Copper Sulfides in the Permian Redbeds of Kansas

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ABSTRACT

Redbed copper sulfide mineralization occurs sporadically within the Permian Wellington Formation of south-central Kansas. The sulfides occur as spore replacement and irregular stringers, and are never of ore-grade concentration in the host gray-green shale or dolomite. Reflected and transmitted light microscopy and electron microprobing of samples prepared from cored material, and X-ray diffractometry and atomic absorption spectrophotometry of other cored material were used to investigate the copper sulfide mineralization.

The paragenetic sequence of ore mineralization is pyrite→chalcopyrite→bornite→digenite→anilite-djurleite→covellite→azurite→malachite. This sequence is interpreted as indicating a drop in copper content of the ore fluid as distance from the source of copper increased. Source of the metal could have been the Wichita Mountains in southern Oklahoma or a geopressured brine from sediments in the Ouachita Mountains in southeastern Oklahoma.

INTRODUCTION

Redbed copper deposits are stratibound copper sulfide occurences which occur as layers or disseminations in organic-rich shales and as replacements of organic material in continental sandstones. Although the ore occurs in dark colored, reduced sediments, the host sequence is generally characterized by substantial amounts of red, oxidized clastics. Such deposits are found in many shales and sandstones in Kansas, Oklahoma and Texas. In these three states, copper sulfide mineralization is more common, but the deposits in shale are of greater economic significance (Johnson, 1976).

Ore-grade material was mined from the Creta copper-bearing shale in south-western Oklahoma from October 1965 to February 1975, when a drop in the price of copper forced the mine to close. The Creta copper shale has an average copper content of 2.3 percent, and chalcocite (Cu_2S) is the mineral that is being mined. At the nearby Magnum copper prospect, malachite ($CuCO_3Cu(OH)_2$) is the most abundant copper mineral identified so far, although chalcocite may be the dominant mineral in the subsurface. The Magnum site averages one percent copper.

In Texas, three prospects have been identified in the San Angelo Formation. In each case the ore mineral is chalcocite, which weathers to malachite and azurite ($Cu(CO_3)_2(OH)_2$) near the surface (Johnson, 1974). The mineralization occurs in shales and mudstones associated with gypsum and dolomite, much as in the Creta and Magnum deposits of Oklahoma. Copper content of the Texas prospects averages between 1 and 2 percent.

As part of the expanding search for economic redbed copper deposits in the Midcontinent region, the Kansas Geological Survey (K.G.S.) began exploratory drilling in Harper, Sedgwick, and Summer Counties in south-central Kansas in the summer of 1975 (Fig. 1). The location of the sixteen drill sites was based upon the known distribution of copper mineralization in outcrop in the study area. A geological map of the three-county study area appears in Figure 1.

Although no ore-grade material was encountered, several areas of subeconomic copper sulfide mineralization were found. The purpose of this thesis is twofold: first, to describe the copper sulfide minerals found in the thesis area and place them in paragenetic sequence, and second, to determine the relationship of the host rock and its depostional history to the copper sulfide mineralization.

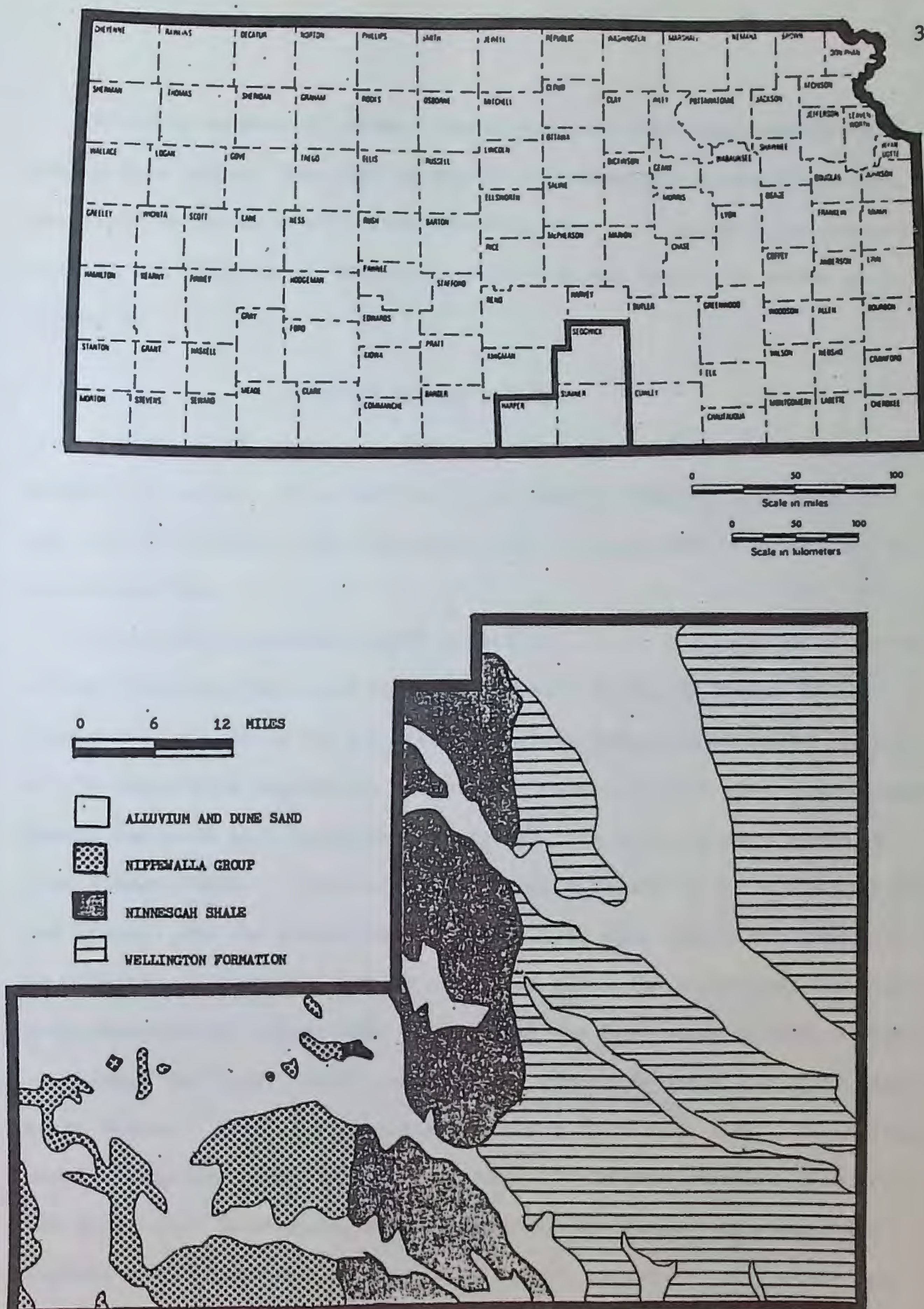

Figure - 1 Kansas Counties with thesis area outlined (above), and geologic map of thesis area (after Waugh and Brady, 1976)

Previous studies of redbed copper sulfides have been undertaken in Kansas (see below), but this is the first investigation which involves the study of cored samples from the subsurface. A township and range map showing the location of the cores drilled by the K.G.S. is shown in Figure 2.

PREVIOUS INVESTIGATIONS

Norton (1939) noted the presence of copper sulfides in the Permian redbeds of Kansas. He stated that chalcopyrite ($CuFeS_2$) and malachite are the ore minerals, but did not provide further details concerning the mineralization.

Hill (1967) examined copper mineralization in the gray-green shales of the Ninnescah Shale and in the Runnymeade Sandstone Member of the Ninnescah, as well as in the Milan Limestone Member which marks the top of the underlying Wellington Formation. Traverses were made from Kingman County eastward into Sedgwick County, and from Harper County eastward into Sumner County. Traverse samples were analyzed by X-ray spectroscopy for copper, and the copper-bearing mineral in each sample was found to be malachite. Among 411 samples collected along the traverses, the highest concentrations of copper were detected in the Runnymeade Sandstone Member.

Waugh and Brady (1976) examined the Ninnescah Shale and Milan Limestone Member. Samples were collected along traverses, both from outcrop and from shallow auger holes. More than 400 samples were obtained from 120 localities in Kingman, Harper, Sedgwick and Sumner Counties. The highest concentrationsof copper found in the course of their study are in the Runnymeade Sandstone Member in Harper County. Waugh and Brady identified the copper-bearing minerals as malachite in association with a small amount of azurite.

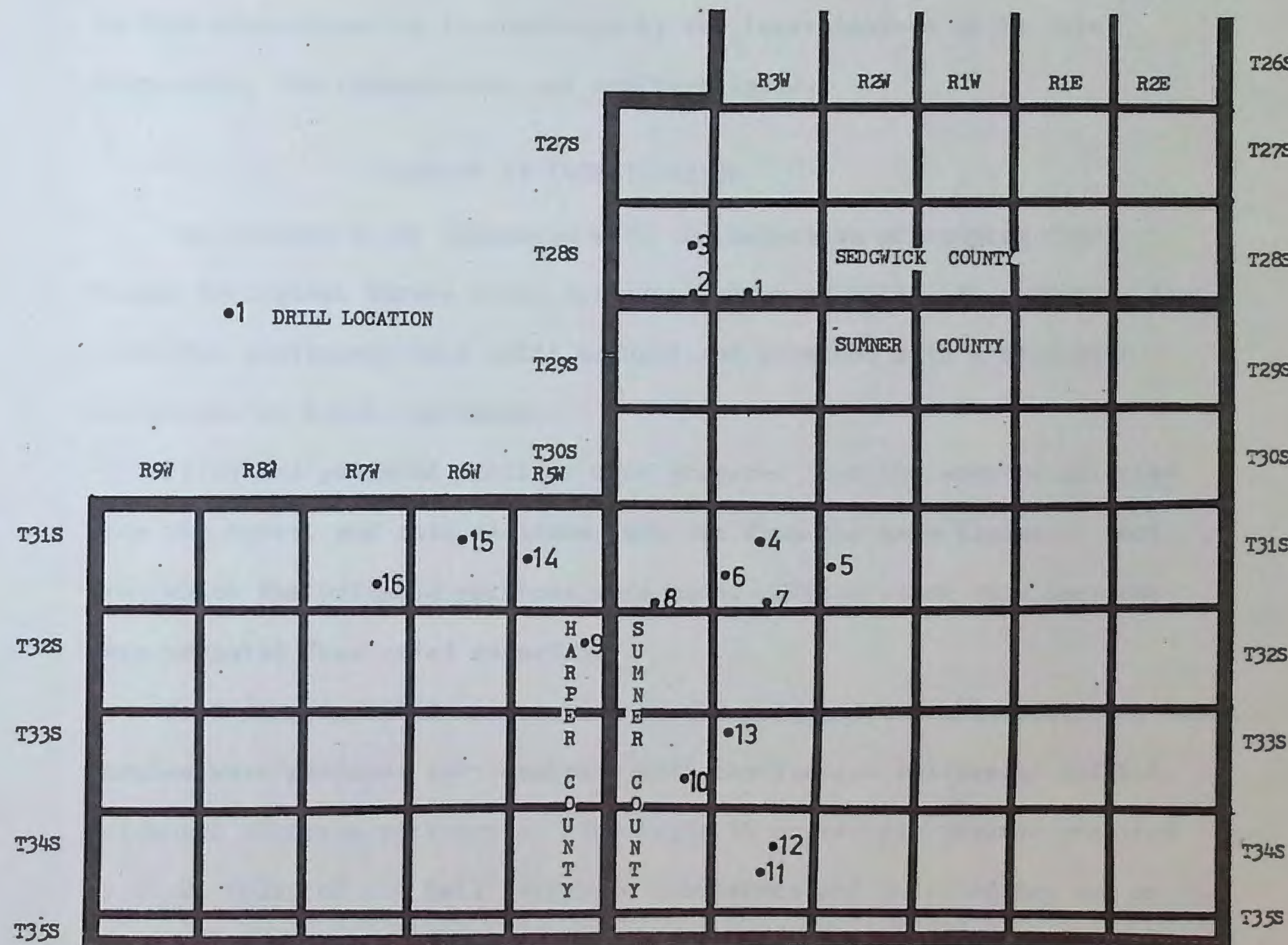

Figure 2 - Location of K. G. S. redbed cores

Long and Angino (1976) investigated copper mineralization in the Milan Limestone Member and reported chalcocite, covellite (CuS), and malachite. The highest copper enrichment found by atomic absorption spectrophotometry is about 1.5 percent, and no zinc enrichment was detected in any of the outcrops sampled by Long and Angino. The copper sulfide mineralization is considered by the investigators to be late diagenetic, low temperature, and sabkha-related.

METHODS OF INVESTIGATION

The present study commenced with the selection of samples from Kansas Geological Survey cores for preparation as polished sections. The cores had previously been split in half and examined with a binocular microscope by K.G.S. personnel.

Fifty-two polished sections were prepared from the samples selected from the cores, and thin sections were cut from the same blocks of rock from which the polished sections were made. Eleven other thin sections were prepared from cored material.

Following detailed examination of the polished and thin sections, seven samples were prepared for analysis with the Indiana University E.T.E.C. automated electron microprobe. The Magic IV correction program prepared by J. W. Colby of the Bell Telephone Laboratory and modified for use on the P.D.P.-11 computer by L. Finger, of the Carnegie Institution (Geophysical Laboratory) of Washington, was used for making Z.A.F. (atomic number, absorbance, and fluorescence) correction of data from the microprobe.

Host-rock mineralogy was investigated by X-ray diffractometry. Four finely pulverized samples of selected redbeds and gray-green shales were run on a Philco X-ray diffractometer at a speed of 2 degrees 2 θ per minute, using Cu K_{α}-radiation.

Atomic absorption spectrophotometry of various dolomite units in the redbed cores was conducted by researchers at the Kansas Geological Survey. Their data have been used in the preparation of this thesis.

LOCAL STRATIGRAPHY AND HOST ROCK DESCRIPTIONS

In the Midcontinent region of the United States, formations belonging to the Guadalupian, Leonardian and Wolfcampian Series contain cupriferous rock units. Stratigraphic units of the Midcontinent Permian are depicted in generalized fashion in Figure 3 (after Johnson, 1976).

Texas

In north-central Texas the Pease River Group of the Guadalupian Series contains copper sulfide deposits which occur in the Blaine Formation (Stroud, et al., 1970); and in the Flowerpot Mudstone Member and Duncan Sandstone Member of the San Angelo Formation (Smith, 1976). The Blaine and San Angelo Formations have a combined thickness which ranges from 610 to 1,150 feet.

Pendary (1964) states that the Blaine Formation comprises alternating beds of gypsum, anhydrite, and carbonate, as well as a few detrital clastic beds. The carbonate beds are dolomites, which are associated with evaporites and which appear to have formed as the result of the dolomitization of pre-existing aragonitic and calcitic sediments.

The Blaine Formation was deposited in a large lagoon surrounded by low, arid to semi-arid landmasses. Copper sulfides occur in sediments of the Blaine Formation that formed in lagoonal environments and in channel-scours. Copper sulfides of the San Angelo Formation occur in sandstones and shales which were deposited in fluvial and deltaic systems. A sabkha-diagenetic model has been proposed by Smith (1976) for the copper sulfides in the San Angelo Formation.

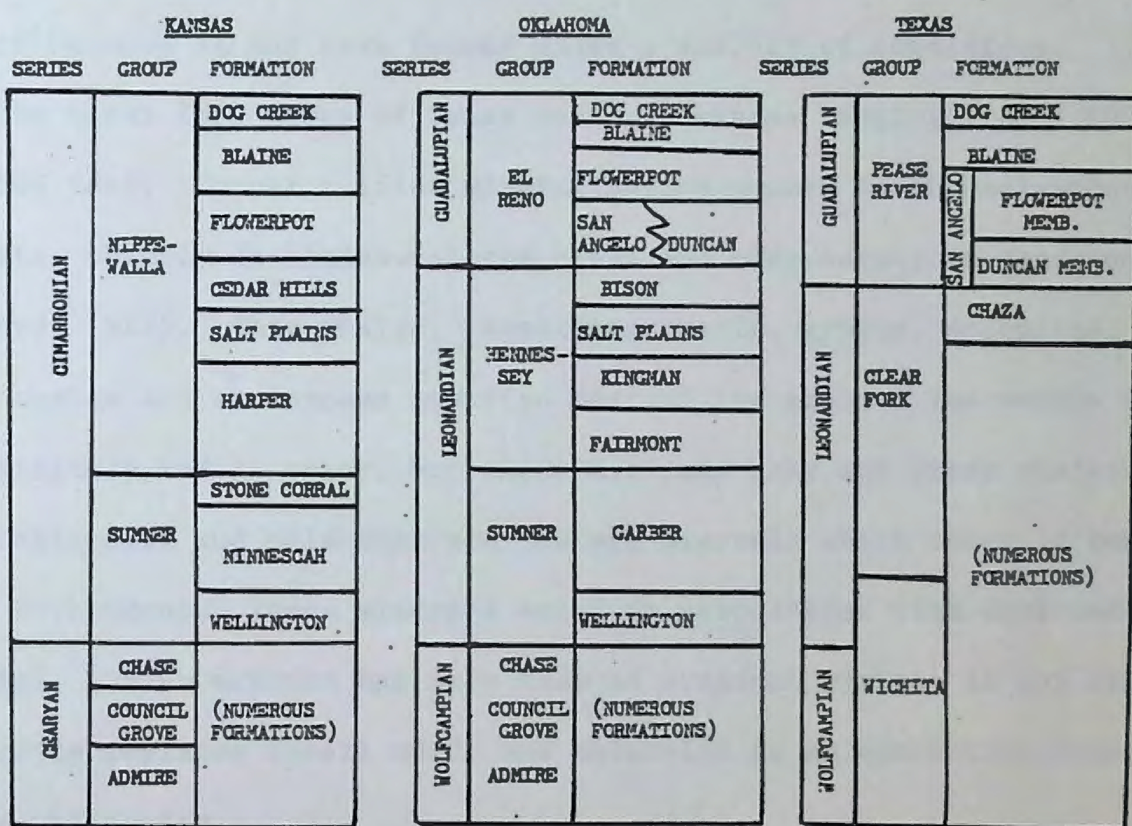

Figure 3 - Generalized stratigraphic column of the Midcontinent Permian (after Johnson, 1976)

Stroud does not mention which copper sulfide mineral occurs in the San Angelo Formation, but Smith (1976) writes that ore minerals in the San Angelo Formation are pyrite, chalcocite, covellite, azurite and malachite. Pyrite has replaced organic matter, chalcocite has replaced pyrite, and azurite and malachite formed during Holocene oxidation of the sulfides. The position of covellite in the paragenetic sequence is unclear because it may have formed under a variety of conditions.

The Clear Fork Group of Texas has a thickness ranging from 1,200 to 1,500 feet. Copper sulfide mineralization occurs in channel-scour deposits, chiefly in bluish-colored clays and more rarely in sandstones (Richard, 1915). Thin shales, limestones, marls, gypsum, dolomites, sandy shales and sandstones comprise most of the group. The strata are predominately red in color, but there are many gray and green shales.

Chalcocite and malachite are the ore minerals which occur in the Clear Fork Group. These minerals occur in association with carbonaceous material, but no mention has been made of original pyrite, if any exists. Chalcocite replaces fossil wood, and malachite is an alteration product of the chalcocite.

In Texas the Wichita Group has a thickness of 1,500 to 1,600 feet in Texas, and copper sulfides occur in sediments deposited in a channeling and scouring environment. The formation comprises shales, limestone, and calcareous marls. The dominant copper sulfide is chalcocite which has replaced fossil wood. Azurite and malachite have formed during alteration of the chalcocite, but no mention has been made of any original pyrite.

Oklahoma

In Oklahoma copper sulfide mineralization occurs in the El Reno Group and in the Sumner Group. The ore minerals occur in the Flowerpot Shale and San Angelo Formations of the El Reno Group, and in the Wellington Formation of the Sumner Group.

The Flowerpot Shale is 185 feet thick and contains two economic cupriferous shales (Dingess, 1976) including the Meadows copper shale (30 to 35 feet below the top of the formation), and the Prewitt copper shale (35 to 40 feet below the top of the formation).

Malachite is the dominant copper mineral in the Meadows copper shale, but most investigations have involved study only of surface exposures of the shale, or exposures in shallow pits. Chalcocite has been identified under 10 to 15 feet of overburden and may be the primary ore.

Chalcocite and chalcocite-digenite ($Cu_{1.8}S$) intergrowths replace pyrite in the Prewitt copper shale. Pyrite formed as a replacement of cases of the megaspore Triletes (Hagni and Gann, 1976). Exact composition of the mineral identified as digenite was not given by these authors. Covellite exists as a local alteration product of the other copper sulfides, and malachite is the most abundant copper mineral in the weathered outcrop.

The Meadows copper shale is a laminated, medium-gray silty shale, and the Prewitt copper shale is a medium-gray, gypsiferous silty shale. The Flowerport Formation was deposited under both brackish-water and marine conditions.

Copper sulfide mineralization found in basal sandstones of the San Angelo Formation is similar to that reported for the same formation in north-central Texas. The name "San Angelo" is applied to the copper-bearing unit in northern Texas and in Oklahoma south of the Wichita Mountains, but north of the Wichita Mountains, the name Duncan Sandstone is applied to equivalent and similar strata.

The Wellington Formation of the Sumner Group has two distinct types of ore mineralization. The first, recognized in south-central Oklahoma, occurs in sandstone deposited in channel-scour environments (Shockey, Renfro, and Peterson, 1974). The second type is more like the kind of ore mineralization examined in this report, and occurs in north-central Oklahoma. Cox (1978) writes that the copper sulfides in north-central Oklahoma occur in fine-grained carbonates and gray shales which were deposited in shallow marine and tidal-flat environments.

In the Wellington Formation of Oklahoma two areas of copper mineralization are known and in each chalcocite is the ore mineral. In south-central Oklahoma, Wellington channel-scour deposits have chalcocite and native silver as the primary ore minerals, and minor amounts of lead, zinc, gold and other metals are present (Shockey, Renfro, and Peterson, 1974). The ore deposit was formed at an oxidation-reduction interface in the sandstone by a copper-silver solution front. In north-central Oklahoma the primary Wellington ore mineral is chalcocite. The chalcocite occurs as fillings of burrows, in silica vugs, and as replacement of earlier pyrite, which itself replaced spore material.

Kansas

This study involves the first examination of cored material from areas of copper mineralization in Kansas. The formations penetrated by the cores include the Ninnescah Shale and the Wellington Formation.

In south-central Kansas the Ninnescah Shale consists predominantly of oxidized, red silty shale, and as such is not a promising unit for copper sulfide mineralization. Malachite occurs in the seven-foot-thick Runnymeade Sandstone Member, which marks the top of the Ninnescah, but cores which I examined do not contain copper sulfides. Logs of the cores appear as Appendix A.

The Ninnescah Shale was penetrated at drill locations 14 and 16, which are situated in the extreme western part of the study area. According to Swineford (1955), 80% of the Ninnescah Shale in this part of the state comprises red siltstone. In the cores, the Ninnescah Shale was distinguished from the underlying Wellington Formation by the generally lighter color of the redbeds, and by the presence of thin sandstones and arenaceous shales.

At drill location 15, which is situated between drill locations 14 and 16, the Wellington Formation was penetrated by the core. It was not penetrated at drill location 14 or 16, where coring commenced beneath the Wellington. All cores from holes east of drill location 15 recovered Wellington Formation material, including the copper sulfide minerals examined in this study. The Wellington can be divided into an upper gray shale member, a middle rock salt member, and a lower anhydrite member. Redbeds are progressively more common in the upper gray shale member towards south-central Kansas (Anderson, 1941).

Wellington beds cored in the study area are classified as part of the upper gray shale member on the basis of generally darker redbeds and alternating thin redbed and gray-green shale units. Only the core from drill location 2 contains material from below the upper gray shale (and redbed) member. Here a thick, salty gray shale unit is encountered, and it is undoubtedly the middle rock salt member. It contains no copper sulfide mineralization.

X-ray diffractometry of four cored samples of shale shows that the mineralogy of Wellington redbeds and gray-green shales is basically similar. Diffractometer patterns were obtained from: 1) a light gray shale from drill location 2; 2) a dark gray shale from the same drill location; 3) a grayish-red shale from drill location 7; and 4) a dark red shale from drill location 15.

Quartz, dolomite, and gypsum produced prominent peaks in each diffractometer pattern, with quartz being more abundant in redbeds than in gray-green shales (as judged by the relative heights of the diffractomemter peaks). No hematite peaks were found, but red shales did have an unusually high background from about 15° to 29°2θ. This high background may have been caused by fluorescence of iron in very fine-grained hematite by Cu K_{α}-radiation. Hematite-stained quartz is illustrated in Figure 4.

Swineford (1955) examined redbeds in the study area in some detail using X-ray diffractometry. Gray-green shales in the Wellington Formation are primarily composed of illite clays, with detectable montmorillinite (smectite) or other expandable mixed-layer minerals. Predominance of illite in the gray-green shales is indicative of deposition under marine conditions. Clay minerals in the Permian redbeds are predominantly illite and chlorite. The purple shales of the Wellington may owe their color to partial reduction of Fe^{3+} by organic matter. Lighter red and red-brown shales in the formation may owe their color to the presence of iron in different valence states (Berendsen, oral communication, 1977).

Quartz grains in the redbeds are larger and more angular than those in gray-green shales. According to Swineford, most of these quartz grains have internal characteristics of igneous (plutonic) quartz. Dolomite and calcite exist in the Wellington Formation as small, rounded grains in micritic dolomite and limestone units. Carbonate veinlets are commonly associated with copper sulfide mineralization in this formation.

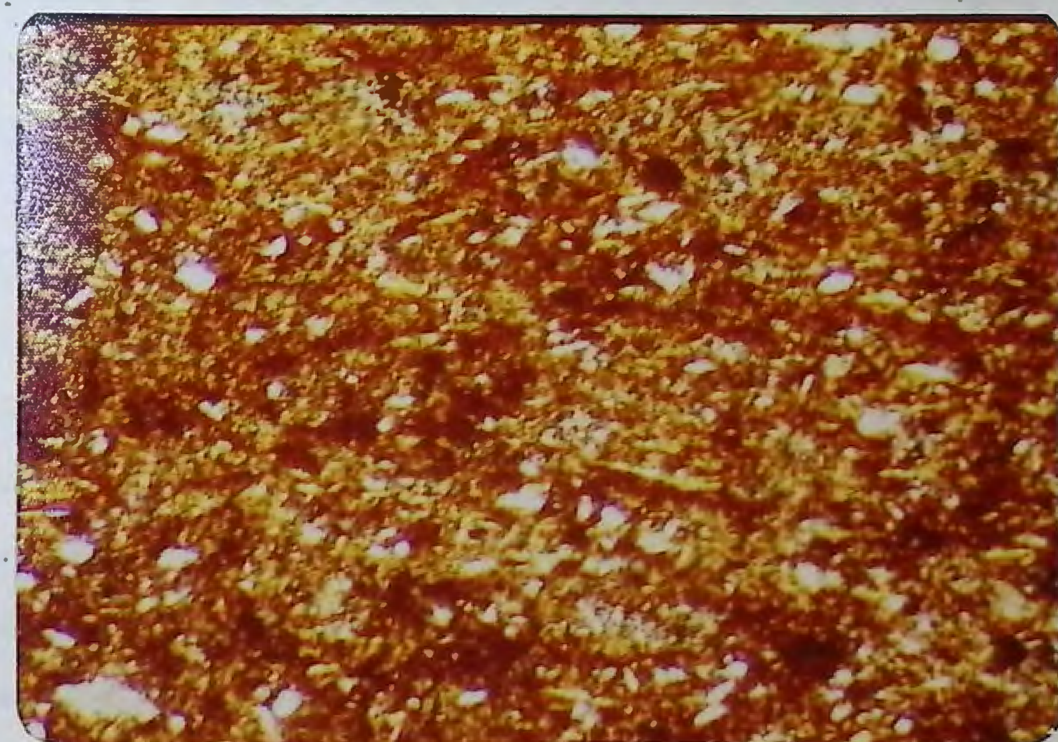

Figure 4 - Hematite-stained quartz in redbed unit
(from drill location #3, 51.30 ft. depth,
plain transmitted light)
⟵ 0.45 mm. ⟶

Swineford (1955) believes that the "Milan Limestone" of the Wellington should be called the "Milan Dolomite" because of its mineral content as determined by X-ray diffractometry. The Kansas Geological Survey has classified most of the carbonate beds in cores described in Appendix A as dolomites.

Veinlets in the Wellington Formation of north-central Oklahoma are described as actually being filled vugs. Cox reports that minor fine calcite grew around the rims of vugs or veinlets, followed by a silica flood that filled remaining voids.

In Kansas, large euhedral carbonate grains rim the veinlets, surrounding and partially replaced by younger, large euhedral quartz crystals. A second generation of very fine-grained quartz is the most abundant mineral phase in the veinlets, and this phase corrodes the surface of older, larger euhedral quartz. Because dolomite predominates over limestone beds, and because copper sulfide mineralization in Kansas is associated either with micritic dolomite or the vugs or veinlets, carbonate in these veinlets may be dolomite. Figure 5 illustrates copper sulfide grains in micritic dolomite, and Figure 6 shows large euhedral quartz grains and younger, fine-grained quartz in a veinlet.

Anhydrite and gypsum may both have precipitated directly from the Permian sea (Kullerud, et al., 1956), with gypsum being deposited as a near-shore facies and anydrite being deposited farther off-shore in deeper water. Some anhydrite may have later hydrated to gypsum. Calcium sulfate logged by the K.G.S. is described as gypsum, and occurs as satin-spar gypsum and as gypsum-shale "mush".

Halite is found in the middle rock salt member of the Wellington Formation, which was penetrated by only one core. Salt casts that are

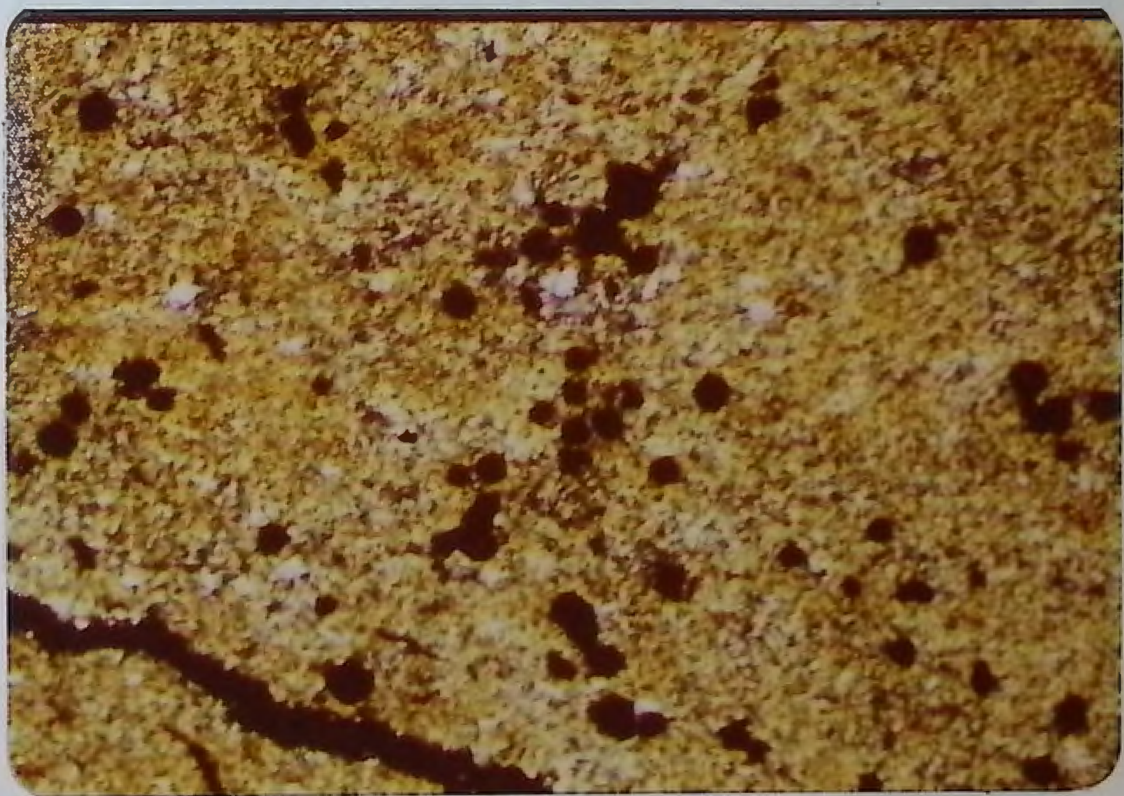

Figure 5 - Copper sulfide grains in micritic dolomite (from drill location #10, 144.50 ft. depth, polarized transmitted light)
← 0.45 mm. →

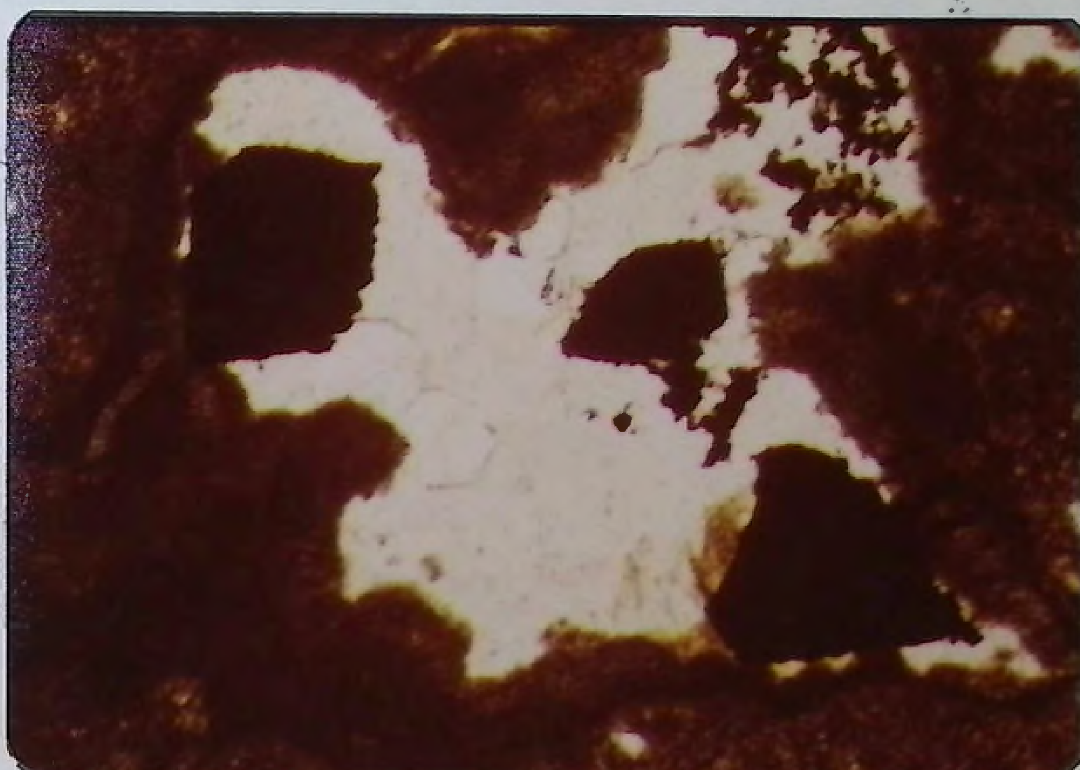

Figure 6 - Copper sulfide grains (black), large euhedral quartz grains (white), and younger fine-grained quartz (tan) in a veinlet (from drill location #7, 53.60 ft. depth, plain transmitted light)

←0.45 mm. →

found in Wellington redbeds suggest halite crystals that have since dissolved away.

Hematite is responsible for the coloration of Permian redbeds in Kansas, and occurs as a thin coating on sand and silt grains. Swineford (1955) identified this coating as hematite because of very weak peaks on the X-ray diffractometer, and reported no large grains of hematite.

Because redbeds in the upper part of the Wellington Formation are discontinuous, the entire formation can be considered to be on thick gray-green shale as far as migration of any ore-forming fluid is concerned. Fully 80% of the Wellington is shale and silty shale, but only 15% is red shale.

Ripple marks and mud cracks visible in surface outcrop in the study area suggests a shallow marine (lagoonal) environment of deposition. Both mechanical and biological agents have extensively reworked many of the beds which contain copper sulfides, and are responsible for creating the vugs that have been filled with the carbonate (dolomite?) whichis so often associated with copper sulfide grains.

The creation of these openings may also have provided pathways for calcium- and magnesium-rich waters that could have dolomitized most of the carbonate beds in the formation. Such a mechanism for dolomitization has been suggested for the Helikian-age Precambrian stratiform copper deposit on Baffin Island, Northwest Territories, Canada (Geldsetzer, 1976). The fluid responsible for the dolomitization could also have transported the copper cations that formed the ore.

ENVIRONMENT OF HOST ROCK DEPOSITION

The Permian-age sediments in the thesis area were deposited in the

Sedgwick Basin, where total thickness of Pennsylvanian and Permian sediments is about 3,500 feet (Lane and Miller, 1965). The Sedgwick Basin is a shelflike, southwardly plunging basin that merges with the Anadarko Basin in northern Oklahoma (Merriam, 1963). The Sedgwick Basin was a shallow sea in Permian time, with isolated patches of fern-like or similar vegetation in the nearby highlands, and was surrounded by brackish-water swamps (Tasch, 1960). Connection with the open sea was provided through the Delaware and Midland basins to the south in eastern New Mexico and western Texas.

In late Pennsylvanian time, the Wichita Mountains were uplifted along the southern margin of the Anadarko Basin. The Wichita Mountains consist of granites, rhyolites, gabbros, and anorthosites. The Ouachita Mountains of southeastern Oklahoma consist predominantly of clastic sediments (Sharp, 1978). Low-angle orogenic faulting formed large, overthrusted blocks of Ouachita sediment in late Pennsylvanian-Permian time.

At the same time that orogenic faulting occured in the Ouachitas, large northwest-flowing rivers drained a broad land area in east Texas (Chenoweth, 1959). These rivers reached the Permian sea in east-central Oklahoma and causes the Wellington Formation in that part of Oklahoma to have a much larger clastic component than does the Wellington of north-central Oklahoma or south-central Kansas.

Cox (1978) believes that the Wichita and Ouachita Mountains were sources for most sediment in the Wellington Formation of Oklahoma. However, Swineford (1955) writes that westward coarsening of Permian-age sediment in south-central Kansas suggests a sediment source in the ancestral Rocky Mountains. This source area would be one of granitic igneous rocks, older sediments, and minor metamorphic rocks, with uplifts in Oklahoma being only a minor source of sediment.

COPPER SULFIDES IN KANSAS

Ore Mineralogy

Covellite (CuS) occurs as a near-surface alteration product of primary coppery sulfides in drill core 7. Within 20 feet of the surface azurite ($Cu_3(CO_3)_2(OH)_2$) surrounds and has replaced grains of "chalcocite" (a chalcocite-like phase described below), which have partially altered to covellite (Fig. 7). The azurite is in turn rimmed by malachite ($CuCO_3Cu(OH)_2$), which penetrates the azurite along cracks (Fig. 8). Azurite and malachite occur only in Wellington dolomites, where dolomite supplied the carbonate needed to form these minerals.

The chalcocite-like phase is present in the southern part of the study area, where it replaces pyrite in a manner very similar to that described in the paragenetic sequence reported for redbed copper deposits in Oklahoma (Fig. 9). In addition to replacement of spore-related pyrite, the chalcocite-like phase also occurs as vertical stringers in gray-green shale, in structures that may have been formed by burrowing organisms (Fig. 10).

At drill location 15 the chalcocite-like phase is clearly related to the replacement of spores. Drill cores 10 and 11 contain the chalcocite-like phase in vertical stringers, and in drill core 13 the sulfide grains have characteristics of both spore related and vertical stringer mineralization. The depth at which the chalcocite-like phase first appears increases from 87 feet at drill location 13 to 107.20 feet at drill location 15.

A transition between ore mineralogies of the southern and northern

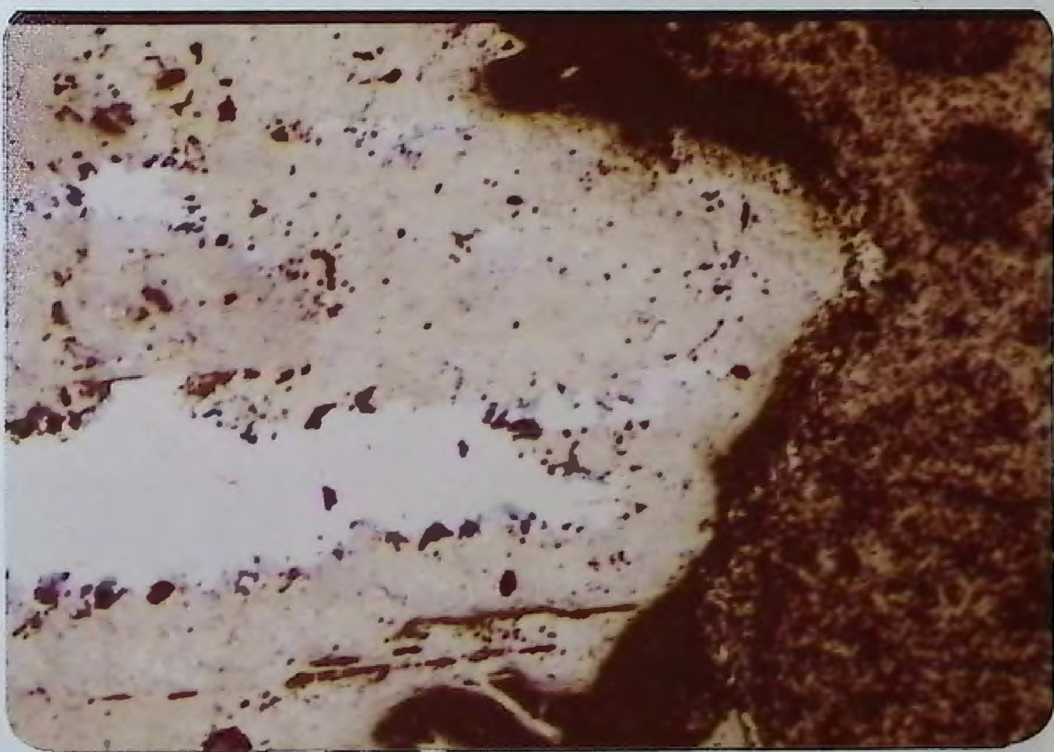

Figure 7 - Chalcocite-like phase (light blue) partially replaced by covellite (dark blue), and surrounded by azurite (light gray) (from drill location #7, 19.70 ft. depth, plain reflected light)

← 0.90 mm. →

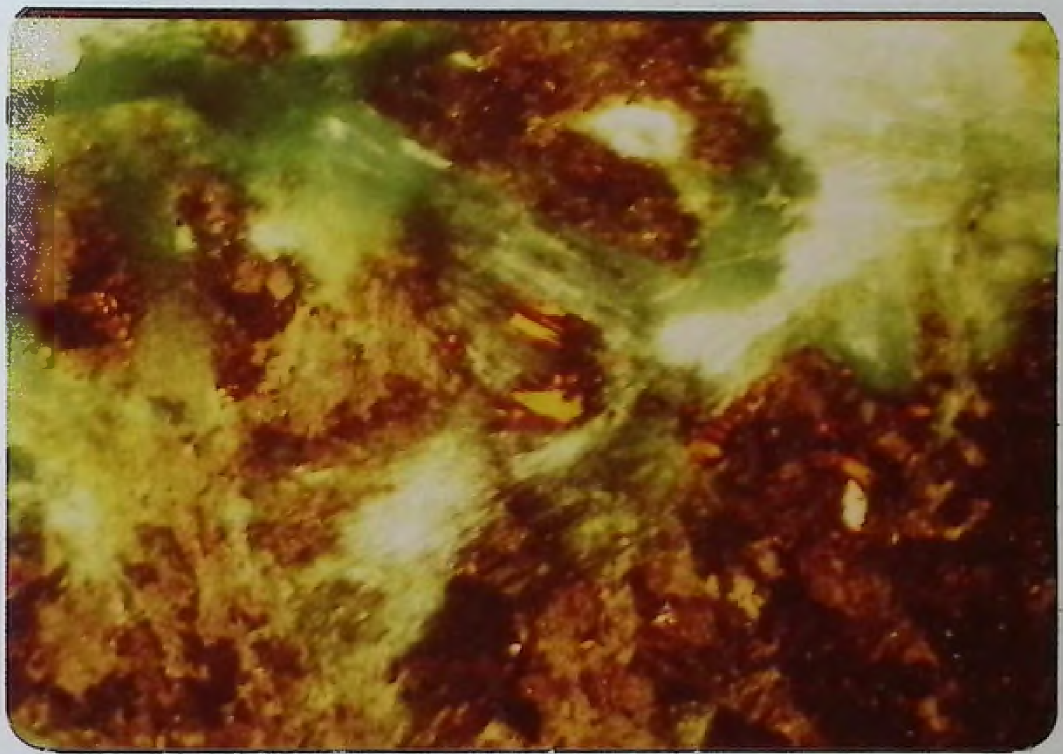

Figure 8 - Malachite (green) penetrating and replacing azurite (brown); covellite (orange) is partially replaced by the azurite (from drill location #7, 19.70 ft. depth, polarized reflected light)

← 0.45 mm. →

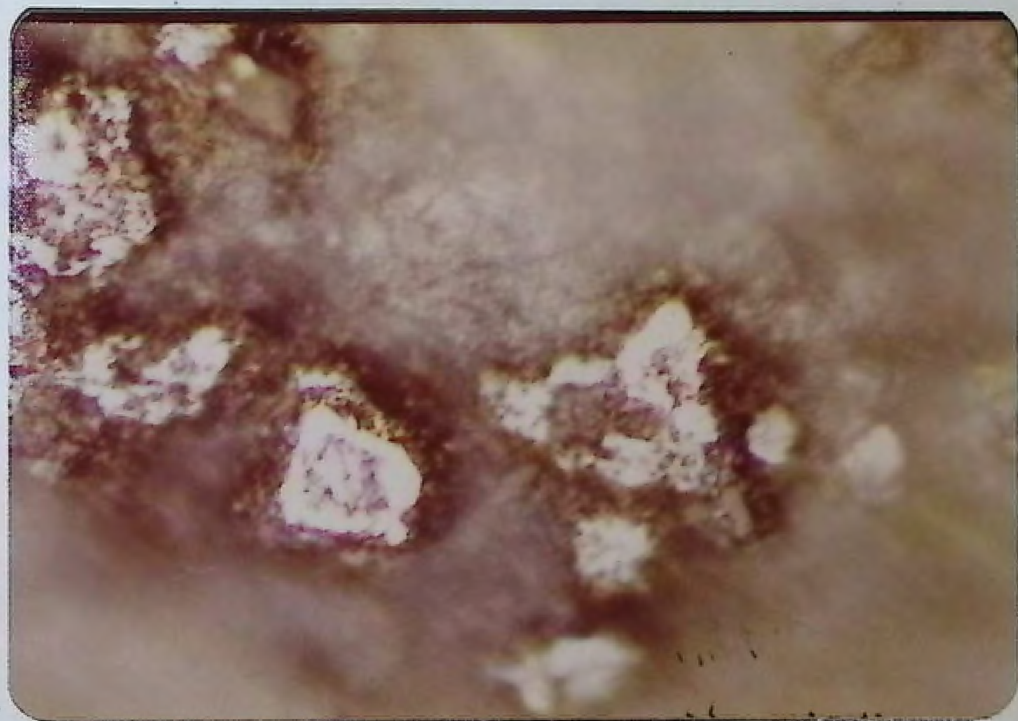

Figure 9 - Chalcocite-like phase (blue) replacing pyrite (white) (from drill location #3, 60:62 ft. depth, plain reflected light)
← 0.45 mm. →

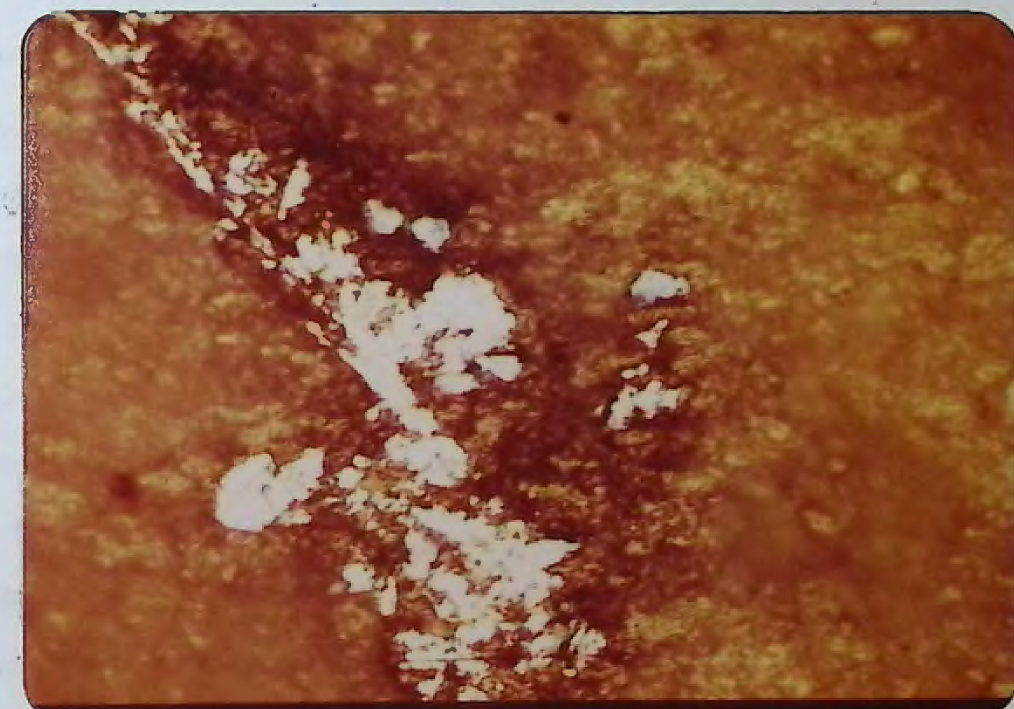

Figure 10 - Chalcocite-like phase (light blue) and covellite (dark blue) in a vertical stringer (burrow?) (from drill location #13, 87.00 ft. depth, plain reflected light)

← 0.45 mm. →

parts of the thesis area occurs at drill location 7. Grains of the chalcocite-like phase are found 19.70 feet below the surface, and grains of chalcopyrite ($CuFeS_2$), partially replaced by bornite (Cu_5FeS_4), occur 55.60 feet beneath the surface in the same core.

Bornite is present in the extreme northern part of the thesis area in drill cores 2 and 3, and is clearly a replacement of chalcopyrite (Fig. 11). Root-like patches of bornite intrude into the chalcopyrite and progressively replace more and more chalcopyrite in grains nearer to the surface. Bornite is first identified at a depth of 52.20 feet in drill core 3, and 74.83 feet in drill core 2, farther to the south. The chalcopyrite occurs as irregular growth around pyrite framboids, with no clear replacement texture (Fig. 12), and as replacement of earlier pyrite. The depth at which chalcopyrite is first identified increases from 60.40 feet in drill core 3 to 83.50 feet in drill core 2.

Under reflected light a dark blue isotropic mineral is observed frequently as a replacement of bornite grains in the cores (Fig. 13). Digenite ($Cu_{1.8}S$) is a copper sulfide which has these optical properties, and is reported from the Prewitt copper shale of Oklahoma as an intergrowth with chalcocite (Cu_2S) (Hagni and Gann, 1976). Morimoto and Gyobu (1971) have determined that digenite is stable in the Cu-Fe-S field and contains about 1% Fe. Electron microprobe analysis was used to determine the exact composition of this phase (it is digenite), and the results of this analysis are presented in the section on sulfide mineral chemistry.

Pyrite $(FeS)_2$ is the ore mineral found at the greatest depth in most of the cores. Pyrite is the first sulfide to form, and occurs as a replacement of the cases of the megaspore <u>Triletes</u> (Fig. 14). Most

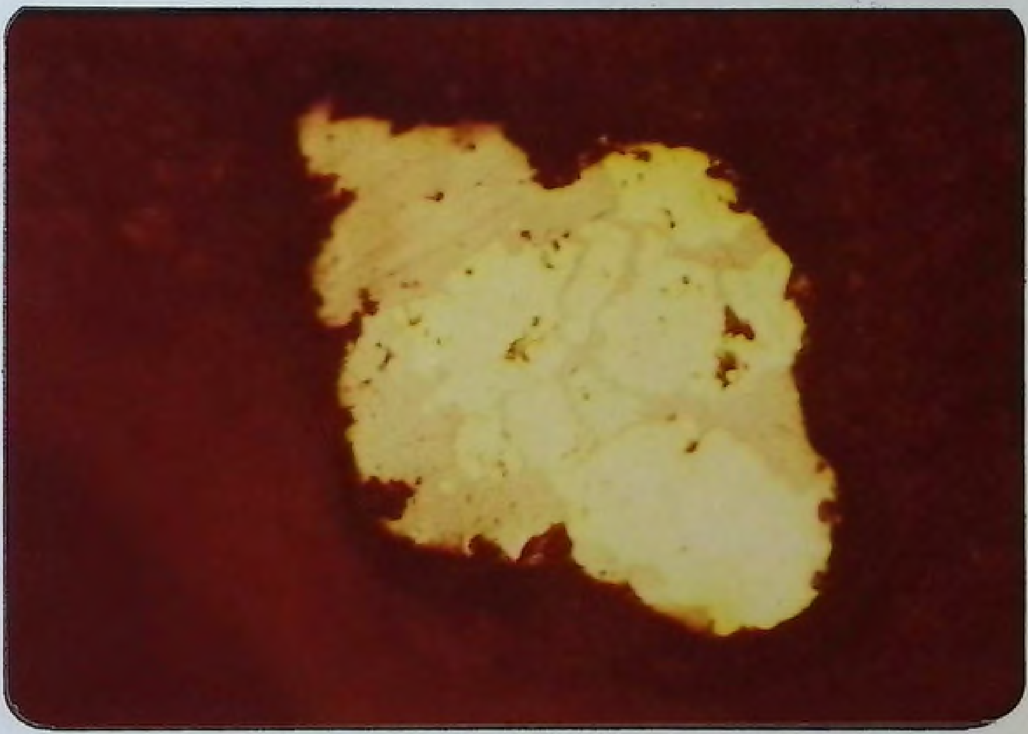

Figure 11 - Bornite (pink) replacing chalcopyrite (yellow) (drill location #3, 52.20 ft. depth, plain reflected light)
← 0.45 mm. →

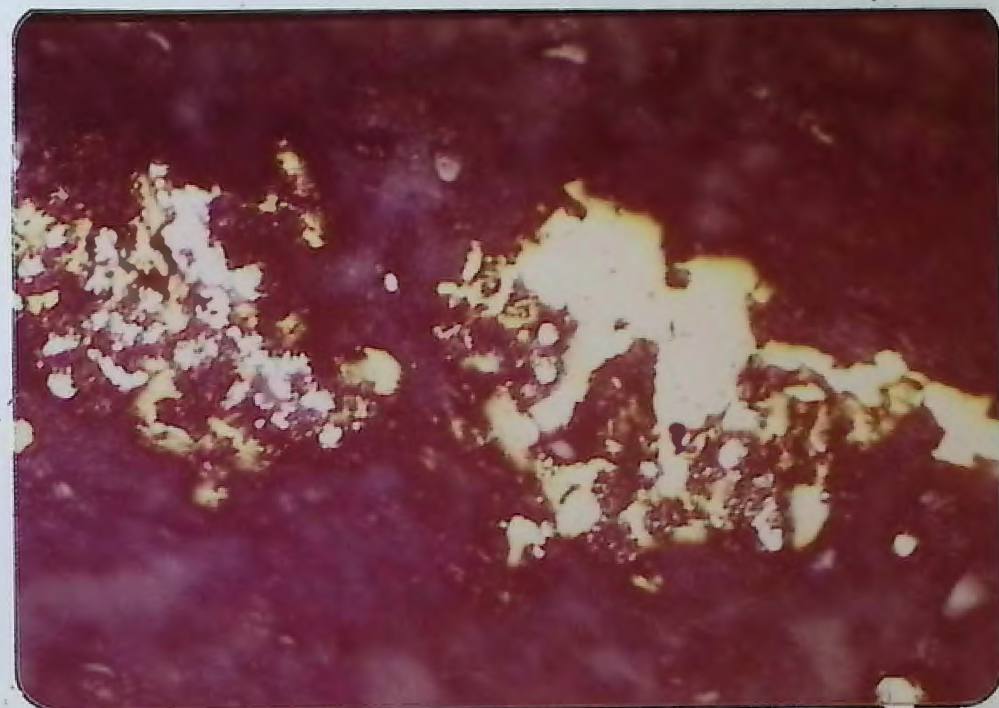

Figure 12 - Chalcopyrite (yellow) as an irregular growth around pyrite (white) (from drill location #3, 60.62 ft. depth, plain reflected light)

← 0.45 mm. →

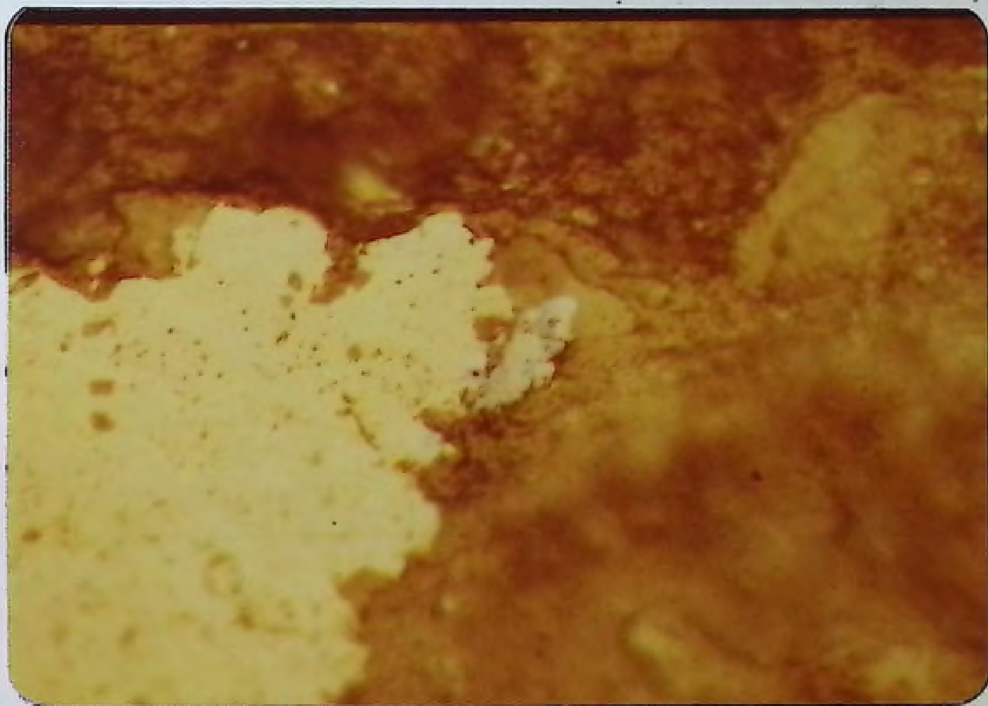

Figure 13 - Digenite (blue) replacing bornite (pink)
(from drill location #2, 75.00 ft. depth,
plain reflected light)
← 0.17 mm. →

Figure 14 - Megaspores replaced by pyrite (from an outcrop in the SE 1/4, Sec. 20, T. 31 S., R. 2 W., plain reflected light)
← 0.45 mm. →

authors agree that in this type of deposit pyrite is syngenetic. Wherever spores are in contact with vugs or veinlets of carbonate (dolomite?) associated with quartz, pyritization is complete. These vugs or veinlets occur in gray-green shales and in dolomite beds. Mineralized spores also occur in fine-grained dolomites which lack veinlets, but dense shales which lack veinlets contain unreplaced spores (Fig. 15).

Galena (PbS) is an uncommon sulfide in the thesis area. This mineral was not identified in any of the cores, but was identified in outcrops of dolomite at three separate localities which are listed in Table 1. These dolomite beds contain many vugs. Most of the vugs are empty, but others contain galena.

SULFIDE MINERAL CHEMISTRY

Sulfide mineral chemistry investigated with an ETEC electron microprobe. This was done in order to determine the degree to which mineral formulas differ from the ideal in sulfides which have been partially replaced by other ore minerals. The following minerals were analyzed: chalcopyrite, bornite, and digenite from drill core 2; "chalcocite" from drill core 13; "chalcocite" and covellite from drill core 7; azurite from drill core 7; and galena from an outcrop in the SE 1/4, Sec. 27, T. 31S., R. 2W.

Chalcopyrite from drill location 2 was analyzed in grains composed wholly of chalcopyrite, as well as in grains which contained both chalcopyrite and bornite. Results of these analyses are presented in Table 2. The greatest deviation from ideal chalcopyrite is a decrease in iron content from an average of one Fe atom per molecule in pure chalcopyrite grains to an average of 0.94 Fe atoms per molecule in

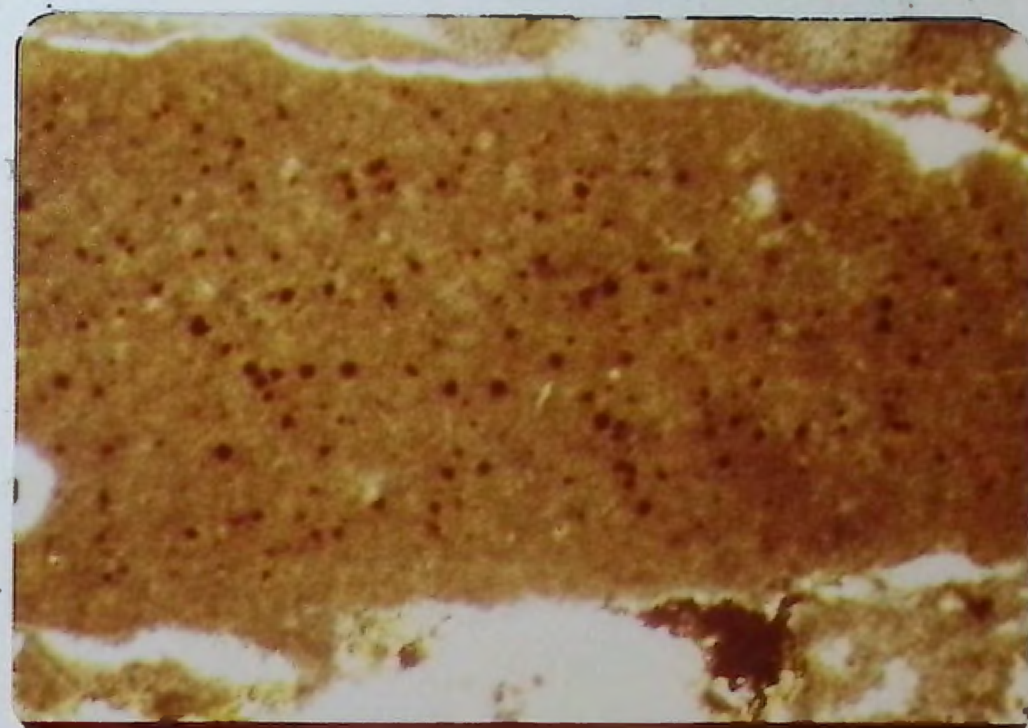

Figure 15 - Unreplaced megaspores of the genus Triletes (from an outcrop in the SE 1/4, Sec. 27, T. 31 S., R. 2 W., plain transmitted light)
←1.5 mm.→

Table 1 - Locations of outcrop samples which contained galena

Sample	Lithology of Host Rock	Location of Outcrop
A	Dolomite	SW 1/4, sec. 28, T. 31 S., R. 2 W.
B	Dolomite	SE 1/4, sec. 27, T. 31 S., R. 2 W.
C	Dolomite	SE 1/4, sec. 20, T. 31 S., R. 2 W.

Table 2 - Results of electron microprobe analysis for chalcopyrite, bornite, and digenite phase from drill location #2 (weight percent)

	Speciman	%Cu	%Fe	%S	Total %	Formula
	1a	34.93	30.85	35.31	101.09	$Cu_{1.01}Fe_{1.01}S_2$
	1b	33.45	30.46	34.58	98.48	$Cu_{1.01}Fe_{1.05}S_2$
	1c	34.64	31.08	34.92	100.64	$Cu_{1.00}Fe_{1.02}S_2$
	1d	33.86	30.18	35.17	99.21	$Cu_{.97}Fe_{.98}S_2$
Chalcopyrite in chalcopyrite grains	1e	35.11	30.06	34.95	100.12	$Cu_{1.01}Fe_{.99}S_2$
	1f	35.79	30.92	35.19	101.90	$Cu_{1.02}Fe_{1.01}S_2$
75 ft. depth	1g	35.06	30.64	35.65	101.35	$Cu_{1.00}Fe_{1.00}S_2$
75 ft.	1h	33.76	30.49	33.79	98.04	$Cu_{1.00}Fe_{1.04}S_2$
	1i	34.73	31.15	34.52	100.40	$Cu_{1.01}Fe_{1.03}S_2$
	1j	34.09	30.30	34.95	99.34	$Cu_{.98}Fe_{.99}S_2$
	Average	34.54	30.61	34.90	100.06	$Cu_{1.00}Fe_{1.01}S_2$
	2a	35.13	29.69	34.87	99.69	$Cu_{1.02}Fe_{.98}S_2$
	2b	34.92	29.09	35.57	99.58	$Cu_{.99}Fe_{.94}S_2$
Chalcopyrite	2c	35.15	29.79	35.43	100.37	$Cu_{1.00}Fe_{.96}S_2$
n chalcopyrite grains	2d	35.04	30.24	34.54	99.82	$Cu_{1.02}Fe_{1.00}S_2$
4..70 ft. depth	2e	34.38	28.96	35.05	98.39	$Cu_{.99}Fe_{.95}S_2$
74.70ft.	2f	35.03	29.30	34.59	98.92	$Cu_{1.02}Fe_{.97}S_2$
	Average	34.94	29.51	35.01	99.46	$Cu_{1.01}Fe_{.97}S_2$
Chalcopyrite	3a	35.04	30.24	34.54	99.82	$Cu_{1.02}Fe_{1.00}S_2$
n chalcopyrite grains	3b	34.38	28.96	35.05	98.39	$Cu_{.99}Fe_{.95}S_2$
4. 70 ft. depth	3c	35.03	29.30	34.59	98.92	$Cu_{1.02}Fe_{.97}S_2$
74.70ft.	3d	35.27	29.35	35.38	97.08	$Cu_{1.01}Fe_{.95}S_2$
	Average	34.93	29.46	34.89	98.55	$Cu_{1.01}Fe_{.97}S_2$

Table 2 - Results of electron microprobe analysis for chalcopyrite, bornite, and digenite phase from drill location #2 (weight percent) (con't.)

	Specimen	%Cu	%Fe	%S	Total %	Formula
Bornite in chalcopyrite-bornite grains 7!4.70 ft. depth	4a	61.03	10.26	25.02	96.31	$Cu_{4.92}Fe_{.94}S_4$
	4b	61.17	10.73	25.73	97.63	$Cu_{4.80}Fe_{.96}S_4$
	4c	61.01	10.46	25.54	97.01	$Cu_{4.82}Fe_{.94}S_4$
	4d	62.20	10.32	25.51	98.03	$Cu_{4.92}Fe_{.93}S_4$
	4e	61.32	10.54	25.38	97.24	$Cu_{4.87}Fe_{.95}S_4$
	4f	60.86	10.71	25.47	97.04	$Cu_{4.82}Fe_{.96}S_4$
	4g	61.24	10.47	25.34	97.05	$Cu_{4.87}Fe_{.95}S_4$
	Average	61.26	10.50	25.43	97.19	$Cu_{4.86}Fe_{.95}S_4$
Digenite in a bornite grain 7!4.70 ft. depth	5a	72.68	1.70	21.76	96.14	$Cu_{1.68}Fe_{.048}S$
	5b	70.92	2.65	23.29	96.86	$Cu_{1.53}Fe_{.065}S$
	5c	71.44	1.88	22.36	95.68	$Cu_{1.62}Fe_{.048}S$
	5d	70.65	2.91	22.70	96.26	$Cu_{1.57}Fe_{.074}S$
	Average	71.42	2.28	22.53	96.23	$Cu_{1.61}Fe_{.054}S$

chalcopyrite-bornite grains.

On the basis of electron microprobe analysis, the digenite can be definitely identified as digenite. The average of all analyses is $Cu_{1.60}Fe_{.059}S$. Morimoto and Gyobu (1971) write that $Cu_{6.9}Fe_{0.1}S_4$ ($Cu_{1.72}Fe_{.025}S$) is nearly in the center of the digenite stability field. The grain that was probed contained digenite as a partial replacement of bornite.

Judging from its optical properties, the chalcocite-like phase that was probed in drill core 13 was a grain of chalcocite. Table 3 lists these electron microprobe results and reveals that the average composition of the probed grain was $Cu_{1.90}S$. This is close to the composition of djurleite ($Cu_{1.96}S$), a copper sulfide optically identical to chalcocite. Detailed examination of the probed section from location 13 showed that a light sulfide phase and a dark sulfide phase existed in this possible djurleite phase. These phases were analyzed, and the dark phase was found to be relatively Cu-rich with an average composition of $Cu_{1.95}S$. The lighter phase was slightly poorer in Cu with an average composition of $Cu_{1.86}S$.

Results of the electron microprobing of chalcocite-like grains in drill location 7 are listed in Table 4. Although not clearly in a grain that was originally a spore, the mineral in this sample has a composition unlike that of djurleite in drill core 13. The average composition is $Cu_{1.73}S$, similar to the composition of anilite ($Cu_{1.75}S$). Anilite is said to be much like chalcocite in appearance (Morimoto and Koto, 1969).

Recent electrochemical studies of the Cu-S system by Potter (1977) have highlighted the phase complexities between c. $Cu_{1.7}S$-$Cu_{2.0}S$. The

Table 3 - Results of electron microprobe analysis for chalcocite-like phase (weight percent) from drill location #13

	Speciman	%Cu	%Fe	Total %	Formula
	6a	78.78	21.46	100.24	$Cu_{1.86}S$
	6b	80.45	21.73	102.18	$Cu_{1.86}S$
	6c	78.79	21.88	100.67	$Cu_{1.81}S$
	6d	79.14	21.53	100.67	$Cu_{1.85}S$
	6e	79.08	21.78	100.86	$Cu_{1.83}S$
	6f	78.33	21.98	100.31	$Cu_{1.80}S$
Chalcocite-like phase (Cu-rich) 85.70 ft. depth	6g	78.61	21.76	100.37	$Cu_{1.82}S$
	6h	78.49	20.88	99.37	$Cu_{1.88}S$
	6i	78.49	21.21	99.70	$Cu_{1.87}S$
	6j	78.06	21.25	99.31	$Cu_{1.86}S$
	6k	78.22	20.79	99.01	$Cu_{1.90}S$
	6l	79.13	21.23	100.36	$Cu_{1.88}S$
	6m	78.70	20.94	99.64	$Cu_{1.89}S$
	6n	78.46	20.62	99.08	$Cu_{1.92}S$
	Average	78.77	21.36	100.13	$Cu_{1.86}S$
	7a	79.51	20.86	100.37	$Cu_{1.93}S$
	7b	80.38	20.79	101.17	$Cu_{1.95}S$
	7c	79.15	20.63	99.78	$Cu_{1.94}S$
	7d	79.43	20.87	100.30	$Cu_{1.93}S$
Chalcocite-like phase (Cu-poor) 85.70 ft. depth	7e	78.73	20.76	99.49	$Cu_{1.91}S$
	7f	79.31	19.98	99.29	$Cu_{2.01}S$
	7g	80.56	20.67	101.23	$Cu_{1.96}S$
	7h	79.31	20.56	99.87	$Cu_{1.95}S$
	7i	79.48	20.61	100.09	$Cu_{1.95}S$
	7j	80.15	20.76	100.90	$Cu_{1.95}S$
	7k	79.75	20.87	100.62	$Cu_{1.94}S$
	7l	80.46	20.88	101.34	$Cu_{1.95}S$
	Average	79.68	20.68	100.37	$Cu_{1.95}S$

Table 4 - Results of electron microprobe analysis for chalcocite-like phase and covellite (weight percent) from drill location #7

	Specimen	%Cu	%S	Total %	Formula
Chalcocite-like phase in chalcocite-like phase covellite grain 19.70 ft. depth	8a	76.22	21.66	97.88	$Cu_{1.78}S$
	8b	76.15	22.50	98.65	$Cu_{1.70}S$
	8c	77.43	22.63	100.06	$Cu_{1.73}S$
	8d	76.45	22.71	99.16	$Cu_{1.69}S$
	8e	77.05	22.11	99.16	$Cu_{1.75}S$
	8f	76.89	22.11	99.00	$Cu_{1.74}S$
	8g	76.70	22.50	99.20	$Cu_{1.71}S$
	8h	75.55	21.99	97.54	$Cu_{1.73}S$
	8i	76.32	22.30	98.62	$Cu_{1.72}S$
	8j	76.73	22.00	98.73	$Cu_{1.76}S$
	Average	76.55	22.25	98.80	$Cu_{1.73}S$
Covellite in chalcocite-covellite grain 19.70 ft. depth	9a	67.14	32.70	99.84	$Cu_{1.04}S$
	9b	65.29	32.90	98.19	$Cu_{1.00}S$
	9c	68.80	30.26	99.06	$Cu_{1.14}S$
	9d	67.07	31.33	98.40	$Cu_{1.09}S$
	9e	73.33	25.63	98.96	$Cu_{1.44}S$
	9f	66.81	33.89	100.70	$Cu_{0.99}S$
	9g	65.85	32.31	98.16	$Cu_{1.03}S$
	9h	66.17	32.42	98.59	$Cu_{1.02}S$
	9i	64.51	32.41	96.92	$Cu_{1.00}S$
	Average	67.22	31.54	98.76	$Cu_{1.08}S$

mineral assemblages found in south-central Kansas confirm these complexities in natural samples. The varied stoichiometries of the copper sulfide minerals in Kansas probably resulted from phase transformations after precipitation from fluids with slightly varying Cu:S ratios.

Based upon Potter's study, the analyses of samples from drill core 13 (Table 3) fall within a compositional range that should contain a djurleite-anilite mixture. In particular, the $Cu_{1.87}S$ phase probably represents a metastable crystallization product. The analyses of samples from drill core 7 indicate a Cu:S ratio that should allow both anilite and covellite to form at the low (<75°C) temperatures postulated for redbed copper deposits.

The section from drill core 7 contains covellite as well as anilite. Electron microprobe results indicate that the average composition of the covellite is $Cu_{1.08}S$, which is quite close to the ideal formula (CuS).

The identification of azurite in the cores was not definitely resolved by optical methods. Comparison of copper content in suspected azurite with that predicted by its ideal formula (shown in Table 5) suggests strongly that the mineral is azurite.

Galena was not recorded in association with any other sulfide minerals. The results of microprobing, shown in Table 6, give an average galena formula of $Pb_{0.99}S$. A ternary diagram of the Cu-Fe-S system, showing the average microprobe analysis for each mineral type, is depicted in Figure 16.

Cu-Pb-Zn CONTENT OF SOUTH-CENTRAL KANSAS DOLOMITES

The staff of the Kansas Geological Survey conducted atomic absorption analyses on selected samples of dolomite from Wellington beds of south-central Kansas. Results of these analyses are shown in Table 7

Table 5 - Results of electron microprobe analysis for azurite (weight percent) from drill location #7

	Specimen	Experimental % Cu	Formula % Cu	Formula % Cu -Experimental % Cu
	10a	50.22	55.31	5.09
	10b	50.65	"	4.66
	10c	49.61	"	5.70
	10d	51.64	"	3.67
	10e	50.82	"	4.49
Azurite	10f	50.67	"	4.64
surrounding	10g	49.75	"	5.56
a chalcocite	10h	51.49	"	3.82
grain	10i	53.22	"	2.09
19.70 ft. depth	10j	51.79	"	3.52
	10k	56.46	"	-1.15
	10l	54.98	"	0.33
	10m	52.10	"	3.21
	Average	51.80	55.31	3.51

Table 6 - Results of electron microprobe analysis for galena from the SE 1/4, Sec. 27, T. 31 S., R. 2 W. (weight percent)

	Specimen	%Pb	%S	Total %	Formula
Galena in outcrop sample	11a	87.01	13.61	100.62	$Pb_{.99}S$
	11b	87.39	13.42	100.81	$Pb_{1.01}S$
	11c	87.19	13.62	100.81	$Pb_{.99}S$
	11d	87.33	13.50	100.83	$Pb_{1.00}S$
	11e	88.01	13.46	101.47	$Pb_{1.01}S$
	11f	86.53	13.43	99.96	$Pb_{1.00}S$
	11g	87.33	13.65	100.98	$Pb_{.99}S$
	Average	87.25	13.53	100.78	$Pb_{1.00}S$

Figure 16 - Electron microprobe data for the Cu-Fe-S system

	Analyzed Phase	Average Formula
1.	Chalcopyrite in pure chalcopyrite grains	$Cu_{1.00}Fe_{1.01}S_2$
2.	Chalcopyrite in pure chalcopyrite grains	$Cu_{1.01}Fe_{.97}S_2$
3.	Chalcopyrite in chalcopyrite-bornite grains	$Cu_{1.01}Fe_{.97}S_2$
4.	Bornite in chalcopyrite-bornite grains	$Cu_{4.86}Fe_{.95}S_4$
5.	Digenite-like phase	$Cu_{1.60}Fe_{.059}S$
6.	Anilite-djurleite intermediate phase	$Cu_{1.86}S$
7.	Djurleite	$Cu_{1.95}S$
8.	Anilite	$Cu_{1.73}S$
9.	Covellite	$Cu_{1.08}S$

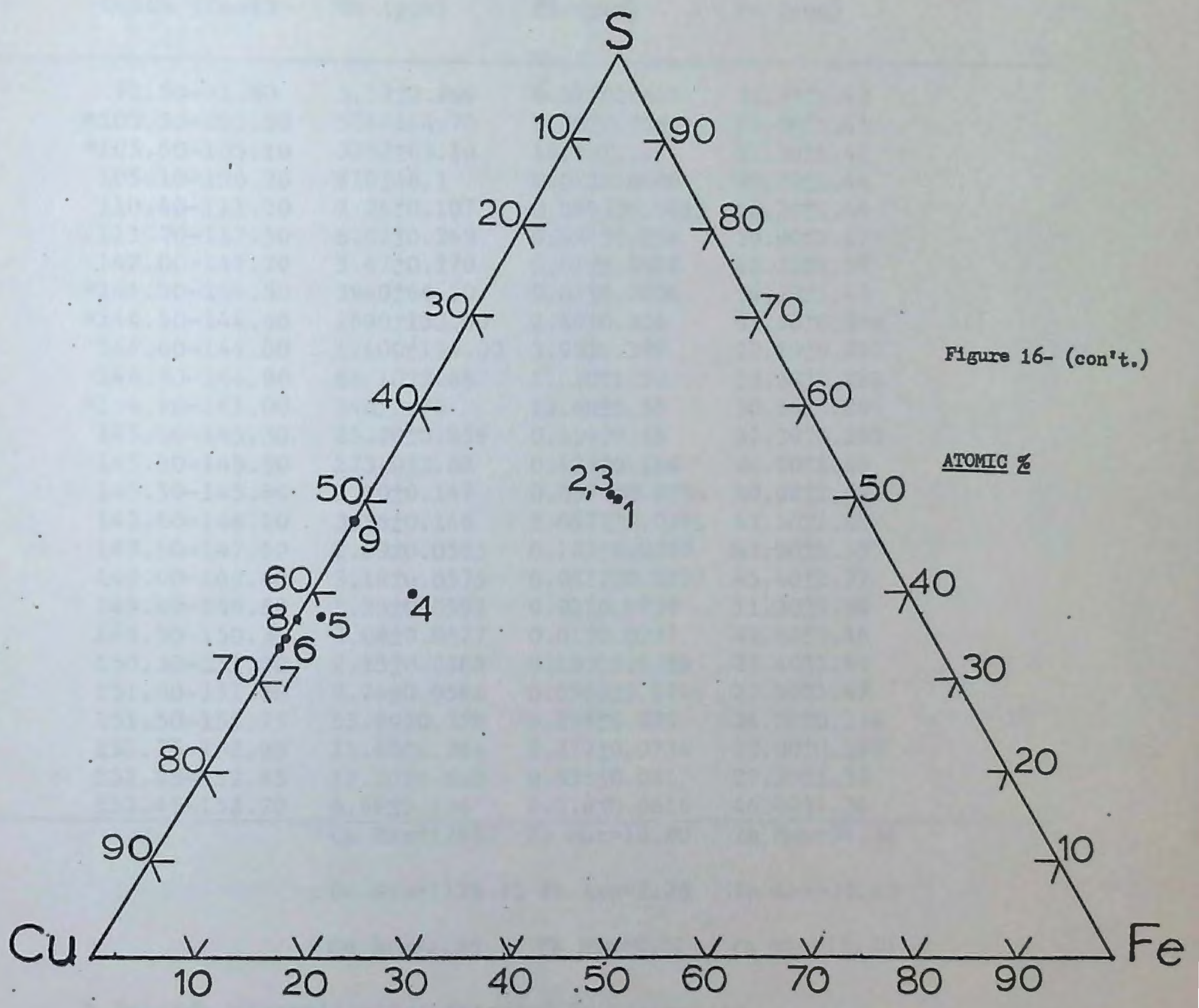

Figure 16- (con't.)

ATOMIC %

Table 7 - Results of atomic absorption spectrophotometry of dolomites in drill location #10

Depth (Feet)	Cu (ppm)	Pb (ppm)	Zn (ppm)
91.50-91.80	5.17±0.269	0.01±0.0618	35.70±1.47
*105.50-105.80	5260±64.70	5.36±0.296	19.00±1.41
*105.80-105.10	3280±65.10	18.80±1.49	31.50±1.42
105.10-106.20	810±66.1	0.01±0.0606	49.70±1.44
110.40-111.20	2.26±0.107	0.0867±0.0613	18.20±1.46
111.20-112.50	8.62±0.269	0.922±0.154	29.90±1.47
142.00-142.20	3.47±0.270	0.01±0.0618	42.30±1.56
*144.30-144.50	3980±66.10	0.01±0.0606	54.30±1.44
*144.50-144.60	2690±132.00	2.45±0.304	31.40±0.289
144.60-144.80	12600±134.00	3.93±0.307	22.10±0.292
144.80-144.90	85.10±2.66	11.10±1.52	23.30±0.289
*144.90-145.00	240±2.70	13.40±1.55	30.10±0.294
145.00-145.30	25.20±0.359	0.154±0.15	32.30±0.280
145.30-145.50	273.0±2.88	0.123±0.148	26.10±1.46
145.50-145.80	3.90±0.147	0.0575±0.0754	50.00±1.49
145.80-146.10	3.35±0.146	0.0572±0.0751	42.10±1.40
147.50-147.60	2.69±0.0583	0.121±0.0747	43.00±1.39
149.00-149.40	3.18±0.0575	0.0217±0.0737	45.40±1.37
149.40-149.50	1.28±0.0592	0.01±0.0759	11.30±0.30
149.50-150.30	3.08±0.0577	0.01±0.0737	42.60±1.46
150.30-151.00	2.15±0.0585	0.103±0.0751	25.40±1.48
151.00-151.50	3.74±0.0582	0.0983±0.0746	27.50±1.47
151.50-151.75	55.90±0.358	0.298±0.075	24.20±0.296
151.75-152.25	11.40±0.286	0.277±0.0734	32.00±0.290
152.25-152.45	12.20±0.620	0.836±0.061	27.20±1.32
152.45-152.70	6.69±0.626	0.518±0.0616	46.00±1.34
	Cu Max=12600	Pb Max=18.80	Zn Max=54.30
	Cu Ave=1129.71	Pb Ave=2.26	Zn Ave=33.18
	Cu Min=1.28	Pb Min=0.01	Zn Min=11.30

* Sulfide mineralization detected by microscopy

and 8. Copper, lead and zinc values were determined in parts per million, and the only metal which showed a pronounced anomaly is copper. In those intervals of the core in which copper concentration reaches its highest level (several thousand parts per million) mineralization can be seen with the unaided eye.

Wherever mineralization was visible in the cores, I collected samples and included this data to demonstrate that the selection of samples was not biased by inablity to detect unmineralized horizons. Also, it serves as qualitative proof that lead and zinc anomalies do not exist in the cores.

PARAGENESIS AND ZONING

Pyrite is the first sulfide to form in the redbed copper sulfide deposits of south-central Kansas. In the northern part of the study area, chalcopyrite may form at the same time as the pyrite or as a replacement of it. Bornite occurs as a later replacement of chalcopyrite, and the digenite-like phase in turn replaces the bornite.

Anilite and djurleite are found in the southern part of the study area. Potter writes the djurleite, anilite and covellite in turn become the stable CuS phase at low temperatures with decreasing Cu:S ratios. The paragenetic sequence is thus djurleite, djurleite plus anilite, anilite, anilite plus covellite, and covellite. The Cu-rich phase (djurleite) and Cu-poor phase (an anilite-djurleite intermediate phase) which occur at a depth of 85.70 feet in drill core 13, the anilite which is partially replaced by covellite 19.70 feet beneath the surface in drill core 7, and the covellite which persists in areas where azurite has replaced anilite at the same depth in drill core 7, might represent such a sequence.

Table 8 - Results of atomic absorption spectrophotometry of dolomites from drill location #13

Depth (Feet)	Cu (ppm)	Pb (ppm)	Zn (ppm)
46.33-47.33	79.50±0.857	1.54±0.0689	35.30±2.14
47.33-47.58	202±1.67	1.19±0.067	42.70±2.09
47.92-48.08	427±1.71	2.81±0.137	32.80±2.14
48.08-48.33	266±1.71	1.18±0.138	33.90±2.14
49.50-49.83	5.77±0.086	2.66±0.139	34.80±2.16
49.83-50.08	18.2±0.106	5.08±0.139	30.00±0.431
50.08-50.25	16.10±0.086	5.13±0.139	29.00±2.16
50.25-50.58	6.58±0.0857	2.15±0.138	44.20±2.14
85.25-85.29	4.03±0.106	0.0501±0.014	4.86±0.433
*85.29-85.75	1770±10.40	2.07±0.136	51.00±2.12
*85.92-86.17	1080±10.50	2.83±0.138	24.20±0.429
*86.17-86.42	1400±8.54	3.05±0.137	30.40±0.427
86.42-86.50	99±3.53	2.23±0.066	34.30±1.27
86.50-86.62	113±3.45	4.10±0.065	28.70±1.32
86.71-87.17	7.1±0.176	0.955±0.066	67.00±1.27
91.00-91.33	3.2±0.070	0.58±0.0263	60.20±1.27
91.33-91.67	2.48±0.068	0.18±0.0256	41.30±1.23
91.67-91.92	3.44±0.0676	0.697±0.0253	51.10±1.22
91.92-92.50	3.51±0.070	0.523±0.0263	71.00±1.27
92.50-92.75	4.51±0.069	0.69±0.0261	56.20±1.25
94.00-94.08	3.43±0.068	0.442±0.025	70.40±1.23
94.08-94.50	2.61±0.069	1.19±0.026	41.50±1.25
94.50-94.67	45.80±0.351	1.48±0.065	38.70±1.27
94.67-94.83	37.60±0.354	1.67±0.066	34.50±1.28
	Cu Max=1770	Pb Max=5.13	Zn Max=71.00
	Cu Ave-233.37	Pb Ave=1.85	Zn Ave=41.17
	Cu Min=2.48	Pn Min=0.050	An Min=4.86

* Sulfide mineralization detected by microscopy

A paragenetic diagram for the sulfides found in the study area is depicted in Figure 17. Galena is not included in the diagram because this mineral is not found in association with any of the other ore minerals.

The transformation of pyrite into chalcocite-like minerals is an important reaction in the southern part of the study area. Although reactions illustrating this replacement can be written in many ways, I have chosen to consider the transportation of Cu and Fe as chloride complexes (see Rose, 1976). A possible reaction is:

$$FeS_2 + 4CuCl° + H_2O \rightleftharpoons 2Cu_2S + 3Cl^- + 2H^+ + FeCl^+ + 1/2\ O_2$$

In the northern part of the study area, pyrite is first associated with chalcopyrite. A formula for this reaction, again assuming a chloride complex as the metal carrier, is:

$$FeS_2 + CuCl° + 1/2\ H_2O \rightleftharpoons CuFeS_2 + Cl^- + H^+ + 1/4\ O_2$$

The chalcopyrite could then be converted to bornite via the reaction:

$$CuFeS_2 + 2H_2S + 4CuCl° \rightleftharpoons Cu_5FeS_4 + 4H^+ + 4Cl^-$$

These reactions suggest that the distinct sulfide assemblages may be related to restrictions in sulfur availability and copper content of the mineralizing fluid. Differences in copper content of the fluid may be a function of the distance between the source of copper and the site of deposition (see below).

Covellite, azurite, and malachite are recent and are directly related to the oxidation of sulfides by modern groundwater. The depths at which other ore minerals first appear in the cores increases to the south in the study area, and are not related to the present land surface.

The apparent depth zonation may not be related to depth beneath the present land surface at all, but may be caused by a basinward zonation

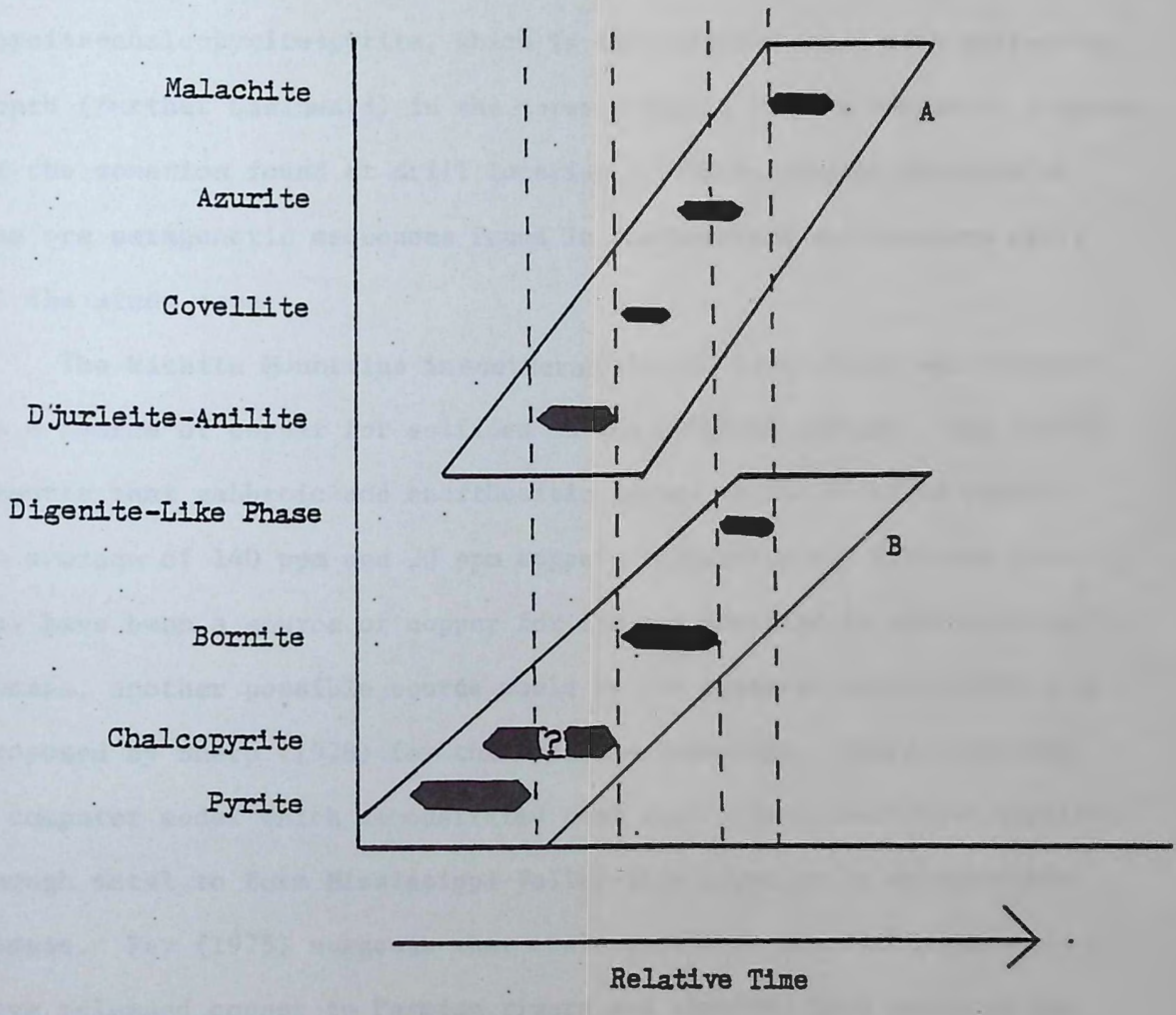

Figure 17 - Paragenetic sequence for copper carbonates and sulfides in (A) the southern part of the study area, and (B) the northern part of the study area; (pyrite) is the original mineral in both sequences

in the sedimentary sequence during Permian time. The upper part of the Wellington Formation in Kansas is a regressive marine sequence (Berendsen, oral communication, 1978). Cheney and Jensen (1962) write that in the basin of sedimentation, pyrite would be replaced by copper sulfides formed from progressively less copper-rich solutions in the direction of sediment transport. This would create a basinward zonation of chalcocite→bornite→chalcopyrite→pyrite, which is the zonation found with increasing depth (further basinward) in the cores. Figure 18 is a schematic diagram of the zonation found at drill location 7, which combines features of the ore paragenetic sequences found in the northern and southern parts of the study area.

The Wichita Mountains in southern Oklahoma have often been proposed as a source of copper for sulfides in the Oklahoma redbeds. Cox (1978) reports that gabbroic and anorthositic groups in the Wichitas contain an average of 140 ppm and 20 ppm copper, respectively. Although this may have been a source of copper for the ore deposits in south-central Kansas, another possible source could be the ruptured geopressured zone proposed by Sharp (1978) for the Ouachita Mountains. Sharp presented a computer model which demonstrated that such a zone could have supplied enough metal to form Mississippi Valley-type deposits in southeastern Kansas. Fay (1975) suggests that chalcopyrite in the Ouachitas could have released copper to Permian rivers and supplied this metal to the Wellington Formation of north-central Oklahoma.

In sedimentary ore deposits such as redbed copper mineralization, Pb and Zn are not believed to travel far from their source in comparison with copper. This may explain why galena is only a very minor ore mineral in the study area, and why zinc minerals do not occur. Sphalerite

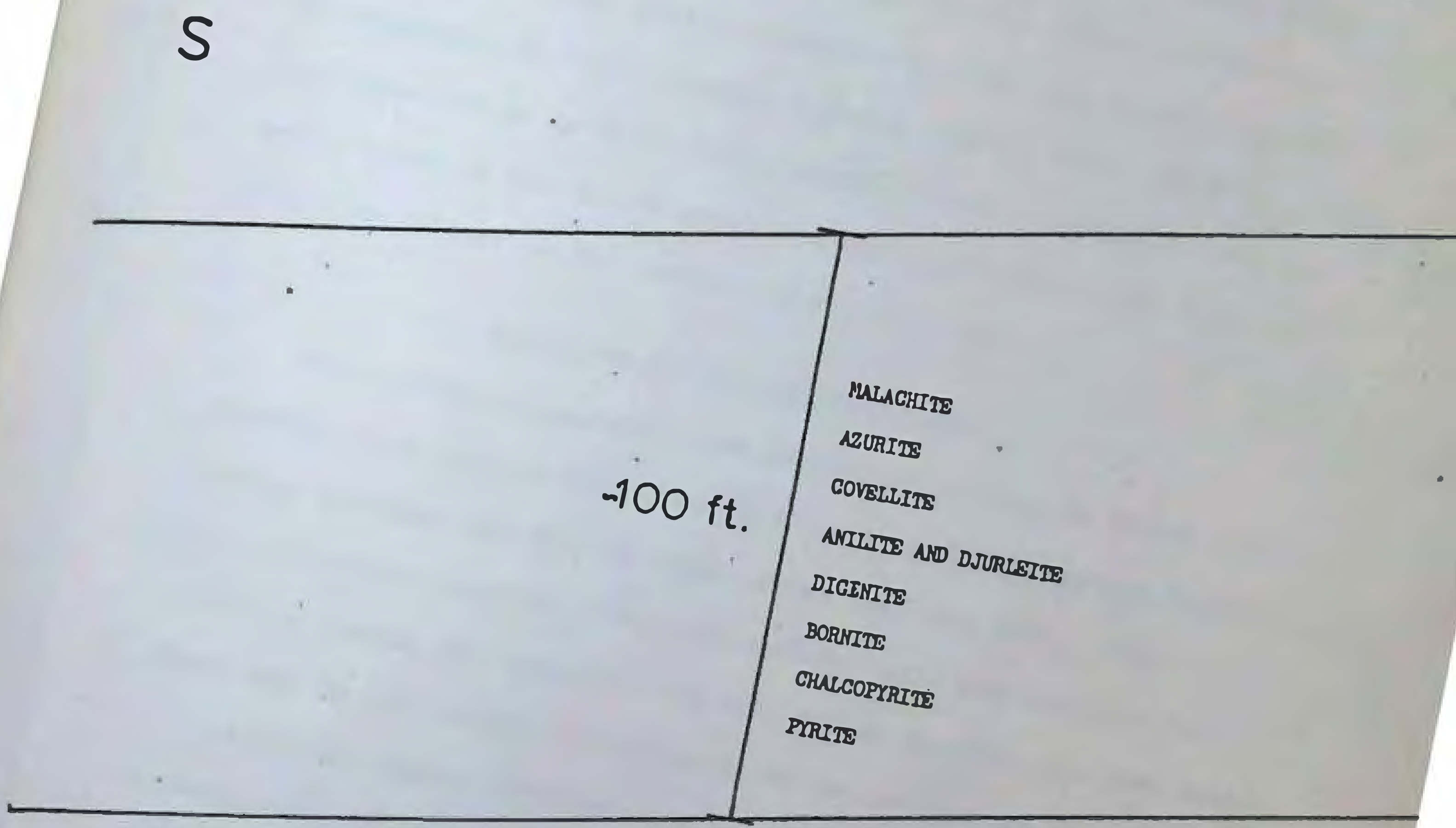

Figure 18 - Schematic diagram of ore zonation at drill location #7 (slanting lines indicate direction of basinward deepening)

(ZnS) has been reported from the Wellington Formation of north-central Oklahoma (Cox, 1978).

Brown (1971) writes that the Nonesuch Shale of Michigan has a copper sulfide zonation that is, in descending order: pyrite→chalcopyrite→bornite→digentie→djurleite→chalcocite. In this formation the source of copper is the Copper Harbor Conglomerate, which lies directly beneath the Nonesuch, so with increased distance from the source of metal, the same zonation as is found in the upper Wellington. Material from the lower parts of the Kansas cores were deposited farther from shore and therefore closer to the possible source of copper.

NATURE OF THE MINERALIZING FLUID

Rose (1976) believes that the mineralizaing fluid in redbed copper deposits is a cuprous chloride-rich brine in equilibrium with hematite, quartz, feldspar and mica at temperatures less than 75°C. Rose writes that evaporites associated with the redbeds could have supplied the chloride anions, and suggests that this mechanism could also have been important in the origin of the Kupferschiefer and Zambian ore deposits.

Although cuprous chloride complexes are generally accepted as the mineralizing fluid in this type of ore deposit, the origin of the fluid is a matter of debate. Davidson (1965) writes that the chloride brines are generated by dissolution of evaporties in the host rock, but Renfro (1974) has suggested a sabkha-type origin for stratiform metalliferous deposits. Sabkhas (evaporite flats) form along the margins of a regressive sea such as that known to have existed in the thesis area during Permian time. According to Renfro's model, ore deposition occurs where metal-bearing non-saline meteoric water encounters reduced areas of coastal algal mats.

I am unable with certainty to attribute Wellington copper sulfide mineralization to the origin postulated by Davidson and Rose or to that suggested by Renfro. One of these explanations is undoubtably responsible, and elements of both could have been involved.

Evaporites leached near the source of copper (either near the Wichitas or in the geopressured brine in the Ouachita sediments) could have created the mineralizing fluid. Also, halite is found directly beneath the Kansas redbed copper sulfides and could have been the source of chloride anions. Meteoric waters which leached chloride could thus have evolved into a potential ore-transporting fluid. The copper sulfide mineralization is associated with dolomitized carbonate beds and with carbonate (dolomite?) veinlets which could have formed when calcium- magnesium-rich waters dolomitized early limestone beds in a sabkha environment, if such an environment did exist.

CONCLUSIONS

The major conclusions reached from this study area:

1) Pyrite, chalcopyrite, bornite, digenite, anilite and djurleite, covellite, azurite, and malachite occur as spore replacements and as stringers in gray-green shales and dolomites in the upper Wellington Formation of south-central Kansas.

2) Electron microprobe studies indicate that the minerals in the Cu-S system exhibit varied chemistry ranging in composition from anilite to djurleite.

3) The paragenetic sequence of the ore mineralization is pyrite→chalcopyrite→bornite→digenite→anilite-djurleite→covellite→azurite→malachite.

4) The zoning sequence is interpretated as indicating a progressively less copper-rich mineralizing fluid as distance from the copper source increases.

5) The source of copper could have been either the Wichita Mountains in southern Oklahoma or a geopressured brine from sediments of the Ouachita Mounts in southeastern Oklahoma.

6) Meteoric water which leached chloride from evaporite units could have deposited the sulfide minerals in a sabkha environment.

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Appendix A

Logs of K.G.S. cores in south-central Kansas
(no cores for drill locations #6, 8, and 9)

Drill location #1

Depth	
28.00' to 28.70'	Limey medium gray shale that is thinly bedded with lighter colored gray shale and carbonate. This interval is highly fractured which results in a poorly preserved section of core. There is considerable Fe and Mn oxide staining along the fractures.
28.70' to 30.25'	Dense dolomite, medium bedded with thin, limey, medium gray shale. This interval is also fractured, and the fracture planes are stained with Fe and Mn oxide as above.
30.25' to 30.65'	Interbedded dolomite and medium gray shale. At about 30.40', a 0.40" porous exists, and may have contained salt that is now leached out.
30.65' to 31.25'	Medium gray shale that is not well-bedded.
31.25' to 31.50'	Well-bedded light gray dolomite interbanded with a medium gray shale. Some of the shale is slightly red in color.
31.50' to 32.00'	Light reddish brown shale; interbedded with minor medium gray shale.
32.00' to 33.40'	Maroon shales and siltstones interbedded with very fine-grained gray shale. Bedding is regular with a few disturbances. Between 32.00' and 32.50', maroon shale and siltstone are interbedded with the gray shale. At the 33.00' level some black shales are also interbedded with the gray shale.
33.40' to 33.55'	Thin unit marked by a 0.40" - 0.80" zone of broken-up and recemented medium gray shale. The lower 0.80" is mainly a medium gray shale with some dolomite laminae.
33.55' to 34.30'	Thinly bedded maroon shale. Dark gray to reddish gray laminae are found throughout this interval. On a small scale bedding is irregular and disturbed.
34.30' to 34.83'	Massive maroon silty shale. The lower contact is abrupt and irregular.
34.83' to 35.00'	Limey maroon shale is interbedded with gray shale and thin limey laminae. The lower contact is abrupt and regular.
35.00' to 35.25'	Massive purple-maroon shale. Very fine-grained gray shale is found throughout the interval, becoming more prominent towards the bottom.

Depth	
35.25' to 35.50'	Medium gray shale interbedded with thin dolomite laminae. Most beds are discontinuous and have a wavey appearance.
35.30' to 35.90'	Medium gray shale. At about 35.75' there is a streak of purplish shale.
51.00' to 51.50'	Medium dark gray shale containing thin, light colored siltstone laminae. Some burrowing and evidence of erosion is present.
51.50' to 52.25'	Medium gray shale containing some dolomite and silty laminae. There is evidence of burrowing.
52.25' to 54.75'	Dark gray shale containing thin, lighter colored dolomite and silty laminae. The laminae are wavey and in many cases are discontinuous. At 53.75' a 0.08" - thick dolomite veinlet is present.
54.75' to 55.50'	Medium gray shale with thin (0.04" - thick) siltstone laminae, which are generally undisturbed. General fractures are perpendicular to the core length are filled with calcite or dolomite.
55.50' to 55.85'	Limestone irregularly interbedded with limey, medium dark gray shale. Between 55.50' and 55.60' there are numerous interclasts of carbonate that vary widely in size and shape. There are also some interclasts of gray shale, but they are much smaller. The gray shale forms wavey beds which are partially disrupted.
55.85' to 56.25'	Light colored limey gray shale interbedded with dolomite laminae.
56.25' to 57.20'	Massive medium gray shale.
57.20' to 57.30'	Dense light gray silty dolomite. Some dark gray shale laminaeare in the bottom of this in interval.
57.30' to 57.42'	Medium and light grayshale or silty shale interbedded with thin (0.04" - thick) dolomite laminae.
57.42' to 57.65'	Medium to dark gray reworked silty shale. Patches of gypsum occur in the bottom of this interval.
57.65' to 58.50'	Dark gray shale interbedded with gypsum. A 0.20" - thick satin spar vein occurs near the top of the interval. In the lower half of the interval about 60% of the section is made of discontinuous gypsum beds which change thickness drastically in thickness along strike.
58.50' to 59.50'	Medium gray shale interbedded with thin light gray discontinuous silty laminae. Gypsum satin spar and gypsum mush.

Depth	
59.50' to 60.00'	Dark gray shale interbedded with thin light medium gray siltstone or dolomitic siltstone laminae. Microscopic cross-bedding is common in the siltstone. An erosional surface at the top of the section is marked by the cutting - out of deformed beds.
60.00' to 60.45'	Dark gray shale with some interbedded gypsum in the top half and minor interbedded silt laminae in the bottom half.
60.45' to 62.95'	In this interval there are seven cycles of sedimentation, each marked by a lower sequence of dark gray shale with interbeds of discontinuous siltsone laminae. The laminae often show cross-bedding and other small scale deformational features. This is followed by a section of reworked medium dark gray shale and broken-up siltstone chips. There is evidence of erosion at the upper and lower contacts. In the bedded part of the third cycle two thick (0.40" - thick) satin spar gypsum beds are present. The cycles thicken towards the top half-foot. Possibly three more cycles are above this interval.
62.95' to 64.00'	Intermixed dolomite, dolomitic medium gray shale, and gray shale. The dolomite occurs mainly as interclasts in the gray shale.
64.00' to 64.40'	Light gray dolomite starts at upper contact as interclasts in a medium gray shale. They increase in number and coalesce to form a dense dolomite.
64.40' to 65.10'	The top 2" consists of medium gray shale that is extensively reworked, underlain by 4" of medium gray, thinly bedded shale and siltstone cemented with shale. The lower 2 1/2" consist of medium dark gray shale containing light medium gray, discontinuous siltstone laminae and one 0.40" - thick dolomite bed at the bottom. Some burrowing is observed in this interval.

Drill location #2

Depth	
39.00' to 39.33'	Gray shale mottled with randomly oriented red shale masses and laminated with very thin (less than 0.04") light gray discontinuous siltstone.
39.33' to 40.08'	Slightly limey medium gray shale laminated with finer light gray discontinuous siltstone. Bedding is well developed with only minor disturbances and some cross-beds.
40.08' to 40.50'	Medium greenish-gray shale containing up to 50% dolomitic and/or silty dolomitic clasts. Clasts seem to be broken up dolomitic material. The amount of dolomitic material increases and the clasts become larger toward the bottom of the interval. One large clast (about 0.40" to 0.80" diameter) may have been a filled-in burrow at the top of the sequence.
40.50' to 41.00'	Limestone with some light gray shale mixed in. Bedding is generally regular with some minor waviness. Between 40.33' and 40.96' there is a 1/2" zone of lithographic limestone. Fractures and joints are stained with Mg and Fe oxides.
41.00' to 41.33'	Silty gray-green shale with thin (less than 0.04") discontinuous light gray siltstone laminae. Spherical red shale balls are found in bedding planes of this interval. The lower contact is abrupt and regular.
41.33' to 42.00'	Massive dark red siltstone. Extensively reworked. The lower contact is abrupt and regular.
42.00' to 42.33'	Dolomitic, massive gray siltstone.
42.33' to 43.33'	Mainly a reddish-brown shale with minor siltstone. Between 42.33' and 42.83' the interval is massive. Between 42.83' and 43.33' there are some bedding features. Between 42.83' and 42.92' there are small interclasts and blebs of gray shale.
43.33' to 43.67'	A transition zone where reddish-brown and gray shales are interbedded. Bedding is generally not distinct and is frequently reduced to boundaryless blebs. The gray shale content increases towards the bottom of the interval.
43.67' to 44.00'	Limey light gray-green siltstone thinly interbedded with gray-green shales. Bedding is only moderately well developed. There are some small irregular red shale masses in this interval.

Depth	
44.00' to 44.17'	Massive purplish-red shale with some gray shale blebs in the upper 2" of the interval. Associated with these blebs is manganese mineralization. These grains appear as minute radial growths.
44.17' to 45.04'	Massive, dense reddish-brown shale.
44.04' to 45.08'	Satin spar gypsum bed.
45.08' to 45.37'	Dolomite. The top 1" consists of broken up clasts of dolomite surrounded by a medium gray shale. In the center, the dolomite is predominent, although numerous small clasts are evident. Towards the bottom dolomite occurs again as clasts in a shale matrix. The amount of shale increases towards the bottom of the interval. Some distrubed bedding is observed.
45.37' to 46.17'	Red shale mottled with gray dolomitic shale. Many of these gray blebs have some recrystallization associated with them. Some of these blebs are also oriented perpendicular to the core. Bedding features are present.
46.17' to 46.42'	Gray shale with small chips of dolomite. Bedding features are indistinct. The lower contact is abrupt and irregular. Fluctuation in the level of this contact is approximately 1".
46.42' to 47.42'	Massive reddish-brown shale.
74.00' to 74.08'	Red and gray shale intermixed as blebs.
74.08' to 74.29'	Massive gray-green shale. Towards the lower contact there seems to be an increase in the concentration of dolomite masses, which are broken up and disturbed.
74.29' to 74.58'	Alternating medium dark gray shale and dolomite. Bedding is fairly regular with some mineralization.
74.58' to 75.42'	Dolomite with thin laminae of medium dark gray shale. Bedding is regular. The lower 2" consist of beds of broken dolomite in gray shale. Some burrowing is evident, and mudcracks are frequently encountered with sulfide grains in them. Thin sections show alternating shale and carbonate grains. A few veinlets of large carbonate grains are in contact with large irregular opaques. Polished sections show: 74.70': chalcopyrite - bornite 74.80': chalcopyrite - bornite - minor digenite 74.83': chalcopyrite - bornite 75.00': chalcopyrite grains.

Depth	
75.42' to 76.29'	Gray-green shale interbedded with thin laminae of dolomite bedding varies from wavey to quite disturbed. Some of these disturbances seem to result from burrowing. Near the lower contact some red shale is mixed with the gray shale.
76.29' to 76.33'	There is a 1/2" bed of satin spar (gypsum).
76.33' to 77.33'	There is gypsum mush mixed with red and gray shales and becomes more gray towards the bottom.
77.33' to 77.42'	Dark gray shale with gypsum filled fractures. There are also some light gray, wavey discontinuous siltstone laminae passing through this interval. The bedding is wavey.
77.42' to 77.50'	Red brown shale with thin laminae of lighter red siltstone.
77.55' to 77.62'	Gypsum mush mixed with red and gray shales.
77.62' to 77.83'	Dark gray shale laminated with thin wavey beds of light gray siltstone. A few red shale blebs are present.
77.83' to 79.25'	Purplish-red gypsum siltstone interbedded with red shale. Bedding is generally regular although on a fine scale all laminae are wavey and discontinuous. Crossbedding can be seen. Rapid thickening and thinning of laminae is common. At 78.50' there is another 1/2" thick bed of satin spar gypsum.
79.25' to 79.26'	Interbedded and mixed purplish-red shale and lighter colored purplish-red and dark gray shale and siltstone. The top half of the section is disturbed. The lower half of the section consists of discontinuous wavey siltstone laminae alternating with shale. Some burrowing is present.
79.46' to 79.71'	Gray shale that is extensively reworked. At 79.58' there is a 1/2" bed of broken-up, gray dolomitic siltstone.
79.71' to 80.08'	Interbedded medium gray and light brown-red shales and siltstones. Bedding is irregular and in places quite disturbed. Burrowing is common.
80.08' to 80.33'	Gypsum mush mixed with gray shale.
80.33' to 80.87'	Red siltstone interbedded with thin laminae of lighter red siltstone and some gray shale. Bedding is regular.

Depth	
80.87' to 81.17'	Mainly a reworked dark purplish-red shale and siltstone. In the middle of this interval there is a 0.80" medium gray shale with minor light gray siltstone laminae.
81.17' to 81.62'	Interbedded medium and dark purplish-red shale and siltstone. Some dark gray-reddish shale siltstone occurs in the form of thin (up to 0.04") laminae. The lower 2.50" are mainly dark gray and light siltstone laminae. The lower 2.50" are mainly dark gray shale and siltstone laminae broken-up and jumbled.
81.62' to 82.08'	The lower 0.80" - 1.18" are massive medium gray shale with some mottling of red-brown shale followed by about 3.93" of massive red-brown shale with minor gray mottling. The top 0.80" - 1.18" is again mainly medium gray massive shale with increasing laminae towards the top.
82.08' to 82.42'	Dolomitic gray shale. Finely laminated with lighter gray siltstone and dolomitic siltstone. Bedding is slightly wavey and discontinuous on a fine scale.
82.42' to 84.50'	Medium dark gray shale. In places massive but mostly extensively reworked as evidenced by small differences in coloration. At 82.67', a 0.80" zone with several dolomite and dolomitic siltstone beds. A polished section at 83.50' contains a very large, irregular pyrite grain.
84.50' to 85.33'	Dolomite, irregularly bedded with some interclasts. Possibly some desiccation of features. At 84.92' there is some dark gray-brown shale found interbedded with dolomite.
85.33' to 85.67'	Gray silty shale, poorly bedded. Interclasts of lighter gray silty shale occur in a dark silty shale.
85.67' to 86.37'	Gypsum mush and satin spar gypsum interbedded with medium dark gray shale. The gray shale is in a gypsum matrix.
86.37' to 86.50'	Very thinly bedded medium gray shale. Nearly massive.
114.00' to 114.33'	Very thinly bedded medium gray shale and lighter gray siltstone. The siltstone is in the form of discontinuous wavey laminae. The interval is nearly massive. Some salt is present in section.
114.33' to 115.00'	Lighter gray salt-shale. There are some minor salt beds near the base of this unit. Generally a massive unit.
115.00' to 115.25'	Salty gray shale that is dolomitic in places. Bedding is partially disturbed, perhaps the result of soft sediment deformation. Between 115.17' to 115.25' there is a 1" salty bed with laminae of darker gray shale.

Depth	
115.25' to 115.62'	Gray-green salty shale that is thinly bedded with laminae of salt and lighter gray siltstone.
115.62' to 116.00'	Massive salty gray-green shale.
116.00' to 116.62'	Slaty dark gray-green shale that is extensively reworked. Between 116.08' to 116.25' there is a red tinted gray shale zone. Scattered throughout this interval are lighter and darker pieces of broken-up laminae. Salt gives a distinctive brownish, speckled appearance.
116.62' to 117.00'	Salty light gray shale. Quite massive.
117.00' to 117.37'	Dark gray salty shale and distinct, broken-up beds of light gray dolomitic salty siltstone.
117.37' to 118.12'	Silty and salty dolomitic black shale. Thinly laminated. The dolomite is frequently broken up and surrounded by thin shale laminae. Evidence for mudcracks throughout interval. At 117.96" there are some vugs filled with gypsum and barite (?).
118.12' to 118.62'	Dark gray salty shale. Bedded with light gray siltstone and some salt blebs.
118.62' to 119.50'	Gypsum mush and satin spar intermixed with medium gray shale and salt. Becomes black in color towards bottom of the interval.

Drill location #3

Depth	
50.00' to 50.08'	Grayish-red-brown shale material that seems to be reworked, and grades into the unit below.
50.08' to 50.42'	Medium dark gray shale containing discontinuous wavey laminae of light medium gray siltstone in the upper part.
50.42' to 50.62'	Massive grayish light red-brown shale that grades into the unit below.
50.62' to 50.75'	Massive medium gray shale containing an increasing amount of purplish red spots that grades into the unit below.
50.75' to 51.30'	Massive purplish red shale.
51.30' to 51.50'	Light red-brown and medium gray shale with wavey, discontinuous light colored siltstone laminae. Some sulfide grains are found in both the red and gray fractions. In the red fraction, the sulfide is surrounded by a gray halo. A thin section from this unit shows red-stained shale with a few large quartz grains and some gray shale.
51.50' to 51.90'	Light medium gray shale and siltstone. The upper 2" - 3" contains wavey, discontinuous siltstone laminae. The lower half is mostly shale and broken-up siltstone laminae. The unit grades into a dolomite at the bottom. A polished section at 51.76' contains chalcopyrite - bornite - minor digenite.
51.90' to 52.71'	Dolomite interbedded with light to medium gray shale and/or dolomitic shale. The shale laminae and thin beds are discontinuous and wavey. A polished section from 51.90' contains chalcopyrite - bornite - digenite. A thin section from the same depth contains carbonate veinlets in contact with round to irregular opaques in a very fine carbonate matrix.
52.71' to 53.25'	Dark gray dolomitic shale interbedded with wavey dolomite and/or dolomitic siltstone laminae. The bedding has been disturbed.
53.25' to 54.33'	Slightly dolomitic red-brown shale. It is massive, with indistinct gray shale beds and gypsum mush interbeds towards the bottom. At 53.83' there is a 1/2" - thick satin spar gypsum bed. At 54.00' there is a 1/2" - thick satin spar gypsum bed. At 54.29' there is a 1/2" - thick satin spar gypsum bed. Between 54.04' and 54.29' there are some minor shales.

Depth	
54.33' to 54.67'	Dark gray dolomitic shale interbedded with wavey, discontinuous siltstone laminae. The bottom part of the interval seems to be reworked.
54.67' to 54.79'	Red gypsum mush mixed with minor amounts of gray shale. A 0.40" - thick satin spar gypsum zone is observed at the top of this interval.
54.79' to 55.90'	Medium dark gray shale interbedded with siltstone laminae and thin beds. Bedding is wavey, thickens and thins, and is discontinuous. It is generally indicative of an outwash plain or deltaic environment of deposition. Long burrows up to 7.87" long can be seen in the core.
55.90' to 56.05'	The above grades into a zone which contains reworked material and is diffusely light red-brown in the center.
56.05' to 56.67'	Dark gray shale interbedded with siltstone laminae and thin beds comprise about 40% of this section. The bedding is wavey, discontinuous, and thickens and thins. There is a 0.79" - 1.18" - thick dark black shale unit in the middle. A polished section from 56.40' contains round chalcopyrite grains, and one irregular grain that is composed of irregular chalcopyrite surrounding pyrite.
56.67' to 56.85'	A zone of gray gypsum mush.
56.85' to 58.33'	Medium dark gray shale and light gray siltstone with very fine-grained sandstone. The bedding is wavey, discontinuous, and thickens and thins. There are very fine grains of sulfide throughout the interval and especially in the upper half.
59.33' to 60.42'	Gray shale. Between 59.33' and 59.58' there is a zone of light gray shale interclasts in a matrix of darker gray shale. Most of the material has been reworked. A polished section from 60.40' contains irregular pyrite grains.
60.42' to 60.62'	A small, light dolomite bed. Bedding comprises dolomite interclasts in a subparallel bedding. Some sulfide mineralization is observed. The upper and lower contacts are abrupt and irregular.
60.62' to 60.75'	Dark gray shale with intensely disturbed bedding clasts and stringers of dolomite are present in the section. A polished section from 60.62' contains spores that have been replaced by pyrite, and irregular chalcopyrite that surrounds other pyrite grains.
60.75' to 60.92'	Thin dolomite bed consisting of a number of thin wavey, partially discontinuous beds. Some burrowing and sulfide mineralization is present.

Depth	
60.92' to 61.25'	Gray shale interbedded with black shales. Small interclasts of dolomite is present in a 0.79" - thick zone at the top of interval. The gray shales have a disturbed appearance. These gray shales also have an interclastic relationship with the black shales.
61.25' to 61.58'	Dark gray shale intermixed with gypsum mush.
61.58' to 61.67'	There is a 1" - thick satin spar gypsum mush.
61.67' to 61.71'	There is a 1/2" - thick gray shale zone.
61.71' to 62.00'	There is a gypsum mush zone. The lower contact is abrupt.
62.00' to 62.83'	Dark gray dolomitic shale. Bedding is quite regular with light and dark gray shale interbeds in the upper half while the lower half is more massive. The lower contact is gradational and regular containing gray shale interclasts in an increasing dolomitic matrix.
62.83' to 63.00'	Dolomite with a disturbed matrix. Towards the upper contact there are numerous gray shale interclasts in a subparallel orientation. A polished section from 62.90' contains pyrite that replaced spores.
63.00' to 63.08'	Massive dolomitic gray shale. The lower contact is gradational.
63.08' to 63.17'	Dolomite. Towards the upper contact it is massive but towards the lower contact it is bedded.
63.17' to 64.00'	Dolomitic dark gray shale that is extensively disturbed with slight dolomite concentrations at: 63.39' (diffused dolomite); 63.67' (diffused dolomite); 63.17' (1/2" bed of dolomite with minor sulfide mineralization). The lower contact is gradational.
64.00' to 64.17'	Dolomite disturbed by stringers of gray shale. This unit also has very fine grains of sulfide scattered throughout the section.
64.16' to 64.50'	Dolomitic gray shale that is extensively reworked.
64.50' to 65.00'	Dark gray shale, thinly interbedded with siltstone.
65.00' to 65.42'	A more massive gray shale with only minor siltstone laminae.
65.42' to 65.54'	Gray shale interbedded with gypsum mush.

Depth	
65.54' to 65.58'	There is a 1/2" gypsum bed (satin spar).
65.58' to 65.96'	Dark gray shale bed that is extensively reworked. Some sulfides have been observed.
65.96' to 66.00'	There is a 1/2" bed of gypsum with both a satin spar and mush texture.
66.00' to 66.08'	Gray shale that is reworked with up to 1% pyrite.
66.08' to 66.12'	There is a 1/2" bed of satin spar gypsum.
66.12' to 66.20'	Dark gray shale, extensively reworked. Pieces of broken-up siltstone and shale laminae are visible.
66.20' to 66.42'	Dolomitic siltstone mixed with dark gray shale. This interval is disturbed.
66.42' to 67.00'	Dark gray dolomitic shale interbedded with discontinuous siltstone laminae. The lower contact is abrupt.
67.00' to 67.25'	Gypsum mush mixed with gray shale. A polished section from 67.02' contains round and irregular pyrite grains.
67.25' to 68.00'	Dark gray shale interbedded with discontinuous, wavey dolomite laminae. This interval is partially reworked. Between 67.25' and 67.29' there is a 1/2" bed of dark gray shale. The entire section contains pyrite mineralizations. At 67.58' there is a 1/4" gypsum bed (satin spar).
68.00' to 68.21'	Gypsum mush and satin spar interbedded with gray shale.
68.21' to 68.33'	Dark gray shale interbedded with siltstone laminae. Pyrite mineralization occurs in this interval. A polished section from 68.20' contains pyrite that has replaced spores.

Drill location #4

Depth	
119.00' to 120.05'	Massive red shale with some reaction halos observed at about the 119.25' level. These halos are generally quite small, less than 0.12" in diameter. At this level there are slicken-slides. Bedding features are absent throughout most of this unit. Between 119.75' and 119.92' there is an interval of small, evenly bedded light red siltstone. The lower contact is abrupt and regular.
120.05' to 120.67'	Light and medium gray colored shale are mixed. The lighter shale appears as interclasts in the medium gray shale. Towards the lower contact this unit becomes more evenly bedded. Mineralization has been observed in the lower few inches in the medium colored gray shale. The lower contact is abrupt and somewhat regular. The light gray material is generally siltstone size.
120.67' to 121.42'	Limestone interbedded with limey gray shale. Some calcite recrystallization appears to have taken place in some of the vugs. The gray shale interbedded with the limestone form irregular wavey beds. The lower contact is abrupt and regular.
121.42' to 121.92'	Medium gray shale thinly bedded with light gray shale near both upper and lower contacts. The middle interval of this unit (121.50' to 121.83') is massive. Some fuzzy gray blebs are observed. The lower contact is abrupt and regular.
121.92' to 122.50'	Massive light grayish-red shale with some gray shale blebs. The upper third is light grayish-red shale, followed by a middle third of light gray shale and by the bottom third of light grayish-red shale. Material in this part seems to be reworked. Irregular patches of light gray occurs in the reddish shale. Some evidence of solution and rehealing in the middle gray part.
122.50' to 123.21'	Gypsum mush mixed with minor red and gray shales. Small uneven bands of vertically oriented gypsum passes through this section. At 123.00' level a 1/2" - thick bed of red shale cuts across this section. Just above this level between 123.04' and 123.17' are large gray shale masses. The lower contact is abrupt and somewhat irregular.
123.21' to 124.17'	Intermixed gray and grayish-red shale. Between 123.21' and 123.67' bedding is indistinct and appears to be reworked (gray and red are interlaced). Between 123.67'

Depth	
	and 124.17' bedding becomes quite regular and even, but the coloration does not follow bedding.
124.17' to 124.42'	Massive off-red shale. The lower contact is gradational.
124.42' to 124.71'	Limey massive gray shale. No mineralization has been observed. The lower contact is abrupt and irregular.
124.71' to 124.95'	Dolomite, irregularly fractured and filled with minor shale. Towards the bottom, larger pieces of shale are imbedded in the dolomite. The shale still some bedding in these pieces. Some barite in the lower part fills what may be vugs or pores. A thin section from 124.90' contains quartz veinlets with undulatory extinction, rimmed by large euhedral carbonate grains.
124.95' to 125.25'	Well-bedded medium gray shale with gray siltstone and gypsum. Gypsum occurs mainly in three or four beds up to 0.20" thick in the lower half. Cross-bedding and ripple marks are common in this section. Small amounts of gypsum present in the section.
125.25' to 125.50'	Mainly light gray dolomite with some thin (up to 0.20") medium gray shale units. In the center some small grains of intermixed gypsum occurs. Towards the bottom some barite is found.
125.50' to 125.83'	Massive limey gray shale. The lower contact is quite abrupt and regular.
125.83' to 129.00'	Massive maroon siltstone and shale. Minor gray shale blebs present between 126.33' and 126.50'. At 128.25' reaction halos with some form of mineralization in the center (possibly pyrite). It seems like most of the section has been extensively reworked, as marked by lighter and darker chips and pieces of maroon shale.
129.00' to 131.55'	Mainly maroon siltstone and shale. There are three zones that stand out in this interval because they contain increased amounts of dolomite: 129.00' to 129.30' 129.95' to 130.40' 130.75' to 130.90' These dolomites are usually in the form of broken-up thin stringers and beds. In the lower most interval the dolomite is more massive. These zones are light off-red in color. The lower contact is gradational and irregular.
131.55' to 132.53'	Light and medium gray and maroon shales and siltstones thinly interbedded. Vertical runners observed (possibly plant roots). In some places bedding is disturbed, but is regular in other places. Becomes more gray and regularly bedded towards the bottom. Possible unconformity.

Drill location #5

Depth	
18.00' to 18.42'	Brownish-red siltstone and shales, thinly and evenly interbedded with limey light red beds (possibly limestone). Several reaction halos have been observed.
18.42' to 18.83'	Alternating limey beds and brownish-red shales and siltstones. Contacts between these thin beds are generally uneven. between 18.42' to 18.50' limey gray silty shale; between 18.50' to 18.58' limey brownish-red shale; between 18.58' to 18.75' limey gray shilty shale; between 18.75' to 18.83' limey brownish-red silty shale; These beds are fractured. Their overall limeyness may result from small limestone stringers passing through this unit.
18.83' to 19.75'	Brownish-red shale with minor gray shale blebs. This interval is fractured. The lower contact is uneven but abrupt. Small plum-like masses of red shale infiltrate below into the gray shale indicating the possibility of organic activity.
19.75' to 20.42'	Gray shale with thin limey light gray stringers, possibly limestone. Bedding is quite even. Good mudcracking features.
20.42' to 21.00'	Limey brownish-red shale with uneven bedding. Mn and Fe mineralization is widespread along bedding planes. This interval is fractured. Mudcracks are common. The cracks themselves are sometimes filled with red-brown shale while the rest is gray.
21.00' to 21.58'	Red shale with some gray shale blebs scattered throughout. Gray shale interclasts seems to concentrate at the 21.42' level. These gray shale clasts seem to be remnants of unaffected original material. Lighter red shale funnels pass vertically through this section. This interval is heavily bioturbated.
21.58' to 21.83'	Limey gray shale with small black shale beds. The black shale beds are generally uneven and discontinuous. There are also thin limestone stringers throughout this section.
21.83' to 21.95'	Mixed gray and red-brown shale with even bedding. Vertical gray filled cracks are common.
21.95' to 22.75'	Red shale interbedded with gray shale beds and blebs. Bedding is moderately disturbed. This part of the core is poorly preserved. The lower contact appears gradational.

Depth	
22.75' to 23.83'	Limey gray shale with a 2" black shale bed between 23.00' to 23.17'. Bedding is even and regular. Between 23.25' and 23.83' the core is poorly preserved and bedding features are obscured. The contact below is abrupt and uneven. Mg mineralization is found along fractures and bedding planes.
23.83' to 25.25'	Massive maroon shale, slightly limey.
25.25' to 27.00'	Maroon shale turning brown-red below 26.00'. At 25.25' there is a 1/2" - thick gray shale. Bedding is partially preserved, but most is extensively reworked.
27.00' to 27.75'	Off gray and brownish-red shale, interbedded. Color changes along bedding. Extensively reworked.
27.75' to 28.15'	Medium dark gray shale containing thin (less than 0.04" - thick) carbonate laminae.
28.15' to 29.33'	Limey red-brown shale with minor blebs of gray shale. The bedding is disburbed. The lower contact is gradational.
29.33' to 30.00'	Limey red-brown shale interbedded with limey gray shale becoming mostly gray towards the bottom.
30.00' to 30.25'	Dolomite containing oxidized red siltstone giving most of the rock a reddish appearance. The lower contact grades into a gray shale at 30.17'.
30.25' to 30.83'	Massive red-brown shale and siltstone. A few minor dis-continuous gray shale laminae are present.
30.83' to 31.60'	Dolomite. Except for the center 1", which is a dense lithographic dolomite, both sides are up to 1/4" - thick dolomitic beds separated by thin (about 0.04" - thick) gray shale units. Bedding is regular and seems to be continuous.
31.60' to 32.00'	Medium gray shale. Mudcracked. Discontinuous patches of brown-red shale increasing towards the bottom. They may be related to the mudcracks in that they tend to form the core of the mudcrack.
32.00' to 33.00'	Red-brown shale.

Drill location #7

Depth	
16.67' to 17.62'	Massive maroon shale with no apparent bedding features.
17.62' to 18.33'	Maroon shale thinly interbedded with thin gray shale. These laminations vary in thickness rapidly over short distances. They are also frequently discontinuous over the short distance across the core. Extremely fine laminations of lighter maroon siltstone are present. These fine laminae are slightly calcareous. The lower contact is abrupt. At 18.25' there is a 1/4" gray shale bed.
18.33' to 18.83'	Off-red colored shale. The bedding is slightly disturbed. Darker red colored shale stringers run erratically throughout this interval. The lower contact is gradational and irregular. Blebs of red shale are found intermixed with the gray shale below. Soft sediment deformation seems to have occurred here as evidence by micro-faulting and the distorted nature of the red blebs.
18.83' to 19.42'	Limey gray shale. The upper contact is gradational and regular. Gray shale is interbedded with red shale blebs and irregular thin stringers of limestone, generally less than 0.04" - thick are common. Except for the occasional limestone stringer bedding features are absent. The lower contact is abrupt and regular.
19.42' to 19.71'	Limestone. There is a small copper sulfide zone at the 19.62' level. Both black- and green-colored forms of malachite have been observed. This horizon is quite small, on the order of 1/4". A polished section from 19.60' contains malachite surrounding and replacing azurite, and also a blade of chalcocite (?) that has partially altered to covellite. This blade is partially replaced by the azurite. A thin section from the same depth contains shale interclasts that have been cemented by carbonate grains. Elsewhere in the thin section, quartz between the shale interclasts is partially replaced by carbonate grains, and the carbonate is partially replaced by malachite.
19.71' to 19.96'	Limestone interbedded with limey gray shale. Bedding is regular, continuous and wavey. Some mineralization along vertical stringers is present. This is likely a manganese compound.
19.96' to 20.62'	Gray shale and siltstone generally massive with mostly a disturbed appearance, some minor wavey beds that might be small, poorly developed ripple marks. The upper contact with the limestone is abrupt and uneven while the lower contact is gradational and even.

Depth	
20.62' to 21.50'	Limey off-red shale becoming more silty towards the bottom. This bed seems to have been disturbed. The lower contact is abrupt and even.
21.50' to 21.80'	Massive gray-green shale.
21.80' to 22.30'	Friable finely intermixed gray and red shale. Bedding is mostly not apparent.
22.30' to 23.30'	Off red shale with laminae of gray shale and limestone along with blebs of gray shale. Between 22.45' and 22.80' gray shale laminae seem to be especially common. The lower contact is sharp and quite regular. The lower part of this bed is massive. In the lower part the red shale is slightly limey.
23.30' to 23.47'	Gray shale containing small (up to 0.04" - thick) limestone clasts that are genrally aligned along what may be bedding. The upper contact is gradational and even. Some clasts are in the upper red shale. The lower contact with the limestone is regular, a 1.18" - thick zone of reworked limestone pieces and shale marks the lower contact.
23.47' to 23.54'	Massive light gray limestone. The upper contact with the gray shale is quite disturbed. Clasts of limestone on the order of 0.40" are in a gray shale matrix. Some of the larger clasts are further broken up by gray shale runner. The lower contact is abrupt and somewhat irregular.
23.54' to 23.75'	Massive limey gray shale.
23.75' to 24.14'	Limeyred shale, massive.
51.58' to 52.25'	Maroon colored shale interbedded with a few gray shale laminae. Some of them are continuous across the core and others are disrupted along the way. Dark red-brown small discontinuous laminae are generally aligned along bedding are common. Bedding is generally irregular.
52.25' to 52.96'	Dark gray shale interbedded irregularlywith red shale, along with a few minor laminae of limestone. Bedding is more regular towards the bottom. Red shale blebs have been observed floating in gray shale with limestone laminae passing through them. In some parts even the gray shale appears to be limey. The lower contact is abrupt and regular.
52.96' to 53.08'	Massive limey red shale. The lower contact is abrupt and regular.
53.08' to 53.45'	Medium gray shale and dolomite. The top half is extensively reworked, becoming more regularly bedded in

Depth	
	lower half. A burrow is visible through the entire interval.
53.45' to 53.92'	Mainly light gray dolomite. At 53.50' and 53.75' are medium gray shale beds up to 1/2" thick. Between 53.50' and 53.75' is mainly dense dolomite with possible mineralization (barite and copper sulfide) at 53.65'. The rest of the material seems to be extensively reworked. A thin section from 53.60' contains extremly turbated gray shale with quartz of two generations between the shale interclasts. Euhedral quartz rims the edges of the formerly open spaces between the interclasts. Finer-grained quartz fills the rest of the space and corrodes the edges of the euhedral quartz crystals. Some opaques are found in the fine-grained quartz.
54.00' to 54.25'	Limey black shale with small discontinuous dolomite laminae patches. There was no mineralization observed.
54.25' to 55.62'	Massive dark maroon shale.
55.62' to 55.67'	A 1/2" - thick gray-green shale bed. This small unit appears to be riddled with copper sulfide grains. Near the lower contact, which is abrupt and regular, the shale becomes predominantly dolomitic. In a polished section from 55.60', chalcopyrite replaces bornite.
55.67' to 56.25'	The top half is half light gray, poorly bedded and broken-up dolomite and half medium gray shale. Burrowing containing copper sulfide mineralization in the interval. The lower half is partially vuggy dolomite and minor shale, with some copper sulfide mineralization.
84.00' to 85.54'	Limey medium dark gray massive shale with minor carbonate or gypsum laminae. About the 84.67' to 84.83' level there seems to be a greater concentration of these laminations. At 85.25' a 1/2" - thick gypsum bed, slicken-sides present above and below the gypsum bed. Some of the sediment deformation causes some waveyness and small scale micro-faulting (normal). The massive shale may have been extensively reworked.
85.54' to 85.67'	Light gray shale, massive. The lower contact is gradational.
85.67' to 85.96'	Massive light off-red shale with very fine gray blebs distributed throughout this interval. The lower contact is gradational.
85.96' to 86.37'	Limey gray shale with minor limestone laminae. At 86.37' there is 5/8" - thick gypsum bed with striations oriented vertically. Slicken-sides are found above and below this unit.

Depth	
86.37' to 86.50'	Massive gray shale. Fractures are filled with thin gypsum layers.
86.50' to 86.90'	Dolomite is interbedded with medium gray shale. Shale is also in the carbonate matrix. At 86.70' a 1" - thick zone characterized by iron staining in dolomite pores and vugs. In the lower several inches the dolomite occurs as discontinuous pieces in the shale.
86.90' to 87.50'	Mainly a medium dark gray shale with thin dolomite laminae as well as discontinuous small pieces (up to 0.20" - thick) aligned along bedding and decreasing towards the bottom. Some rusty mineralization as above associated with the dolomite.
87.50' to 88.92'	Massive brownish-red shale.
88.92' to 89.50'	Mainly massive shale. Color changes from light gray at the top to dark gray at the bottom.
89.50' to 90.72'	Mixed medium gray shale and dolomite. The upper contact is quite sharp as the lower contact is more gradational. This interval is about half dolomite which occurs as disconnected blebs generally elongated parallel to the bedding. Alternating layers are either richer in carbonate or shale. Some burrowing is observed. Carbonate becomes dominant in the bottom 2".
90.72' to 91.07'	Dominantly dolomite with regular thin shale laminae. Some bioturbation is evident. The lower contact is quite abrupt. At 90.72' there is a 1" layer of iron staining.
91.07' to 91.42'	Dark gray shale with thin (less than 0.04") dolomite laminae throughout the interval.

Drill location #10

Depth	
90.00' to 90.50'	Mainly brownish red siltstone with finely disturbed bedding.
90.50' to 91.50'	Brownish red siltstone with alternating minor small gray-green shale laminae increasing in number towards the bottom. These gray-green shales are mostly not continuous across the core, as they either taper out or end abruptly. Possibly the result of post-depositional disturbances.
91.50' to 91.67'	Gray shale. The upper inch contains 0.04" - thick discontinuous dolomite stringers (10%) and the lower inch 50% shale and 50% dolomite. The dolomite is chaotic, contact with the brownish red siltstone below is diffuse. Shale particles are oxidized preferably over the dolomite.
91.67' to 92.50'	Brownish red siltstone with worm-like burrows. At 92.00' bedding is irregular. The upper contact with the gray-green shale is not observable because of the poor condition of the core, some chips indicate an abrupt contact.
92.50' to 92.75'	50% gray and 50% brownish-red shale, unevenly disturbed becoming less to the bottom and resembling more burrows.
92.74' to 94.00'	Brownish red siltstone with indistinct bedding. At 93.75' the color changes to a medium brown. At 94.00' gray shale begins to appear as small interbedded layers with red siltstone. Gray shale layers increase in both number and thickness down the section.
94.00' to 95.00'	Brownish-gray and minor brownish red shale interbedded in a somewhat more regular manner. Both upper and lower contacts are gradational over a short interval.
95.00' to 98.00'	Massive dark maroon siltstone with very minor gray shale interbeds at 96.50'. Reaction halos frequently have centers with some form of mineralization, possibly pyrite. At 95.84' massive maroon siltstone becomes less massive siltstone to gray shale, contains minor amounts of gray shale. At 96.34' a couple of inches of well bedded medium brown red and maroon shale changes to more irregular bedded siltstone containing gray worm burrows at 96.50'.
105.50' to 105.83'	Limey dolomite with some small gray interbeds near the base of this unit. The limey dolomite is 0.25" thick. Secondary quartz is present in vugs. A thin section from 105.60' shows interclasts of shale with small carbonate grains between the shale interclasts.

Depth	
105.83' to 106.00'	Limey gray-green shale. A polished section from 106.00' contains chalcocite (?) stringers. A thin section from the same depth contains some unreplaced spores.
106.00' to 106.25'	Gray-green siltstone. The lower contact is uneven and abrupt.
106.25' to 106.50'	Dark maroon siltstone, some mottling caused by gray-green irregular clast-like material (approximately 0.12" average size).
106.50' to 107.58'	Light to medium brown-red siltstone, indistinctly bedded to massive, minor worm burrows. Between 106.75' to 107.20' medium brown-red siltstone, thinly bedded, bedding is fairly regular in the upper half and is more disturbed towards the bottom. Between 107.20' and 107.58' light brown-red massive siltstone.
107.58' to 108.33'	This section of core is poorly preserved. There is an abrupt change to dark maroon siltstone, fractured, slickenslides are common, possibly due to movement along gypsum-filled fractures.
108.33' to 110.00'	More massive dark maroon siltstone. At 108.50' there is a 1/4" - thick gypsum bed.
110.10' to 110.50'	Dark maroon and gray siltstone. The gray occurs as broken-up patches (50%) in the dark maroon shale.
110.50' to 111.10'	Light gray shale and gypsum. Satin spar beds up to 0.20"-thick near the top of unit. Gypsum content increases to the center (up to 90%) and occurs as a mush. At 111.10' a 3/4" - thick satin spar bed occurs.
111.10' to 111.17'	Faintly bedded medium gray shale. The lower contact with the red shale is very sharp.
111.17' to 111.50'	Light red silty shale mixed with small gray and red shale blebs, gives a grayish mottled appearance.
111.50' to 111.91'	Red shale decreasing and gray shale gradually increasing with depth forming a gradational contact with a limey gray shale. Some small dolomite clasts are present.
111.91' to 112.25'	Gray shale interbedded with dolomite. Between 111.91' to 112.25' massive gray shale unit with dolomite blebs along what looks like bedding. Between 112.00' to 112.25' gray shale interbedded with dolomite, and these carbonate beds are 1/2" thick. Bedding is more or less regular.

Depth	
112.25' to 112.67'	Dark maroon siltstone heavily mottled with gray siltstone. The upper contact is gradational over a short distance and the lower contact is abrupt. There is no apparent bedding features. This section of core is poorly preserved.
112.67' to 114.00'	Massive dark maroon siltstone with minor burrowing.
140.00' to 141.00'	Thinly but generally well bedded dark purplish red siltstone beds made up of alternating layers of lighter colored more silty units and dark colored shaly units. Thin units exhibiting differential oxidation suggests small mudcracks or minor gray mottling.
141.00' to 141.60'	Massive dark purplish red shale with indistinct minor gray mottling.
141.60' to 142.00'	Mainly maroon siltstone and shale with gray shale distributed throughout.
142.00' to 142.17'	Alternating gray and dark maroon shale, unevenly bedded. Dolomitic and light gray laminae run through both gray and maroon shales. Some burrowings.
142.17' to 142.67'	Mainly dark maroon shale with minor gray shale blebs at 142.67'. The gray shale bedding is uneven moderately disturbed in places. Light gray laminae are present.
142.67' to 143.00'	Massive dark maroon shale with minor gray shale. This interval of core is poorly preserved.
143.00' to 144.33'	Poorly consolidated, appears to be massive dark maroon shale, fractured in places.
144.33' to 145.50'	Interbedded dolomite and gray shale. Between 144.92' to 145.33' within this interval mineralization could not be found. This interval is mainly dolomitic interbedded with gray shale. A polished section from 144.40' contains vertical stringers of chalcocite (?) with two grains of covellite replacing the chalcocite. Irregular veinlets of chalcocite are found in a polished section from 144.70', associated with quartz veinlets in a shaley matrix. Between 145.44' to 145.50' limey gray shale interbedded with dolomite.
145.50' to 145.75'	Dark, massive, maroon siltstone.
145.75' to 146.33'	Gray and maroon shales intermixed. Resembles large scale mud cracking in some places. Some maroon shales transect gray shales.

Depth	
146.33' to 146.67'	Mainly gray silty shale with minor amounts of maroon silty shale, bedding is wavey to somewhat irregular, and some burrowings. At 146.45' there is a 0.12" - thick gypsum bed.
146.67' to 147.08'	Medium brownish red shale intermixed with gray shale. Gray shale occurs as irregular blebs and patches somewhat suggestive of mudcracks. Mostly a random mixing, bedding is indistinct and discontinuous.
147.08' to 147.17'	Gray shale with red and light red filled mud cracks.
147.17' to 147.42'	Red shale with small gray shale blebs.
147.42' to 147.58'	Gray shale with small red shale blebs.
147.58' to 147.83'	Gypsum mush, unevenly bedded with red siltstone and some satin spar gypsum layers.
147.83' to 148.50'	Maroon siltstone interbedded with lighter red and gray shales. Turns purplish near the base. At 147.92' there is a 1/4" - thick gypsum bed. Between 148.42' and 148.50' light maroon and gray shales are interbedded with increasing size and number.
148.50' to 149.00'	Gray shale interbedded with purplish red and light brown siltstone. Bedding is regular, some ripple markings are suggested in the light gray shale laminae.
149.00' to 149.42'	Dark gray shale with thin light gray shale laminae.
149.42' to 149.50'	Gypsum mush.
149.50' to 150.33'	Well-bedded gray shale with thin (0.04 - 0.08" - thick) red brown siltstone laminae and some light gray siltstone laminae. Load marks on gray shale by reddish siltstone and micro-cross bedding are present.
150.33' to 151.00'	Dense brown-red limey shale with blebs of light red shales.
151.00' to 151.50'	Limey gray shale, massive.
151.50' to 152.00'	Dolomite with thin, wavey stringers of dolomitc gray shale. Between 151.58' and 157.75', barite and minor copper sulfide occurs. Barite grains fill vugs and concentrate along bedding planes. Some quartz is associated with barite. A polished section from 151.50' contains veinlets in which one generation of quartz rims the margins of the veinlets, and a younger generation in the center contains opaques.
152.00' to 152.25'	Upper half is limestone mixed with gray-green shale, both

Depth	
	have disturbed appearance and are not well bedded. The lower part is gray-green shale with thin (up to 1mm) limestone stringers.
152.25' to 152.55'	Medium dark gray dolomitic shale and intermixed shaley dolomite. The lower 1" is mainly dolomitic shale, below is 1/2" of shaley dolomite with minor shale stringers. The bottom 1" is dolomitic shale with discontinuous wavey, shaley dolomitic stringers.
152.55' to 152.67'	Medium gray massive shale, the lower contact is gradational.
152.67' to 153.08'	Maroon shaly siltstone with thin regular bedding.
153.08' to 153.17'	Satin spar gypsum.
153.17' to 153.50'	Red siltstone with up to 50% gray shale interbeds. The irregular bedding gives a mottled appearance.
153.50' to 154.00'	Maroon siltstone with some gray shale that is usually associated with gypsum mush. At 154.00' there is a 1/4" - thick gypsum layer.
154.00' to 154.08'	Gypsum mixed with red and gray shales.
154.08' to 154.50'	Purple limey shale and purplish limestone, irregularly bedded.

Drill location #11

Depth	
32.00' to 32.15'	Dense maroon siltstone, which at 32.15' turns into a disturbed siltstone, and the disturbed areas are filled in with lighter brown-red siltstone.
32.15' to 33.50'	Maroon disturbed siltstone. Size of the clasts is generally about 0.12" but larger pieces up to 0.40" are common.
33.50' to 34.55'	The rock is a brown-red color, lighter at the bottom, and is disturbed. Irregular light-gray patches up to 1" long make up 10% of the rock, towards the bottom the clasts take on a gray color.
34.55' to 35.50'	Mixed light-gray shale and dolomite or dolomitic shale content decreases towards the bottom, half of the shale shows distinct bedding, but bedding is wavey and disturbed on a small scale.
35.50' to 36.50'	Light cream to reddish dolomite, contains irregular thin (up to 0.04" - thick) shale stringers in all kinds of orientations, at 35.65' a 1/2" - thick brown-red limey siltstone unit, at 35.75' fossils, brine shrimp.
36.50' to 36.85'	Silty dolomite having mostly irregular patches of red-brown silt and shale giving it a mottled appearance, some of it is roughly aligned along bedding and turns light gray siltstone to shale, they have the appearance of mud-cracks later filled with dolomite.
36.85' to 37.90'	Mainly a silty dolomite having very light reddish-brown appearance, minor red brown and gray (less than 0.04"- thick) shaley intervals, also contains minor foriegn clasts at 36.95', fossils (brine shrimp) at 37.00', 37.15', and 37.50'.
37.90' to 38.30'	Mixed mottled light gray and red-brown siltstone, some fossils on bedding planes, no apparent bedding.
38.30' to 40.00'	Massive deep brownish-red siltstone, very friable.
40.00' to 40.30'	Massive maroon siltstone.
40.30' to 41.30'	Maroon siltstone laminated by a distinct gray discontinuous unit (1/2"- thick) the gray occurs as patches transgressing faint bedding, then turns into finely bedded light brown-red to gray siltstone, becoming more distinct at 40.55' and losing its bedding at 40.80'. The whole unit becomes more mottled towards the bottom and is again terminated by a discontinuous dominant gray (1/2" - thick) unit at the top.

Depth	
41.30' to 41.50'	Red-brown disturbed shale broken-up, unit, friable.
41.50' to 42.65'	Maroon siltstone, massive with a few reaction halos in the top and bottom portion. In the center a distinct disturbed zone (2" - thick) which is more friable, bedding is indistinct to nonexistent, small clasts common, most of the material seems to have been disturbed or reworked.
42.65' to 43.20'	Maroon changing to light red-brown siltstone, the rock is friable due to mudcracking and being disturbed. There are several 0.04" - thick gypsum stringers.
43.20' to 44.30'	Dolomitic limestone interbedded with gray shale. Between 43.33' to 43.58' disturbed, there is no observable bedding, only a few blebs of gray. Between 43.33' and 43.58' limestone interbedded with limey shale (gray), bedding is moderately disturbed by soft-sediment deformation. Between 43.75' and 43.90' mainly dolomitc limestone. Between 44.12' and 44.30' massive limey gray shale with small interclasts of limestone, the lower contact is abrupt but irregular.
44.30' to 45.30'	Massive red-brown siltstone, minor amounts of gray spotting, section highly disturbed with angular fragments in matrix.
45.30' to 45.45'	Massive gray siltstone, upper and lower contacts are irregular.
45.45' to 46.10'	Massive light and dark red-brown shales intermixed with gray reaction halos, bedding wherever present is indistinct, friable.
46.10' to 47.45'	Massive gray siltstone. At 46.14' there is a 1/2" - thick red siltstone bed, small reaction halos are present, as are thin discontinuous beds marked by siltier material.
46.45' to 47.40'	Massive red-brown siltstone with gray reaction halos up to 1/2" in diameter.
59.00' to 60.30'	Massive maroon shale.
60.30' to 60.65'	Interbedded maroon shale and light brown red siltstone, minor gray mottling, bedding is wavey and broken-up, probably due to burrowing.
60.65' to 61.65'	Purplish-red to maroon siltstone, over most of the interval lighter colored angular chips (up to 0.20" long) are surrounded by a darker matrix. This is possibly due to mudcracking.

Depth	
61.65' to 62.85'	Interbedded dolomitic siltstone and minor shale, the shale is either dark brown-red or gray, the dolomitic siltstone is much lighter colored, several cycles can be distinguished; between 61.65' to 62.10' mainly red shale; between 62.10' to 62.45' mainly gray; between 62.45' to 62.75' dominantly gray; between 62.75' to 62.85' half red and half gray; all gray below this interval, the amount and intensities of the red color diminshed downward, the whole interval is bedded, bedding planes are wavey and partially disturbed, and individual beds are mainly (0.04"- thick). The gray units are less distinctly bedded, and they are characterized by accumulations of silty dolomite. Vugs up to 1.60" in diameter and linedwith gypsum became smaller towards the bottom. They make up to 1-2% of the rock.
62.85' to 63.40'	Light gray dolomitic siltstone and minor gray green shale much like above. The unit is totally disturbed mechanically. There is possibly some burrowing. Downward small pieces of dolomite occurs as chips (about 0.12" in diameter) in the rock.
63.40' to 63.50'	Dolomitic siltstone containing surrounded chips of dolomite up to 0.40" in diameter. The rock is very disturbed, has no continuous bedding, and towards the bottom of the unit it becomes a patchy gray and maroon dolomitic siltstone.
63.50' to 63.75'	Half light gray and half maroon patchy intermixed siltstone, which also contain minor (0.07" - thick) gypsum ribbons.
63.75' to 65.00'	Dark maroon shale and siltstone, massive appearance but may have been extensively reworked, minor amounts of intermixed gray shale towards the bottom, also some gypsum stringers.
65.00' to 67.10'	Poorly consolidated mixed gray and maroon siltstone, material possibly extensively reworked.
67.10' to 67.50'	Mainly maroon bedded shale, some gray patched towards the top.
83.00' to 84.50'	Massive dark maroon shale with a few (less than 0.5%) small (0.04" in diameter) gray reaction halos, there is an abrupt lower contact.
84.50' to 85.25'	Silty dolomite and gray shale intermixed, the gray shale is more prominent in the top half, making up to 50% of the rock. In the lower half it makes up to 25%. The shale shows a certain degree of bedding but is wavey and broken-up,. gypsum seems to be mixed with dolomite.
85.25' to 86.15'	Mixed gray silty dolomite and red-brown shale, the shale is well bedded in the top half and becomes disturbed in

Depth	
	the bottom half. Beds are generally on the order 0.07" - 0.12" thick, some burrowing is apparent.
86.15' to 86.50'	Completely disturbed section marked by angular pieces of shale and siltstone is a light brown-red silty dolomitic matrix.
86.50' to 87.50'	Shale and silty shale, brownish-red in color mixed with gray, patched and streaks of the same material making up to 30% of the section. Poorly consolidated, no apparent bedding, mudcracks are present, has the appearance of being reworked.
87.50' to 88.00'	Mainly intermixed shale and siltstone, about 20% of the section is red-brown colored along definite horizons. This interval is characterized by distinct although broken-up and wavey bedding, some burrows present, in a way this interval and the one below is similar to the bottom half of 85.25', 85.15' and 86.15' - 86.50'. Fossil brine shrimp is gray shale at 87.60.
88.00' to 88.35'	Broken-up, completely disturbed section. Some obviously broken-up beds range in color from light to dark brown-red.
88.35' to 89.60'	Essentially dark maroon, massive siltstone, no bedding features observed. At 88.75' a 1/2" gray siltstone band having sharp but wavey contacts, contains gypsum. At 89.00' there is evidence of burrowing.
89.60' to 89.85'	Shale unit characterized by gray shale which is mudcracked. The mudcracks are engulfed by maroon shale or siltstone.
89.85' to 91.70'	Dark maroon siltstone, a little gray-maroon band towards the bottom (around 90.50'). Minor amount of small (up to a few tenths of an inch wide) reaction halos.
102.00' to 102.05'	Light gray shale and interbedded minor dolomitic limestone.
102.05' to 104.10'	Dark maroon siltstone changing to gray siltstone at the base.
104.10' to 104.25'	Light gray shale with minor dolomitic limestone. The top contact is gradational, dolomitic limestone occurs as patches and seems to be related to deposition from flowing water.
104.25' to 104.85'	Mainly dolomitic limestone. Minor thin discontinuous beds of gray shale, some secondary calcite and/or gypsum.

Depth	
	A polished section from 104.75' contains a chalcocite (?) veinlet.
104.85' to 105.05'	Gray shale. Polished section from 105.00' contains pyrite that is partially replaced by chalcocite (?). There are also some chalcocite (?) vertical stringers, possibly related to burrow structures.

Drill location #12

Depth	
31.50' to 32.75'	Massive purplish-maroon shale, minor scattered reaction halos, at 32.00' several thin, dolomite-filled fractures.
32.75' to 33.75'	Friable purplish-maroon shale, with uneven (usually vertical) burrowings or mud cracks filled with a lighter red-brown shale, also a fair amount of very thin calcite or dolomite-filled fractures.
33.75' to 34.33'	Maroon shale, with thin (up to 0.08" - thick) discontinuous beds of light brown colored siltstone making up 5% of the rock.
34.33' to 34.58'	Dark maroon shale, friable.
34.58' to 34.79'	Gray siltstone mixed with light maroon siltstone, bedding is irregular and faint.
34.79' to 34.96'	Massive maroon siltstone.
34.96' to 35.12'	Dolomitic lightgray shale.
35.12' to 35.33'	Dolomite (limestone) mixed with minor amounts of gray shale, some green colored stains, many vugs containing recrystallized calcite, and near the lower contact gray-green shales are encountered.
35.33' to 36.25'	Massive maroon siltstone with some shales in parts.
36.25' to 36.42'	Maroon siltstone containing irregular gray siltstone patches (up to 3.94" in diameter, making up 35% of the rock).
36.42' to 36.67'	Maroon shale.
36.67' to 36.92'	Light brown-red siltstone turning into gray siltstone below.
36.92' to 37.08'	Massive limey light gray shale.
37.08' to 37.33'	Dolomite limestone with malachite staining along bedding planes and some fine copper sulfide grains scattered about this interval. At 37.25' considerable recrystallization has occurred in vugs.
37.33' to 37.63'	Limey light gray friable shale, massive, with an abrupt lower contact.

Depth	
37.63' to 38.46'	Massive maroon shale. Between 37.63' and 37.71' the coloring is a lighter maroon possibly because of mixing with gray shale above, some slicken-slides surfaces are present.
39.50' to 39.75'	Limey light gray shale, regularly bedded for the most part, the top 0.08" is more silty and massive.
39.75' to 40.40'	Gray dolomitic siltstone, thinly bedded with white siltstone. Between 40.04' to 40.08' there are some red siltstone interbeds, and below 40.17' the siltstone has good shale partings mainly due to thin gypsum layers.
40.40' to 40.50'	Light purplish massive red silty shale.
40.50' to 41.08'	Hard, massive maroon siltstone, minor shale with minute reaction halos scattered throughout interval.
41.08' to 41.75'	Friable maroon silty shale, with small reaction halos scattered throughout interval, becoming more massive towards the bottom.
41.75' to 43.50'	Massive maroon siltstone with reaction halos up to 0.20" in diameter (most prominent between 42.80' and 43.15').
43.50' to 43.58'	Massive, hard silty dolomite.
43.58' to 44.08'	Massive, purplish red silty shale mixed with numerous small clasts of gray siltstone and 0.08" layer of predominently gray siltstone.
44.08' to 44.25'	Friable, brown to maroon silty shale, with minor reaction halos.
44.25' to 45.00'	Alternating light and dark gray shale, somewhat reddish in a few places. Thinly bedded with ripple-marks.
56.00' to 58.25'	Red siltstone; between 56.00' to 56.92' maroon siltstone, bedding is irregular and appears to be disturbed (root casts and possibly stromatolites); between 56.92' to 57.21' maroon siltstone is interbedded with lighter red to gray siltstone, bedding is also disturbed by root casts; between 57.21' and 58.08' massive maroon siltstone; between 58.08' and 58.12' satin spar gypsum; between 58.12' and 58.25' massive maroon siltstone minor gypsum along fracture planes.
58.25' to 58.42'	Maroon and gray silty shale.
58.42' to 48.71'	Massive light gray shale with minor silty laminae.

Depth	
58.71' to 58.92'	Dolomite, massive with minor gray shale.
58.92' to 59.17'	Medium gray siltstone interbedded with siltstone laminae.
59.17' to 59.67'	Medium gray and red siltstone intermixed, bedding is quite disturbed, and more predominent towards the bottom.
59.67' to 61.25'	Medium brownish red siltstone, the top half and the bottom halves are dark maroon siltstone, and about 40% very fine sand laminae, giving a fairly well bedded appearance.
61.25' to 62.50'	Massive, purplish red shale.

Drill location #13

Depth	
46.50' to 48.67'	Red siltstone with worm burrowings that have been filled with gray silty shale, mainly found between 46.50' and 48.00' and between 46.50' and 47.50' Evenly bedded, massive dark maroon, greater than 1% burrows that are up to 0.40" in diameter. Between 47.50' and 48.67' slightly coarser dark maroon shale, more crumbly appearance, few burrows, at 48.20' grades to a lighter maroon.
48.67' to 48.75'	Red siltstone interbedded with gray silty shale forming a gradational contact with the unit below, this interval of core is poorly preserved, bedding appears to be irregular.
48.75' to 49.17'	Limey gray shale with thin limestone stringers, fractured interval, massive.
49.17' to 49.42'	Limestone, up to 1% malachite grains and stains along fractures and in vugs, limestone interclasts are common, Fe and Mg staining along fractures is common.
49.42' to 49.83'	Limey gray-green shale with thin limestone interbeddings, the shales of this interval are fractures.
49.83' to 50.17'	Dark maroon siltstone, massive, contacts above and below are abrupt.
50.17' to 51.00'	Light maroon siltstone, massive with worm burrows.
51.00' to 51.42'	Limey red and gray shale, fractured, friable.
51.42' to 51.75'	Limestone, unevenly bedded with thin laminae of shale, small limestone interclasts are scattered throughout interval, considerable calcite crystal growth in vugs, Fe/Mg stains in fractures, no observed copper sulfide mineralization.
51.75' to 52.00'	Limey gray shale, unevenly bedded.
52.00' to 52.50'	Red siltstone with minor limey gray shale, unevenly bedded.
52.50' to 52.92'	Limey red shale intermixed with minor gray shale, bedding is regular, the limey gray shale content increases towards the lower contact to 30%.
52.92' to 53.00'	Gray shale.
85.00' to 85.25'	Dark maroon siltstone, massive, the lower contact with a gypsum bed is abrupt.

Depth	
85.25' to 85.29'	A 1/2" - thick gypsum bed with striationoriented perpendicular to the bedding, bed changes position by following fractures for short distances (post gypsum adjustment).
85.29' to 85.67'	Gray shale, massive. A polished section from 85.40' contains chalcocite (?). Lower contact is gradational.
86.67' to 86.58'	Limestone. Between 86.25' and 86.33' there is a band of gray shale interbeds.
86.58' to 86.67'	Massive off red siltstone, the lower contact is gradational.
86.67' to 86.92'	Massive, gray siltstone, the lower contact is abrupt.
86.92' to 87.42'	Limey, gray shale interbedded with limestone. A polished section from 87.00' contains grains of chalcocite (?). A thin section from the same depth contains stringers of opaques.
87.42' to 90.00'	Mainly dark maroon siltstone, poorly preserved interval of core; between 89.00' and 90.00' there are some gray chips and gypsum fragments; at 88.80' there is 1 cm of uneven dark gray shale beds; below 88.80' the color changes from maroon to a dark purplish red at 89.75'.
90.00' to 91.00'	Thinly bedded dark purplish red silty shale.
91.00' to 92.75'	Mainly gray shale interbedded with light red brown shale; between 91.58' and 91.67' there is a 1" - thick layer of massive gypsum mixed with gray and red shales. Between 91.67' and 92.42' gray shale with some red shale that is interbedded with lighter red shale. Between 92.42' and 92.75' mainly dolomitic limestone with a disturbed matrix, the lower contact is gradational.
92.75' to 94.00'	Off red siltstones and shales, limey, poorly bedded, fragments scattered throughout. Between 92.75' and 92.92' off red limey shale with thin limestone stringers, limestone interclasts are common at 93.75' and there is a minor gray shale interbedded with a red shaley siltstone. The bedding varies from even to moderately chaotic, the lower contact with the gray shale is abrupt.
94.00' to 94.50'	Limey gray shale with dolomitic limestone interclasts in the upper half. Massive.
94.50' to 95.33'	Limestone with thin interbeds of limey gray shale. Wavey, limey gray interbedding throughout the unit. A few small

Depth	
	pyrite and chalcocite (?) grains are present in a polished section from 94.00'. A thin section from the same depth has quartz veinlets that contain opaques.
95.33' to 95.58'	Black and gray shale mixed with limestone interclasts. Copper sulfides are observed in limey gray shale and limestone masses. In a polished section from 95.40', an unreplaced spore and chalcocite grain are visible.
95.58' to 95.75'	Thinly bedded gray shale.
95.75' to 96.50'	Off red shale with some minor gypsum beds and thin discontinuous gray shale. Between 96.00' and 96.08' there is a 1" - thick satin spar gypsum bed. Between 96.42' and 96.50'; off red shale occurs with discontinuous gray shale blebs, more prominent in the lower half.
96.50' to 96.67'	Massive, disoriented gypsum bed mixed with gray shale. Black specks in shale, prominent at the shale/gypsum contact.
96.67' to 96.92'	Massive red shale.
96.92' to 97.25'	Limestone mixed with red shale blebs, some black specks are observed, the lower contact with the gray shale is gradational.
97.25' to 97.67'	Limey gray shale, interbedded with red shale and some limestone bedding is generally uneven.
97.67' to 98.00'	Red shale with blebs of darker red shale.

Drill location #14

Depth	
16.00' to 16.17'	Gray siltsone.
16.17' to 16.29'	Massive red brown shale.
16.29' to 16.58'	Mixed red and gray siltstone.
16.58' to 18.62'	Massive red siltstone.
18.62' to 19.08'	Thinly bedded gray shale and siltstone.
19.08' to 20.00'	Mixed red-brown and gray siltstone and shale. Some of it is thinly bedded with siltstone laminae.
20.00' to 22.83'	Massive light red-brown siltstone.
22.83' to 23.00'	Gray silty shale.
23.00' to 24.00'	Mixed red and gray silty shale.
24.00' to 25.33'	Massive red silty shale.
25.33' to 26.00'	Mixed red and gray silty shale.
26.00' to 26.54'	Light red-brown siltstone, massive. Massive light red-brown siltstone.
26.54' to 28.33'	Interbedded medium gray shale and light gray dolomite.
28.33' to 26.83'	Light red siltstone, with minor gray shale.
26.83' to 29.04'	Gray shale.
29.04' to 30.50'	Light red-brown siltstone that is sandy in places. Some solution cavities.
30.50' to 32.00'	Dark red siltstone, massive.
35.00' to 36.33'	Gray-green shale.
36.33' to 37.00'	Mixed gray and red silty shale.
37.00' to 38.33'	Light red siltstone, thinly laminated. Between 37.67' and 38.17' there is a lighter red sandstone unit.
40.00' to 40.67'	Light red-brown siltstone with faint gray blebs.
40.67' to 41.33'	Light reddish gray siltstone.
41.33' to 41.83'	Red siltstone and shaly siltstone.

Depth	
41.83' to 42.00'	Gray siltstone.
42.00' to 42.33'	Red silty shale.
42.33' to 42.62'	Gray calcareous shale.
42.62' to 43.50'	Lighter red silty shale with some gray shale blebs.
43.50' to 45.17'	Gray shale, partially calcareous.
45.17' to 45.83'	Off red and gray shale intermixed with slicken-sides.
45.83' to 46.50'	Limey gray shale with some siltstone laminae.
46.50' to 47.17'	Red silty shale with some gray blebs.
47.17' to 48.08'	Limestone.
48.08' to 49.25'	Mixed gray and purplish red shale, dolomitic in places.
49.25' to 49.70'	Gray and red shale.

Drill location #15

Depth	
102.00' to 104.62'	Massive red siltstone with some shaley beds. Small and minor gray siltstone laminae are also present. There is some gypsum along fracture surfaces with possibly some copper sulfides at 103.50' to 104.00' Fractures with gray walls are common. Between 104.00' and 104.62' there are gypsum growths mainly along planes cutting bedding features. Between 104.42' and 104.62' there are gray siltstone interclasts in red siltstone as well as undulating laminae. The lower contact is gradational.
104.62' to 105.00'	Light and slightly darker gray interbedded siltstone and shale. The entire interval is riddled with black specks, but because they are so minute in size their identity is difficult to determine. Bedding is inclined, discontinuous, broken-up, and wavey. The lower contact is gradational.
105.00' to 106.33'	Red siltstone, generally massive as it seems to have been extensively reworked. The upper contact is quite irregular. There are numerous interclasts of gray siltstone and brownish shale scattered about this unit. Some rounded gypsum blebs are also found within this unit.
106.33' to 107.33'	Light and slightly darker gray interbedded siltstone. Small laminae of red siltstone are also present but they represent a minor component. The same specks are found in this interval as mentioned above. At 106.96' there is considerable chalcocite found in fractures. The occurrence of chalcocite in this fashion is common in the 106.33' to 107.33' interval. A polished section from 107.20' contains pyrite partially replaced by chalcocite (?).
107.33' to 107.62'	Massive, reworked red-brown siltstone.
107.62' to 107.87'	Gray siltstone with minor shale. Between 107.62' and 107.79' there is a light gray reworked siltstone with darker gray siltstone blebs mixed together. Between 107.79' and 107.87' there is darker shale interbedded with lighter gray siltstone laminae. A polished section from 107.70' contains round grains of chalcocite (?). A thin section from the same depth contains opaque grains that have grown together to form a more-or-less continuous band.
107.87' to 108.04'	Massive reworked red siltstone with thin light red streaks.
108.04' to 108.67'	The upper half is interbedded and interlaminated with light gray siltstone and medium-dark gray shale. Laminae

Depth	
	are wavey, discontinuous, crosscutting, etc. Two beds consist mainly of light gray siltstone, but extremely fine laminae stand out. The lower half consits of reworked medium-dark gray shale and siltstone laminae. Bedding dips at about 10°.
108.67' to 111.67'	Mainly dark red siltstone and shale with masses of gray siltstone and shale mixed in. This interval is extensively reworked and appears as gray material that is progressively oxidized. Some patches of original laminae and beds are still recognizable. At 109.33' there is a 1/4" - thick gypsum bed present along with masses of disoriented gypsum. At 110.42' there are more masses of disoriented gypsum. At 111.50' there is darker gray siltstone mixed in. The lower contact is sharp and is marked by a thin bed of gypsum.
111.67' to 112.29'	Light and dark gray interbedded siltstone. Bedding is disturbed by burrowing and minor faults. Minor copper sulfide grains are observed mostly at the 112.17' level. The lower 1" consists of reworked gray siltstone and shale.
112.29' to 112.50'	Massive reworked dark red-brown siltstone.
116.00' to 116.33'	Mixed red-brown and medium gray siltstone and silty shale. This material is extensively reworked. Some patches of laminted material are disturbed throughout.
116.33' to 117.71'	Mixed red-brown and medium dark gray siltstone and shale. Gypsum in the form of patches and satin spar gypsum beds up to 0.20" - thick makes up 25% of the interval. Soft sediment deformation is prominent.
117.71' to 118.25'	Red-brown siltstone that is heavily reworked probably the result of soft sediment deformation. Gypsum as a mush makes up about 15% of the interval.
118.25' to 118.58'	Dark gray and minor red intermixed siltstone. Gypsum satin spar bed and gypsum mush are present in the reworked interval.
118.58' to 119.50'	Mainly gypsum mush (70%) disturbed throughout with a few satin spar beds. Red-brown and medium gray siltstone or silty shale surrounds and is caught up in the mush.
119.50' to 120.92'	Interbedded medium gray shale and light gray siltstone. The siltstone occurs as thin beds and laminae. They are mostly wavey and discontinuous. Crosscutting features are common. Burrowing also observed. Pyrite occurs between 119.50' to 119.75'. Throughout this interval about half of the siltstone is oxidized, giving rise to a red band across the core.

Depth	
120.92' to 121.42'	The upper 3" is medium gray siltstone and shale. This material is extensively reworked. The lower portion is more red-brown in color while remaining a siltstone. The lower contact is irregular and contains a 1/4" - thick satin spar bed.
121.42' to 123.00'	Mainly a red siltstone with some gray siltstone interbedding, fracture filling and blebs. Between 121.42' and 121.83' the interbedding is more apparent although somewhat still indistinct. Between 121.83' to 123.00' the interval is more massive except for the gray siltstone filled fractures. There are minor amounts of gypsum blebs present throughout most of the section. Most of the interval is extensively reworked and/or deformed.
123.00' to 123.42'	Intermixed dark gray and light brownish-red siltstone and gypsum. The interval is extensively reworked. It seems as if the gray shale was being progressively oxidized.
123.42' to 123.75'	Interbedded dark gray shale and light gray siltstone. The interbedding is mainly in the form of laminae on the order of 0.40" - 0.80" thick. The laminae are discontinuous and cross cutting is common. A 0.12" - thick satin spar gypsum bed is present.
123.75' to 124.42'	Medium gray intermixed shale and siltstone. Patches of laminated material can be recognized. Some gypsum patches are found throughout the interval. An irregular area of light red oxidized material occurs near the bottom.
124.42' to 125.50'	Light grayish red siltstone with minor small shale particles.
125.50' to 126.00'	Medium gray siltstone becoming more shaley towards the bottom. Evidence of reworking is present at the bottom (patches of broken-up laminated material).
126.00' to 127.67'	Massive intermixed medium gray and dark red-brown siltstone and shale. About 5% dark red-bown, becoming more gray and silty towards the bottom.
127.67' to 128.50'	Mixed medium red-brown and gray siltstone and/or shaley siltstone. This interval has been extensively reworked as evidenced by streaks and patches of laminated blebs. At 128.25' there is a 1" - thick discontinuous gypsum mush bed.
128.50' to 131.33'	Medium gray reworked, massive silty shale or shaley siltstone. Indications of previously broken-up laminae. There

Depth	
	are several satin spar gypsum beds in the middle of the interval. There is also gypsum mush in the same interval (130.58' to 130.83').
132.50' to 133.00'	Interbedded medium gray shale and light gray siltstone. The siltstone is in the form of thin (up to 0.12" - thick) beds and laminae. Discontinuous, wavey and cross-cutting typify this bedding.
133.00' to 133.75'	Mainly reworked and massive medium gray shale and minor siltstone. Laminae of previous beding can be seen.
133.75' to 134.58'	Mainly a medium gray reworked siltstone with minor shale. Broken-up laminae are common. At 133.83' a 0.08" - thick zone of dark gray shale and light gray siltstone laminae. This zone is rich in sulfides.
134.58' to 135.83'	Massive dark red-brown silty shale. Poorly preserved core. Some minor gypsum in fractures and gray reaction halos in the upper few inches.
135.83' to 136.00'	Finely interlaminated dark gray shale and light gray siltstone which are discontinuous, wavey, and cross-cutting.

Drill location #16

Depth	
34.60' to 34.11'	Massive, gray fine-grain sandstone with some coarse sand grains.
34.11' to 36.10'	Rusty cōlored fine-grained sandstone.
36.10' to 36.60'	Massive, reddish-gray sandstone.
36.60' to 37.60'	Grayish-red fine-grained sandstone.
37.60' to 37.11'	Interbedded gray and light red fine-grained sandstone.
37.11' to 38.40'	Massive, fine-grained red sandstone.
44.40' to 44.11'	Massive, red, fine-grained sandstone.
44.11' to 45.40'	Red fine-graind sandstone with gray blebs, slightly calcareous (from a calcite cement).
45.40' to 46.40'	Massive, red, fine-grained sandstone.
46.40' to 48.00'	Red fine-grained sandstone with many small gray blebs.
49.00' to 49.60'	Gray, fine-grained sandstone with calcite cement.

References

Anderson, G. E., 1941, Origin of line of color change in redbed deposition: Geological Society of America Bull., v. 52, p. 211-216.

Berendsen, P., 1977, personal communication.

________, P., 1978, personal communication.

Brown, R., 1971, Zonation in the White Pine Copper, Ontonagan County, Michigan: Econ. Geology, v. 66 p. 543-573.

Cheney, E. S., and Jensen, M. L., 1962, Comments on biogenetic sulfides (discussion of comment by C. F. Davidson (1962)): Econ. Geology, v. 57, p. 624-627.

Cox, R. E., 1978, Subsurface geochemical exploration of stratibound copper in Lower Permian redbeds of north-central Oklahoma: unpublished Master's thesis, Oklahoma State University, 117 p.

Davidson, C. F., 1965, A possible mode of origin of stratibound copper ores: Econ. Geology, v. 60, p. 942-954.

Dingess, P. R., 1976, Geology and mining operations at the Creta deposit of Eagle-Picher Industries, Inc.,: in Stratiform copper deposits of the Midcontinent region, a symposium, K. S. Johnson and R. L. Croy, eds., Okla. Geological Survey, Circ. 77, p. 15-24.

Fay, R. O., 1975, A possible origin for copper in Oklahoma: Okla. Geology Notes, v. 35, p. 151-153.

Geldsetzer, H., 1976, Syngenetic dolomitization and sulfide mineralization: in Ores in Sediment, G. C. Amstutz and A. J. Bernard, eds., Springer-Verlag, New York, P. 115-127.

Hagni, R. D., and Gann, D. E., 1976, Microscopy of copper ore at the Creta Mine, southwestern Oklahoma: in Stratiform copper deposits of the Midcontinent region, a symposium, K. S. Johnson and R. L. Croy, eds., Okla. Geological Survey, Circ. 77, p. 40-50.

Hill, W. E., Jr., 1967, Copper in redbeds of south-central Kansas: Kansas Geological Survey Bull. 187, pt. 1, p. 13-14.

Hills, J. M., 1942, Rhythm of Permian seas -- A Paleogeographic study: Am. Assoc. Petroleum Geologists Bull., v. 26, p. 217-255.

Kullerud, R. O., Fairchild, P., and McGregor, D., 1956, Gypsum in Kansas: Kansas Geological Survey Bull. 113, 110 p.

Johnson, K. S., 1974, Permian copper shales of southwestern United States: in Gisements Stratiformes Et Provinces Cupriféres, I. DeMagnée, P. Evard, and J. Moreau, eds., Sociéte Geologique De Beligigue, p. 383-393.

References (con't.)

_______, 1976, Introduction to symposium: in Stratiform copper deposits of the Midcontinent region, a symposium, K. S. Johnson and R. L. Croy, eds., Okla. Geological Survey, Circ. 77, p. 1-2.

Lane, C. W., and Miller, D. E., 1965, Geohydrology of Sedgwick County, Kansas: Kansas Geological Survey Bull. 176, 100 p.

Long, D. T., and Angino, E. E., 1976, Occurence of copper sulfide in the (Permian age) Milan Dolomite, south-central Kansas: Econ. Geology, v. 71, p. 656-661.

Merriam, D. F., 1963, The geologic history of Kansas: Kansas Geological Survey Bull. 162, 317 p.

Morimoto, N., and Gyobu, A., 1971, The composition and stability of digenite: The American Mineralogist, v. 56, p. 1889-1909.

_______, and Koto, K., 1969, Anilite, Cu_7S_4, a new mineral: The American Mineralogist, v. 54, p. 1256-1268.

Norton, G. H., 1939, Permian redbeds of Kansas: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1751-1819.

Pendery, E. C. 3rd, 1964, Carbonate petrology of Blain Formation (Permian), north-central Texas (abs.): Am. Assoc. Petroleum Geologists Bull., v. 48, p. 541.

Potter, R. W., 2nd, 1977, An electrochemical investigation of the system copper-sulfur: Econ. Geology, v. 72, p. 1524-1542.

Richard, L. M., 1915, Copper deposits in the "redbeds" of Texas: Econ. Geology, v. 10, p. 366-380.

Renfro, A. R., 1974, Genesis of evaporite-associated stratiform metalliferous deposits -- a sabkha process: Econ. Geology, v. 69, p. 33-45.

Rose, A. W., 1976, The effect of cuprous chloride complexes in the origin of redbed copper and related deposits: Econ. Geology, v. 71, p. 1036-1048.

Sharp, J. M., Jr., 1978, Energy and momentum transport model of the Ouachita Basin and its possible impact on the formation of economic mineral deposits: Econ. Geology, v. 73, p. 1057-1068.

Shockey, P. N., Renfro, A. R., and Peterson, R. J., 1974, Copper-silver solution fronts at Paoli, Oklahoma: Econ. Geology, v. 69, p. 226-268.

Smith, G. E., 1976, Sabkha and tidal-flat facies control of stratiform copper deposits in north Texas: in Stratiform copper deposits of the Midcontinent region, a symposium: K. S. Johnson and R. L. Croy, eds., Okla. Geological Survey, Circ. 77, p. 25-39.

References (con't.)

Stroud, R. B., et al, 1970, Production potential of copper deposits associated with Permian redbed formations in Texas, Oklahoma, and Kansas: U. S. Bureau of Mines, Report of Investigations No. 7422, 103 p.

Swineford, A., 1955, Petrology of Upper Permian rocks in south-central Kansas: Kansas Geological Survey Bull. 111, 179 p.

Tasch, P., 1960, Paleoecological observations of the Wellington Salt (Hutchinson Member): Trans. Kansas Acad. Science, v. 63, p. 24-30.

Waugh, T. C., and Brady, L. L., 1976, Copper occurrences associated with Permian rocks in south-central Kansas: in Stratiform copper deposits of the Midcontinent region, a symposium, K. S. Johnson and R. L Croy, eds., Okla. Geological Survey, Circ. 77, p. 76-79.

Zeller, D. E., 1968, The stratigraphic succession in Kansas: Kansas Geological Survey Bull. 189, 81 p.

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