The Copper and Uranium Deposits of the Coyote District, Mora County, New Mexico

By C. M. Tschanz, D. C. Laub, and G. W. Fuller

U. S. ATOMIC ENERGY COMMISSION
BUTTE SUB-OFFICE-SLEB
RECEIVED
AUG 1 1955
A.M. P.M.
7,8,9,10,11,12,1,2,3,4,5,6
4

Trace Elements Investigations Report 356

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OFFICIAL USE ONLY

OFFICIAL USE ONLY

Geology and Mineralogy

This document consists of 81 pages,
plus 8 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE COPPER AND URANIUM DEPOSITS OF THE COYOTE DISTRICT, MORA COUNTY, NEW MEXICO*

By

C. M. Tschanz, D. C. Laub, and G. W. Fuller

December 1954

Trace Elements Investigations Report 356

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

---

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

OFFICIAL USE ONLY

USGS - TEI-356

GEOLOGY AND MINERALOGY

Distribution (Series A)	No. of copies
Argonne National Laboratory	1
Atomic Energy Commission, Washington	1
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Butte	1
Division of Raw Materials, Casper	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Hot Springs	1
Division of Raw Materials, Ishpeming	1
Division of Raw Materials, Phoenix	1
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, Washington	3
Exploration Division, Grand Junction Operations Office	1
Grand Junction Operations Office	1
Technical Information Service, Oak Ridge	6
Tennessee Valley Authority, Wilson Dam	1
U. S. Geological Survey:	
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington	1
Geophysics Branch, Washington	1
Mineral Classification Branch, Washington	2
Mineral Deposits Branch, Washington	4
E. H. Bailey, Menlo Park	1
A. L. Brokaw, Grand Junction	1
N. M. Denson, Denver	1
M. R. Klepper, Spokane	1
A. H. Koschmann, Denver	2
J. D. Love, Laramie	1
L. R. Page, Washington	1
C. B. Read, Albuquerque	1
Q. D. Singewald, Beltsville	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver	2
TEPCO, RPS, Washington, (including master)	3
	47

CONTENTS

ILLUSTRATIONS

TABLES

THE COPPER AND URANIUM DEPOSITS OF THE COYOTE DISTRICT, MORA COUNTY, NEW MEXICO

By C. M. Tschanz, D. C. Laub, and G. W. Fuller

ABSTRACT

The copper and uranium-vanadium deposits of the Coyote district, Mora County, N. Mex., are confined to the lower 2,000 feet of the Sangre de Cristo formation of Pennsylvanian and Permian age. A narrow belt of deposits in steeply dipping or overturned rocks extends for 7 miles along Coyote Creek south of Guadalupita.

Earlier studies showed that the copper deposits contained uranium, but both the reserves and the uranium content of the copper-bearing shale are too low to permit the recovery of uranium. However, small, commercial grade uranium deposits have been discovered in sandstone.

Small lenses of copper-bearing carbonaceous shale, siltstone, limestone or sandstone, interbedded with predominantly red rocks, are present at intervals at 12 or more stratigraphic levels. The better deposits, in carbonaceous shale, average about 2 percent copper. The copper content of the other rocks is usually lower, but small concentrations may contain 6 percent copper. The principal copper minerals are chalcocite and malachite. Chalcocite replaces wood and forms nodules that contain small, variable amounts of pyrite, bornite, covellite, and rarely, uraninite.

The uranium deposits occur as small closely spaced pockets that are commonly localized by sedimentary structures within one or more fluviatile arkosic sandstone beds near the middle of the formation,

particularly where carbonized wood, clay galls, and rock fragments are abundant. The uraniferous sandstone is commonly stained pink by hematite that probably was introduced with the uranium. The color increases in intensity with the radioactivity.

The outcrops of the uranium deposits are typically inconspicuous, but close inspection shows they contain malachite, chalcopyrite, black vanadium minerals of micaceous habit, metatyuyamunite and microscopic grains of an unidentified black uraniferous substance. The proportion of copper, uranium, and vanadium is variable and any metal may be dominant.

The metals probably were derived from pre-Cambrian granitic rocks. Copper and minor amounts of uranium were deposited in local stagnant basins by reaction with hydrogen sulfide and decaying organic material. The uraniferous shales and the copper deposits are believed to be syngenetic, or nearly so, but the uranium deposits in sandstone are epigenetic and probably were deposited from ground waters with a possible hydrothermal admixture. The uranium and vanadium may have been reconcentrated from earlier, low-grade, syngenetic deposits.

Total copper ore reserves averaging about 1.45 percent are probably less than 46,000 tons, and the average ore body contains less than 1,000 tons. The small size of known, commercial-grade uranium pockets and the small total uranium reserves will permit small scale mining only under favorable conditions. Further exploration probably would increase the uranium reserves but no large deposits are expected.

INTRODUCTION

Location and accessibility

The Coyote district is in Mora County in the north-central part of New Mexico (fig. 1). The district can be reached from Las Vegas by traveling 28 miles north on New Mexico State Highway 3 to Mora, then 8 miles north on State Highway 38, then 2 miles east on an unimproved road. The district also can be reached by turning off Highway 3 at La Cueva and following State Highway 21 for 6 miles, then traveling 2 miles west to Lucero on an unimproved road and 3 miles north along Coyote Creek to the south end of the area. The roads in the district are ungraded and in poor condition. The nearest railroad shipping points are Watrous or Las Vegas. The closest uranium mill and buying station is at Shiprock, N. Mex. Sufficient water is probably available in Coyote Creek for a small mill.

Topography

The narrow north-south valley of Coyote Creek approximates the boundary between the gently dipping Permian and Mesozoic rocks of the High Plains to the east and the Pennsylvanian and pre-Cambrian rocks of the Southern Rocky Mountains to the west. The district is on the east flank of a north-south hogback between Coyote Creek on the east and Turquillo Valley on the west.

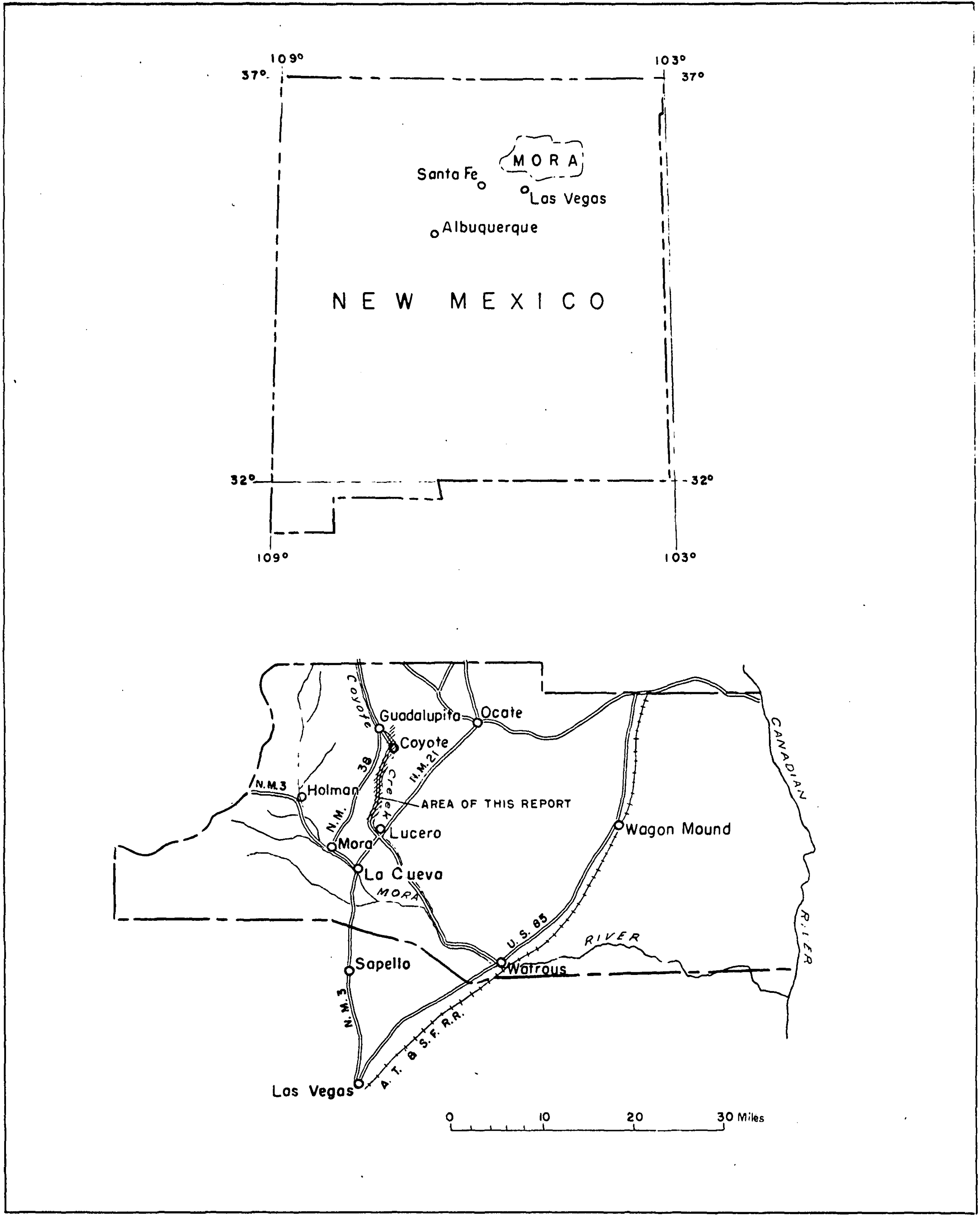


Figure 1
INDEX MAP
OF
MORA COUNTY, NEW MEXICO

Previous work

The copper deposits of the district have been known over 50 years. Brief descriptions of the district have been published by Lindgren, Graton, and Gordon (1910, p. 109); Lasky and Wooton (1933, p. 84); Harley (1940, p. 42-43). In 1944, Read, Sample, and Shelton of the U. S. Geological Survey examined the deposits and described them in a brief unpublished report. Bachman and Read (1952) discovered radioactive material in the district in 1951. Gott and Erickson (1952) visited the district and showed that the radioactivity was caused by uranium. As a result, the U. S. Geological Survey began an intensive study of the district for the Atomic Energy Commission, first by Zeller and Baltz (1952, 1954) and later by the writers.

The district is shown in a geologic map of the Ocate area by Bachman (1953). A generalized topographic and geologic map of most of the district on a scale of 1:12,000 is included in a report by Zeller and Baltz (1954).

Purpose and methods

Preliminary work in the Coyote district in 1952 showed that the copper-bearing carbonaceous shales contained small amounts of uranium. As the carbonaceous shales were widespread, there was the possibility of very large reserves of low-grade copper ores from which uranium might be recovered as a byproduct. The present study was begun primarily to evaluate this possibility. Secondary objectives were to gather data on the origin of the deposits and the relationship between the copper and uranium deposits. As work progressed, the uranium content of the copper-bearing shales was discovered to be negligible and exploration plans were revised to evaluate the newly discovered uranium-vanadium deposits in sandstone.

The most promising areas were mapped on a scale of 1 inch to 200 feet. In addition 2 small areas were mapped on a scale of 1 inch to 50 feet. The total area mapped was about 1.5 square miles.

The most promising deposits were explored by about 200 shallow hand-dug trenches and 25 shallow jeep-auger holes. The trenches were sampled and mapped on a scale of 1 inch to 5 feet.

Three hundred and thirty nine soil samples and 457 botanical samples were collected. Wherever possible, soil samples and botanical samples were collected at the same site to permit comparison of the results of the two prospecting methods.

Three hundred fifty-one samples were collected from the copper and uranium deposits. Two hundred and ten samples were submitted for quantitative chemical analyses, 22 were analyzed by semiquantitative spectrographic methods, and 5 were submitted for mineral identification by X-ray diffraction techniques. About 70 polished sections, 6 thin sections, and several heavy mineral concentrates, were studied. Four autoradiographs were made and studied. Several samples of uranium ore have been submitted for age determination but the results are not yet available.

Five months in the summer and fall of 1953 and 2 weeks the following spring were spent in field work.

Acknowledgments

All analytical work was done in the Denver laboratories of the U. S. Geological Survey. The spectrographic analyses were made by G. W. Boyes and P. J. Dunton, the X-ray analyses by W. F. Outerbridge, the equivalent uranium determinations by S. Furman and E. J. Fennelly, and the selenium analyses were made by J. L. Siverly. Chemical analyses for copper, uranium, and vanadium were made by E. C. Mallory, J. W. Patton, W. D. Goss, J. Wahlberg, J. P. Schuch, W. Mountjoy, D. L. Stockwell, E. J. Fennelly, H. E. Bivens, J. E. Wilson, D. L. Skinner, and R. F. Dufour. Rapid colorimetric analyses for trace amounts of copper and zinc were made by H. E. Crowe and J. H. McCarthy.

The plant and soil samples were collected by Warren R. Martin. The writers are indebted to H. D. Zeller and E. H. Baltz, Jr., who freely loaned their maps, notes, and specimens. Appreciation is due J. G. McGrath for the operation of the jeep-mounted auger.

This work is part of a program of exploration for radioactive raw materials undertaken by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GEOLOGY

Geologic history

During Pennsylvanian and early Permian time, the Ocate-Guadalupita area was part of a geosyncline, the Rowe-Mora trough, which was flanked by rising geanticlines of pre-Cambrian rocks that were part of the Colorado Mountains or ancestral Rocky Mountains (Read and Wood, 1947, p. 266). The axis of the geosyncline, which trends northwest, was about 12 miles west of the district. The rising positive areas furnished great volumes of sediments to the basin, which was occupied by a sea during the deposition of most of the Magdalena group. Marine sedimentation recurred intermittently during the deposition of the lower part of the Sangre de Cristo formation, but most of the sediments were deposited under subaerial conditions..

The sea invaded the region repeatedly after the deposition of the Sangre de Cristo formation. Bachman (1953) believes that the Glorieta sandstone of late Permian age probably is a beach sand deposited as the sea transgressed northward. Triassic and Jurassic sediments are partly shallow marine and partly continental in origin. A major marine invasion lasted most of Cretaceous time.

In early Tertiary time, regional compression deformed the rocks in the district and buckled the site of the present Sangre de Cristo Mountain system into a broad anticlinorium. Pre-Cambrian rocks rode eastward over the Pennsylvanian rocks along steep reverse faults on the east flank of the rising mountains. The rocks within and just east of the zone of reverse faults were steeply tilted or overturned to form the series of hogbacks in which the district is located (Northrup, Sullwold, MacAlpin, and Rogers, 1946; Bachman, 1953). This narrow, upturned belt parallels the east flank of the mountains northward and as far south as Las Vegas.

The sedimentary rocks further east were gently folded to form the Jarosa syncline and the Ocate anticline. The axes of these north-trending folds are 3 miles and 6 miles east of Coyote Creek, respectively.

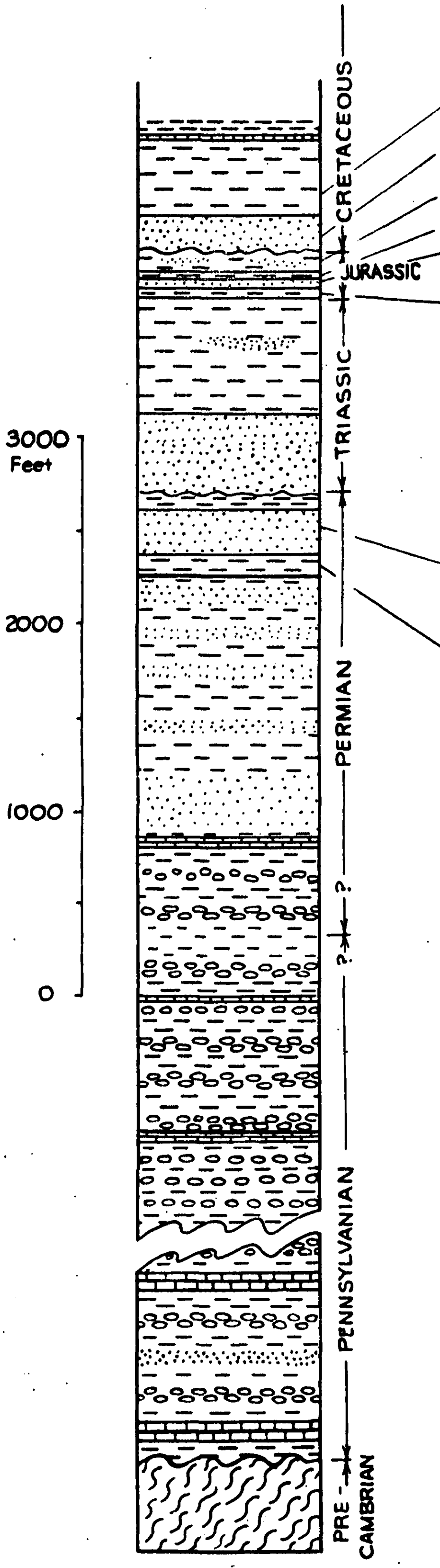
Two ages of late Tertiary or early Quaternary basalt flows covered all older rocks. The older flows originally covered most of the district, but only scattered erosional remnants remain.

Stratigraphy

Four main groups of rocks in the Coyote district are: 1) igneous and metamorphic rocks of pre-Cambrian age; 2) sandstone, arkose, siltstone, limestone, and shale of Pennsylvanian, Permian and Triassic age; 3) basalt flows of late Tertiary or Quaternary age; and 4) Quaternary gravel and alluvium. The distribution of these rocks is shown in the general geologic map of the district in figure 2. A graphic section of the sedimentary rocks from pre-Cambrian to the Benton formation of Cretaceous age is shown in figure 3. The Jurassic and Cretaceous rocks are included in figure 3 to permit comparison of the stratigraphy of the Coyote district with that of other uranium districts. The reader is referred to the work of Bachman (1953) for descriptions of these units.

Pre-Cambrian rocks

Pre-Cambrian rocks in fault contact with the Magdalena group crop out along the west side of the district. These pre-Cambrian rocks are chiefly quartzite with minor amounts of pegmatite, schist, and gneiss. Coarse-grained pink granite, diabase, diorite, amphibolite, pegmatite, and quartz veins are common in the pre-Cambrian areas of northern New Mexico and Colorado. Fragments of many of these rocks are found in the Pennsylvanian and Permian sedimentary rocks.



Benton formation, 400 feet.
Brown to gray fissile marine shale and limestone

Dakota sandstone, 180 feet, buff to gray medium-grained sandstone

Morrison formation, 150 feet, interbedded brown sandstone and variegated shale

Wanakah formation, 25 feet, gray and brown shale, sandstone, limestone

Ocate sandstone, 50 feet, gray, massive, cross laminated sandstone
Probably correlative with Entrada

Naranjo formation, 15 to 64 feet, interbedded brownish-red sandstone, siltstone, shale

Chinle formation, 640 feet.
Brownish-red and maroon shale and siltstone with a few discontinuous sandstone lenses.

Santa Rosa sandstone, 425 feet.
Brownish-red sandstone, in part conglomeratic, and shale

Bernal formation, 100 feet
Brownish-red siltstone and fine-grained sandstone

San Andres formation
Glorieta sandstone member, 266 feet
Gray to light-brown, medium-grained sandstone, cross-laminated in part. May intertongue with Sangre de Cristo formation

Yeso formation, 0 to 100 feet.
Brownish-pink siltstone, intertongues with Sangre de Cristo formation
Generally absent north of Lucero

Sangre de Cristo formation, 3000 to 3300 feet
Brownish-red arkosic pebble conglomerate, sandstone, and shale with minor gray shale and limestone. Generally correlative with Abo formation. Basal part intertongues with upper part of Magdalena group.

Magdalena group, 3500 to 10,000 feet
3500 feet exposed but total thickness is probably nearer 10,000 feet. Pre-Cambrian rock in fault contact with base of exposed section. Exposed rocks are brown and buff sandstone, arkosic pebble conglomerate and shale interbedded with gray marine limestone.

PRE-CAMBRIAN
Quartzite and minor schist, gneiss, pegmatite in area
Granite abundant elsewhere

FIG. 3- GENERALIZED COLUMNAR SECTION OF THE SEDIMENTARY ROCKS OF THE COYOTE DISTRICT AND SURROUNDING REGION

Magdalena group

Description

A regional angular unconformity separates the pre-Cambrian rocks from the Magdalena group of Pennsylvanian age.

The Magdalena group 12 miles west of Guadalupita near Chacon, consists of four units, Bachman (1953). The basal unit, 3,800 feet thick, is equivalent to the Sandia formation and consists of sandstone and arkose with minor shale and limestone. The next higher unit, about 1,000 feet thick, is bituminous and slightly calcareous, friable and fissile shale. The third unit consists of 2,800 feet of interbedded arkose, sandstone, shale, and limestone. The upper unit, 3,000 feet thick, consists of brownish to reddish-brown sandstone, arkose, and shale interbedded with gray marine limestone.

The section at Chacon is more than 10,000 feet thick and is dominantly marine. However, only about 3,500 feet of the upper part of the Magdalena group is exposed in the Coyote district. Bachman (1953) believes a large part of the Magdalena group is cut out by reverse faults along the west side of the district (fig. 2).

The marine sedimentary rocks of the Magdalena group in the Coyote district are yellow-brown, buff, or gray in contrast to the predominantly reddish continental sedimentary rocks of the Sangre de Cristo formation. On a regional scale the marine sedimentary rocks of the Magdalena group grade laterally and vertically into the Sangre de Cristo red beds (Northrup, and others, 1946). For further details on the regional stratigraphic relationships of both Pennsylvanian and Permian formations, the reader is referred to the publications by K. G. Brill (1952), G. O. Bachman (1953), and C. B. Read and G. H. Wood (1947).

The contact of the Magdalena group with the overlying Sangre de Cristo formation in the district was arbitrarily placed at the color change from gray or brown to red about 140 feet above a 25-foot fossiliferous limestone. In other parts of New Mexico the upper contact of the Magdalena group is placed at the top of the highest marine limestone, but in this area, several thin marine limestones occur in the lower 950 feet of a red-bed sequence that is indistinguishable from the Sangre de Cristo formation.

Fossils

The 25-foot-thick limestone 140 feet below the contact contains abundant marine fossils, including algae (?), corals, bryozoans, sponges, brachiopods, crinoids, and mollusks. The fossils listed below were identified by members of the U. S. Geological Survey.

Brachiopods (identified by Mackenzie Gordon)

- Meekella striatocostata (Cox)
- Dictyoclostus sp.
- Linoproductus cf. L. platyumbonus Dunbar and Condra
- Echinoconchus semipunctatus (Shepard), var.
- Neospirifer cf. N. latus Dunbar and Condra
- Composita subtilita (Hall)
- Composita ? sp.

Mollusks (identified by Mackenzie Gordon)

- Pteria sp.
- Allorisma sp.
- Worthenia sp. (identified by Ellis Yochelson and Brookes Knight)

Bryozoans (identified by Helen Duncan)

Fistulipora sp., massive form

Polypora sp.

Rhabdomeson sp.

Corals (identified by Helen Duncan)

Caninoid corals (<u>Pseudozaphrentoides</u> as interpreted by Moore and Jeffords)

Clisiophyllid corals (<u>Neokoninckophyllum</u> as interpreted by Moore and Jeffords)

The overall affinities according to Mackenzie Gordon and Helen Duncan suggest a middle Pennsylvanian, or at least, a post-Morrow age. The range of the species is little known in New Mexico but there is nothing to suggest a late Pennsylvanian or Permian age.

The species to which <u>Linoproductus</u> and <u>Neospirifer</u> are compared are confined to the Kansas City and Lansing Groups of the Missouri Series in Kansas and Nebraska, according to Dunbar and Condra. The corals bear a greater resemblance to species from the upper Marble Falls and Smithwick (post-Morrow lower Pennsylvanian) of Texas than to other described species, according to Helen Duncan.

A scale tree, probably <u>Lepidodendron</u>, found in arkose in the upper part of the Magdalena group indicates that marine conditions were not universal.

Sangre de Cristo formation

The Sangre de Cristo formation overlies the Magdalena group with apparent conformity in the Coyote district, but it interfingers with the upper part of the Magdalena Group on a regional scale.

Description

In the Guadalupita area, the formation is between 3,000 and 3,200 feet thick (fig. 4); along the Mora River 6 miles south of the district, Bachman (1953) found the thickness to be 3,300 feet. The formation is divided into 6 units for convenience of description. These units carry through the district in a general way, but they are not shown on the large scale maps because of the uncertainty in tracing individual lenticular beds across faults, covered areas, and areas not mapped in detail. The lithology of these units is shown in table 1.

A detailed columnar section of the middle, or principal ore-bearing part, of the formation in Area D is given in figure 5. Further details of the lithology are shown on the large-scale geologic maps of areas A to C and E to I, figures 6 through 13, respectively. Two notable characteristics of the Sangre de Cristo formation shown on these maps are: (1) the many abrupt facies changes and, (2) the small size of the stagnant basins in which the gray and black shales were deposited. No bed extends the length of the district.

Fossils

Carbonized plant remains and fossil wood replaced by silica, calcite, chalcocite, or rarely, pink barite are the most common and widely distributed fossils in the Sangre de Cristo formation. Particularly well-preserved plant remains are found in pit G2 and in the uraniferous siltstone in Area A.

A Permian (?) conifer, *Lebachia*, was reported in the northernmost pit in area C (Zeller and Baltz, 1954) and *Calamites* and *Lepidodendron* have been tentatively identified by the authors.

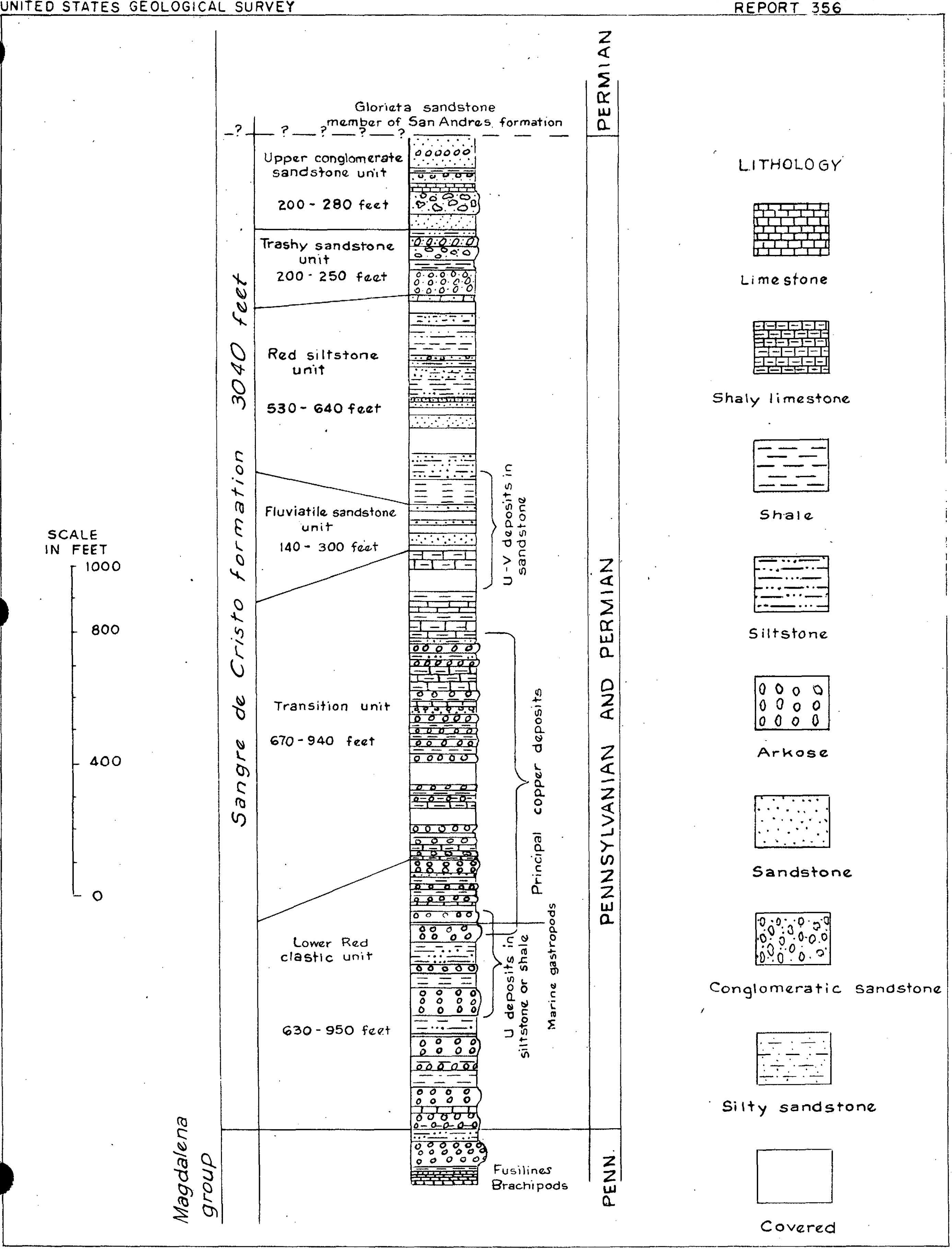


FIG. 4-COMPOSITE COLUMNAR SECTION OF THE SANGRE DE CRISTO FORMATION, COYOTE DISTRICT, MORA COUNTY, NEW MEXICO

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 356

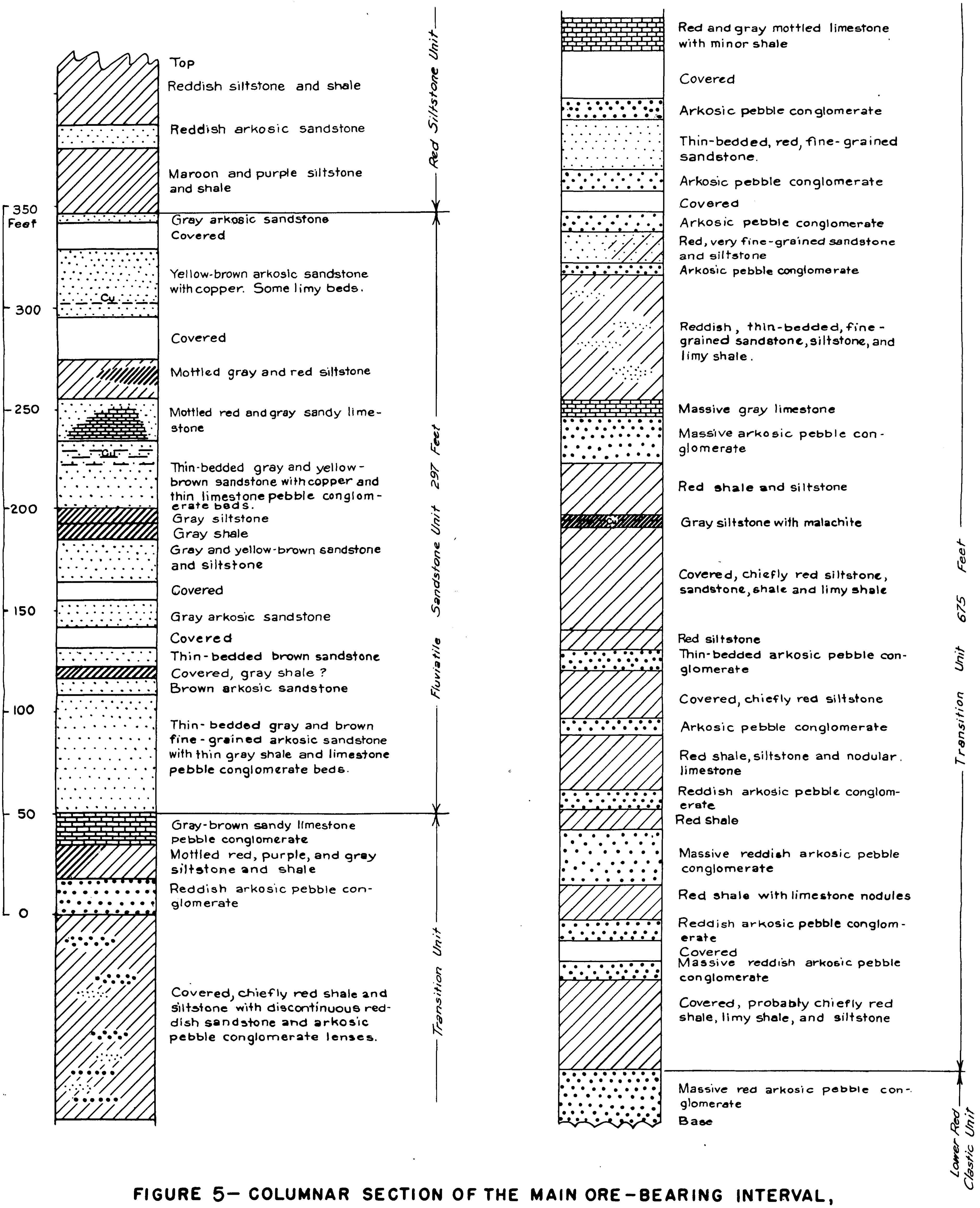
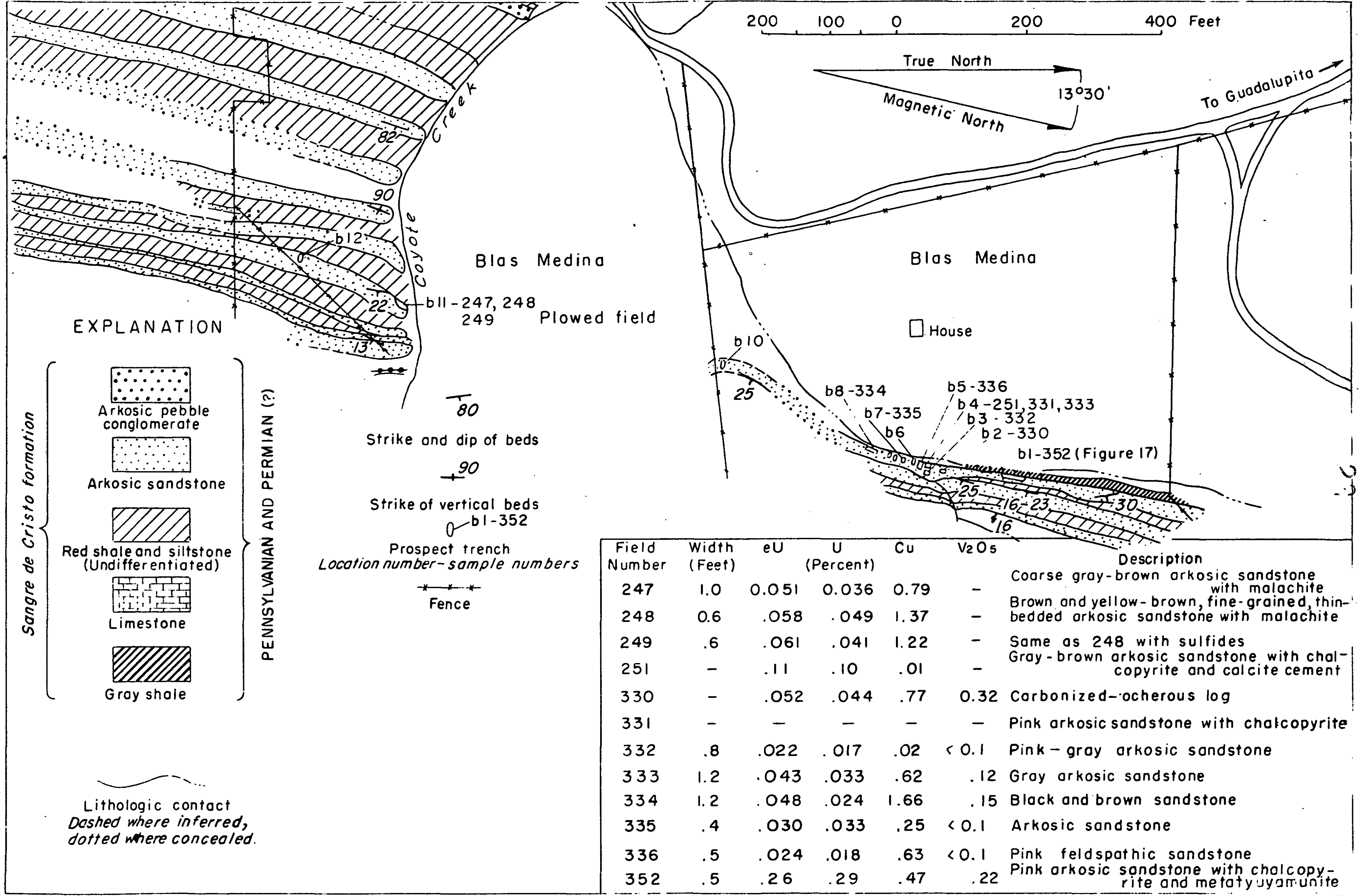


FIGURE 5— COLUMNAR SECTION OF THE MAIN ORE-BEARING INTERVAL, SANGRE DE CRISTO FORMATION, AREA D



Field Number	Width (Feet)	eU	U (Percent)	Cu	V_2O_5	Description
247	1.0	0.051	0.036	0.79	–	Coarse gray-brown arkosic sandstone with malachite
248	0.6	.058	.049	1.37	–	Brown and yellow-brown, fine-grained, thin-bedded arkosic sandstone with malachite
249	.6	.061	.041	1.22	–	Same as 248 with sulfides
251	–	.11	.10	.01	–	Gray-brown arkosic sandstone with chalcopyrite and calcite cement
330	–	.052	.044	.77	0.32	Carbonized-ocherous log
331	–	–	–	–	–	Pink arkosic sandstone with chalcopyrite
332	.8	.022	.017	.02	< 0.1	Pink-gray arkosic sandstone
333	1.2	.043	.033	.62	.12	Gray arkosic sandstone
334	1.2	.048	.024	1.66	.15	Black and brown sandstone
335	.4	.030	.033	.25	< 0.1	Arkosic sandstone
336	.5	.024	.018	.63	< 0.1	Pink feldspathic sandstone
352	.5	.26	.29	.47	.22	Pink arkosic sandstone with chalcopyrite and metatyuyamunite

Geology by D. C. Laub and C. M. Tschanz, 1953

FIGURE 7. — GEOLOGIC MAP OF AREA B SHOWING URANIUM DEPOSITS, COYOTE DISTRICT, MORA COUNTY, NEW MEXICO

Table 1.--Description of the Sangre de Cristo formation

	Thickness (feet)
Conglomeratic sandstone unit Sandstone, reddish gray, friable, massive and cross-bedded, conglomeratic, with abundant well-rounded sand-grains and chert and quartzite pebbles up to 3 inches in diameter. Interbedded with few beds of mottled silty limestone and shale. Sandstone in upper half weathers to smooth, rounded rim. May include beds equivalent to Yeso formation and lower part of the Glorieta sandstone member of San Andres formation. Unmineralized.	200-280
Variegated sandstone unit Sandstone, gray, brown, and red; medium- to coarse-grained, poorly sorted, arkosic, fluviatile. Interbedded with thin red shales, siltstones, and limestones. Many cut-and-fill structures and abundant fragments of limestone, quartz, quartzite, siltstone, greenstone, and vein quartz. Unmineralized.	200-250
Red siltstone unit Shales and siltstones, predominantly red, maroon, or chocolate; limy or micaceous. Many thin beds of silty limestone and fine-grained, red, silty sandstone. Some silicified wood at base. Unmineralized.	530-640
Fluviatile sandstone unit Sandstone, gray or brown, well-sorted, thin-bedded, cross-bedded, or massive; fine- to medium-grained. Interbedded with thin gray shales, limy shales, and limestone pebble conglomerates.	140-300

Table 1.--Description of the Sangre de Cristo formation--Continued

	Thickness (feet)
Fluviatile sandstone unit--Continued	
Sand-filled scours and channels common. Beds lenticular; some beds, limy; poorly sorted, coarse, with abundant clay galls, carbonized wood, and foreign rock fragments. Uranium deposits with vanadium and copper (figs. 7 and 10).	
Transition unit	670-940
Arkosic pebble conglomerate, reddish gray, massive, alternating with red, gray, or black, micaceous, carbonaceous or limy shales and siltstones. Many thin limestone and limy shale beds in upper part. Carbonized or silicified wood locally abundant. Copper in local gray or black lenses at 10 horizons; some uranium (figs. 8 and 12).	
Red arkose unit	630-950
Arkosic pebble conglomerates, reddish gray, 20 to 80 feet thick. Coarse, massive beds alternating with red, chocolate, or maroon, shales, limy shales, and micaceous siltstones. Few thin limestone beds, some fossiliferous and marine. Arkoses contain abundant angular quartz, feldspar grains and granite fragments up to three-fourths inch in diameter, carbonized, silicified or calcitized wood and magnetite seams along the bedding. A thin gray micaceous uraniferous shale or siltstone bed in Areas A and C. A few copper-bearing carbonaceous shales. (See figs. 6 and 13.)	

Several fossiliferous, marine limestones or siltstones are present in the lower 950 feet of the formation. Brachiopods, pelecypods, crinoids, nautiloids, and gastropods, chiefly bellerophontids, have been collected. The marine fossils listed in table 2 have been identified by members of the U. S. Geological Survey.

Table 2.--Marine fossils of the Sangre de Cristo formation.

Fossil	Locality	Identified by
Linoproductus sp.	i12, figure 13	M. Gordon, Jr.
Myalena sp.	BZ 21, figure 2	S. A. Northrup
Pelecypods, indet.	i6, figure 13	E. L. Yochelson
Hypselentoma ?	i6, figure 13	E. L. Yochelson
Bellerophontid, gastropod, indet.	i6, figure 13	E. L. Yochelson
Pseudorthoceras cf. P. knoxense (McChesney)	i6, figure 13	M. Gordon, Jr.

A number of copper-bearing shales either contain marine fossils or are overlain by fossiliferous limestones.

The genus *Hypselentoma* is known only from the Upper Pennsylvanian in the mid-continent region (Yochelson, written communication). If the range is the same in the Coyote district then at least the lower 950 feet of the formation is Pennsylvanian.

Conditions of deposition

Most of the Sangre de Cristo formation appears to be first-cycle sediments deposited in a deltaic, floodplain, or fluviatile environment near the source areas. The source areas were high during the deposition of the lower units of the formation, but the presence of thin, marine limestone beds shows that the basin of deposition was intermittently below sea-level.

The thickness and grain size of the coarser beds decrease upward and the proportion of limestone or shale increases as the relief of the source areas became lower. The lower 2 units show a cyclic sequence of sediments; these have been called cyclothems of the piedmont type.

Locally, particularly during deposition of the Transition unit, swamps, lagoons and stagnant ponds existed on the flood plain. According to Yochelson (written communication) the abundance of Hypselentoma (?) in a thin limestone bed at pit i6 and the near absence of other marine fossils "could mean shallow-water environment with restricted circulation of sea water."

The sandstones of the Fluviatile sandstone unit (table 1) were apparently deposited in the channels of meandering streams on a floodplain of low relief.

The coarse, poorly-sorted, conglomerate sandstone beds above the Red siltstone unit may indicate renewed uplift or a new source area. The uppermost unit appears to be a series of beach deposits on a fluctuating seacoast.

Yeso formation

The Yeso formation pinches out near Lucero and is not present in the mapped area. It consists of brownish-pink siltstone that has a lighter color and finer texture than the Sangre de Cristo formation. The description of this and succeeding units is from Bachman (1953).

Glorieta sandstone

The Glorieta sandstone member of the San Andres formation is the only member of the formation exposed in the district. The member consists of about 266 feet of gray to light-brown, medium-grained sandstone. It forms the prominent cliff along the east side of the district.

Bernal formation

The Bernal formation consists of interbedded brownish-red siltstone and fine-grained sandstone about 100 feet thick. A disconformity separates the Bernal formation and Glorieta sandstone. The Bernal, Glorieta, and Yeso formations are all Permian.

Santa Rosa sandstone

The Santa Rosa sandstone of Late Triassic age is exposed in the southeast corner of the area (fig. 2), lying disconformably on the Bernal formation. It consists of 425 feet of brownish-red shale and sandstone. The units above the Santa Rosa sandstone are not exposed in the district and are not described though they are included in figure 3.

Quaternary (?) basalt

Five volcanic centers are present a short distance north and east of the Coyote district. The nearest is less than a mile east of the north end of the district. Two ages of extensive basalt flows (Bachman, 1953) cover large areas along the east and north sides of the district. The older flows originally covered the Coyote district, but only remnants remain as mesa cappings on vertical beds of older rocks (fig. 2). The five volcanic plugs and the flow-rocks (Bachman 1953) in the Ocate area belong to the later period of eruption. No evidence of a genetic relationship between the basalt and the deposits has been found.

Structure

The Coyote district is in a Laramide (?) belt of deformation along the east flank of the Sangre de Cristo Range. The rocks east of the district are warped into gentle folds; the rocks west of Coyote Creek are turned up sharply along a north-south axis. In the belt of mineralization the dips are steep to overturned, and farther west the beds are overturned and cut by steep reverse faults. Bedding attitudes within the belt of mineralization suggest the forces of deformation were torsional and increased in intensity northward. The strike changes progressively northward from N. 20° W. to N. 20° E. (fig. 2). At the south end the beds dip 80° E. Northward the dip passes through the vertical and the overturned beds in the northern part dip 50°-75° W. The degree of overturn increases westward throughout most of the district.

Several high-angle reverse faults were mapped by Bachman (1953) in pre-Cambrian and Pennsylvanian rocks along the west side of the district. The pre-Cambrian rocks have been thrust eastward several thousand feet over Pennsylvanian rocks cutting out a large part of the Magdalena group.

Several northwest-striking oblique faults with lateral displacement of less than 300 feet were mapped in Areas A, E, and F (figs. 6; 9; 10). Several minor northeast-striking oblique faults were mapped in Area H (fig. 12).

Some faults clearly offset the ore zones; however, the lack of marker beds makes correlation across the faults difficult.

The arkoses are sheared and bleached in areas of closely spaced faulting. Although several ore deposits are near major faults, there is no evidence of mineralization along these faults (figs. 9 and 10).

Mineral deposits

The mineral deposits of the Coyote district (fig. 2) are confined to lenticular beds of gray, brown, black, or pink sedimentary rocks in the lower 2,000 feet of the Sangre de Cristo formation. Copper and uranium minerals have not been found in the red, chocolate, or maroon rocks that make up most of the formation.

The ore minerals are sparsely distributed, and individual deposits are small. Copper deposits typically contain negligible amounts of uranium, and the uranium deposits contain small but variable amounts of copper.

Uranium deposits occur in sandstone and micaceous siltstone; copper deposits occur in several rock types, but most of the ore bodies are in black carbonaceous shale.

The Fluviatile sandstone unit (table 1) contains most of the uranium deposits. Most of the copper deposits are in lower units, particularly in the Transition unit.

The locations of the mineral deposits and the sample data are shown on the large scale maps of the individual areas, figures 6 to 13. The location of samples outside these areas are shown in figure 2, and the analyses are given in table 3.

Copper deposits

Description

Copper deposits occur in 4 rock types: (1) carbonaceous shale or siltstone, (2) arkosic pebble conglomerate, (3) micaceous sandstone, and (4) nodular limy shale or limestone. The deposits are richest and most abundant in black, carbonaceous shale lenses and in adjacent parts of gray shale or arkosic pebble conglomerate beds. Sandstones normally contain low-grade disseminated deposits, and copper deposits in limestone are rare and unimportant.

Table 3.--Data for samples outside areas of large scale maps.

Samples listed in order of appearance on map (fig. 2) from south to north.

Field number	Width (feet)	eU (percent)	U (percent)	Cu (percent)	Lithology
BZ-31	-	0.003	0.002	5.24	Sandstone with carbon.
BZ-32	-	.004	.003	6.76	Dark-gray carbonaceous clay shale.
8	-	.002	-	1.97	Carbonaceous shale.
163	1.5	.002	-	.01	Gray shale.
164	1.0	.003	-	.19	Light and dark-gray shale.
165	1.4	.003	-	.06	Gray shale with carbon.
BZ-27	-	.003	.002	.020	Greenish-gray clay shale.
20	-	-	-	-	Unaltered chalcocite nodules.
21*	-	.003	-	1.06	Fossiliferous limestone.
BZ-22	-	-	-	-	Marine fossils in sandy limestone.
BZ-23	-	-	-	-	Marine fossils in sandy limestone.
BZ-21	-	.005	.003	.005	Greenish-gray clay shale.
25	-	.001	-	-	Gray-green and red shale.
BZ-20	-	.009	.004	1.81	Carbonaceous shaly sandstone.
26*	1.2	.003	-	2.00	Gray-green carbonaceous shale.
27	1.2	.004	-	-	Gray-green carbonaceous shale.
28	-	.001	-	3.46	Light colored arkosic sandstone.
29	-	-	-	-	Mineralized carbonaceous wood.
31	-	.003	-	-	Silicified wood with copper.
32	3.0	.003	-	1.27	Gray-carbonaceous shale.

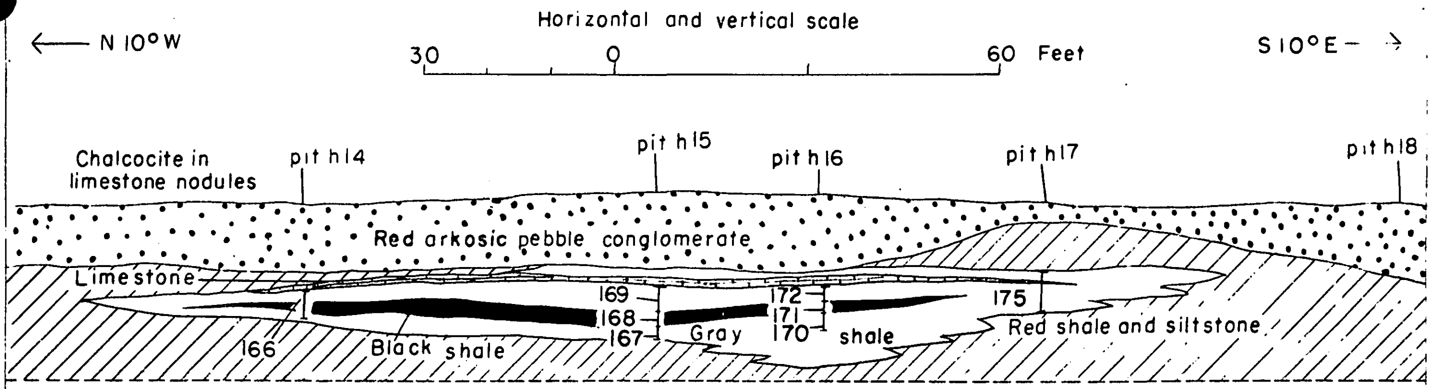
*Note: Semiquantitative spectrographic analyses given in table 4.

Table 3.--Data for samples outside areas of large scale maps.--Continued.

Samples listed in order of appearance on map (fig. 2) from south to north.

Field number	Width (feet)	eU	U	Cu	Lithology
		(percent)			
53	5.7	.003	-	0.08	Red siltstone, gray micaceous shale.
54	-	0.004	-	0.84	Gray-green siltstone and shale.
52	-	.005	-	-	Brown fine-grained sandstone.
49*	3.0	.003	-	.02	Green shale with copper.
50*	8.7	.003	-	.76	Green shale with copper.
51	-	.003	-	-	Gray-green shale with copper.
BZ-6	-	.002	.001	.005	Greenish-gray clay shale.
BZ-5	-	.018	.014	6.13	Black carbonaceous shale.
55	-	.009	-	-	Carbonaceous shale.
56	-	.005	-	-	Gray-green shale from dump.
57	-	-	-	-	Chalcocite nodules and replaced wood.

The copper deposits are confined to sedimentary rocks that probably were deposited in small, stagnant basins. The association of the copper deposits and this sedimentary facies is so distinct that it suggests a genetic relationship. Most of the copper deposits are in black shale lenses in the Transition unit. The black shale lenses are enclosed in gray-green shale that contain a little copper and grade into barren red shale or limestone. Detailed sections of 2 typical ore bodies are shown in figures 14 and 15. The sequence of rock types in figure 14 probably marks successive stages in the filling of a local basin. The restricted extent of the favorable host rocks, the black shales, limits the size of ore bodies.

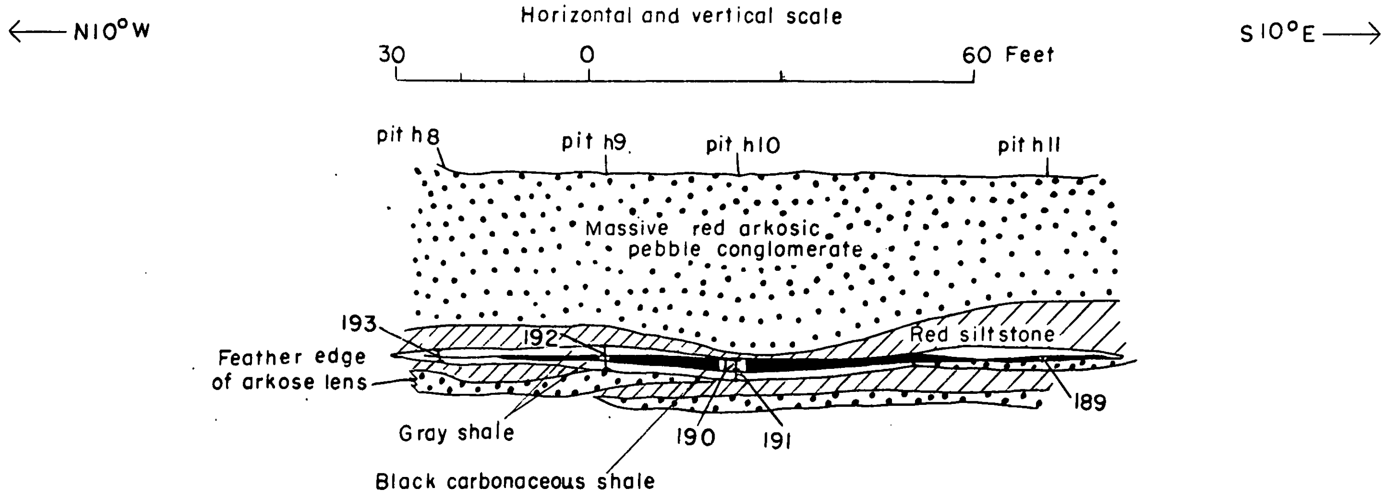


SAMPLE DATA

Field Number	Thickness (Feet)	eU	U (Percent)	Cu	Description	Field Number	Thickness (Feet)	eU	U (Percent)	Cu	Description
166	4.2	0.007	0.006	1.27	Gray shale with carbon	170	2.5	0.003	-	0.60	Gray shale
167	2.0	0.003	-	0.37	Gray siltstone	171	2.5	0.003	-	1.49	Black "
168	2.4	0.005	-	1.21	Black shale	172	2.0	0.002	-	0.05	Gray "
169	4.0	0.004	-	0.46	Gray limy shale	175	6.5	0.004	-	0.015	" "

Geology by C.M. Tschanz and D.C. Laub, 1953

FIGURE 14-SECTION ALONG COPPER LENS, AREA H, SHOWING TYPICAL RELATIONSHIP OF COPPER TO ROCK TYPES



SAMPLE DATA

Field Number	Thickness (Feet)	eU	U (Percent)	Cu	Description
189	0.4	0.022	0.019	1.09	Black shale and arkose
190	1.5	0.005	0.001	3.53	" "
191	3.8	0.003	-	0.10	Gray-green siltstone
192	3.2	0.008	0.005	1.05	Gray and black shale
193	2.0	0.007	0.006	0.58	Yellow-green and black shale

Geology by C.M. Tschanz and G W. Fuller, 1953

FIGURE 15.- SECTION ALONG COPPER LENS, AREA H, SHOWING CONCENTRATION OF COPPER AND URANIUM IN CARBONACEOUS SHALE

The ore bodies are tabular bedded deposits 100 to 300 feet in greatest diameter and 1 to 6 feet thick. The copper content ranges from 1 to 6 percent. The average ore lens is 2 or 3 feet thick and contains about 1.5 percent copper. None of the deposits contains more than 7,500 tons of ore and few contain more than 1,000 tons.

The ore contains chalcocite nodules less than 2 inches in diameter, but nodules as large as a man's head have been reported. Most nodules are not radioactive, although a few highly radioactive nodules were found at pits G2, E15, and E16.

Mineralogy

The principal copper minerals are blue and gray chalcocite, malachite, and azurite. Azurite and malachite commonly occur as disseminated grains or coatings on chalcocite nodules or mica flakes. The chalcocite nodules contain small amounts of pyrite, bornite, covellite and vitrain. Uraninite was identified in a chalcocite nodule from pit G2, figure 11, by A. Rosenzweig of the Atomic Energy Commission (Zeller and Baltz, 1954).

Woody cell structure is well preserved in many chalcocite nodules, (figure 16A and B) and all stages of chalcocite replacement can be found. Normally the cell walls are vitrain and the cores are filled with sulfides. A few nodules have a concentric banded structure that may be marked by slender groups of pyrite crystals radiating from the center.

Chalcocite also occurs in dense limestone nodules near pits b14 and A62. In a few places the dense limestone core of the nodules is surrounded by concentric layers of coarse, acicular brownish calcite that

Figure 16-A. Photomicrograph of longitudinal section of carbonized wood (dark gray) replaced by blue chalcocite (gray) which contains residual grains of pyrite and bornite (not visible). Polished section. X 50.

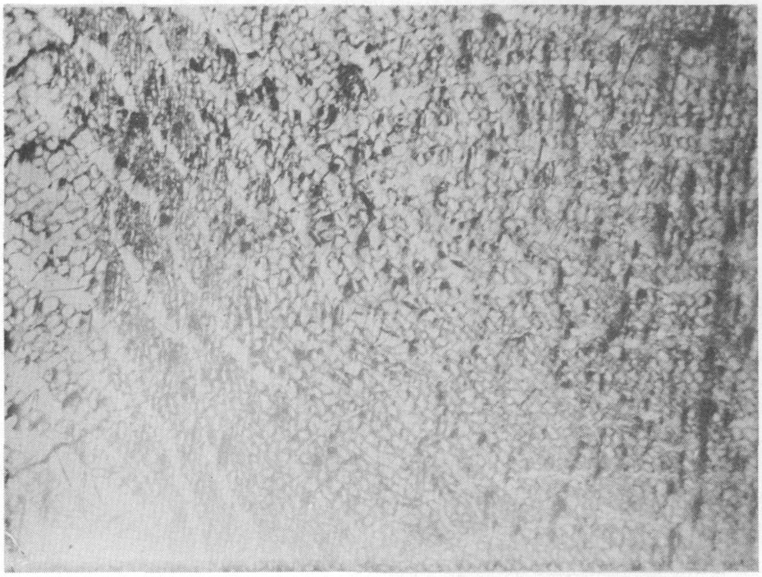


Figure 16-B. Photomicrograph of cross-section of carbonized wood (dark gray) replaced by gray chalcocite (gray) and minor covellite (not visible). Shows cell structure and growth rings. Polished section. X 50.

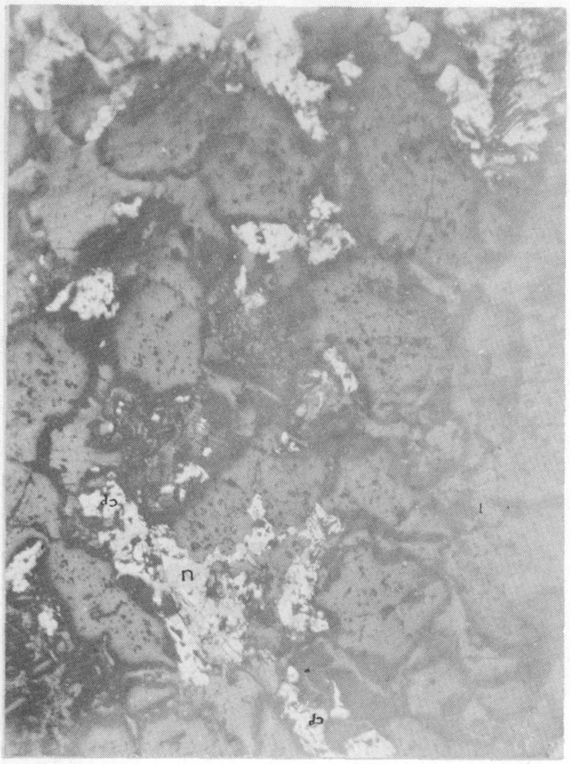


Figure 16-C. Photomicrograph of uraniferous sandstone, Medina property, pit b-4. Quartz and feldspar (dark gray, high relief) and calcite (dark gray, low relief) replaced by chalcopyrite (cp) and black uraniferous substance (u). Polished section. X 50.

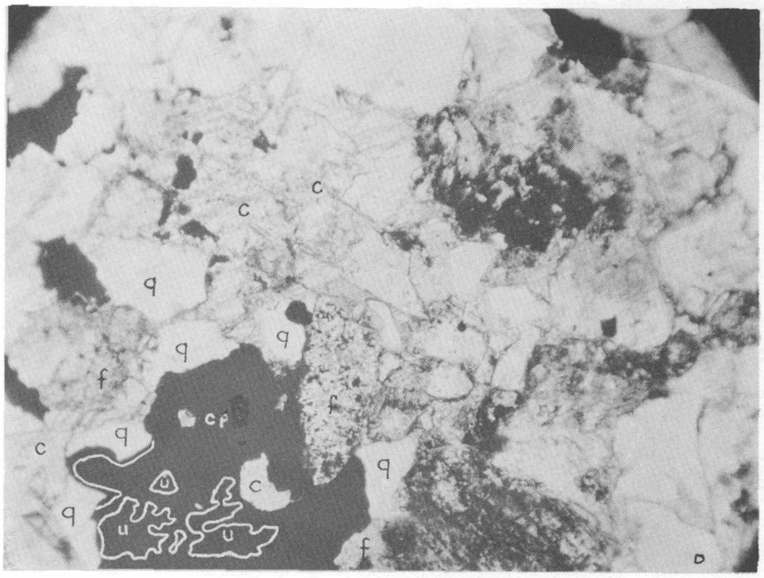


Figure 16-D. Photomicrograph of hematitic uraniferous sandstone, Medina property, pit b-4. Quartz (q), hematite-impregnated feldspar (f), and calcite (c) replaced by chalcopyrite (cp) and black uraniferous substance (u). Thin section. X 70.

contains malachite. Chalcocite is rare in sandstone, but the outer edge of a pebble conglomerate bed adjacent to copper-bearing shale may contain up to 14 percent copper, chiefly as chalcocite.

Pyrite is replaced by copper sulfides, and many of the nodules probably were originally pyrite and vitrain. Bornite and chalcopyrite are more abundant in nodules that contain pyrite. Covellite and chalcocite are the important minerals where replacement is nearly completed (fig. 16 B). The paragenetic sequence is (1) vitrain and pyrite (2) chalcopyrite and bornite (3) chalcocite, and (4) covellite. Malachite and azurite are believed to be weathering products. The paragenetic sequence is in the order of increasing copper content and decreasing iron content of the sulfides. The chalcocite (possibly digenite?) has a distinct blue color in some nodules where pyrite, bornite, and chalcopyrite have been almost completely replaced (fig. 15 A). The blue color is typical of a chalcocite-covellite solid solution, which may contain up to 8 percent covellite at room temperature. The blue chalcocite is interpreted by some to indicate a temperature of formation over 75°C (Edwards, 1947). Copper-bearing samples contain less vanadium, lead, and rare earths than uranium samples (table 4.)

Uranium deposits

The uraniferous shales and siltstones are very low grade and all uranium deposits of commercial interest are in sandstone. The uranium deposits may or may not contain significant amounts of copper or vanadium.

Uranium and vanadium minerals are commonly concentrated in scours filled by sandstone that contains abundant clay galls, rock fragments, and carbonized wood (fig. 17). Most of the ore pockets are less than 2 feet thick and 10 feet long. A number of closely-spaced, isolated deposits within a favorable sandstone generally are separated from other groups by long intervals of barren sandstone. The ore pockets are surrounded by lower grade material, and radioactivity may be continuous between adjacent deposits.

The outcrops of the ore bodies are inconspicuous. Metatyuyamunite is locally abundant, but recognizable uranium minerals are not visible in many deposits.

The uranium deposits in sandstone.

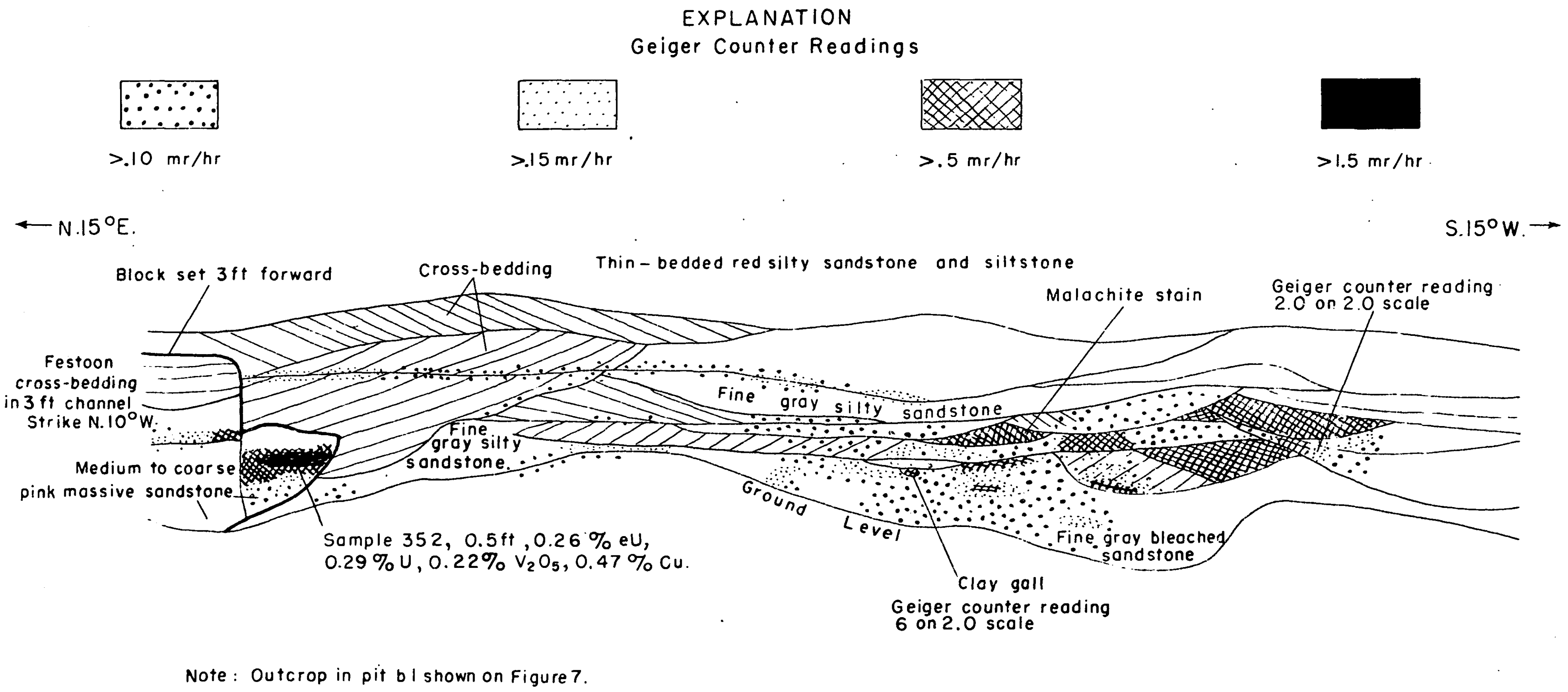
Area B, Blas Medina property.--All the uranium deposits in Area B are probably in the same, gently dipping arkosic sandstone about 1,670 feet above the base of the formation. Uranium was found in all the trenches except b5 and b7 but ore was found only in trenches bl and b4.

The ore in pit b4 is in a hard, limy, massive, medium-grained, pink sandstone which fills a scour about 10 feet in diameter. The ore, 4 to 6 inches thick, contains abundant, small grains of disseminated chalcopyrite; metatyuyamunite is rare. Chalcopyrite has been found only in Area B.

In pit bl, figure 17, the sandstone is composed of several sets of cross-strata separated by curved, troughlike erosion surfaces. Uranium is concentrated along clay seams, in clay galls, or along discontinuities between sets of cross-strata.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 356



Geology by D. C. Laub and C. M. Tschanz, 1953

FIGURE 17.—— OUTCROP OF ORE SANDSTONE ALONG LEDGE,
BLAS MEDINA PROPERTY, COYOTE DISTRICT, MORA COUNTY, NEW MEXICO

0 5 10 FEET
Horizontal and vertical scale

In the spring of 1954 radioactive material was discovered in 2 massive, grayish-pink arkosic sandstone beds 1,000 to 1,300 feet north of pit b1. The sandstone beds, 6 to 8 feet thick, are separated by 20 feet of siltstone. Fine-grained malachite is the only visible ore mineral. The radioactive layer in the center of each sandstone bed is 1 to 2 feet thick. Readings up to 0.2 milliroentgens per hour on the Geiger counter were obtained, but samples were not collected.

Area F, Arturo Le Deux property.--A massive, pink, medium-grained, limy, micaceous arkosic sandstone contains uranium and vanadium between pits f9 and f12 (fig. 10). The sandstone ranges in thickness from a feather edge to 4 feet and crops out intermittently at the surface. This sandstone is about 770 feet above the base of the formation and is enclosed in a copper-bearing gray shale containing thin seams of black shale. Metatyuyamunite is concentrated in micaceous seams at the contact of the sandstone and the shale in pit f11 and disseminated through the sandstone in pit f9. A high grade pocket encountered 2 feet below the surface in the feather edge of the sandstone in pit f11 probably extends to the north end of pit f12. The ore between depths of 2 and 4 feet is less than 2 feet thick. The radioactivity is not above background count south of pit f12 and north of pit f8 and other uranium deposits were not found at this horizon. The sample data (fig. 10) suggest that uranium has been leached from the uraniferous shale and redeposited in the adjacent sandstone. The lack of control by sedimentary structures within the sandstone and the close association with a copper-bearing shale are exceptional.

Three nearly vertical fluviatile sandstone beds between 1,920 and 1,960 feet above the base of the Sangre de Cristo formation contain uranium or vanadium deposits in the eastern part of Area F. The middle or main uranium-bearing sandstone is a gray-brown, poorly-sorted, massive, limy sandstone 6 or 8 feet thick. This sandstone contains isolated concentrations of uranium in each pit between f19 and f26. Pockets of uranium ore occur chiefly in poorly defined lenses of coarse, pink, limy sandstone that contains carbonized wood, gray or black clay galls and limestone fragments. The pink color is distinctive and becomes more intense as the radioactivity increases. Black micaceous vanadium minerals impregnate the sandstone along bedding planes and partly surround the uranium pockets. The black color of clay galls in high-vanadium ore probably is the result of adsorbed vanadium but at least part of the vanadium is in the clay mineral structure. The ore-grade material is less than a foot thick except in pits f23 and f26 where metatyuyamunite is abundant.

Several vertical slickensided joints, cut the sandstone between pits f23 and f26. One joint contains non-radioactive caliche and iron oxides. A narrow zone of sandstone adjacent to this joint is barren; beyond this is a zone impregnated with black vanadium minerals that is parallel to the joint and partly envelopes a small uranium pocket.

The lowest of the three sandstone beds contains small vanadium deposits, but the uranium content is low.

The highest of the three sandstone beds is represented by a group of small, isolated, hard, white, massive, fine-grained, limy sandstone lenses at about the same stratigraphic position above the main ore-bearing sandstone. Several of these lenses contain uranium but not copper or vanadium. The part of the lenses that contains uranium is pink, as in pits f28, f32, and f33.

An ore-grade layer 3 to 5 inches thick, parallels a slickensided bedding plane in the middle of a 3-foot massive, limy sandstone bed in pits f32 and f33. The layer is apparently continuous between these pits and may extend 50 feet further north. The deep pink ore-grade material grades into barren white sandstone.

Uraniferous siltstone and shale.

A uraniferous, micaceous, marine siltstone and shale bed overlain by a thin bed of fossiliferous marine limestone in Area A is correlated with a similar uraniferous rock sequence in Area C. If this correlation is correct, the basal 330 feet of the Sangre de Cristo formation is missing in Area C, as 670 feet of beds intervene between the uraniferous siltstone and the apparent base of the formation in Area A but only 340 feet in Area C. If the uraniferous siltstones are correlated, the uraniferous sandstone beds in Area F can be correlated with those in Area C. The discrepancy in thickness of the basal beds may be the result of non-deposition or, more probably, faulting that has cut out the basal part of the formation in Area C.

The uraniferous siltstone averages 2 feet in thickness and can be traced more than 5,000 feet in Area A and 1,500 feet in Area B. The bed is exposed down dip through a vertical distance of 200 feet. Samples from many trenches show that the lithology and the uranium content are remarkably uniform. Nine segments of this bed in Area A (fig. 6) and one in Area C (fig. 8) contain an average of 0.01 percent uranium. Elsewhere the uranium content is about half as great.

The uraniferous beds cannot be traced between Area A and Area C. Near the south end of Area A the siltstone grades into radioactive sandstone, which contains some malachite. The siltstone facies between Areas A and C may be replaced by sandstone.

Mineralogy of uranium deposits.

The chief ore minerals in the uranium deposits in sandstone are: metatyuyamunite, an unidentified uraniferous substance, black micaceous vanadium minerals similar to "roscoelite," chalcopyrite, and malachite. Uraninite has not been identified in any of the uranium deposits in sandstone. Uranium and vanadium minerals have not been recognized in the uraniferous siltstone.

Most of the uranium in Area B is apparently in hematite(?) and especially in black uraniferous ferric (?) substance that gives positive tests for uranium, iron, and copper but does not give an X-ray diffraction pattern. Not all of the black "mineral" contains uranium, but it is difficult to distinguish between the two varieties visually. Fragments or irregular surfaces of the uraniferous substance in oblique light appear black, but polished surfaces in a light source perpendicular to the surface appear gray. Grains viewed under either oblique or vertical light commonly show a red internal reflection. The uraniferous substance, under the microscope, is seen to be interlocked with chalcopyrite which it apparently replaces (figs. 16 C and D). Both minerals replace calcite, and to a lesser extent, quartz and altered feldspar. Both minerals occur chiefly as fine disseminated grains that are clearly later than calcite which is later than the sand grains. A few detrital grains contain chalcopyrite and a black substance but the amount of metal so deposited is negligible.

A heavy mineral concentrate, sample 251, composed chiefly of chalcopyrite (50 percent), the unidentified substance (30 percent), and small amounts of quartz, feldspar, tourmaline, and accessory minerals, was submitted for semiquantitative spectrographic analyses after crusher steel was removed (table 4). The uraniferous substance is probably a metamict or amorphorous ferric oxide. Calculations from semiquantitative spectrographic data indicate that the uranium content of the uraniferous ferric oxide is less than 3 percent.

It is suggested that the difference in physical properties between the black, uraniferous ferric substance and the hematite may be the result of changes caused by radiation from a much greater uranium content.

Most of the sedimentary rocks of the Sangre de Cristo formation are feldspathic. The ore-bearing sandstones contain 30-40 percent quartz, 30-40 percent feldspar, 20-30 percent calcite, 0-5 percent muscovite, 0-20 percent rock fragments, and a little hematite and nontronite. The feldspar is chiefly oligoclase and microcline. Although potash feldspar was not detected in the 5 samples studied by X-ray diffraction techniques, much of the feldspar shows the characteristic gridiron pattern of microcline and orthoclase may be present.

As a rule, except in the upper uraniferous sandstone in Area F, the calcite content of the radioactive sandstone is higher than the content of nonradioactive sandstone. Calcite replaces quartz and particularly, altered feldspar; and it also fills fractures in these minerals. Where replacement is advanced, the detrital grains are represented by corroded residuals no longer in contact with one another. Some of the calcite in Area F is high in manganese. The genetic significance of these facts will be discussed in the section on origin.

The pink color of some uraniferous sandstone ore is caused by dusty grains of hematite, which coat quartz grains and impregnate altered feldspar grains and foreign rock fragments. Most of the dusty hematite tested gives a positive test for uranium.

Chemical characteristics of uranium-bearing sandstone.

The amount and relative proportions of uranium, vanadium, copper and certain minor constituents vary greatly as shown by the selected chemical data in tables 4 and 5.

In general the uraniferous sandstones of the Coyote district have a higher content of copper, lead, rare earths and other minor constituents than the uranium ores in the Morrison and Shinarump formations of the Colorado Plateau. Lead and the rare earths are concentrated in the

Table 4. Spectrographic, chemical, and radioactivity analyses of selected copper and uranium samples, Coyote district, Mora County, New Mexico*.

Samples arranged in groups by rock types, in order of decreasing uranium content

SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES IN PERCENT

Field number	Trench number	eU (percent)	U (percent)	Cu (percent)	V_2O_5 (percent)	Si	Al	Ca	Mg	Na	K	Pb	Ba	Fe	Ti	Mn	Cr	Co	Ni	Cu	Ag	Mo	Zn	Zr	B	Sr	Ga	Sc	Ce	La	Nd	Sm	Y	Dy	Er	Gd	Yb	U	V	Be	Description
355	f 11	0.81	0.85	-	2.92	xx.	x.	x.+	0.x+	0.x+	x.-	0.ox+	0.ox	x.-	0.x-	0.x-	0.oox	0.oox+	0.oox+	x.	0.ooox+	0.oox-	0.	0.ox-	0.oox	0.oox+	0.oox-	0.ooox+	0.ox+	0.oox+	0.ox+	0	0.ox	0.oox+	0.oox	0.ox-	-	0.x+	0.x+	0.ooox+	Pink micaceous sandstone, abundant carbon, metatyuyamunite. Ge .oox.
186	f 11	.18	.20	1.27	-	xx.	x.	x.-	.x+	x.-	x.-	.ox+	.ox	x.-	.x	.ox+	.oox	.oox	.oox	x.-	.ooox-	0	0	.ox-	.oox-	.oox+	0	.oox-	.ox	.oox+	.ox-	0	.oox+	0	0	0	-	.x-	.ox+	.ooox	Micaceous sandstone and shale, carbonaceous shale, metatyuyamunite.
33	f 9	.081	-	.45	-	xx.	x.	x.+	.x	.x	x.-	.oox+	.ox	.x	.x	.x-	.oox-	.oox-	.oox-	.x	Tr.	0	0	.ox-	.oox	.oox+	.ooox	.ooox-	0	0	0	0	.ox-	0	0	0	.ooox+	.ox+	.x-	.ooox	Pink micaceous arkosic sandstone metatyuyamunite.
352	b 1	.26	.29	.47	.22	xx.	x.	xx.	.x	.x+	.x+	.ox+	.ox+	x.-	.ox+	.ox+	.oox	.oox	.oox -	.x+	Tr.	Tr.	0	.oox	0	.ox+	Tr.	.oox-	.ox	.oox+	.ox-	0	.ox	.oox+	.oox+	.oox+	-	.x	.ox	.ooox-	Pink arkosic sandstone with chalcopyrite and black uranium mineral. Ge Tr.
349	f 26	.20	.18	.20	2.07	xx.	x.-	x.	x.+	.x	.x+	.ox+	.ox	x.-	.ox	.ox+	.oox	.ooox+	.oox-	.x-	Tr.	Tr.	.ox	.oox	0	.ox-	Tr.	0	0	0	.ox	0	.ox+	.oox+	.oox+	.ox-	-	.ox+	.x-	Tr.	Coarse pink arkosic sandstone with black clay galls and metatyuyamunite.
346	f 26	.046	.041	.09	1.36	xx.	x.	x.-	.x+	.x+	.x+	.ox+	.ox	x.-	.x	.ox+	.oox	.oox-	.oox-	.ox+	Tr.	0	.ox-	.oox+	Tr.	.ox-	0	.oox-	0	0	.ox-	0	.ox	.oox+	.oox	.oox	-	.ox+	.x-	.ooox-	
251	b 4	.11**	.10**	.01**	-	xx.	x.-	x.	.x	.x-	0	>1%	.x+	xx.	x.-	.x+	.oox+	.oox-	.oox-	x.+	.oox-	.ox-	0	.x-	.oox+	.oox+	Tr.	.oox	.ox+	.ox	.ox+	.ox+	.x-	.ox	.ox	.ox	.oox+	.x+	.ox	.ooox	Nonmagnetic heavy mineral concentrate of pink, arkosic sandstone with black uranium mineral and chalcopyrite.
89	F 9	-	-	-	-	x.	x.	.x+	.x+	.x	.x+	.x+	.ox	x.	.x-	.ox	.oox	.oox+	.oox+	x.	.oox-	.oox-	.ox	.ox-	Tr.	.oox-	Tr.	.oox+	Tr.	0	.ox	.ox	.x+	.ox+	.ox+	.ox+	-	.x	.x	.oox-	Limonitic sandstone from center of carbonized log. P .x; As .x.
149A	I 15	.004	-	-	-	.x+	.x	.x-	.ox	Tr.	0	.oox+	.ox+	x.	.ox	Tr.	.ooox+	0	Tr.	xx.	.oox	.oox+	0	.oox-	0	.oox-	0	0	0	0	0	0	Tr.	0	0	0	0	0	.oox-	0	Carbonized log replaced by chalcocite. Bi .oox.
201	a 19	.044	.029	.15	-	xx.	x.+	.x	.x+	.x+	x.-	.ox-	.ox	x.	.x	.ox-	.oox+	.oox-	.oox	.ox+	Tr.	Tr.	0	.ox-	.oox-	.oox+	Tr.	.oox-	0	0	0	0	.ox-	0	0	0	.oox-	0	.ox	.ooox	Buff micaceous siltstone and shale
416	c 6	.019	.012	.08	.17	xx.	x.+	.x+	.x+	.x+	x.-	.ox-	.ox+	x.	.x	.ox+	.ox-	.oox	.oox	.ox+	.ooox-	.oox-	.ox	.ox-	.oox	.oox+	Tr.	.oox-	0	Tr.	0	0	.oox+	0	0	0	.ooox-	0	.ox	.ooox	Buff micaceous siltstone and sandstone.
216	a 17	.019	-	.15	-	xx.	x.+	.x	.x+	.x+	x.-	.oox	.ox-	x.	.x	.ox	.oox+	.ox-	.oox	.x-	Tr.	0	0	.oox+	.oox-	.oox+	.oox-	.oox-	0	Tr.	0	0	.oox+	0	0	0	.ooox+	0	.ox-	.ooox	Buff and gray siltstone and shale.
70	C 6	.008	.005	2.38	< .1	xx.	x.+	.x	.x+	.x	x.-	.oox	.ox-	x.-	.x-	.ox-	.oox+	.ooox+	.oox	x.	.ooox	0	0	.oox+	.oox-	.oox	.oox-	.oox-	0	0	0	0	.oox-	0	0	0	.oox-	0	.ox-	.ooox	Black carbonaceous shale with chalcocite nodules.
337	C 6	.010	.004	2.63	-	x.	x.	.x	.x+	.x	x.-	.oox	.ox	x.-	.x	.ox-	.oox+	.ooox+	.oox	x.	.ooox	0	0	.oox+	.oox-	.oox	Tr.	.oox-	0	Tr.	0	0	.oox	0	0	0	.oox-	0	.ox-	.ooox	
40	E 15	.008	-	2.74	-	xx.	x.+	.x+	.x	.x	x.-	.oox-	.ox	.x	.x	.ox	.oox+	.ooox+	.oox	x.	.ooox	.ooox	0	.ox-	.oox	.oox+	.ooox	.oox-	0	0	0	0	.oox	0	0	0	.ooox	0	.oox-	.ooox	Gray or green shale with fine carbonized plant remains and copper.
60	C 19	.004	-	.15	-	xx.	xx.	x.-	x.-	.x	x.-	.oox-	.ox	x.-	.x	.ox	.oox+	.oox-	.oox	.x-	0	0	0	.ox	.oox	.ox-	.ooox	.oox	.oox	.oox-	0	0	.oox	0	0	0	.ooox-	0	.ox-	.ooox	
49***	-	.003	-	.02	-	xx.	xx.	x.	x.-	.x	x.-	.oox-	.ox	x.-	.x	.ox	.ox-	.oox-	.oox	.ox	0	0	0	.ox-	.oox	.oox+	.ooox	.oox	.oox+	.oox	0	0	.oox	0	0	0	.ooox	0	.ox-	.ooox	
50***	-	.003	-	.76	-	xx.	xx.	x.+	x.-	.x-	x.-	.oox-	.ox	x.-	.x	.ox+	.oox+	.oox-	.oox	.x+	.ooox	0	0	.ox-	.oox	.oox+	.ooox	.oox	.oox	.oox-	0	0	.oox-	0	0	0	.ooox-	0	.ox-	.ooox	
26***	-	.003	-	2.00	-	xx.	xx.	.x	x.-	.x	x.-	.oox-	.ox	.x+	.x+	.ox-	.ox-	.oox-	.oox	x.	.ooox-	0	0	.ox-	0	.oox	.oox+	.ooox	0	.oox	0	0	.oox	0	0	0	.ooox-	0	.ox-	.ooox	
14	G 2	.002	-	.06	-	xx.	x.+	x.+	.x+	.x	x.-	.oox	.ox	.x	.x	.x	.oox+	.ooox	.oox-	.x-	Tr.	0	0	.ox-	.oox	.ox-	Tr.	.ooox	0	.oox	0	0	.oox	0	0	0	.ooox-	0	.ox	.ooox-	
43	e 5	.006	-	4.08	-	xx.	x.+	.x	.x+	.x+	.x+	.oox	.ox	.x	.x	.ox-	.oox+	.ooox	.oox-	x.	.oox+	.ooox	0	.ox-	.oox	.oox	.ooox	.oox-	0	0	0	0	.oox-	0	0	0	.ooox	0	.ox	.ooox-	Green coarse arkosic sandstone with chalcocite.
21***	-	.003	-	1.06	-	x.+	x.-	xx.	x.-	.x	.x+	.oox-	.ox-	.x-	.ox	x.-	.oox-	0	.ooox+	.x+	.ooox-	0	0	.oox	.oox	.ox-	0	Tr.	0	0	0	0	.oox	0	0	0	.ooox-	0	.oox	0	Fossiliferous limestone with chalcocite and malachite.
Standard spectrographic sensitivity						.001	.001	.001	.005	.05	1.0	.001	.0001	.001	.001	.0005	.0005	.0005	.0005	.0001	.0001	.001	.05	.001	.005	.0001	.001	.001	.05	.005	.001	.01	.001	.05	.005	.05	.0005	.05	.001	.0001	

Example of notation: xx., over 10; .x+, -.464 to 1.0; .x,-.215 to .464; .x-,-.000 to .215; Tr., near threshold amount; 0, below threshold amount; -, not looked for.
(percent)

* Spectrographic analyses by G. W. Boyes, P. J. Dunton, Denver Laboratory, U. S. Geological Survey. Radioactivity analyses by S. Furman, E. J. Fennelly, Denver Laboratory, U. S. Geological Survey.
Chemical analyses by D. L. Stockwell, J. Wahlberg, E. C. Mallory, D. L. Skinner, E. J. Fennelly, J. W. Patton, P. Schuch, W. Mountjoy, H. E. Crowe, N. E. Bivens, R. F. Dufour, Denver Laboratory, U. S. Geological Survey.

** Assay figures are for bulk sample.

*** Locations shown on figure 2.

Table 5. Chemical characteristics of uranium-bearing sandstone.

Field number	Pit number	eU (percent)	U (percent)	Cu (percent)	V_2O_5 (percent)	Se (ppm)	eU/U	V/eU	Description
251	b 4	0.11	0.10	0.01	---	---	1.10	---	Massive, fine- to medium-grained pink, limy arkosic sandstone. May contain green clay galls, carbonized wood, chalcopyrite and uraniferous iron oxide (?).
351	f 33	.044	.036	.02	< 0.1	3	1.22	< 1.27	
350	f 32	.038	.033	.02	< .1	---	1.15	< 1.45	
332	b 3	.022	.017	.02	< .1	---	1.30	< 2.54	
355	f 11	0.81	0.85	---	2.92	50	0.95	2.0	Metatyuyamunite in micaceous sandstone.
352	b 1	.26	.29	.47	.22	---	.76	.47	Coarse massive pink sandstone, chalcopyrite.
186	f 11	.18	.20	1.27	---	---	.90		Micaceous siltstone and sandstone.
353	f 12	.068	.019	---	---	---	3.58	---	Do.
187	f 12	.063	.042	.89	---	---	1.50	---	Do.
249	b 10	.061	.041	1.22	---	---	1.49	---	Brown arkosic sandstone.
248	b 10	.058	.049	1.37	---	---	1.14	---	Thin-bedded brown arkosic sandstone.
247	b 10	.051	.036	.79	---	---	1.42	---	Do.
334	b 7	.048	.024	1.66	.15	9	2.00	1.74	Limy arkosic sandstone.
333	b 4	.043	.033	.62	.12	---	1.30	1.56	Limy arkosic sandstone with carbon.
349	f 26	0.20	0.18	0.25	2.07	---	1.10	5.66	Coarse mottled pink and black, limy, arkosic sandstone with abundant clay galls, rock fragments, and carbon. Some metatyuyamunite.
345	f 23	.075	.038	.17	1.22	---	1.97	8.97	
346	f 26	.046	.041	.09	1.36	---	1.10	10.95	
344	f 23	.042	.027	.10	.90	---	2.55	11.95	
343	f 18	.015	.006	.02	.29	---	2.50	10.8	

radioactive sandstone and, with uranium, in the heavy mineral fraction (sample 251, table 4). The highest rare earth content is found in the limonitic sandstone core of a carbonized log, sample 89. The rare earth content of this sample exceeds the uranium and vanadium content. The few selenium analyses (table 5, figs. 6; 9) suggest the selenium content is higher in the uraniferous rocks, particularly in the high-grade sandstone, but the data are not conclusive.

The eU/U ratio (table 5) may give an indication of the amount of uranium that has been leached from the sample. The thorium content of these rocks is below 0.0X, the spectrographic threshold, and can be ignored because the radioactivity of thorium is only about one-fifth that of the same amount of uranium. Where uranium is in equilibrium with its daughter products the ratio is 1.0. If selective leaching or precipitation of daughter products can be ignored, ratios much greater than 1.0 indicate recent leaching of uranium and ratios less than 1.0 suggest that uranium has been recently reprecipitated. This interpretation is less hazardous where the uranium content is appreciable (over 0.05 percent) where the ratio is greater than 2.0 and where there is corroborating field evidence.

The eU/U ratios (table 5) and the field evidence indicate that leaching and redeposition of uranium occurs locally on a small scale. The eU/U ratio ranges from 2.0 to 4.0 in siltstone and shale, and uranium is apparently leached from the uraniferous shale and redeposited in adjacent sandstone in some areas.

Geochemical prospecting

Geochemical prospecting techniques were tried in the hope that deposits hidden under alluvium might be detected. A total of 457 botanical and 339 soil samples were collected. Wherever possible, soil and botanical samples were collected at the same place to determine which prospecting method was more satisfactory. The botanical samples were collected only from the foliage of the plants in order to minimize the effect of the different metal content between different parts of the same plant and growth of different ages.

In general the results were disappointing and neither method appears to be well-suited to detecting small deposits of this type. A poor correlation between plant and soil data was obtained. This may be partly the result of the extraction of metals from the soil by plant roots. Several trenches dug beneath trees that contained high copper or uranium failed to disclose copper minerals or radioactivity in the bed rock. In area I, plant and soil data gave an entirely different pattern even though only the needles of ponderosa pine were sampled. The copper values in ponderosa pine outlined most of the copper deposits but neither the lead and zinc anomalies for ponderosa pine nor the anomalies for all 3 metals in soil samples were obviously related to the ore bodies.

The reasons for the failure are: (1) prevalent surface wash, (2) different metal content of each rock type, (3) small size of rock units and ore bodies so that the root circle of plants often overlaps several beds of different rock.

Samples were collected of the foliage of ponderosa pine, pinon, juniper, and scrub oak. The metal content varies greatly, but the metal content of the pines was higher than the metal content of the other trees.

The soil and ashed plant samples were analyzed for copper, lead, and zinc by rapid colorimetric methods. All 3 metals were determined in plant samples, but only lead and zinc were determined in 255 soil samples. Uranium was determined by the fluorimetric method in 159 representative botanical samples.

Origin

In this section a tentative theory of origin of the deposits is postulated that is consistent with the mineralogical, chemical, and field relationships known to the authors. Such a theory is of necessity speculative; whether the ores did, in fact, form by the postulated processes remains to be demonstrated and depends on the correctness of certain assumptions that appear reasonable in the light of current physico-chemical knowledge but cannot be proved. The ideas expressed in this section are primarily the responsibility of the senior author.

Briefly, the metals now concentrated in the deposits are considered to have been derived from the pre-Cambrian terrain and to have been concentrated by syngenetic sedimentary processes, and, in the case of the uranium deposits in sandstone, reconcentrated by warm chemically-active ground water with a possible juvenile component. Copper and uranium were partly separated because they were deposited in different chemical environments by different mechanisms. Copper was deposited as a sulfide by H_2S, but uranium probably was adsorbed on a ferric hydroxide precipitate. The origin of each type of deposit is discussed separately in detail on the following pages and an overall summary is given at the end of the section on origin.

Copper deposits.

The copper and associated uranium in the copper-bearing shales probably were derived chiefly from pre-Cambrian rocks. Many small copper deposits of pre-Pennsylvanian age are found in the pre-Cambrian rocks of northern New Mexico. The metals probably were derived partly from these deposits but chiefly from acidic igneous rocks, which contain an average of 16 grams of copper per metric ton (0.0016 percent) according to Rankama and Sahama (1950).

The carbonaceous copper deposits are in local stagnant basin shale facies characterized by abundant carbonized plant remains and ferrous iron. The enclosing barren red rocks are colored by ferric oxides; they do not contain carbonaceous material, though plant imprints remain. The highest copper and uranium values in the shales are found in those with the most carbonaceous material. Copper probably was deposited in local swamps, lagoons or lakes in an oxygen-deficient environment which favored the carbonization of plant material and reduced iron to the ferrous state.

Copper, iron and a little uranium from the pre-Cambrian terrain probably were transported in solution by surface or ground waters to local anaerobic basins where copper and iron were precipitated as sulfides by hydrogen sulfide generated by the decay of organic material or the reduction of sulfates by anaerobic bacteria. A small part of the uranium was precipitated as uraninite. A little was probably adsorbed on carbon, ferric hydroxide, or humic compounds, but much of the uranium may have remained in solution or suspension to be deposited elsewhere.

The metal content and the form in which the metals were transported in solution are unknown, but the metal content need not have been high if the process was long continued.

Microscopic study shows that carbonized wood was replaced first by pyrite and then by copper sulfides in the following order: chalcopyrite, bornite, chalcocite, blue chalcocite with excess CuS and covellite. Only pyrite and chalcocite are quantitatively important. The proportion of copper progressively increases and the proportion of iron and sulfur progressively decreases in each succeeding member of the series with the exception of sulfur in covellite. The amount of sulfide ion in solution seems to have been the critical factor determining the mineralogy. The concentration of iron in solution was probably always greater than the concentration of copper because of its greater abundance in rocks and because it would be regenerated as iron-bearing sulfides were replaced by copper-bearing sulfides. Sulfide ion would be continuously generated by decay of organic matter or by reduction of sulfates by anaerobic bacteria, but the sulfide ion content of the solution fell as deposition of sulfides continued if the sulfur content of the minerals formed at each stage is a fair indication of the sulfide ion content of the solution. The solubility of iron sulfide is less than the solubility of copper sulfide therefore pyrite began to precipitate first. Once the solubility product of copper sulfide was reached, however, mixed copper-iron sulfides began to precipitate and, as the sulfide ion concentration fell, sulfides progressively richer in copper were precipitated as a result of the greater affinity of copper for sulfide ion in acid aqueous solution. The mineralization process would be terminated by the exhaustion of sulfide or copper ion in solution or by changes in pH or oxidation potential. The very low uranium content (less than 0.01 percent) of the black copper-bearing shales can be explained partly by the low concentration and relatively high solubility of uranium in acid swamp water (pH 4.0-4.5) and partly by the fact that iron was precipitated as a sulfide rather than as a flocculent hydroxide which could adsorb uranium. The near-absence of pitchblende which might be expected to form in this environment probably indicates that the solubility product was seldom exceeded because the oxidation potential was low enough. It must be tentatively concluded that the uranium and iron remained in solution or colloidal suspension in the excurrent waters to be deposited elsewhere. The writers are aware that many factors are ignored in the foregoing analysis.

The deposition of copper probably began with the establishment of anaerobic conditions, but it may have continued after the enclosing sediments were buried and through the period of diagenetic changes. Many chalcocite nodules have a concretion-like structure that indicates slow, gradual growth. Isolated masses of chalcocite are present in the cores of some limestone nodules. In strict terminology, these deposits are not syngenetic but rather semi-syngenetic or penecontemporaneous with sedimentation and diagenetic processes. The presence of sulfide concretions, the association of copper with rocks deposited in a foul-bottom environment, regardless of type, and the absence of copper in these same rock types deposited under other conditions strongly support a penecontemporaneous origin for the copper deposits. An alternate and, to the writers, less likely hypothesis would have the metals extracted from ground waters by adsorption or reduction after burial of the enclosing rocks. A third, and untenable, hypothesis would have the copper deposits formed by the accumulation of detrital grains of copper minerals derived from pre-existing deposits. The association of copper with carbonaceous, foul-bottom sedimentary rocks is unmistakable whatever the origin of the deposits.

Uranium deposits.

Uranium and vanadium as well as copper probably were derived from pre-Cambrian rocks, but unlike the copper deposits, the deposits of uranium and vanadium are, in part, epigenetic.

Pre-Cambrian pegmatites and/or quartz veins contain uranium-bearing minerals in the Petaca, Ojo Caliente, Elk Mountain, Rociada, and Gallinas Canyon districts. The uranium-bearing minerals include uraninite, gummite, uranophane, samarskite, betafite, fergusonite, euxenite(?) and hatchettolite (Jahns, 1946). These minerals are associated with niobium, tantalum, thorium, lithium, beryllium, or bismuth minerals. The nearest of these districts, the Rociada district, is about 15 miles south of the Coyote district. Several radioactivity anomalies have been detected in pre-Cambrian and Pennsylvanian rocks by radiometric surveys along the west side of the Coyote district. Part of the uranium came from the pegmatites, but most of the uranium probably was derived from granitic rocks. Studies of the arkoses derived from granite in the Powder River Basin of Wyoming show that possibly as much as two-thirds of the uranium in granitic rocks is present in disordered intergranular phases or is loosely held on the surface of mineral grains and can be released by mechanical disintegration without much chemical weathering (Harold Masursky, oral communication). Rankama and Sahama (1950) report 3.963 grams of uranium per metric ton in granitic rocks and the wide distribution of radiometric anomalies in the granites and simple granite pegmatites of the pre-Cambrian areas near Guadalupita suggests that this average figure may be too low for these granites. Different investigators report (Rankama and Sahama, 1950) the average vanadium content of igneous rocks to be 150 and 315 grams of vanadium per metric ton. The vanadium content of granites is much lower; various investigators report between 1 and 30 grams per metric ton for granites or acidic igneous rocks (Rankama and Sahama, 1950). The vanadium content is highest in gabbros and dolerites and part of the vanadium may have been derived from these rocks in the pre-Cambrian terrain rather than from granite. Erosion of the source areas furnished enough uranium and vanadium to account for the amount concentrated in the deposits if an efficient process of concentration was available.

The uranium content of natural waters is very low except in the vicinity of uranium mines or districts where the waters may contain from several hundred to several thousand parts per billion. The uranium content of natural waters is very sensitive to changes in pH. On the basis of present information, waters with a pH of 6.5 do not contain more than 1 to 6 ppb (Phillip Fix, oral communication), but waters with a pH of 5.5 may contain several hundred parts per billion (ppb) although the average in areas of uraniferous rocks probably is on the order of 10 ppb. The uranium content of waters derived from the pre-Cambrian terrain must have been between the extreme limits of 1 and 100 ppb. A sample of domestic water from a well in the Guadalupita district contained 15 ppb, and this figure does not seem unreasonable for natural waters from which the uraniferous shales were deposited. Considering the widespread occurrence of uraniferous rocks and sulfide deposits in the source areas, the waters in restricted drainages may even have had a uranium content as high as 50 ppb and a pH as low as 4.0 for short periods of time where oxidizing sulfide deposits lowered the pH. A large flow from an old tunnel draining the several square miles of a gold district has 80 ppb uranium and a pH of 2.5 (Phillip Fix, oral communication). Using a figure of 10 ppb, the syngenetic uranium deposits in shale or siltstone represent a concentration ratio of 10,000 to 20,000 and the epigenetic deposits in sandstone represent a ratio higher than 100,000. Such high concentration ratios require efficient mechanisms of concentration operative in extremely dilute solutions. The adsorption mechanism postulated in this paper is believed adequate, although the adsorption of ferric hydroxide has not been fully tested. The scavenging power of activated charcoal and other compounds used in the laboratory to remove traces of deleterious ions from water shows the ability of some adsorptive compounds to remove metallic ions from extremely dilute solutions.

Uraniferous siltstone.--These deposits, though generally similar to the copper-bearing shale, differ from them in several important respects. The uraniferous siltstone has a higher uranium (01. to .02 percent) and iron content and a much lower content of copper and carbonaceous matter than the black shale. The vanadium content is generally less than a few hundredths percent, only slightly higher than that of the copper-bearing shales. Copper is present as malachite but sulfides or uranium minerals have not been found. Some uranium may be in detrital minerals containing rare earths, but most of it is probably adsorbed on iron oxides or on clays, mica, and carbonaceous material.

There is no reason to doubt a syngenetic or penecontemporaneous origin for the uraniferous siltstone. The uranium-bearing beds are persistent and the uranium content is relatively uniform. The differences in metal content between the uraniferous siltstone and the copper-bearing shale probably reflect differences in the conditions of deposition.

The hypothesis outlined in the following paragraph is suggested to explain the observed separation of uranium and copper and to indicate a direction for further research.

The uraniferous siltstone probably was deposited in a lagoon which had limited access to the sea. Anaerobic conditions were much less extreme than in the black shales and consequently the lagoonal water was more nearly normal. Both the pH and the oxidation potential probably were higher than in the foul-bottom environment in which the black shales were deposited. The absence of sulfides, the lower copper content, and the higher uranium content of the siltstone probably are all indirect consequences of the low content of carbonaceous matter and hence the near-absence of hydrogen sulfide. Under these conditions an effective mechanism for the precipitation of copper did not exist and the iron probably was precipitated as ferric hydroxide which readily adsorbs uranium rather than as a sulfide which does not.

Uranium and copper minerals probably could not precipitate from the dilute near-neutral or slightly acid, mildly oxidizing waters and uranium was probably adsorbed on or coprecipitated with iron compounds such as ferric hydroxide that later dehydrated to form limonite. The precipitation of iron hydroxide and uranium was probably initiated by the mixing of excurrent water from the swampy flood-plain and the foul-bottom basins in which the copper was deposited with the marine water of the lagoon. Colloids tend to be flocculated by sea water and recent data indicate that uranium is effectively removed from an acid, iron-rich solution (pH 2.9) from which ferric hydroxide is precipitating when the solution is neutralized (pH 6.0). The acidity of swamp water (pH 4-4.5) would be neutralized by mixing with sea water (pH 8.1-9.6), and the uranium would be adsorbed on colloidal ferric hydroxide coagulated by sea water. If the sedimentation rate in the lagoon was low, a considerable concentration of uranium might occur in a long period of time.

Uranium-vanadium deposits in sandstone.--The uranium-vanadium deposits in sandstone differ in several important respects from the copper deposits and the uraniferous siltstone notably in the much higher uranium and vanadium contents. The metals, like those in the other deposits, are believed to have been derived from pre-Cambrian rocks, but these deposits are epigenetic and probably formed long after the sandstone was deposited. A two-stage epigenetic origin is postulated.

Three processes by which the deposits could have formed are (1) extraction and reconcentration from earlier low-grade syngenetic deposits by ground waters or hydrothermal solutions, (2) direct derivation from previous deposits or igneous rocks in the pre-Cambrian source areas, or (3) addition of uranium and vanadium from a magnetic source. None of these possibilities can be disproved but the first is most probable and the last is unlikely.

The absence of uranium, vanadium, and copper along the major faults and the lack of a known magmatic source for these metals argue against a simple hydrothermal origin; however, hydrothermal solutions probably were active in the district as shown by the sericitization of sheared arkose and the replacement of detrital quartz and feldspar by calcite and hematite. No indication of the source of the hydrothermal solutions has been found; they may have been derived from the basalt plugs east of the district or from an unknown body at depth. A relationship cannot be demonstrated between sericitized ground and uranium deposits and the role of a hydrothermal component in the formation of the deposits can be questioned if the less clearcut alteration changes described in the following paragraphs can be explained some other way.

Normal surface or ground water probably could not cause the replacement of quartz and feldspar by calcite. If calcite were introduced by a normal cementation process, the sand grains should be nearly in contact but the grains are corroded and isolated where replacement is advanced. The high manganese content of some calcite and the extensive replacement of quartz and feldspar in most uranium deposits seem to require the introduction of some calcite by chemically active fluids, perhaps at elevated temperature. If this conclusion is correct, it is reasonable to ascribe the calcitization to an early stage of the solution responsible for the deposition of iron and uranium.

A direct relationship between the hematitic alteration and the uranium is shown by the field and laboratory evidence. Hematite, nontronite, and the uraniferous ferric oxide are considered products of warm, chemically-active ground water with a possible juvenile component. Fresh feldspar and chalcopyrite on the outcrops suggest that the hematitic alteration is not related to surface oxidation. The iron in nontronite, a montmorillonite-type clay with ferric iron, cannot be added without destroying the structure of the clay mineral, for example, by the adsorption of iron on a montmorillonite clay in normal ground water. The iron must have been introduced at the time nontronite was formed and the formation of nontronite, except by the weathering of ferro-magnesian minerals, probably requires a high ferric iron concentration and temperatures higher than normal ground waters.

To explain the field and laboratory evidence we tentatively postulate a two-stage epigenetic theory of origin that the uranium deposits in sandstone are epigenetic and were leached and redeposited from earlier syngenetic uranium deposits containing from 0.005 to 0.03 percent uranium. Such a hypothesis is speculative because the evidence is not conclusive.

Barren, chemically-active hydrothermal(?) solutions are believed to have migrated along the Laramide(?) faults and through permeable beds. The warm active acid solutions sericitized the arkoses near the channels and leached iron, uranium, vanadium and calcium from the low-grade **uraniferous** rocks through which they moved. A large part of the uranium in the shale was loosely held by adsorption and hence was readily removed from the shale adjacent to the faults. The ability of such hydrothermal solutions to sericitize the rocks and to leach iron and uranium is shown by Phair's study of the altered radioactive quartz bostonite in the Front Range of Colorado. Phair (1952) found that an appreciable part of the uranium and iron were leached from the altered quartz bostonite dikes near the pitchblende deposits.

The acid solutions spread out in permeable sandstone beds and merged with the ground water system whose circulation may have been reactivated by folding. The ground water with its juvenile(?) component flushed the sandstones picking up more metal. The movement of the ground water was controlled by the permeability, porosity and structure of the aquifers. In favorable sedimentary structures, uranium-vanadium and iron deposited by chance in pH, oxidation potential, complex-ion destruction, or flocculation of a colloidal suspension by dilution or mixing of solutions of different characteristics. It is suggested that uranium compounds could not form under the existing conditions, and the uranium and rare earths were adsorbed on or coprecipitated with ferric hydroxide formed when the originally acid solutions neutralized by dilution or reaction with calcite. The ferric hydroxide might have remained in suspension and continued to move with the ground waters until flocculated by some mechanism such as mixing with waters containing dissolved salts or strained out by decrease in pore size of the sandstone. The flocculent precipitate may have continued to adsorb uranium from migrating ground waters until the unbalanced charges were fully neutralized. Precipitation of ferric hydroxide begins at a pH of 3.0-3.5 and virtually all the uranium will be removed from an iron-rich solution by the time a pH of 6 is reached. The marked concentration of rare earths in uraniferous iron oxides (samples 251 and 89, table 4) might also be explained by adsorption or coprecipitation on ferric hydroxide because their behavior is generally similar to the behavior of uranium. Vanadium, where present, seems to be in the clay minerals or adsorbed on carbonized wood. Probably most of the vanadium is in a vanadium hydromica formed by incorporation of vanadium in the structure during the recrystallization of a pre-existing clay mineral. The proportions of uranium, vanadium, and copper were controlled by the characteristics of the sediments and the density, temperature, pH, oxidation potential and metal content of the solution.

The favorable sites of deposition within scours contained carbonized wood, relict(?) chalcopyrite, calcite, clay galls and abundant rock fragments including limestone. Such rocks must have been deposited at a low oxidation potential under conditions similar to the copper deposits if the chalcopyrite is syngenetic. If the chalcopyrite is epigenetic, a change from early reducing conditions to late oxidizing conditions is indicated because chalcopyrite contains ferrous iron and hematite contains ferric iron. This suggests the possibility that part of the hematite is derived from early pyrite and chalcopyrite by the action of oxidizing solutions. Such a process would form strongly acid solutions. Hematite formed from early pyrite is common in hydrothermal uranium deposits and apparently forms during the deposition of uranium. However, iron or primary uranium minerals were not identified by X-ray techniques in 5 uranium samples; this suggests that these elements are in metamict or amorphous compounds rather then well-crystallized minerals and lends support to the idea that the uranium was adsorbed on a flocculent precipitate of ferric hydroxide later dehydrated to form hematite. Further support is given by the fact that the precipitation of uranium oxide and presumably other uranium compounds is inhibited by a high concentration of carbonate ion. This may explain the apparent absence of primary uranium minerals in the deposits in sandstone.

The principal arguments against a syngenetic origin for the uranium-vanadium deposits in sandstone are the difficulty in explaining (1) the sericitization of sheared arkose, (2) the extensive replacement of quartz and feldspar by calcite and hematite, and (3) the presence of both early sulfides containing ferrous iron and late ferric iron oxides containing uranium and rare earths. The uranium content of the uraniferous siltstone probably represents the maximum that can be expected in syngenetic deposits formed under conditions that existed in the Coyote district unless the uranium content of the water was abnormally high at certain times. An abnormally high uranium content in water can be expected only where the water is acid and waters more acid than those that deposited the black shale (pH 4.0-4.5) could hardly be expected in a terrain containing limestone. The uranium content of the black shale and uraniferous siltstone is low compared to the sandstone deposits, but the total amount is much greater. The uranium content of a syngenetic uranium deposit is limited by the sedimentation rate and by the suggestion that uranium is readily removed by adsorption in slightly acid or neutral waters and hence is dispersed. The uranium content of the syngenetic deposits in the Coyote district is comparable to the content of most other syngenetic deposits with the exception of a few deposits like the presumably syngenetic Swedish Kolm [ash-rich coal(?)] that have a much higher organic content.

Given a sufficient volume of solution and an efficient mechanism of concentration, uranium deposits might be formed from very dilute solutions, even from the ground waters existing in the district today. A water sample from a well in the central part of the district contained 0.015 ppm uranium (Zeller and Baltz, 1954). Several high uranium values in ponderosa pine in Area E were not reflected in the bed rock, and the uranium probably was extracted from dilute ground water percolating through the sheared ground.

Although a few clastic grains containing chalcopyrite and a black substance have been seen in the uranium ore, microscopic evidence proves that virtually all the uranium is later than the calcite cement. The absence of niobium, tantalum, thorium and other elements derived from the uranium-bearing pegmatites and the scarcity of the resistant minerals of these elements proves that amounts of uranium, vanadium and rare earths contributed by the heavy minerals is negligible and indicates that most of the uranium was not derived from the pegmatites.

<u>Summary</u>.

Copper and smaller amounts of uranium and vanadium freed by erosion of the pre-Cambrain terrain were transported to the basins of deposition in solution. The metals were removed from solution by different mechanisms operating under different conditions and this caused a partial separation of metals. The copper and part of the iron in solution were precipitated as sulfide in local anaerobic basins where carbonaceous shale was accumulating but most of the uranium and some iron remained in the still acid excurrent water, either in solution or suspension until the pH approached 6 by dilution in lakes or lagoons or by reaction with limy sediments. A large part of the uranium probably was dispersed upon neutralization by adsorption in clays but a considerable concentration of uranium occurred where the still acid excurrent waters mingled with sea water in a marine lagoon where the sedimentation rate was slow. Here colloidal suspension of ferric hydroxide would be coagulated and remaining iron would be precipitated as ferric hydroxide. The uranium forced out of solution by increase in pH upon dilution would be adsorbed on or coprecipitated with the iron hydroxide which later dehydrated to form hematite or limonite.

Following Laramide(?) orogeny warm acid ground waters with a chemically-active (hydrothermal?) component migrating through sheared ground and along faults leached lime, iron, uranium, vanadium and rare earths from the uraniferous sedimentary rocks and mingled with the ground waters in the sandstone aquifers. The waters were neutralized by dilution or reaction with the calcite cement of the sandstones and uranium and rare earths were adsorbed on ferric hydroxide precipitated in favorable sedimentary structures.

Comparison with other copper-uranium deposits

Copper-uranium deposits similar to the deposits in the Coyote district have been found in arkosic red beds, at least partly equivalent to the Sangre de Cristo formation, in several areas marginal to the ancestral Rocky Mountains.

The Cutler formation contains small copper-uranium deposits in the Big Indian Wash district and the Lockhart Canyon-Indian Creek area of Utah (Dix, 1953). The Abo formation, equivalent in part to both the Cutler formation and the Sangre de Cristo formation, contains copper deposits in the Scholle, Zuni Mountain, and Jemez Springs districts of New Mexico. Uranium has been reported from the Scholle and Jemez districts. Small copper-uranium deposits have been found in the Maroon formation, a partial equivalent of the Sangre de Cristo formation in the Huerfano Park and La Veta Pass areas, Huerfano and Costilla Counties, Colo. The Garo property, Park County, Colo. (Gott, 1951) has produced a small tonnage of uranium ore from a sandstone in the Maroon(?) formation. The Cutler-Abo-Sangre de Cristo-Maroon formations form a continuous arkosic red-bed unit. The deposits in the Lockhart Canyon-Indian Creek area of Utah and the deposits in the Maroon formation of Colorado resemble the sandstone deposits in the Coyote district. The deposits near Garo and La Veta, Colo. and in the Coyote district have a similar structural setting along the flanks of the Sangre de Cristo Mountain system.

The occurrence of similar deposits in arkoses deposited on the flanks of areas of Pennsylvanian uplift in widely separated areas suggest that other similar deposits exist. The similarities to the deposits of the Coyote district further suggest that ore guides at Guadalupita may be applicable to prospecting in other areas.

Copper deposits of the red-bed type, some of which contain small amounts of uranium, are present in the Poleo or Aqua Zarca sandstone lentils of the Chinle formation of Triassic age in the Cuba, Abiquiu, Cobre Basin, Copper City, and Gallinas districts all of which surround the

Nacimiento uplift in New Mexico. Uranium has been reported from the Chinle formation, near Coyote north of the Nacimiento uplift and near Sabinosa along the Canadian River east of Las Vegas, N. Mex. These deposits are similar to those described in this report. Uranium deposits might be found in sandstone which do not contain important quantities of copper in other red-bed copper districts.

GUIDES TO ORE DEPOSITS

The ore guides described below pertain to the Coyote district, but they may have a wider application as indicated in the preceding section.

In prospecting for copper deposits special attention should be directed to parts of the Sangre de Cristo formation that contain abundant limestone or gray shale beds because the ore-bearing black shale lenses are enclosed in gray shale and often grade into limestone.

The uranium deposits are in one or more brown or gray fluviatile sandstone beds near the middle of the Sangre de Cristo formation. The outcrops are inconspicuous and a counter is necessary for prospecting. Chalcopyrite, malachite, or black vanadium minerals and the distinctive pink color of the sandstone are the best ore guides, but they are easily overlooked. The most favorable spots within a sandstone are cut-and-fill structures, especially where the sandstone is coarse and contains abundant gray or black clay galls, foreign rock fragments and carbonized wood. The red or maroon sediments probably can be ignored because evidence of mineralization has not been found in them.

CONCLUSIONS

The uranium content of the copper deposits and the uraniferous siltstone is too low to permit the recovery of uranium under present-day conditions. The uranium deposits in sandstone are small but a small production might be expected under favorable conditions. Further exploration probably will increase the uranium reserves but large deposits are not expected. Geochemical prospecting methods are not suitable because of the steep dip of the beds and small size of the mineral deposits.

A large part of the value of the present investigation, in the opinion of the authors, lies in the genetic implications and practical application of the relationships discovered between copper deposits and the uranium-vanadium deposits. Some of the more important relationships, chosen for their possible application to the search for uranium deposits in other areas, are listed below:

(1) The best copper deposits are in the local black, carbonaceous shale lenses and have a negligible uranium content.

(2) The only commercial-grade uranium deposits are low in copper and occur in several gray or brown **fluviatile** sandstone beds and are localized by small sedimentary structures similar to those in the Morrison and Shinarump formations. It is suggested that uranium deposits may be found in fluviatile sandstone in other "red bed" copper districts but that the conditions favorable for the formation of commercial uranium deposits are different from the conditions favorable for red bed copper deposits.

(3) The copper-bearing shale and the uraniferous siltstone are essentially syngenetic but the uranium-vanadium deposits in sandstone probably are much younger and may have formed from low-grade syngenetic deposits by groundwaters with a hydrothermal(?) component following Laramide (?) orogeny. If this theory of origin is correct, the search for uranium deposits in arkosic red bed units should be directed to areas where favorable sandstone beds are folded or faulted particularly surrounding younger intrusives. It is suggested that undiscovered uranium deposits may exist along the flanks of the present mountains where limy sandstone beds in sediments of the Cutler-Abo-Sangre de Cristo-Maroon lithology are exposed.

(4) It is suggested that the coprecipitation with or adsorption on ferric hydroxide offers a mechanism by which uranium deposits can form even where uranium compounds (minerals) cannot form. This process is operative in acid oxidizing solutions between a pH of 3 and 6 and applies equally to syngenetic and epigenetic deposits. It is suggested that the ferric hydroxide is usually precipitated by reaction with calcite. The same adsorption process is believed to cause the concentration of rare earths. The uranium in both the siltstone and the sandstone probably was concentrated by this mechanism. If the foregoing is true, the search for large, low-grade uranium deposits need not be limited to sedimentary rocks rich in organic material but should be extended to certain fine-grained sedimentary rocks containing iron oxides formed in the manner noted.

(5) The distinct pink color imparted by hematite introduced with uranium is the best ore guide to the sandstone deposits. The difference between this color and the red, chocolate, or maroon color of the barren red beds is subtle but distinctive.

LITERATURE CITED

Bachman, G. O., 1953, Geology of a part of northwestern Mora County, New Mexico, U. S. Geol. Survey: Oil and Gas Inv. Map, OM 137.

Brill, K. G., Jr., 1952, Stratigraphy in the Permo-Pennsylvanian Zeugogeosyncline of Colorado and Northern New Mexico: Geol. Soc. America Bull., v. 63, p. 809-880.

Dix, G. P., Jr., 1953, Reconnaissance of the uranium deposits of the Lockhart Canyon-Indian Creek area, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4038, Tech. Inf. Service, Oak Ridge.

Edwards, A. B., 1947, Textures of the ore minerals and their significance, Australasian Institute at Mining and Metallurgy, p. 74-76.

Gott, G. B., and Erickson, R. L. 1952, Reconnaissance of uranium and copper deposits in parts of New Mexico, Colorado, Utah, Idaho and Wyoming: U. S. Geol. Survey Circ. 219.

Harley, G. T., 1940, The geology and ore deposits of northeastern New Mexico: New Mexico Bur. Mines Bull. 15, p. 42-43.

Jahns, R. H., 1946, Mica deposits of the Petaca district, Rio Arriba County, New Mexico: New Mexico Bur. Mines Bull. 25.

Lasky, S. G., and Wooton, T. P., 1933, The metal resources of New Mexico and their economic features: New Mexico Bur. Mines Bull. 7, p. 84.

Lindgren, W., Graton, L. C., and Gordon, C. H., 1910, Ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 79, 109.

Northrup, S. A., Sullwold, H. H., Jr., MacAlpin, A. J., and Rogers, C. P. Jr., 1946, Geologic maps of a part of the Las Vegas basin and of the foothills of the Sangre de Cristo Mountains, San Miguel and Mora Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 54.

Phair, George, 1952, Radioactive Tertiary porphyries in the Central City District, Colorado, and their bearing on pitchblende deposition: U. S. Geol. Survey TEI-247, U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, p. 43-44.

Rankama, K., and Sahama, Th. G., 1950, Geochemistry, University of Chicago Press, p. 594, 634, 697.

Read, C. B., and Wood, G. H., 1947, Distribution and correlation of Pennsylvanian rocks in late Paleozoic sedimentary basins of northern New Mexico: Jour. Geol., v. 55, no. 3.

Zeller, H. D., and Baltz, E. H., Jr., 1954, Uranium-bearing copper deposits in the Coyote district, Mora County, New Mexico: U. S. Geol. Survey Circ. 334.

UNPUBLISHED REPORTS

Bachman, G. O., and Read, C. B., 1952, Uranium-bearing copper deposits near Guadalupita, Mora County, New Mexico: U. S. Geol. Survey Trace Elements Memo. Rept. 435.

Gott, G. B., 1951, Garo uranium deposits, Park County, Colorado: U. S. Geol. Survey Trace Elements Memo. Rept. 222.

Read, C. B., Sample, R. P., and Shelton, J. S., 1944, The Guadalupita copper prospects, Mora County, New Mexico: U. S. Geol. Survey. Unpublished manuscript.

Zeller, H. O., and Baltz, E. H., Jr., 1952, Uranium-bearing copper deposits in the Coyote mining district, Mora County, New Mexico: U. S. Geol. Survey Trace Elements Memo. Rept. 556.