A GEOCHEMICAL AND PETROGRAPHIC SURVEY OF THE WELLINGTON FORMATION, NORTH-CENTRAL OKLAHOMA

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PREFACE

This study deals primarily with the delineation of occurrences of copper mineralization in the subsurface Wellington Formation of north-central Oklahoma. In order to accomplish this objective the litho-stratigraphy, geochemistry, and petrography of well cuttings from the Wellington Formation were examined in some detail.

The writer thanks Dr. Zuhair Al-Shaieb, thesis adviser, for suggesting the problem and providing assistance and guidance throughout the study. Dr. John Shelton and Dr. Gary Stewart, thesis committee members, offered invaluable assistance on many occasions. Thanks is also due to Dr. Richard Thomas and Dr. Hobart E. Stocking for critically reviewing the manuscript.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Lower and Middle Permian strata cropping out along a belt from north-central Texas to south-central Kansas, have been the object of considerable investigation in recent years for potential economic concentrations of copper. The discovery of the Creta copper deposit in Jackson County, Oklahoma, in 1963 and the opening there of the only profitable mining venture in the region by Eagle-Pitcher Industries, sparked interest in exploration. The present investigation studies a geologically similar, stratigraphically-controlled occurrence of copper mineralization in the Wellington Formation of north-central Oklahoma.

Renfro (1974), Jacobsen (1975), and Rose (1976) have used the region as an example in their models for sedimentary copper deposits.

Purpose

The purposes of this investigation were sixfold: (1) subsurface delineation of cupriferous strata in the study area; (2) correlation of subsurface data with surface and subsurface data by Raasch (1946) and Shelton (1979); (3) study of the relationship of the copper concentration to those of lead, zinc, manganese, barium, silver, cadmium, and cobalt; (4) correlation of element concentraion, lithology, color, and sedimentary structures; (5) examination of sulfide phase using grain-mounted thin sections of selected cuttings, and the determination of paragenetic relationships; and finally (6) study of the relationship between copper mineralization and depositional environment of the host rocks, and comparison with various genetic models.

Area of Investigation

The study is restricted to strata of the Wellington Formation and base of the Garber Sandstone, of the Sumner Group which crop out in Noble, eastern Garfield and Kingfisher Counties, and western Payne County (Fig. 1). In the subsurface the Sumner Group is a wedge-shaped unit that thickens to 2400 feet at the western boundary of the area of investigation.

Geographically the subsurface area is bounded by the northern boundaries of Noble and Garfield Counties (T. 24N.), the western boundary of Garfield County (R. 8W.) and T. 18N. in northern Payne, Lincoln, and Kingfisher Counties.

Numerous deposits of copper in the Permian beds have been reported in the literature. South and west of the Wichita uplift the belt of copper-bearing Permian strata crops out in Cotton, Tillman, Jackson, Greer, and Kiowa Counties, along a trend of approximately N. 20W. north of the Wichitas the beds are present in a north-south belt from Garvin County in the south, through McClain, Cleveland, Oklahoma, Logan, Kingfisher, Payne, and Noble Counties, to Kay and Grant Counties along the Kansas border (Fig. 2).

Previous Work

Haworth and Bennett (1901) first reported copper within the area in a water well near Hillsdale in the northwestern part of T. 24N. R.

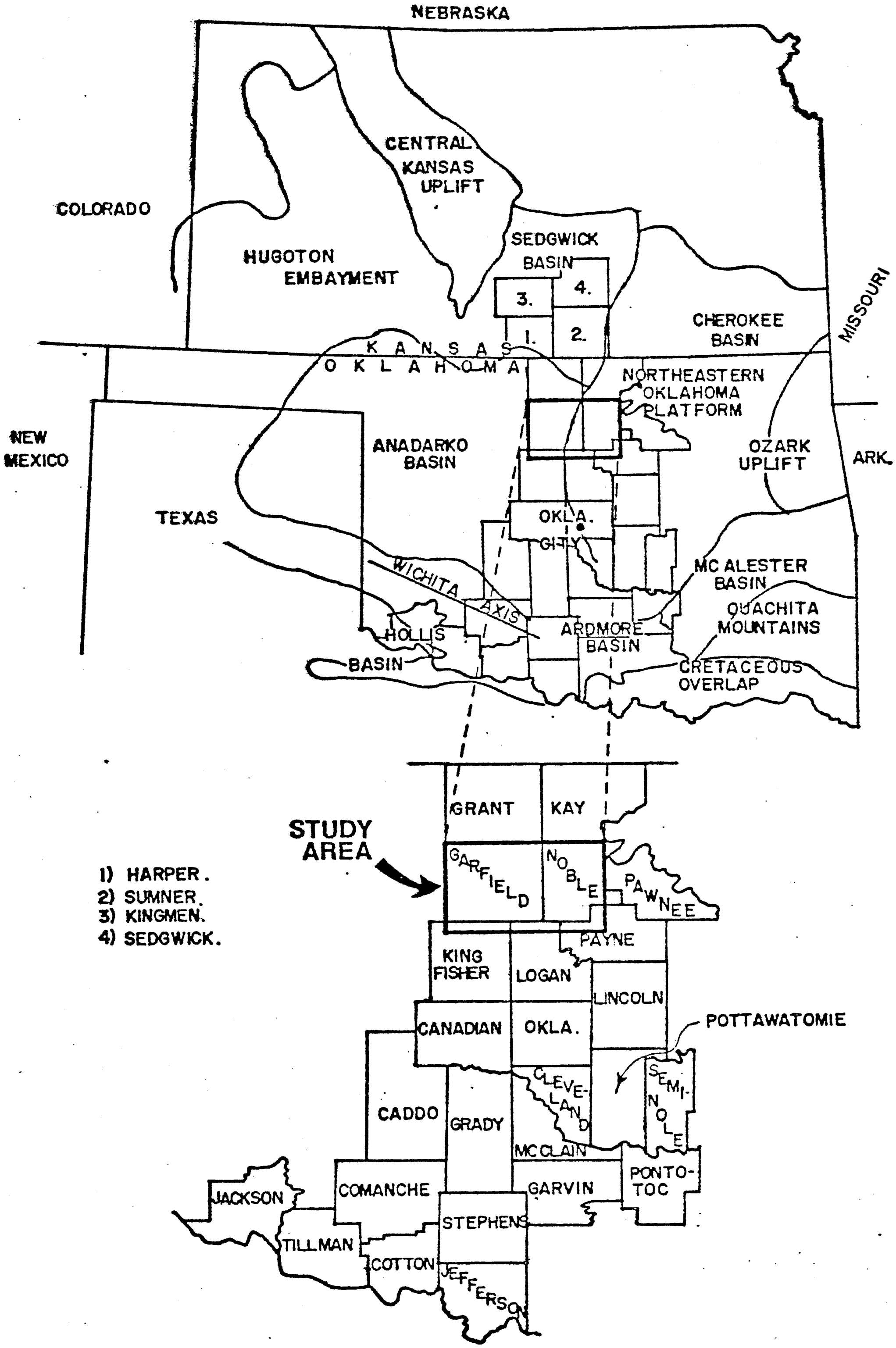


Figure 1.--Index map of the area showing the regional setting.

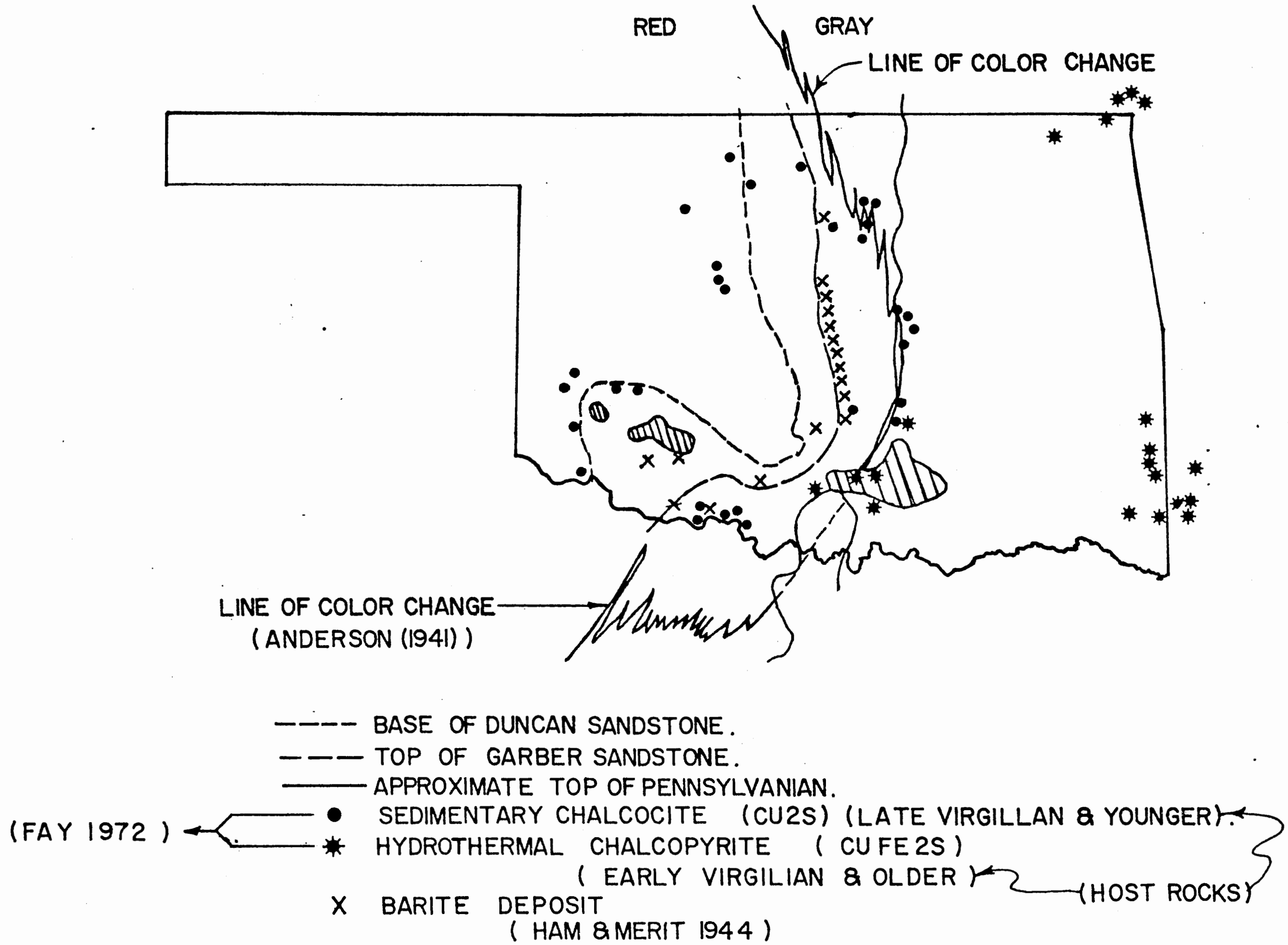


Figure 2.--Location copper and barite deposits in Oklahoma.

8W., Garfield County. Native copper occurred as thin foil-like plates in a six-inch seam on red clay of what is now mapped as the Hennessey Shale. Reiter (1920) reported that native copper was found in at least three shafts dug in the Hillsdale area. Tarr (1910) reported briefly on chalcocite (Cu_2S) and chalcopyrite (CuFeS) replacing fossilized wood in a sandstone, north of Stillwater. Rogers (1916) made polished sections from these beds and discussed the paragenesis of the minerals. Merritt (1940) reviewed the known occurrences of copper in Oklahoma after visiting the various localities. Stroud and others (1971) summarized the copper-production potential of Texas, Oklahoma, and Kansas. Shockey and others (1974) described the small copper-silver deposit near Paoli in T. 4N. R. 1W. from which several wagonloads of ore were removed at the turn of the century. Ham and Merritt (1944) described the distribution of barite nodules in the Garber and Wellington Formations. Heine (1975) classified the copper-bearing deposits of southwestern Pawnee, northern Payne, and southeastern Noble Counties on the basis lithofacies. The Noble County Surveyor (Shelton, 1979) has informally recorded occurrences of barite, malachite, and galena in that county. North (1939), Swineford (1955), Hill (1967), Long and Angino (1975), and Waugh and Brady (1976) reported on copper in the Sumner Group of south-central Kansas.

Aurin and others (1926) established the stratigraphic names for divisions of the Leonardian Series presently in use. Clark and Cooper (1927) summarized the stratigraphy of the area. Page (1955) and Talley (1955) correlated the subsurface of the eastern part of the area by electric logs and sample cuttings. Billings (1956) mapped the surface geology of eastern Noble County. Raasch (1946) made detailed measured sections of the upper Wellington Formation and studied the famous "insect beds" of western Noble County. Paleontological studies of the unusual assemblage of fossils in the Wellington Formation which include discussions of a stratigraphy and sedimentology have been made by Olson (1967), Carlson (1968), Tasch (1961, 1962, 1964), and Tasch, Kidson, and Johnson (1969). Shelton (1979) mapped and synthesized the surface and subsurface geology of Noble County including an areal geologic map, measured section, correlation of the surface with the subsurface, a shallow structural contour map, and a discussion of the depositional environment. Ross (1972) and Garden (1973) extended this work southward into central and western Payne County.

CHAPTER II

METHODS

Sample Selection and Logging

The Oklahoma Geological Survey made available well cuttings from its well log library. Samples from 29 wells were logged from the surface or from the first collected sample through the Herington Limestone. Lithological Percentage logs (Maher, 1964) were made rather than interpretive logs, because a more objective treatment would be more useful in statistical comparison of the chemical analyses for each sample with its actual lithological composition. Three east-west cross sections were prepared: from T. 24N. R. 8W. to T. 24N. T. 1W.; from T. 22N. R. 5W. to T. 22N. R. 1W.; and from T. 20N. R. 8W. to T. 20N. R. 1W.

The lithology on the percentage logs is divided into six categories: sandstone, siltstone, shale, limstone, marlstone, and gypsum; the color is divided into seven categories: white, brown, maroon, red, gray, green, and black. In addition the predominant lithology of mudstone was characterized as lumpy (massive), fissile, desiccated, or interbedded (shale and siltstone). Fossils and sulfide minerals were recorded.

Preparation of Samples and Analytical Procedures

A cut of sample was generally taken at 20-foot intervals for chemical analysis. However, more closely spaced samples were taken from the upper Wellington Formation. Unfortunately, during the drilling, cuttings were not collected regularly at shallow depths; a practice that results in gaps in several logs.

Each sample was ground to -80 mesh. One gram was digested in 20 milliliters of hot aqua regia (one part concentrated HNO_3 and three parts concentrated HCl). Sample solutions were filtered and diluted to 50 milliliters.

More than 900 samples were analyzed for copper, lead, zinc, and manganese using a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer. Approximately 25% of the samples were analyzed for silver, cadmium, and cobalt. The samples of wells on the southern cross section (C-C') were also analyzed for barium. All samples were analyzed according to standard procedures listed in the Perkin-Elmer Analytical Methods Manual.

Data Display and Sources of Error

The Statistical Analysis System package program generated plots of depth versus common logarithms of the concentration values of copper, lead, zinc, manganese, and barium. The plots of copper, lead, and zinc were drafted with the electric logs and percentage lithologic logs to produce composite logs to a scale of 1 inch equals 100 feet (Pl. 3-6). Four cross sections, using the composite logs, show a cupriferous zone in the upper Wellington Formation.

A shallow structure map of the area was contoured on the top of the Herington Limestone. A copper isoconcentration map to the same scale as the structure map contours the copper content of the cupriferous zone in the subsurface Wellington Formation.

The collection of the samples faithfully at the recorded intervals is a matter up to the discretion of the driller and roughnecks. This is a problem, particularly at shallow depths which drill quickly and are of little interest in exploration for petroleum. As mentioned above, the shallow samples were, in many cases, erratically collected leaving gaps in the record.

Metallic contamination from scalings off the drill bit or the interior of the drill pipe was also occasionally a problem. Passing a magnet over each sample removed most of the metal contamination. Three samples that were heavily contaminated with steel were separated into two groups--magnetics removed and magnetics unremoved. The removal had the effect of reducing the zinc content of the samples by an average of 38% but did not affect the copper, lead, manganese, cobalt, cadmium, or silver content of these samples. These results are consistent with the conclusion that galvanized (zinc-plated) steel may have contaminated some of the samples. The effect of this contamination, however, was minimized by the use of a magnet.

CHAPTER III

GEOLOGIC SETTING

Stratigraphy

Permian beds in the cupriferous belt of Texas, Oklahoma, and Kansas are divided into three groups (Fig. 3):

1. the Chase Group of the Wolfcampian Series;
2. the Sumner Group of the Leonardian Series; and
3. the El Reno Group of the Leonardian Series.

The Oklahoma Geological Survey (Havens, 1977) has recently proposed a new stratigraphic system in which the lower Permian Wolfcampian Series is supplanted by the upper Pennsylvanian Gearyan Series (Fig. 2). The Herington Limestone is proposed to be the uppermost formation of the Pennsylvanian.

For the purposes of this study, the stratigraphic nomenclature of Dunbar (1960) and McKee (1967) is used. The Chase, Sumner, and El Reno Groups all contain beds which are anomalously cupriferous. The Chase Group was studied by Heine (1975). The El Reno Group, which crops out to the west of the study area, is stratigraphically equivalent to the copper deposits of southwestern Oklahoma and north-central Texas, but contains little unoxidized sedimentary rock favorable to the concentration of copper (Fay, 1957).

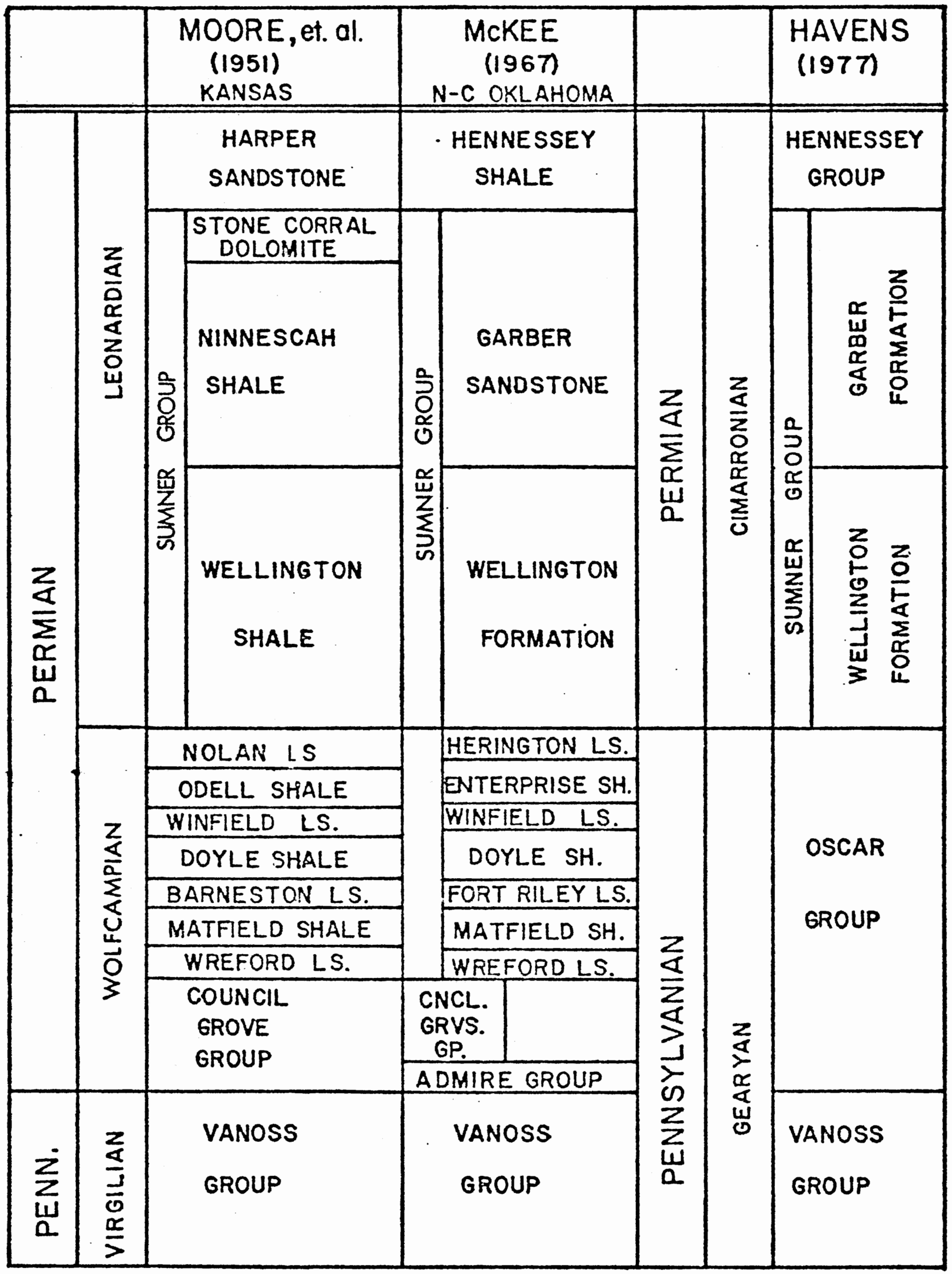


Figure 3.--Correlation chart of Pennsylvanian-Permian stratigraphy.

Chase Group

The upper formations of the Chase Group are easily identifiable marker beds because of their lithology and distinctive character on electric logs. They consist of a series of three thin, laterally persistent, limestones separated by two shales. The lowermost limestone is the Fort Riley Limestone. It is overlain by the Doyle Shale, the Winfield Limestone, the Enterprise Shale, and the Herington Limestone. The limestones are thin and become more dolomitic and more impure southward (Shelton, 1979).

The Fort Riley Limestone is a 30- to 40-foot thick unit composed of five thin limestone beds. In southern Noble County the formation has been mapped as the base of a sandstone in the overlying Doyle Shale (Shelton, 1979).

The Winfield Limestone is 120 to 140 feet above the Fort Riley Limestone. It grades form a thinkly-bedded, 2-foot thick, fossiliferous grainstone in northern Noble County, to a calcitic sandstone, 6- to 8-feet thick, in T. 22N. R. 2E., to a 1-foot thick nodular limestone in T. 21N. R. 2E. in southern Noble County (Shelton, 1979).

The Herington Limestone, about 70 feet above the Winfield Limestone, records the last normal marine period of deposition in the region. It grades from a fossiliferous grainstone and packstone less than 8-feet thick in northern Noble County to a red, dolomitic, brecciated, nodular micrite with interbedded sandstone in the southern part of the county (Shelton, 1979).

Wellington Formation

At the type section of the Wellington Formation in south-central Kansas the unit consists predominantly of greenish-gray mudstone interbedded with reddish-brown, maroon, and gray mudstone. It contrasts sharply in color with the overlying red-colored Ninnescah Shale. The Milan Dolomite is the uppermost member of the Wellington Formation in Kansas (Ver Weibe, 1937). It contains some barite and malachite mineralization (Swineford, 1955).

In Oklahoma the Garber-Wellington contact is less distinct since the upper beds of the Wellington become gradually more reddish and sandy similar to the overlying Garber Sandstone at about the latitude of southern Noble County (Shelton, 1979).

Patterson (1933) divided the Wellington in Logan and Lincoln Counties into an upper Fallis Sandstone Member and a lower Iconium Shale Member. Neither Raasch nor Shelton found this classification useful in Noble County. Raasch divided the Wellington into six members, with a total thickness of 820 feet. They are from the base up: (1) the basal sandstone sequence, 15 feet; (2) the anhydrite sequence, 195 feet; (3) the Otoe Sandstone member, 115 feet; (4) the Midco member, 225 feet; (5) the Billings Pool member, 52 feet; and (6) the Antelope Flats member, 190 feet. Shelton measured a composite thickness of 850 feet in the Wellington Formation and divided the formation into four unnamed units divided by three key sandstone beds. Plate 1 correlates a lithologic profile plotted from Raasch's measured section with profile from Shelton (1979).

Garber Sandstone

The Garber Sandstone was named (Clark and Cooper, 1927) after exposures near Garber in eastern Garfield County. It consists of red clay shales, red sandy clays, and red sandstones. Clark and Cooper (1927) divided the Garber into a lower Lucien Shale Member, 250 feet thick, and an upper Hayward Sandstone Member, 350 feet thick. Shelton (1979) reported that sandstones in the upper Wellington were not lithologically distinct from those of the lower Garber. Raasch (1946) considered the base of the Garber Sandstone to be the first "heavy" sandstone unit. However, the Wellington-Garber contact on his measured section is distinguished principally by the change in color from maroon in the Wellington "Antelope Flats" member to bright red in the Garber Sandstone.

In Logan, Oklahoma, and Cleveland Counties immediately south of the study area barite rosettes occur near the base of the Garber Sandstone (Ham and Merritt, 1944).

No detailed study of the Garber Sandstone of north-central Oklahoma has been made.

Structural Framework

The Nemaha Ridge, the main structural element of the region, separates the Anadarko Basin to the west and southwest from the northeastern Oklahoma Platform (Fig. 1). To the north of an east-west hinge line the Anadarko Basin is characterized by shelf-type sedimentary rocks. Southward from the hinge line the strata thicken greatly to form a geosyncline. The Anadarko Basin was an area of continuous subsidence and deposition during Pennsylvania-Permian time when up to

27,000 feet of sediment was deposited in what is now the deepest part of the basin (Ham and Wilson, 1967).

The Upper Pennsylvania Virgilian Series, deposited during the last major phase of tectonism affecting the Arbuckle and Wichita uplifts to the south, marks the beginning of a regressive phase of deposition. The rate of subsidence in the basin slowed, and the shoreline retreated to the south and west. Continuous deposition of the Late Pennsylvanian Virgilian Series and Early Permian Wolfcampian Series was characterized by typical transgressive-regressive depositional cycles. The Middle Permian Leonardian and Guadalupaian Series of continental red beds and evaporites are characterized by desiccation cycles. They represent the final phase of filling of the basin after downwarping had ceased (Rascoe, 1962).

Fig. 4 shows the structure of the area based on deformation of the Permian Herington Limestone. It is quite similar to the interpretation of structure of the Middle Pennsylvania strata of Oklahoma by Fritz (1978), and Shelton's (1979) structure map, also on the Herington Limestone in Noble County.

The Nemaha Ridge is a narrow belt of high angle faulting that was exposed as a highlands during Early and Middle Pennsylvanian time (Bale, 1955). Faulting and folding along this lineament produced many structures favorable for the entrapment of petroleum. In fact, some of the more prolific fields in the Mid Continent Region are found along this lineament. In the study area the Lovell, Lucien, Garber, Breckenridge, Antelope, Billings, and Tonkawa fields are located along structures related to the Nemaha Ridge (Bale, 1955). The structural contour map (Fig. 4) indicates that the effect of the ridge changes at

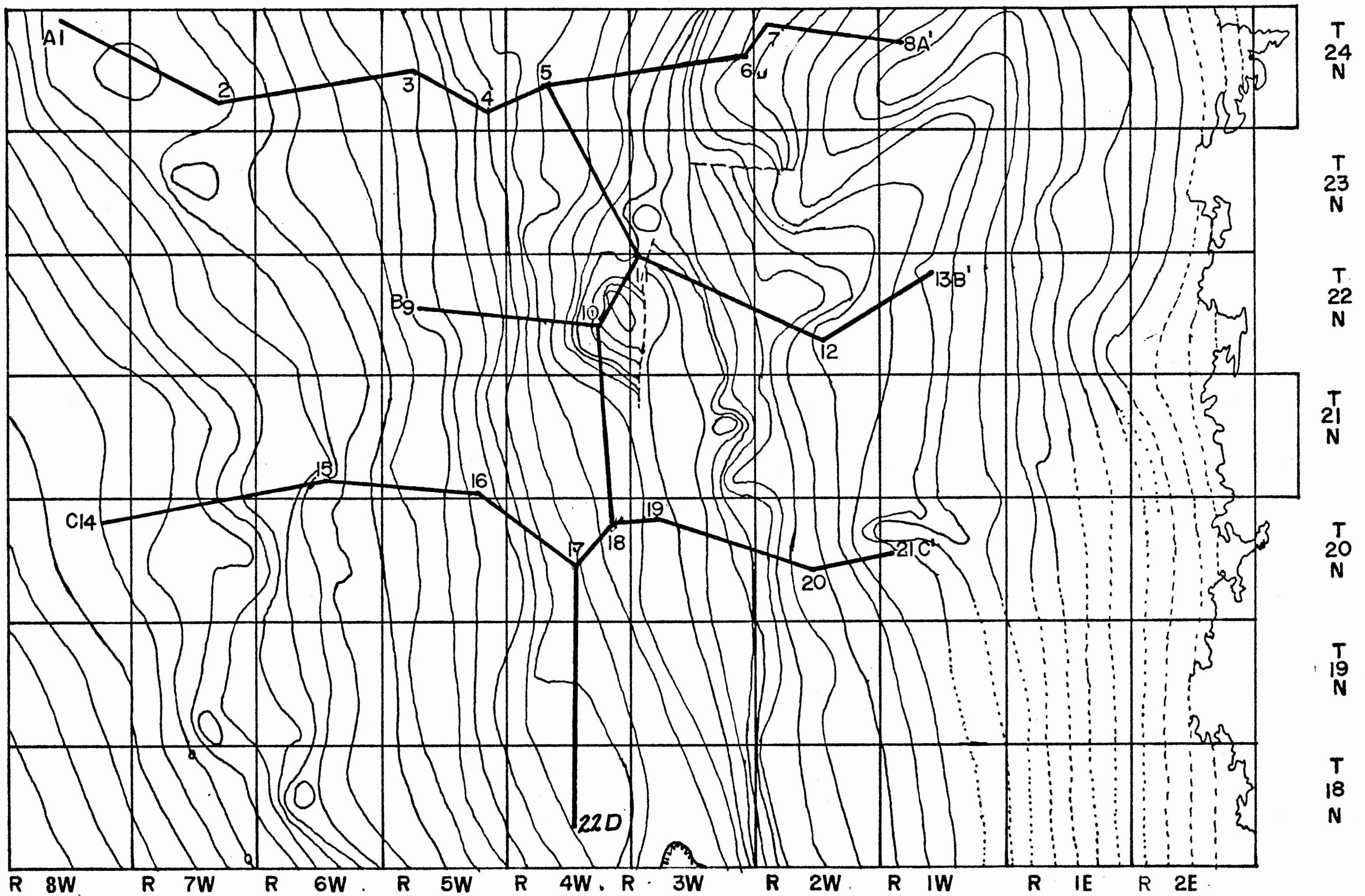


Figure 4.--Structural contour map on the Herington Limestone. Scale: 1/500,000. Anomalies shown superposed on westerly dip. Contour interval, 50 feet. Surface exposure indicated to the east. Lack of data indicated by dashed lines.

about the Lovell Dome in T. 19N. R. 4W. South of the Lovell Dome the ridge results from a high angle fault, with the downthrown block on the west in the Pennsylvanian (Fritz, 1978). At that position it has about 200 to 500 feet of displacement and the fault trends N10°W. North of the Lovell Dome the ridge is composed of a series of domes, half-horsts, and horsts widening to the north and bounded on the east flank by faults trending N25°E (Fig. 4).

The tectonics and sedimentation of the Northeastern Oklahoma Platform are similar to that of the Northwestern Oklahoma Shelf because the Nemaha Ridge was submerged after Middle Desmoinesian time (Fambrough, 1963).

Depositional Framework

The lithology of Wellington Formation of the study area is a predominantly mudstone sequence sand-rich to the south and carbonate-rich to the north, which forms the eastern rim of an evaporite basin. The depositional environment of the Wellington Formation was an arid tidal flat, which produced a varied and complexly interrelated suite of subenvironments. The Wellington is distinct from the underlying Chase Group by the absence of marine limestones. The Hollenberg Limestone Member is found in the Wellington of Kansas, however. Each of the limstones of the Chase Group thins out to the north of the next underlying limestone (Shelton, 1979). The overlying Garber Sandstone is distinct from the Wellington in being a completely continental deposit (Raasch, 1946; Olson, 1967).

Evaporites

No evaporites crop out in the Wellington Formation in the study area. Raasch's (1946) anhydrite sequence, however, thickens markedly in the subsurface to become the predominant lithology of the formation along the western boundary of the area. Using electric logs, Shelton (1979) delineated the eastern limit of gypsum/resistive dolomite facies in the lower Wellington with a north-northwest trend from T. 20N. R. 2W. to T. 24N. R. 1E. The lack of variety of the anhydrite sequence compared with the beds above and below suggests relatively rapid, uniform depositional processes.

Until recently it was widely held that evaporites were deposited in large standing bodies of water, such as lakes or lagoons, when they evaporated to the point of precipitation of evaporite minerals. However, modern analogues to deposition of ancient evaporites is now considered to be salt-encrusted desert flats called sabkhas. The sabkhas are inland and above high tide and are occasionally flooded during high winds. They are generally landward of algal mats which develop in the intertidal zone (Bathurst, 1975). Rapid evaporation of the pools of flood water causes saline groundwater to be drawn up by capillary action through the underlying porous and unconsolidated sediments. Gypsum precipitates in the substrata causing the magnesium: calcium ratio to increase so that the associated algal mat in the intertidal zone are altered to dolomite (Bathurst, 1975).

Sedimentary structures diagnostic of a sabkha environment are found in the Wellington evaporites. "Chicken-wire" texture according to Butler (1969) is caused by extreme compaction of the gypsum compaction to produce anhydrite nodules with enterolithic folds. This "chicken-wire" texture was present throughout the gypsum samples from the well cuttings.

At approximately the western limit of the study area salt becomes a significant proportion of the evaporites. According to Jordan and Vosberg (1963) the Champlin #1 Boehm test contains about 50% salt between depths of about 1200 and 1600 feet (the Anhydrite sequence). No salt was noted in the samples described immediately east of this well, however. This discrepance is probably caused by dissolution of the salt by the drilling fluid. West of the study area Adkison (1960) constructed cross-sections from Barber County, Kansas, to Caddo County, Oklahoma. They show the presence of salt but in considerably smaller proportions to the anhydrite than indicated by Jordan and Vosberg.

Jordan and Vosberg estimated the Wellington of western Oklahoma to have 15,500 square miles of salt deposits with an average thickness of 225 feet, although they did not actually delineate the limits of the Wellington salt. The Wellington salt extends into Kansas where it is equivalent to the thinner, shallower Hutchinson Salt Member of the Wellington Formation of central Kansas.

Sandstones

To the south of the study area the Wellington-Garber Formations contain multistoried and multilateral sandstone bodies that represent a deltaic complex at about the Oklahoma City area. Lobes of deltaic and interdeltaic sands extend northward into Logan and Lincoln Counties. To the north of the area the number and thickness of carbonate units greatly increase and the sandstones are almost absent (Ver Weibe, 1937). The sandstones also tend to pinch out westward into the subsurface.

The following summarizes the conclusions of Shelton (1979) who mapped and described eight sandstone units in the Wellington of Noble County. A unit generally occurs as a disconnected series of lenses at an approximately consistent stratigraphic interval. Shelton distinguished two types of genetic units. Those with undulatory bases initial dip, and small-scale cross bedding that showed much variation in paleocurrent direction were considered to be tidal creek deposits. Stream deposits were considered as those with medium-scale cross bedding, which showed a more consistent paleocurrent direction. The paleocurrents indicate that depositional strike was N60°E to N70°E and the depositional slope was north-northwest.

Based on the paleocurrent data, Shelton concluded that the source of terrigenous classics was from streams coming from the southeast, i.e., the Ouachitas.

Mudstones

Two major types of mudstone are present in the Wellington: (1) lumpy claystone which tends to be red or a reddish color, but which also may be shades of purple, maroon, gray-green, and gray; and (2) fissle, laminated shale, which is green, gray, black, olive, or brown. The lumpy and fissile varieties commonly are interstratified. A third variety is the intraformational conglomerate composed of clay pebbles, generally carbonate-rich, in a carbonate-rich matrix.

The Wellington-Garber mudstones show a regular sequence of color changes which are distinctive to most of the study area. The red color, however, persists ~~to a~~ stratigraphically lower in the section in a southward direction. From Raasch's measured sections and the present subsurface work a general color sequence is suggested in Table I for stratigraphic interval studied.

TABLE I

CORRELATION OF SUBSURFACE SEQUENCE OF COLORS WITH RAASCH'S MEASURED SECTION

Color	Stratigraphic Unit (Lithology)
(1) RED, red-orange, light green	LOWER GARBER (lumpy claytone)
(2) PURPLE, MAROON, gray-green	ANTELOPE FLATS MEMBER (lumpy claystone
(3) YELLOW, BROWN, maroon, gray-green	BILLINGS POOL MEMBER (siltstone silty sandstone, lumpy and fissile mudstone)
(4) DARK GREEN, DARY GRAY black, maroon	MIDCO MEMBER (fissile shale interstratified siltstone and fissile shale, lumpy mudstone)
(5) BROWN, REDDISH-BROWN, GRAY	OTOE MEMBER (very fine sandstone, siltstone fissile and lumpy mudstone)
(6) REDDISH-BROWN, GRAY	ANHYDRITE SEQUENCE (subfissile shale, gypsiferous shale)
(7) RED, GRAY-GREEN, BROWN black, maroon, yellow	ENTERPRISE SHALE (fissile and subfissile shale, lumpy mudstone, interstratification, siltstone)

Since the colors are determined by the depositional environment, not stratigraphic position, the colors correspond to the stratigraphic units only within the area of Noble County where Raasch made his measured section.

In the subsurface the complete sequence of colors is sometimes not found, particularly towards the south (Well #22). In some wells the color changes from red to maroon to gray without the intermediate stages. If the dark green, yellow, and gray-black beds are taken to be indicative of brackish-to-fresh water conditions, their omission may be taken to represent an uninterrupted change from normal marine to subaerial conditions at that location.

The sequences of beds both above and below the anhydrite sequence are to varying degrees repetitious in the distribution of lithology, colors, structures, and fossils.

Raasch and Tasch (1964) have both constructed models for the upper Wellington cyclic sedimentation. The salient difference between the sequence above the anhydrite from that below the anhydrite is the absence of marine limestones in the upper Wellington Formation.

The coloration of mudstone is principally a function of the mixing of red hematite, green illite and chlorite, and black organic matter and iron sulfide. Swineford (1955) supported the conclusion that the Permian red beds of Kansas were formed from transport of detrital red clay from an oxidized tropical soil. It is widely held today, however, that red pigmentation originates, in place, from the aging and dehydration of iron hydroxides (Van Houten, 1972) or by oxidation of ferromagnesian silicates (Walker, 1967). McBride (1974) reported that red, maroon, and purple pigments are post-depositional and produced by reddening of sediments in the soil zone in a sub-humid to semi-arid tropical climate having wet and dry seasons. Purple and maroon are produced by a thicker coating of hematite stain or coarser hematite crystals. McBride found that green beds are produced by bleaching of red or photo-red beds by interstratal percolation of reducing water derived from fluvial channels overlying the green beds. He also concluded that brown beds are generally siltstones where the amount of hematite is insufficient to coat the grains evenly; cyclic varicolored sediments are coastal lacustrine; and maroon-purple beds are the result of generation of a more mature soil profile than red beds.

Shelton (1979) reports that x-ray diffractograms of 14 mudrock samples by the Oklahoma Geological Survey indicate illite, chlorite, and kaolinite to be the principal clay minerals in the Wellington formation. In the upper middle member (Midco member), however, kaolinite is absent while vermiculite is present.

Carbonates

Dolomitic, light gray, argillic, platey-to-laminited algal boundstones or stromatolites occur in thin units in the upper middle Wellington Formation (Midco member). These include the "saltcast" bed, the "lower mudcrack" bed, the "insect" bed, and the "upper mudrack" described by Raasch (1946), and the "new insect" bed described by Tasch (1962). The algal boundstone beds are quantitatively a minor proportion of the upper Wellington Formation, but have been studied in detail by Raasch (1946), Tasch and Zimmerman (1964), and Tasch, Kidson, and Johnson (1969) for their rich and unusual fossil assemblage and complex, repetitious depositional sequence.

The laminated structure is caused by the trapping of fine-grained particles in the algal mat which form alternating salt-rich (light) and organic-rich (dark) layers (Tasch, Kidson, and Johnson, 1969). About half of the algal boundstones have mudcracks on their upper surfaces indicating subaerial exposure (Raasch, 1946). The"saltcast" bed has hopper halite casts on its upper surface (Raasch, 1946). Chalococite, cuprite, and malachite were noted by Raasch in the "insect" bed near the top of the upper Midco member at E½ sec. 3, T. 21N. R. 1W. (Pl. 2).

Algal-mat boundstones may be confused with cornstones which they resemble (Steel, 1974). McBride's (1974) paleosoil interpretation of the origin of red and purple mudstone and the presence of lungfish burrows are consistent with a paleosoil origin of several, thin, non-fossiliferous, silty to argillic carbonates within the red and maroon beds of the Garber Sandstone and Antelope Flats member of the Wellington Formation. They were not correlatable between wells. Most are about 50% carbonate and contain a framework of siltstone or very fine-grained sanstone. The color is light gray and contains fine specks of organic matter or iron sulfide. According to Steel (1974) the carbonates, originally called cornstones are analogous to caliches forming in modern soil profils of semi-arid regions. The cornstones are most prevalent in non-marine, cyclic sequences. Authigenic calcite progressively fills in and displaces detrital grains of the host sediment by evaporation and precipitation from vadose water. The mechanism is similar to that of gypsum formation in sabkhas but is indicative of less arid seasonal wet-and-dry conditions than are required for the formation of gypsum.

Paleontology

The fossil assemblage of the upper Wellington is dominantly vertebrates and arthropods. The single most abundant fossil is Cyzicus, a conchostran branchiopod which flourishes in fresh-to-brackish water. Tasch (1964) found Cyzicus at regular intervals in the algal-mat boundstones. He interpreted the recurrence as being part of a paleolimnological cycle.

The most notable invertebrates are the famous insect beds studied by Raasch (1946) and Tasch (1962) in the Midco member and containing at least 12 insect orders. The insect beds occur at four sites in Noble County (Pl. 2) and one site in Kay County. Thousands of specimens are concentrated in these few small sites which Tasch (1962, 1964) has interpreted as being evaporated fresh water ponds formed in shallow depressions along the shoreline.

Other invertebrates found in the upper Wellington are the eurypterid, Eurypterus, (Decker, 1938) in a sandstone of the Otoe member (lower middle unit); the horseshoe crab, Anacontium, in the Midco member (upper middle unit) (Raymond, 1944); and Lingula (Hall, 1966), in the Midco member (upper middle unit).

The upper Wellington also contains abundant plant remains particularly in the Antelope Flats member (upper unit), Billings Pool and upper Midco member (upper middle unit) (Raasch, 1946; Shelton, 1979).

Olson (1967) and Carlson (1968) studied the vertebrate fauna of the Wellington and Garber, consisting of fish, amphibians, and reptiles (Pl. 2). The lungish Gnahoriza is found in estivation burrows of fresh water ponds indicating a paleoclimate of alternating wet and dry seasons. In sharp contrast to the terrestrial fauna of the Garber sandstone and Wellington fresh and brackish water fossil assemblage is the normal marine fauna of the underlying Herington and Winfield limestones which contain brachoopods, bryozoans, molluses, and fusilinids (Raasch, unpublished; Shelton, 1979).

Summary

In summary the Wellington Formation was deposited as a regressive depositional sequence characterized by desiccation cycles. The overall depositional environment was a tidal flat with an arid climate characterized by a variety of subenvironments: tidal mudflats, which formed lumpy, massive mudstones; intertidal flats and paralic ponds and small lakes, in which laminated, dolomitic algal-mat boundstones and shaley dolomitic mudstones interstratified with siltstone and thin sandstone layers were deposited; tidal creeks and tidal channels which deposited the sandstone units; and sabkhas, in which gypsum developed as a result of early diagenetic processes.

CHAPTER IV

INTERPRETATION OF GEOCHEMICAL DATA

Interpretation of the geochemical data obtained during this study first requires a brief description of the geochemistry of copper.

The geochemical behavior of copper has been classified as chalcophilic ("sulfur loving") by Goldschmidt (1954) showing virtually no lithophilic ("rock-forming") and little siderophilic ("native-metal forming") tendencies. Surficial weathering readily oxidizes the sulfides to oxy-salts and oxides.

The average crustal abundance of copper is 50 ppm (Levinson, 1974). In sedimentary rocks copper has an average content of 45 ppm in shales, less than 1 ppm in sandstones, 4 ppm in carbonates (Turekian and Wedepohl, 1961), and 20 ppm in evaporites (Rickard, 1974).

Copper is an element of intermediate mobility in the surficial environment. It, therefore, lends itself to geochemical exploration by the sampling of soils and stream sediments (Dall'Aglio, 1972).

Interpretation of Geochemical Maps and Correlation Sections

The surface geochemical map of Noble County (Pl. 2) was produced by the students of an exploration geochemistry class at Oklahoma State University in 1975. Stream sediment samples were taken at a density of one per square mile. The bulk of the samples had copper concentrations of less than 20 ppm. Three anomalous values of greater than 40 ppm were found in the northwest part of the county at the following locations: SW¼ sec. 9, 23N. 1W.; NE¼ sec. 32, 23N. 2W.; and NE¼ sec. 12, 22N. 1W.

These anomalous copper values are located within the outcrop area of non-red mudstones, siltstones, and algal-mat boundstones of the Upper Wellington Formation. These are the Midco, Billings Pool, and Antelope Flats members of Raasch's (1936) measured section (Pl. 1).

Locations where surface occurrences of galena, barite, and copper minerals have been reported are also plotted on Pl. 2. These are all found near the upper Midco member - lower Billings Pool member contact with the exception of some malachite found by Shelton (1979) just above the Herington Limestone near the eastern edge of the county.

It is interesting to note that in terms of their stratigraphic position, the barite rosettes which occur at the base of the Garber Sandstone in Cleveland and Oklahoma Counties (Fig. 2), and the barite and malachite-bearing Milan Dolomite in south-central Kansas, are located just above the cupriferous horizon in the upper Wellington Formation.

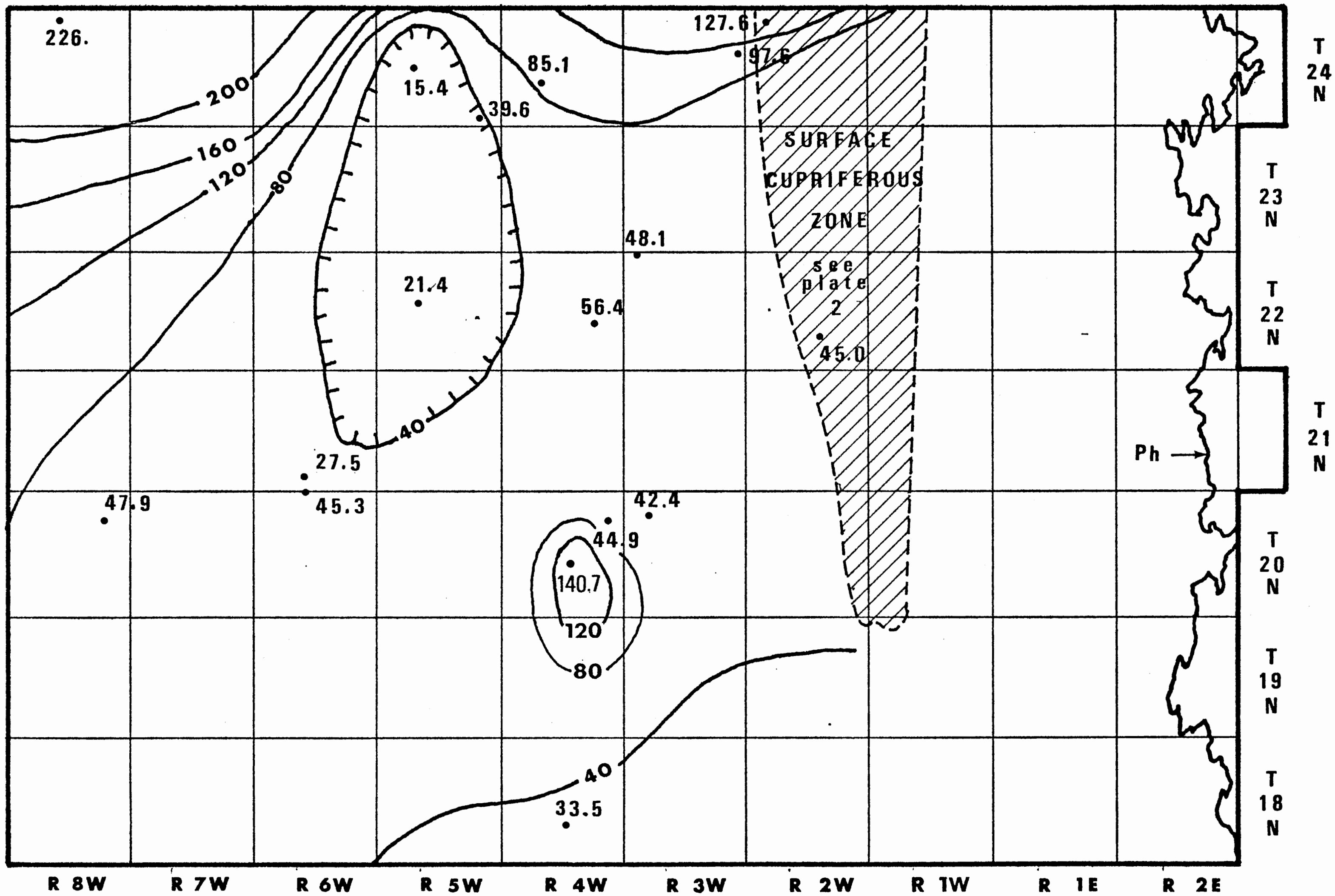
The correlation sections (Pl. 3-6) extend correlation of the cupriferous horizons in the upper Wellington Formation into the subsurface by combining the log plots of copper, lead, and zinc concentrations (ppm) from well cuttings with lithological percentage logs and electric logs. As with surface samples, the high concentrations correspond to the zone of non-red, relatively less oxidized strata, which comprise grey-green, maroon, black, and gray shaley mudstones and siltstones and algal-mat boundstones.

The subsurface geochemical data from the 15 wells analyzed that penetrated the upper Wellington Formation, is further summarized by a copper isoconcentration map (Fig. 5). The ppm values used in Fig. 5 are the means for the copper concentrations obtained from samples within a stratigraphic interval which sometimes contain cupriferous strata and is correlated to be the upper Midco member, the Billings Pool member and the base of the Antelope Flats member of the Wellington Formation. This interval ranges from 180 to 300 feet in thickness. Additional data relevant to Fig. 5 including the depths of the intervals averaged, the number observations, and the ppm values for copper, lead, zinc, manganese, and barium are tabulated in Appendix D.

The highest mean copper values for this interval are 226.0 ppm for Well #1 (sec. 4 to 24 N. R. 8W.) and 140.7 ppm for Well #17 (NW¼, sec. 22, to 20N. R. 4W.). The value for copper in Well #17 was considerably reduced by the selective removal of sulfide grains for thin section mounting (see Chapter V). Fig. 5 clearly shows that the overall trend of copper values increase in a northward direction with the exception of Well #17.

Since each of the samples analyzed consisted of assortments of rock chips of heterogenous lithology, the actual element concentrations of the respective lithologies are not known with certainty. Therefore, four groups of samples composed of chips typical of two distinctive lithologies were segregated by hand and analyzed. The segregated lithologies were gray mudstone and red mudstone, cornstone and red claystone, limestone and mudstone, and gypsum and mudstone. The results are shown in Table II.

The test showed that copper is about 50% higher in the gray



SCALE: 1 / 500,000

Figure 5.--Subsurface copper isoconcentration map of a stratigraphic interval in the upper Wellington Formation.

mudstone than the red mudstone while the cornstone has 500% more copper than red claystone from the same sample. The limestone sample (the Herington Limestone, Well #12, Pl. 4) contained an anomalous copper concentration of 699 ppm. However, no copper mineralization was detected visually.

TABLE II

ANALYSES OF LITHOLOGY/COLOR SEGREGATED SAMPLES (PPM)

	Cu	Pb	Zn	Mn	Ba	Ag	Cd	Co
Gray Mudstone	14	10	43	880		2.5	2.0	48
Red Mudstone	9	7	45	280		2.0	1.0	35
Cornstone	21	0	15	250	848	1.0	0.5	30
Red Claystone	3.5	15	25	685	200	0.5	0.5	40
Limestone	699	60	28	1830	470	2.5	2.0	80
Mudstone	15	30	42	1770	280	1.0	1.0	60
Gypsum	7	15	28	7		3.2	2.5	25
Mudstone	24	20	45	420		2.8	2.2	14

Zinc and lead values are not significantly different in the red and gray mudstone samples, and these elements are only slightly more concentrated in red claystone over cornstone and mudstone over gypsum.

Manganese concentrations in gray mudstone are more than 200% greater than those from mudstone. Gypsum, an orthochemical precipitate, contains lower concentrations of all of the five major elements analyzed, especially manganese which is virtually absent in gypsum. Manganese concentrations are low in cornstones segregated from red claystone, but manganese values from limestone and mudstone segregates are similar.

Barium, like copper, is concentrated in cornstone over red claystone and limestone over mudstone.

Interpretation of Statistical Data

The number of observations, mean, median, minimum value, maximum value, standard deviation and coefficient of variation of the samples analyzed during this study are listed in Table III.

The sample mean, $\overline{X}$, describes the central tendency or average of the sample population. It is calculated as

$$\overline{X} = \frac{\Sigma x_i}{n}$$

where Σx refers to the sum of a given set of values and n is the number of values.

The standard deviation, s, describes the dispersion about the mean. It is calculated from the sample variance, s^2, as

$$s = + \sqrt{s^2}$$

where the sample variance is calculated as

$$s^2 = \frac{\Sigma(x_i - \overline{X})^2}{(n - 1)}$$

where Σx refers to the sum of a given set of values and n is number of values.

TABLE III

MODAL ANALYSES OF ELEMENT CONCENTRATIONS (PPM)

Element	N	Mean	Median	Min. Value	Max. Value	Standard Dev.	Coef. of Var.
Cu	884	32.26	16.5	2	1000	72.68	2.253
Pb	886	33.29	20	0	2580	118.58	3.562
Zn	886	52.13	40	10	950	51.79	.9934
Mn	757	615.12	495	3	4120	459.54	.7471
Ba	290	249.95		21	4428	297.29	1.193
Ag	294	2.41		0.2	12.0	1.35	.560
Cd	294	2.04		0.0	8.0	1.19	.5833
Co	283	36.32		5	760	45.46	1.252

The coefficient of variability is an indication of the degree of skewness of the population. It is calculated as

$$C = \frac{x}{X}$$

The coefficient of variation is greater than one for the lead, (3.562), copper (2.253), and barium (1.193) concentrations. These high coefficient of variation values are the result of the positive skewness of the population caused by the presence of a mineralized population. The higher value for lead than copper is caused by two extreme values of 2580 ppm and 2350 ppm.

The distribution of trace elements in the earth's crust tends to be log-normally rather than normally distributed (Ahrens, 1965). This means that when the population is plotted on frequency distribution histograms they will appear positively skewed on an arithmetic scale and approximately normally distributed when plotted on a logarithmic scale (Ahrens, 1965).

Grouped frequency distributions for the elements copper, lead, zinc, manganese, and barium are plotted on a histogram with a $\log_{10}$ scale (Fig. 6).

Fig. 6 indicates that the copper analyses contain two populations. The grouped mode of the larger population (15-20 ppm) corresponds to the values of the red mudstone and gypsum-rich samples. The smaller peak at 50-63 ppm corresponds to the values for the non-red, less-oxidized Wellington strata.

The lead population (Fig. 6) is less dispersed than that for copper and approaches a log-normal distribution with a grouped modal peak of 20-25 ppm. Small negative peaks for both copper and lead are caused by

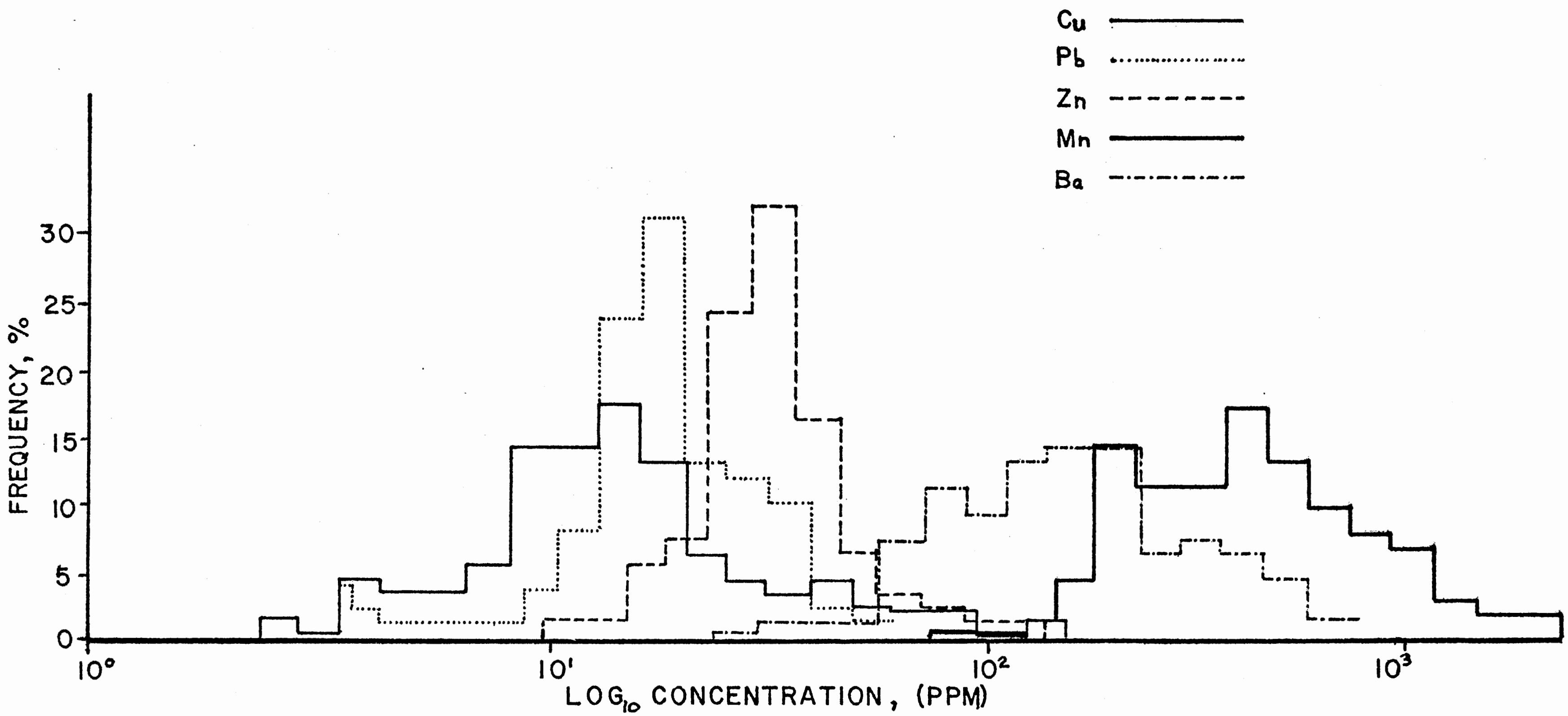


Figure 6.--Frequency distribution histograms of PPM concentrations for copper, lead, zinc, manganese, and barium.

the lack of resolution of the instrument at low values near the limit of detection.

Zinc (Fig. 6) exhibits the most narrow dispersion of the five elements analyzed with a modal peak of 36-45 ppm.

Manganese shows a bimodal distribution with a grouped modal peak at 447-562 and a secondary peak at 224-282 ppm. The low-manganese population represents the samples diluted with manganese-poor gypsum. High manganese values are associated with sandstones and siltstones particularly the Garber Sandstone and the sandy facies of the Wellington towards the south.

The histogram for barium (Fig. 6), like lead, is affected by the low sensitivity of the atomic absorption spectrophotometer at element values close to its detection limits. Barium shows a modal peak ranging between 178 ppm and 282 ppm. The secondary peaks, 89 ppm to 112 ppm and 447 ppm to 562 ppm, are partly created by rounding errors. Barium, to a lesser degree than manganese, is characterized by concentration in the arenaceous samples and dilution in gypsiferous samples.

Determination of the threshold value or dividing line between the background population and the anomalous population is not possible if the overlap is too great (Brooks, 1972). The most accurate means of determining the threshold value is to plot cumulative frequency on probability paper (Tennant and White, 1959). Each population should be represented by a straight line if the population is log-normally distributed and a log-normal scale is used for the abscissa. The break in slope is taken as a threshold value.

The cumulative frequency plot for copper (Fig. 7) indicates the presence of three populations segregated by breaks in the slope of the

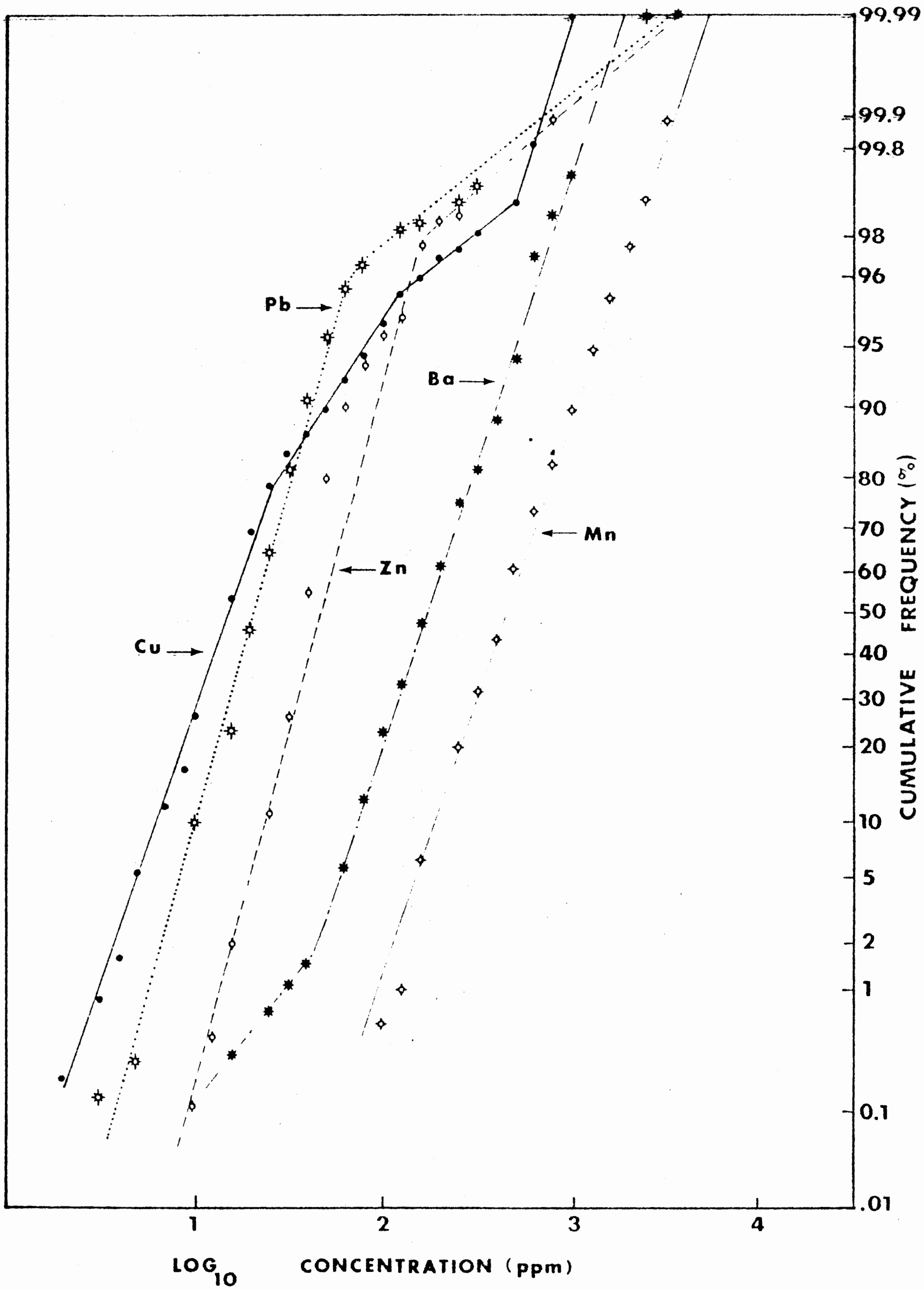


Figure 7.--Cumulative frequency plots of PPM concentrations for copper, lead, zinc, manganese, and barium.

line at 25 ppm and 125 ppm. The less-than-25 ppm population consists of copper-poor, red mudstone and gypsum-bearing samples. The 25 ppm to 125 ppm population consists of the unmineralized, non-red mudstone and carbonate-bearing samples which would have a higher background content of copper. The samples greater than 125 ppm are the mineralized population.

Two analyzed wells (#1 and #17), which contain prominent visible copper mineralization, are the only wells with values above the threshold for the interval averaged for the copper isoconcentration map (Fig. 5). Minor copper anomalies are also associated with the Herington Limestone interval.

Lead and zinc (Fig. 7) show breaks in the cumulative frequency plots at 60 ppm and 75 ppm, respectively (Fig. 7). Lead and zinc show smaller anomalous populations than copper. The high lead and zinc values are usually found below the cupriferous zone in the Wellington Formation. Lead anomalies are more erratic than zinc anomalies. Two very high lead anomalies occur 2580 ppm (Well #17 at 190 feet in Garber Sanstone, 250 feet above copper anomalies with visible mineralization in the upper Wellington Formation) and 2350 ppm (Well #10 at 520 feet, associated with high zinc values and below a copper zone at 380-500 feet), but lead mineralization was not visible in either sample. Zinc anomalies are more subdued than lead but in a zone 20-300 feet beneath the copper anomalies.

Barium and manganese (Fig. 7) lack a break-in-slope indicative of an anomalous population. Both elements had, however, minor breaks-in-slope at the low-concentration end of the scale caused by the trace element-poor, gypsum-rich samples.

Cadmium, silver, and cobalt determinations were run for selected samples. No significant anomalies were detected. Cadmium values correlated best with zinc while silver correlated best with copper. Cobalt values are very narrowly dispersed. There a single anomalous cobalt value (760 ppm) associated with a high barium (4480 ppm) and high copper (680 ppm) concentration.

CHAPTER V

ORE PETROGRAPHY

Twelve thin sections representing a zone of mineralization in the upper Wellington Formation, from Well #17 section 22, T. 20N. R. 4W., were made of selected grain mounted chips. These sections show pyritic replacement of wood fragments, spores, and disseminated organic matter in calcareous siltstone and algal-bound, argillic dolomite. In some grains the sulfides occur as nodules impregnating very fine grained sandstone. The wood fragments and spores, which were not completely replaced, have also undergone some coalification.

Fig. 8 shows the polished grain of chalcocite-anilite replacing pyrite which was analyzed by microprobe analysis. The mineral composition of this grain as determined by microbe analysis is given in Table IV. The analysis used the Magic IV-Colby computer program on the AMX Model ARL Microprobe Spectrometer.

The microprobe analysis indicates that the copper sulfide mineral is not true chalcocite but a mixture of djurleite ($Cu_{1.96}S$) and anilite ($Cu_{1.75}S$). Anilite, a newly discovered mineral (Morimoto and Koto, 1969), has not previously been reported in North America. However, the anilite-djurleite mixture, which is the only form in which anilite is known to occur, has probably been reported as digenite ($Cu_{1.8}S$) (Morimoto and Koto, 1970). Anilite-djurleite mixtures occur in the CuS-CuS_2 system and are associated with covellite (CuS) (Morimoto and Gyobu (1971).

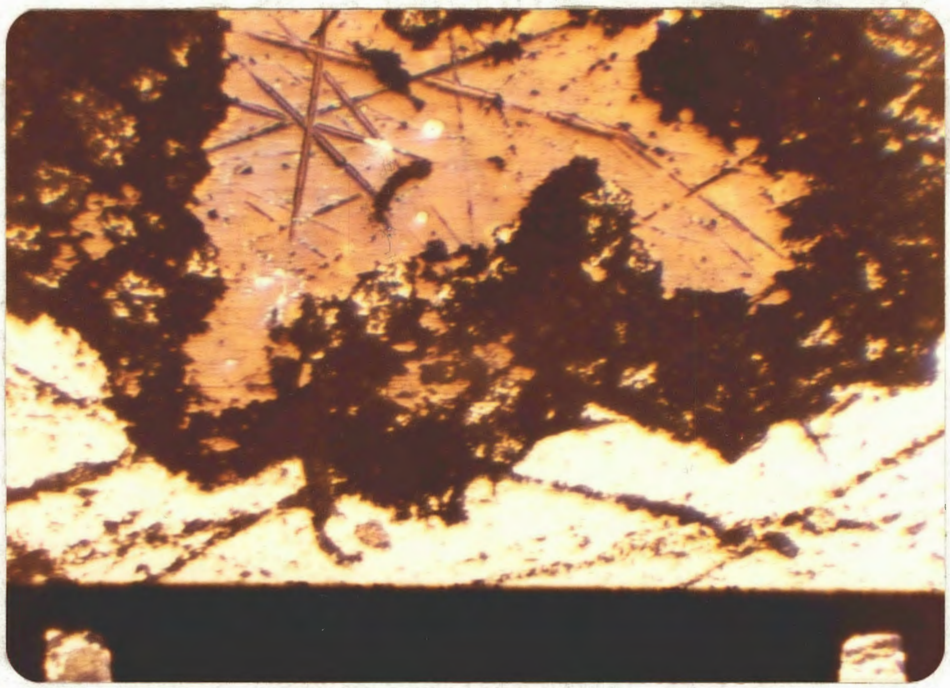


Figure 8.--Djurleite-anilite replacing pyrite. Dark areas are caused by pitting. Polished section, X100.

TABLE IV

MICROPROBE ANALYSIS OF PYRITE, ANILITE AND DJURLEITE

Mineral	Weight % Cu	Fe	Zn	S	Total %	Calculated Composition
Pyrite	.53	43.80	---	55.67	101.53	$Fe_{(903)}Cu_{(.01)}S$
Pyrite	.79	45.40	---	53.81	100.00	$Fe_{(.968)}Cu_{(.01)}S$
Pyrite	.67	46.20	---	55.13	100.00	$Fe_{(.998)}Cu_{(.01)}S$
Anilite	75.26	.44	.18	24.13	100.01	$Cu_{(1.574)}Cu_{(.01)}S$
Djurleite	79.08	.58	---	20.31	99.97	$Cu_{(1.96)}Fe_{(.02)}S$

The calculated analysis for anilite of $Cu_{1.574}$ S is below the acceptable range $Cu_{1.70-1.77}$ S for anilite. The variance might be caused by the presence of covellite. Positive identification of anilite in the slide would require x-ray diffraction.

Morimoto and Koto (1970) report that anilite is the stable phase at room temperature, while above $70^{o}\pm3^{o}$C anilite breaks down to high digenite and covellite. Clark and Sillitoe (1971) report that anilite from the Mina Estrella, Atacama, Chile, breaks down at 58^{o}C to a digenite-type solid solution series. The presence of anilite in the slide, however, does not necessarily indicate a formation temperature of less than 58^{o}C, since digenite is metastable at room temperatures and breaks down to form an anilite-digenite mixture unless a sufficient amount of iron is present in the crystal (Morimoto and Gyobu, 1971).

Visible copper mineralization in Wells #1 and #2 differ from that of Well #17 in that the host rock is relatively free of sand and silt-sized particles. The host rocks are light gray, algal-bound dolomicrites that occur as thin units interbedded with gray, shaley mudstone. The carbonate has undergone some recrystallization along vein and fracture fillings. The chalcocite occurs with quartz and pyrite as fillings of vugs and veinlets in the micrite and as very fine-grained disseminations in the micrite.

CHAPTER VI

THE NATURE AND ORIGIN OF COPPER MINERALIZATION IN THE UPPER WELLINGTON FORMATION

The Permian Stratiform Copper Province of Texas, Oklahoma, and Kansas

The overall characteristics of the Wellington Formation and the copper mineralization it contains exhibit similarities to a number of stratiform "red bed" copper deposits from around the world. In particular the Wellington is a part of cupriferous province in the Permian strata of Texas, Oklahoma, and Kansas.

Stroud and others (1970) grouped the Permian copper deposits of Texas into three zones: (1) channel scour deposits, (2) alluvial fan or deltaic deposits, and (3) lagoonal (basinal) deposits. Copper in the sandstones was found to be concentrated in fossilized wood, other plant material, and sometimes gypsum, at or near, the base of sandstone beds underlain by impermeable beds of mudstone or shale (Stroud and others, 1970). They found the sandstone-type deposits to be of more limited lateral extent than the shale-type deposits although the sandstone-type may have higher ore grades.

Smith (1974) reevaluated the sedimentological interpretation of Stroud and others (1970). He considered the "lagoonal" deposits to be tidal flat, algal-bound shale beds; the "alluvial channel scour" deposits to be tidal channel deposits; and the "alluvial fan or deltaic" deposits to be a combination of basal tidal channel fill, delta front-distributary bar, and tidal sandflat sandstone beds. Smith (1974) found mineralization to occur as chalcocite replacing pyrite with minor covellite replacing chalcocite.

At the Creta deposit in southwestern Oklahoma, copper mineralization in the Flowerpot Shale is confined to 6- to 18-inch, gray, silty shale capped by a thin gypsum bed and enclosed in a "red bed" sequence (Johnson, 1976). A tidal flat with an arid climate was probably the depositional environment, although Johnson (1976) postualtes the Flowerpot Shale was deposited under brackish-to-marine conditions. Mineralization occurs as digenite ($Cu_{1.8}S$) and true chalcocite replacing pyrite, with minor replacement of chalcocite-digente by covellite (Hagni and Gann, 1976). A limited occurence of chalcopyrite is found a few feet above principal chalcocite zone and rare galena occurs 6 feet above chalcocite zone (Kidwell and Bower, 1976). The Magnum deposit, 15 miles north of Creta, is stratgraphically several feet higher in the Flowerpot Shale. It contains malachite rather than chalcocite as the principal ore mineral. It is considered an oxidized analogue of the Creta deposit (Lockwood, 1972).

A copper-silver deposit occurs in sandstone paleochannels in the Wellington/Garber Formations at Paoli in Garvin County, Central Oklahoma (Shockey and others, 1970; Stroud and others, 1970). Mineralization occurs as a solution front at an oxidation-reduction interface which is virtually identical to uranium roll fronts in sandstones (Shockey and others, 1970). Chalcocite and native silver are the ore minerals (Shockey and others, 1974). A similar copper-silver deposit in sandstone occurs nearby in Byers in McClain County. Barite occurs as a gangue mineral at this deposit (Stroud and others, 1970).

Heine (1975) followed a classification similar to Stroud and others (1970) in describing deposits of the Wolfcampian Series of Payne and southeastern Noble Counties of Oklahoma. He found most of these small deposits to be of the "deltaic-interdeltaic" type hosted by sandstones. The ore mineral was malachite (Heine, 1975).

Copper occurrences in the Permian of south-central Kansas are concentrated in two stratigraphic horizons, - the Milan Dolomite, the uppermost member of the Wellington Shale (Long and Angino, 1975; Waugh and Brady, 1976); and Runnymede Sandstone Member of the Ninnescah Shale (Waugh and Brady, 1976). Host rocks are argillic dolomitic in the Milan Dolomite (Long and Angino, 1975), and gray or gray-green shale or siltstone in the Runnymede Sandstone (Waugh and Brady, 1976). Long and Angino (1975) found the principal ore minerals to be chalcocite and covellite with malachite as an oxidation product. Only malachite and azurite were found by Waugh and Brady (1976).

Some of the copper mineralization studied here, in the Wellington Formation, is associated with sand-rich facies in the south. However, most of the mineralization was found in the north occurring in algal-bound, shaley dolomites similar to the occurrences in Kansas.

Significant Characteristics of Copper Mineralization in the Wellington Formation

Interpretation of the lithostratigraphic, geochemical and petrographic data indicates that the occurrences of copper mineralization in the upper Wellington Formation exhibit the following significant characteristics:

1. Copper mineralization occurs in a relatively less oxidized stratigraphic interval than the overlying "red beds" and the underlying evaporite beds;
2. Copper mineralization is hosted by laminated, clay-rich, algal-mat dolomites green, gray, and black dolomitic shaley mudstones with thin interstratified, fine-grained sandstone layers;
3. The mean copper content in the mineralized stratigraphic interval increases in a northward direction.
4. Increase in copper content is related to a decrease in coarse clastics and a concurrent development of organic-rich algal-mat dolomites and non-red, less oxidized mudstones.
5. Comparison of the copper isoconcentration map (Fig. 5) with the structural contour map (Fig. 4) fails to show any spatial relationship between copper content and structural elements in the area such as faults or flanks of anticlines.
6. No alteration of the host rock has been noted and no gangue minerals are associated with the copper zone (although barite is common in the area).
7. A poorly defined zonation of lead and zinc content occurs in the strata beneath the copper-rich zone.
8. Copper mineralization is localized by organic-rich material such as plant debris and the organic-rich layers of algal-bound or stromatolitic dolomites, and also by sharp permeability changes along the contact between mudstone and thin, interbedded sandstone layers.
9. In thin section the copper sulfides are seen to replace pyrite

crystals and coalified spores and wood fragments.

10. The copper sulfides were tentatively identified as anilite and djurleite mixtures, low temperature varieties of the chalcocite family.

Genetic Models for Copper Mineralization in the Wellington Formation

Several postulated genetic models for stratiform "red bed" copper mineralization were compared with copper mineralization in the Wellington Formation. Each model was evaluated by determining which best predicts the data collected in this study. The models can be grouped into three categories: epigenetic, syngenetic, and diagenetic.

Epigenetic Model

Evidence for an epigenetic origin of mineralization could be inferred from localization or enrichment of deposits along favorable sites such as faults, or the flanks of anticlines according to the model of Davidson (1965). Such structural control would indicate that the mineralization post-dated lithification and deformation of the host rock. Germanov (1971) and Feostakov (1973) report that the Dzhezkazgan deposits of southeastern Russia occur on the flanks of anticlines.

No correlation was found, however, between structural features and copper content in the area studied (see characteristic 5 above). For example, Wells #10 and 11 on the flank of a faulted anticline in T. 22N. R. 3-4W. show relatively little mineralization. On the other hand wells with visible copper mineralization are not located near any tectonic structures.

Facies, rather than structural control of mineralization; lack of evidence of an igneous intrusion at depth or hydrothermal alteration; and the low temperature variety of chalcocite (anilite-djurleite) tentatively identified by microprobe analysis, all argue against an epigenetic origin for the copper mineralization in the upper Wellington Formation.

Syngenetic Model

The similar stratiform geometry, lithostratigraphy and depositional environments for the host rocks of "red bed" copper deposits throughout the world have led workers to conclude that the "Corocoro" of Bolivia (Entwistle and Goin, 1955; Ljunggren and Meyer, 1964) and "Kupferschiefer" of central Europe (Wedepohl, 1964), and the Zambian "Copperbelt" (Mendelsohn, 1961) cupriferous provinces were formed syngenetically.

There is a close resemblance between the lithostratigraphy of the Wellington Formation and that of these three provinces. One significant difference, however, is that in the "Corocoro", "Kupferschiefer", and "Copperbelt" thick evaporites overly the copper zone. This is the reverse of the regressive sequence of the Wellington Formation.

A stratigraphic zonation of copper succeeded upwards by lead and then zinc occurs in the "Kupferschiefer" according to Wedepohl (1964), and in the "Copperbelt" according to Mendelsohn (1961). These workers concluded that the metal zonation was created by deposition in marine environments successively further from the shorline.

From 80% to 90% of the copper in present day fresh water systems is deposited at or near the fresh water/salt water interface according to Rickard (1974). He found a considerable enrichment of the copper/transition metal ratio in the near shore sediments compared to their ratios in nearby freshwater streams from which the sediments were deposited. A zonation of copper, lead, and zinc is found in modern nearshored sediments with copper being most enriched nearest to shore (Rickard, 1974).

Since the Wellington Formation is a regressive sequence then the sequence of copper-lead-zinc zonation should be reversed if the zonation was syngenetically formed. Chemical analysis of the well cuttings (Appendix C) indicates that the lead and zinc are zoned beneath copper (although the data is more consistent for zinc than for lead). However, a diagenetic or epigenetic model could explain the reversal in the order of metal zonation as the result of a reversal in the direction of movement of mineralizing fluids which probably emanate from the associated evaporite beds (Rose, 1976; Davidson, 1965; Brown, 1974). Therefore, this evidence in favor of the syngenetic model is inconclusive.

The syngenetic model provides a mechanism for a relative increase in copper through changes in depositional facies, but it does not explain the concentration of ore grade copper mineralization.

Rickard (1973) attempted to extend the model of Berner (1964) on the formation of syngenetic pyrite at the sediment/water interface to the formation of syngenetic non-ferrous sulfides. He concluded that the only source for increasing the non-ferrous metal supply above the concentration found in normal sea water is vulcanism contemporaneous with the formation of the sulphides. Although vulcanism is associated with most of the important red bed copper deposits in the world, there is no evidence for the presence of vulcanism in the Permian System of the Midcontinent.

Therefore, with the possible exception of low level anomalies in which no mineralization was detected, the syngenetic model cannot account for the high copper contents in the Wellington Formation.

Diagenetic Models

Formation of copper mineralization by diagenesis involves only the operation of the normal processes of lithification of the sediments without invoking a volcanic, magmatic, or unusual synsedimentary event as the mechanism for copper concentration.

The replacement textures (characteristics 9 and 10 above) seen under the microscope are clearly diagenetic. Similar replacement of syngenetic or early digenetic pyrite by diagenetic chalcocite has been reported from most stratiform copper deposits around the world including the Creta Mine of southwestern Oklahoma (Hagni and Gann, 1976), and the San Angelo Formation of north Texas (Smith, 1974).

The major copper reservoir in the Earth's hydrosphere is subsurface water which averages about 13 ppb copper (Rickard, 1974). While making up only 13% of the hydrosphere, subsurface water contains about 58% of the mass of the hydrosphere's copper (Richard, 1974). Furthermore, subsurface water of the Na-Ca-Cl type characteristic of oilfield brines contains copper concentrations averaging 250 ppb (Richard, 1974). Carpenter and others (1974) found that oilfield brines associated with the Louann Salt of Mississippi have had extremely high concentrations of lead and zinc capable of producing Mississippi Valley-type lead-zinc deposits.

Stability studies by Helgeson (1969) have shown the copper chloride complexes become increasingly stable with increasing temperature and chlorinity. Rose (1976) concluded that copper chloride complexes ($CuCl_3^{-2}$ and $CuCl_2^{-1}$) could produce solubilities of 100/ppm copper at 75^{o}C and 0.5M Cl. Such a chloride brine, similar to oilfield brines but more oxidized, would be in equilibrium with hematite and could precipitate copper upon encountering reducing conditions. Dewatering of statigraphically associated evaporites could be the source of chlorine in the brines. The oxidation of iron in the sediments to form hematite could release copper, thus providing a source of copper to be leached by the chloride brines.

Rose (1976) emphasizes the importance of the stratigraphic association of copper mineralization with evaporites. In the southern part of the study area Well #17 contains visible copper mineralization in the upper Wellington Formation which is not present in the surrounding wells studied. It likewise contains a thicker sequence of gypsum beds developed beneath the copper mineralized zone than the surrounding wells.

Renfro (1974) suggested that the early diagenetic processes by which coastal sabkhas are formed is a mechanism by which copper mineralization occurs in stratiform deposits associated with evaporties. In the arid sabkha environment saline, landward-flowing, oxidized, metal-rich ground water would pass through the algal-mat facies underlying the sabkha to reach the surface. The algal-mat facies is generally saturated with hydrogen sulfide generated by bacteria. Smith (1974) found this model best explained the facies-controlled mineralization in the Permian San Angelo Formation of north Texas.

The environment of deposition postulated by Smith (1974) for the San Angelo Formation of north Texas is striking in similarity to Shelton's (1974) interpretation of the depositional environment of the Wellington Formation in Noble County. Both formations were deposited upon a tidal flat with an arid climate and consist of a number of subfacies with mud-rich, sand-rich, gypsiferous and dolomitic lithologies. It is likely that reexamination of the sedimentology of other stratiform copper deposits may lend support to the sabkha diagenetic model.

Diagenetic models best account for the data on copper mineralization in the Wellington Formation. Two diagenetic models have been reviewed, the sabkha diagenetic model of Renfro (1974) and Smith (1974), and the chloride brine-late diagenetic model of Rose (1976). Several lines of evidence favor the chloride brine-late diagenetic model for copper mineralization in the upper Wellington Formation:

1. The replacement of sizable pyrite and coalified wood fragments and spores is probably a late diagenetic event;
2. Subsurface chlorite brines can leach copper from the sediments through which they migrate and carry more copper in solution than less saline, near surface waters flowing through sabkhas;
3. The sabkha model is too specialized, It only accounts for the mineralization of the algal-mat facies in the tidal flat environment.

CHAPTER VII

CONCLUSIONS

The principal conclusions of this study are as follows:

1. The Wellington Formation in the subsurface of Noble and Garfield Counties is a part of a regressive sequence in which deposition occurred in a tidal flat environment with an arid climate, transitional from marine to terrestrial, and which includes a number of subenvironments with sand-rich, mud-rich, gypsiferous, and dolomitic lithologies. The Wellington tidal flats were more sand rich to the south and more mud-rich and dolomitic to the north. Regressive desiccation cycles produced rapidly deposited, evaporite sequences during their saline phases in sabkhas, which thicken greatly in a westward direction.
2. Copper mineralization occurs in the upper Midco, Billings Pool, and lower Antelope Flats members of the Wellington Formation, which are relatively less oxidized than the overlying "red beds" and the underlying evaporites. It is hosted by laminated, clay-rich, algal-bound dolomites, and green, gray and black, dolomitic shaley-mudstones with thin interstratified sandstone.
3. The mean copper content of the mineralized stratigraphic interval increases in a northwards direction. It is related

to a decrease in the volume of coarse clastics, the concurrent development of organic-rich dolomitic algal-mat boundstones and non-red, less oxidized mudstones.

4. No correlation was found between structural features and copper content in the area studied.

5. The cumulative frequency distribution of the chemical analyses of well cuttings indicated that copper was distributed into three populations in the strata examined: low-copper red mudstone and gypsiferous strata, 0-25 ppm; non-red mudstone and carbonate strata, 25-125 ppm; and mineralized strata, greater than 125 ppm.

6. High lead and zinc values usually occur below the cupriferous zone in the Wellington strata. However, lead anomalies are more erratic than zinc anomalies.

7. Only one barium anomaly and no manganese anomalies were detected. Both barium and manganese had high concentrations in sand-rich lithologies and low concentrations in gypsum-rich lithologies.

8. Mineralization is localized by organic material such as wood fragments, spores, and other plant debris, which have been partly coalified, and the dark layers of algal-bound dolomites.

9. The copper minerals present are apparently djurleite and anilite, low temperature members of the chalcocite sulfie family.

10. The origin of copper mineralization is best accounted for by a diagenetic model proposed by Rose (1976) in which copper-rich chloride brines emanating from the underlying evaporite

beds precipitated copper upon encountering reducing conditions in organic-rich beds in the upper Wellington Formation.

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APPENDICES

APPENDIX A

KEY TO BEDS IN RAASCH'S MEASURED SECTION

Detail from Plate 1

Number	Note
1	"UPPER POLO" BED
2	"TRACK" BED
3	"RACKET" MUDSTONE
4	"LOWER" POLO BED
5	"FERN" BED
6	"OHIO STATE" BED
7	"WHITE ROCK" BED
8	BASAL"ANTELOPE FLATS" SANDSTONE
9	RIBBON BANDED MUDSTONE
10	BASAL "BILLINGS POOL" SANDSTONE
11	"ESTHERIA" SANDSTONE
12	UPPER MUDCRACK BED
13	ESTHERIA BLACK SHALE
14	"INSECT" BED
15	"LOWER MUDRACK" BED
16	"SALT CAST" BED
17	"FALSE INSECT" BED

APPENDIX B

LOCATIONS OF THE WELLS SAMPLED

AND ANALYZED

Well No.	Operator	Lease	Location
1	Champlin	#1 Mackey	Sec 4, T. 24N., R. 8W.
3	Amerada	#1 Zaloudek	SW¼ Sec. 17, T. 24N., R. 5W.
4	Berry	#2 Johndrow	NW¼ Sec. 36, T. 24N., R. 5W.
5	Gulf	#1 Hendric	SW¼ Sec. 21, T. 24N., R. 4W.
5	Fain	#1 Schnackenberg	Sec. 21, T. 24N., R. 4W.
6	Gypsy	#1 Dickman	NE¼ Sec. 13, T. 24N., R. 3W.
7	Stanolind	#1E Compton	SE¼ Sec. 6, T. 24N., R. 3W.
8	Continental	#1 Manny	SW¼ Sec. 8, T. 24N., R. 1W.
9	ITIO	#1 Kitchens	NE¼ Sec. 17, T. 22N., R. 5W.
10	Ohio	#1 Smythe	SW¼ Sec. 23, T. 22N., R. 4W.
11	Cities Service	Mariner	NW¼ Sec. 6, T. 22N., R. 3W.
12	Stanolind	#7 Devore	NW¼ Sec. 23, T. 22N., R. 2W.
13	Blair	#1 Rolling	NW¼ Sec. 9, T. 22N., R. 1W.
14	Deardorff	#1 Gungoll	NE¼ Sec. 11, T. 20N., R. 8W.
15	Lewis	#1 Clark	Sec. 3, T. 21N., R. 6W.
17	Delaney	#1 Roberts	NW¼ Sec. 22, T. 20N., R. 4W.
18	Gulf	#1 Decker	NW¼ Sec. 12, T. 20N., R. 4W.
19	Watchorn	#1 Kaiser	NW¼ Sec. 8, T. 20N., R. 3W.
20	Champlin	#1 Graves	SE¼ Sec. 21, T. 20N., R. 2W.
21	Ohio	#1 Hubbartt	SE¼ Sec. 18, T. 20N., R. 1W.
22	Ellison	#1 Strange	Sec. 27, T. 18N., R. 4W.

APPENDIX C

CHEMICAL ANALYSES OF THE WELL CUTTING SAMPLES

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

----- LOCATION=1. CHAMPLIN #1 MACKEY SEC.4, T.24N, R8W -------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	200	12	25	39	455		1.0	2.0	23
2	220	6	25	47	540				
3	300	7	25	52	500				
4	400	7	20	45	610				
5	520	5	20	30	260				
6	540	6	15	30	160				
7	560	5	15	37	260				
8	580	5	25	36	275				
9	600	5	20	37	210				
10	620	5	15	38	305				
11	640	23	20	36	1215				
12	660	5	20	35	1010				
13	700	5	20	43	270				
14	720	6	25	54	1350				
15	740	12	20	43	485				
16	760	8	20	50	720				
17	780	7	20	51	745				
18	800	6	25	51	540				
19	820	5	20	43	975				
20	840	7	25	41	975				
21	860	6	20	48	530				
22	880	7	20	48	595		0.5	0.5	23
23	900	11	20	59	660		1.0	0.5	30
24	920	25	20	54	515		1.0	0.5	30
25	940	1000	25	46	535		1.5	1.5	35
26	960	910	25	57	515		1.0	1.5	20
27	980	27	20	49	490		1.0	1.0	20
28	1000	14	35	43	530		1.5	1.0	25
29	1020	14	25	46	625		1.0	1.0	25
30	1040	16	35	44	420				
31	1060	13	35	65	525				
32	1080	20	20	44	355				
33	1100	13	35	50	450		1.5	1.0	38
34	1120	12	30	46	385		1.0	2.5	
35	1140	14	35	82	330		1.5	0.0	40
36	1160	16	25	55	320		1.5	0.5	25
37	1200	10	25	66	255		1.0	0.5	20
38	1220	8	20	48	185		0.5	0.0	25
39	1240	10	25	48	275		1.0	1.0	25
40	1260	14	35	438	255		1.0	1.0	25
41	1280	13	25	58	285		1.0	1.5	20
42	1300	13	100	75	295		1.0	1.0	25
43	1320	12	80	57	250		1.0	1.0	25
44	1340	55	35	57	270		0.5	1.5	25
45	1400	12	25	48	280				
46	1420	14	25	47	250				
47	1440	13	35	49	240				
48	1460	10	35	45	250				
49	1480	10	30	48	260				
50	1500	63	100	50	260				
51	1520	11	35	69	240				
52	1540	14	30	44	300				
53	1580	12	30	47	280				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

----- LOCATION=1. CHAMPLIN #1 MACKEY SEC.4, T.24N, R8W -------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	200	12	25	39	455		1.0	2.0	23
2	220	6	25	47	540				
3	300	7	25	52	500				
4	400	7	20	45	610				
5	520	5	20	30	260				
6	540	6	15	30	160				
7	560	5	15	37	260				
8	580	5	25	36	275				
9	600	5	20	37	210				
10	620	5	15	38	305				
11	640	23	20	36	1215				
12	660	5	20	35	1010				
13	700	5	20	43	270				
14	720	6	25	54	1350				
15	740	12	20	43	485				
16	760	8	20	50	720				
17	780	7	20	51	745				
18	800	6	25	51	540				
19	820	5	20	43	975				
20	840	7	25	41	975				
21	860	6	20	48	530				
22	880	7	20	48	595		0.5	0.5	23
23	900	11	20	59	660		1.0	0.5	30
24	920	25	20	54	515		1.0	0.5	30
25	940	1000	25	46	535		1.5	1.5	35
26	960	910	25	57	515		1.0	1.5	20
27	980	27	20	49	490		1.0	1.0	20
28	1000	14	35	43	530		1.5	1.0	25
29	1020	14	25	46	625		1.0	1.0	25
30	1040	16	35	44	420				
31	1060	13	35	65	525				
32	1080	20	20	44	355				
33	1100	13	35	50	450		1.5	1.0	38
34	1120	12	30	46	385		1.0	2.5	
35	1140	14	35	82	330		1.5	0.0	40
36	1160	16	25	55	320		1.5	0.5	25
37	1200	10	25	66	255		1.0	0.5	20
38	1220	8	20	48	185		0.5	0.0	25
39	1240	10	25	48	275		1.0	1.0	25
40	1260	14	35	4 38	255		1.0	1.0	25
41	1280	13	25	58	285		1.0	1.5	20
42	1300	13	100	75	295		1.0	1.0	25
43	1320	12	80	57	250		1.0	1.0	25
44	1340	55	35	57	270		0.5	1.5	25
45	1400	12	25	48	280				
46	1420	14	25	47	250				
47	1440	13	35	49	240				
48	1460	10	35	45	250				
49	1480	10	30	48	260				
50	1500	63	100	50	260				
51	1520	11	35	69	240				
52	1540	14	30	44	300				
53	1580	12	30	47	280				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

----- LOCATION=1. CHAMPLIN #1 MACKEY SEC.4, T.24N, R8W -------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	200	12	25	39	455		1.0	2.0	23
2	220	6	25	47	540				
3	300	7	25	52	500				
4	400	7	20	45	610				
5	520	5	20	30	260				
6	540	6	15	30	160				
7	560	5	15	37	260				
8	580	5	25	36	275				
9	600	5	20	37	210				
10	620	5	15	38	305				
11	640	23	20	36	1215				
12	660	5	20	35	1010				
13	700	5	20	43	270				
14	720	6	25	54	1350				
15	740	12	20	43	485				
16	760	8	20	50	720				
17	780	7	20	51	745				
18	800	6	25	51	540				
19	820	5	20	43	975				
20	840	7	25	41	975				
21	860	6	20	48	530				
22	880	7	20	48	595		0.5	0.5	23
23	900	11	20	59	660		1.0	0.5	30
24	920	25	20	54	515		1.0	0.5	30
25	940	1000	25	46	535		1.5	1.5	35
26	960	910	25	57	515		1.0	1.5	20
27	980	27	20	49	490		1.0	1.0	20
28	1000	14	35	43	530		1.5	1.0	25
29	1020	14	25	46	625		1.0	1.0	25
30	1040	16	35	44	420				
31	1060	13	35	65	525				
32	1080	20	20	44	355				
33	1100	13	35	50	450		1.5	1.0	38
34	1120	12	30	46	385		1.0	2.5	
35	1140	14	35	82	330		1.5	0.0	40
36	1160	16	25	55	320		1.5	0.5	25
37	1200	10	25	66	255		1.0	0.5	20
38	1220	8	20	48	185		0.5	0.0	25
39	1240	10	25	48	275		1.0	1.0	25
40	1260	14	35	438	255		1.0	1.0	25
41	1280	13	25	58	285		1.0	1.5	20
42	1300	13	100	75	295		1.0	1.0	25
43	1320	12	80	57	250		1.0	1.0	25
44	1340	55	35	57	270		0.5	1.5	25
45	1400	12	25	48	280				
46	1420	14	25	47	250				
47	1440	13	35	49	240				
48	1460	10	35	45	250				
49	1480	10	30	48	260				
50	1500	63	100	50	260				
51	1520	11	35	69	240				
52	1540	14	30	44	300				
53	1580	12	30	47	280				

CHEMICAL ANALYSES OF THE WELLINGTIN-GARBER IN PARTS PER MILLION

-- LOCATION=1. CHAMPLIN #1 MACKEY SEC.4, T.24N, R8W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
54	1600	10	30	47	270				
55	1620	13	30	51	315				
56	1640	13	5	40	280				
57	1660	12	5	42	250				
58	1680	18	30	48	260				
59	1700	17	30	42	330				
60	1720	12	30	38	265				
61	1740	12	20	34	250				
62	1760	15	30	37	250				
63	1780	24	35	46	235				
64	1800	12	25	33	245				
65	1820	14	30	32	260				
66	1840	14	25	38	235				
67	1860	12	20	42	245				
68	1880	11	25	42	280				
69	1900	16	35	34	255				
70	1940	11	35	36	250				
71	1980	11	35	41	260				
72	2000	10	20	54	270				
73	2020	10	20	36	245				
74	2040	12	25	55	280				
75	2060	11	20	62	265				
76	2080	12	25	41	265				
77	2100	12	25	53	270				
78	2120	12	30	38	280				
79	2160	12	25	43	285				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

- LOCATION=3. AMERADA #1 ZALOUDEK NE SW SEC. 17, T.24N, R.5W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	340	5	20	36	370				
2	410	4	15	31	210				
3	440	5	20	29	405		0.5	0.5	28
4	530	15	40	53	930				
5	560	5	20	33	310		0.5	1.0	28
6	590	5	20	31	235				
7	620	5	20	37	305				
8	650	8	20	37	210				
9	680	6	20	39	590				
10	710	5	20	33	505				
11	740	14	30	54	460		1.0	1.0	30
12	770	5	15	37	335		0.5	0.5	25
13	800	6	10	47	535				
14	830	15	15	48	470				
15	860	17	30	54	520				
16	890	17	20	52	510				
17	920	16	30	43	455				
18	950	19	15	39	395				
19	980	11	25	104	395		1.0	1.0	35
20	1010	16	25	62	445				
21	1040	12	30	71	385				
22	1070	15	20	56	415				
23	1100	14	20	59	405				
24	1130	12	15	48	290				
25	1160	8	15	50	215				
26	1190	13	20	53	345				
27	1220	27	15	71	495		0.5	0.5	25
28	1250	16	20	43	265				
29	1280	14	15	49	305				
30	1310	15	20	44	370				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

---- LOCATION=4. BERRY #2 JOHNDROW NW NW SEC. 36, T.24N,R.5W ----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	410	8	20	27	1300		1.0	0.5	18
2	430	11	25	30	1115		1.0	0.0	25
3	460	7	15	34	1080				
4	480	7	10	34	795				
5	500	16	10	38	660				
6	520	9	10	41	395				
7	540	9	15	52	575		2.0	1.5	30
8	570	52	25	45	610		1.0	1.0	45
9	590	43	25	51	655		1.5	0.5	45
10	610	71	20	58	590		1.0	1.5	35
11	630	97	25	56	650		1.0	2.0	25
12	650	21	20	53	600			0.5	
13	670	15	25	44	425		1.0	1.0	20
14	690	25	30	154	555		1.5	1.5	30
15	710	24	25	60	580			1.5	
16	730	16	25	55	490				
17	750	32	25	45	450				
18	770	18	25	58	525				
19	790	18	25	60	510				
20	810	21	25	63	450				
21	830	22	25	52	580				
22	850	15	15	42	595				
23	890	18	17	52	595				
24	910	32	15	46	495				
25	930	18	13	41	315				
26	950	18	25	47	470				
27	970	19	20	46	490				
28	990	14	15	47	500				
29	1010	11	10	44	685				
30	1020	32	15	62	255				
31	1050	12	15	46	225				
32	1070	13	25	39	520				
33	1090	13	25	42	255				
34	1110	15	15	38	330				
35	1130	19	30	59	335		1.0	0.5	25
36	1150	36	15	47	265		0.5	0.5	28
37	1170	13	30	42	205		3.5	1.0	25
38	1190	16	35	42	215				
39	1210	16	30	40	205				
40	1230	17	30	40	185				
41	1250	13	25	38	230				
42	1270	18	20	54	185				
43	1290	19	30	39	215				
44	1350	12	25	39	240				
45	1370	12	30	30	200				
46	1390	14	25	124	185				
47	1410	35	30	57	220				
48	1430	15	20	47	170				
49	1510	34	25	190	295		1.0	3.5	35

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=5. FAIN #1 SCHNACKENBURG SEC.21,T.24N,R.4W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	160	16	43	40					
2	200	21	38	25					
3	250	8	23	31					
4	300	8	28	24					
5	350	20	28	25					
6	400	8	28	21					
7	420	10	23	51					
8	440	15	28	24					
9	460	8	23	24					
10	490	7	28	35					
11	500	11	20	50					
12	510	8	23	31					
13	520	7	23	25					
14	540	7	23	25	685		1.0	2.0	
15	550	473	28	33	700		3.0	2.5	25
16	560	8	20	27	435		1.5	1.5	25
17	570	13	30	33	420		1.5	2.0	30
18	580	68	23	28	455		1.5	2.0	25
19	590	133	28	28	740		2.5	2.0	35
20	600	96	35	35	730		3.0	2.5	40
21	620	6	20	22	505		1.5	2.0	15
22	640	105	38	42	700		2.5	2.0	25
23	660	64	35	39	690		2.5	2.5	30
24	680	63	35	36	710		3.0	2.0	20
25	700	27	43	165	585		3.5	4.0	
26	710	26	50	63					
27	720	24	38	40					
28	740	24	35	28					
29	760	22	65	425					
30	790	28	58	26					
31	800	18	38	38					

CHEMICAL ANALYSES OF THE WELLINGT(N-GARBEF IN PARTS PER MILLION

- LOCATION=5. GULF #1 HENDRIC W: SW SW SEC 21,T.24N, R.4W --

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	608	17	50	51					
2	620	24	58	47					
3	650	33	60	61					
4	670	23	55	34					
5	690	23	43	44					
6	710	20	50	34					
7	730	13	43	37					
8	760	18	38	40					
9	780	23	38	39					
10	800	24	38	38					
11	820		35	36					
12	840	22	38	39					
13	860	20	43	34					
14	880	19	43	38					
15	910	23	38	41					
16	930	36	43	48					
17	950	18	50	40					
18	970	19	43	60					
19	990	19	43	40					
20	1000	75	38	45					
21	1020	19	38	51					
22	1040	18	45	32					
23	1060	20	43	37					
24	1080	19	50	40					
25	1100	16	38	35					
26	1120	15	43	31					
27	1140	16	45	33					
28	1160	18	43	33					
29	1180	16	45	46					
30	1200	17	50	36					
31	1220	17	45	32					
32	1240	18	50	35					
33	1260	14	23	31					
34	1280	18	35	35					

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=6. GYPSY #1 DICKMAN N1 SW NE SEC. 13 T.24N R.3W -----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	100	294	35	87	930		4.0	2.0	35
2	120	540	35	37	890		4.5	2.5	30
3	140	37	30	39	585		3.5	1.5	25
4	160	19	23	40	570		3.5	1.5	30
5	200	17	35	46					
6	220	18	35	58					
7	240	58	43	58					
8	270	51	50	54					
9	300	30	35	52					
10	320	19	38	47					
11	340	13	35	67	670		3.5	2.5	40
12	360	51	43	70	540		3.5	1.5	43
13	400	82	70	50	490		2.5	1.5	45
14	460	97	30	41					
15	480	73	50	72					
16	500	66	58	64					
17	510	13	70	45					
18	520	43	145	36	275		2.5	2.0	25
19	540	22	30	36					
20	560	29	30	54					
21	570	41	30	96					
22	590	53	38	26	440		3.0	2.5	25
23	600	102	30	40	265		2.5	2.5	30
24	640	27	20	35					
25	660	31	35	42					
26	680	16	13	165	310		3.0	3.0	25
27	700	21	7	60					
28	710	67	20	25					
29	730	20	13	30					
30	780	31	23	26					
31	800	50	38	25					
32	820	26	35	50					
33	830	40	38	56					
34	860	46	65	38					
35	880	18	43	28					
36	900	30	38	51					
37	920	34	20	50					
38	940	103	28	23	325		2.5	2.0	35
39	960	63	30	24	325		2.5	1.5	30
40	990	189	35	65	270		3.0	2.5	35
41	1010	50	23	30					
42	1030	185	23	50	515		3.5	2.5	10
43	1050	85	43	180	365		4.5	5.0	35
44	1070	15	23	30					
45	1090	107	30	45	520		3.5	4.0	15
46	1100	33	13	25	125		2.0	1.5	15
47	1130	51	45	48	360		4.5	3.5	13
48	1150	23	38	115	310		4.0	3.5	20
49	1170	61	60	170	380		4.0	4.0	20

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

-- LOCATION=7. STANOLIND #1E COMPTON SW SW SE SEC.6,T.24N,R.2W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	1	123	23	29	620		3.0	2.0	30
2	20	128	30	45	740		3.0	2.0	25
3	40	62	68	50	945		4.0	2.0	30
4	60	168	53	66	750		4.0	4.0	53
5	80	33	20	46	600		3.0	2.0	20
6	120	40	30	53	545		5.0	2.0	40
7	140	85	23	50	540		3.5	1.5	30
8	160	15	35	54	560		3.5	1.5	25
9	180	22	38	80	750		3.5	2.5	20
10	200	600	43	41	700		5.0	2.5	40
11	220	16	30	40					
12	240	29	20	42					
13	260	19	38	36					
14	280	23	23	40					
15	300	57	30	65	1010		3.0	2.0	25
16	320	26	30	35					
17	360	9	15	39					
18	380	23	28	40					
19	400	23	45	108	655		3.0	2.0	25
20	420	35	38	81	885		3.5	2.5	20
21	440	15	38	44					
22	460	8	23	35					
23	480	15	38	29					
24	500	31	23	33					
25	520	19	5	37					
26	560	24	7	38					
27	580	16	7	171	265		2.5	2.0	25
28	600	73	13	29	255		3.0	2.0	25
29	620	14	15	17	215		3.5	2.5	20
30	640	15	15	19					
31	660	14	15	42					
32	680	18	13	27					
33	700	18	23	38					
34	720	18	13	38					
35	740	13	23	225	175		3.0	2.5	20
36	760	14	15	33					
37	780	15	28	43					
38	810	11	30	29					
39	830	9	23	23					
40	850	15	20	26					
41	870	18	23	57					
42	890	14	20	23					
43	930	7	23	22					
44	980	10	23	50	155		2.5	2.0	13
45	1020	174	20	25	205		2.0	1.5	20

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

- LOCATION=8. CONTINENTAL #1 MANN NW NW SW SEC. 8,T24N,R.1W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	230	10	15	43					
2	250	73	20	50					
3	270	13	20	44					
4	290	11	13	40					
5	310	25	20	40					
6	330	22	35	44					
7	350	17	38	50					
8	370	30	75	62					
9	390	20	15	133	395		4.0	3.5	35
10	410	20	15	35					
11	430	19	23	32					
12	450	12	20	33					
13	470	16	38	57					
14	490	16	50	71					
15	510	19	35	32					
16	530	17	35	180	425		4.0	3.0	40
17	550	59	13	35	325		2.5	2.0	25
18	570	14	13	29					
19	590	9	15	50					
20	610	9	8	37					
21	630	24	35	55					
22	650	11	20	30					

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=9. ITIO #1 KITCHENS N ! NE SEC. 17, T. 22N, R.5W ----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	300	15	40	50	450		4.0	2.0	40
2	320	18	50	205	620		3.0	2.0	50
3	340	10	30	39	440				
4	360	10	33	34	670				
5	380	15	33	31	1220				
6	420	14	40	84	830				
7	480	14	40	84	780		4.0	1.0	60
8	540	10	33	45	320				
9	580	10	40	33	185				
10	600	22	40	28	1340		4.5	1.0	60
11	620	16	40	40	560		3.0	2.0	80
12	660	11	10	38	820		3.0	1.0	80
13	720	17	5	39	500		2.5	1.0	35
14	750	10	10	42	300		1.5	1.0	70
15	790	10	5	40	500				
16	810	14	0	39	480				
17	840	14	5	43	880		2.5	2.0	48
18	841	9	7	45	280		2.0	1.0	35
19	870	65	18	48	245				
20	910	16	18	41	390				
21	930	12	23	41	250				
22	980	15	15	42	350				
23	1020	16	18	43	350		3.0	2.5	50
24	1040	14	28	46	240				
25	1060	18	20	48	300				
26	1160	15	23	49	250				
27	1090	18	18	82	220				
28	1200	14	20	44	265				
29	1220	29	18	50	280				
30	1230	28	20	42	280				
31	1240	35	15	39	260				
32	1270	15	20	42	240				
33	1300	14	10	45	250				
34	1320	20	15	55	265				
35	1450	19	28	50	250				
36	1470	20	35	50	270				
37	1480	17	25	55	270				
38	1490	16	25	55	260				
39	1520	18	38	53	250				
40	1550	16	45	50	300				
41	1570	16	28	49	235				
42	1590	15	43	55	290				
43	1620	27	35	50	265				
44	1640	16	33	53	285				
45	1690	16	28	48	290				
46	1700	17	10	47	270				
47	1710	16	15	48	305		2.5	2.0	50
48	1730	21	18	160	315		2.0	3.0	50
49	1740	19	23	58	265				
50	1750	25	28	45	295				
51	1770	24	35	42	240				
52	1790	15	3	37					

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

---- LOCATION=10. OHIO #1 SMYTHE NE NE SW SEC. 23, T.22N,R.4W ------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	156	12	20	33	1430		3.5	2.0	45
2	160	13	30	36	1430		3.5	3.0	40
3	180	14	20	38	1390		3.0	2.5	45
4	200	37	10	48	1000		2.0	1.0	35
5	380	238	15	47	830		2.5	1.5	35
6	440	20	13	55	515		2.5	1.6	35
7	480	40	20	60	645		3.0	2.0	40
8	490	29	315	145	720		4.0	4.5	50
9	500	68	35	143	625		3.5	3.5	45
10	520	31	2350	143	740		4.5	4.0	50
11	540	34	25	55	500		2.5	1.5	30
12	580	33	43	75	755				
13	600	34	45	44	940				
14	620	13	15	50	690				
15	650	26	18	50	395				
16	660	54	33	44	570				
17	680	11	28	46	460				
18	700	13	15	45	525				
19	720	17	23	68	520				
20	730	54	50	43	915				
21	740	34	63	45	910				
22	800	17	30	45	305		2.5	2.5	25
23	801	6	25	15	13		3.0	2.0	13
24	820	21	15	54	380		1.5	1.5	25
25	840	35	20	58	285				
26	860	30	5	48	310				
27	880	27	15	55	275		2.5	2.0	20
28	920	28	18	100	300		2.5	2.5	20
29	940	28	18	39	480		2.5	2.0	25
30	941	10	0	44	3		3.0	3.0	13
31	960	28	20	50	475		3.0	2.5	25
32	961	6	13	26	5		3.5	2.5	18
33	980	27	15	45	330				
34	1090	33	20	70	185		1.5	1.5	25
35	1000	25	20	158	355		3.0	3.5	35
36	1020	20	25	203	255		3.0	3.0	40
37	1060	44	28	70	245		2.0	2.0	35
38	1070	39	30	150	285		4.0	4.0	40

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

LOCATION=11. CITIES SERVICE MARIN IR NW NE NW SEC. 6, T.22N,R.3W -

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	170	10	35	61	650		4.0	2.0	40
2	190	10	30	76	2380		4.0	3.0	50
3	220	25	30	78	505		4.0	2.0	50
4	230	10	20	59	320				
5	250	15	15	71	145				
6	270	10	28	48	410				
7	300	9	20	44	850		2.0	1.5	25
8	340	13	20	45	550		1.5	1.0	15
9	380	10	28	46	415		2.0	1.5	35
10	410	17	23	44	495		1.5	1.0	35
11	440	115	20	49	715		2.5	1.5	45
12	470	107	25	55	735		2.5	1.0	45
13	490		20	58					
14	500	27	25	56	450				
15	510	20	30	63	675				
16	540	20	28	133	435				
17	570	25	28	42	480				
18	600	31	28	62	510				
19	630	40	35	40	460		2.5	1.0	40
20	660	26	28	44	475				
21	690	30	28	45	490				
22	720	17	15	47	430				
23	760	24		40	580		2.0	1.0	
24	790	20	40	42	510		2.0	1.0	45
25	820	19	28	36	540		2.0	0.5	45
26	850	26	25	53	540				
27	880	28	25	32	485				
28	920	30	18	50	340				
29	950	25	38	50	385				
30	980	18	23	39	320				
31	990	24	45	45	270				
32	1020	20	38	36	215				
33	1050	12	28	34	295				
34	1080	23	58	36	300				
35	1090	22	50	950	270		2.5	3.5	40
36	1100	20	38	36	385				
37	1130	24	40	41	415				
38	1160	18	28	37	385				
39	1180	23	20	32	380				
40	1190	20	28	33	400				
41	1200	45	38	33	400				
42	1220	11	28	32	370				
43	1250	14	28	32	365				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

---- LOCATION=12. STANOLIND #7 DEVORI NE SW NW SEC.23,T.22N,R.2W ----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	20	10	20	48	185		3.0	3.0	60
2	60	10	20	33	187		1.0	2.0	30
3	90	41	46	62	3252		3.0	3.0	46
4	100	113	40	71	2150		4.0	5.0	60
5	125	20	50	63	1385		3.0	3.0	50
6	203	29	500	285	980		4.0	7.0	50
7	220	22	28	110	810				
8	240	15	15	88	875				
9	290	50	110	74	2000				
10	350	10	40	92	4120				
11	370	10	33	66	1340				
12	400	12	33	55	685				
13	430	16	25	87	1195				
14	470	12	15	72	2270				
15	490	12	20	49	765				
16	510	22	45	62	1220				
17	560	13	25	27					
18	600	20	50	39	1460		4.0	4.5	70
19	630	26	10	66	875		2.5	3.0	80
20	640	20	10	29	92		1.5	2.0	60
21	658	14	10	46	840		7.0	2.0	60
22	680	28	70	105	2170		4.0	3.0	70
23	690	15	40	135	308		1.0	1.0	70
24	710	15	30	42	1770		3.0	4.0	60
25	701	699	60	28	1830		2.5	2.0	80
26	740	23	110	172	1430		10.0	8.0	100
27	750	18	60	170	755		5.5	4.0	60
28	770	10	10	52	555				
29	780	15	20	53	620		3.0	1.0	50
30	800	18	28	59	705				
31	810	125	60	54	1110				
32	830	15	30	78	705		4.0	2.0	70
33	870	20	28	75	1205				
34	880	22	20	60	830				
35	920	10	100	90	400		2.5	1.0	50
36	939	15	28	78	560				
37	949	29	10	83	1300				
38	971	13	28	68	715				
39	1000	10	5	90	190		2.5	1.0	50

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=13. BLAIR #1 ROLLING NE NE NW SEC. 9, T.22N,R.1W ----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	200	12	35	78	655	410	3.5	2.5	40
2	220	20	20	36	580	210			
3	240	38	25	37	850	240	2.5	1.5	30
4	250	25	25	55	530				
5	280	10	20	45	970				
6	300	10	15	46	855				
7	420	10	20	61	1375				
8	460	16	40	48	1260				
9	480	10	20	53	510				
10	500	13	30	45	1285	440	3.0	2.0	40
11	520	12	28	51	785				
12	540	13	20	44	775				
13	560	10	33	39	1100				
14	590	10	40	51	1315				
15	610	20	35	32	1085	360	3.0	3.0	50
16	660	37	35	22					
17	680	26	40	44	970	660	5.0	3.0	40
18	720	60	20	38	695	210	3.0	2.0	60
19	730	15	35	46	675	790	3.0	3.0	50
20	750	15	33	62	720				
21	790	20	20	170	885				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=14. DEARDORF #1 GUNGOLL SW NE SEC. 11, T.20N, R.8W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	600	6	5	27	635	237			
2	640	8	16	26	1241	528			
3	660	17	15	21	1275	396	2.0	2.0	40
4	680	4	15	24	545	484	4.0	2.0	30
5	700	4	10	26	515	490	12.0	2.0	25
6	720	6	10	25	360	536			
7	740	3	10	23	465	270			
8	760	4	10	22	640	396			
9	780	8	15	35	370	391			
10	800	7	30	28	630	490			
11	840	10	20	25	720	506			
12	880	3	15	19	1140	253			
13	920	2	15	23	1135	446			
14	960	4	20	27	1025	204			
15	1000	3	15	27	500	143			
16	1040	93	40	24	310	220	1.5	1.0	30
17	1060	15	5	23	270	352	1.5	1.0	15
18	1080	36	10	28	285	418			
19	1100	8	20	29	550	352			
20	1120	13	10	34	450	231			
21	1140	6	20	33	680	369			
22	1160	21	10	34	590	138			
23	1180	48	10	39	730	143			
24	1200	37	18	64	440	198			
25	1220	84	15	41	400	187	0.5	1.0	25
26	1260	165	35	36	495	176	2.5	1.5	35
27	1300	26	60	41	480	150	3.0	2.0	20
28	1340	19	30	63	450	100	3.0	2.0	30
29	1400	20	35	60	470	190	4.0	3.0	25
30	1420	13	30	55	455	100	3.0	2.0	25
31	1460	21	40	44	520				
32	1480	16	30	64	465	110	3.5	3.0	30
33	1520	16	30	48	380				
34	1560	13	25	44	395				
35	1600	12	25	61	375				
36	1640	25	25	57	345				
37	1680	12	25	44	410				
38	1720	21	25	51	340				
39	1740	13	20	51	330				
40	1760	19	25	57	290				
41	1780	21	28	43	270				
42	1800	19	18	47	365				
43	1820	13	20	47	370	110	3.0	1.5	30
44	1860		20	53	330	45	3.0	2.0	25
45	1880	17	25	60	285				
46	1920	15	15	45	185				
47	1960	18	18	82	225				
48	1980	22	25	46	220				
49	2020	15	20	50	210				
50	2040	19	20	43	220				
51	2060	15	20	47	270				
52	2080	21	20	39	220				
53	2110	16	25	36	285				

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

- LOCATION=14. DEARDORF #1 GUNGOLL SW NE SEC. 11, T.20N, R.8W -

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
54	2120	11	25	43	285				
55	2140	12	18	35	195				
56	2160	12	15	36	185				
57	2180	14	18	41	290				
58	2200	13	15	45	385	155	3.0	2	30
59	2220	13	15	40	275	180	2.5	3	35
60	2230	26	20	59	255	120	3.5	2	45

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--------- LOCATION=15. LEWIS #1 CLARK SEC. 3 T.21N, 6W -----------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	375	9	10	21	1200	682	2.0	2	40
2	395	7	10	15	1335	55	1.5	2	15
3	425	2	5	10	295	451			
4	505	4	25	25	590	457			
5	645	5	30	35	850	319			
6	765	10	20	36	580	374			
7	815	4	15	26	375	616			
8	865	7	15	22	365	281			
9	880	6	20	31	425	572			
10	900	16	10	29	435	440			
11	920	184	10	44	300	209	1.5	2	25
12	940	68	235	39	510	292	1.5	2	50
13	960	44	25	38	420	292			
14	970	22	25	36	465	242			
15	980	23	25	36	410	264			
16	1070	20	20	45	400	215			
17	1080	17	35	64	415	248	2.0	2	40
18	1100	27	20	47	300	198			
19	1120	17	20	40	355	253			
20	1140	31	25	77	395	215	2.0	2	20
21	1180	13	20	22	440	176			
22	1280	17	10	41	335	187			
23	1402	33	20	40	270	281			
24	1500	36	15	62	250	242			
25	1540	17	15	34	270	138			
26	1580	25	15	42	235	110			
27	1600	22	20	40	235	77			
28	1640	20	15	48	245	193			
29	1680	14	20	35	265	132			
30	1700	21	20	42	265	149			
31	1720	18	20	33	245	154			
32	1740	18	24	43	274	215			
33	1760	20	25	38	265	182			
34	1800	76	25	37	290	99	1.5	2	20
35	1810	90	20	37	300	99	1.5	2	30
36	1830	17	20	33	300	105			
37	1850	17	25	40	300	99			
38	1860	17	23	35	330	105			
39	1880	27	20	38	335	83			
40	1900	60	20	45	330	143	2.0	2	25

CHEMICAL ANALYSES OF THE WELLINGTIN-GARBER IN PARTS PER MILLION

----- LOCATION=17. DELANEY #1 ROBERTS NE SE NW SEC. 22 T.20N,R.4W -----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	185	9	10	23	325	264			
2	220	8	10	21	590	253			
3	260	19	5	52	660	264			
4	290	44	2580	112	410	286	1.5	0.5	60
5	320	8	15	13	1160	246			
6	340	7	15	15	1035	127			
7	360	11	10	15	1210	413			
8	380	9	55	19	1390	330			
9	400	8	10	16	850	413			
10	420	10	10	20	705	501			
11	430	10	10	19	505	650			
12	450	11	10	13	810	677			
13	460	8	10	17	1390	231			
14	470	6	10	12	640	230			
15	480	7	10	16	620	259			
16	490	7	10	16	660	237	2.0	3.0	5
17	510	8	10	17	780	440	1.5	3.5	5
18	520	680	60	25	355	4428	2.5	3.0	760
19	530	6	5	15	90	132			
20	540	35	10	15	305	127			
21	550	162	20	48	465	644	1.5	2.0	30
22	560	63	.15	39	500	750	1.5	1.0	40
23	570	50	10	35	510	143	1.5	1.0	18
24	580	57	5	33	530	40	1.5	1.5	25
25	590	56	20	222	180	506			
26	600	350	20	38	935	418	2.5	2.0	25
27	610	420	40	36	990	121	4.0	2.0	50
28	620	73	20	33	645	330	2.0	1.0	30
29	640	115	20	37	1240	341	2.5	1.5	30
30	650	115	20	44	1270	1249	2.5	2.0	35
31	660	23	35	46	1115	237			
32	670	18	30	45	955	264			
33	680	15	30	43	1120	171			
34	690	225	40	52	1060	181	2.0	2.0	80
35	700	29	25	41	825	259			
36	720	76	55	300	1000	264	3.5	6.0	50
37	730	31	20	68	1185	253	3.5	5.0	20
38	740	18	20	69	500	154			
39	770	18	35	42	590	110			
40	800	24	20	41	830	209			
41	820	45	25	35	380	94			
42	840	17	20	41	740	132			
43	860	19	15	35	720	198			
44	880	20	20	39	689	132			
45	900	14	25	59	610	237			
46	920	10	20	42	390	66			
47	940	5	15	36	905	88			
48	970	10	15	38	970	154			
49	990	15	10	35	545	105			
50	1030	16	10	38	545	121			
51	1060	5	10	45	650	110			
52	1100	26	25	36	510	105			
53	1120	16	15	61	385	55			

CHEMICAL ANALYSES OF THE WELLINGTIN-GARBER IN PARTS PER MILLION

----- LOCATION=17. DELANEY #1 ROBERTS NE SE NW SEC. 22 T.20N.R.4W -----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	185	9	10	23	325	264			
2	220	8	10	21	590	253			
3	260	19	5	52	660	264			
4	290	44	2580	112	410	286	1.5	0.5	60
5	320	8	15	13	1160	246			
6	340	7	15	15	1035	127			
7	360	11	10	15	1210	413			
8	380	9	55	19	1390	330			
9	400	8	10	15	850	413			
10	420	10	10	20	705	501			
11	430	10	10	19	505	650			
12	450	11	10	13	810	677			
13	460	8	10	17	1390	231			
14	470	6	10	12	640	230			
15	480	7	10	16	620	259			
16	490	7	10	16	660	237	2.0	3.0	5
17	510	8	10	17	700	440	1.5	3.5	5
18	520	680	60	25	355	4428	2.5	3.0	760
19	530	6	5	15	90	132			
20	540	35	10	15	305	127			
21	550	162	20	48	465	644	1.5	2.0	30
22	560	63	15	39	500	750	1.5	1.0	40
23	570	50	10	35	510	143	1.5	1.0	18
24	580	57	5	33	530	40	1.5	1.5	25
25	590	56	20	222	180	506			
26	600	350	20	38	935	418	2.5	2.0	25
27	610	420	40	36	990	121	4.0	2.0	50
28	620	73	20	33	645	330	2.0	1.0	30
29	640	115	20	37	1240	341	2.5	1.5	30
30	650	115	20	44	1270	1249	2.5	2.0	35
31	660	23	35	46	1115	237			
32	670	18	30	46	955	264			
33	680	15	30	43	1120	171			
34	690	225	40	52	1060	181	2.0	2.0	80
35	700	29	25	41	825	259			
36	720	76	55	300	1000	264	3.5	6.0	50
37	730	31	20	68	1185	253	3.5	5.0	20
38	740	18	20	68	500	154			
39	770	18	35	42	590	110			
40	800	24	20	41	830	209			
41	820	45	25	35	380	94			
42	840	17	20	41	740	132			
43	860	19	15	35	720	198			
44	880	20	20	39	689	132			
45	900	14	25	59	610	237			
46	920	10	20	42	390	66			
47	940	5	15	35	905	88			
48	970	10	15	38	970	154			
49	990	15	10	35	545	105			
50	1030	16	10	38	545	121			
51	1060	5	10	45	650	110			
52	1100	26	25	36	510	105			
53	1120	16	15	61	385	55			

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

-- LOCATION=17. DELANEY #1 ROBERTS NE SE NW SEC. 22 T.20N,R.4W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
54	1140	25	25	43	375	72			
55	1170	10	20	53	540	61			
56	1200	53	15	36	315	88			
57	1220	14	20	26	360	134			
58	1250	7	13	20	175	64	1.0	1.5	15
59	1270	25	70	55	245	98			
60	1290	16	30	50	430	162			
61	1300	55	25	30	505	225			
62	1320	7	15	15	310	69	2.5	0.5	35
63	1340	508	60	120	450	181	6.0	4.0	
64	1360	18	30	40	295	142			
65	1380	11	20	30	420	215			
66	1400	16	18	30	555	161			
67	1420	13	35	30	465	103			
68	1440	31	30	30	500	118			
69	1460	32	25	30	615	132			
70	1480	12	25	30	545	108			
71	1500	79	25	35	510	157			
72	1520	27	25	30	475	220			
73	1540	38	50	30	675	137			
74	1560	54	25	35	470	157			

CHEMICAL ANALYSES OF THE WELLINGTIN-GARBER IN PARTS PER MILLION

---- LOCATION=18. GULF #1 DECKER SW,SW/NW SEC.12, T.20N, R.4W -----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	380	10	15	40	940	205			
2	400	18	20	34	675	310			
3	460	8	15	37	695	235			
4	480	11	15	63	1680	705			
5	500	12	20	67	720	325	1.5	1.0	25
6	520	10	10	67	1125	360	2.0	1.0	30
7	540	52	20	78	1215	450	2.0	1.0	30
8	560	6	15	43	685	190	2.0	1.5	30
9	580	120	20	85	2350	250	3.0	3.0	40
10	590	65	20	43	2080	345	2.5	2.0	35
11	600	98	30	42	2165	190	2.5	2.0	20
12	620	35	35	49	1540	160	2.5	2.5	30
13	630	41	25	62	1575	295	2.5	2.0	30
14	640	11	30	84	1000	175	2.0	1.5	40
15	660	11	30	70	915	125	2.5	2.0	30
16	680	10	20	68	910	125	2.5	2.5	35
17	700	18	35	58	775	210	2.5	2.5	35
18	720	19	50	63	850	240	2.5	3.0	30
19	740	23	30	50	560	175	2.0	2.5	20
20	760	26	25	49	680	90			
21	780	22	35	166	825	110			
22	800	25	40	150	910	75	2.5	3.5	35
23	820	42	90	142	940	85	2.0	5.0	30
24	840	31	50	111	1410	210	2.0	3.0	40
25	860	59	30	110	540	110	2.0	1.5	25
26	880	92	15	57	905	115	2.0	3.0	30
27	900	13	15	57	530	195	2.0	1.5	30
28	920	13	15	68	935	140	1.5	1.5	30
29	940	6	20	59	660	150	1.5	1.5	30
30	960	9	30	53	890	150	2.0	2.0	30
31	980	198	40	108	625	195	4.0	3.0	50
32	1020	48	25	53	465	85	1.5	1.5	25
33	1040	111	35	189	670	85	2.0	3.0	40
34	1060	76	45	79	1075	60	2.5	3.0	45
35	1080	30	30	59	665	110	2.0	3.0	40
36	1100	18	22	59	682	66	2.5	3.0	20
37	1120	13	20	94	580	95	2.0	3.0	30
38	1140	57	20	56	520	40	3.0	4.0	35
39	1160	18	20	63	465	80	2.5	4.0	
40	1180	102	30	124	570	25	3.5	4.0	30
41	1200	139	45	82	575	110	2.5	3.0	20
42	1300	65	40	97	495	75	3.0	4.0	40

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

----- LOCATION=19. WATCHORN #1 KAISIR NE/NW SEC .8 T.20N R.3W ------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	390	4	15	25	685	200	0.5	1.0	30
2	391	21	0	15	250	818	0.5	0.5	40
3	410	5	25	35	1645	127			
4	430	6	20	35	690	225			
5	450	5	15	25	500	171			
6	470	9	15	35	1425	284			
7	490	8	20	30	1000	421			
8	510	16	15	25	1060	490			
9	520	5	15	40	1240	240			
10	540	6	10	90	550	83			
11	550	57	10	35	525	167			
12	570	57	10	35	690	108			
13	590	55	20	35	800	122			
14	610	14	30	40	1060	132			
15	650	24	45	45	455	98			
16	670	103	40	45	410	59			
17	690	24	100	85	1265	176	3.0	4.0	25
18	720	11	45	80	740	216			
19	750	45	30	55	715	157			
20	780	34	55	35	1155	88			
21	810	21	40	35	535	113			
22	840	36	60	40	1210	124			
23	870	6	15	40	240	103			
24	890	3	5	20	140	21			
25	910	13	30	70	540	144			
26	930	7	15	40	640	191			
27	950	7	10	40	505	103			
28	970	6	17	45	1040	81			
29	990	6	20	35	235	176			
30	1010	16	20	35	235	88			
31	1030	17	42	42	375	273			
32	1050	14	15	40	215	77			
33	1070	16	15	45	500	72			
34	1090	11	20	25	415	94			
35	1110	19	15	35	535	99			
36	1130	18	20	35	520	88			
37	1150	16	25	35	290	88			
38	1190	21	35	50	510	33			
39	1210	14	21	52	216	272			
40	1230	15	30	65	525	242	2.5	2.0	18
41	1240	36	45	100	510	566	2.5	2.5	20

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

-- LOCATION=20. CHAMPLIN #1 GRAVES NE/SE SEC. 21, T.20N,R.2W ---

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	100	18	40	65	705	523	.5	6	40
2	185	6	25	55	1110	270			
3	205	7	20	30	1590	478			
4	225	12	25	35	2300	226			
5	380	23	25	35	630	160			
6	400	14	20	55	1140	83			
7	420	10	20	40	1125	154			
8	440	9	15	45	635	171			
9	460	83	15	35	320	270			
10	490	67	20	40	740	149			
11	510	5	20	50	855	105			
12	520	19	20	40	230	204			
13	540	58	20	45	380	369			
14	560	37	20	35	1110	215			
15	580	18	20	40	420	198			
16	600	74	20	40	470	330	.5	1	23
17	620	16	20	45	300	160			
18	640	12	15	45	750	484			
19	660	13	15	40	970	209			
20	680	5	20	45	1600	517			
21	700	163	15	25	275	193			
22	720	14	25	35	290	130			
23	740	10	20	40	1425	630			
24	760	27	20	35	395	65			
25	780	5	25	40	855	175			
26	800	8	20	40	815	265			
27	820	16	20	50	870	170			
28	830	33	20	50	740	150			
29	840	56	35	50	1785	240			

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

--- LOCATION=21. OHIO #1 HUBBARTT N1/SW/SE SEC. 18, T.20N, R.1W ----

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	220	8	30	56	2520	649	2.0	2.0	30
2	280	12	50	33	950	358	3.0	3.0	35
3	240	5	30	45	2100	187	1.0	1.0	25
4	260	35	20	33	1710	149	1.0	1.0	25
5	290	5	25	43	3000	253	0.2		
6	310	6	35	40	1605	396	1.5	1.5	30
7	330	8	50	52	740	110			
8	350	5	35	43	390	347			
9	380	3	15	34	245	319			
10	400	4	20	47	305	187			
11	420	19	20	43	1405	622	1.0	1.0	30
12	440	15	25	55	1510	215			
13	460	51	43	53	1250	380			
14	480	19	45	33	505	132			
15	500	7	40	37	2750	308			
16	520	6	35	35	1950	275			
17	540	7	75	37	2590	561			
18	560	5	30	44	415	198			
19	580	10	75	33	1425	94	2.0	1.5	35
20	600	7	80	38	940	165			
21	640	13	25	54	870		1.0	1.0	70
22	680	18	20	53	1310		2.0	2.0	30
23	700	200	15	50	1320		6.0	2.0	
24	780	80	185	755	3450		4.0	7.0	
25	840	18	15	68	740		1.0	2.0	
26	860	16	15	59	750		1.0	2.0	
27	880	18	12	60	770		2.0	2.0	25
28	940	16	10		680		1.0	2.0	20

CHEMICAL ANALYSES OF THE WELLINGTON-GARBER IN PARTS PER MILLION

----- LOCATION=22. ELLISON #1 STRAIGE SEC. 27 T. 18N, R. 4W ------

OBS	DEPTH	CU	PB	ZN	MN	BA	AG	CD	CO
1	200	7	25	18	1590		2.0	2.0	30
2	380	11	30	37	930		2.0	0.5	40
3	400	7	30	28	2650		1.5	1.0	25
4	500	8	35	27	1080		1.5	1.0	20
5	660	8	20	29	660				
6	680	8	30	32	470				
7	700	6	45	34	890				
8	720	7	35	34	395				
9	740	5	25	22	690		0.5		20
10	760	6	30	33	540		1.0	0.5	20
11	780	104	35	27	540		0.5	1.0	25
12	800	99	20	32	835		1.5	1.0	30
13	820	23	15	39	415		0.5	0.5	30
14	840	16	13	39	735		1.0	0.5	23
15	860	7	15	44	565		1.0	0.5	25
16	880	20	20	42	940		1.0	0.5	35
17	900	10	10	36	555		1.0	0.5	30
18	920	22	25	39	630		1.0	0.0	40
19	940	10	10	124	710		0.5	1.0	20
20	980	24	35	40	1025				
21	1020	11	10	47	590				
22	1040	9	10	38	405				
23	1060	8	10	35	370		0.5	1.0	25
24	1080	9	15	40	910				
25	1100	8	10	37	465				
26	1120	8	15	39	870				
27	1140	7	15	36	565				
28	1160	13	15	40	625				
29	1180	10	10	45	415				
30	1200	10	15	39	590				
31	1220	16	20	37	595				
32	1240	12	15	41	320				
33	1260	20	10	32	340				
34	1280	18	20	37	475				
35	1300	21	10	38	270				
36	1320	21	10	44	670				
37	1340	12	15	35	350				
38	1360	12	10	35	370				
39	1380	9	10	32	340				
40	1400	12	15	44	340				
41	1420	22	8	34	350				

APPENDIX D

MEANS OF THE ELEMENT CONCENTRATIONS BY WELL

FROM THE UPPER WELLINGTON FORMATION

Well No.	Depth Interval	No. Obs.	Cu	Pb	Zn	Mn	Ba
1	970-1160	12	226.0	26.7	52.7	432.8	-
3	740-980	10	15.1	21.1	57.8	410.0	-
4	570-750	9	39.6	24.0	62.7	550.0	-
5	550-720	12	85.0	32.5	45.5	606.0	-
6	100-500	8	91.6	40.3	55.1	667.9	-
7	0-200	9	127.6	36.3	51.4	670.0	-
9	870-1160	8	21.4	20.3	44.7	296.8	-
10	280-580	14	56.4	287.1	81.5	727.0	-
11	330-540	9	48.1	26.5	62.0	557.5	-
12	0-220	6	45.0	132.8	118.2	1715.4	-
14	1040-1260	10	47.9	17.5	35.0	427.7	235.1
15	920-1140	9	45.3	44.0	46.6	397.0	242.8
17	520-720	19	106.3	24.1	65.6	823.9	347.9
18	550-780	13	44.9	24.5	62.4	1443.5	230.5
19	550-780	9	42.4	38.5	49.0	781.5	132.3
22	780-980	15	35.5	19.8	42.2	695.0	-

VITA

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Candidate for the Degree of

Master of Science

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