UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE ROBINSON AND WEATHERLY URANIFEROUS PYROBITUMEN DEPOSITS NEAR PLACERVILLE, SAN MIGUEL COUNTY, COLORADO

By

V. R. Wilmarth and R. C. Vickers

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THE ROBINSON AND WEATHERLY URANIFEROUS PYROBITUMEN DEPOSITS, NEAR PLACERVILLE, SAN MIGUEL COUNTY, COLORADO

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ABSTRACT

Uranium deposits that contain uraniferous pyrobitumen of possible hydrothermal origin occur at the Weatherly and Robinson properties near Placerville, San Miguel County, Colo. These deposits were mined for copper, silver, and gold more than 50 years ago and were developed for uranium in 1950.

The Robinson property, half a mile east of Placerville, consists of the White Spar, New Discovery Lode, and Barbara Jo claims. The rocks in this area are nearly horizontal sandstones, shales, limestones, and conglomerates of the Cutler formation of Permian age and the Dolores formation of Triassic and Jurassic (?) age. These rocks have been faulted extensively and intruded by a Tertiary (?) andesite porphyry dike. Uranium-bearing pyrobitumen associated with tennantite, tetrahedrite, galena, sphalerite, chalcopyrite, bornite, azurite, malachite, calcite, barite, and quartz occurs in a lenticular body as much as 40 feet long and 6 feet wide along a northwest-trending, steeply dipping normal fault. The uranium content of eleven samples from the uranium deposit ranges from 0.001 to 0.045 percent uranium and averages about 0.02 percent uranium.

The Weatherly property, about a mile northwest of Placerville, consists of the Black King claims nos. 1, 4, and 5. The rocks in this area include the complexly faulted Cutler formation of Permian age and the Dolores formation of Triassic and Jurassic (?) age. Uranium-bearing pyrobitumen and uranophane occur along a northwest-trending, steeply dipping normal fault and in the sedimentary rocks on the hanging wall of the fault. Lens-shaped deposits in the fault zone are as much as 6 feet long and 2 feet wide and contain as much as 9 percent uranium; whereas channel samples across the fault zone contain from 0.001 to 0.014 percent uranium. Tetrahedrite, chalcopyrite, galena, sphalerite, fuchsite, malachite, azurite, erythrite, bornite, and molybdite in a gangue of pyrite, calcite, barite, and quartz are associated with the uraniferous material. In the sedimentary rocks on the hanging wall, uranium-bearing pyrobitumen occurs in replacement lenses as much as 8 inches wide and 6 feet long, and in nodules as much as 6 inches in diameter for approximately 100 feet away from the fault. Pyrite and calcite are closely associated with the uraniferous material in the sedimentary rocks. Samples from the replacement bodies contain from 0.007 to 1.4 percent uranium.

INTRODUCTION

Uraniferous pyrobitumen _/ deposits occur in vein deposits at the Weatherly and Robinson properties

_/Pyrobitumens as defined by Abraham (1944, p. 60) are: native substances of dark color; comparatively hard and non-volatile; composed of hydrocarbons, which may or may not contain oxyginated bodies; sometimes associated with mineral matter, the non-mineral constituents being infusible and relatively insoluble in carbon disulfide. In this report, the terms pyrobitumen and hydrocarbon are used interchangeably.

near Placerville, in the western part of the San Juan Mountains, San Miguel County, Colo. (fig. 1). These deposits were studied by the U. S. Geological Survey, on behalf of the U. S. Atomic Energy Commission, for the purpose of determining the uranium reserves, mode of occurrence, and extent of these deposits.

Location and accessibility

The Weatherly property is about a mile northwest of Placerville, in secs. 26 and 27, T. 44 N., R. 11 W., New Mexico principal meridian. This property can be reached by a jeep road from Colorado Highway no. 62, about a mile northeast of the junction of Colorado Highways nos. 62 and 145 (fig. 1). The Robinson property is a mile by jeep road east of Placerville, in sec. 35, T. 43 N., R. 11 W., New Mexico principal meridian. Placerville is on State Highway 145 and the abandoned Rio Grande Southern railroad.

History and production

The ore deposits at the Weatherly and Robinson properties were developed primarily for copper about 1900. Hess (1911, p. 151) reported that a carload of ore, shipped in 1902 from the Weatherly property, then the Evans claims, contained 14.8 percent copper and 0.11 ounces of gold, and 3.5 ounces of silver per ton. No ore has been produced from the Robinson property. Soon after 1902, the mine at the Weatherly property was abandoned and it was not until 1950 that the claims were relocated for uranium. The claims are known as the Black King nos. 1, 4, and 5 and were located by H. S. Weatherly, H. B. Weatherly, and G. E. Weatherly, all of Grand Junction, Colo.

The Robinson property consists of the White Spar, New Discovery Lode, and Barbara Jo claims. These claims were located for uranium in 1950 and are owned by Mr. Boyd Robinson of Grand Junction, Colo.

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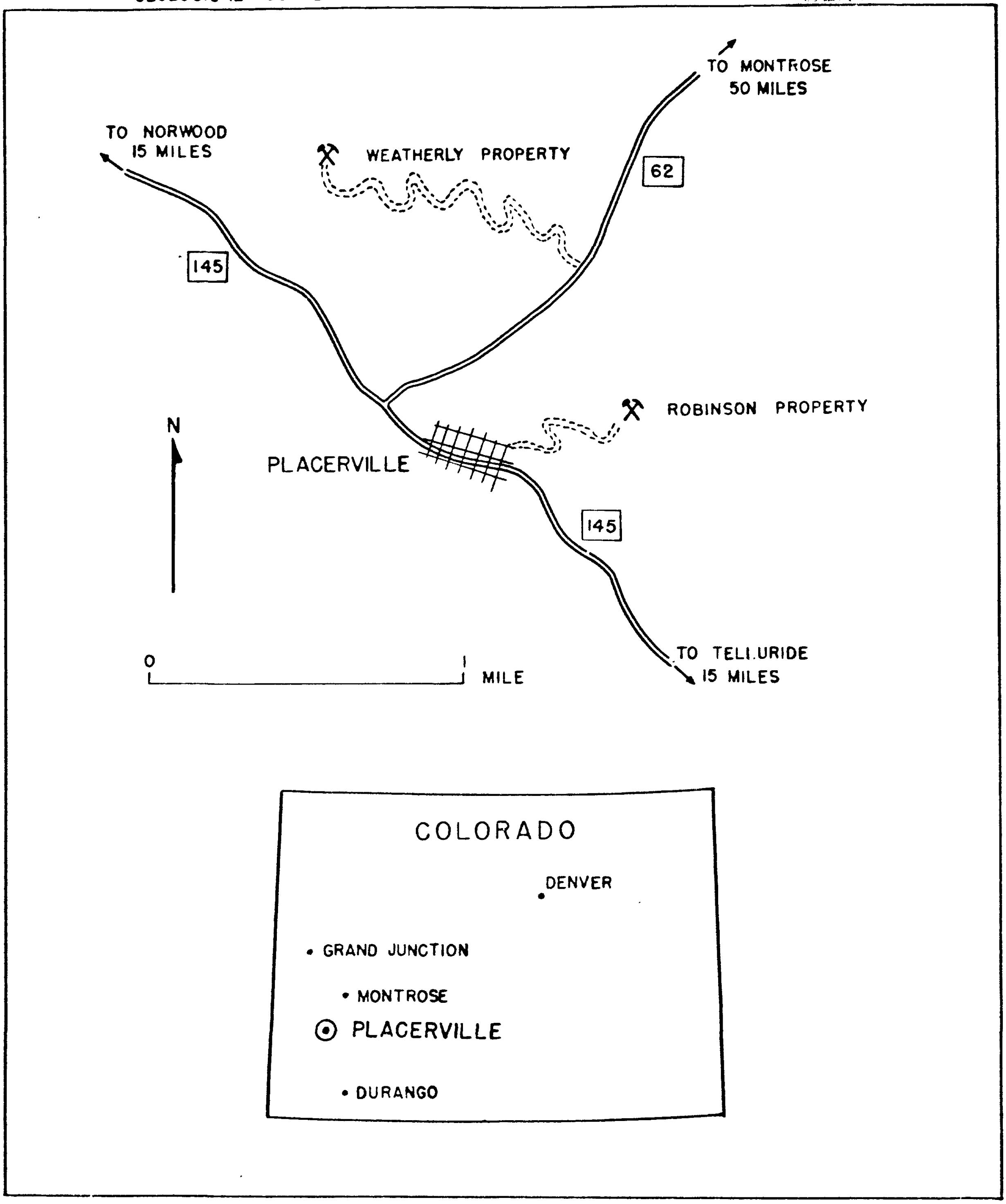

FIGURE 1.— INDEX MAP OF THE PLACERVILLE AREA, SAN MIGUEL COUNTY, COLORADO

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Previous investigations

Comprehensive descriptions of the geology and of the ore deposits in the Placerville area have been given by Fischer (1937, pp. 906-952 and 1942, pp. 363-394), Hess (1911, pp. 142-160 and 1933, pp. 455-480), and Hillebrand and Ransome (1900, pp. 120-144). In 1947 Fischer, Haff, and Rominger (1947) described in detail the vanadium deposits in this area. Hess (1911) was the first to describe the uraniferous pyrobitumen in the vein deposits at the Weatherly and Robinson properties. Later, Gruner and Gardiner (1950, pp. 3-10) described briefly the uranium-bearing pyrobitumen deposits. Kerr, Rasor, and Hamilton (1951) described and identified uraninite as the principal source of the uranium in the pyrobitumen deposits. Morehouse (1951) of the Atomic Energy Commission described briefly the deposits.

Field work

The writers spent 3 weeks in July and August 1951 mapping by telescopic alidade and plane table the geology and topography of approximately one-fourth square mile surrounding each deposit (figs. 3 and 4). Radiometric examination and detailed sampling of the individual properties have been completed.

Acknowledgments

It is a pleasure to acknowledge the cooperation and assistance of Mr. Hugh Weatherly and Mr. Boyd Robinson.

GENERAL GEOLOGY

The uranium deposits herein described are on the north slope of the San Miguel River valley and on the western edge of the San Juan Mountains. In the Placerville area complexly faulted, but nearly horizontal sedimentary rocks have been intruded by small bodies of igneous rocks. The sedimentary rocks consist of shales, sandstones, conglomerates, and limestones that range from Permian to Cretaceous in age. The igneous rocks consist of basic dikes and small diorite stocks. The uranium deposits occur along northwest-trending faults that cut the sedimentary and igneous rocks.

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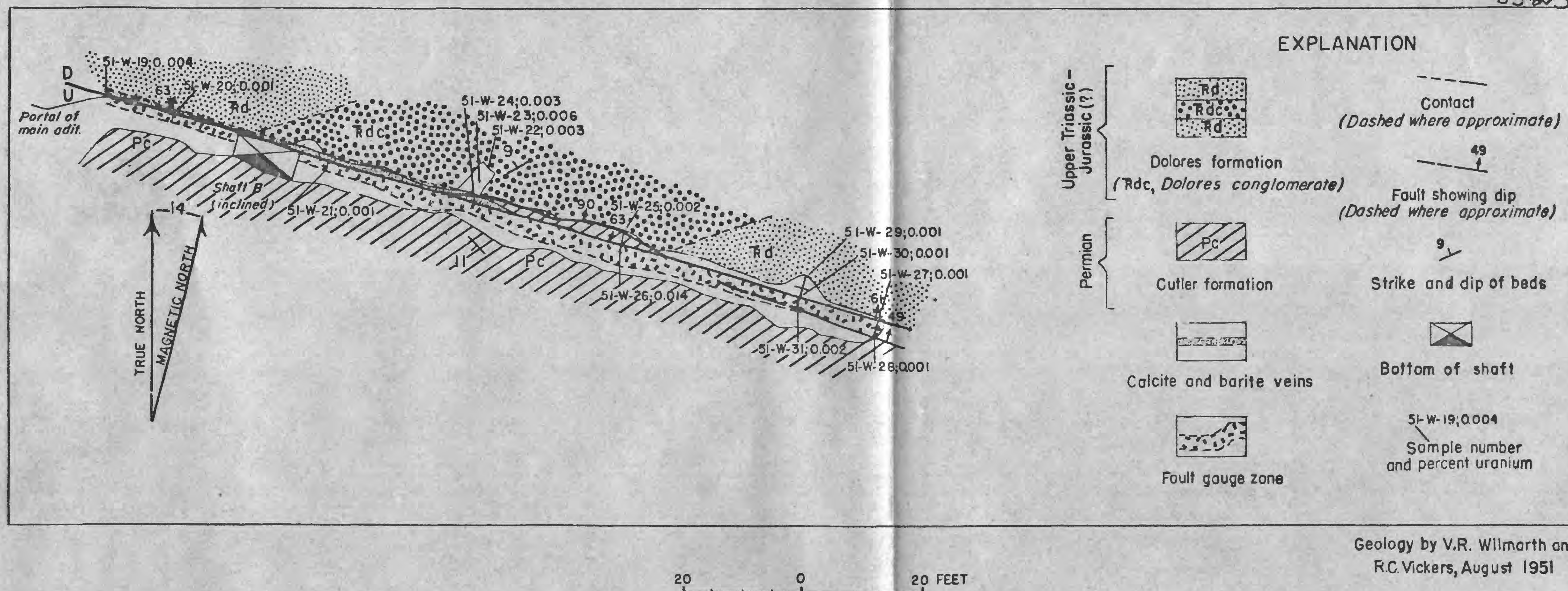

Geology by V.R. Wilmarth and R.C. Vickers, August 1951

FIGURE 4.- GEOLOGIC MAP OF MAIN ADIT, WEATHERLY PROPERTY, SAN MIGUEL COUNTY, COLORADO

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Stratigraphy

The sedimentary rocks exposed in the Placerville area are shown in table 1. The formations of paramount interest are the Entrada sandstone from which uranium and vanadium ore has been produced and the Dolores and Cutler formations which contain the uraniferous pyrobitumen deposits.

The Cutler formation of Permian age crops out over vast areas in the lower part of the San Miguel River valley. According to Burbank (1947, p. 421) this formation is from 1,000 feet to 2,000 feet in thickness and consists of maroon sandstones, pinkish grits, and conglomerates alternating with reddish sandy shales and earthy limestones. The different facies commonly grade into one another and are not mappable units. Fossils are uncommon, but several unidentified fragments of vertebrate fossils were found at the Robinson property.

The Dolores formation of Triassic and Jurassic age consists of sandstones, conglomerates, shales, and limestones, and is conformable with the underlying Cutler formation in the Placerville area.

The Entrada sandstone conformably overlies the Dolores formation (fig. 2). In the Placerville area, this formation is the host rock for the uranium and vanadium deposits that have been described by Fischer, Haff, and Rominger (1947), Fischer (1942), and Hess (1911).

Structure

Intrusion of igneous bodies, folding of the sedimentary rocks, and the development of radial fissure systems occurred in the Placerville area during late Tertiary time. The forces accompanying the intrusions folded all the sedimentary rocks to a regional dip that ranges from 3° to 15° SW. The beds strike N. 55° to 75° W. Departures from the regional dip occur in narrow zones adjacent to the major faults.

In addition to the prevailing regional dip, the dominant structural features of the Placerville area are northwest-trending, steeply dipping normal faults. Most of these faults have a vertical displacement of less than 100 feet, although, the major faults have a throw of several hundred feet. The major faults are longitudinal faults; that is, they nearly parallel the strike of the beds and are characterized by comparatively large displacement, great lengths, and wide zones of fractured rocks. As these faults have been the loci for the deposition of the copper, silver, and uranium-bearing minerals, they probably extend to great depths and tapped deep sources of ore-forming solutions. Figures 2 and 3 show the detailed structural features at the Robinson and Weatherly properties.

Table 1.--Generalized section of strata exposed in the San Miguel River Canyon at Placerville, San Miguel County, Colorado

Age	Formation	Member	Thickness (feet)	Description
Upper Cretaceous	Dakota sandstone		100-300	Gray and brown conglomerate sandstone
	Morrison		575	Thick bedded, light-colored sandstone interbedded with red and gray shale
Upper Jurassic		Wanakah	50	Buff to light-gray sandstone including the black bituminous Pony Express limestone at the base. This formation pinches out westward in the Placerville area.
	Entrada sandstone		50	Thick-bedded, cross-bedded, buff to light-gray sandstone
Triassic to Jurassic	Dolores		500	Red shales, sandstones, limestones, and limestone pebble conglomerate. A 70-foot thick bed of massive reddish-gray sandstone at top of the formation may be equivalent to the Wingate sandstone. A 10-20-foot bed of coarse-grained white conglomeratic sandstone at the base may be equivalent to the Shinarump conglomerate.
Permian	Cutler		Upper 500 feet exposed	Maroon shales, sandstones, limy sandstones, and arkosic sandstones. Conglomerate beds as much as 30 feet thick are common.

ECONOMIC GEOLOGY

Ore deposits in the Placerville area consist of uranium-vanadium-chromium bedded deposits in the Entrada sandstone and uraniferous pyrobitumen in base metal sulfide veins along faults in the Cutler and Dolores formations. The deposits in the Entrada sandstone that have been mined for uranium and vanadium have been described in detail by Fischer, Haff, and Rominger (1947).

The base metal sulfide veins that contain uranium at the Robinson and Weatherly properties were formed by fracture filling and by replacement of shattered beds along northwest-trending normal faults that dip steeply to the north. Pitchblende and uranium-bearing pyrobitumen are closely associated with tetrahedrite, tennantite, chalcopyrite, bornite, sphalerite, and galena, named in order of abundance. Almost all of the copper-bearing sulfides have been oxidized and locally, covellite, malachite, and azurite are abundant. Secondary nickel, molybdenum, and uranium minerals are also present.

ROBINSON PROPERTY

Uranium-bearing pyrobitumen occur along a northwest-trending fault zone on the Robinson property, in sec. 35, T. 44 N., R. 11 W., New Mexico principal meridian. (See figs. 1 and 2.) Figure 1 shows the relative location of the property and figure 2 shows the geology of the area surrounding the Robinson property. Radioactive material was discovered early in 1950 in the dump material at a 19-foot inclined shaft (shaft A, fig. 2). In subsequent examinations radioactive material was found in a 25-foot inclined shaft, 20 feet to the west, but none was found in a 15-foot inclined shaft, 60 feet to the east of Shaft A, nor in the 75-foot inclined shaft (shaft B). Numerous small prospects occur along the fault zone. In the eastern part of the mapped area an adit has been driven for 75 feet on a northwest-trending fault zone that contains copper minerals. This fault zone is barren of radioactive material.

Geologic setting

The sedimentary rocks at the Robinson property (fig. 2) are horizontal to gently southwesterly dipping beds of the Cutler formation of Permian age conformably overlain by the Dolores formation of Triassic and Jurassic (?) age. The sedimentary rocks have been intruded by an andesite porphyry dike of Tertiary (?) age. Normal faults cut all of the rocks and have been the loci for deposition of base metal sulfides and uranium-bearing pyrobitumen.

Sedimentary rocks

Only the upper part of the Cutler formation is exposed at the Robinson property (fig. 2). The exposed beds are composed of thick coarse conglomerates interbedded with dark maroon sandstones, shales, sandy limestones and white arkosic sandstones. Topographically, the conglomerate beds form both rounded and near vertical slopes. Four conglomerate beds, exposed in this area, contain well-rounded boulders of granite, greenstone, gneiss, quartzite, and schist, as much as 8 inches across, cemented by a fine-grained aggregate of quartz, feldspar, and hematite-rich carbonate material. The conglomerate beds are characteristically dark maroon but locally they have a greenish color, where greenstone boulders predominate.

Adjacent to fault No. 1 (fig. 2), the sedimentary rocks are bleached and locally contain abundant calcite and barite stringers. The bleached sandstones contain abundant quartz, altered feldspar grains, and calcite as fine-grained interstitial material or as coarse-grained vein material. The angular to subrounded quartz and feldspar grains, as much as 1.2 mm across, have been replaced by fine-grained calcite and sericite. Commonly pyrobitumen occurs as fracture fillings and as coatings on the quartz and feldspar. Sericitization of the feldspar grains is complete.

The exposed lower 60 feet of the Dolores formation in the mapped area at the Robinson property (fig. 2) consists of a basal quartz pebble conglomerate overlain by red to light grey fine grained sandstones, red shales, and red to grey limestones. The basal conglomerate can be readily recognized and is, therefore, the most easily correlated bed in this area. It ranges from 12 to 22 feet in thickness and is a hard, white to light-grey, coarse-grained rock composed of rounded to sub-angular quarts grains as much as an inch across, sparse jasper pebbles, and fossilized bones.

Igneous rocks

Igneous rocks of Tertiary (?) age crop out at the Robinson property (fig. 2). An andesite porphyry dike that averages 6 feet in width can be traced along the strike for about 500 feet in the mapped area. The dike, where exposed, characteristically forms a wall that stands as much as 8 feet above the surrounding rocks.

The andesite porphyry is dark-greenish-black on fresh surfaces, but is dark brown on weathered surfaces. In hand specimens clear, glassy labradorite phenocrysts in an aphanitic groundmass are visible. In thin sections some of the phenocrysts are well formed but most have irregular boundaries. The component minerals are plagioclase 70 percent, magnetite 12 percent, biotite 8 percent, and the accessory minerals, quartz and ilmenite, constitute 10 percent. The labradorite phenocrysts are as much as 10 mm in length and have been replaced along cleavage planes and crystal boundaries by chlorite, biotite, and andesine. Fine-grained aggregates of calcite, chlorite, biotite, and hematite in rounded masses as much as 2 mm across are believed to be psuedomorphous after early ferromagnesian minerals. The fine-grained groundmass is composed essentially of andesine, labradorite, and biotite. Labradorite crystals as much as 0.3 mm in length have been replaced, in part, by later andesine and biotite which are intersertal to the labradorite phenocrysts. The calcite, which is locally abundant, as interstitial fillings probably was derived from the adjacent sedimentary rocks. Small blades of ilmenite are present in some of the altered magnetite crystals.

Structure

The sedimentary strata, in general, dip gently southwest and strike northwest, but there is considerable variation in the dip and strike of the beds. The general attitude of the Cutler formation ranges from horizontal to a dip of 10° to 15° SW. and the strike ranges from N. 55° W., to N. 66° W. The beds adjacent to the faults, however, dip as much as 70°. The beds in the Dolores formation strike N. 75° W. and dip from 3° to 4° SW. In the western part of the mapped area, an andesite porphyry dike strikes N. 86° W. and dips 70° N.; in the eastern part it strikes N. 60° to 85° E. and dips 80° to 85° N. (fig. 2).

The major structural features are steeply dipping northwest to northeast trending normal faults. The most conspicuous of these is Fault No. 1 which is a normal fault, dipping steeply northward, and is entirely within the Cutler formation. The attitude of the fault is not constant within the mapped area. In the western part the fault strikes N. 38° to 70° W. and dips 61° to 74° N., whereas, in the eastern part, it strikes N. 68° to 82° E. and dips 85° N. In the underground workings this fault is marked by a gouge zone that ranges from 2 feet to 22 feet in width. Near shaft A the gouge zone is composed of bleached sandstones, shales, and limestones, all impregnated by uraniferous pyrobitumen, tetrahedrite, chalcopyrite, pyrite, secondary copper minerals, and composite calcite-barite veins as much as 9 feet thick. The vertical displacement on Fault No. 1 is approximately 500 feet. This was determined by comparing detailed stratigraphic sections at the mine with similar sections in an unfaulted area, about 2 miles east. Faulting of the Cutler formation against the Entrada sandstone, along the ridge half a mile to the east of the mapped area also suggests a large displacement along Fault No. 1.

Two northwest-trending normal faults, Fault No. 2 and Fault No. 3 cut the sedimentary rocks. Fault No. 2 is traceable along the strike for about 500 feet and is marked by a gouge zone that contains calcite and barite veins and secondary copper minerals as thin coatings on fracture surfaces. The fault zone is as much as 3 feet thick. The vertical displacement ranges from 6 to 30 feet. Fault No. 3 strikes N. 42° to 58° W., and can be traced on the surface for nearly 450 feet. It is best exposed in the adit, where secondary copper minerals coat fracture surfaces and calcite and barite veins fill fractures in the fault zone that attains a thickness of 3 feet. The vertical displacement along Fault No. 3 south of the adit is about 10 feet, but to the north the displacement along the fault is nearly 30 feet.

Many joints and minor fractures in the Cutler formation adjacent to the faults commonly are filled by calcite and barite. These veins strike N. 43° to 66° W. and dip from 70° SW. to 75° NE.

Ore deposits

The ore deposits at the Robinson property can be classed on the basis of mineralogy as uraniferous pyrobitumen veins that contain copper, silver, lead, and zinc sulfides, as non-radioactive copper deposits, and as calcite-barite veins. The hypogene sulfide minerals associated with uranium-bearing pyrobitumen, named in order of abundance, are tennantite, tetrahedrite, chalcopyrite, bornite, galena, and sphalerite in a gangue of pyrite, barite, calcite, with minor quantities of quartz. Chalcocite, azurite, and malachite, alteration products of chalcopyrite are common. The principal ore minerals in the copper deposits are tetrahedrite, tennantite, chalcopyrite, bornite, and covellite in a gangue of calcite, barite, and pyrite. Calcite-barite veins fill many fissures adjacent to the faults. These veins contain minor quantities of secondary copper minerals but are barren of radioactive materials. The surface outcrops of the mineralized zones are commonly marked by secondary copper minerals. The uranium deposit is restricted to a single zone on the hanging wall of Fault No. 1, but the copper deposits are found at several localities along this fault and the subsidiary faults. In general the deposition of the sulfide minerals and the uranium-bearing pyrobitumen was controlled by normal faults and minor fractures adjacent to the faults.

Uranium deposits

Uranium-bearing pyrobitumen is localized along Fault No. 1 in a gouge zone that is as much as 6 feet in width and extends westward from Shaft A for about 40 feet. No radioactive material was found along Fault No. 1 east of Shaft A.

The uranium deposit has a lenticular shape. At Shaft A the rocks at the surface are not radioactive, but radioactive material was detected on the hanging wall of the fault at about 8 feet below the collar of the shaft.

The absence of radioactive material near the surface may be due to leaching by ground waters. At the bottom of Shaft A the radioactive zone is as much as 6 feet wide. In the open cut 20 feet west of Shaft A, radioactive layers of fault gouge, as much as 1 foot wide are interfingered with calcite and barite veins; the rocks at the bottom of the shaft are not radioactive. In general, the radioactive zone appears to pinch out along the strike of the fault, but to widen at depth.

At Shaft A the hanging wall of the fault consists of an altered limy sandstone that contains minute disseminated crystals of pyrite and rounded, irregular masses of uraniferous pyrobitumen with inclusions of pyrite, chalcopyrite, tennantite, and tetrahedrite. On the footwall is a 6-foot-wide gouge. Veinlets of calcite and barite as much as 4 inches wide cut the gouge and extend into brecciated sandstones and shales. The gouge and brecciated rocks are impregnated with uraniferous pyrobitumen, tennantite, tetrahedrite, chalcopyrite, pyrite, sphalerite, and galena. Covellite, malachite, and azurite are abundant locally. Four channel samples, 51-W-54, 55, 56, 57 (table 2), taken progressively away from the fault across the 6-foot wide gouge zone, contained 0.045, 0.033, 0.018, and 0.009 percent uranium. These results indicate that most of the uranium is concentrated within 3 feet of the fault plane and this zone is the richest in pyrobitumen. Fault material from the hanging wall of the fault contains only 0.007 percent uranium.

Copper deposits

The primary copper minerals named in order of abundance are tennantite, tetrahedrite, chalcopyrite, and bornite. These minerals occur in the fault zone along Faults No. 1, No. 2, and No. 3, and in calcite-barite fissure veins adjacent to these faults. Chalcocite, covellite, azurite, and malachite are the oxidation products of the primary copper minerals. Minor quantities of galena, sphalerite, and pyrite are associated with the copper minerals.

In the adit, chalcopyrite with minor tetrahedrite occurs in narrow veins and as disseminations in the fault gouge on the footwall of Fault No. 3. Azurite and malachite are the principal secondary copper minerals and coat fracture surfaces in the fault zone and wall rocks. The gangue minerals are pyrite, calcite, and barite. The fault zone ranges from 6 inches to 2 feet in width. North of the adit, secondary copper minerals were found along the trace of the fault on the surface.

The fault zone along Fault No. 2 has not been mineralized extensively and only minor quantities

Table 2.--Analyses of samples from the Robinson property, San Miguel County, Colorado _/

Sample number	Equivalent uranium (percent)	Uranium (percent)	Remarks
51-W-1	0.023	0.021	9-foot channel around bottom of shaft A, hydrocarbon-bearing sandstone
51-W-51	.001	.001	Barite vein in basal Dolores formation
52	.001	.001	Copper ore from caved adit
53	.009	.007	1-foot of altered Cutler sandstone from shaft A
54	.046	.045	1.5 feet of fault gouge, shaft A
55	.033	.033	1.5 feet of fault gouge, shaft A
56	.021	.018	2 feet of fault gouge, shaft A
57	.011	.009	2 feet of copper-stained fault gouge, shaft A
58	.004	.004	2.5 feet of fault gouge from south of carbonate vein, shaft B
59	.002	.002	2 feet of altered shale at fault, shaft B
60	.002	.002	2 feet of fault gouge zone, shaft B
61	.012	.013	3 feet of fault zone - north fault, altered sandstone, shaft B
62	.006	.004	4 feet of altered sandstone in fault zone, shaft B
63	.001	.002	3.5 feet of fault gouge from west wall shaft east of shaft A
64	.001	.001	3 feet of altered sandstone and shale from fault zone: prospect pit 100 feet west of shaft A
65	.002	.001	1.5 feet of altered shale from fault zone: 75 feet inclined shaft
66	.003	.001	1 foot of altered shale from fault zone: 75-foot inclined shaft
67	.001	.001	1 foot of altered shale from fault zone: 75-foot inclined shaft
68	.001	.002	4 feet of fault gouge zone from 75-foot inclined shaft
69	.001	.001	3.5 feet of altered Cutler sandstone from 75-foot inclined shaft
70	.002	.001	2 feet of fault gouge, footwall fault, from 75-foot inclined shaft
71	.001	.001	2 feet of fault gouge, from 75-foot inclined shaft

_/U. S. Geological Survey Trace Elements Section Denver Laboratory.

of azurite and malachite were found where this fault cuts the basal conglomerate of the Dolores formation.

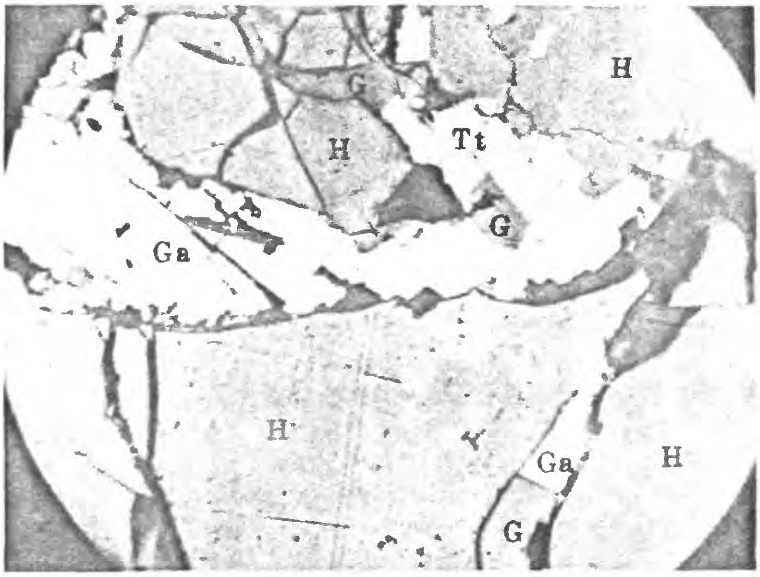
Calcite-barite fissure veins as much as 2 feet wide and 50 feet long occur in the Cutler formation north of Fault No. 1 (fig. 2). The principal vein material is coarsely crystalline calcite with minor quantities of barite, azurite, and malachite. The veins consist of calcite crystals as much as 8 inches in length perpendicular to the vein walls with many open vugs in the center of the vein. The secondary copper minerals coat fracture surfaces and occur as linings on the walls of the vugs. No primary copper minerals were identified and the veins are not abnormally radioactive.

Mineralogy

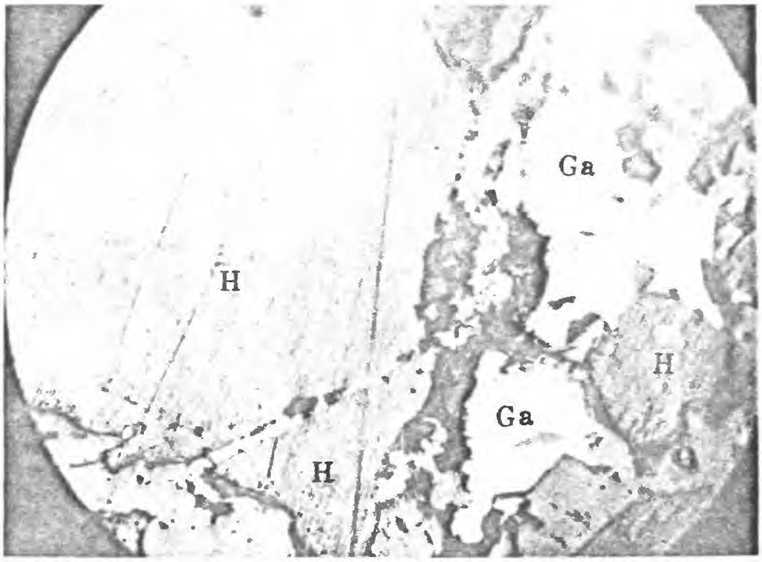
Uraniferous pyrobitumen, the only uranium-bearing material found by the writers, is jet black, has a resinous luster and a conchoidal fracture. It is insoluble in hot concentrated sulfuric, nitric, and hydrochloric acids and in organic reagents. In reflected light, the pyrobitumen is medium grey, ranges in hardness from A to C, and is isotropic to faintly anisotropic. There are no apparent megascopic differences between the isotropic and anisotropic varieties of pyrobitumen. A selected sample of uranium-bearing pyrobitumen contained 30.59 percent ash, and 0.93 percent equivalent uranium in the ash. The unashed pyrobitumen contains 0.35 percent equivalent uranium. A semi-quantitative spectrographic analysis of the ash is given below:

10-20 (percent)	1-10 (percent)	0.1-1.0 (percent)	0.01-0.1 (percent)	0.001-0.01 (percent)	0.0001-0.001 (percent)
silicon	aluminum	manganese	titanium	silver	beryllium
calcium	iron	sodium	molybdenum	boron	
	lead	barium	tin	cobalt	
	potassium	yttrium	strontium	chromium	
	magnesium	uranium	vanadium	gallium	
		copper	zinc	nickel	
				zirconium	
				scandium	

The uraniferous pyrobitumen occurs as fracture fillings, and as small rounded masses disseminated in the fault zone and adjacent wall rocks. Commonly, these pyrobitumen masses are surrounded and veined by later sulfides and calcite (plate 1). This association suggests that the pyrobitumen has aided in precipitating the later sulfide minerals.



A. Fractured hydrocarbon (H) filled and partially replaced by galena (Ga), tetrahedrite (T), and calcite (G). Reflected light, X100.



B. Fractured hydrocarbon (H) filled and partially replaced by galena (Ga) and calcite (G). Reflected light, X100.

Plate 1. Photomicrographs of polished sections of specimens from the Robinson property (shaft A), San Miguel County, Colorado.

Pyrite, the earliest and most abundant sulfide, is closely associated with the pyrobitumen. It occurs as small irregular masses and narrow fissure fillings in the calcite veins and as disseminations and replacement bodies in the pyrobitumen in the fault zone. Euhedral pyrite grains occurs only in the calcite veins. The pyrite has been extensively fractured and replaced along the fractures by the later sulfides (plate 2).

Galena is a minor mineral in the deposits. It is closely associated with tetrahedrite, chalcopyrite, and sphalerite in the uranium deposit, but it was not found by the writers in the copper deposits. The galena occurs as irregular masses in calcite veins, and as fracture fillings and replacement blebs in pyrite and pyrobitumen (plate 1).

Tetrahedrite, the most abundant copper mineral in the uranium deposit, occurs as fracture fillings and replacement blebs in the fractured and altered wall rocks along Fault No. 1. Polished sections of the ore shows the tetrahedrite in mutual boundary contact with galena in the pyrobitumen (plate 1-A) and as fracture fillings in pyrite and calcite veins (plate 2-A). Tetrahedrite also occurs as small masses that surrounds the uraniferous pyrobitumen in the fault zone and in the calcite veins.

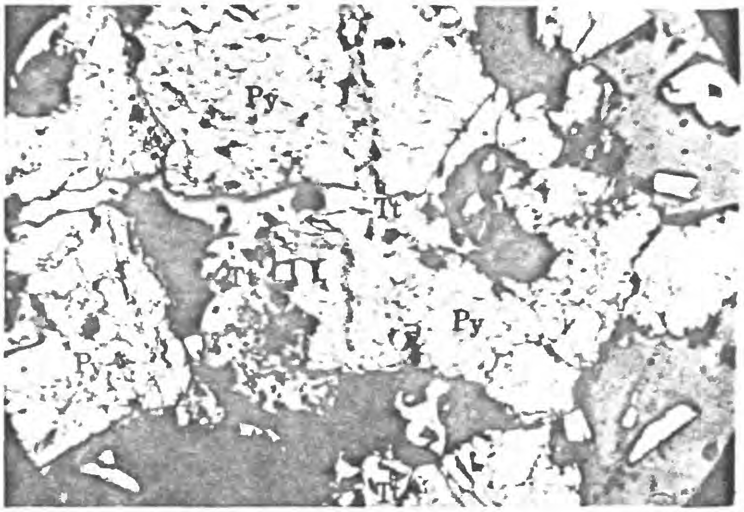
Tennantite is the most abundant mineral in the copper deposits that occur along Fault No. 1, about 1,400 feet east of Shaft A, (plate 3). It has not been identified in the uranium deposit.

Small quantities of chalcopyrite and bornite are associated with sphalerite in specimens from the uranium deposit (plate 2-B). The chalcopyrite and bornite has been replaced by covellite along fractures and grain boundaries. The sphalerite occurs as ex-solution blebs in the chalcopyrite and as small irregular masses associated with tetrahedrite and pyrite in veins in the fault zone (plate 2-B). Sphalerite does not occur in the copper deposits.

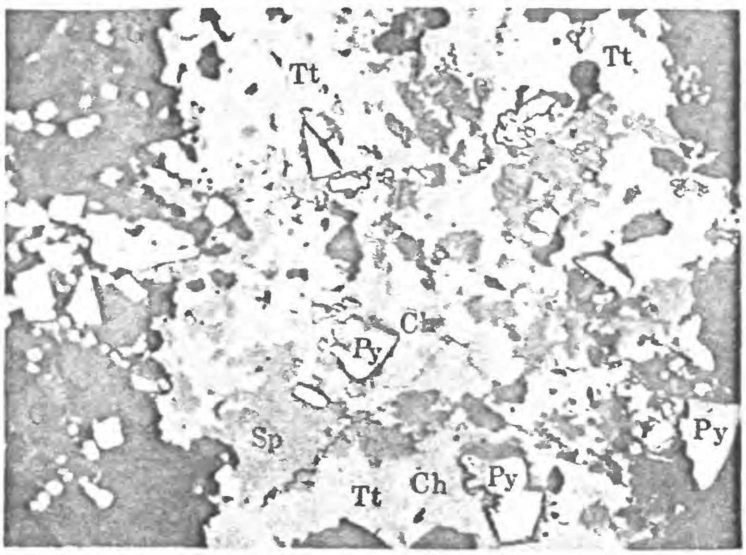
Malachite and azurite are abundant as surface coatings along fracture surfaces in the fault zone and adjacent wall rocks.

The gangue minerals in the uranium deposits, named in the order of their abundance are calcite, barite, and quartz. A detailed study of these minerals in the copper deposit was not made, but in hand specimens of the ore, calcite and barite are the principal minerals.

Two ages of calcite are easily recognized in the uranium deposit. The early calcite is predominantly light grey to white, fine- to coarsely-crystalline mineral. It is the principal introduced mineral and occurs as veins

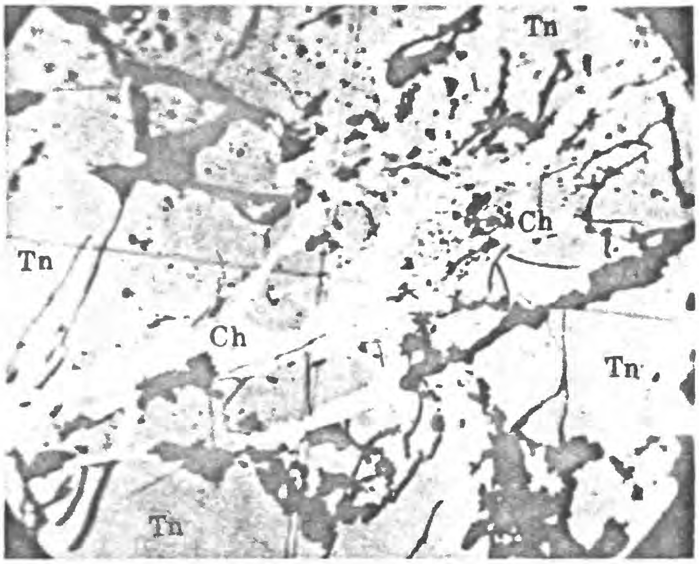


A. Pyrite (Py) veined and replaced by tetrahedrite (Tt). Dark gray is calcite. Reflected light, X100.

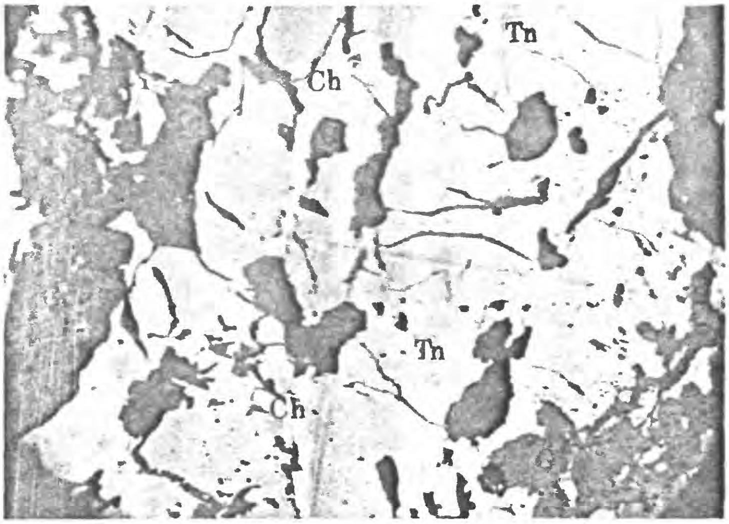


B. Pyrite (Py) embayed by tetrahedrite (Tt), sphalerite (Sp), and chalcopyrite (Ch). Gangue is calcite (G). Reflected light, X100.

Plate 2. Photomicrographs of polished sections, Robinson property, San Miguel County, Colorado.



A. Tennantite (Tn) veined by chalcopyrite (Ch) and gangue which is mostly calcite (G). Reflected light, X100.



B. Tennantite (Tn) veined by chalcopyrite (Ch) and gangue which is mostly calcite (G). Black is open spaces. Reflected light, X100.

Plate 3. Photomicrographs of polished sections of specimens from the Robinson property, copper prospect 1,400 feet east of Shaft A, San Miguel County, Colorado.

in the fault zone and adjacent rocks. The early calcite forms crystals as much as 8 inches in length perpendicular to the vein walls. Barite, azurite, and malachite coat fractures in the vein calcite and are interstitial to many of the calcite crystals. A semi-quantitative spectrographic analysis showed that several other elements are present also in the vein calcite. The approximate percentages of the major elements are tabulated below:

Al	Ba	Ca	Mg	Mn	Pb	P	Si	Sr
0.01-0.1	0.1-1.0	10.0-80.0	0.1-1.0	0.1-1.0	0.01-0.1	0.1-1.0	0.1-1.0	0.1-1.0

A white fine-grained calcite that occurs as fracture fillings in the pyrobitumen and in the calcite veins was the last mineral deposited, and is probably of secondary origin.

Coarsely crystalline barite is abundant locally in the calcite veins and in the fault zone. Thin sections of the calcite vein material shows that the barite is interstitial to the calcite crystals and locally replaces the calcite.

Quartz crystals replaced by calcite and barite occur at the edges of many of the calcite veins. The quartz crystals were deposited prior to the vein calcite and the barite.

Because of the small quantities of sulfides present in the uranium deposit a complete study of the paragenesis of the ores is difficult. However, the following relationships are clearly shown: (1) calcite and barite were deposited in the fault zone, (2) deposition of the uraniferous pyrobitumen and most of the pyrite, (3) minor movement along the fault fractured the previously deposited minerals, (4) the main period of the sulfide mineral deposition and (5) deposition of calcite.

Grade

The uranium content of the material sampled at the Robinson property ranges from 0.001 to 0.045 percent. The material with the highest uranium content was found at the bottom of Shaft A, where five channel samples (table 2), 51-W-1, 53, 54, 55, and 56, aggregating 15 feet in length were cut across the fault zone. The weighted average of these five samples is 0.02 percent uranium.

The only other locality where abnormal radioactivity was detected was in the shaft 50 feet west of Shaft A. A three-foot channel sample across the fault zone at the bottom of this shaft contained

0. 013 percent uranium. Four other channel samples, 51-W-58, 59, 60, and 62, totalling 10 1/2 feet across the fault zone each contained less than 0. 005 percent uranium. Samples collected at all of the other mine workings contained insignificant quantities of uranium. The analytical data pertaining to the samples collected at the Robinson property are tabulated in table 2.

WEATHERLY PROPERTY

The Weatherly property (fig. 1) approximately a mile northwest of Placerville, consists of the Black King no. 1, no. 4, and no. 5 claims. These claims were located for uranium in 1950, as the result of discovery of uranium-bearing pyrobitumen in an abandoned copper mine. The main mine workings (figs. 3 and 4, and plate 4) consist of an adit 143 feet in length, a vertical shaft, two inclined shafts, and numerous prospect pits. Sixty feet west of these workings is a partly caved adit, about 22 feet in length.

Geologic setting

The rocks at the Weatherly property (fig. 3 and plate 5) consist of nearly horizontal sedimentary rocks of the Cutler formation of Permian age overlain by the Dolores formation of Triassic and Jurassic (?) age. These rocks have been displaced by normal faults, the largest of which, Fault No. 1, trends northwest and has a vertical displacement of about 180 feet. This fault and the adjacent rocks have been the loci for the deposition of the uranium-bearing pyrobitumen, nickel, cobalt, molybdenum, lead, zinc, copper, and silver minerals.

There are no igneous rocks exposed at the Weatherly property, but an andesite porphyry dike cuts the Cutler formation about half a mile southwest of the mapped area.

Rocks

Within the mapped area at the Weatherly property (fig. 3), the exposed beds of the Cutler formation are approximately 300 feet thick. The beds consist of conglomerate lenses with interbedded maroon sandstones, shales, and limestones, and a bed of white arkosic sandstone. The conglomerate

View looking east along the strike of fault No. 1. Shaft A at left and main adit in center.

Plate 4. Photograph of the mine workings at the Weatherly property, San Miguel County, Colorado.

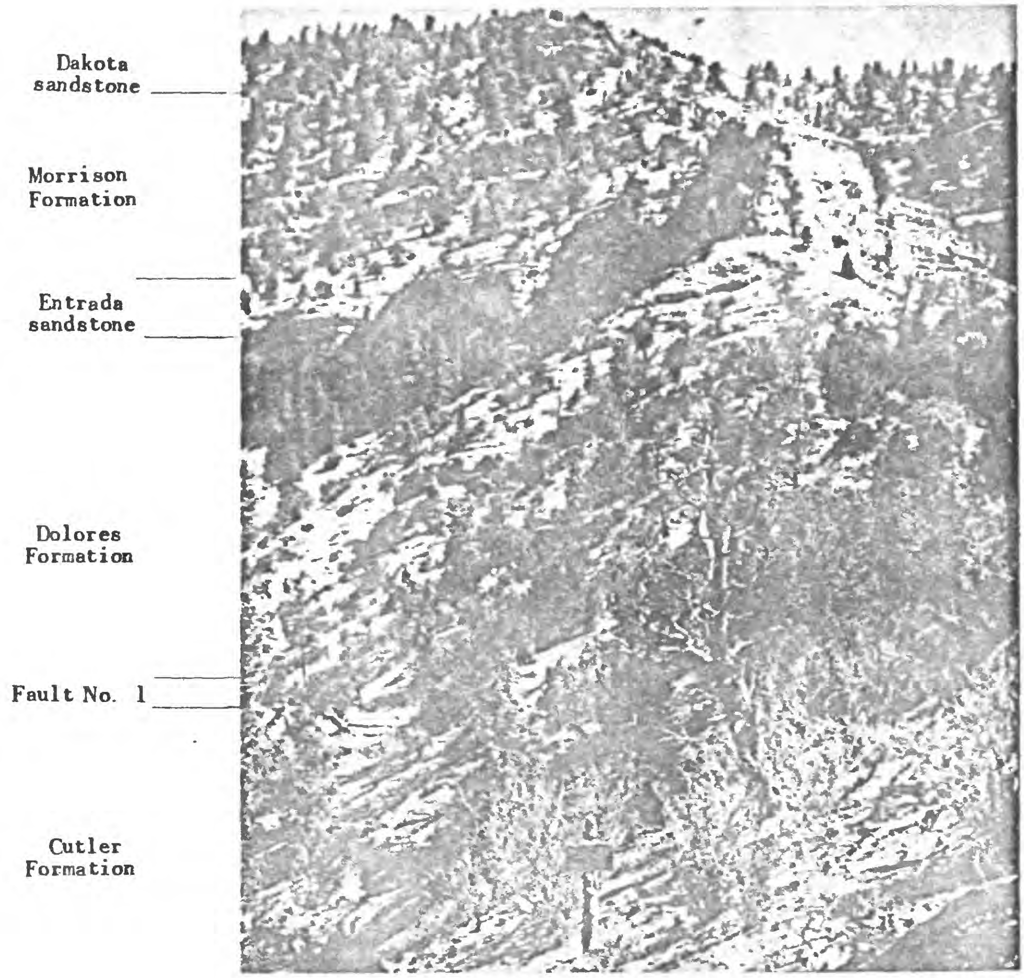


Plate 5. Photograph showing topography and strata at the Weatherly property, San Miguel County, Colorado.

beds are similar in texture and composition to the Cutler conglomerates at the Robinson property and as at the Robinson property they are bleached and calcitized adjacent to the faults. In general, the degree of bleaching diminishes away from the faults; the most intensely bleached zone, as much as 30 feet wide, is on the footwall of fault No. 1. Local bleaching occurs along bedding planes for as much as 75 feet away from the fault. The contact between the bleached and unbleached rocks is commonly irregular but in the underground workings the contact is marked by calcite filled joints. Radioactive pyrobitumen pellets occur in both the bleached and unbleached shales, but in the unbleached rocks the pyrobitumen pellets are surrounded always by a bleached zone. A bed of light gray arkosic sandstone, as much as 20 feet thick, forms a prominent cliff below the mine workings at the Weatherly property. It is coarse-grained and consists of quartz and feldspar fragments that average one-fourth inch across cemented by fine-grained calcite, quartz, and limonite. The shales above and below the arkosic sandstone contain rounded white spots, as much as half an inch across, that are probably the result of the reduction of iron by plant remains.

A nearly complete section of the Dolores formation (fig. 3) is exposed at the Weatherly property. A detailed measured stratigraphic section, 394 feet thick is given in table 3. Approximately a mile southeast of Weatherly property in an apparently unfaulted section, the Dolores formation is 526 feet thick. The Dolores formation is characteristically bright red in contrast to the dark maroon of the Cutler formation, but at the Weatherly property, the Dolores beds have been bleached extensively and only locally are they red. The basal quartz conglomerate at the mine has been faulted complexly and ranges from a feather edge to as much as 6 feet in thickness. It is composed of rounded to subangular quartz pebbles, as much as one inch across that are cemented and partially replaced by calcite, pyrite, pyrobitumen, and fuchsite. In the eastern part of the area (fig. 3) the basal conglomerate has been cut by three faults and, except for the pyrite, pyrobitumen, and fuchsite (chrome- mica), the rock is similar in composition and texture to the conglomerate at the mine. Thin section studies of the basal conglomerate show that fragments of quartz, limestone, and siltstone, as much as 5 mm across, make up the bulk of the rocks. Euhedral pyrite, altered feldspar grains, and small replacement blebs of hydrocarbon are abundant locally. Coarse-grained calcite is the cementing material, and has been replaced partly by pyrobitumen along grain boundaries. Limonite stain is common in some of the conglomerate.

Table 3.--Detailed stratigraphic section of the Dolores formation at the Weatherly property, San Miguel County, Colorado

	Feet
Entrada sandstone	
Sandstone, buff to light-gray, massive to cross-bedded.	50
Dolores formation	
Sandstone, gray to reddish, massive, limy.	70
Shales and sandstone, red to green-gray, thin-bedded, sandy.	40
Sandstone, light buff, coarse-grained, limy.	1
Shale, red to brown, limy, thin-bedded.	5
Limestone, reddish-brown to gray, fine-grained, sandy.	6
Fault zone (3' zone)	
Shale, gray to red.	7
Sandstone, dark gray, thin-bedded, limy.	20
Pebble conglomerate, limestone.	4
Shale, red to green, limy.	8
Limestone, dark gray to black, thin-bedded, sandy.	68
Conglomerate, dark gray, limestone.	7
Limestone, light to dark gray, sandy.	1
Conglomerate, dark-gray, limestone.	3
Limestone, dark gray, sandy, thin-bedded.	5
Limestone, black, sandy with pyrite concretions.	9
Limestone, gray, mottled, shaly.	14
Limestone, dark-gray, massive	1
Limestone, dark-gray to brown, sandy.	10
Conglomerate, gray, limestone.	53
Limestone, buff, thin-bedded, sandy, conglomeratic.	21
Pebble conglomerate, dark gray.	4
Limestone, buff, fine-grained, sandy.	2

Table 3. -- Detailed stratigraphic section of the Dolores formation at the Weatherly property, San Miguel County, Colorado - Continued

	Feet
Covered by talus.	8
Limestone, light-gray to brown, thin-bedded.	11
Conglomerate, green, limy.	4
Conglomerate, dark-gray, limy.	2
Covered by talus.	3
Limestone, light-gray, sandy.	7
Total thickness measured ------	394

Above the basal conglomerate, the Dolores formation consists of a series of interbedded, thin-bedded limy shales, sandstones, siltstones, limestones, and limestone conglomerates (table 3). The upper bed of the Dolores formation is a massive bed of dark-gray to greenish-gray sandy limestone as much as 75 feet thick. It is characterized by nodules of secondary pyrite as much as 2 inches across and is a prominent cliff former in this area.

Structure

The predominant structural features in this area are the northwest-trending normal faults and the smaller but, more abundant, northeast-trending normal faults. The sedimentary rocks south of Fault No. 1 (fig. 3) strike N. 60° W. and dip 4° S., but dip as much as 11° adjacent to the faults. Between Fault No. 1 and Fault No. 2, the beds are faulted extensively and strike N. 32° to 72° E. and dip 4° to 25° NW.

Fault No. 1 and Fault No. 2 are the dominant structural features at the Weatherly property. Fault No. 1 strikes N. 57 to 83° W., dips 62° to 70° N., and can be traced along the strike for more than 700 feet in the mapped area. Calcite and barite veins mark the fault zone at the surface. In the underground workings (fig. 4), the fault zone ranges from 2 to 5 feet in width and is composed of calcite and barite veins in faulted Cutler sandstone, and fragments of the adjacent wall rocks, all impregnated by uraniferous pyrobitumen, sulfide minerals, and secondary copper, cobalt, and molybdenum minerals. Movement along the fault has placed the basal conglomerate of the Dolores formation against the upper part of the Cutler formation. The vertical displacement of this fault is approximately 200 feet.

The strike of Fault No. 2 ranges from N. 63° W. to N. 60° E., and the dip ranges from 70° to 82° N. The trace of the fault on the surface can be followed for over 1,000 feet. Fault No. 2 is entirely within the Dolores formation. Small quantities of barite, galena, sphalerite, and secondary copper minerals occur in the fault zone. The displacement of Fault No. 2 is estimated to be about 150 feet.

The principal subsidiary faults, Nos. 3, 4, and 5, trend northeast, dip steeply to the north and displace the beds as much as 45 feet. Calcite and barite veins, minor non-uraniferous pyrobitumen and secondary copper minerals occur locally in the fault zones. Subsidiary tension faults just north of the mine workings trend northeast, dip steeply to the northwest and have displaced the basal Dolores conglomerate as much as 3 feet.

The joint system is well developed and consists of one set that strikes from N. 10° E. to N. 45° E. and dips from vertical to 85° SE. The other set strikes from N. 65° W. to west and dips from vertical to 80° S. Calcite fills many of the joints.

Uranium deposit

Uranium-bearing pyrobitumen the most abundant uraniferous material at the Weatherly property, occurs in the fractured rocks along Fault No. 1 and in the thin-bedded siltstone north of this fault. Autunite and uranophane have been identified in specimens from the dump material. In the fault zone, the uraniferous pyrobitumen is intimately associated with tetrahedrite, galena, sphalerite, erythrite-annabergite, molybdite, azurite, and malachite in a gangue of pyrite, calcite, barite, and quartz. In the siltstone the radioactive pyrobitumen occurs with pyrite and calcite. The uranium content of samples from this deposit ranges from 0.001 to 9 percent (table 4).

The best exposure of the fault zone that contains the uraniferous pyrobitumen is in the main adit (fig. 4) and in shaft A (fig. 3). This zone ranges from 2 to 5 feet in width and is traceable along Fault No. 1 from Shaft A eastward for approximately 140 feet. Although the fault zone is mineralized to a small degree east and west of this area, no radioactive pyrobitumen was found. In the main adit the fault gouge on the hanging wall is as much as 2 feet wide and is composed of layers of gouge alternating with calcite veins.

Table 4.--Analyses of samples from the Weatherly property, San Miguel County, Colorado_/

Sample number	Equivalent uranium (percent)	Uranium (percent)	Remarks
51-W-6	0.002	0.001	2 feet of fault gouge filled with calcite veins
7	.001	.001	2.5 feet of fault gouge
8	.002	.001	2 feet of fault gouge, Fault No. 1
9	.001	.001	2 feet of fault gouge - foot wall
10	.001	.001	2 feet of altered Cutler sandstone - foot wall
11	.001	.001	2 feet of fault gouge zone
19	.003	.004	1.5 feet of fault gouge zone with calcite stringers, main adit, portal
20	.001	.001	1.5 feet fault gouge zone, main adit
21	.001	.001	2 feet fault gouge zone, main adit
22	.003	.003	2.5 feet limestone, main adit
23	.006	.006	5.5 feet chromium-bearing quartz conglomerate, main adit
24	.003	.003	1.5 feet fault gouge, main adit
25	.001	.002	1 foot of fault gouge, main adit
26	.017	.014	1.5 feet lens of pyrobitumen, main adit
27	.003	.001	1.5 feet fault gouge, main adit
28	.003	.001	1.5 feet fault gouge, main adit
29	.002	.001	2 feet limestone, main adit
30	.001	.001	2 feet fault gouge and calcite veins, main adit
31	.001	.002	2 feet fault gouge, main adit
32	.001	.001	9 feet chip-channel across barite vein, in prospect pit north of Fault No. 2
34	.001	.001	Silicious barite vein material, 100 feet east of 51-W-32
35	.003	.002	2-foot channel of fault gouge zone in adit 80 feet east of the shaft

_/U. S. Geological Survey Trace Elements Section Denver Laboratory.

Table 4.--Analyses of samples from the Weatherly property, San Miguel County, Colorado_/--Continued

Sample number	Equivalent uranium (percent)	Uranium (percent)	Remarks
51-W-36	0.52	0.70	2-inch wide uraniferous pyrobitumen vein, 150 feet northwest of shaft A
37	.59	.24	1-inch wide uraniferous pyrobitumen vein, 100 feet northwest of shaft A
38	.015	.007	5 feet limestone, 90 feet northwest of shaft A
39	1.1	1.33	Specimens hand picked uranium-bearing pyrobitumen from dump material
40	0.009	0.008	3 feet limestone, 20 feet east of inclined shaft
41	.002	.002	3 feet altered Cutler sandstone, in foot wall 10 feet from fault
42	.003	.002	3 feet altered Cutler sandstone, in foot wall, 30 feet from fault
43	.001	.001	Cutler sandstone
44	.002	.001	Altered foot wall consisting of sandy Cutler limestone, 20 feet from fault
45	.001	.001	Unaltered foot wall consisting of sandy Cutler limestone, 80 feet from fault
47	.023	.019	4 feet radioactive limestone, 30 feet north of shaft
48	.27	.23	8-inch vein of uraniferous pyrobitumen west side of shaft
49	.043	.033	5 feet radioactive siltstone, west side of shaft
50	.019	.015	2 feet fault gouge zone, 12 feet down in shaft A
92	9.0	9.0	Selected specimen of pyrobitumen from the main adit

Small masses of non-radioactive pyrobitumen with accessory pyrite occur locally in the fault gouge. A few small crystals of galena and sphalerite occur in the calcite veins. The footwall of the fault consists of a gouge zone as much as 3 feet wide bordered by highly fractured and calcite-rich Cutler sandstones and shales.

In the small adit west of the main adit (fig. 3), calcite fills fractures in a 2-foot wide gouge zone on the footwall of Fault No. 1. No pyrobitumen or sulfide minerals were found, but small quantities of secondary copper minerals coat fracture surfaces in the gouge zone. No abnormal radioactivity was detected in this adit; the uranium content of a channel sample across the fault zone is 0.002 percent uranium.

The uranium content of fifteen samples from the gouge zone along Fault No. 1 ranges from 0.001 to 9 percent (table 4). The sample locations are shown in figure 3 and figure 4. These analyses show that only selected samples contain more than 0.1 percent uranium. The uranium content of sample 51-W-92, a selected specimen of the richest uranium ore exposed in the main adit is 9 percent. It is from a podlike body as much as 6 feet long and 3 feet wide that occurs about 2 feet from the fault on the hanging-wall side. This sample consists of uranium-bearing pyrobitumen, rounded quartz grains, calcite veinlets, pyrite crystals, fuchiste and fragments of wall rock. Such material grades into barren fault gouge. Sample 51-W-26, a channel sample across part of the pod-like body contains 0.014 percent uranium.

Uranophane that sparingly coats fracture surfaces is the only secondary uranium mineral found by the writers, but Hess (1911) reported autunite in specimens from this mine.

The owners report that a 5-foot cross-cut driven into the hanging wall of Fault No. 1 a few feet west of sample locality, 51-W-26, intersected a pod-like body of highly radioactive pyrobitumen. Specimens of pyrobitumen from this body contained as much as 10 percent uranium. Samples of uraniferous pyrobitumen from a pocket at the breast of drift along Fault No. 1 twenty-five feet west of the bottom of shaft A contain more than 1 percent uranium.

Hypogene sulfide minerals were not found in place in the main adit, but in Shaft A, tetrahedrite, chalcopyrite, galena, and sphalerite occur mostly adjacent to Fault No. 1, and principally in a zone, as much as 2 feet wide, on the hanging-wall side. These sulfide minerals fill fractures and form replacement masses in the fault zone. Small quantities of galena and sphalerite occur in calcite veinlets that cut the fractured rocks in the fault zone. Secondary copper carbonates are abundant as coatings on fracture surfaces in the fault zone and in specimens that contain tetrahedrite, chalcopyrite, bornite, galena, and sphalerite from the old mine dumps. In Shaft A the spatial relation of the sulfide minerals and the uranium-bearing pyrobitumen is well shown. In the hanging wall of Fault No. 1, the sulfides occur in a zone adjacent to the fault, whereas, the uranium-bearing pyrobitumen is concentrated in a zone farther from the fault. Secondary erythrite and molybdite coat fracture surfaces in specimens of fault zone material collected from the mine dump, but these minerals were not found in place, and no primary cobalt or molybdenum minerals have been identified in the ore.

The size and shape of the sulfide ore bodies are only generally known. Small quantities of sulfide minerals occur with the uranium-bearing pyrobitumen along Fault No. 1 for a length of about 140 feet. In shaft A, the sulfide minerals form a zone as much as 2 feet wide, but in the main adit this zone is estimated to be about 3 feet wide. Semi-quantitative spectrographic analysis indicates that the fault material from the main adit and Shaft A contains from 0.1 to 1.0 percent copper, chromium, and zinc; 0.01 to 0.1 percent lead and a trace silver.

Uranium-bearing pyrobitumen, occurs in the Cutler and Dolores formations north of Fault No. 1 as nodules, as lenses that parallel the bedding, and as disseminations. The area of sedimentary rocks known to contain uraniferous pyrobitumen is poorly defined, but according to the available radiometric data, the radioactive area is approximately as shown on figure 3. The prevailing rock in the Dolores formation that contains the uraniferous pyrobitumen is a white to light grey calcareous siltstone.

The uraniferous pyrobitumen nodules are abundant, especially near the small adit, 90 feet north of Fault No. 1 and they range from a tenth inch to two inches in diameter. The contact between the nodule and the siltstone is sharp and in many places it is marked by thin calcite veins. Many nodules consist of pyrobitumen and calcite veinlets, but in some are rounded masses of unreplaced siltstone. Selected samples of pyrobitumen nodules contain as much as 1.4 percent uranium, whereas, the siltstone adjacent to the nodule contains 0.001 percent uranium. The pyrobitumen lenses that parallel the bedding are as much as 8 inches thick and 6 feet long. They are well exposed in the open cut near

Shaft A and near the small adit, 90 feet north of Fault No. 1. The uranium content of the pyrobitumen lenses as shown by analyses of channel samples 51-W-36, 37 and 48, ranges from 0.23 to 0.7 percent. Limonite is a common secondary mineral and occurs generally in fractures in the pyrobitumen.

Mineralogy

The uranium at the Weatherly property is contained in uranium-bearing pyrobitumen, pitchblende, and in minor quantities of secondary uranophane. Primary tetrahedrite, chalcopyrite, sphalerite, galena, pyrite with secondary molybdite, azurite, malachite, and erythrite-annabergite in a gangue of calcite, quartz, and barite are associated with the uranium minerals. Uraniferous and non-uraniferous pyrobitumen occur at the Weatherly property.

Uranium-bearing pyrobitumen from the siltstone north of Fault No. 1 and from the fault zone along Fault No. 1, is black, highly lusterous, has a conchoidal fracture, and is easily polished. It is insoluble in hot nitric, hydrochloric, and sulfuric acids and in organic reagents.

In reflected light the uraniferous pyrobitumen from the replacement bodies in the siltstone is faintly anisotropic, but the uraniferous pyrobitumen from the fault zone is isotropic. Both types of pyrobitumen are medium gray and range in hardness from B to D; there are no other apparent microscopic differences.

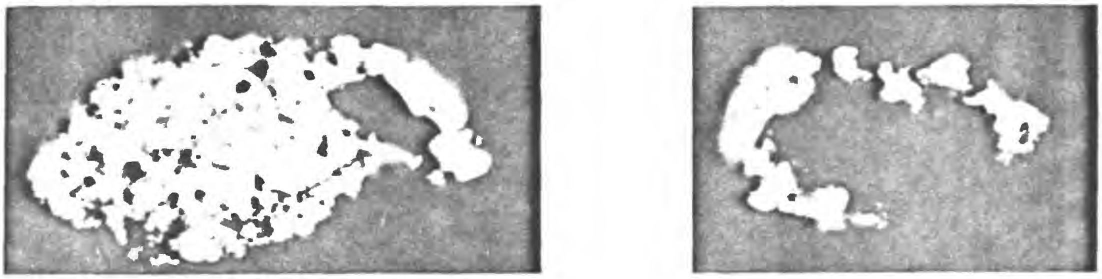
Spectrographic analysis of selected samples (table 5), of pyrobitumen from the siltstone, and the fault zone, indicate that the uraniferous pyrobitumen of the siltstone contains greater quantities of aluminum, iron, and calcium. X-ray analysis shows quartz and pitchblende in a sample of the pyrobitumen from the fault zone that contains 9 percent uranium, but only quartz and calcite were found in a sample of nodular pyrobitumen from the siltstone that contain 1.4 percent uranium.

Autoradiographs and alpha track plates of the uranium-bearing pyrobitumen indicate that the uraniferous material is quite evenly distributed, both in the vein and replacement types (plate 6). Although one selected specimen of pyrobitumen contains as much as 9 percent uranium, the alpha track plates of this specimen show an even distribution of the radioactive material. By using a magnification in reflected light of 350 diameters, many minute, blebs of foreign material that have not been identified,

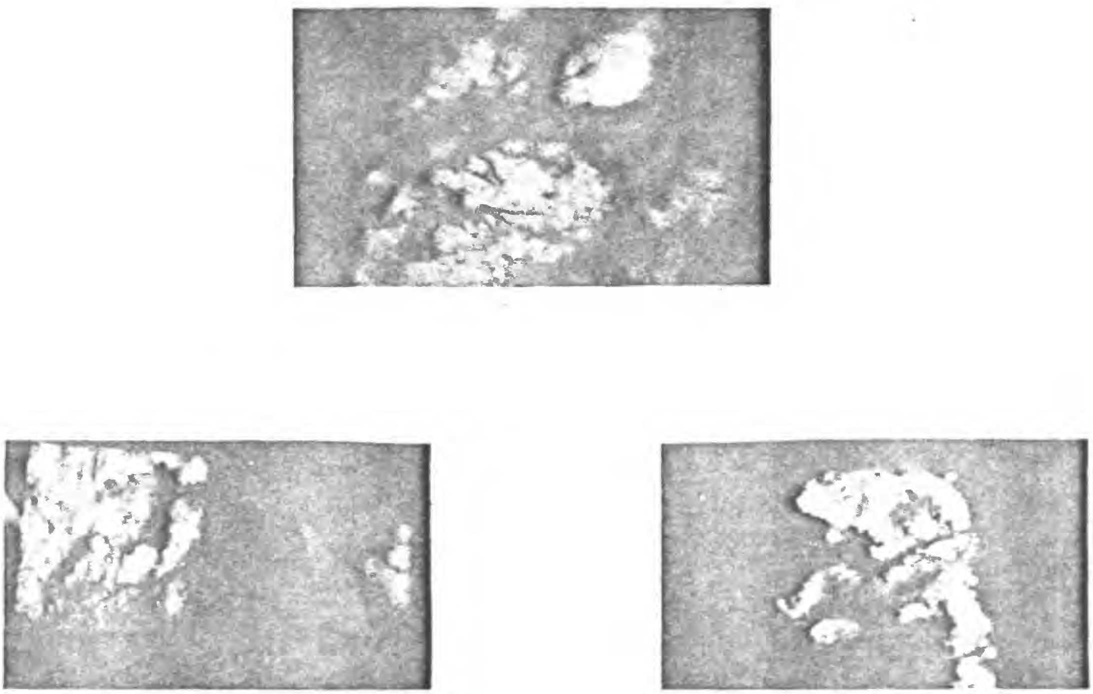
Table 5. --Semi-quantitative spectrographic analyses of selected pyrobitumen specimens, Weatherly property, San Miguel County, Colorado 1/ - 36

Sample No.	Description	Uranium 2/ (percent)	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	Ag	B	Ba	Be	Bi	Co	Cr	Cu	Mo	Ni	Pb	Sr	U	V	Y	Zr	Sc
51-W-89	in calcareous siltstone	1.2	X.	X.	.X	.0X	.00X	X.	.X	-	-	Tr	.0X	-	-	.000X	.00X	.000X	.000X	.000X	.00X	.00X	.X	.00X	.000X	.000X	-
-90	Vitreous pyrobitumen nodule	1.2	X.	.X	.X	.0X	.00X	X.	.X	-	-	Tr	.0X	-	-	.000X	.000X	.00X	.00X	.00X	.00X	.00X	.X	.000X	.000X	.000X	-
-91	Black material surrounding vitreous pyrobitumen nodule	0.51	XX.	X.	.X	.0X	.00X	X.	.X	-	-	.00X	.00X	-	-	.00X	.00X	.00X	-	.00X	.00X	.00X	.X	.00X	.000X	.00X	-
-92	Black pyrobitumen nodule in calcareous siltstone	9.0	X.	.X	.X	-	.00X	X.	.00X	.00X	.00X	Tr	.00X	.000X	.00X	.00X	.0X	.00X	.0X	.00X	.0X	.00X	X.	.0X	.000X	-	-
-93	Black pyrobitumen nodule in calcareous siltstone	0.78	X.	X.	.X	.0X	.00X	X.	.0X	-	-	.00X	.0X	.000X	-	.000X	.000X	.000X	.00X	.000X	.00X	.00X	.X	.000X	.00X	.00X	-
-93A	Altered wall rock surrounding Sample No. 51-W-93.	0.001	XX.	X.	X.	.X	.0X	X.	.X	.0X	-	.00X	.00X	-	-	-	.00X	.00X	.00X	-	.00X	.0X	-	.00X	.00X	.0X	.00X
-94	Pyrobitumen nodule in calcareous siltstone.	1.4	X.	X.	.X	.0X	.00X	X.	.X	.0X	-	.00X	.X	.000X	-	.00X	.000X	.00X	.00X	-	.0X	.00X	.X	.000X	.0X	.00X	-
-94A	Wall rock surrounding Sample No. 51-W-94.	0.18	XX.	X.	X.	.X	.0X	X.	.X	.0X	-	.00X	.0X	Tr	-	-	.00X	.00X	.00X	-	.00X	.00X	.X	.00X	.00X	.0X	.00X

1/ U.S.G.S. Trace Elements Section Denver Laboratory
2/ Chemical analysis.
Looked for but not found: As, Au, Cd, Ce, Ga, Ge, In, Hf, Hg, La, Li, Nb, P, Pd, Pt, Re, Rh, Sb, Sc, Sn, Ta, Th, Tl, Te, W, and Zn.
Tr= Near the threshold amount of element.



A. Specimens from the lenticular bodies along fault No. 1. Dark areas are mostly quartz (vein type).



B. Specimens of the nodular replacements. Dark veinlets are mostly calcite (replacement type).

Plate 6. Autoradiographs of uranium-bearing hydrocarbon from the Weatherly property, San Miguel County, Colorado. Actual size. White areas are concentrations of radioactivity.

could be seen in the pyrobitumen, but no alpha tracks that originated from a common source could be found in the film viewed under the same magnification.

An analysis of heavy mineral separates of the uranium-bearing pyrobitumen from the fault zone showed that most of the uranium is concentrated in the fraction with specific gravity of less than 2.86. This fraction is composed essentially of pyrobitumen. The uraniferous pyrobitumen will react with sodium fluoride flux to produce a light yellow-green fluorescense.

In the Dolores basal quartz pebble conglomerate just north of the main adit uranophane, a bright yellow hydrous calcium uranium silicate, occurs as thin coatings on fracture surfaces. The uranophane was identified by X-ray powder patterns, and spectrographic analysis showed that uranium, calcium, and silica are major constituents.

Pyrite, the most abundant sulfide at the Weatherly property, is the only sulfide mineral found in contact with the uranium-bearing pyrobitumen. It occurs as euhderal grains, as rounded masses as much as 3 mm across, and in narrow veins in the pyrobitumen and adjacent wall rocks. Along fault No. 1 pyrite is abundant as small rounded masses and as discrete grains disseminated through the fault zone.

Tetrahedrite, chalcopyrite, and minor sphalerite were found in place only at Shaft A. The tetrahedrite occurs as massive vein fillings, as small replacement bodies in the fault zone, and as disseminations in the calcite-barite veins. A semi-quantitative spectrographic analysis of the tetrahedrite shows that it contains about equal quantities of antimony and arsenic. Chalcopyrite and minor sphalerite vein and partially replace the tetrahedrite along fractures. Secondary malachite, azurite, and chrysocolla are associated with these minerals as coatings on fracture surfaces.

Molybdite, the yellow molybdenum oxide, was found as coatings on dump material from the sulfide-rich fault zone. Gruner and Gardiner (1950, p. 9) believe that dark blue stains associated with black, powdery material from selected dump sample is the result of decomposition of ilsemannite, the hydrous molybdenum oxisulfate. None of the blue material was found by the writers.

Erythrite-annabergite, secondary cobalt-nickel minerals occurs in minor quantities as thin coatings on pyrobitumen-rich material from the fault zone. Semi-quantitative analysis of the material showed about equal quantities of cobalt and nickel. This mineral was found only on dump rock and no primary cobalt or nickel minerals have been identified.

A chromium-bearing silicate, previously described and identified as fuchsite by Kerr and others (1951), occurs on the hanging-wall side of Fault No. 1 as narrow fissure veins and as rounded aggregates in the Dolores basal quartz conglomerate. A semi-quantitative spectrographic analysis of the purest material that could be obtained showed that the fuchsite contains 10 to 20 percent silica, 10 to 20 percent aluminum, 1 to 10 percent iron, 1 to 10 percent magnesium, 1 to 10 percent potassium, 1 to 10 percent chromium, and 0.1 to 1 percent vanadium. In the conglomerate the fuchsite is closely associated with uraniferous pyrobitumen, pyrite, and sphalerite.

The gangue minerals are calcite, barite, quartz, and limonite of which calcite and barite are the most abundant. The calcite occurs as veins in the fault zone and is also the most abundant cementing material. Spectrographic analysis of selected specimens of calcite from the veins shows traces of lead, zirconium, strontium, and magnesium. The vein calcite is the earliest mineral deposited and is restricted to the fault zones and joints and to fractures in the sediments adjacent to the faults. A late stage of calcite is present and occurs as fracture fillings in the pyrobitumen, sulfide minerals, and in the vein calcite.

Barite is found in calcite veins and as narrow veins in fault zones. The euhedral barite in the calcite veins cuts grain boundaries and in general appears to replace the early calcite. It is a common gangue mineral at both properties.

Limonite is an alteration product of pyrite and occurs as coatings in fractures in the sedimentary rocks and in the fault zone.

Clear, euhedral quartz in minor quantities occurs at the borders of many calcite veins. The quartz crystals are as much as 0.16 mm across and have been replaced by the vein calcite and barite. In general the quartz does not constitute over 2 percent of the calcite veins.

The paragenesis of the sulfide ores at the Weatherly property is pyrite, tetrahedrite, chalcopyrite, sphalerite, and galena. Calcite veins that contain galena and sphalerite cut the uraniferous pyrobitumen and this indicates that the sulfides were deposited later than the pyrobitumen. This sequence of mineralization is similar to that of the Robinson property. The position of fuchsite in the mineral sequence is not clear but it probably was contemporaneous with the pyrobitumen and pyrite. The minerals erythyrite, molybdite, azurite, and malachite are products of oxidation of primary minerals.

Grade

The uranium content of the material sampled at the Weatherly property ranges from 0.001 to 9 percent.

Because of the erratic distribution of the uraniferous pyrobitumen in the sedimentary rocks north of Fault No. 1, a representative sample is difficult to obtain. Two channel samples, 51-W-47 and 51-W-49 (table 4), of the siltstone contain 0.019 and 0.033 percent uranium, but samples of the pyrobitumen from nodules and lenses contain from 0.23 to 1.33 percent uranium.

A 1.5 channel sample, 51-W-26, across a lens of uraniferous pyrobitumen adjacent to Fault No. 1 in the main adit contains 0.014 percent uranium, but specimens of the pyrobitumen contain as much as 9 percent uranium. All other channel samples in the main adit contain less than 0.002 percent uranium; channel samples in the fault zone contain from 0.001 to 0.006 percent uranium.

ORIGIN OF DEPOSITS

The similarity in structure, mineralogy, and mode of occurrence of the uranium deposits at the Weatherly and Robinson properties suggests that these deposits were formed during the same general period of mineralization. According to Kerr et al., (1951, p. 25) and Gruner and Gardiner (1950, p. 9), the uranium deposit at the Weatherly property is probably hydrothermal in origin. The following hypotheses are suggested by the writers for the origin of the ore deposits at these deposits.

1) The pyrobitumen is hydrothermal in origin. There is evidence to show that the period of hydrothermal activity at the Weatherly and Robinson properties involved 2 stages of mineralization. The calcite, pyrite, and barite were deposited during stage 1, and the base-metal sulfide minerals during stage 2. Because the period of deposition of the uraniferous and non-uraniferous pyrobitumen is intermediate in the paragenetic relationships at these deposits, the implication is strong that the pyrobitumen is also hydrothermal in origin. The variation in uranium content of the pyrobitumen is believed due to the degree of concentration of an organo-uranium complexes.

2) During upward migration along fracture of solutions from which calcite, barite, uranium, compounds, and the sulfide minerals were deposited, oil was extracted from a reservoir rock and carried upward. Deposition of calcite, barite, and pyrite from the solutions left a solution rich in the constituents of the base-metal sulfides. Because uranium, in general, does not form sulfides, it may have been preferentially absorbed by parts of the crude oil and deposited as uraniferous pyrobitumen. Concentration of the heavy hydrocarbon molecules that may have resulted from the natural fractionation by variation in temperature and pressure controlled the amount of uranium that was absorbed. That the hydrocarbon resulted from the solidification of an oil is supported by the discovery of crude oil-bearing vugs in the sediments near the faults at the Weatherly property. 3) Uranium-bearing solutions of hydrothermal orgin introduced uranium into a crude oil that was trapped in the faults and adjacent fractured sedimentary rocks. 4) The uranium was transported from an unknown source by petroleum (crude oil). Such a mode of transport is possible if the uranium carried by crude oil is associated with special organic substances that are concentrated by volatilization, oxidation, and polymerization. While the uranium content of crude oil seldom exceeds 0.0007 percent, it has been found (Erickson, R. E., personal communication) that the uranium in an average crude oil is concentrated as much as 1000 times when the oil is ashed. The uranium content of some of the residues thus obtained from crude oils is comparable to that of the uraniferous pyrobitumens of the Placerville area. However, in the mapped areas non-radioactive pyrobitumens associated with calcite, barite, and sulfide minerals are locally abundant along minor faults. Therefore, it appears that the uranium content of the original crude oil prior to its deposition in the fractures and sedimentary rocks was low and that the local concentrations of uraniferous pyrobitumen are the result of the selective concentration on uranium by the pyrobitumen. 5) The uranium in the pyrobitumen was deposited originally as a discrete mineral, which was later replaced by petroleum compounds. According to Davidson and Bowie (1952, pp. 12-16), the hydrocarbon-uraninite complexes of the Witwatersrand ores in South Africa were formed by the polymerization of methane through contact with discrete grains of pitchblende. Such a method of origin seems incompatable in view of the even distribution of uranium in the uraniferous pyrobitumen and the absence of discrete masses of select pitchblende in ores from the Weatherly and Robinson properties. In the mineralographic

studies of ores no evidence was found that indicates that a primary uranium mineral was replaced by pyrobitumen.

The following hypothesis is favored by the writers because it seems to offer the best explanation for the inconsistent uranium content of the pyrobitumen and the localization of the pyrobitumen in the deposits. As calcite, barite, and base metal sulfides are undoubtedly hydrothermal, the post-calcite pre-sulfide position of the pyrobitumen strongly suggests that it too was deposited from hydrothermal solutions. The absence of recognizable discrete primary uranium minerals in these deposits indicates that the conditions for uranium deposition favored the precipitation of complex uranium-bearing pyrobitumens rather than simple uranium compounds.

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