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RECONNAISSANCE OF URANIUM AND COPPER DEPOSITS IN PARTS OF NEW MEXICO, COLORADO, UTAH IDAHO, AND WYOMING

By Garland B. Gott and Ralph L. Erickson

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By Garland B. Gott and Ralph L. Erickson

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ABSTRACT

Because of the common association of uranium and copper in several of the commercial uranium deposits in the Colorado Plateau province, a reconnaissance study was made of several known deposits of copper disseminated through sandstone to determine whether they might be a source of uranium. In order to obtain additional information regarding the relationship between copper, uranium, and carbonaceous materials, some of the uraniferous asphaltite deposits in the Shinarump conglomerate along the west flank of the San Rafael Swell were also investigated briefly.

During this reconnaissance 18 deposits were examined in New Mexico, 8 in Utah, 2 in Idaho, and 1 each in Wyoming and Colorado.

Commercial grade uranium is not associated with the copper deposits that were examined. The uraniferous asphaltites in the Shinarump conglomerate of Triassic age on the west flank of the San Rafael Swell, however, are promising sources of commercial uranium.

Spectrographic analyses of crude oil, asphalt, and bituminous shales show a rather consistent suite of trace metals including vanadium, uranium, nickel, copper, cobalt, chromium, lead, zinc, and molybdenum. The similarity of the metal assemblage in the San Rafael Swell asphaltites to the metal assemblage in crude oil and other bituminous materials suggests that these metals were concentrated in the asphaltites from petroleum. However, it is possible that uranium minerals were already present before the hydrocarbons were introduced and that some kind of replacement of uranium minerals by carbon compounds was effected after the petroleum migrated into the uranium deposit.

The widespread association of uranium with asphaltic material suggests that it also may have been concentrated by some agency connected with the formation of petroleum. The problem of the association of uranium and other trace metals with hydrocarbons should be further studied both in the field and in the laboratory.

INTRODUCTION

Copper, in varying proportions, is associated with uranium in many of the sandstones on the Colorado Plateau. This association is thought to have resulted from the deposition of these two metals under similar chemical conditions. To test this theory and to search for new sources of uranium, a reconnaissance was made of some of the known copper deposits in sandstones of other areas on and adjacent to the plateau.

This reconnaissance was made on behalf of the Atomic Energy Commission during the summer of 1951 in parts of New Mexico, Colorado, Utah, Idaho, and Wyoming. The results are summarized in this report.

The location, age of host rock, mineralogy, radioactivity, chemical analyses, and a brief description of the deposits that were examined are tabulated in table 1. Arbitrary numbers have been assigned to each deposit and these numbers refer to the same deposits in both table 1 and figure 1. The information about the deposits in each State is briefly summarized below.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to Charles B. Read of the Geological Survey, for unpublished maps and reports of many of the deposits that were examined during this investigation. They are also indebted to various members of the U. S. Geological Survey, Denver laboratory, for spectrographic, chemical, and radiometric analyses. A. T. Myers, spectrographer, and C. A. Horr, chemist, who are responsible for the analyses of hydrocarbons, are carrying out investigations concerning the association of uranium and other metals with hydrocarbons, which will be the subject of a later report.

THE COPPER AND URANIUM DEPOSITS

The deposits examined during this investigation are in northern New Mexico, southeastern Utah, southwestern Colorado, southeastern Idaho, and southwestern Wyoming. Within this region post-Cretaceous intrusive and extrusive rocks cover large areas and pre-Cambrian rocks are exposed in many of the major Paleozoic orogenic belts. However, late and post-Paleozoic sedimentary rocks, principally of continental origin, are most abundant. Thousands of feet of varicolored, but predominantly reddish, aeolian and fluvial sandstones and conglomerates that alternate with lesser amounts of shales, sandy shales, and clays are the most prominent components of the sedimentary sequence. The rocks of this sequence range in age from Pennsylvanian to Recent.

The copper deposits appear to fit a classification consisting of two general types: deposits in which the controlling factors of deposition appear to have been the presence of carbonaceous material and relatively high porosity, and deposits in which the predominant controlling factor appears to have been faulting or fracturing.

The deposits, for the most part, range in size from a few cubic inches of sandstone containing a small amount of copper to many thousands of tons of copper-bearing rock. Some of the deposits have been intermittently mined in the past, but under present conditions it is doubtful if any of them could be mined profitably.

The copper minerals are most abundant in light-gray, fluvial, carbonaceous, argillaceous, porous sandstones of Permian and Triassic age. Chalcocite is probably the primary copper mineral of most of the deposits in their present form. It occurs as a replacement of carbonized plant remains, as interstitial grains and nodules disseminated through the sandstones, and as fracture fillings. The secondary carbonates and silicates have been deposited adjacent to the chalcocite, but in some places they cement the sand grains where copper sulfides are not present.

The most abundant copper minerals in the deposits are malachite, chalcocite, azurite, and chrysocolla. Malachite is the most prominent mineral, but its bright color and its presence, in some places, as a coating or halo around chalcocite grains and nodules may result in disproportional estimates of the two minerals. Azurite is present in much smaller quantities than malachite but, nevertheless, is widespread. Chrysocolla is most abundant in the Copper City and Pintada-Pastura districts in New Mexico. Covellite was identified in about one-third of the deposits. Chalcopyrite, cuprite, copper sulfates, and native copper are sparingly present in a few deposits.

During a two-day reconnaissance of the San Rafael Swell in Utah, a few of the uraniferous asphaltite deposits were briefly examined. The deposits about which the writers have obtained information are not known to be extensive, but a similar deposit at Temple Mountain, on the southeastern corner of the San Rafael Swell, apparently contains comparatively large resources of uranium. The asphaltic material occurs as rounded grains, stringers, pods, and irregular masses in the Shinarump conglomerate. Small quantities of uranium-bearing carbonized wood are also present. The hydrocarbons apparently range from an asphalt largely soluble in carbon disulfide to residual asphaltites (or pyrobitumens?) that are only slightly soluble in carbon disulfide. The residual asphaltites contain more uranium and other metals than do the soluble asphalts.

Several metals are present in the asphaltites including Fe, Ti, Co, Cu, Mo, Ni, Pb, U, V, and Zn. Compounds of these metals are present in the asphaltite-bearing rock and include pyrite, arsenopyrite(?), zinc-nickel-cobalt sulfate, chalcopyrite, bornite, chalcocite, covellite, malachite, azurite, paraschoepite(?), and metatorbernite.

Spectrographic analyses of a few asphaltite samples from this area show that the metal suite in the asphaltites is the same as is present in crude oils. This suggests that the metals in the asphaltites may have been concentrated from crude oil by a combination of volatilization, oxidation, and polymerization resulting in a concentration of the metal-bearing asphaltenes and other heavy hydrocarbons. More extensive investigations to determine the metal compounds and their relationship to the organic constituents in a greater number of bituminous materials are needed, however, before the source of the metals can be definitely established.

New Mexico

Cuba, Abiquiu, and Gallina districts

The deposits in the Cuba district, on the west flank of the Sierra Naciemiento uplift (deposits 1, 2, and 3), and in the Abiquiu and Gallina districts, on the east flank of this uplift (deposits 4 and 5), are in the Triassic Poleo sandstone lentil of the Chinle formation,

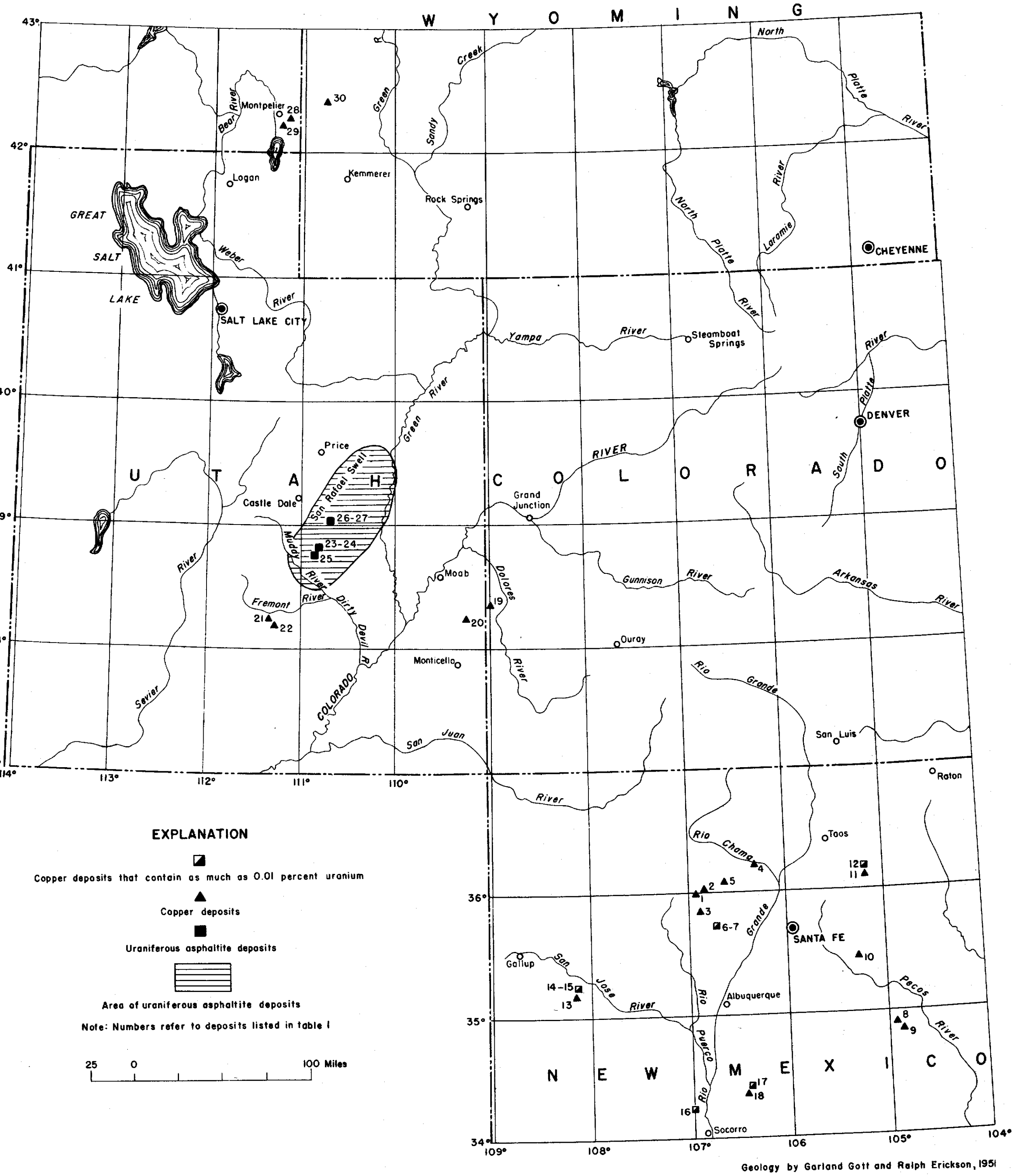

Figure 1.--Some copper and uranium deposits in parts of New Mexico, Colorado, Utah, and Wyoming.

an equivalent of the Shinarump conglomerate. Deposits 1, 2, and 3 have been productive mines; deposit 4 has been prospected by means of six short tunnels; and deposit 5 consists of insignificant amounts of copper minerals that were exposed during road construction. The dip of the Poleo sandstone lentil at these deposits ranges from horizontal to about 30 degrees. Carbonized wood, carbonaceous clay beds, and high permeability are features that are common to all these deposits. Copper minerals, chiefly malachite, chalcocite, azurite, and chrysocolla occur in fractures, disseminated through the sandstone, and surround and replace carbonized wood. Some of the carbonized wood is slightly radioactive but no uranium minerals are visible. The Poleo sandstone lentil consists of subangular to subrounded quartz grains and a minor amount of feldspar. Many of the quartz grains show secondary growth producing sharp crystal faces. Chalcocite grains occur chiefly in the interstices between quartz grains and are largely oxidized to malachite, which forms the cement of the sandstone. Chalcocite also fills fractures in, and replaces, quartz and feldspar. Feldspar, which comprises 5 to 10 percent of the rock, is preferentially replaced by malachite, whereas fractured quartz grains are preferentially veined with chrysocolla.

Undistorted cell structure is prominent in polished sections of chalcocitized wood. A few residual grains of pyrite in chalcocite show "ice-cake" texture (Tolman, 1916, p. 407) and suggest that the wood was originally replaced by pyrite and later by chalcocite. Small amounts of covellite replace chalcocite to form "rim" texture (Edwards, 1947, pp. 83-96).

Jemez Springs district

The copper deposits at the Spanish Queen mines (deposits 6 and 7) in the Jemez Springs district, on the east flank of the Sierra Naciemiento uplift, are in the Abo formation of Permian age(?). The Abo at this locality is a yellow to reddish-brown medium-grained massive arkosic sandstone, of fluvial origin, that contains several carbonaceous shale layers as much as 4 inches thick and a small quantity of carbonized wood fragments. Chalcocite, malachite, and azurite are associated with the carbonaceous shale and carbonized wood. Selected pieces of the most radioactive carbonized plant remains from the easternmost mine contain as much as 0.01 percent uranium. Radon has accumulated in the west mine.

A radioactive travertine has been deposited around Jemez Springs, 5.7 miles upstream from the Spanish Queen mines. No uranium was detected in the travertine by chemical analyses and, accordingly, it is believed that the radioactivity is caused by radium.

Zuni Mountain and Scholle districts

The copper minerals in the Zuni Mountain district in Valencia County (deposits 13, 14, and 15) and the Scholle district in Torrance County (deposits 17 and 18) are also in the Abo formation. Copper minerals in these districts occur with carbonized wood fragments and are present along the contacts between gray shale and arkosic sandstone beds. The woody material is slightly radioactive.

Pintada-Pastura district

The deposits at the Guadalupe mine and the Pintada lode in the Pintada-Pastura district, Guadalupe County, are in the San Andres formation of Permian age and the Santa Rosa sandstone of Triassic age. The Guadalupe mine (deposit 9) is in a structural depression, which Read (personal communication, 1951) attributes to subsidence resulting from solution of evaporites in the underlying San Andres formation. Copper sulfides partly replace carbonized wood and are disseminated in the Santa Rosa sandstone. Patches of massive sandstone beds are silicified and impregnated with black manganese oxides. Malachite forms botryoidal surfaces along cracks and joints and is disseminated in the sandstone.

The Pintada lode (deposit 8), near San Ignacio in Guadalupe County, is in the San Andres formation. The copper minerals, chalcocite and secondary carbonates and silicates, are in a calcareous fine-grained light-gray sandstone. The chalcocite occurs as tiny intergranular grains; the secondary copper carbonates and silicates occur along bedding planes, as fracture fillings, disseminated in the sandstone, and in association with stringers of gypsum. No carbonaceous material was observed at this prospect.

Tecolote district

Only one small copper prospect, the Bonanza(?) (deposit 10), was located in the Tecolote district near Las Vegas. Small patches of malachite are in the Permian arkosic sandstone at this locality. No abnormal radioactivity was detected.

Guadalupita district

A copper-uranium-bearing black shale (deposit 12) of Permian age, 2 to 3 miles south of Guadalupita on Coyote Creek, contains 2 percent copper and 0.01 percent uranium. The abnormal radioactivity of the shale was first discovered in 1951 by Charles B. Read and George O. Bachman, both of the Geological Survey. The shale is about 5 feet thick and is vertical. It is nonmarine and is overlain and underlain by arkosic sandstones of Permian age. Chalcocite, pyrite, and malachite are the most abundant minerals. The shale is a potential source of commercial copper and uranium. If it could be mined for copper, the uranium might be recovered as a byproduct of the copper.

San Acacia district

A deposit near San Acacia (table 1, no. 16) in shear zones in volcanic rocks, contains small quantities of torbernite(?) and carnotite(?), together with secondary copper minerals, calcite, and quartz. One sample selected from the dump material contained 0.026 percent uranium.

Colorado

The Cashin mine

The Cashin mine (deposit 19) in Montrose County consists mainly of a 3,000-foot tunnel along a mineralized brecciated zone of vertical or near-vertical fractures in cross-bedded massive Wingate sandstone of Jurassic(?) age. The original ore body, now mined out, was 1 to 20 feet wide and contained argentiferous copper sulfides. Chalcocite, azurite, malachite, blue copper sulfate, and black manganese oxides coat the walls of the tunnel. The copper minerals occur mostly along the fractures, but in places they are along bedding planes in the more porous unfractured sandstone. The presence of a heavy coating of copper salts on the walls and roof of the tunnel illustrates the effects of recent solution and redeposition. No abnormal radioactivity was detected in the tunnel. The deposit is probably of hydrothermal origin.

Utah

The copper and uranium deposits that were examined in Utah include the Big Indian mine 5 miles south of La Sal, two small copper prospects in the Capitol Reef area near Torrey, and five deposits of uraniferous asphaltites along the west side of the San Rafael Swell in Emery County. A brief description of these deposits follows:

The Big Indian mine

The Big Indian mine, 5.2 miles south of La Sal (deposit 20), is developed by an open-cut about 200 feet long, 100 feet wide, and 20 to 30 feet deep. The abandoned shafts are not accessible. The deposit is in sandstone beds of the Dakota(?). The copper-bearing sandstone is about 20 feet thick. It is a porous coarse- to medium-grained sandstone that is overlain and underlain by dark-gray carbonaceous shale. The deposit is not abnormally radioactive.

The deposit is in a northwest-trending fault zone. The movement along this fault zone has resulted in a series of fractures in the sandstone, which are exposed in the open pit. Copper carbonates with small amounts of chalcocite and chrysocolla are concentrated in fractures and along bedding planes and are disseminated in the sandstone. Manganese oxide stains give the rock a black- and white-speckled appearance. Small amounts of carbonaceous material are scattered through the sandstone and in some places copper minerals have been deposited around lenses of this material.

Although the genesis of the deposit is not clear because most of the ore has been mined out, the occurrence of the copper minerals along fractures and faults suggests that this deposit may be of hydrothermal origin. This conclusion was reached previously by Read (personal communication, 1951), who suggested a telethermal origin for this deposit.

Torrey district

Two copper prospects were examined in the Torrey district in Wayne County, Utah. No abnormal radioactivity was detected and very little copper was observed at either prospect. Deposit 21 is in siltstones and limestone of the Moenkopi formation of Triassic age. The workings of the deposit consist of an inclined adit and a tunnel, both of which are caved near the portals. Ten feet of flaggy, calcareous siltstone, overlain by 10 to 12 feet of well-bedded vuggy limestone are exposed in the adit. A weathered zone about 6 inches thick separates these two units. Malachite and azurite are concentrated mostly in one 18-inch bed of vuggy limestone.

Large boulders of vuggy recrystallized and brecciated limestone on the dump suggest that this deposit was localized in fractures or along a fault zone and perhaps was formed by hydrothermal solutions.

Deposit 22 contains small amounts of copper carbonate stain on a buff sandstone of the Moenkopi formation. The prospect has been developed by an open-cut, 30 feet long, 30 feet wide, and 7 feet deep; and by a 25-foot shaft in the bottom of the pit. No copper minerals were observed in the bottom of the shaft and no abnormal radioactivity was detected at the prospect.

The San Rafael Swell district

The San Rafael Swell is a northeast-trending elongate dome that is about 70 miles long and 25 to 30 miles wide. Sedimentary rocks of Permian age are exposed along the crest of this anticline and progressively younger rocks ranging from Triassic to Late Cretaceous in age are exposed along the flanks. Five uranium deposits along this anticline were examined by the writers. The deposits consist of uraniferous asphaltites locally disseminated through the Shinarump conglomerate. Although this investigation of the San Rafael Swell district is incomplete, the data that were obtained are included here because they might aid in current and future studies.

Uranium-bearing hydrocarbons with physical characteristics similar to those along the west flank of the San Rafael Swell have been known by a variety of names including anthraxolite, carburan, huminite, and thucholite. Ellsworth (1928) gave the name thucholite to a uranium- and thorium-bearing hydrocarbon from a pegmatite in the Parry Sound district in Ontario. Since that time the term thucholite has been generally used to include all uranium-bearing hydrocarbons. By custom, however, the term thucholite seems to have a genetic connotation implying that the material is of hydrothermal origin. Inasmuch as the writers are not prepared to assign the uraniferous asphaltites of the San Rafael Swell to a specific genetic classification, the term will not be used in this report with reference to these particular deposits.

In the San Rafael Swell area uranium and a small amount of copper are associated with hard lustrous asphaltite pellets, stringers, and small irregular masses, and to a lesser extent with carbonized plant material. This uranium-bearing carbonaceous material is disseminated in the Shinarump conglomerate, which in this area is predominantly composed of poorly sorted silty conglomeratic sandstone.

The Lone Tree deposit (no. 27) is in the lower part of the Shinarump conglomerate. At this locality the Shinarump conglomerate is an argillaceous conglomeratic sandstone that contains shale fragments and uraniferous asphaltite pellets and stringers. The essential constituents of the rock are poorly sorted angular to subrounded quartz grains, pieces of porphyritic volcanic flow rock as much as 1/2 inch in diameter, and gray shale fragments that were probably incorporated from the underlying gray shale bed. These constituents are in a clay matrix that turns blue after application of benzidine. This suggests the presence of some montmorillonitic material. The larger quartz grains are subrounded and many of them are heavily fractured; others are mosaic patches of sutured grains. Patches of secondary calcite surround quartz grains and are partially replaced along cleavage planes by iron oxides. Uranium is associated with hard lustrous pellets of asphaltite as much as 1/2 inch in diameter and with discontinuous stringers of asphaltite as much as 1 inch thick. These pellets and stringers are contained in the more porous parts of a 3-foot bed of coarse-grained argillaceous sandstone and conglomerate. A small fault with about 3 feet of displacement appears to define one boundary of the deposit. The asphaltite-bearing bed is overlain and underlain by compact gray shale. Individual asphaltite pellets contain as much as 3.28 percent uranium and spectrographically detectable amounts of Ag, As, Co, Ni, Cr, Cu, Mo, V (table 2, nos. 15 and 17); the overlying shale bed contains 0.015 percent equivalent uranium, and the underlying shale bed contains 0.008 percent equivalent uranium.

Visible secondary uranium minerals are relatively rare. A yellow uranium mineral, tentatively identified as paraschoepite, occurs as patches along bedding planes, as discontinuous stringers in the clay matrix, and as a replacement of calcite. Inasmuch as the paraschoepite(?) is obviously the last mineral to have formed, it seems evident that it was deposited from solutions that leached the uraniferous asphaltite.

Polished sections of asphaltite pellets from the Lone Tree group of claims show two types of hydrocarbon: a gray isotropic part that is fractured, possibly as a result of contraction and oxidation, during the last stages of volatilization and a later, much less abundant, light-gray hydrocarbon that fills some of the fractures. Other fractures are filled with a nonopaque gangue mineral, probably gypsum. Pyrite, the most abundant metallic mineral in the section, occurs as small irregular grains and patches in the older hydrocarbon. Examination of the sections with oil immersion lens (X 560) reveals tiny grains of chalcopyrite and a few grains of a white metallic mineral that may be arsenopyrite. Spectrographic analyses indicate that between 0.1 to 10.0 percent arsenic (table 2, nos. 15 and 17) is present in the asphaltite pellets.

Reyner (1950) examined the Lone Tree deposit in 1950 and estimated that it contained no more than 100 tons of 0.20 percent uranium oxide. This estimate, however, was largely based on samples obtained from an adit 18 feet long and 10 feet wide.

The Dalton group of claims (deposit 26) is about 1 mile south of the Lone Tree group. Gray shale is exposed in the roof of three short adits and this is underlain by lenticular alternating fine- to medium-grained sandstone and pebble conglomerate. Uraniferous asphaltite in the form of grains, blebs, stringers, elongate pods, and fracture fillings occurs through a thickness of about 3 feet and is particularly abundant in the conglomeratic parts of the sandstone about 20 feet above the base of the Shinarump conglomerate. Radioactivity is apparently restricted to the asphaltite, which contains as much as 5.0 percent equivalent uranium and 1.34 percent uranium. Individual grains are as much as 1/2 inch in diameter, and pods and lenses are as much as 20 inches long and 4 inches thick. Some of the pods and lenses have a center core of granular pyrite, and in other pods and lenses the pyrite is disseminated but appears to replace the asphaltite.

Polished sections of the uraniferous asphaltite show that pyrite invades the hydrocarbon and replaces the quartz grains producing embayed irregular grains. Most of the pyrite masses have "exploding-bomb" texture (Graton and Murdock, 1913, p. 37) and are surrounded by gangue minerals, probably carbonates. Minute blebs of chalcopyrite, chalcocite, and covellite can be detected in the asphaltite with the oil immersion lens (X 560). Covellite occurs chiefly in tiny discontinuous fractures in the asphaltite.

A similar association of uranium with hard lustrous asphaltite is found at the Ronnie, Jerry, and Frenchy mine (deposit 23) in SW$\frac{1}{4}$ sec. 20, T. 23 S., R. 10 E. Small vitreous uraniferous asphaltite grains, 0.5 to 1.0 millimeters in diameter, are disseminated through a thickness of about 25 feet of gray sandstone in the lower part of the Shinarump conglomerate. The asphaltic sandstone is overlain by a nonradioactive conglomerate that contains numerous clay layers. The mine workings consist of a short tunnel about 7 feet high, which has been driven into the asphaltic sandstone. In addition to uraniferous asphaltite, numerous fossil logs with silicified centers and radioactive carbonized rims as much as 15 inches in diameter are imbedded in the lower part of the sandstone. The carbonized material in these logs contains from 0.1 to 1.0 percent uranium. A 7-foot channel sample of the sandstone contained 0.03 percent uranium, and a concentrate of the asphaltite grains contained 0.30 percent equivalent uranium. Spectrographic analyses of the asphaltite concentrate are given in table 2, no. 19.

Above the entrance to the tunnel, a recently formed deposit of pink zinc-nickel-cobalt sulfate coats the nearly vertical sandstone cliff. The metals probably were derived from the asphaltite and carbonized wood.

Polished sections of the asphaltic sandstone show minute grains of metallic minerals, chiefly chalcopyrite and cobalt-nickel minerals, in quartz grains, along fractures, and along the contact of asphaltite and quartz. These minerals were not observed in the hydrocarbon.

Pyrite with cell, ice-cake, and exploding-bomb textures is the chief metallic mineral observed in polished sections of the carbonized wood. Minute blebs of chalcopyrite are scattered at random in the wood.

The host rock is an argillaceous medium-grained gray asphaltic sandstone. Quartz grains are strongly fractured. Malachite, azurite, metatorbernite, gypsum, and chalcedonic quartz are the secondary minerals.

About 1/2 mile south of the Ronnie, Jerry, and Frenchy mine in the SW$\frac{1}{4}$ sec. 20, T. 23 S., R. 10 E., 1,000 feet of uranium- and copper-bearing sandstone and shale of the Shinarump conglomerate has been exposed by bulldozer exploration (deposit 24). The exposed beds consist of red clay and shale at the base, overlain by the following rocks: 4 feet of radioactive asphaltic sandstone; 5 to 15 feet of gray, green, and red shales; 5 feet of brown pebble conglomerate; as much as 6 feet of lenticular cross-bedded soft white sandstone; and 5 to 15 feet of conglomeratic sandstone. The highest degree of radioactivity occurs in the asphaltic sandstone in a rather persistent 4-inch thick zone of sooty fossil plant fragments. A few isolated woody fragments are strongly radioactive.

At the time the writers examined the deposit, no minable thickness of ore had been exposed.

Ground waters have redistributed copper and uranium as copper carbonates and metatorbernite on joints and fractures in the sandstone and the underlying shale beds. Two small adits, one 5 feet long and the other 15 feet long, have been excavated in the shale. The radioactivity in these adits averages between 0.10 and 0.15 milleroentgens per hour.

Bornite, chalcopyrite, covellite, and chalcocite were observed in a polished section of uraniferous black material that is either asphaltite or carbonized wood. Bornite and chalcopyrite show a texture that may be due either to exsolution or to replacement of bornite by chalcopyrite along preferred crystallographic directions. The latter interpretation is favored. Covellite preferentially replaces bornite; chalcocite replaces chalcopyrite and bornite and is partly replaced along the margins by covellite.

Deposit 25, an operating mine in the NE$\frac{1}{4}$ sec. 31, T. 23 S., R. 10 E., is one of the most promising deposits examined. The mine workings consist of a 50-foot tunnel, 6 to 15 feet wide, in the lower part of the Shinarump conglomerate. An 8-foot channel sample cut in the tunnel contained 0.31 percent uranium. One selected sample of carbonaceous material that is either asphaltite or carbonized wood contained 1.2 percent equivalent uranium. Abnormally high radioactivity is associated with numerous layers of carbonized plant remains 1/16 to 1/8 inch thick and with disseminated asphaltite grains in light-gray medium-grained sandstone. No secondary uranium minerals were identified in the mine, but small amounts of yellow and blue-green stain and copper carbonates are present near and at the base of surface exposures of the Shinarump.

The Shinarump conglomerate is about 150 feet thick at this locality and consists of alternating lenticular beds of sandstone and conglomerate. The lower 1 to 15 feet of the exposed beds is abnormally radioactive for about 400 feet along the outcrop. The radioactivity of these rocks ranges from 0.15 to 20.0 milleroentgens per hour.

Source of the uranium in the asphaltites

It has been suggested that the rounded uraniferous asphaltite pellets in the San Rafael Swell are detrital and were eroded from a previously existing but unknown uraniferous asphaltite deposit (Gilluly, and Reeside, 1928, pp. 93-94; Hess, 1933, p. 458; and Wyant, 1952). The conclusion was reasonable because any alternative to a detrital hypothesis would require a rather complicated mechanism by which the cavities could have formed prior to the introduction of hydrocarbons. Nevertheless, the writers consider that the following evidence contradicts the view that the asphaltite grains are detrital:

(1) Although much of the uraniferous asphaltite is in the form of rounded grains, some of it is in the form of stringers, elongate pods, lenses, heavy stains, and irregular masses that conform to the shape of the sand grains.

(2) Some of the rounded grains have a botryoidal surface. Such a surface is inconsistent with a detrital hypothesis.

If the hydrocarbons are epigenetic, as the writers believe, either of the following two general hypotheses can be postulated to account for the concentration of uranium in the asphaltite. (1) The uranium was present in the Shinarump conglomerate before the hydrocarbons migrated into it. When the hydrocarbons did come in contact with the uranium minerals, the uranium was transferred into the hydrocarbon fluids. The hydrocarbons most closely associated with the uranium was then polymerized by alpha particles to a high polymer. When the anticline was breeched by erosion, the unpolymerized liquid and gaseous hydrocarbons escaped, leaving the immobile solid uraniferous hydrocarbons behind. (2) The uranium and other metals were transported in solution by migrating petroleum from more distant uranium deposits including the petroleum source bed.

A discussion of these hypotheses follows: the hypothesis that thucholite results when alpha particles polymerize hydrocarbons that have been introduced into a uraniferous deposit has apparently received considerable support from Ellsworth (1928), Spence, (1930), and Davidson and Bowie (1951, pp. 1-9). After a study of the thucholite-bearing pegmatites in the Parry Sound district of Ontario, Ellsworth (1928) concluded that both the uranium and the hydrocarbons were of hydrothermal origin. He believed that alpha radiation from uraninite crystals polymerized gaseous hydrocarbons and that the higher polymer replaced the uraninite crystals resulting in thucholite in the form of uraninite pseudomorphs. In a discussion of a similar deposit in the same district, Spence (1930) noted that the thucholite was in the form of cubic crystals, irregular masses, nodules, pellets, minute veinlets, and is associated with a "petroleumlike" oil. He differed somewhat from Ellsworth in concluding that the thucholite probably "is not a primary constituent of the pegmatite" but was formed later by the replacement of uranium by carbon and the effects of radiation on oil that had migrated into the pegmatite.

After a study of the thucholite in the Rand conglomerate of the South African gold fields, Davidson and Bowie (1951, p. 1) concluded "that thucholite is not a true mineral but a complex of uraninite with hydrocarbon of hydrothermal origin, resulting from a polymerization or condensation of hydrocarbon fluids effected by radiations from uranium ore." They believe that the Rand thucholite represents a replacement of mesothermal pitchblende by late hydrothermal hydrocarbons.

Thus, the investigators of other uranium-bearing hydrocarbon deposits have concluded that the first step in the formation of thucholite is the presence of uranium minerals, and that the second step is the introduction of hydrocarbons (gaseous in the opinion of Ellsworth, and of Davidson and Bowie, and fluid in the opinion of Spence) around a uranium mineral.

Although a hydrothermal origin for both the uranium and hydrocarbons has been postulated for most of the deposits studied by the authors referred to above, the effects would be the same if uranium and hydrocarbons of any origin were brought together.

The asphaltite pellets in the Lone Tree deposit of the San Rafael Swell are as much as one-half inch in diameter. The presence of such large grains can be interpreted to mean that a uranium mineral formerly occupied the space now filled with the asphaltite pellet, and that the hydrocarbon replaced the uranium, possibly in much the same manner as suggested by Ellsworth, Spence, Davidson, and Bowie. Autoradiographs, however, indicate that the radioactive elements are homogeneously distributed throughout the asphaltite and this seems to contradict the view that nonuraniferous hydrocarbon gases or fluids were polymerized around a radioactive nucleus.

The San Rafael Swell was a structure ideally suited to the accumulation of petroleum compounds before it was breeched by erosion. Within this structure the uraniferous asphaltites are in the Shinarump conglomerate, a stratigraphic unit well known for the many uranium deposits that occur within its boundaries. If we accept the prerequisite that hydrocarbons must be brought into an area affected by alpha radiation before a thucholite-type deposit can be formed, it is not surprising that uraniferous hydrocarbons are present along the flanks of the San Rafael Swell.

The hypothesis that the uranium and other metals were transported by fluid hydrocarbons is strongly supported by the presence of the same suite of metals in the asphaltites as are present in crude oils, gilsonite, and black shales. Spectrographic analyses tabulated in table 2 show that, so far as known, all these materials contain rather consistent quantities of vanadium, nickel, copper, cobalt, molybdenum, lead, zinc, and chromium.

Numerous other analyses of crude oils and the ash of crude oils indicate that vanadium, nickel, and copper are concentrated in the asphaltic portion of the crudes. Analyses of 17 oils from the Second Baku and two oils from the Apsheron Peninsula show that vanadium, nickel, and copper oxides comprise 50 to 90 percent of the ash (Gulyaeva, Itkina, and Romm, 1941). It is noteworthy that these metals are equally high in the ash of filtered oils, suggesting that they are present as organic compounds and are not present as mechanical admixtures. Romm (1946) demonstrated that the vanadium content of sedimentary rocks of the Ural-Volga region was roughly proportional to the bitumen content of the rocks. Bituminous limestones and dolomites contained 18 to 119 ppm vanadium; nonbituminous limestones and dolomites contained only a trace or no vanadium.

Dunstan (1924) reported that the ash of crude oil from Maidon-i-Naftun, Persia, contained 5.03 percent vanadium pentoxide and 2.70 percent nickel oxide, and that 15 grams of ash showed two-thirds as much radioactivity as 1 gram of uranium-nitrate.

Unkovskaya (1940, p. 380) has found that waters related to petroleum are 5,000 times higher, and petroleum itself is 50,000 times higher in uranium than is sea water.

A crude oil extract from the Spergen limestone collected in St. Genevieve County, Mo., contains between 0.01 and 0.1 percent uranium (table 2, no. 12). A petroliferous limestone in the Uinta formation in northeastern Utah contains about 0.02 percent uranium. The ash of gilsonite from Uintah County, Utah contains between 0.01 and 0.1 percent uranium (table 2, no. 14). The ash of petroleum coke from the refinery at Casper, Wyo., contains 0.2 percent uranium (table 2, no. 13). Uranium-bearing asphalts and asphaltites associated with structures favorable for the accumulation of oil are known in several places within the United States, including the deposits along the San Rafael Swell, and in limestones and dolomites in the Texas Panhandle helium-bearing natural gas field. Many black marine shales, commonly considered to be the source beds for much of our petroleum, contain significant quantities of uranium.

The known data, therefore, clearly indicate that appreciable quantities of the metallic constituents of the San Rafael Swell asphaltites, including uranium, are present in heavy fractions of petroleum, asphalt, and bituminous shales perhaps, as suggested by Rankama and Sahama (1949), in the form of metal-organic-porphyrin compounds. This suggests that the metals in the asphaltite of the San Rafael Swell area were concentrated from petroleum.

The high concentration of metals in the asphaltites may have been the result of natural fractionation caused by pressure, temperature, and porosity differences, perhaps resulting in the concentration of the heavier fractions in some parts of the reservoir. After the reservoir was exposed by erosion all the lighter fractions would have been flushed out and the immobilized heavier metal-bearing fractions would have been left behind.

If future investigations show that the metals normally found in hydrocarbons have a genetic relationship with crude oil and its source beds, new methods and techniques might be developed that would assist in the discovery of uranium deposits.

Idaho

Two copper prospects were examined in southeastern Idaho: the Evening Star claim (deposit 28), and the Bonneville claim (deposit 29). The Evening Star claim is 7 miles east of Montpelier along U. S. Highway 89. Malachite and azurite, the principal copper minerals in this deposit, are associated with carbonaceous material in a sandstone bed in the Ankareh shale of Triassic age. One adit, 20 feet long, 4 feet wide, and 4 feet deep, follows the bed, which dips 25° and strikes S. 80° W. A trench extends for 20 feet in front of the portal.

The mineralized bed is a 4-foot medium-grained arkosic well-indurated quartz sandstone. It weathers dull brown but fresh surfaces are light gray. Scattered fragments of carbonized plant material have been crushed into thin films parallel to the bedding planes. Pieces of carbonaceous material selected for their radioactivity contain 0.003 percent uranium. Most of the copper minerals are localized along the bedding planes by the residual plant material but small amounts of malachite are disseminated through the sandstone. The prospect probably contains less than 1 percent copper.

The Bonneville(?) prospect west of Montpelier (deposit 29) also is a submarginal copper deposit and is not detectably radioactive. The underground workings are inaccessible. The mine dump, about 100 feet long and 20 to 30 feet wide, consists chiefly of light-gray well-cemented sandstone, possibly from the Ankareh shale, with small amounts of copper carbonate stain. Fragments of carbonized plant material are disseminated through the rock. The beds strike north and dip 57° E.

Wyoming

The Old Copper mine (deposit 30), 30 miles northeast of Cokeville, was the only copper prospect examined by the writers in Wyoming. The mine workings are inaccessible and the dump material was not detectably radioactive. The lessee, Mr. Dan S. Shickich of Kemmerer, Wyo., reported that a 600-foot tunnel and 125-foot shaft constitute the mine workings.

The dump material is composed of light-gray well-cemented sandstone. A few pieces of sandstone are stained with malachite, and one specimen contained chalcopyrite, covellite, and chalcocite. No carbonaceous material was observed.

CONCLUSIONS

Variation in the factors that controlled the deposition of copper and uranium minerals apparently has resulted in two general types of deposits: deposits in which deposition of the ore minerals was controlled by permeability and carbonaceous material, and deposits in which the deposition of the minerals was structurally controlled.

The copper and uranium in many deposits have been concentrated by carbonaceous materials, including carbonized plants and hydrocarbons. Copper has been redistributed as carbonates along joints, fractures, and disseminated in sandstones adjacent to carbonaceous material. Most of the enclosing sandstones are light in color, porous, micaceous, often arkosic; and most of the areas of mineralization are near large folds or orogenic belts. In contrast, the structurally controlled deposits are localized along faults, shear zones, and associated joints and fractures where carbonaceous material is not present.

The source of the uranium in the uraniferous asphaltites is questionable, but it either had been concentrated at its present point of localization before the introduction of the hydrocarbons or it was transported by the hydrocarbons from an unknown source. On the basis of the available information the latter hypothesis is preferred by the writers.

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Table 1.--Radiometric and chemical analyses of samples from some uranium and copper deposits in sandstone

No.	District, mine name, State	Location	Formation	Type of sample	Radioactivity: Milleroentgens per hour[a] (maximum)	Radioactivity: Equivalent uranium (percent)	Chemical analyses (percent): U	Chemical analyses (percent): V_2O_5	Chemical analyses (percent): Cu	Serial no.	Mineralogy	Remarks
1	Cuba district, Copper City mines, N.Mex.	C. NW$\frac{1}{4}$ sec. 1, T. 20 N., R. 1 W.	Poleo (Triassic).	-------------	0.07	------------	-----	----	----	--------	Chalcocite, covellite, pyrite, malachite, azurite, chrysocolla, cuprite(?), hematite.	Copper minerals are concentrated in fractures, in sandstone marginal to fractures, in porous light-gray sandstone along bedding planes, around and in carbonized wood fragments. Some of the wood is slightly radioactive. In thin section, silicic feldspar is preferentially attacked by malachite whereas fractured quartz grains are preferentially veined with chrysocolla. Chalcocite occurs chiefly in the interstices between quartz grains, fills and replaces fractures across quartz and feldspar grains, and replaces wood preserving undeformed cell structure. Wood cells originally filled and replaced by pyrite.
2	Cuba district, Eureka mines, N. Mex.	NE$\frac{1}{4}$ sec. 32, T. 21 N., R. 1 E., $\frac{3}{4}$ mile northeast of Eureka Lodge, which is on State Route 126.	----do---------	-------------	.04	------------	-----	----	----	--------	----do----------	The mine development consists of about 400 ft of underground workings in nearly flat-lying light-gray sandstone. Repeated cycles of sedimentation are represented. The cycles begin with coarse conglomerate in which carbonaceous material is sparsely present and range through progressively finer-grained sandstones, some of which contain carbonaceous material. Two factors appear to have influenced deposition of the copper minerals: porosity and the presence of carbonaceous material. Copper is more concentrated in the highly porous slightly carbonaceous conglomerate than it is in the more carbonaceous but less porous sandstone.
3	Cuba district, San Miguel mine, N. Mex.	NE$\frac{1}{4}$ sec. 24, T. 19 N., R. 1 W.	----do---------	-------------	.03	------------	-----	----	----	--------	Chalcocite, covellite, pyrite, sphalerite(?), malachite, azurite, chrysocolla.	Extensive underground workings are abandoned and inaccessible. Plant fragments have been replaced by chalcocite and later oxidized to malachite and azurite. The copper carbonates also fill fractures and in some places are disseminated in noncarbonaceous sandstone. Secondary copper minerals fill fractures and replace quartz and feldspar grains. Iron-rich sphalerite(?) has mutual boundary texture with chalcocite; both contain relict grains of pyrite.
4	Abiquiu district, Cobre Basin mines, N. Mex.	About 7 miles northeast of Abiquiu, center of W$\frac{1}{2}$, of T. 24 N., R. 6 E.	----do---------	-------------	.04	------------	-----	----	----	--------	Chalcocite, malachite, azurite.	The light-gray Poleo sandstone has been prospected by at least six short tunnels on the east side of Copper Canyon. Copper mineralization is found in carbonaceous sandy clay, in light-gray sandstone, and as halos surrounding clay galls. Most of the carbonaceous material is in the form of carbonized wood.

5	Gallina district, near Jarossa, N. Mex.	Southern part of T. 22 N., R. 3 E.	Paleo (Triassic).	-------------	0.02	------------	-----	-----	----	--------	Chalcocite, covellite, malachite.	Copper-stained sandstone has been exposed during road construction. The copper minerals are associated with carbonized wood, and the carbonates are also disseminated in noncarbonaceous arkosic sandstone. The chalcocite and malachite fill fractures in quartz grains.
6	Jemez Springs district, Spanish Queen mine (east), N. Mex.	4 miles south of Jemez Springs. (Unsurveyed.)	Abo (Permian)-	Slightly radioactive carbonized wood.	.3	0.01	0.01	0.03	5.45	52320	Chalcocite, covellite, pyrite, malachite, azurite.	The principal workings consist of a tunnel about 100 ft long in nearly flat-lying medium-grained iron-stained arkosic sandstone. Carbonized wood is in part chalcocitized. Slightly radioactive beds as much as 1 inch thick contain abundant malachite and some azurite. The quartz grains are fractured and veined with malachite. Malachite and azurite also coat and impregnate layers of muscovite.
7	Jemez Springs district, Spanish Queen mine (west), N. Mex.	----do----------	----do---------	-------------	.2	------------	-----	-----	----	--------	---do---------	An east-west tunnel and one crosscut are in massive buff argillaceous arkosic sandstone that contains gray carbonaceous shale beds up to 4 in. thick. Copper carbonates fill open fractures, coat the tunnel walls, and are associated with carbonized wood. The radioactivity of one small patch of carbonized plant fragments near the portal of the mine is 0.2 milleroentgens per hour. The radioactivity caused by radon within the mine is 0.1 milleroentgens per hour. No uranium minerals were recognized.
8	Pintada-Pastura district, Pintada lode, N. Mex.	NW¼ sec. 14, T. 8 N., R. 19 E., about 3 miles east of the village of San Ignacio.	Chupedera (Permian).	-------------	.04	------------	-----	-- --	----	--------	Chalcocite, malachite, azurite, chrysocolla.	Copper has been mined from a roughly elliptical-shaped pit about 100 ft long, 50 ft wide, and 10 to 15 ft deep. The copper minerals are disseminated through the sandstone and are present in open fractures. The sandstone is much finer-grained than it is at any of the other localities examined. Chalcocite fills the interstices between quartz grains and partly replaces quartz.
9	Pintada-Pastura district, Guadalupe mine, N. Mex.	Sec. 6, T.7 N., R.20 E. about 15 miles southwest of Santa Rosa.	Santa Rosa (Triassic).	Mineralized sandstone.	.03	.000	.000	.02	.22	52327	Chalcocite, covellite, pyrite, malachite, azurite, chrysocolla, secondary phosphate.	The mine workings consist of a series of open pits 15 to 20 ft deep in a deposit about 1,500 ft long. The copper minerals are in a well-bedded to massive sandstone. Steeply dipping and broken beds have been attributed by C.B. Read to slumping as a result of removal of underlying Permian evaporites. The copper minerals occur as disseminations parallel to bedding planes, as botryoidal masses in open fractures, and in association with carbonized plant fragments. The sandstone is silicified and the feldspars are sericitized. Chalcocite replaces pyritized wood, occurs in intergranular spaces in the sandstone, and is in veinlets cutting quartz grains. A secondary phosphate of the apatite group fills pore spaces between quartz grains.

Table 1.--Radiometric and chemical analyses of samples from some uranium and copper deposits in sandstone--Continued

No.	District, mine name, State	Location	Formation	Type of sample	Radioactivity: Milleroentgens per hour[a] (maximum)	Radioactivity: Equivalent uranium (percent)	Chemical analyses (percent): U	Chemical analyses (percent): V_2O_5	Chemical analyses (percent): Cu	Serial No.	Mineralogy	Remarks
10	Tecolote district, Bonanza(?) prospect, N. Mex.	2½ miles S-SW of Tecolote Mountain; on northwest slope of mesa known as Burro Hill; 8 miles southwest of Las Vegas.	(Permian)-----	------------	.02	------------	-----	-----	----	--------	Malachite------	Malachite stains a Permian arkosic sandstone at one small prospect.
11	Coyote Creek district, N. Mex.	2 to 3 miles south of Guadalupita on west side of Coyote Creek. (Unsurveyed.)	Sangre de Christo (Permian).	Manganese-stained copper-bearing sandstone.	.05	.005	.001	.04	2.85	52321	Chalcocite, malachite, azurite.	Five to ten tons of copper ore are near the east side of the road that is parallel to Coyote Creek. The mine from which the ore was transported was not located. The copper minerals are in a porous medium- to coarse-grained arkosic Permian sandstone. The copper carbonates are disseminated in the sandstone and apparently are more concentrated in the most porous beds. In thin section, the sandstone has a sutured-mosaic texture. Abundant silicic feldspar grains are strongly sericitized. Chalcocite and malachite preferentially replace feldspar. Malachite coats and impregnates layers of muscovite.
12	---do---------	---do-----------	---do----------	Permian black shale.	.1	.010	.009	.20	2.15	52326	Chalcocite, pyrite, malachite.	Chalcocite and malachite are disseminated in a poorly exposed 5-ft thick nonbituminous black shale that is overlain and underlain by Permian arkosic sandstones.
13	Zuni Mountain district, N. Mex.	20 miles west of Grants, N. Mex., west side of T. 11 N., R. 12 W.	(Pre-Cambrian)-	------------	.03	------------	-----	-----	----	--------	Malachite, azurite.	Copper carbonates are in a nearly vertical shear zone that cuts a granite gneiss. The underground workings apparently are extensive, but they are inaccessible.
14	---do---------	West side of T. 11 N., R. 12 W.	At the contact of Permian and pre-Cambrian.	------------	.2	------------	-----	-----	----	--------	Malachite, azurite, chrysocolla, fluorite, calcite.	The contact between a red gneissic granite and the Permian arkose-conglomerate is exposed in a shallow prospect pit. Copper carbonates, fluorite, and calcite occur as fillings in open fractures. The copper minerals also are disseminated through the conglomerate and are along biotite-rich layers in the granite gneiss.
15	Zuni Mountain district, Mirabel mine, N. Mex.	----do-----------	Abo (Permian)--	Mineralized sandstone; Manganese-stained sandstone.	.15 .06	.009 .004	.009 .002	.02 .02	4.50 .32	52322 52323	Chalcocite, malachite, azurite, chrysocolla, hematite.	Two strip pits each about 50 ft long, 25 ft wide, and 10 to 15 ft deep contain secondary copper minerals. These minerals are most abundant in open fractures, in porous arkosic sandstone beds that alternate with impervious unmineralized clay beds, and in thin bands immediately above and below the impervious clay beds. Slightly radioactive material is present in a few thin beds but for the most part the deposit is not radioactive. Quartz and sericitized feldspar grains are veined and replaced by chalcocite and malachite.

16	San Acacia district, N. Mex.	Sec. 10, T. 1 S., R. 2 W., 6 miles west of San Acacia.	Andesitic lavas (Tertiary).	Slightly radioactive dump material.		0.031	0.026	0.03	4.78	52324	Native copper, chalcocite, chrysocolla, malachite, cuprite, torbernite(?), carnotite(?).	The mine workings consist of a shaft that is now filled with water to about the 40-ft level. Carbonate- and copper-bearing rock is on the dump. These minerals are in a brecciated shear zone in an amygdaloidal trachyandesite and are concentrated mostly along the andesite-carbonate contacts. The original flow rock is almost totally replaced by calcite that is cut by stringers of vein quartz.
17	Scholle district, N. Mex.	Sec. 3 or 4, T. 2 N., R. 5 E.	Abo (Permian)--	Grab sample from the pit that contains radioactive material.	.15	.021	.014	.03	.25	52325	Chalcocite, covellite, malachite, azurite.	The mine is about one-quarter mile south of the railroad in the second canyon east of the Scholle post office. The stripping operations have been on a limited scale, but the local inhabitants report that the underground operations were extensive. The copper minerals are associated with radioactive and non-radioactive carbonized wood and are disseminated through the matrix of the sandstone. The sandstone in one shallow pit is radioactive. This material contains carbonized wood and small irregular pellets of lustrous asphaltite. The feldspars are partly altered to sericite and are preferentially replaced along cleavage planes by copper carbonates. Patches of white secondary phosphate locally cement the sandstone.
18	----do----------	Sec. 3 or 4, T. 2 N., R. 5 E.	----do---------	------------	.03	------------	-----	-----	----	--------	Malachite-----	The deposit is about 1 mile east of Scholle post office on east side of the highway. Copper carbonate stains joint planes in a massive flat-lying brown sandstone that is exposed in several shallow prospect pits.
19	Cashin mine, Colorado.	Near Utah and Colorado boundary and 3½ miles south of Colorado State Route 90.	Wingate (Triassic).	------------	.03	------------	-----	-----	----	--------	Chalcocite, malachite, azurite, copper sulfate.	A tunnel about 3,000 ft long is in a nearly vertical breccia zone. The greatest concentration of ore minerals is in the most intensely brecciated part of this zone. The copper minerals were deposited in the open fractures and in the porous sandstone near the fractures. The effects of recent solution and redeposition are apparent throughout the mine. This deposit is probably of hydrothermal origin.
20	Big Indian mine, Utah.	T. 29 S., R. 24 E., 5.2 miles south of La Sal, Utah.	Dakota (Cretaceous).	------------	.02-.03	------------	-----	-----	----	--------	Chalcocite, malachite, azurite.	An open-cut about 200 ft long, 100 ft wide, and 20 to 30 ft deep constitutes the accessible workings. The deposit is in Dakota sandstone and is on the northeast side of a northwest-trending fault. Copper occurs along fractures and joints and also is disseminated in the sandstone. The most conspicuous minerals are malachite and azurite, but some chalcocite is present.

Table 1.--Radiometric and chemical analyses of samples from some uranium and copper deposits in sandstone--Continued

No.	District, mine name, State	Location	Formation	Type of sample	Radioactivity: Milleroentgens per hour[a] (maximum)	Radioactivity: Equivalent uranium (percent)	Chemical analyses (percent): U	Chemical analyses (percent): V_2O_5	Chemical analyses (percent): Cu	Serial no.	Mineralogy	Remarks
21	Torrey district, Utah.	About 11 miles east of Teasdale, sec. 31(?), T. 29 S., R. 6 E.	Moenkopi (Triassic).	------------	.02-.04	------------	-----	-----	----	--------	---do---------	A tunnel and an inclined adit, both caved, constitute the development. The copper minerals are in siltstones and limestones of the Moenkopi formation. Copper carbonates are concentrated mostly in an 18-in. porous limestone bed.
22	Torrey district, Utah.	Sec. 8(?), T. 30 S., R. 6 E.	Moenkopi (Triassic).	------------	.02-.03	------------	-----	-----	----	--------	Malachite, azurite.	A copper-stained buff sandstone is exposed in an open-cut 30 ft long, 30 ft wide, and 4 to 7 ft deep.
23	San Rafael Swell district, Ronnie, Jerry and Frenchy mine, Utah.	SW¼ sec. 20, T. 23 S., R. 10 E., west side of San Rafael Swell.	Shinarump (Triassic).	7-ft channel asphaltic sandstone.	[b] .4	.033	.030	-----	----	53817	Uraniferous asphaltite and carbonized wood, chalcopyrite, chalcocite, pyrite, malachite, azurite, metatorbernite, gypsum.	The mine workings consist of a tunnel in the lower part of the Shinarump conglomerate. The uranium is associated with two types of carbonaceous material: lustrous interstitial grains of asphaltite disseminated through the sandstone and carbonized wood. The chalcopyrite and chalcocite occur as small blebs in fractures in hydrocarbon and along contacts between quartz grains and hydrocarbon. Autoradiographs indicate that the radioactivity is uniformly distributed through the asphaltite.
				Uraniferous hydrocarbon concentrate.	--------------	.30	-----	-----	----	53809		
24	San Rafael Swell district, Utah.	SW¼SW¼ sec. 20, T. 23 S., R. 10 E., west side of San Rafael Swell.	---do--------	------------	15-20	------------	-----	-----	----	--------	Uraniferous carbonized wood and asphaltite, bornite, chalcopyrite, chalcocite, covellite, pyrite, malachite, azurite, metatorbernite.	About 1,000 ft of bulldozer trenches have been made along the steep slope and near the base of the Shinarump conglomerate. The exposed beds consist of sandstone, conglomerate, and gray, green, and red shale. The radioactivity is abnormally high along the excavation. The highest radioactivity is associated with carbonized wood and asphaltic sandstone, but some of the shales are also radioactive. As yet, no minable thickness of ore has been revealed. Polished sections show that sulfides fill fractures in the asphaltites. Bornite and chalcopyrite show a texture that may be either exsolution or replacement of bornite by chalcopyrite along preferred crystallographic directions. Chalcocite replaces chalcopyrite and bornite. Covellite replaces the edges of chalcocite.
25	San Rafael Swell district, mine name unknown, Utah.	NE¼ sec. 31, T. 23 S., R. 10 E., west side of San Rafael Swell.	---do----------	8-ft channel asphaltic sandstone.	[b] 1.0	.31	.31	-----	----	53818	Uraniferous asphaltite, carbonized wood, pyrite, malachite, copper sulfate(?), unidentified yellow secondary uranium mineral, gypsum.	The development consists of a tunnel 50 ft long and 6 to 15 ft wide in the lower part of the Shinarump conglomerate. The Shinarump conglomerate in the tunnel is made up of white medium-grained sandstone with carbonaceous material and reworked clay fragments. Both carbonized plant fragments and disseminated asphaltite grains are present. Secondary copper minerals stain the surface rocks near the base of the Shinarump conglomerate.
				Uraniferous hydrocarbon or carbonized wood.	--------------	1.2	-----	-----	----	53810		
26	San Rafael Swell district, Dalton Group of claims, Utah.	About 4 miles south of bridge on San Rafael River. West side of San Rafael Swell. (Unsurveyed.)	---do----------	Asphaltite--	[b] 0.5	5.0	1.34	-----	----	53808	Uraniferous asphaltite, pyrite, chalcopyrite, chalcocite, covellite, malachite.	The development consists of three short adits into the Shinarump conglomerate; the longest adit is at least 20 ft above the base of the sandstone. Uraniferous asphaltite is present as grains up to ½ in. across and as lenses and pods up to 20 in. long. Pyrite is abundant and in many places is associated with the uraniferous asphaltite.

27	San Rafael Swell district, Lone Tree claims, Utah.	About 3 miles south of bridge on San Rafael River. West side of San Rafael Swell. (Unsurveyed.)	Shinarump (Triassic).	One uraniferous asphaltite pellet.	11	2.9	3.28	-----	----	53656	Uraniferous asphaltite, pyrite, chalcopyrite, arsenopyrite pyrite(?), paraschoepite(?).	The lone Tree Group of claims have been prospected in one place by a 30-ft tunnel and a crosscut of about equal length. Uraniferous asphaltite is present in bands as much as 1 in. thick and in disseminated pellets as much as ½ in. across. Secondary uranium minerals are sparingly present. Autoradiographs indicate a uniform distribution of radioactivity throughout the asphaltite pellets.
				Gray clay above uraniferous asphaltite.	----------------	.015	------	-----	----	53815		
				Gray clay below uraniferous asphaltite.	----------------	.008	------	-----	----	53814		
28	Montpelier district, Evening Star claim, Idaho.	Southern part of T. 12 S., R. 45 E.	Ankareh (Triassic).	Carbonized plant remains.	.04-.05	.005	.003	-----	----	53819	Malachite, azurite.	The workings consist of one adit about 20 ft long, 4 ft wide, and 4 ft deep. Copper carbonates are associated with carbonized plant fragments in the Ankareh(?) shale of Triassic age. The carbonized plant fragments are detectably radioactive.
29	Montpelier district, Bonneville prospect, Idaho.	Sec. 9, T. 14 S., R. 4 E.	----do---------	------------	[c]20-30c/m	-----------	-----	-----	----	------	Malachite, chrysocolla, chalcocite.	The mine dump is about 100 ft long and 20 to 30 ft wide. The dump material was derived from underground workings that are now inaccessible. The copper minerals are in a steeply dipping light-gray well-cemented sandstone, and they are associated with carbonized plant remains.
30	Cokeville district, "Old Copper" mine, Wyoming	NW¼ sec. 7, T. 28 N., R. 117 W.	(?)	------------	.02-.03	-----------	-----	----	----	------	Chalcopyrite, covellite, malachite, azurite.	The lessee, Mr. Dan S. Schickich, of Kemmerer, Wyo., has reported that a 600-ft tunnel and a 125-ft shaft constitute the development at this mine. The dump material is composed of a light-gray well-cemented sandstone that contains slight quantities of copper minerals. No fossil wood was observed.

[a]Field determination made with a Geiger counter equipped with a 6-inch gamma-beta probe.
[b]Average.
[c]Radioactivity measurement made with an uncalibrated Geiger counter.

Table 2.--Spectrographic analyses of some crude oils, asphalts, and carbonaceous shales

[Note: .000X, .00X, .0X, .X, X, and XX means 0.0001 to 0.001, 0.001 to 0.01, 0.01 to 0.1, 0.1 to 1.0, 1.0 to 10.0, and 10.0 to 100.0 percent, respectively.]

No.	Serial no.	Location	Type material	Ash (percent)	Fe	Ti	As	Co	Cr	Cu	Mo	Ni	Pb	U	V	Zn	Remarks
1	15616	NE¼NE¼SE¼ sec. 9, T. 27 S., R. 4 E., Kansas.	Crude oil	0.002	X.	.0X	--	.00X	.0X	.X	.00X	X.	.0X	--	X.	.0X	
2	16249	SW¼SW¼NE¼ sec. 11, T. 28 S., R. 4 E., Kansas.	---do-----	.002	.X	.X	--	.X	X.	.X	.00X	X.	.X	--	X.	.X	
3	16253	NW¼ sec. 11, T. 28 N., R. 4 E., Kansas.	---do-----	.005	X.	.X	--	.00X	.X	X.	--	X.	.X	--	X.	.X	
4	16266	NE¼ sec. 35, T. 18 S., R. 16 W., Kansas.	---do-----	.0025	.X	.X	--	.0X	.X	.0X	.00X	X.	.X	--	X.	.X	
5	17912	SW¼ sec. 23, T. 18 S., R. 16 W., Kansas.	---do-----	.0075	X.	.X	--	.0X	.0X	.X	--	X.	.X	--	X.	.X	
6	18331	SW¼NW¼ sec. 25, T. 28 S., R. 5 E., Kansas.	---do-----	.0005	.X	.X	--	.00X	.X	XX.	.00X	X.	.X	--	X.	.X	Ash of crude oils from Kansas and Texas.
7	18345	C. sec. 12, T. 34 S., R. 6 E., Kansas.	---do-----	.002	.X	.X	--	.X	.0X	.X	.00X	X.	.0X	--	X.	.X	
8	18353	Talco Field, Texas ---	---do-----	.001	.X	.0X	--	.0X	.0X	.0X	.00X	.X	.00X	--	X.0	--	
9	18356	1½ miles east of Breckenridge, Tex.	---do-----	.003	X.	.X	--	.00X	.0X	XX.	.00X	.0X	.X	--	.X	X.	
10	18357	3 miles east of Breckenridge, Tex.	---do-----	.003	X.	.0X	--	.00X	.0X	X.	.00X	.X	.X	--	.X	X.	
11	18363	28 miles east of Dumas, Tex.	---do-----	.02	X.	.X	--	.00X	.0X	.0X	.00X	X.	.X	--	X.	--	
12	57023	Oil extract from Spergen limestone, Ste. Genevieve County, Mo.	Crude oil-	Not ashed-	.X	.X	--	.000X	.00X	.000X	.00X	.0X	.00X	.0X	.0X	.0X	Crude oil.
13	62937	Refinery, Casper, Wyo.	Petroleum coke.	.24	--	--	.X	.0X	X.	.X	.0X	XX.	.X	.X	.X	.0X	
14	58336	Bonanza vein, Uintah County, Utah.	Gilsonite-	.3	X.	X.	--	X.	.00X	.0X	.X	X.	.0X	.X	.X	.0X	Ash of gilsonite.
15	58097	Lone Tree claim, San Rafael Swell, Emery County, Utah.	Asphaltite pellets.	62.0	XX.	.X	X.	.X	.0X	X.	.X	.X	.X	XX.	.0X	--	Ash of asphaltite.
16	58100	Dalton claim, San Rafael Swell, Emery County, Utah.	---do-----	17.0	X.	.X	X.	.0X	.00X	X.	.X	.0X	.X	X.	.00X	--	Do.
17	54656	Lone Tree claim, San Rafael Swell, Emery County, Utah.	---do-----	Not ashed-	.X	.0X	.X	.00X	.000X	.X	.0X	.00X	.0X	X.	.00X	--	
18	53808	Dalton claim, Emery County, Utah.	---do-----	---do-----	.X	.000X	--	--	--	.X	.00X	.000X	.00X	.X	--	--	
19	53809	Ronnie, Jerry, French mine, San Rafael Swell, Emery County, Utah.	---do-----	---do-----	.X	.0X	--	.00X	.000X	.X	--	.00X	.00X	.X	.000X	.0X	
20	54418	Dirty Devil mine, San Rafael Swell, Emery County, Utah.	---do-----	---do-----	.X	.0X	.X	.00X	.000X	X.	.00X	.00X	.00X	X.	.00X	.0X	Asphaltites.
21	55539	Texas Panhandle-------	---do-----	---do-----	.0X	.00X	X.	.0X	--	.00X	.00X	.X	.00X	.X	--	--	
22	54415	Laramie County, Wyo.	Graneros shale drill samples.	---do-----	X.	X.	--	.00X	.0X	.0X	.000X	.00X	.00X	--	.0X	--	
23	54289	Locality unknown; Texas.	Woodford shale of Ellison.	Not ashed-	X.	X.	--	.00X	.00X	.0X	--	.00X	.000X	--	.0X	--	Carbonaceous shale.
24	58337	North Vernon, Ind.----	New Albany shale.	---do-----	X.	.X	--	.00X	.00X	.0X	.0X	.00X	.00X	--	.0X	--	
25	54292	Ste.Genevieve County, Mo.	Black shale in Spergen limestone.	---do-----	.X	.X	--	.00X	.0X	.00X	.00X	.0X	.0X	X.	.X	--	

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