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COPPER IN THE FLOWERPOT SHALE (PERMIAN) OF THE CRETA AREA, JACKSON COUNTY, OKLAHOMA

by

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Copper in the Flowerpot Shale (Permian) of the Creta Area, Jackson County, Oklahoma

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ABSTRACT

Bedrock strata of the Creta area consist of clastic sediments and evaporties of Medial Permian age. They are nearly horizontal and are undisturbed by faulting. Two persistent copper-bearing greenish-gray shale beds in the upper part of the Flowerpot Shale are present in the central part of the area. The main bed, here referred to as the "lower copper bed," is 6 inches thick and lies 10 feet below the Kiser Dolomite Bed. The other bed, 5 feet below the Kiser, is about 4 inches thick and is here referred to as the "upper copper bed." Both beds were studied in the relatively good exposures of the low scarp face capped by the Kiser in a 5-mile-long outcrop belt southeast of Creta.

The "lower copper bed" has the greater economic potential in the district. It is characterized by a copper content ranging from 2.65 to 4.45 percent and averaging about 3.8 percent for approximately 3 miles in the central part of the outcrop belt. The "upper copper bed" has little economic potential because its copper content ranges only from 0.38 to 1.27 percent, averaging about 0.8 percent.

Malachite is generally the only copper mineral in both beds. Other copper minerals, found only in nodules that apparently form at the weathered face of the "lower copper bed," are brochantite, chalcocite (?), and cuprite(?). Precious metals, such as gold and silver, are notably lacking.

The copper and boron contents of other shale layers in the upper part of the Flowerpot were investigated for genetic interpretations, and the "lower copper bed" was found to contain 2,500 to 4,000 times more copper and twice as much boron as the common shales of the district. All geologic considerations suggest that copper was deposited from the sea water syngenetically with the shale beds. The original copper minerals have not been observed, and the modern deposits consist of epigenetically formed minerals, of which malachite is the dominant species.

Over an area of 1,000 acres the inferred reserves in the "lower copper bed" are 70,000 tons of copper, available by stripping overburden ranging from 1 to 40 feet in thickness.

INTRODUCTION

The occurrence of copper minerals in Permian strata of western Oklahoma has been known from the time of Marcy's explorations in 1852. While traveling in the area that is now a part of Jefferson County, Oklahoma, the Marcy party observed many small pieces of copper ore weathered from outcropping beds of shale and sandstone of the Early Permian Wichita Formation. Other similar occurrences in redbeds were reported in Bulletin 1 of the Oklahoma Geological Survey by Gould, who stated that green copper stains and local copper nuggets were widely distributed in Major, Woods, Kingfisher, Blaine, Caddo, McClain, and Greer Counties (Gould, Hutchison, and Nelson, 1908, p. 78).

In a later work, Merritt (1940) described copper mineralization in a broad belt extending from the south-central Oklahoma region of Jefferson, Cotton, and Comanche Counties northward through Garvin and McClain Counties into the north-central Oklahoma region of Payne, Pawnee, Grant, and Garfield Counties. The pattern of occurrence is everywhere the same. Chalcocite and malachite are the common minerals, occurring in Permian shale and sandstone as encrustations, impregnations, veinlets, or small nodules. Chalocite also occurs in the form of chalcocitized wood, some pieces of which are as much as 6 inches long and 1 inch in diameter. In describing copper deposits of southern Cotton County, Fath (1915) determined that the chalcocite of nodules in sandstone had replaced calcite cement and that the chalcocite nodules in shale originated by the replacement of marcasite.

Prospect pits and even tunnels had been used to explore some of the more promising outcrops in western Oklahoma, according to early accounts, but all resulted in financial failure owing to the lean grade of the ore and small size of the deposits. It was therefore of considerable interest when, in the spring of 1962, Kenneth E. Smith of Vinson, Oklahoma, sent to the Geological Survey a sample of green shale impregnated with an exceptionally high concentration of malachite. Mr. Smith guided the writers to the outcrop near Creta from which it had been collected. Field observation proved that the malachite was contained within a bed of shale 6 inches thick, almost one-half as thick as the world-famous and long-worked Kupferschiefer (copper shale) bed of Late Permian age (Zechstein) near Mansfeld, Germany.

Judging that the bed might be commercially significant if it could be shown to have regional distribution, an investigation was made by surface mapping and sampling. The results of this investigation form the basis for the present report, in which it is concluded that the "lower copper bed" extends continuously along the outcrop for 3 miles and has an average copper content of 3.8 percent. A second, or "upper copper bed," 3 to 4 inches thick, occurs within the district but is much leaner in copper. Reserves, inferred from the outcrop study of the "lower copper bed," are 70,000 tons of copper, available by stripping overburden 1 to 40 feet in thickness. Evaluation by drilling doubtless will show larger reserves in the district, most of it under overburden 40 to 160 feet thick.

In addition to acknowledging with thanks the services of Mr. Smith in calling attention to the copper occurrence, the writers are indebted to John A. Schleicher for making chemical and spectrographic analyses in the geochemical laboratory of the Oklahoma Geological Survey, and to Charles J. Mankin and William H. Bellis for making X-ray diffractograms in the X-ray laboratory of the School of Geology at The University of Oklahoma. Plates for the report were drafted by Roy D. Davis and Eileen Krall of the Oklahoma Geological Survey. On the geologic map accompanying the report (pl. I), much of the outcrop trace of the Haystack Gypsum Member of the Blaine Formation has been slightly modified from unpublished mapping by Richter (1960, pl. I).

GEOLOGY OF THE CRETA AREA

General Statement

As defined in this report the Creta area comprises 23 square miles in the southwestern part of Jackson County, Oklahoma (pl. I). It lies immediately north of Red River near the southwestern corner of the State, 120 air-line miles southwest of Oklahoma City and 15 miles southwest of Altus, the county seat of Jackson County. Creta, at the northwest corner of the mapped area, and the only named locality within it, formerly was a small agricultural community but is now just a wheat-shipping station of the St. Louis-San Francisco Railway. State Highway 44 extends through the northern part of the area parallel to the railroad, and many secondary roads provide easy access to other parts of the area.

Outcropping rocks are sedimentary strata of Permian age, dipping about 40 feet per mile to the southwest. They appear to be nearly flat-lying and are undisturbed by faulting. Excellent outcrops of the upper part of the Flowerpot Shale and lower part of the overlying Blaine Formation are found in the area. The Duncan Sandstone, underlying the Flowerpot, is not present in the area but crops out about 6 miles to the east. The Duncan, Flowerpot, and Blaine Formations are in the El Reno Group and are assigned stratigraphically to the lower part of the Guadalupean Series of the Permian System by Dunbar (1960, pl. 1).

Of greatest importance to this report is the Flowerpot Shale, in the upper part of which the copper-bearing beds occur. It crops out generally as a plain of low relief, sparsely covered with short grass suitable for grazing dairy and stock cattle. Where alluvial soil is present, the plain is flat, and wheat, cotton, and sorghum are grown. It is slightly dissected into a badlands at the base of the Blaine escarpment, which rises to the southwest above the plain to a maximum height of 120 feet. The escarpment of the Blaine Formation is dissected and notably benched, individual benches being supported by gypsum and dolomite beds, and the top itself, capped by the Mangum Dolomite Bed, has the form of mesas and outlying buttes.

Duncan Sandstone

The Duncan Sandstone in southwestern Oklahoma consists of light-gray and reddish-brown sandstones and siltstones interbedded

with reddish-brown and greenish-gray shales. It has an interfingering contact with the overlying Flowerpot Shale and is a deltaic deposit which thins westward and northwestward from the town of Duncan in Stephens County. The Duncan probably is correlative with the San Angelo Formation of north-central Texas.

Beds in the basal 20 feet of the Duncan crop out about 12 miles east of Creta, where they are fine- to medium-grained cross-bedded sandstones interbedded with gray-green claystone conglomerates. The upper part of the formation, as well as its contact with the Flowerpot Shale, is concealed by alluvium and terrace deposits along Salt Fork of Red River through central Jackson County. Thickness of the Duncan Sandstone is not known from drilling, yet scattered information suggests that the formation is as least 50 feet thick.

No copper mineralization has been observed in the poor exposures of Duncan Sandstone in Jackson County. Fifty miles northeast of Creta, near Gotebo in Kiowa County, sparsely distributed nodules of copper minerals occur in sandstone in the basal part of the formation.

Flowerpot Shale

The Flowerpot Shale has been correlated from south-central Kansas through western Oklahoma into north-central Texas. It consists mainly of reddish-brown shale with thin interbeds of gypsum, dolomite, siltstone, sandstone, and greenish-gray shale. A substantial thickness of rock salt and interbedded salty shale occurs in this formation in subsurface. These beds extend nearly to the surface, as shown by the occurrence of salt-water springs emanating from Flowerpot outcrops.

Total thickness of the Flowerpot Shale in the Creta area is not presently known, as its base is poorly exposed and not easily recognized. Roth (1945, p. 902-904) measured 274 feet of Flowerpot in north-central Texas, 75 miles south-southwest of Creta; and Scott and Ham (1957, p. 15) reported about 160 feet of Flowerpot in southeastern Beckham County, Oklahoma, 40 miles north of Creta. In the vicinity of Creta the Flowerpot Shale probably is about 200 feet thick.

Most strata in the Flowerpot Shale of western Oklahoma were deposited in a marine environment, as is shown by the abundance of salt in subsurface and by thin beds of gypsum and dolomite both in subsurface and on the outcrop. Twenty-five miles north of Creta, Wilson (1960) obtained hystrichosphaerids and a scolecodont from a shale layer 30 feet below the top of the Flowerpot. The occurrence of these microfossils has been interpreted to indicate a shallow-marine or brackish-water environment (Wilson, 1962, p. 33).

Copper mineralization similar to that observed in the upper part of the Flowerpot Shale in the Creta area occurs at approximately this stratigraphic position elsewhere in southwestern Oklahoma, mostly in concentrations visually estimated at about 0.5 to 1 percent copper. The copper-bearing region extends discontinuously as far north and east as the Sentinel area near the Kiowa-Washita county line.

Two units in the upper part of the Flowerpot Shale are widely distributed and have been correlated regionally. Both of them, the Chaney Bed below and the Kiser Bed above, are characterized as gypsum beds 1 to 4 feet thick that are locally underlain by thin dolomites and at places are represented by the dolomites alone. The copper-bearing shales that are the subject of this report are midway between the Chaney and Kiser Beds. Both of the beds are valuable stratigraphic markers and have been correlated from southwestern Washita County and northwestern Kiowa County, through Beckham, Harmon, Greer, and Jackson Counties, Oklahoma, into north-central Texas.

Chaney Bed.—In southwestern Oklahoma the Chaney Bed is massive white gypsum 1 to 4 feet thick, generally 30 to 60 feet below the top of the Flowerpot Shale. Locally the gypsum is underlain by several inches of microgranular dolomite.

In the Creta area the Chaney is 45 to 50 feet below the top of the formation and consists of white gypsum 3 feet thick, underlain by 4 inches of platy microgranular light-gray dolomite. At places the gypsum has been removed by solution or is eroded, and only the dolomite remains. The best exposures of this bed in the area are in NW¼ sec. 3, and NE¼ sec. 15, T. 1 S., R. 22 W. (pl. I). It locally forms a bench several feet high, but in most places the outcrops are covered by colluvium.

Kiser Bed.—The Kiser bed is the uppermost persistent unit in the Flowerpot Shale of southwestern Oklahoma. Most commonly it is 20 to 30 feet below the top of the formation. Generally a shaly greenish-gray gypsum, it locally grades into relatively pure white gypsum and at places contains thin beds of microgranular dolomite. Gypsum has not been observed in this unit throughout Jackson County, but a dolomite bed at the stratigraphic position of the Kiser is herein considered to be equivalent or closely related to it.

In the Creta area the Kiser Bed consists of platy microgranular light-gray dolomite in a bed 6 inches thick. Shale lies immediately above and below the Kiser, and the dolomite commonly caps an escarpment 10 to 15 feet high. In this area the Kiser is 25 to 30 feet below the top of the Flowerpot and supports the main escarpment below the gypsum and dolomite ledges of the Blaine Formation.

Blaine Formation

Overlying the Flowerpot is the Blaine Formation. It has been correlated from south-central Kansas through western Oklahoma into north-central Texas. The Blaine consists chiefly of thick gypsum beds interstratified with reddish-brown and greenish-gray shale. Individual gypsum beds are commonly 5 to 30 feet thick, and the intervening shales have the same range of thickness. Relatively thin dolomite beds underlie most of the gypsum layers.

Strata in the Blaine Formation were deposited in a marine environment. Dolomite and gypsum are typical evaporation products of desiccating seas, and in western Oklahoma they represent the transgressive phases of cyclic inundations. Evaporites were not deposited during the regressive phases, when instead fine clastic material was carried far from the existing shore and deposited widely over the floor of the shallow sea. The cyclic nature of deposition of the Blaine Formation in southwestern Oklahoma has been dealt with by Ham (1960).

In southwestern Oklahoma the Blaine is 150 to 200 feet thick and consists of seven or eight gypsum beds separated by shales. The gypsum units are commonly underlain by thin dolomites. Individual gypsum and dolomite beds of the Blaine Formation are stratigraphically persistent and have been traced throughout southwestern Oklahoma. The Creta area of this report is included within a larger area mapped by Richter (1960, pl. 1).

The Haystack Gypsum Member is the basal unit of the formation in southwestern Oklahoma and is the only gypsum bed of the Blaine considered in this report. It is commonly 8 to 25 feet thick. A thin dolomite occurs at some localities at the base of the gypsum.

In the Creta area the Haystack consists of massive white gypsum, 12 feet thick, locally containing 1.5 feet of shale near the top. Four inches of microgranular light-gray dolomite is at the base of the gypsum in the southern part of the area. This dolomite contains widely scattered bedding encrustations of malachite, much too dispersed to have more than scientific interest. The gypsum bed commonly forms a low bench, although at many places the top and base are covered by colluvial debris.

COPPER IN THE CRETA AREA

General Statement

Two persistent copper-bearing greenish-gray shale beds in the upper part of the Flowerpot Shale are present in the Creta area. The main bed, here referred to as the "lower copper bed," is 6 inches thick and lies 10 feet below the Kiser Dolomite Bed. The other bed, 5 feet below the Kiser, is about 4 inches thick and is here referred to as the "upper copper bed." Both beds have been examined in the relatively good exposures of the low scarp face capped by the Kiser in a 5-mile-long outcrop belt southeast of Creta. The study was not extended beyond the Creta area as these beds are covered by colluvium for tens of miles to the north and south.

The "lower copper bed" has the greater economic potential in the district. It is characterized by a copper content ranging from 2.65 to 4.45 percent and averaging 3.8 percent for about 3 miles in the central part of the outcrop belt. In the northern and southern parts of the district this same bed contains little copper, and, as a result, the outcrop limits of possible ore in the immediate area are firmly established. The "upper copper bed" has little economic potential because its copper content ranges only from 0.38 to 1.27 percent, averaging 0.79 percent.

Malachite is the dominant copper mineral found in both beds, although azurite was observed at one place. Other copper minerals, found only in nodules that apparently form at the weathered face of the "lower copper bed," are brochantite, chalcocite(?), and cuprite (?). Precious metals, such as gold and silver, are notably lacking.

The copper and boron content of other shale layers in the upper part of the Flowerpot was investigated for genetic interpretations, and the "lower copper bed" was found to contain 2,500 to 4,000 times more copper and twice as much boron as the common shales of the district. Aside from these differences in copper and boron content, the "lower copper bed" and other shales in the area appear to be alike.

The nearly flat-lying strata are undisturbed by folding or faulting, and no post-Cambrian igneous activity is known. All geologic considerations suggest that copper was deposited from sea water syngenetically with the shale beds. The original copper minerals have not been observed, and the modern deposits consist of epigenetically formed minerals of which malachite is dominant.

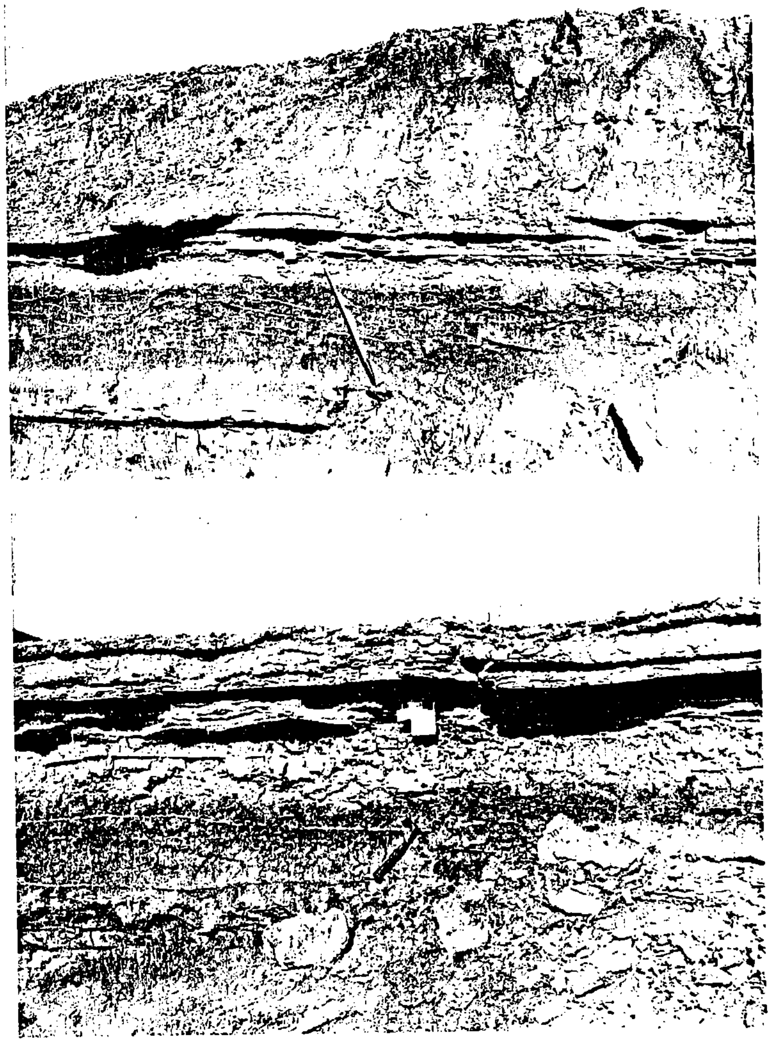
"Lower Copper Bed"

The "lower copper bed" is a 6-inch layer of greenish-gray shale containing malachite. It lies midway between the Kiser and Chaney Beds, and immediately below a 1-foot layer of impure gypsum, which in the Creta area is sufficiently persistent to be a stratigraphic marker. Underlying the "lower copper bed" is 1.0 foot of greenish-gray shale that appears identical to the "lower copper bed," except for its much lower copper and boron content. The contact between these two shale layers is abrupt, and both beds have a remarkably uniform thickness in the area.

Significant copper mineralization in the "lower copper bed" evidently is restricted to the 3-mile belt in the central part of the Creta area. The bed is well exposed at most places and is best seen in the scarp face capped by the Kiser Bed (fig. 1). The same bed of shale can be positively identified in good exposures to the north and south, yet in these exposures the bed contains little or no malachite, and chemical analyses show less than 0.5 percent of copper (pl. II).

In the central area three outcrop channel samples of the "lower copper bed" were analyzed by wet method for copper and by the emission spectrograph for other elements (table 1). The copper content ranges from 4.45 percent at measured section B to 4.29 percent at measured section C and 2.65 percent at measured section D. The average of 3.8 percent copper is indicative of the grade of ore that might be mined. In addition to copper, the samples contain traces of other metals such as chromium, cobalt, lead, manganese, nickel, vanadium, and zirconium. Traces of silver also are present, but gold is absent.

Malachite ($CuCO_3 \cdot Cu(OH)_2$) is the dominant copper mineral. It is of secondary origin and is commonly found in the oxidized



portions of copper-ore deposits throughout the world. Conspicuous on the outcrop by virtue of its emerald-green color, it occurs in the Creta area as encrustations and as radiating fibrous aggregates, commonly 2 to 3 mm in diameter, along bedding planes and fractures of the shale (fig. 2). A hand-picked sample of these encrustations and aggregates, representing the kind of material that might be concentrated from the shale if it were commercially worked, was analyzed chemically and by X-ray diffraction. The sample consists of malachite admixed with quartz and clay (fig. 9) and contains 45.72 percent copper together with trace amounts of chromium, lead, manganese, nickel, vanadium, and zirconium (table 1). Silver in one part per million was detected by the emission spectrograph, but gold could not be identified. It is therefore clear that concentrates from the "lower copper bed" would be valuable only for their copper content, as the concentrations of other metals are too low for recovery.

The only other copper mineral found in the "lower copper bed" is azurite. A blue mineral with composition $2CuCO_3 \cdot Cu(OH)_2$, azurite also is of secondary origin and is commonly found associated with malachite in the oxidized portions of copper-ore deposits. In the Creta area it was found at one locality, SE¼ SE¼ SW¼ sec. 10, T. 1 S., R. 22 W., by digging into the "lower copper bed" through 1 foot of overburden. Here the azurite is intermixed with malachite in shale.

Below the "lower copper bed," scattered on the scarp face and on level ground at the base of the escarpment, are numerous malachite-impregnated nodules. Most of them are highly irregular and

Figure 1. Outcrops of "lower copper bed" in gully at measured section D, SE¼ SW¼ NE¼ sec. 15, T. 1 S., R. 22 W.

(Upper) The "lower copper bed," 6 inches thick, is marked at left center by the white sample bag, near the end of the shovel handle. Within it at this locality is a conspicuous seam of satin spar gypsum. Next above is a 1-foot bed of massive gypsum weathered into an overhanging ledge. At the top of the exposure is the Kiser Dolomite Bed, loose white blocks of which are weathering down the slope. Midway between the Kiser and the "lower copper bed" is the "upper copper bed," 3 inches thick at this locality. The Chaney Gypsum Bed, 10 feet below the "lower copper bed," is exposed at the bottom of the stream 100 feet to the left of the exposure shown in the photograph.

(Lower) Closer view of the "lower copper bed" taken 50 feet to the right of the view shown in the upper photograph. Six-inch white sample bag indicates position of the "lower copper bed," which is underlain by 1 foot of noncupriferous greenish-gray shale. Underlying the greenish-gray shale, with marked color contrast shown just above hammer head, is reddish-brown shale containing satin spar veins. The capping bed of the exposure is the 1-foot massive gypsum that overlies the copper-bearing shale.

are ½ to 1 inch in diameter (fig. 3), although some are as much as 3 inches long. The nodules consist of clay, quartz, and gypsum cemented chiefly by malachite and brochantite, which have been precipitated in various concentrations and in various forms of growth (fig. 4). A few cavities present inside the nodules are wholly or partly lined with encrusting malachite, generally in the form of clustered bright-green needles. Brochantite, a basic copper sulfate ($CuSO_4 \cdot 3Cu(OH)_2$), occurs as finely divided grains with malachite in the clay matrix and as cross-cutting veinlets. It was identified principally from the X-ray-diffraction patterns (fig. 10) and evidently is an important constituent in all the nodules.

TABLE 1.—COPPER AND TRACE-ELEMENT CONCENTRATIONS IN SAMPLES FROM "LOWER COPPER BED"

(Concentrations given in weight percent; J. A. Schleicher, analyst)

Element	*6-inch shale bed, measured section B*	*6-inch shale bed, measured section C*	*7-inch shale bed, measured section D*	*Hand-picked malachite aggregates, NE¼ NE¼ NW¼ sec. 15, T. 1 S., R. 22 W.*
Copper[1]	4.45	4.29	2.65	45.72
Aluminum	M[2]	M[2]	M[2]	M[2]
Barium	0.05	0.05	0.02	0.01
Boron	0.025	0.025	0.02	0.01
Calcium	M	M	M	M
Chromium	0.01	0.01	0.005	0.002
Cobalt	0.02	0.02	0.01	0.005
Gallium	0.003	0.003	0.002	0.0005
Gold	—	—	—	—
Iron	M	M	M	M
Lead	0.02	0.02	0.005	0.015
Magnesium	M	M	M	M
Manganese	0.15	0.15	0.15	0.08
Nickel	0.005	0.005	0.003	0.002
Potassium	M	M	M	M
Silicon	M	M	M	M
Silver	0.0001	0.0001	0.0001	0.0001
Sodium	M	M	M	M
Strontium	10	0.02	0.15	—
Titanium	0.25	0.25	0.25	0.30
Vanadium	0.02	0.02	0.01	0.0075
Zirconium	0.04	0.04	0.02	0.01

[1] Analyses by wet method. All other elements determined semiquantitatively on Jarrel-Ash 1.5-meter emission spectrograph.
[2] M=present in excess of 0.5 percent.

Brochantite forms under conditions of relatively low acidity, especially in arid regions, and is a secondary mineral found in association with malachite and azurite in the oxidized portions of copper deposits. This is the first reported occurrence of brochantite in Oklahoma.

About half the nodules contain tiny opaque grains that are tentatively identified as chalcocite and cuprite. These minerals are not concentrated sufficiently to be recognized with certainty on the X-ray diffractograms, and the numerous peaks of malachite and brochantite may mask the peaks of minerals that occur in lesser

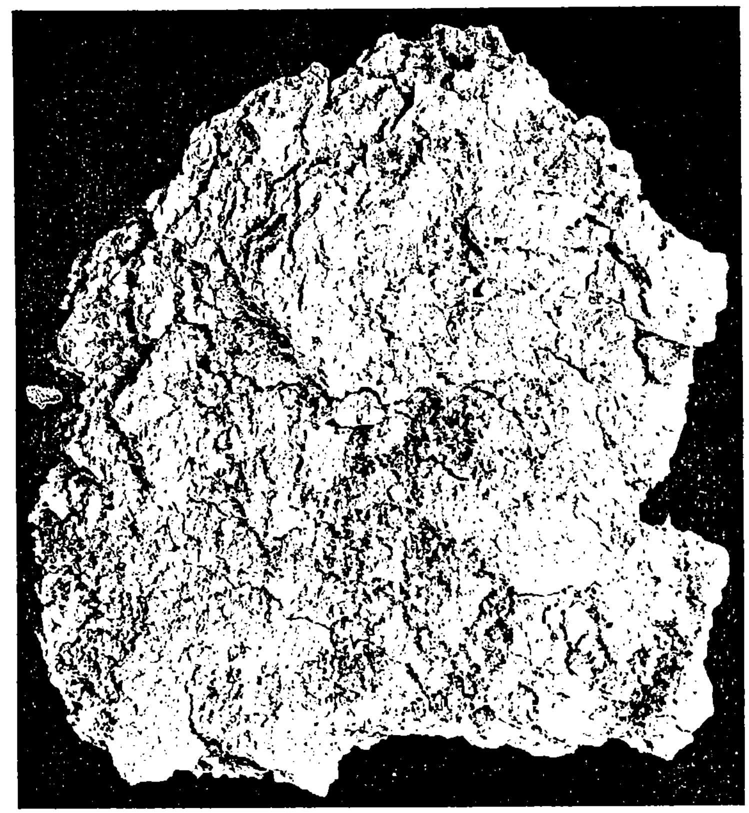


Figure 2. Malachite-impregnated shale of the "lower copper bed," x3, from the NE¼ NE¼ NW¼ sec. 15, T. 1 S., R. 22 W. Prominent encrustations of bright-green malachite, mostly along bedding partings of the shale, appear as darker gray areas in the photograph.

abundance. The chalcocite(?) occurs as black grains, many of them prominently divided into rectangular plates that are separated by invading malachite and brochantite (figs. 5, 6). Around the chalcocite(?) is finely granular cuprite(?), opaque and dull-red to bronze in reflected light. Both opaque minerals are strongly clustered in dark patches, mostly in the interior of the nodules.

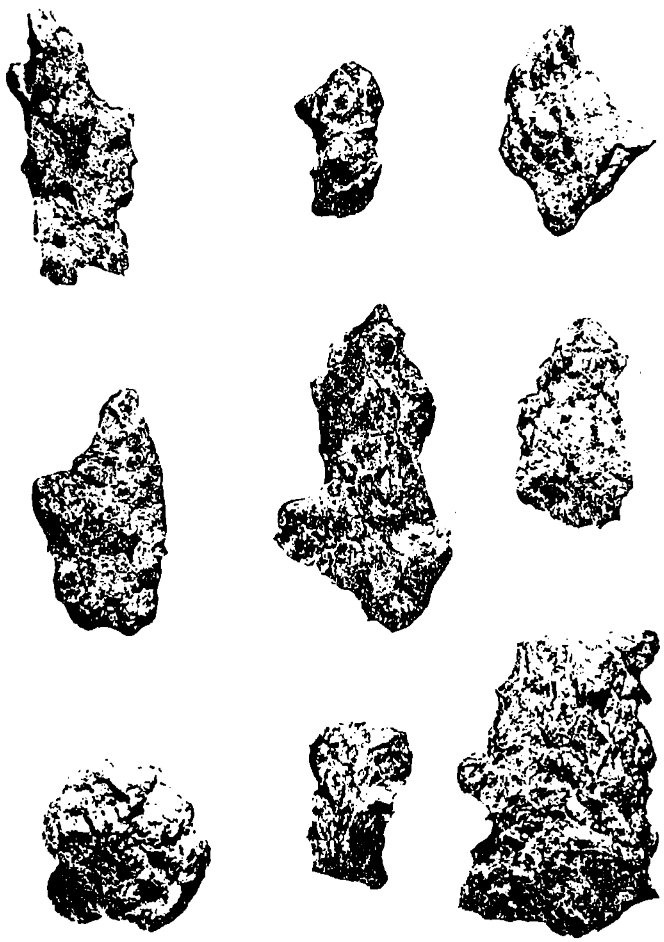


Figure 3. Typical copper-bearing nodules weathering from the "lower copper bed," x1.9, at measured section B, SW¼ SW¼ NW¼ sec. 3, T. 1 S., R. 22 W. The irregular shape results from random growth of malachite and other copper minerals which cement a clay-gypsum-quartz matrix.

Clear selenite gypsum has been deposited in open cavities and veinlets of some nodules, and well-developed needles of malachite locally accompany the growth of this gypsum (fig. 7).

Another form taken by malachite and brochantite, in specimens that weather down the slope below the "lower copper bed," is as a pseudomorphous replacement of cuboid crystals with sharply depressed faces (fig. 8). The crystal form is like that of hopper-shaped halite cubes and of gypsum crystals such as have been observed in the Flowerpot Shale in Beckham County. Probably the original mineral in the Creta area also was gypsum that grew in the copper shale.

The copper nodules and cubiform pseudomorphs were not found within the "lower copper bed" itself. Because they are abundant on the scarp face below the bed and are absent on the scarp face above the bed, however, they must be genetically related to the "lower copper bed." Either the nuggets are present within the bed, but have not been encountered by the present writers, or they have been formed at the weathered surface by concentration of the more

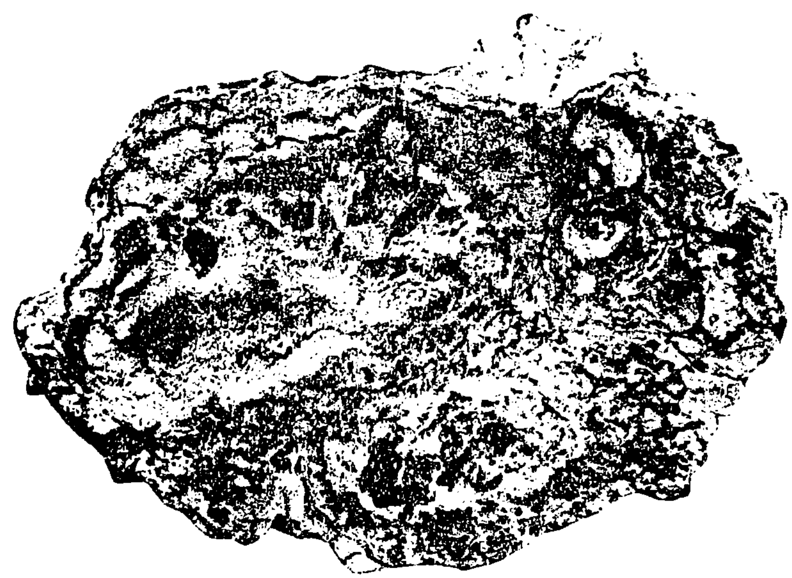


Figure 4. Polished section of a copper nodule illustrated in figure 3, showing colloform growth and the areas of greatest malachite concentration (dark gray). The specimen is 2 cm (0.75 inch) in long diameter.

finely disseminated malachite encrustations and aggregates in the shale bed. So far as known, brochantite occurs only in the nodules, not having been identified as encrustations in shale at the outcrop face.

"Upper Copper Bed"

Approximately 5 feet above the "lower copper bed" is a layer of greenish-gray shale which locally contains visible amounts of malachite. This bed, here referred to as the "upper copper bed," lies about 5 feet below the Kiser Bed and 14 feet above the Chaney Bed.

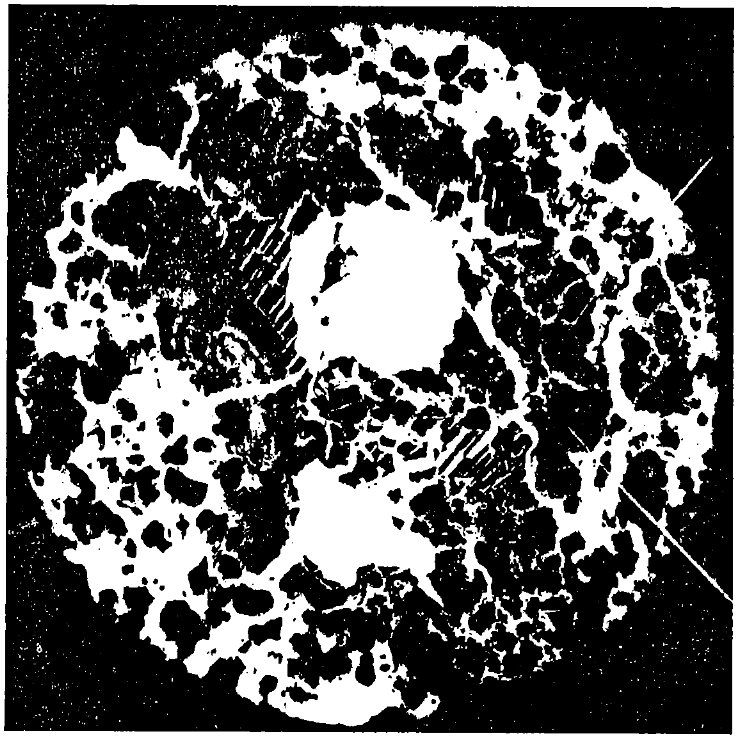


Figure 5. Photomicrograph of a copper nodule showing malachite and brochantite (white and light gray) as cavity fillings, irregular replacement masses, and thin veinlets. The dark material divided into rectangular prisms is black chalcocite(?), with which is associated finely granular cuprite(?). Diameter of field is 0.9 mm. Plain light.

It is generally underlain and overlain by reddish-brown shale, and locally a thin bed of gypsum or dolomite is present at the base. The total thickness of the "upper copper bed" is 0.3 to 1.4 feet, but malachite was observed only in about 4 inches of the bed, commonly in the upper part.

The "upper copper bed" is exposed in the scarp face capped by the Kiser (fig. 1), although at most places even these exposures are poor, as they are concealed by slope debris. It is exposed well enough, however, to permit channel sampling of the cupriferous part of the bed at four localities in the Creta area. Chemical analyses of these samples (pl. II; table 3) show less than 0.10 percent copper in the southern part of the area and copper in amounts ranging from

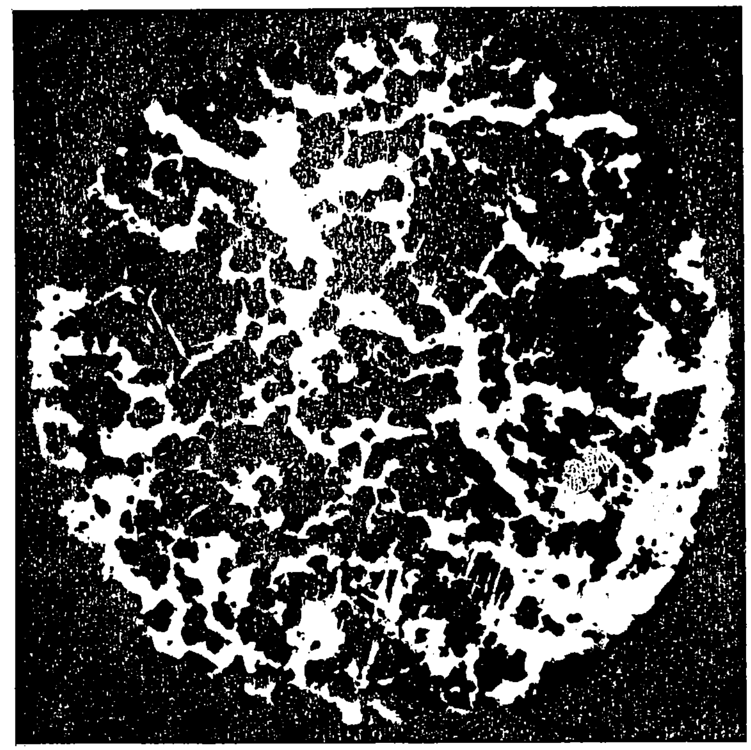


Figure 6. Photomicrograph showing maximum concentration of opaque minerals in a copper nodule. Black lamellar chalcocite(?) and finely granular cuprite(?) are cut through by veinlets of malachite and brochantite. Field diameter is 0.95 mm. Plain light.

Figure 7. Photomicrograph of a copper nodule showing needles of malachite that grew in clear gypsum of a cavity filling. Length of field is 0.7 mm. Plain light.

0.38 to 1.27 percent in the central and northern parts. The northernmost sample, at measured section A (pl. II), contains 1.27 percent copper, or three times more than in the "lower copper bed" at the same locality. Over a distance of approximately 4 miles the average copper content of the "upper copper bed" is 0.79 percent. Conceivably a bed of this low tenor might be worked in conjunction with the mining of the "lower copper bed."

The sole copper mineral observed in the "upper copper bed" is malachite, occurring as encrustations and radiating fibrous aggregates, generally 2 to 3 mm in diameter, along fracture and bedding planes in the shale. Copper-bearing nodules of the type that weather out locally from the lower bed have not been observed on the scarp face between the upper and lower beds.

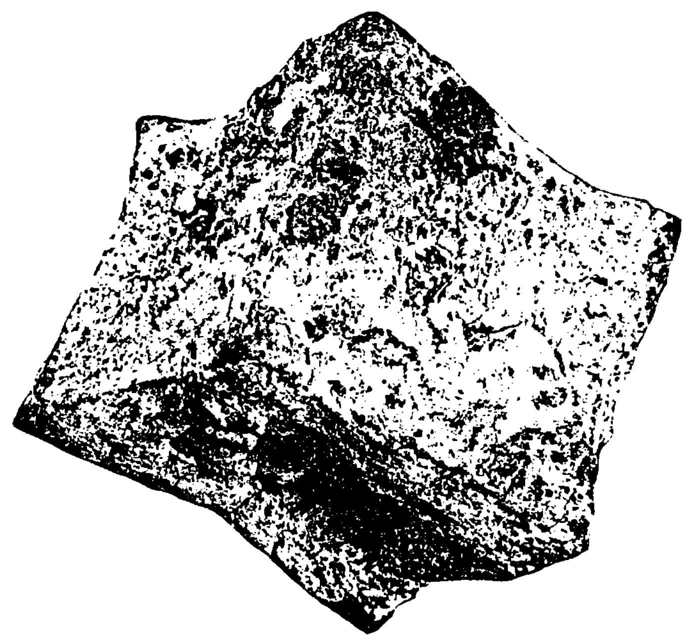


Figure 8. Pseudomorph of malachite and brochantite after a cubiform crystal, probably of gypsum, from the "lower copper bed" at measured section B, x5. The crystal faces are deeply impressed.

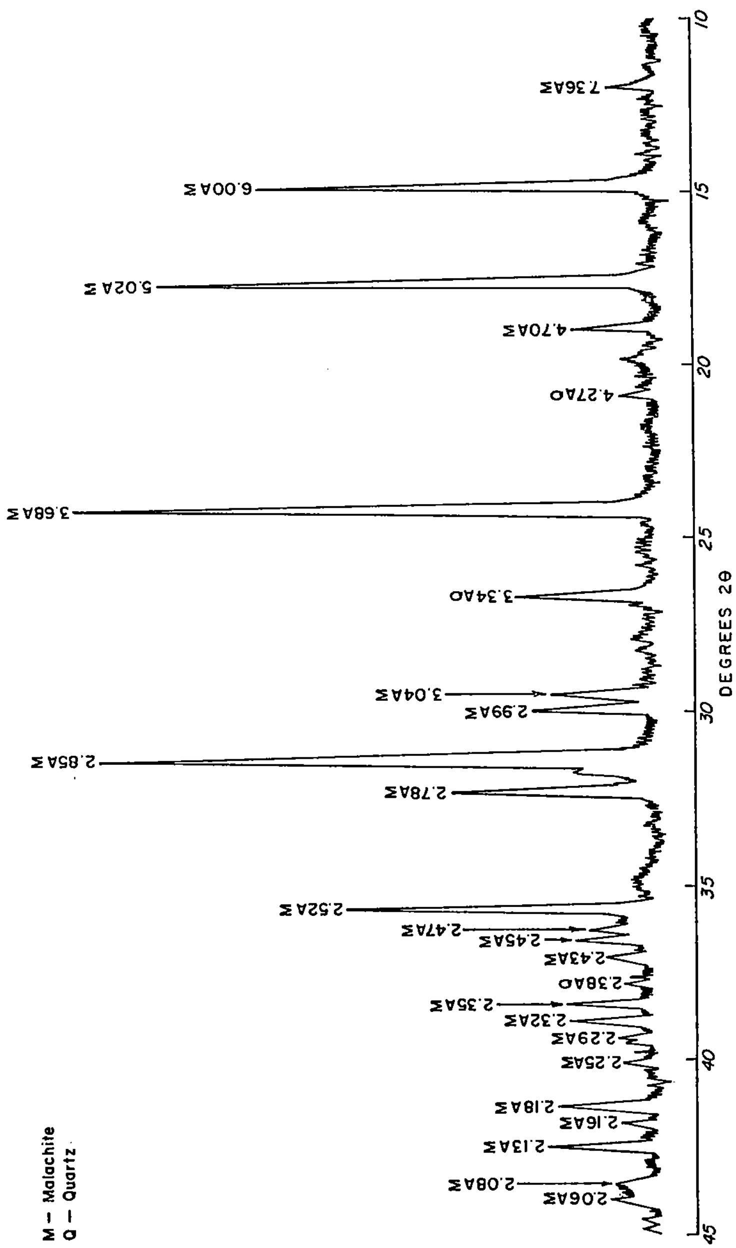


Figure 9. X-ray diffractogram of hand-picked green copper encrustations in the "lower copper bed," NE¼ NE¼ NW¼ sec. 15, T. 1 S., R. 22 W. The material is virtually pure malachite but also contains some quartz and clay.

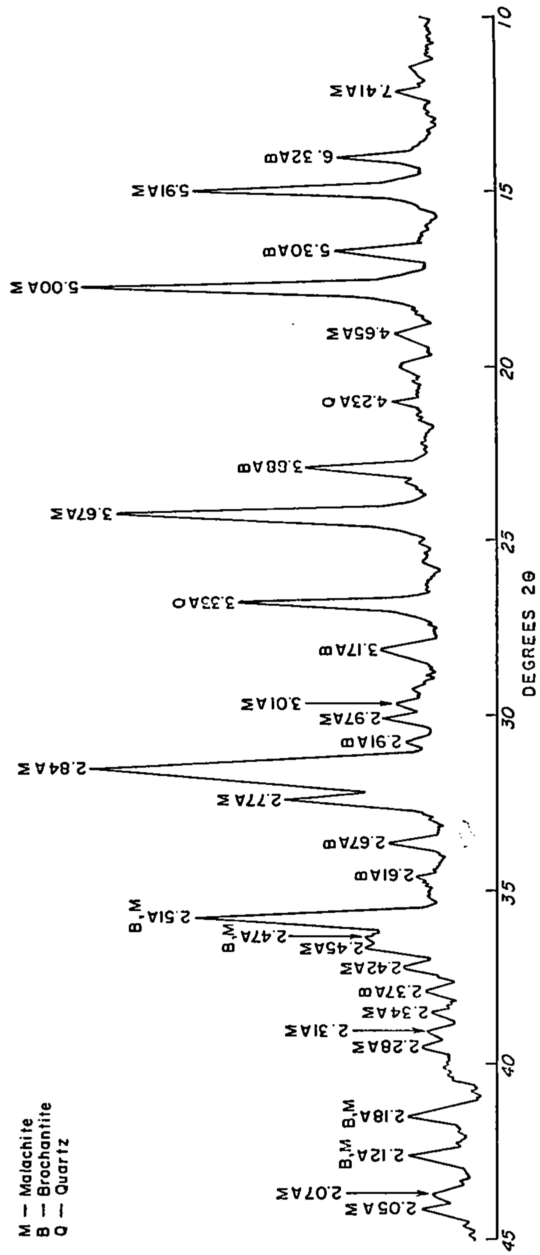


Figure 10. X-ray diffractogram of a copper-bearing nodule from the "lower copper bed" at measured section B, SW¼ SW¼ NW¼ sec. 3, T. 1 S., R. 22 W. Malachite and brochantite are dominant.

Reserves

In the Creta area the copper of the "lower copper bed" has a higher concentration and greater lateral persistence than have other known occurrences in western Oklahoma, and the bed may have commercial significance as a copper ore. It is 6 inches thick and has an average copper content of about 3.8 percent over an outcrop distance of 3 miles.

Although no drilling or trenching was done for this project, it is believed that copper mineralization extends underground in the same range of concentrations as indicated on the outcrop. Tributaries of Gypsum Creek have eroded the copper shale bed into a sinuous outcrop pattern (pl. I), giving more than 0.5 mile of exposure at right angles to the northwest strike of the bed. Persistence in concentration and occurrence of malachite near the heads of valleys, as well as on the outward spurs, indicates that the distribution of this mineral within the bed is reasonably uniform. Furthermore, malachite is known to occur in subsurface outside the Creta area, a minor amount having been observed in the upper part of the Flowerpot at a depth of 215 feet in cores drilled near Duke, 12 miles north of Creta. Despite these inferences, however, drilling downdip from the outcrops will be needed to evaluate the distribution and tenor of the "lower copper bed."

The copper bed is favorably disposed for strip mining by removal of rock overburden not more than 40 feet thick in an area of 1,000 acres. For convenience in setting forth areas of inferred reserves in relation to thickness of overburden, the geologic map (pl. I) has been used. On this map the outcrop of the Flowerpot Shale has been subdivided into two areas: area a_1, in which overburden above the "lower copper bed" is 1 to 10 feet thick, and area a_2, in which the overburden is 10 to 40 feet thick. An average copper content of 3.8 percent is used in estimating reserves for that part of the Creta district for which analyses were made of outcrop samples, including only the areas outlined as a_1 and a_2 on plate I in sec. 34, T. 1 N., R. 22 W., and sec. 3, E½ sec. 4, and secs. 9, 10, 14, 15, 16, T. 1 S., R. 22 W. As thus calculated, the inferred copper content is 16,900 short tons under overburden less than 10 feet thick, and 51,700 tons under overburden 10 to 40 feet thick, or a total of 68,600 short tons of copper in the ground under less than 40 feet of overburden (table 2).

Table 2.—Inferred Reserves of Copper in the "Lower Copper Bed" in the Creta Area

	Area (acres)	*Inferred copper content (short tons)*	*Overburden thickness (feet)*
Area a_1	250	16,900	Range 0-10, avg. 5
Area a_2	750	51,700	Range 10-40, avg. 25
Total	1,000	68,600	

Southwestward above the top of the Flowerpot Shale rises the benched escarpment of the Blaine Formation, which increases the overburden by as much as 120 feet. This additional thickness is probably well in excess of that which could be economically removed.

The "upper copper bed," 4 inches thick and with an average of about 0.8 percent copper, is 5 feet above the "lower copper bed" and would be removed by any stripping to work the "lower copper bed." No reserves have been calculated for it, as the tenor probably is too low for copper ore.

In considering the recovery of metal values from the "lower copper bed," it is clear from the chemical analyses that only copper could be expected.

Origin

In the southwestern United States copper minerals occur at numerous localities in stratified rocks of Permian, Triassic, and Jurassic age. The host rocks to the copper minerals are generally gray or light brown, but the dominance of red sandstone and shale in the associated sequence had led to a characterization of the deposits as "red beds copper." States in which such occurrences are common include Arizona, Utah, Colorado, New Mexico, Texas, and Oklahoma (Fischer, 1937; Merritt, 1940; Soulé, 1956).

The chief minerals in the "red beds" copper deposits are chalcocite and malachite. Lesser amounts of bornite, chalcopyrite, chrysocolla, and native copper also occur in some deposits. Chalcocite is considered to be the normal primary mineral from which the secondary minerals have been derived. The copper minerals occur as fissure fillings, as nodular masses, as pseudomorphs after other minerals or fossil wood, or as interstitial replacement masses.

Commonly the deposits are lenticular or occur in definite beds. Most deposits in a particular area are restricted to a single strati-

TABLE 3.—QUANTITATIVE ANALYSES OF COPPER AND BORON IN SAMPLES FROM THE FLOWERPOT SHALE

(J. A. Schleicher, analyst)

Measured-Section and Sample Number	*O. G. S. Lab. No.*	*Thickness of Sample (feet)*	*Lithologic Description*	*Copper* (Weight %)*	*Boron† (ppm)*
A-1	10475	0.4	Shale, greenish-gray; locally contains flakes of malachite; analysed sample contained malachite. "Upper copper bed"	1.27	118
A-2	10474	1.0	Shale, greenish-gray	0.22	107
A-3	10473	0.5	Shale, greenish-gray; no malachite observed. "Lower copper bed"	0.41	133
A-4	10472	1.3	Shale, greenish-gray	0.08	145
B-1, B-2	10463	0.2	Gypsum, white, very finely crystalline (Haystack Gypsum Member of Blaine Formation)	0.0025	---
B-3	10462	0.5	Shale, reddish-brown	0.0005	115
B-4	10461	0.5	Shale, reddish-brown	0.0006	116
B-5	10460	0.3	Shale, greenish-gray	0.0017	82
B-6	10459	0.5	Dolomite, light-gray, microgranular, platy, compact	<0.0005	---
B-7	10458	0.9	Shale, greenish-gray; locally contains flakes of malachite; analysed sample did not contain visible malachite. "Upper copper bed"	0.38	90
B-8	10442	0.5	Shale, greenish-gray; contains much malachite; analysed sample contained malachite. "Lower copper bed"	4.45	250
B-9	10457	1.0	Shale, greenish-gray	0.17	127
B-10	10456	0.5	Shale, reddish-brown	0.0014	112
B-11	10455	0.5	Shale, reddish-brown	0.0005	111
C-1	10454	0.5	Shale, reddish-brown	0.0013	133
C-2	10443	0.5	Shale, greenish-gray; contains much malachite; analysed sample contained malachite. "Lower copper bed"	4.29	250
C-3	10453	0.5	Shale, reddish-brown	0.0009	112
D-1	10452	0.5	Shale, reddish-brown	0.0008	123
D-2	10451	0.3	Shale, greenish-gray; locally contains malachite; analysed sample contained malachite. "Upper copper bed"	0.73	110
D-3	10444	0.6	Shale, greenish-gray; contains much malachite; analysed sample contained malachite. "Lower copper bed"	2.65	200
D-4	10450	0.5	Shale, reddish-brown	0.0009	118
E-1	10466	0.5	Shale, reddish-brown	0.0028	125
E-2	10465	0.5	Shale, greenish-gray; locally contains flakes of malachite; analysed sample did not contain visible malachite. "Upper copper bed"	0.0115	120
E-3	10464	0.5	Shale, greenish-gray	0.0375	130

* Analyses by wet method in samples containing more than 0.10% copper. Smaller amounts determined on Jarrel-Ash 1.5-meter emission spectrograph.

† All determinations on Jarrel-Ash 1.5-meter emmission spectrograph.

graphic unit, although at places more than one copper-bearing unit is found in the same formation.

Most "red beds" copper deposits are too small, or have too little copper, to be economically exploited. The tenor is generally about 2 percent copper but ranges from a few tenths of 1 percent to nearly 10 percent. Numerous attempts to mine these deposits have ended in failure. One exception is the Stauber mine in Guadalupe County, New Mexico (Soulé, 1956, p. 24-28). It was operated intermittently from 1925 through 1954, and the grade of ore was from 1 to 5 percent copper. It was more than 2 percent in 1954. Malachite is the dominant copper mineral at the Stauber mine, and it occurs in sandstone 2 to 17 feet thick at the base of the Dockum Formation of Triassic age.

Copper deposits of the Creta area share many features with those in other southwestern states. Problems relating to origin also are similar. In southwestern Oklahoma the copper-bearing beds are nearly horizontal. Near Creta they are undisturbed by faulting, and there is no other apparent structural feature, such as anticlinal or synclinal folding, which might favor the epigenetic concentration of copper from the Permian strata of the region into two thin copper-bearing shales. Furthermore, the known igneous intrusions of southwestern Oklahoma are older than the Late Cambrian Reagan Sandstone, and in the Creta district these igneous rocks lie unconformably beneath the Reagan Sandstone at a probable depth of 12,000 feet. As a result it is most difficult to appeal to a hydrothermal source for the copper in these Permian sediments. A sedimentary origin under stratigraphic control is preferred by the writers, the copper being derived from sea water and deposited with the clastic sediments.

In Permian time in southwestern Oklahoma the source of most clastic sediments lay to the east and perhaps southeast, as some of the sediments are coarser in that direction, and many of them grade into evaporites in subsurface to the west. Probably this source area was rich in copper and was the ultimate source of that element. Weathering of igneous rocks in the nearby Wichita Mountains could not have supplied copper to the Flowerpot Shale of the Creta district, for those mountains were not then exposed, already having been covered in earlier Duncan time.

A marine origin of the "lower copper bed" is supported by investigations of the clay minerals in the shale. Clay minerals, notably illite, are believed to indicate increasing salinity by their increasing boron content (Frederickson and Reynolds, 1960). Many shale samples collected from the upper Flowerpot in the Creta area, shown by X-ray-diffraction investigations to be composed dominantly of illite, were analyzed for boron (pl. II; table 3). Normal red shales and green shales alike contain boron averaging 115 parts per million, whereas shale of the "lower copper bed" is conspicuous in containing more than twice that amount of boron. The two samples containing the highest concentrations of copper, respectively 4.45 and 4.29 percent, also contained the highest percentage of boron, 250 parts per million. These data suggest that the copper minerals were deposited in water of higher salinity than of the water in which the associated shales were laid down. Presumably the original copper mineral was chalcocite, which has now been converted into malachite by weathering in the zone of oxidation.

Addendum

After the manuscript for this report was sent to press, additional information was obtained from two trenches cut downdip from the outcrop of the "lower copper bed" in the Creta district. Observations in the trenches and chemical analyses of samples from them prove (1) that the "lower copper bed" persists in thickness and copper content for at least 300 feet horizontally, back from the outcrop, (2) that chalcocite is the dominant copper mineral under moderately thin cover a short distance downdip from the outcrop, and (3) that the malachite-brochantite nodules are restricted in their occurrence to weathered outcrops.

The first trench, 800 feet south of the center of the north line of sec. 10, T. 1 S., R. 22 W., 50 feet horizontally downdip from the outcrop, was started at the top of the Kiser Dolomite Bed. It reached the top of the "lower copper bed" at a depth of 9.4 feet. The bed is 7 inches thick, greenish gray, and contains bright-green malachite in the form of encrustations and subhorizontal or cross-cutting veins as much as 1 mm thtick. Channel samples from the trench, analyzed by J. A. Schleicher, show that the 7-inch "lower copper bed" contains 3.41 percent copper, whereas the underlying 10 inches of greenish-gray shale contains 0.42 percent copper.

The second trench, about 500 feet N. 75° W. of the first trench, is 300 feet downdip from the nearest outcrop. Trenching was begun at the top of the Kiser Dolomite Bed, and the top of the "lower copper bed" was reached at a depth of 10.4 feet, immediately below a bed of impure gypsum 0.7 foot thick. Malachite is absent from this bed but copper occurs on it as finely divided chalcocite (Cu_2S). Not visually detectable, the chalcocite was identified through X-ray-diffraction studies by Charles J. Mankin and William H. Bellis. It is alpha (low-temperature) chalcocite. Consecutive 2-inch channel samples of the gray shale at and below the stratigraphic position of the "lower copper bed" were analyzed by Schleicher. The upper four samples, representing 8 inches of gray shale which include the "lower copper bed," contain in descending order 2.40, 3.30, 5.86, and 3.85 percent copper, or an average of 3.85 percent in the 8-inch stratum. The lower three samples, representing 6 inches of gray shale below the "lower copper bed," contain an average of 0.12 percent copper.

In the fresh exposures of neither trench were nodules of malachite and brochantite found, thus confirming the previous observations that such nodules originate by weathering at the outcrop face.

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