

GEOLOGY OF URANIUM DEPOSITS OF THE SHINARUMP AND CHINLE FORMATIONS ON THE COLORADO PLATEAU

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ABSTRACT

Significant uranium deposits are known in two formations of Late Triassic age on the Colorado Plateau: the Shinarump conglomerate and the Chinle formation. Major ore deposits in the Shinarump are mined in the Monument Valley area of Arizona and the White Canyon area of Utah. Important deposits of uranium in the Chinle formation are known in the Big Indian Wash-Lisbon Valley area and the Temple Mountain area, both in Utah, as well as the Cameron area in Arizona.

The Shinarump conglomerate is a continental deposit consisting dominantly of light-gray sandstone with lenses of grit and conglomerate, and lesser interbedded mudstone. Basal Shinarump fills former stream channels cut in underlying beds. Carbonaceous plant material is a common constituent of this filling. Commercial ore is restricted to channel fill. Ore preferentially lies low on the flanks of these channels or at their base.

Ore bodies in the Shinarump conglomerate tend to be elongated parallel to channel trends and commonly are localized along a sandstone-mudstone interface.

The Chinle formation is predominantly a fluvial sequence of red to brown siltstones and mudstones interbedded with sandstones and conglomerate. Carbonaceous plant remains are widely distributed in the formation, and asphaltite occurs locally. Ore bodies in the Chinle are not restricted to channels nor to any one stratigraphic unit in the formation; however, most major deposits occur in sandstones or coarser clastics within the lower half of the formation. In some of the larger ore deposits in the Chinle formation at Big Indian Wash major ore controls appear to be structural rather than sedimentary.

Copper, copper-uranium, and vanadium-uranium deposits have been found in both these formations. Oxidized and unoxidized ore minerals commonly occur together, resulting in rather exten-

sive mineralogic suites. The dominant economic mineral in most deposits is uraninite. Ore minerals occur mainly as disseminations in sandstones, siltstones, and conglomerates and as grains replacing carbonaceous plant material and calcite cement.

Localization of ore in channel-fill and other permeable clastic units suggests that transmissivity is a dominant physical ore control. Geochemically, the place of ore deposition appears to be largely determined by the distribution of such substances as carbonaceous matter, calcite, certain clays, and possibly pyrite capable of causing precipitation of the uranyl ion through changes in Eh and pH, as well as by adsorption and base-exchange phenomena. Where uranium occurs in an asphaltite-uraninite complex, as at Temple Mountain, the hydrocarbons are regarded as having migrated into the ore zone later than the uraninite.

Bleaching of or other discoloration of red beds, both below and above certain uranium deposits in the Shinarump and Chinle formations, suggests alteration associated with ore deposition. Isotopic age determinations indicate that uranium is epigenetic; the source of the uranium is not known.

INTRODUCTION

The diverse geology of uranium in the Shinarump conglomerate and the Chinle formation of Late Triassic age on the Colorado Plateau is illustrated by individual descriptions of six mining districts or mines of major economic and geologic importance: Holiday Mesa district, Happy Jack mine, Calyx mines, Big Indian Wash-Lisbon Valley district, Delta mine, and Cameron mining district.

GENERAL GEOLOGY

The Shinarump conglomerate is exposed over large areas in the southern part of the Colorado Plateau (fig. 73). It is a fluvial deposit composed mainly of light-gray fine- to medium-grained sandstone, with lenses of very coarse sandstone and conglomerate, and lesser intercalated mudstone. Major ore-producing areas in the Shinarump are the Monument Valley and White Canyon areas (fig. 73), where ore occurs in basal sandstones and conglomerates filling former stream channels.

The more widespread Chinle formation gradationally overlies the Shinarump and disconformably overlies the Moenkopi where the Shinarump is absent. The Chinle consists of fluvial red, purple, gray, and variegated mudstone and siltstone, with some interbedded sandstone and conglomerate. The Chinle is the source of most of the uranium in the Big Indian Wash-Lisbon Valley area, Utah, and lesser amounts in the southern part of the San Rafael Swell, Utah, and the Cameron area in Arizona. Ore occurs in several stratigraphic units of the Chinle formation, but the Moss Back sandstone member is currently the most productive.

Uranium ore deposits may be classified, according to associated metals, into these types: uranium, copper-uranium, copper-uranium-vanadium, and uranium-vanadium types. All are represented in the deposits

selected for illustration, although the uranium-vanadium type accounts for the greatest production.

The age of uranium mineralization on the Colorado Plateau, based on the ratio of lead to uranium age determinations, is Late Cretaceous or early Tertiary (Stieff and Stern, 1953). Furthermore, field studies of many deposits indicate that the ore is epigenetic (Isachsen, Mitcham, and Wood, 1955). The source of the uranium is unknown.

The rapid growth in economic importance of these formations is shown by their yielding an increase in uranium from 15 percent to more than 40 percent of the total production of the Plateau during 1952-55.

HOLIDAY MESA

Holiday Mesa district is on the west side of the Monument Valley uranium area (fig. 73) and 1 mile northwest of Oljeto Trading Post, San Juan County, Utah. D. E. Trimble (1952) first found uranium ore on Holiday Mesa. The ore bodies in the Monument Valley area range in content from a few tons to several hundreds of thousands of tons.

Structure.—Holiday Mesa is on the steeply dipping eastern limb of the Organ Rock anticline, one of several asymmetrical folds superimposed on the Monument upwarp. The mesa is on the lower inflection of the structure, where the easterly dip decreases from 8° to 2°. Joint sets trend north and northeast and are more common on the west end of the mesa. Frequency of joints in the Shinarump decreases where the unit thickens in former stream channels.

Stratigraphy and sedimentation.—In the Monument Valley area former stream channels as much as 275 feet deep and 3,000 feet wide were cut into the Moenkopi formation and filled with Shinarump clastic rocks. All ore deposits in the area occur in the Shinarump sediments in these channels and in downward extensions of ore into the underlying Moenkopi formation and De Chelly sandstone member of the Cutler formation. Channel filling generally contains greater amounts of mud-pellet and quartz-pebble conglomerates than the more widespread medium- to coarse-grained inter-channel sandstones.

Occurrence of ore.—Ore bodies on Holiday Mesa and elsewhere in Monument Valley are generally elongated parallel to channel trends (fig. 74) and lie near the base of the channels. As a result of regional folding, the apparent bottom of the channel on Holiday Mesa was tilted down-dip and corresponds with areas of highly anomalous radioactivity as measured in drill holes by gamma-ray logging. The occurrence of ore, however, appears to correspond more closely with the original erosional scour (fig. 74).

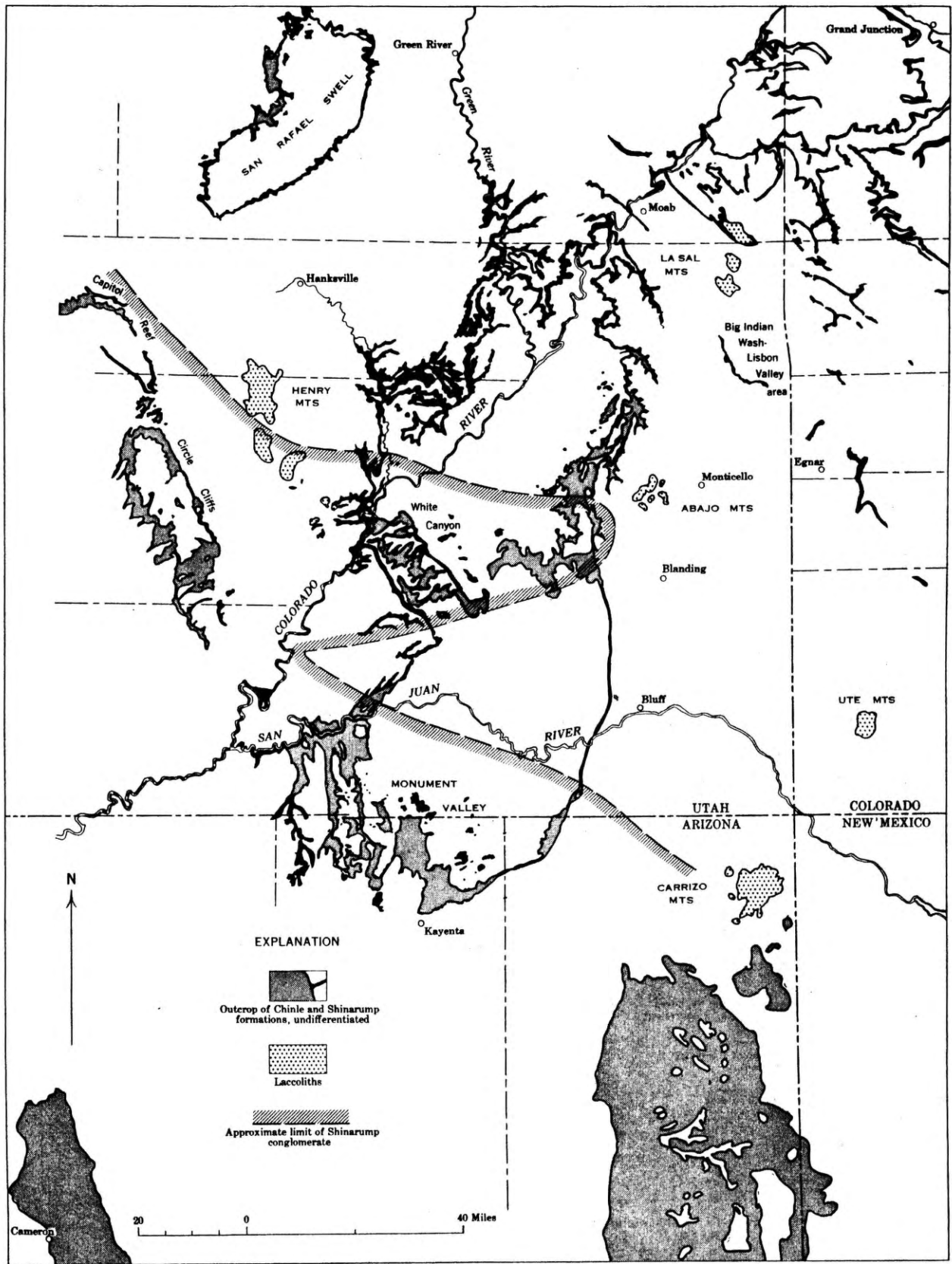


FIGURE 73.—Outcrop of Chinle and Shinarump formations and laccoliths on the Colorado Plateau.

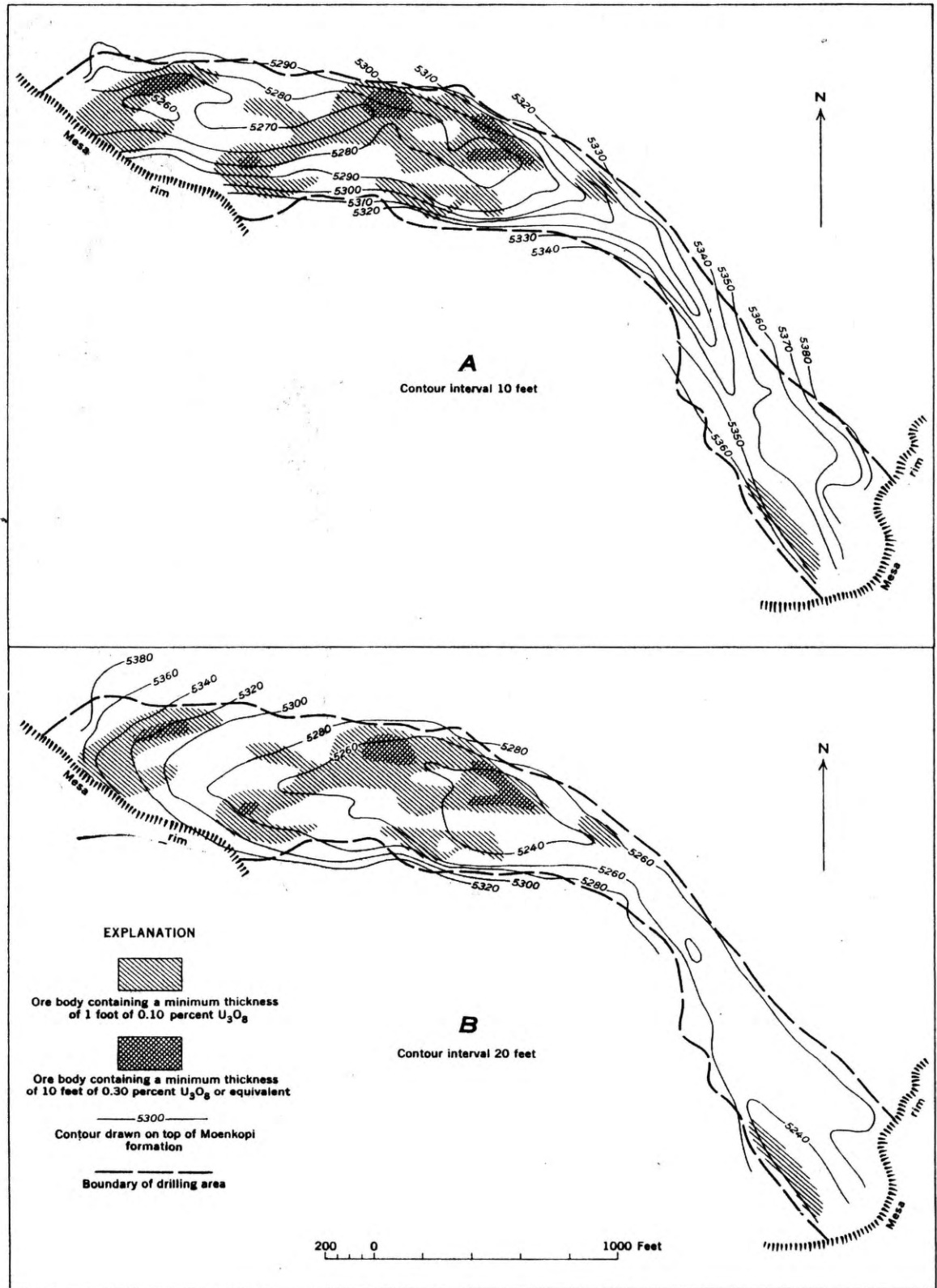


FIGURE 74.—Relation of ore to the pre-Shinarump surface of the Moenkopi formation: A, before regional folding; B, after regional folding (that is, at present).

On Holiday Mesa the grade of the uranium ore bodies decreases gradually toward their edges, both laterally and vertically; thus, weakly mineralized sandstone may extend considerably beyond the limits of commercial ore (fig. 74). Elsewhere in Monument Valley material of ore grade generally ends abruptly. Empirically, the optimum quantity of mudstone associated with ore deposition appears to be 10 to 20 percent, but several ore bodies (fig. 75) are found in zones of greater mudstone content. Areas containing greater than 25 percent mudstone appear to have been relatively impermeable barriers. Large pellets and blocks of Moenkopi material, occurring generally near the contact, contain only trace amounts of uranium. Carbonized plant remains are abundant in the Holiday Mesa channel and probably helped concentrate the uranium.

Immediately beneath the Shinarump conglomerate the Moenkopi formation has been altered to different depths from yellowish-brown to chalky-white clays by reduction and almost complete removal of ferric iron. In oxidized areas of Monument Valley a study of the colors of altered mudstone in ore-bearing, in slightly

mineralized, and in barren ground indicates a general correlation between intensity of mineralization and intensity of alteration; favorability of the ground increases as the alteration colors range from yellowish brown through gray and green to chalky white (terms are those of the National Research Council color chart). In unoxidized areas the range of alteration colors is more restricted. Holiday Mesa was the first unoxidized area to be studied in this manner, and there an order of color favorability for unoxidized areas was assumed from the uranium contents of drill holes. The colors correlate well with ore (fig. 76) except at the east end of the mesa. Here, the broad flat part of the channel was apparently unfavorable for uranium deposition although large quantities of mineralizing solutions may have passed through the zone. The eight colors most indicative of ore on Holiday Mesa did not occur in the altered mudstones examined on Flatiron Mesa, an area of almost no ore.

The general correlation between ore and thickness of altered Moenkopi appears to be due to passage of greater quantities of mineralizing solutions over a given part of the Moenkopi-Shinarump contact. In some

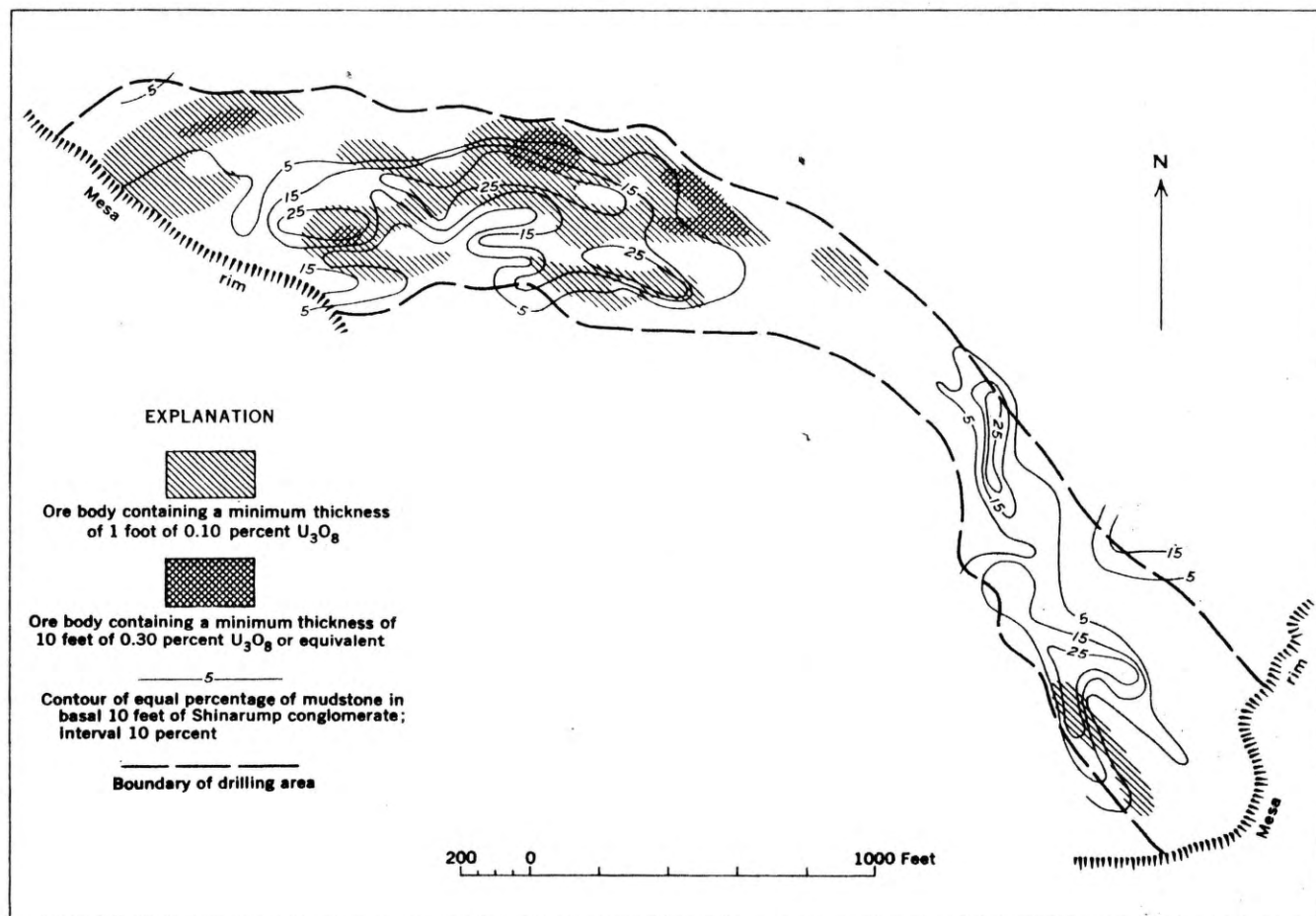


FIGURE 75.—Relation of ore to percentage of clay in lowermost 10 feet of Shinarump conglomerate.

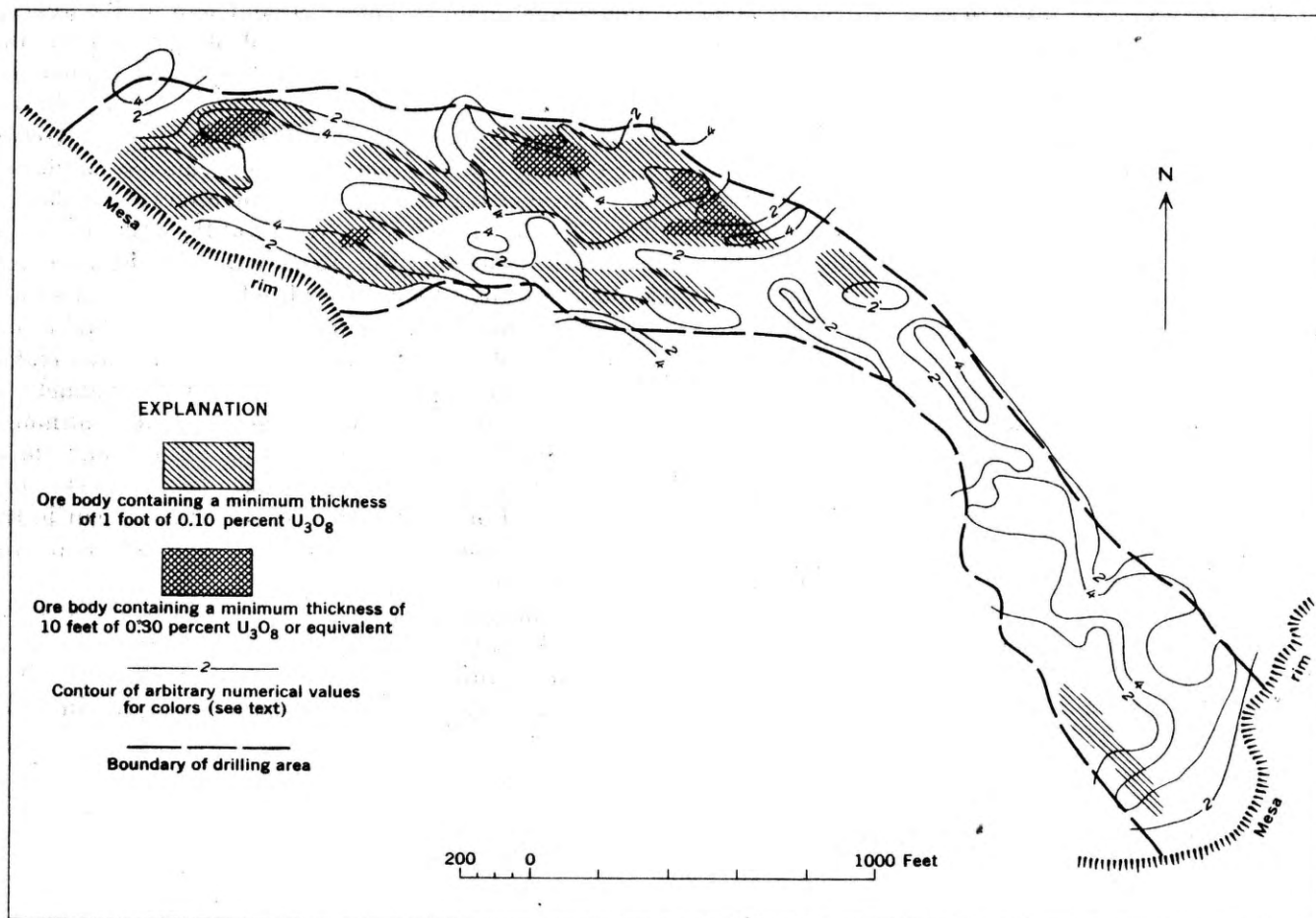


FIGURE 76.—Relation of ore to color of altered rock.

places, the thickness of the altered zone varies inversely with the mudstone content of the overlying Shinarump because the mudstone in the Shinarump also has been altered, possibly lowering the reducing ability of the solutions, and because increased mudstone content lessens permeability near the contact and thus decreases the volume of solution reaching the Moenkopi.

Mineralogy.—Unoxidized ore minerals on Holiday Mesa are uraninite and montroseite(?). The secondary minerals corvusite, tyuyamunite, hewettite, torbernite, and volborthite occur in the more oxidized areas within a few hundred feet of the mesa rims (E. B. Gross, personal communication). The ratio of vanadium to uranium averages about 2.5:1 on Holiday Mesa and increases eastward across Monument Valley. Chalcocopyrite and bornite are widespread in the unoxidized ore zone; assays of copper average about 0.5 percent at Holiday Mesa, with copper content decreasing eastward. The host rock is composed of detrital quartz, kaolinite, and chert; cementing materials are silica, calcite, and iron oxide.

Supergene alteration.—Migration of copper-bearing acidic solutions away from the uranium-vanadium ore

body during oxidation, and precipitation of copper carbonates as a halo surrounding ore, are indicated by a graph of assays along a mineralized rim on Holiday Mesa (fig. 77). High vanadium:copper ratios in the oxidized west and east ends of the mesa (fig. 78) correspond very closely with more intense mineralized zones. In unoxidized parts of the deposit within the mesa, however, the copper content is relatively uniform and vanadium:copper ratios largely reflect vanadium concentrations. Comparison of figures 74A and 78 indicates a general relationship between primary uranium and vanadium concentrations in the unoxidized parts of the mesa. A close relationship between localization of uranium and vanadium is shown in the oxidized zone. This may be the result of uranium being precipitated in direct proportion to the quantity of vanadate ions available.

Ore controls and guides.—Ore controls and guides for the Monument Valley area, in general, and Holiday Mesa, in particular, are as follows: (1) ore occurs in and below Shinarump scour and fill sediments in stream channels cut into the Moenkopi formation, (2) areas of marked change from clean sandstone to

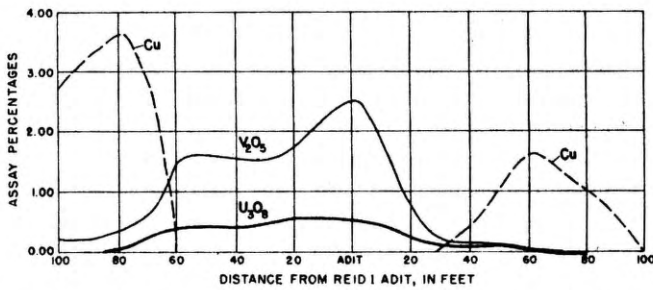


FIGURE 77.—Comparison of assays of samples taken at 1-foot intervals along the contact of the Moenkopi and Shinarump formations, west end of Holiday Mesa ancient channel.

about 25 percent mudstone are favorable for uranium deposition, (3) both thickness and intensity of alteration in mudstones of the Moenkopi increase adjacent to ore, (4) occurrence of secondary copper minerals may suggest ore bodies nearby, and (5) radioactivity increases gradually toward ore bodies in relatively broad, flat-bottomed channel fillings.

Sediments that fill ancient stream channels in the Shinarump have two characteristics that may be useful in tracing their courses in mesas capped by that formation: the tendency for joints to be more widely

spaced on the thicker channel sediments, and the tendency for channel fills to have higher topographic relief because greater compaction of the flanking sediments of the Moenkopi formation has arched them upward.

HAPPY JACK MINE

The Happy Jack mine in White Canyon, San Juan County, Utah (fig. 73), was first located as a copper prospect in 1900 and was mined in 1906 and in 1914. Butler, Loughlin, Heikes, and others (1920) included the property, then called the Blue Dike, in their compilation of Utah ore deposits, and were the first to note uranium sulfate in the mine. The Happy Jack was the first copper-uranium deposit in the Shinarump conglomerate to produce primary uraninite and copper sulfide ore, and uranium has been mined there since late 1949.

Regional structure.—The White Canyon mining district is on the gently dipping west flank of the Monument upwarp. Beds have a nearly uniform N. 15° W. strike, and dip 1½° to 2½° SW. A few minor northwest-trending vertical faults occur in the district,

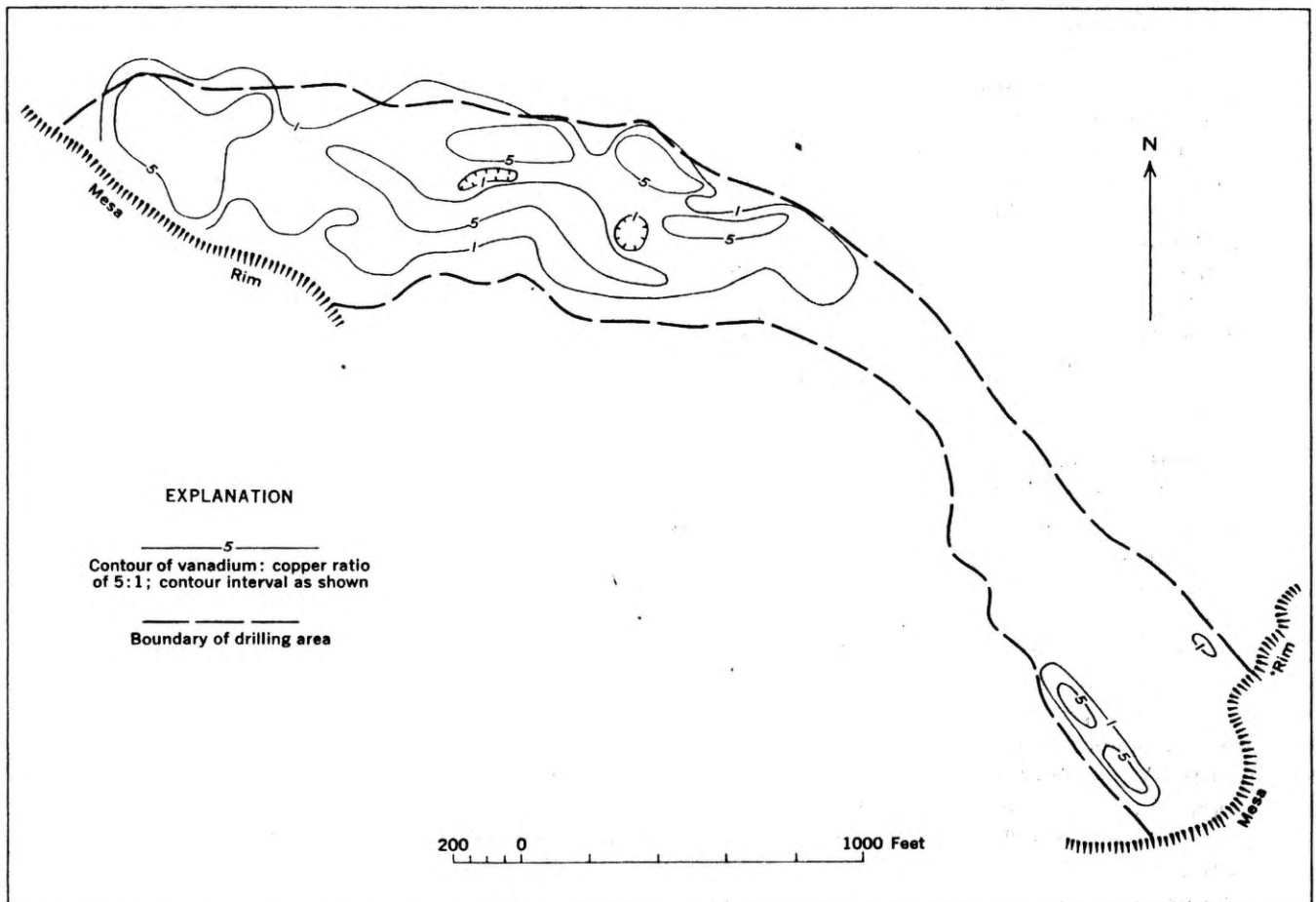


FIGURE 78.—Vanadium to copper ratios of assays from uranium-bearing cores.

but none are near the mine. A vertical joint system is developed in some beds; the dominant set strikes N. 50° E., and the minor set strikes N. 55° W. The diorite and monzonite intrusive masses of the Henry Mountains (Hunt, 1953), 18 to 20 miles west of the mine, are the closest known outcrops of igneous rocks.

Stratigraphy.—Sedimentary rocks exposed in the White Canyon district range from the Hermosa formation of Pennsylvanian age to the Navajo sandstone of Jurassic age. The Happy Jack mine and other deposits of the district are in the Shinarump conglomerate, which had a northeast source. The Shinarump locally has an upper and a lower unit. Ore is restricted to the lower unit which contains poorly sorted, coarse- to fine-grained quartz sandstone and siltstone and fills former stream channels in the underlying Moenkopi formation. The cement is composed of unidentified clay minerals containing shards suggesting a pyroclastic derivation. The upper unit, which extends into interchannel areas, is a light-gray fine- to coarse-grained conglomeratic sandstone. Coalified plant fragments, while present in both units, are more abundant in the lower and more lenticular unit.

Occurrence of ore.—Sedimentary structures, rather than tectonic structures, appear to influence ore localization. Miller (1953) states that three types of fractures occur in the Happy Jack mine: joints, small faults (displacement 1-foot) caused by regional tension, and minor faults resulting from differential compaction. He says that no primary uranium mineralization is associated with any of these.

In the Happy Jack mine, as elsewhere in the White Canyon district, ore deposits are confined to fluvial sediments in ancient stream channels (Dodd, 1950; Miller, 1953; Lowell, in preparation). Broad shallow depressions in the Moenkopi surface may have controlled the erosion and deposition by Shinarump streams. In the vicinity of the Happy Jack the first sediments to fill the former stream channels are extremely lenticular. The Happy Jack deposit is in a broad shallow basin on the Moenkopi surface, with a restricted channel outlet to the southwest (fig. 79A). Maximum relief from the lowest point in the depression to the divide separating it from the Sunrise-Gonaway channel to the east is about 28 feet. The basin containing the Happy Jack deposit is 600 to 700 feet across and has a relief of only 10 feet. The Sunrise-Gonaway channel averages 500 feet in width and has been scoured 10 to 12 feet into the top of the Moenkopi formation. Most ore is in the deeply scoured parts of the channels, and only a minor amount extends onto the flanks.

A positive correlation exists between ore and parts of the channel containing abnormal amounts of mud-

stone interbedded with the sandstone in the lower 10 feet of the Shinarump (fig. 79B). A plot of the distribution of carbonaceous fossil plant material within the ore-bearing basal 10 feet of the Shinarump indicates a coincidence of carbonaceous concentrations with areas of high mudstone.

Mineralogy.—Gruner (1952, p. 14) has identified the following suite of minerals from the Happy Jack ore body:

<i>Primary (unoxidized)</i>	<i>Secondary (oxidized)</i>	
	URANIUM MINERALS	
uraninite	zippeite johannite torbernite	uranopilite schoepite metazeunerite
	COPPER MINERALS	
chalcopyrite bornite chalcocite covellite	antlerite chalcanthite malachite	brochantite azurite cyanotrichite
	OTHERS	
pyrite galena sphalerite gersdorffite	goethite jarosite ilsemanite barite (Co,Fe)SO ₄ ·4H ₂ O (unnamed) MgSO ₄ ·6H ₂ O (unnamed and not previously described)	siderotil erythrite sulfur gypsum

The major uranium ore mineral in the Happy Jack mine is uraninite, which occurs in very fine granular masses and sometimes as colloform blebs less than three microns in size. It replaces fossil wood fragments and, where associated with chalcopyrite, shows preferential replacement of cell walls, whereas chalcopyrite fills the cells. The contact of uraninite with chalcopyrite, chalcocite, and covellite is always irregular. Miller (1953) and Gruner and Gardiner (1950) have commented on quartz boundaries being indented by replacing sulfides, but we have seen etched quartz only where it is in contact with uranium minerals. Secondary overgrowths on quartz grains, common in the Shinarump, have been replaced locally by uraninite. More of the clay cement is replaced by uraninite than are the quartz sand grains. Uraninite veinlets as wide as ½ inch cut across 2-inch beds of mudstone.

Alteration.—Beneath many of the Shinarump channel fillings the normal hematitic red of siltstones and sandstones of the Moenkopi formation has been altered to light gray or tan. It is postulated that this alteration, though present in some barren areas, may be an effect of the mineralizing fluids. Ore-bearing rocks of the Shinarump are either gray or light orange-brown, and barren sandstone is generally pale red.

The Happy Jack deposit well illustrates changes effected by an oxidizing environment on the primary

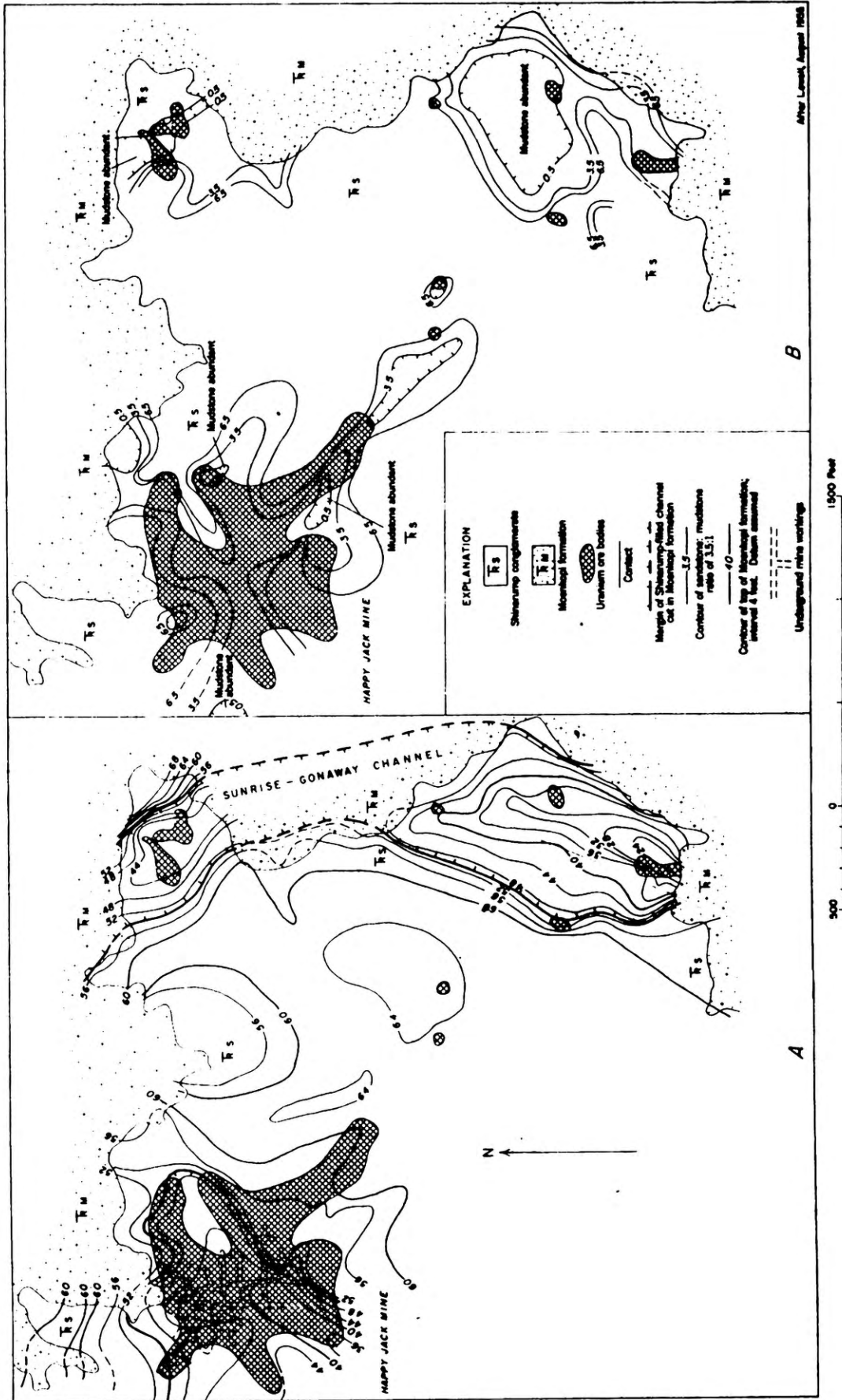


FIGURE 79.—Maps showing distribution of ore, Happy Jack mine and vicinity, White Canyon, San Juan County, Utah: A, structure contour map of the top of the Moonkopi formation showing distribution of ore in the scours; B, distribution of ore relative to mudstone abundance in Shinarump rocks filling scours.

After Lamm, August 1955

uranium oxide-copper sulfide ore (Dodd, 1950). Because of relatively impermeable overlying rocks, oxidation of the Happy Jack deposit has progressed horizontally inward from the exposed rim of the mesa rather than vertically down from the mesa cap. Oxidation has progressed more rapidly than erosion and has developed a secondary ore zone, generally paralleling the outcrop, in which copper sulfides have been altered almost completely to copper sulfates or carbonates (fig. 80). Uraninite has been altered locally to schoepite, the hydrated oxide, or more commonly to the sulfates zippeite and johannite, and rarely to the sulfate uranopilite and the phosphate torbernite.

Sulfate waters resulting from oxidation have preferentially removed uranium from its radioactive decay products during recent time (Dodd, 1950) and have left the uranium unevenly distributed (fig. 80).

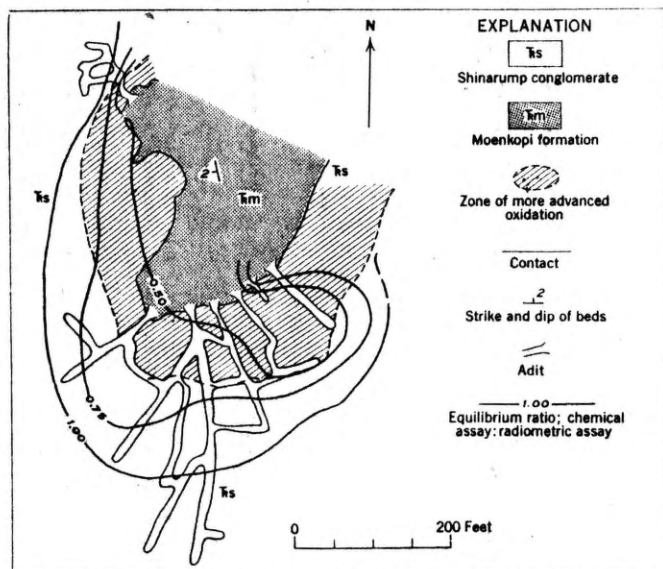


FIGURE 80.—Zone of oxidation and equilibrium ratios, Happy Jack mine, White Canyon, San Juan County, Utah.

Genesis.—An epigenetic origin of the deposits has been proposed (Dodd, 1950; Miller, 1953). This is corroborated by the isotopic determinations of an age of 55 million years (Stieff and Stern, 1953) for two specimens from the Happy Jack mine. Because the ore is localized in channels, it is believed the ore-bearing fluids migrated laterally, controlled by permeability. Precipitation appears to have been caused by changes in pH or Eh accompanying changes of content of such substances as carbonaceous material, pyrite, and clay minerals in the host rock. There is no evidence that changes of temperature or pressure precipitated the uranium whose source is unknown.

CALYX MINES

The Calyx group of mines are on Temple Mountain near the southern part of the San Rafael Swell, Emery County, Utah (fig. 73 and insert, fig. 82). The larger ore bodies contain reserves measured in the tens of thousands of tons.

Structure.—The San Rafael Swell is a broad, relatively flat, asymmetrical upwarp. Temple Mountain, an erosional remnant within the swell, contains a complex, altered collapse zone that is described by Keys and White (this volume). The Calyx mines lie south of the collapse area in beds dipping 8° to 11° SE.

Stratigraphy and sedimentation.—Sedimentary rocks exposed in the San Rafael Swell range from the Coconino sandstone of Permian age to the Morrison formation of Jurassic age.

Major uranium-vanadium ore in the Calyx area occurs in the Moss Back sandstone member of the Chinle formation. The host rock is a gray medium-to coarse-grained sandstone containing discontinuous lenses of conglomerate and mudstone and abundant coalified wood fragments. Calcite cement is common in the Moss Back elsewhere in the San Rafael Swell, but in the Calyx area the dominant cement is asphaltite. Coalified wood fragments are common in the Moss Back. The ore-bearing sandstone in the Calyx No. 3 mine rests upon a green mudstone along a gently undulating contact marked by scours as deep as 3 feet and is overlain by a quartz-pebble conglomerate in mudstone matrix, ranging from 6 inches to 3 feet in thickness.

Economic geology.—Uranium occurs in several formations of the Temple Mountain collapse zone (Keys and White, this volume), but major production has come from the Moss Back in the Calyx mines area (named from the prevailing method of opening the mines through large calyx drill holes). Ore deposits in the Moss Back are elongate tabular bodies with marginal fingerlike extensions projecting outwards as much as 50 feet (Witkind, Robeck, Barton, and Izett, 1954). Deposits are about 300 feet long, 20 feet wide, and 4 feet thick, and tend to be elongated downdip (Keys and White, this volume).

Within the host rock, ore occurs as disseminations in sandstone around carbonized logs, against mudstone contacts, as stringers along cross-laminae, and as irregular pods and blebs. Three types of hydrocarbons are associated with the ore-bearing sandstone throughout the area (Baumgardner and Noble, 1955); namely: liquid hydrocarbon which is a nonuraniferous, dark-brown to black, combustible fluid of the viscosity of heavy oil; dull resinous asphaltite, a plastic, nonuraniferous solid which melts and burns readily when ignited,

emitting a petroliferous odor; and uraniferous asphaltite, a brittle subvitreous solid which emits a sulfur dioxide odor when heated but which does not sustain a flame. The distribution of these types of hydrocarbons in the only Calyx mine mapped in detail, the Calyx No. 3, is as follows: liquid hydrocarbon occurs predominantly above the ore-bearing sandstone, rarely within it; the dull resinous variety is restricted mostly to barren zones within the ore, although occasionally pellets of this material are found within ore; brittle asphaltite is found only in the uranium ore and is everywhere uraniferous (Baumgardner and Noble, 1955).

Mineralogy.—The practically unoxidized Temple Mountain uranium-vanadium ore has been commonly referred to as uraniferous asphaltite. However, Weeks and Thompson (1954) advocate classification of the ore on the basis of mineral assemblage as “pitchblende associated with a hard carbonaceous substance variously described as high-rank coal or polymerized petroleum residu (thucholite?).” On the basis of preliminary study, Stieff and Stern (*in* Witkind, Robeck, Barton, Izett, 1954) have suggested that the chief uranium mineral may be coffinite.

Montroseite is found in unoxidized ore. Corvusite and vanadium hydromica are common; other oxidized uranium and vanadium minerals reported from Temple Mountain (Witkind, Robeck, Barton, and Izett, 1954) are: carnotite, tyuyamunite, metazeunerite, schroekingite, zippeite, rauvite, metatorbernite, uvanite, pintadoite, hewettite, and pascoite. The vanadium:uranium ratio of the ores is about 3:1.

Ore guides and genesis.—Guides to ore in the Calyx area include carbonaceous plant remains and abnormal thickness of the ore-bearing sandstone (Witkind, Robeck, Barton, and Izett, 1954). In the Calyx No. 3 mine, Baumgardner and Noble (1955) consider impermeable mudstone at the base of the ore zone as a criterion of the presence of ore.

Distribution of the three classes of hydrocarbons shows that their volatile content decreases in direct proportion to proximity to uranium. It is argued that the Temple Mountain occurrences originated as primary uranium deposits of the uraninite-montroseite type, similar to the ores of Big Indian Wash. Fluid hydrocarbons were later introduced and subsequently polymerized to varying degrees by radiations from uranium, the degree of polymerization depending upon nearness to uranium. This interpretation disagrees with the hypothesis of Gott and Erickson (1952) that the uranium was introduced simultaneously with the fluid hydrocarbons. During polymerization, uraninite was replaced in part to form the present asphaltite-uraninite (pitchblende) association; such a mechanism for the

formation of naturally occurring hydrocarbon-uraninite complexes has been advanced by Davidson and Bowie (1951). This interpretation would also explain the anomalous “corrosion” and “replacement” of quartz sand grains by asphaltite, for replacement of quartz by uraninite from hydrous mineralizing solutions (a phenomenon commonly observed in nonasphaltic ore bodies), was followed by replacement of uraninite by introduced hydrocarbons.

The age of a sample of asphaltic uraninite ore for this area has been calculated by isotope ratios (Stieff and Stern, 1954) to be 60 million years.

BIG INDIAN WASH-LISBON VALLEY MINING DISTRICT

The Big Indian Wash-Lisbon Valley uranium district is in San Juan County, Utah (fig. 73). The first uranium mined in the area came from the Big Buck mines in the Cutler formation where small-scale production began in 1948 and continued sporadically until 1953. Uranium was first discovered in the Chinle formation in 1952.

Structure.—Large uranium deposits occur on the southern flank of the northwest-trending Lisbon Valley anticline. Large laccoliths occur 6 miles to the north and 25 miles to the southwest (fig. 73). Shoemaker (1954a) presents evidence for a Late Cretaceous age of these intrusive bodies.

The Lisbon Valley anticline is a salt structure formed primarily by plastic flowage and local thickening of salt and gypsum (Baker, 1933; Dane, 1935; Stokes, 1948). The Lisbon Valley fault, a major displacement, and minor associated faults cut the anticline longitudinally and place the Jurassic Morrison formation in contact with the Pennsylvania Hermosa formation (fig. 81). This fault dips steeply northeast and has a stratigraphic throw of at least 3,800 feet. Movement along this fault is thought to have resulted from differential uplift of the footwall block during intrusion of salt and gypsum rather than collapse of the hanging-wall block afterward; this interpretation is based on the fact that the upthrown southwest side is considerably more domed, more steeply dipping, and more fractured than the downthrown side (Isachsen, 1954).

The major joints along the anticline are longitudinal, a feature shown to be characteristic of flexures resulting from vertical forces (Gilkey, 1953). Transverse joints are less evenly distributed and less pronounced than longitudinal joints. Besides the longitudinal and transverse tension joints there are many oblique shear joints (Dahl, Fisk, Volgamore, and others, 1955) and a number of unevenly distributed fracture zones which lack noticeable displacement but are reflected in the development of small, straight, valleys trending between N. and N. 10° E. These fracture zones were first described by W. H. Bucher (oral communication),

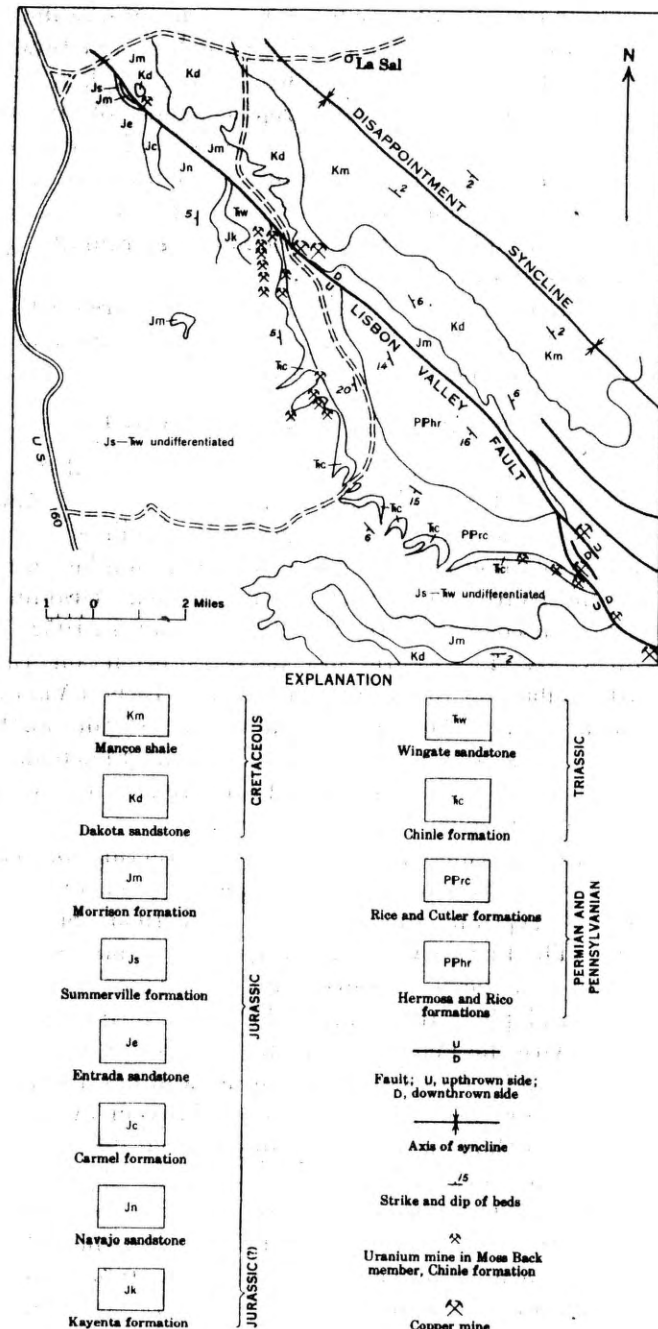


FIGURE 81.—Generalized geologic map of Lisbon Valley, San Juan County, Utah.

who noted that some of them have a close spatial relation to ore bodies. He interpreted such zones as reflected deep-seated faults.

Stratigraphy and sedimentation.—Sedimentary rocks exposed in the district range from the Hermosa formation of Pennsylvanian age to the Mancos shale of Late Cretaceous age. Ore in the Chinle is restricted to the basal Moss Back sandstone. At some places the ore horizon lies directly on bevelled beds of the more steeply dipping Cutler formation; at others it is separated from the Cutler by a few feet of barren gray mud-

stone of the Chinle formation. The Moenkopi formation which underlies the Chinle to the west and east does not crop out here; perhaps it was pinched out lower on the flanks of the anticline.

Rapid horizontal and vertical changes of facies, characteristic of a fluvial deposit, are common in the Moss Back. Scour and fill, crossbedding, and ripple marks, all characterizing turbulent flow, are widespread. Laminar flow is represented in some beds by stream lamination. Intraformational unconformities are commonly exposed in mine walls but can seldom be traced more than a few hundred feet. The trend of sedimentary structures in the ore zone at Big Indian Wash indicate that the clastic rocks of the Moss Back came from the southeast.

Occurrence of uranium and vanadium.—In the Big Indian Wash-Lisbon Valley area, uranium deposits lie within a half-mile-wide strip which borders the Chinle escarpment and parallels the strike of beds for a distance of 15 miles. Most known ore bodies are in the northern part of the anticline, adjacent to Big Indian Wash. All are elongated approximately parallel to the strike of the beds and all except one are 6,200 to 6,700 feet above sea level. The single exception, which is about 5,840 feet above sea level, lies along the Lisbon Valley fault in the southern part of the mining district. Maximum thickness of ore in the Moss Back is 30 feet and the average is 8 feet. Host rocks include medium- and fine-grained sandstone, siltstones, and conglomerates containing pebbles of mudstone and limestone. The host rock enclosing the best ore is fine- to medium-grained quartz sandstone with calcareous cement. Coalified plant matter is widespread in the ore bodies but the average content, even in rich ore, may not exceed 0.5 percent (Steen, Dix, Hazen, and McLellan, 1953). Ore does not impregnate the host rock uniformly, nor does it follow in detail primary sedimentary structures such as bedding; instead it characteristically occurs in small irregular pods, blebs, and stringers which only roughly parallel bedding.

Mineralogy.—The mineralogy and petrography of the deposits have been described by Steen and others (1953); Gruner, Rosenzweig, and Smith (1954); and Gross (1955). The dominant ore mineral is uraninite, which contains minute intergrowths of coffinite; the most abundant vanadium minerals are vanadium hydromica, and montroseite with very fine intergrowths of doloresite. The oxidized minerals tyuyamunite, corvusite, and pascoite are developed along and adjacent to joint surfaces.

Both uraninite and montroseite replace calcite cement, and uraninite replaces coalified logs and carbonaceous debris. Calcite fills cells in carbonized wood; uraninite replaces cell walls and locally extends into

cells by replacement of calcite. It is suggested that calcite is diagenetic and thus prevented the flattening of logs by compaction. Pyrite is fairly abundant and commonly replaces fossil plant material. Small quantities of barite, fluorite, greenockite, sphalerite, and galena have also been reported. Chalcopyrite and malachite are very rare. Dominant detrital minerals in the sandstones and siltstones are angular to sub-angular quartz, plagioclase, and microcline; muscovite is abundant locally. Calcite fills interstices, corrodes quartz along grain surfaces, and in ore replaces feldspar to a minor extent; other cements are quartz, barite, clay aggregates, and chlorite. Microscopic examination indicates that primary uranium minerals were introduced contemporaneously with pyrite and chalcopyrite, and later than the cement (Gross, 1955).

Alteration.—Near ore bodies there is a tendency for the gray-green color which characterizes the ore horizon to extend into overlying mudstones of the Chinle formation which are generally red. This change is attributed to differences in color of the clay fraction, which are not yet understood, and to abstraction of hematite. According to W. K. Keller (oral communication), no difference exists in gross mineralogy between the red and green clays.

Ore controls and genesis.—Controls of ore deposition, both known and postulated, may be classified into three categories: local, areal, and regional.

Permeability, as reflected in lithologic types, is an important local control. In addition, the distribution of such substances as carbonaceous matter, pyrite, calcite, and possibly certain clays, has influenced the localization of ore, probably by causing precipitation of the uranyl ion through changes in Eh and pH, as well as by adsorption and base-exchange phenomena.

Localization of ore in ancient-channel fill, as advanced by Dix (1954), has not been adequately tested by subsurface data compiled to date. The close spatial relation between ore and fracture zones trending N. 10° E., strongly suggests a fracture control of ore solutions as advanced by W. H. Bucher (oral communication).

The Lisbon Valley anticline appears to have exerted the most important areal control of ore deposition as exemplified in the apparent restriction of ore to a narrow vertical interval. A general anticlinal control of ore was initially postulated in 1953 by Steen and others.

Two peculiarities of stratigraphy associated with the Lisbon Valley anticline that may have influenced ore localization are: (1) the absence beneath ore of the relatively impermeable mudstones of the Moenkopi and its probable occurrence downdip as a cap for hypothetical rising ore solutions (Dahl, Fisk, Volgamore, and others, 1955), and (2) the bevelled surface of the

Cutler formation beneath the Moss Back which provides permeable arkose lenses as possible conduits for hypothetical ore solutions rising along the Lisbon Valley fault (R. R. McLellan, oral communication). The occurrence of copper deposits along the fault (Isachsen, 1954) suggests the plausibility of copper-uranium zoning in the district, with ore solutions gaining entry along the Lisbon Valley fault.

Proximity of the Big Indian Wash-Lisbon Valley mining district to the La Sal and Abajo laccolithic mountains to the north and southwest (fig. 73) is considered significant by many geologists. The laccoliths, consisting mainly of diorite porphyry and monzonite porphyry, with minor syenite intrusive bodies (Hunt, 1954), may have both a chemical and a structural relation to neighboring uranium deposits. Shoemaker (1954b) notes that the syenite of the La Sal Mountains is anomalously enriched in copper and suggests that a rough zonal relation may be indicated between copper and uranium deposits around the La Sal Mountains.

A nonhydrothermal source for the uranium has been proposed by Gruner, Rosenzweig, and Smith (1954) who suggest that uranium was leached by ground water from volcanic tuffs and reprecipitated in its present sites.

DELTA MINE

The Delta mine is in the southern part of the San Rafael Swell, Emery County, Utah (fig. 73 and insert, fig. 82). The anomalous surface radioactivity of the Delta mine outcrop was discovered first by members of a U. S. Atomic Energy Commission airborne scintillometer crew in June 1952 (G. E. Klosterman, written communication).

Structure.—The Delta deposit is localized along the southern edge of a structural terrace on a monocline which forms the southern margin of the San Rafael Swell, one of several major upwarps on the Colorado Plateau (fig. 82). Neighboring faults and dikes of analcite diabase are also shown on figure 82. A vertically dipping conjugate joint system is developed in competent beds of the area; joint sets strike north-east and northwest.

Stratigraphy.—Sedimentary rocks exposed in the San Rafael Swell range from the Coconino sandstone of Permian age to the Jurassic Morrison formation. Copper-uranium-vanadium ore occurs in the Chinle and is restricted to the lower third of a sandstone lens, 33 feet above the base of the formation (Keys, 1955). The lens is 31 feet thick at the mine and pinches out several hundred feet to the north and south. The Moss Back is unmineralized at the Delta mine and lies above the ore horizon, separated from it by 23 feet of mudstone.

The host is a massive fine- to medium-grained sand-

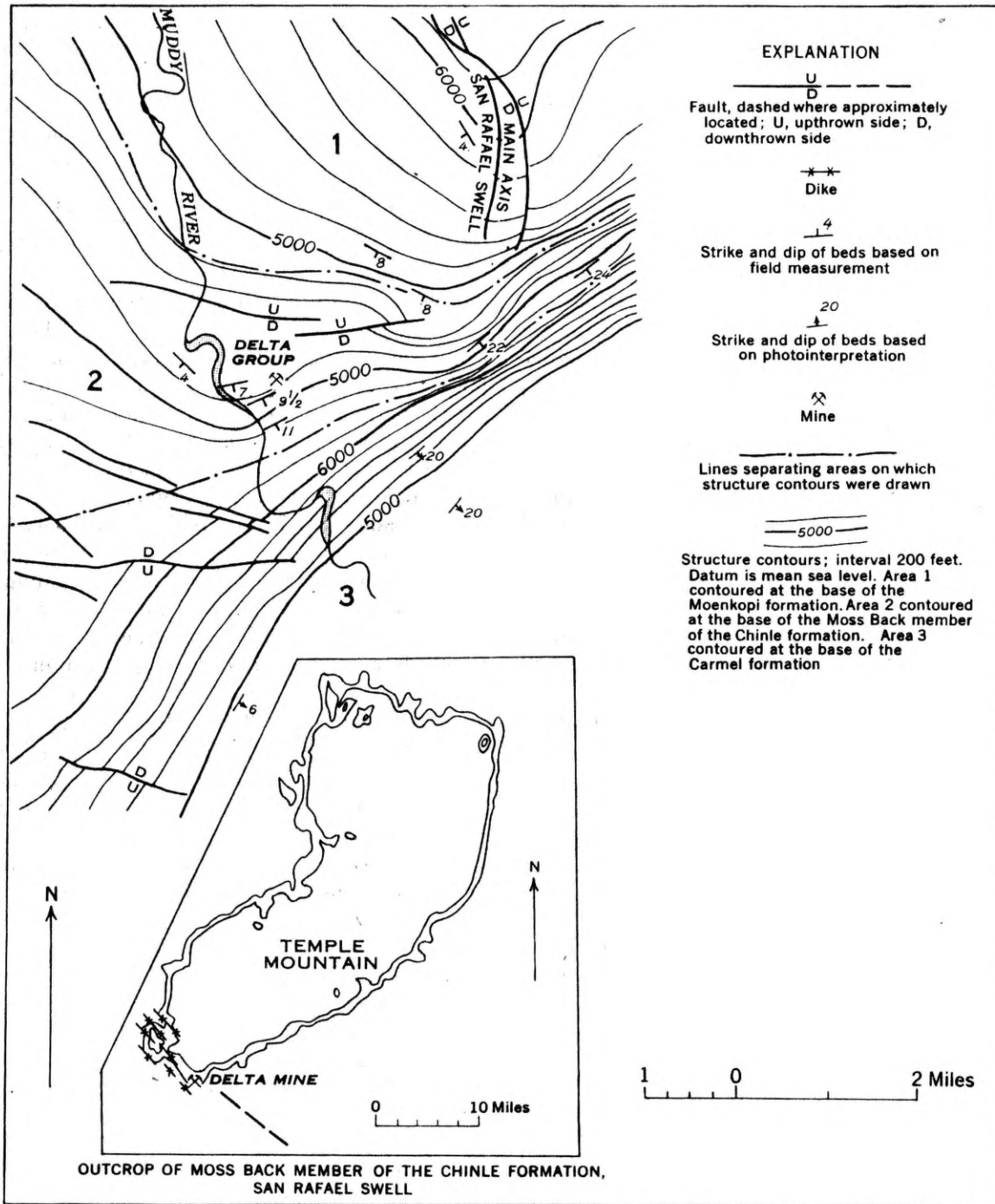


FIGURE 82.—Maps showing structure of the Delta mine area and outcrop pattern of the Moss Back sandstone in the San Rafael Swell, Emery County, Utah.

stone containing widespread coalified plant remains. Within this unit the most favorable rock is thin-bedded, fine-grained, micaceous sandstone with interbedded mudstone. In strongly mineralized areas in the mine, all rocks including mudstone, are ore bearing. Ore lies on a relatively impermeable basal green mudstone containing illite and kaolinite.

Occurrence of ore.—The Delta ore body is crudely

oblong with the longer dimension trending northeast. Thickness of ore is highly variable; the maximum is 20 feet (Keys, 1955).

Plotting the distribution and intensity of joints did not reveal any relation to localization of primary minerals.

Irregularities at the base of the ore zone are shown in figure 83. Most ore occurs where the base of the

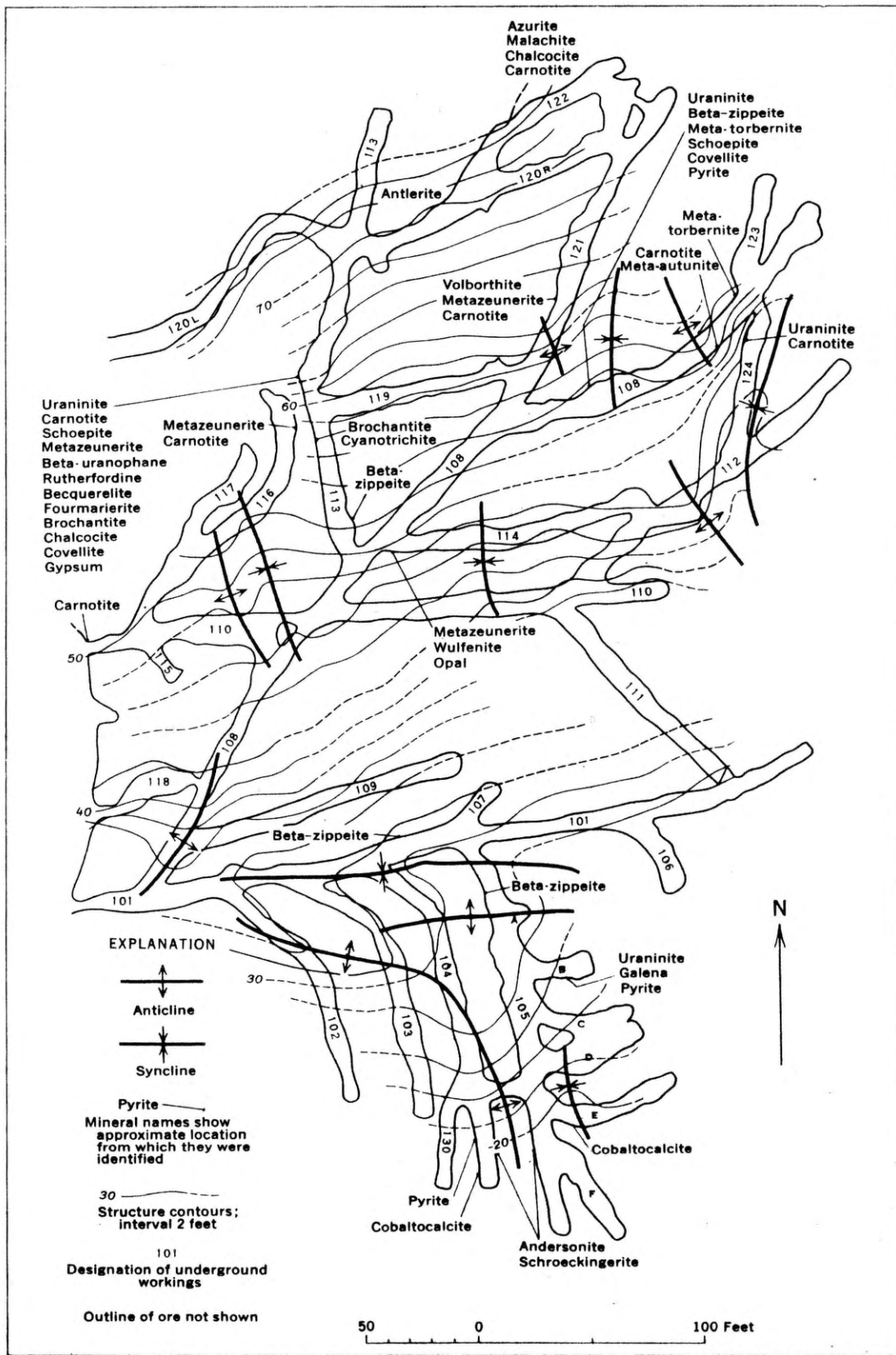


FIGURE 83.—Structure contours on the base of the ore-bearing sandstone, Delta mine, San Rafael Swell, Emery County, Utah.

ore is undulatory. Whether these undulations are due to scouring, differential compaction, or flexuring is a matter of conjecture. Because the Chinle is a fluvial deposit, the first two alternatives are logical.

Mineralogy.—Carnotite and zippeite disseminated in sandstone account for most of the ore; uraninite locally replaces fossil logs (Keys, 1955). Disseminated secondary uranium minerals surround these logs as halos with radii as much as 25 feet. Other secondary uranium minerals are listed according to locality of collection (fig. 83). Associated nonuranium minerals, excluding the detrital grains, are pyrite, galena, chalcocite, covellite, wulfenite, volborthite, cobaltocalcite, malachite, azurite, brochantite, chalcantite, and antlerite. The uranium to vanadium ratio is highly variable, ranging between 10:1 and 1:5.

Alteration.—A distinct mineral zoning occurs in the Delta mine; in the northern workings copper minerals are abundant, particularly malachite and azurite which occur in several 2-foot thick beds containing as much as 11 percent copper (Keys, 1955). Areas which have escaped oxidation contain uraninite in association with chalcocite and covellite. In the central part of the mine, the dominant oxidized uranium mineral is carnotite, with torbernite and metazeunerite increasing northward. In the southern workings, beta-zippeite is the principal secondary ore mineral. Galena and cobaltocalcite occur in the southern workings, but are lacking elsewhere in the deposit (Keys, 1955).

The copper and uranium were introduced contemporaneously or nearly so as in the Happy Jack ore body. Zoning of uranium minerals in the Delta mine is considered by the writers to have resulted from downdip supergene redistribution of elements within an original primary copper-uranium-vanadium ore body. Vanadium may have been introduced as montroseite or as a vanadium-bearing clay or both. The absence of montroseite and its oxidation product, corvusite, and the affinity of carnotite for clay-rich sandstone with interbedded mudstone, however, suggest vanadium-bearing clay. The mechanism of redistribution was probably oxidation of copper sulfides to provide the sulfate ion which in turn mobilized the uranyl ion. This ion was then transported downdip and reprecipitated as relatively insoluble carnotite, torbernite, and metazeunerite by vanadate, phosphate, and arsenate ions respectively. In the absence of these anions the uranyl ion could be transported still further until precipitated as a sulfate (beta-zippeite) or one of a number of minor secondary minerals (fig. 83).

Alteration of red mudstones to green can be seen in the mine, but assay values are independent of these color variations (Keys, 1955).

CAMERON MINING DISTRICT

In 1952 Charles Huskon, a Navajo Indian, made the first discovery of important uranium mineralization in the Chinle formation near Cameron, Ariz. (figs. 73 and 84). This area, containing about 20 mines, is on the west flank of the Black Mesa basin, a few miles east of the East Kaibab monocline in an area having a uniform dip of 1° to 2° NE. (Hinckley, 1955). Fracturing is common; a major joint set strikes northwesterly and a less apparent set strikes northeasterly. However, no relation between structure and mineralization has been observed.

The Permian Kaibab limestone and the Triassic Moenkopi, Shinarump, Chinle, and Wingate formations, as well as scattered basic lava flows and cinder cones of late Tertiary age, crop out in the area. All the important ore deposits (fig. 84) are in the lower 60 feet of Gregory's C member of the Chinle formation (Gregory, 1917), which is normally a purple to gray mudstone. Uranium is concentrated in the somewhat sandy and silty mudstone lenses which occupy ancient scours. Scours have a general northeasterly elongation and are as great as 40 feet in depth and 750 feet in width. Ore is concentrated in the lower parts of scours, particularly in areas containing accumulations of carbonaceous debris. Besides these lenticular deposits, some commercially unimportant scattered pods of ore-grade material occur throughout the C member of Gregory (1917) in the vicinity of fossil wood.

Ore occurrence.—Ore bodies are roughly elliptical in plan view and saucer-shaped in cross section. The largest ore body in the Cameron area is 450 feet long and 300 feet wide. The thickest section of ore-grade material measures 11 feet.

Ore bodies may occupy a number of different positions within scours. Huskon No. 1 and No. 3 (fig. 84) are uniformly mineralized ore bodies which fill the lower parts of scours and have a horizontal upper surface. Highest grade ore occurs at the base of scours and in concentrations of carbonaceous material. Huskon No. 2 (fig. 84) and No. 10 are examples of irregular podlike ore bodies within a scour and which were apparently controlled by concentrations of carbonaceous plant material and by variations in permeability of the scour and fill sediments. These pods range in size from less than 1 ton to 1,000 tons and from low-grade ore to high-grade uraninite-impregnated carbonaceous fragments. Huskon No. 7 (fig. 84) is a transition between the lens and pod forms.

Mineralogy.—Principal ore minerals are metatorbernite, meta-autunite, and uraninite, with minor amounts of uranophane, sabugalite, metazeunerite, and

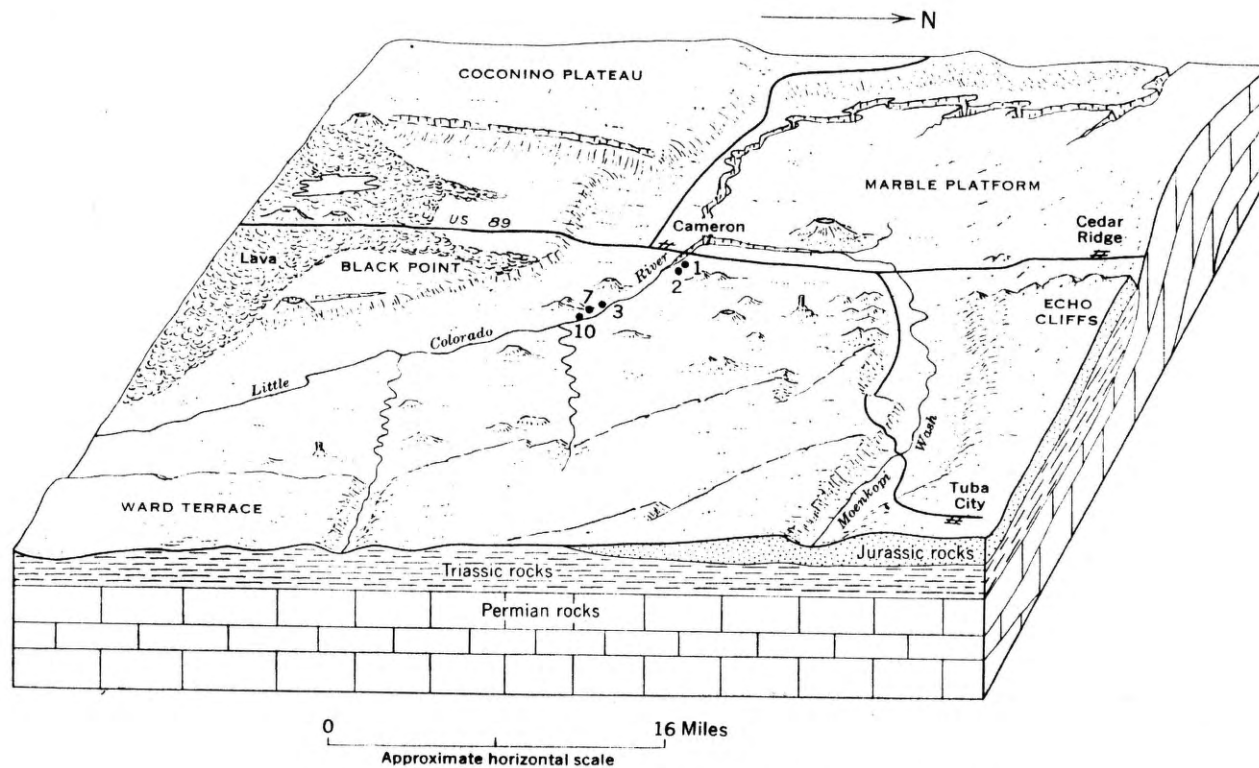


FIGURE 84.—Block diagram of area near Cameron Ariz., showing location of Huskon claims 1, 2, 3, 7, and 10.

zippeite (Gruner, Gardiner, and Smith, 1954). Gangue minerals are montmorillonite, quartz, kaolin and sericite (from feldspar), gypsum, limonite, jarosite, pyrite, calcite, barite, smaltite, and sphaerocobaltite. Vanadium content in the ores is low, attaining a maximum ratio to uranium of 1:7. Ore bodies in the area lie at shallow depths and are almost completely oxidized.

Alteration.—All ore bodies in the area are surrounded by light-brown to yellowish-brown alteration halos which cut across the normal purple and gray beds of the Chinle C of Gregory (1917). These halos are characterized by a high content of jarosite and hydrous iron oxides, sericitization of feldspar, and an increase in trace amounts of molybdenum near the ore (Hinckley, 1955).

Ore controls and ore guides.—Ore is restricted to the lower 60 feet of the Chinle C of Gregory (1917), occurs in ancient scours containing mudstone of relatively high sand and silt content, and is closely associated with carbonaceous material, some of which it impregnates. An increase of cobalt bloom (sphaerocobaltite) and trace amounts of molybdenum near the ore has been noted.

CONCLUSIONS

This study of uranium ore bodies and ore districts in the Shinarump and Chinle formations on the Colorado Plateau did not reveal clearly any specific type of genesis.

Known or hypothetical areal controls of primary ore localization are diverse, including Triassic erosional and depositional features, and subsequent tectonic structures as old as Laramide age. Also some ore bodies after oxidization have been partially redeposited in Recent time by ground-water circulation.

Localization of ore in channel fill and other permeable clastic units suggests that transmissivity is a dominant physical ore control. Geochemically, the loci of ore deposition appear to be largely determined by the distribution of such substances as carbonaceous matter, pyrite, calcite, and certain clays capable of precipitating the uranyl ion through changes in Eh and pH, as well as by adsorption and base exchange. Where uranium occurs in an asphaltite-uraninite complex, as at Temple Mountain, the hydrocarbons are regarded as having been introduced, as fluids, later than the uraninite.

Although the source of the uranium is unknown, isotopic age determinations indicate that the uranium is epigenetic.

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