-gray clay.

Jurassic(?) rocks

Glen Canyon group

Wingate sandstone.--The Wingate sandstone was not studied in detail by the authors in the White Canyon area. Gregory (1938, p. 54) has described the formation as consisting of about 300 feet of reddish-brown fine-grained cross-bedded massive sandstone. The beds form a vertical cliff capping the higher points in the area.

On the south rim of Frey Canyon the lowermost 30 to 40 feet of the Wingate consists of laminated coarse- to fine-grained sandstone with fluvial-type cross-bedding. The fine-grained sandstone above these basal beds is probably of eolian origin.

Kayenta formation.--The Kayenta formation caps the Wingate sandstone in many places; it was not examined during the present examination. The Kayenta consists largely of fine-grained red fluvial sandstone.

Navajo sandstone.--Remnants of Navajo sandstone cap the Kayenta in a few places, but are inaccessible in the area studied.

STRUCTURE

The sedimentary rocks of the White Canyon area dip 1° to 2° SW., except in the western part of the area, near the Colorado River, where the dips steepen. The upper beds of the Organ Rock tongue and the lower beds of the Moenkopi formation have been folded into minor flexures in the western part of the mapped area.

The rocks in the different formations are strongly jointed, especially in the western part of the mapped area. Many of these joints are traceable from the top of the Moenkopi formation through the Organ Rock tongue and the Cedar Mesa sandstone member of the Cutler formation in the bottom of the canyon. Just northwest of the mapped area some similar fractures, which displace beds of the Cedar Mesa sandstone member, appear to be faults.

The three most prominent joint systems trend due east, N. 65°-75° W., and N. 65°-75° E. All have vertical dips. The Organ Rock tongue and the Moenkopi formation have been bleached in a zone as much as 3 feet wide along some of these joints. Less prominent joints, also with vertical dips, strike nearly north.

Fractures in the sandstones in the Shinarump conglomerate trend generally parallel to the main jointing in the area. A few inches to a foot of movement has taken place along some of these fractures.

URANIUM DEPOSITS

The principal known uranium deposits in the White Canyon area are shown in figure 2 and plate 1. All the ore produced has come from the Shinarump conglomerate where the uranium, commonly associated with copper, occurs in disseminated deposits in the sandstone and in veins along fractures. Uranium and copper minerals also make up low-grade disseminated deposits and vein deposits in the sandstones of the lower part of the Chinle formation and the sandstones and siltstones of the Moenkopi formation.

The uranium ore in the Shinarump conglomerate occurs principally in the lower third of the formation; the thickness of the ore-bearing sandstones in few places exceeds 10 feet, and in most deposits is less than 5 feet.

Localization of deposits

Relation of deposits to channel fills

In other parts of the Colorado Plateau most of the uranium minerals are reported to be chiefly in deposits that fill ancient channels in the Shinarump and Morrison formations. The belief that these channel fills are a primary factor in the localization of ore bodies has been one of the more potent arguments in favor of a syngenetic origin of the uranium. In the White Canyon area, although most of the larger ore bodies are in channel deposits, many small deposits are in the base of the Shinarump and along the contact between the Shinarump and Moenkopi formations where there is no evidence of channeling and subsequent filling. Conversely, many obvious channels have no copper or uranium minerals.

Examples of deposits in channel fills are as follows: (1) The Hideout claim is in a channel 50 to 75 feet wide and about 7 feet deep. Uranium and copper minerals are in the lower 5 feet of the channel fill, and form a deposit about 50 feet wide. However, vertical fractures in the Shinarump conglomerate have also been mineralized at the Hideout claim.

(2) The Posey mine in Red Canyon is in a deposit filling a channel 40 to 50 feet deep and about 175 feet across.

(3) Scenic no. 2, Scenic no. 4, Frey no. 4, and Yellow John claims are all in obvious channels.

Examples of deposits outside of channel fills are as follows: (1) The deposits of the Jerry and Bankrupt claims are in a purplish sandstone 10 to 15 feet above the base of the lower unit of the Chinle formation. The uranium minerals appear to be associated with a fractured zone rather than with any channel fill.

(2) Along the southwest side of Frey Canyon the contact between the Shinarump and Moenkopi formations has been mineralized with little or no relation to the channels. Frey no. 1 claim is in a shallow indistinct channel, but east of this claim, the lower 2 feet of the Shinarump and the upper 3 feet of the Moenkopi contain sporadic uranium(?) minerals along more than one-fourth mile of their outcrop.

(3) At the Woodenshoe(?) claim the Shinarump conglomerate lies with apparent conformity on the Moenkopi formation. Uranium and copper minerals in the Shinarump appear to follow a set of east-west fractures. A channel within the Shinarump is filled with gray siltstone and fine-grained sandstone, and this fill has fewer uranium and copper minerals than the enclosing sandstone.

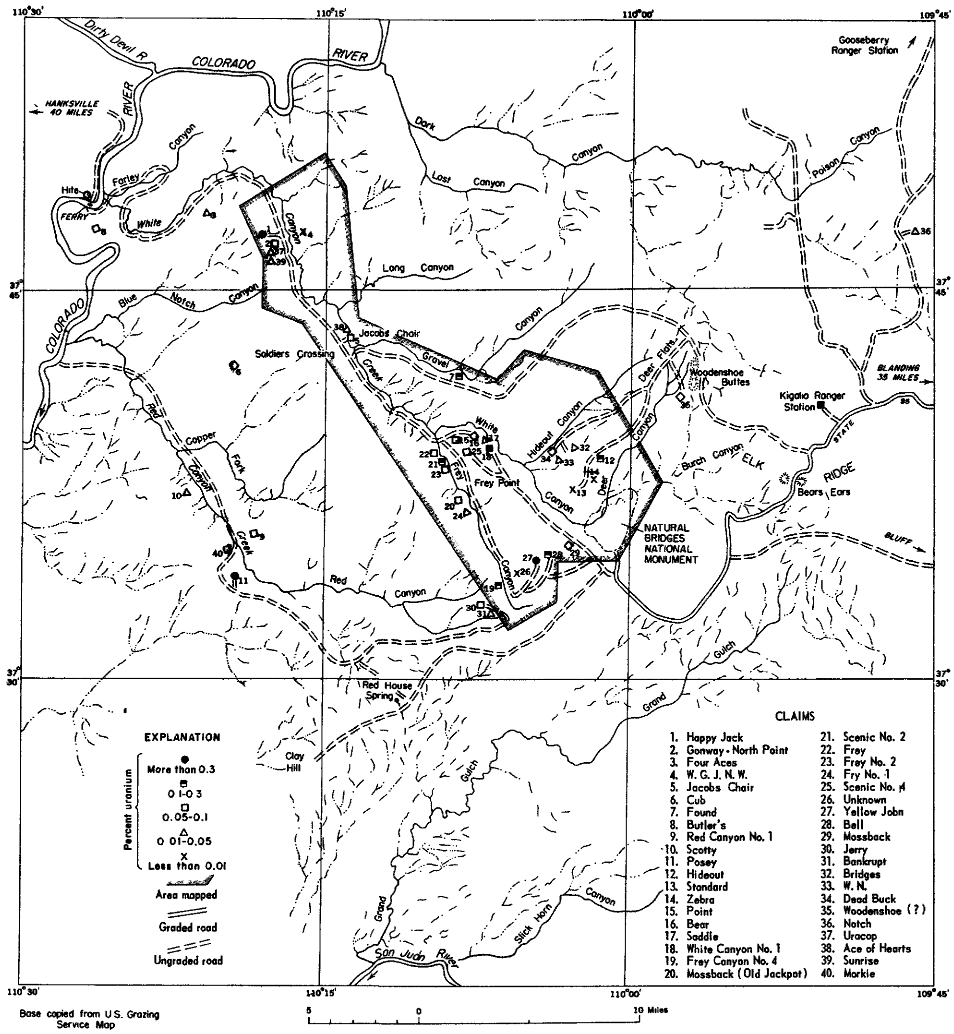

Figure 2. --White Canyon and surrounding area, San Juan County, Utah.

In addition to the above rather clear-cut examples, many of the uranium deposits in White Canyon are in beds that may or may not be channel fills. Among these is the Happy Jack mine, the largest known deposit in the district. At this locality there is no obvious channeling or scouring, but a structure-contour map prepared by the Atomic Energy Commission does show a broad shallow depression on the top of the Moenkopi formation. Whether this "sag" represents a broad indistinct channel or whether it indicates a small structure is not apparent.

Relation of deposits to structure

In many deposits, copper and uranium minerals coat fracture surfaces. Most of these exposures do not penetrate beyond the oxidized zone, and the minerals are secondary.

Deposits where the ore minerals are in fractures are as follows: (1) The Woodenshoe(?) claim has already been mentioned as a deposit not related to channel fill. In this deposit, secondary copper and uranium minerals follow fractures and apparently spread from these fractures into and along bedding planes. Much of the secondary copper is in discrete blebs along the fractures, suggesting that small masses of sulfides had been oxidized in place.

(2) Mineralization of fractures at the Hideout claim has already been mentioned.

(3) In the Moenkopi formation on the north side of White Canyon opposite the Happy Jack mine a vertical fracture is filled with a silica vein containing uraniferous chalcocite. The vein has little lateral persistence; whereas its vertical extent is indeterminable. The top of the vein as exposed is about 20 feet below the top of the Moenkopi, which is overlain directly by shales of the Chinle formation.

(4) In the Happy Jack mine bornite, chalcopyrite, covellite, and pitchblende fill closely spaced parallel fractures in the sandstone and form veinlets as much as one-fourth inch wide parallel to these fractures. Polished sections of highly uraniferous sandstone are markedly banded as a result of this structure.

In addition to mineralized fractures, the sandstones of the Shinarump conglomerate are jointed into blocks a few inches to 10 feet across. Many of these joints are discontinuous; some have been deflected in crossing between beds. These joints are especially common above many of the higher-grade deposits and in these deposits the channel fills are generally closely jointed or shattered. In contrast, channel fills that are only slightly fractured tend to be barren or have very low grade deposits.

Relation of deposits to chemical controls

The precipitation of the copper and uranium minerals has been localized, at least in part, by the chemistry of some components of the Shinarump conglomerate. Both copper and uranium minerals replace logs and other carbonized vegetal matter, and uranium seems to be especially common in some of the charcoal fragments. In addition, some clay balls in the sandstone evidently were favorable host rocks and have been highly mineralized. On the other hand, megascopically similar balls have apparently inhibited the ore-bearing solutions. These latter remain unmineralized, although surrounded by copper and uranium salts.

Summary

It is obvious that the three factors controlling deposition of the ore minerals are interrelated, and that a locality where all are present is more likely to be the site of a large ore body than a locality that shows only one of these factors. The fact that many channels that are unmineralized are associated with only a few fractures, plus the fact that many of the uranium and copper minerals are associated with channels where fractures are abundant, suggests that the fractures were the primary routes of the ore-forming fluids and that the porous rocks of the channel fills were merely favorable host rocks in which the solutions migrated.

Mineralogy of the deposits

The uranium occurs as the oxide, either as pitchblende or uraninite, in at least three deposits: the Happy Jack, Posey, and Hideout mines. Both hard (primary?) and soft (secondary?) pitchblende have been identified. Secondary uranium hydrous sulfates, phosphates, oxides, and silicates occur with the oxide minerals in these properties, and in others where the oxides have not been found. The secondary uranium minerals in the White Canyon area include the following:

Schoepite-Becquerelite .... $2UO_3 \cdot 3H_2O$

Johannite .... $(Cu, Fe, Na_2)UO_3 \cdot SO_3 \cdot 4H_2O$

Torbernite .... $CuO \cdot UO_3 \cdot P_2O_5 \cdot 12H_2O$

Phosphuranylite .... $3UO_3 \cdot P_2O_5 \cdot 6H_2O$

Uranophane .... $CaO \cdot 2UO_3 \cdot 2SiO_2 \cdot 6H_2O$

Zippeite .... Hydrous uranium sulfate.

In many deposits carbonized wood, iron and manganese oxides, and veinlets of hydrocarbon are abnormally radioactive, and the source of this radioactivity is being investigated. Some of the manganese oxides are known to contain uranium.

Base-metal sulfides have been found in every deposit in the White Canyon area that has been explored beyond the oxidized zone. These sulfides include chalcopyrite, chalcocite, bornite, covellite, arsenopyrite(?), galena, sphalerite, and pyrite. At the Happy Jack mine pyrite appears to have been the earliest of the sulfides, followed by bornite, chalcopyrite, covellite, and pitchblende. The relative ages of the other sulfides have not been determined. Gold and silver have been reported in assays from the Happy Jack mine. The copper minerals are associated with the uranium in all the principal uranium deposits, and are also found in the Shinarump conglomerate where little, if any, uranium occurs. The secondary copper minerals in the oxidized zones are the hydrous sulfates and carbonates. Malachite, azurite, brochantite, antlerite, chalcanthite, and chalcoalumite have been identified. Gangue minerals include quartz, clay minerals, and iron and manganese oxides in all the deposits; and alunite, calcite, gypsum, pyrite, jarosite, vein quartz, allophane, gibbsite, opal, and chalcedony in some deposits. Erthyrite, halotrichite, and cobaltoan siderotil have been identified at the Happy Jack mine. Cobalt-bearing pickoringite has been identified at the Scenic no. 4 claim.

In some of the deposits, later silica has been introduced into sandstone of the Shinarump conglomerate, producing veinlets through the rock and crystal faces on the quartz grains. At least one period of silica veining is believed to have followed the formation of the base-sulfide minerals of the Happy Jack mine. Calcite, iron oxides, copper carbonates, and jarosite have embayed the quartz grains in some deposits, partially replacing many of the quartz outgrowths.

Alunite fills some fractures and apparently has replaced siltstone and sandstone of the Shinarump adjacent to these fractures. Spectrographic analysis indicates that the alunite is the potassium variety, and not the natro or sodium type (Weeks, Alice, personal communication). Alunite has been found at the Gonway, North Point, and Markay nos. 2 and 3 claims.

Calcite is a cement in many sandstones of the Shinarump conglomerate and is a coating on fractures in the upper sandstone at the Gonway and North Point claims. It is finely crystalline and replaces both microcline and quartz.

Gypsum is a fracture filling in siltstone of the Shinarump conglomerate at the North Point and Gonway claims and replaces wood fragments in sandstone of the Shinarump at the Jacobs Chair claim.

Pyrite is disseminated in the sandstones of most of the uranium deposits, and is believed to be one of the earliest of the sulfide minerals. Brown "freckling" in some of the sandstones of the Shinarump conglomerate may be pyrite crystals that have been altered to hydrous iron oxides.

In the siltstones of the Shinarump conglomerate of many deposits, jarosite is commonly associated with carbonized wood, and in sandstones of the Shinarump, it forms a cement between the grains and replaces some of the feldspar and quartz. The jarosite is believed to be an alteration product of pyrite.

Allophane forms yellow, greenish-blue, and pale-blue opalescent coatings on fractures cutting siltstones of the Shinarump and Moenkopi formations at the North Point and Gonway claims. The mineral fluoresces intense yellow. A white clay-like mineral, identified as gibbsite, forms coatings and nodules on the allophane.

Locally tan and black opal cements sand grains and veins the sandstone at the North Point and Gonway claims. The tan opal has an intense yellow fluorescence. Both are associated with abnormally radioactive sandstone. Chalcedony forms a cement in some of the radioactive sandstones in the White Canyon area.

Siltstones of the Moenkopi formation have been bleached creamy-white for as much as 5 feet beneath some deposits in altered Shinarump conglomerate. Bleaching appears to have been more intense in the western part of the mapped area, especially the area near the Happy Jack mine. In some localities the beds of the Moenkopi formation have been bleached for as much as 1 foot from veins of copper and uranium minerals.

Origin of the ores

The origin of the copper-uranium ores of the Colorado Plateau has been disputed for many years. Two main hypotheses have arisen, each with a large and impressive number of adherents. The first and probably the most widely advocated hypothesis suggests that the ores are syngenetic, that is, they were formed at the same time as the enclosing sedimentary rocks. Later, ground water may have dissolved and reprecipitated the constituents, but the essential materials were already present in the original sediments. The second hypothesis suggests that the ores are of igneous origin and were precipitated from hydrothermal solutions. A third hypothesis, which has attracted fewer followers, suggests that the elements of the ores originated in the volcanic tuffs of the Chinle and Morrison formations and were subsequently leached and redeposited.

The study of the White Canyon area is still in its early stages. Both the general geologic mapping and the detailed mapping of the ore deposits is less than half completed; laboratory studies of the ores have just been started. It is probably too soon to draw definite conclusions about the origin of the ores of this district. Nevertheless, the field relations and the mineralogy of the deposits in the White Canyon area seem to support the hydrothermal hypothesis. The significant features can be summarized as follows:

(1) Many of the deposits apparently are controlled by fractures. These mineralized fractures are not confined to the Shinarump conglomerate, but are sparsely present in both the Moenkopi and Chinle formations. Fractures apparently controlled some of the ore deposition even in mineralized channel fills. This suggests that the fractures were the primary route of the ore-forming solutions, and that the channel fills were favorable host rocks with both physical and chemical features that favored precipitation of the minerals.

(2) The mineral suite of the area is typically hydrothermal. Especially suggestive of hydrothermal deposits are galena, alunite, hard (primary?) pitchblende, and the arsenic minerals. Although every mineral found in the district may have been precipitated from comparatively cool water, the repeated occurrences of the entire assemblage over the whole area suggests hydrothermal origin.

(3) Recent unpublished investigations by Stieff and Stern of the Geological Survey indicate that pitchblende from the Happy Jack mine has a lead/uranium ratio that would indicate an age of 55 to 60 million years (that is, early Tertiary). Other determinations by Stieff and Stern indicate about the same age in years for uranium deposits in the Shinarump and Morrison formations elsewhere in the Colorado Plateau. The youngest accepted age for Upper Triassic formations is 150 million years. This seems incompatible with the syngenetic hypothesis, unless it is assumed that some major event caused contemporaneous solution and redeposition of the ore minerals in all formations of the plateau.

Therefore, pending further investigation, the authors favor the hypothesis that the ores are of deep-seated origin and were brought to their present locations in early Tertiary time by hydrothermal solutions. This mode of origin, however, has not been proven, and the reader is reminded that these conclusions are subject to change.

Grade

Figure 2 indicates the estimated grade of rock from some of the properties in the White Canyon area. A grade in excess of 0.2 percent uranium must be maintained for most operators to realize a profit. Some ore shipped from the Happy Jack, Posey, Bell, and Yellow John mines is said to contain more than 0.3 percent uranium.

Copper is contained in most of the ore, commonly in concentrations less than 1.0 percent, although more than 5.0 percent copper has been reported by Granger and Beroni (1950, pp. 16-19) in individual samples.

Production

Although the White Canyon area was prospected as early as 1880, the only metal produced prior to 1949 was a small amount of copper. In 1951 uranium and copper were being produced from the Happy Jack, Yellow John, and Bell mines in White Canyon, and the Posey mine in Red Canyon. Seven others with favorable possibilities are idle. These properties are the Frey no. 4, White Canyon no. 1, Hideout, Scenic no. 4, Scenic no. 2, Gonway and North Point, Dead Buck, and W. N. claims. In 1950 the Vanadium Corp. of America erected a pilot mill for the processing of uranium ore east of the Colorado River, opposite Hite, Utah. This mill has been receiving ore exclusively from the Happy Jack mine.

The ore from all other properties is trucked to Monticello, Utah, where it is crushed and shipped to the Simplot Co. mill, Salt Lake City.

RESULTS OF WORK

Ore criteria

Although the origin and local controls of the copper-uranium ores are still matters for debate, experience both in the White Canyon area and elsewhere in the Colorado Plateau shows that certain physical and chemical features are characteristic of mineralized areas, and that the presence of one or more of these features may indicate concealed ore bodies.

The following section, intended to aid future prospecting in the White Canyon district, is a brief discussion and evaluation of the features associated with ore deposits. These features are grouped in three categories: first, features observed only in mineralized areas; second, features apparently associated with some deposits but observed also in unmineralized areas; and third, features that are associated with deposits in other parts of the plateau but that show little relation to the ore deposits in White Canyon.

Features observed only in mineralized areas

1. Visible uranium minerals.
2. Sulfide minerals.
3. Secondary copper sulfates and carbonates.
4. Alunite(?).
5. Hydrocarbons.

Visible uranium minerals.--Visible secondary uranium minerals, zippeite, johannite, and torbernite, were noted in the following claims (in order of their significance): Happy Jack, Posey, Hideout, Frey no. 4, White Canyon no. 1, Yellow John, Bell, Jerry, North Point, Gonway, Scenic no. 2, Scenic no. 4, Sunrise no. 1, and Ace of Hearts (fig. 2). These secondary uranium minerals may indicate the presence of a uranium-bearing sulfide deposit beyond the oxidized zone.

Sulfide minerals.--Sulfide minerals chalcocite, bornite, covellite, pyrite, arsenopyrite, chalcopyrite, galena, and sphalerite were noted in the following claims (in order of their significance): Happy Jack, Posey, Hideout, Frey no. 4, Yellow John, Bell, Found, Jerry, W. G. J. N. W., Scenic no. 2, Woodenshoe(?), Jacobs Chair, and Bankrupt (fig. 2). These sulfide minerals may indicate the presence of a uranium deposit.

Secondary copper minerals.--Disseminated secondary copper minerals may indicate the presence of a uraniferous-sulfide body. Near the surface these minerals are principally the hydrous sulfates and carbonates, and are found disseminated and as fracture coatings.

Alunite.--A white clay mineral, identified by X-ray diffraction as alunite, occurs in some of the uranium deposits, both along fractures and along bedding planes. Alunite is common in the North Point, Gonway, and Woodenshoe(?) claims (fig. 2).

Hydrocarbons.--Hydrocarbons were noted in veinlets and as globules in some of the copper-uranium deposits in the White Canyon district. The following claims, arranged according to their significance, contain probable hydrocarbons: Happy Jack, Posey, Hideout, Woodenshoe(?), and Four Aces (fig. 2). The hydrocarbons are commonly uraniferous, and may indicate a favorable ore zone.

Features observed at many deposits
but seen in unmineralized areas as well

The association of several of these features may indicate an area favorable for prospecting.

0. Bleaching and alteration of the Moenkopi formation.
1. Fracturing.
2. Iron and manganese staining.
3. Carbonized wood fragments and vegetal material.
4. Channel filling.
5. Jarosite(?).
6. Facies change within the Shinarump conglomerate.

Bleaching and alteration in the Moenkopi formation.--Bleaching and alteration in the Moenkopi formation below the Shinarump conglomerate was noted at some of the more favorable uranium prospects. The following claims showed considerable bleaching and alteration associated with fracturing in the Moenkopi: Happy Jack, Gonway, North Point, and Found (fig. 2). This bleaching, however, is not present under many deposits and its absence does not make an area favorable. Little or no bleaching was noted at the Frey no. 4 and Woodenshoe(?) claims.

Fracturing.--Close fracturing of the sandstones and conglomerates of the Shinarump is in some places a favorable criterion for prospecting. The fractured zones associated with the copper-uranium bodies generally show a considerable shattering of the rock.

Iron and manganese staining.--A red, brown, and black coating commonly occurs on fractures and outcrop surfaces over a large portion of the sandstones and conglomerates of the Shinarump and Chinle formations. However, iron and manganese staining is especially common near some areas showing considerable sulfides, and secondary copper and uranium minerals.

Carbonized wood fragments and vegetal material.--Carbonized wood fragments and vegetal material are relatively abundant in the Shinarump conglomerate. Many of these carbonized remains, especially the charcoal fragments, are highly uraniferous, and may suggest a favorable area for subsurface prospecting. Other outcrops containing carbonized wood are not radioactive.

Channel filling.--Many channels are cut into the Moenkopi formation and are filled by the Shinarump conglomerate, especially in upper White Canyon. Only a few of them, however, contain appreciable amounts of uranium or copper minerals. Included in this group are the Posey, Hideout, Bell, Yellow John, Frey no. 4, and Scenic no. 4 claims (fig. 2).

Jarosite(?).--Yellow jarosite(?) coats many fractures and outcrop surfaces of the Shinarump conglomerate and is commonly associated with a gray silty sandstone. This mineral is present in many of the uranium deposits, but it has also been noted where no radioactivity could be detected.

Facies change within the Shinarump conglomerate.--Conglomerates and sandstones of the Shinarump conglomerate commonly contain clay, shale, and siltstone lenses that are mildly radioactive, but generally these lenses are low-grade and too small to produce any commercial uranium ore.

Features not apparently related to ore deposits

1. Massive sandstone.

2. Conglomerate.

3. Hydrous mica.

4. Freckled limonite.

Four criteria have been used as prospecting guides in other uranium-bearing areas. In the White Canyon area they bear little relation to the ore bodies and are considered by the writers to have little importance in finding concealed uranium deposits.

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