Depositional history of the Des Moinesian Series (Pennsylvanian), type region in central Iowa

by

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TABLE OF CONTENTS

INTRODUCTION

Several studies have been published on the Des Moinesian Series in Kansas (Bass, 1936; Moore, 1936, 1949; Jewett, 1941, 1945), Oklahoma (Levorsen, 1927), Missouri (Cline and Greene, 1950), and south central Iowa (Cline, 1941; Laury, 1968; Brown et al., 1977), but in the type region of central Iowa, there have been only three major investigations in the past 100 years. The present study, an interpretation of the depositional history of the type region, was conducted because of this void in the knowledge of Pennsylvanian stratigraphy in Iowa. A correct interpretation of the depositional history is also of economic importance, and may aid in locating new coal and clay deposits and aquifers in the area.

This interpretation of the depositional history is based on primary and secondary structures, fossils, and clay mineral assembleges of the individual rock units in seven exposures in the City of Des Moines and in one drill core northwest of the city. Although the sediments do not contain an abundance of diagnostic primary and secondary structures or fossils, they, along with the lateral and vertical trends in clay mineral abundance, lend themselves to an interpretation of their depositional history by comparison to modern day examples.

PREVIOUS STUDIES

The first studies on the geology of the area were conducted by military personnel. In July of 1841, Lieutenant John C. Fremont, acting for the War Department, surveyed the Des Moines River Valley for the establishment of a military post. While surveying the area, he collected fossils from the beds exposed along the Des Moines River above the confluence with the Raccoon River. A list of the fossils collected by Lt. Fremont was included in a report of the expedition of J. N. Nicollet (1841). In 1843 Captain James Allen and his company of First Dragoons established Fort Des Moines along the Des Moines River. His notes, written while in command of the fort, gave an early account of the topography and geology of the area.

The first extensive work on the geology of the area was not begun until 1849. During that summer, Dr. D. D. Owen located and described the major exposures along the Des Moines River. In 1856 Worthen described some of the exposures near the city. The first major report on the area and on the Pennsylvanian stratigraphy of Iowa was by Charles R. Keyes (1894). In his report on the geological formations of Iowa, Keyes discussed the lithology and stratigraphy of the Coal Measures. He also proposed that they be divided into the Des Moines and Missouri Stages. The lower Coal Measures, which consisted primarily of shallow marine to coastal deposits, would be named the Des Moines Stages and the upper Coal Measures, which consisted largely of marine beds, would be named the Missouri Stage. In his "Geology of Polk County," H. F. Bain (1896) examined the geology of the area in greater detail than any previous study. His report described the physiography, stratigraphy, and mineral resources of the county. From the exposures, he constructed a geological cross section beneath the City of Des Moines from the State Capitol grounds, north along the Des Moines River and west along the Raccoon River. The last major report on the Pennsylvanian stratigraphy in the area was by C. S. Gwynne (1940), who studied the coal and clay resources of the area and described the strata exposed in a few of the quarries.

In 1974 L. G. Pratt compiled a list of the coal companies that operated in the area for 130 years and discussed the history of coal mining operations in the city. His report contained a wealth of historical information on mining in the area.

MINERAL RESOURCES

After Captain James Allen and A. N. Hays opened the first coal shaft and stone quarry in 1843, Polk County became an area of active coal and clay operations for over one hundred years. With excellent railroad facilities, Des Moines had an economic advantage over other coal mining areas by being able to supply areas in northern and western Iowa as well as adjoining states.

Before 1870 most of the coal was mined for local consumption because it was easily obtained near the surface. One such operation, opened by Wesley Redhead and a dozen associates of the Des Moines Coal Company in 1864, worked a slope north of Des Moines until exhausted. It is of historical interest to note that Redhead is credited for being the first to substitute the ton for the bushel as the unit of measurement for coal (Olin, 1965).

By 1870 local industrial demands had exceeded the supply of near-surface coal, and it became evident that a more systematic method of mining was needed. In 1871 the Eureka shaft opened on the south side of Des Moines to exploit deeper deposits of coal. It was later taken over by the Eureka Coal Company. In 1870 Redhead, convinced that even thicker veins laid deeper, began prospecting near the Seventh St. Bridge, south of the Raccoon River. He was unsuccessful until June 2, 1873, when he struck a five-foot vein of coal, 125 feet down. A loan was secured and the mine opened under the name Black Diamond but was later renamed the Pioneer. It was equipped with the most advanced machinery and by 1876 was employing 150 men to produce 200 tons per day (Olin, 1965; Pratt, 1974).

After Redhead's discovery, many other coal companies came into existence. By 1876, 11 coal companies were operating in the Des Moines area, most of which were organized after 1873. The Watson Coal Company, which had a shaft at 15th and the Rock Island tracks, was one of the largest mines in Polk County. From June 1875 to June 1876, 45,000 tons were produced at a value of $100,000. In 1879 John Walters and George Carver opened Giant shafts Nos. 1 and 2 at 16th and Walker and 20th and Grand, respectively. Many of these tunnels extended into the Capitol grounds. By the late 1800's, most of the upper coal veins were exhausted, but many small mines continued to work at different levels, and by 1881 Polk County had 22 coal mines in operation. The peak of coal production came in 1917 with 1,845,839 short tons being extracted that year (Olin, 1965; Pratt, 1974).

Production decreased after World War I, and by 1921 extraction fell to 750,351 short tons for that year. In 1943 only 5 coal companies were in operation. Between 1948 and 1953, Polk County had no operating coal mines, but from 1954 to 1959, the Hopkins Mine operated the last coal mine in the county (Pratt, 1974).

Although Des Moines has an extensive history of manufactured clay goods, the literature pertaining to it is not as readily obtainable as that of coal. Bain (1896) noted that Des Moines produced, at that time, more paving brick than any other location west of the Mississippi and that it was mined from three materials: alluvium, loess, and Pennsylvanian age shales. C. S. Gwynne (1940) discussed the operations of several clay companies in his report on the mining activities of the county. He also recorded the stratigraphy in several of the quarries that were operating at the time.

Just before World War II, there were 10 operating manufacturers of clay goods, but today only two exist. The largest of these is owned by Can-Tex Industries, which currently mines two areas just north of the city limits on the east and west sides of the Des Moines River. The second is Goodwin Tile and Brick Company which is operated by Charles and Tony Caligiuru and is located at Southeast 18th and Hartford.

STRATIGRAPHY OF THE DES MOINES SERIES

Regional Sedimentation Patterns

From early to middle Pennsylvanian times, several structural features existed in the mid-continent area of the United States. A small geosynclinal area occurred in north-central Arkansas and eastern Oklahoma. This depression, the Arkoma Basin, occupied an east-west trough about 100 miles long. A broad, unstable shelf extended from the basin north into the type region of the Des Moinesian Series in central Iowa. South of the shelf and northeast of the Arkoma Basic existed a positive area, the Ozark Uplift. To the west of the shelf was a broad depression, the Forest City Basin, which occupied an area in northwestern Missouri, eastern Kansas, and southwestern Iowa. The Nemaha Ridge, an intracratonic positive area, existed west of the Forest City Basin (Krumbein and Sloss, 1959; Branson, 1962).

Sedimentation patterns differed in each basin, and lithofacies maps of sand and shale strongly suggest that the source area was derived from disturbances further south of the Arkoma Basin and north of the Forest City Basin. Early Pennsylvanian clastic sediments of the Morrowan and Atokan Series were deposited in the Arkoma Basin but thinned rapidly northward upon the shelf. The earliest deposits in the Forest City Basin were clastic sediments of Atokan age. Starting in late Atokan or early Des Moinesian times, extensive sedimentation began on the shelf and in the Forest City Basin but was only approximately one-tenth as thick as the strata in the Arkoma Basin. In the Arkoma Basin, Des Moinesian age sediments were predominantly shales with massive sandstone tongues, while cyclic clastic sediments, including those in the type region, were deposited on the shelf and in the Forest City Basin (Branson, 1962).

By the end of Des Moinesian times, the Arkoma Basin had ceased to exist as shown by the fact that later sediments of the Missourian and Virgillian Series were of uniform thickness. These sediments were deposited in southwestern Iowa over Des Moinesian age sediments (Branson, 1962).

Stratigraphic Nomenclature

The Des Moines Formation was proposed by Keyes (1894, p. 85) as the lower division of the Pennsylvanian System in Iowa. He derived the name of the formation from the river that flows through the major outcrops in central Iowa. Keyes believed that the Des Moines Formation was composed of marginal marine to coastal deposits and should be separated from the upper, predominately marine deposits, which he called the Missourian Formation. Although he did not state that the region around the City of Des Moines was the type region, recent workers have considered the section to be based in this area (Branson, 1962; Dunbar and Rodgers, 1957).

In the years following Bain's report (1896), the literature pertaining to the strata of the type region has been scarce, and only a few areas in Iowa have been correlated with other locations in surrounding states. In Iowa, the Geological Survey considers that the Des Moinesian Series probably include the Cherokee and Marmaton groups. The strata exposed in the type region are located in the Cherokee group, but the exact stratigraphic position of the section within the group is in doubt because correlation with other areas of known stratigraphic positions is lacking.

The term, Cherokee shales, was proposed by Haworth and Kirk (1894), but Moore (1949) later named them the Cherokee group. The lower portion of the Cherokee group has not been subdivided in Iowa, but the upper part has been divided from oldest to youngest into the Munterville limestone, Seahorne limestone, Wiley coal, Whitebreast coal, Ardmore limestone, Wheeler coal, and the Bedford coal. It is probable that the strata in this study are located in the upper divisions because they correlate to the upper portions of a core section that contains the most complete stratigraphic record in the area. This correlation is discussed in the text below.

Stratigraphy of the Study Area

General stratigraphic relationships

In this study, the Pennsylvanian stratigraphy of the City of Des Moines is based on one core section, CP-47, obtained from the Iowa Geological Survey and seven exposures, five in clay quarries and two in hillsides. The core contains 379 ft. of Pennsylvanian sediments, but the exposures in the city correspond to the units (as designated by the Survey) in CP-47 that lie between 63 ft., 8 in. (unit 8) and approximately 150 ft. (unit 21) to 159 ft., 2 in. (unit 23) below the surface. The correlation with CP-47 is based on a similarity of lithologic sequences and corresponding thicknesses.

The lower section consists primarily of mudstones to the north and sandstones to the south, while the upper section contains carbonates and shales. The basal sequence in CP-47, units 21 to 23, consists of dark to light mudstones that contain plant fossils, but further to the south, a facies change to coals, underclays, and sandstones occurs. This is overlain by units 19 and 20, which consist of a sequence of dark red and light blue to gray mudstones to the north that become argillaceous sandstones to the south. In turn, this is overlain by a thin coal, a thin smut, and a dark fissile shale with carbonate lenses, which have been designated as units 18, 17, and 16, respectively. A thin dolomite, unit 15, was the youngest bed studied in detail because it was the uppermost unit that was laterally persistent and easily recognizable over the entire section (Figure 1).

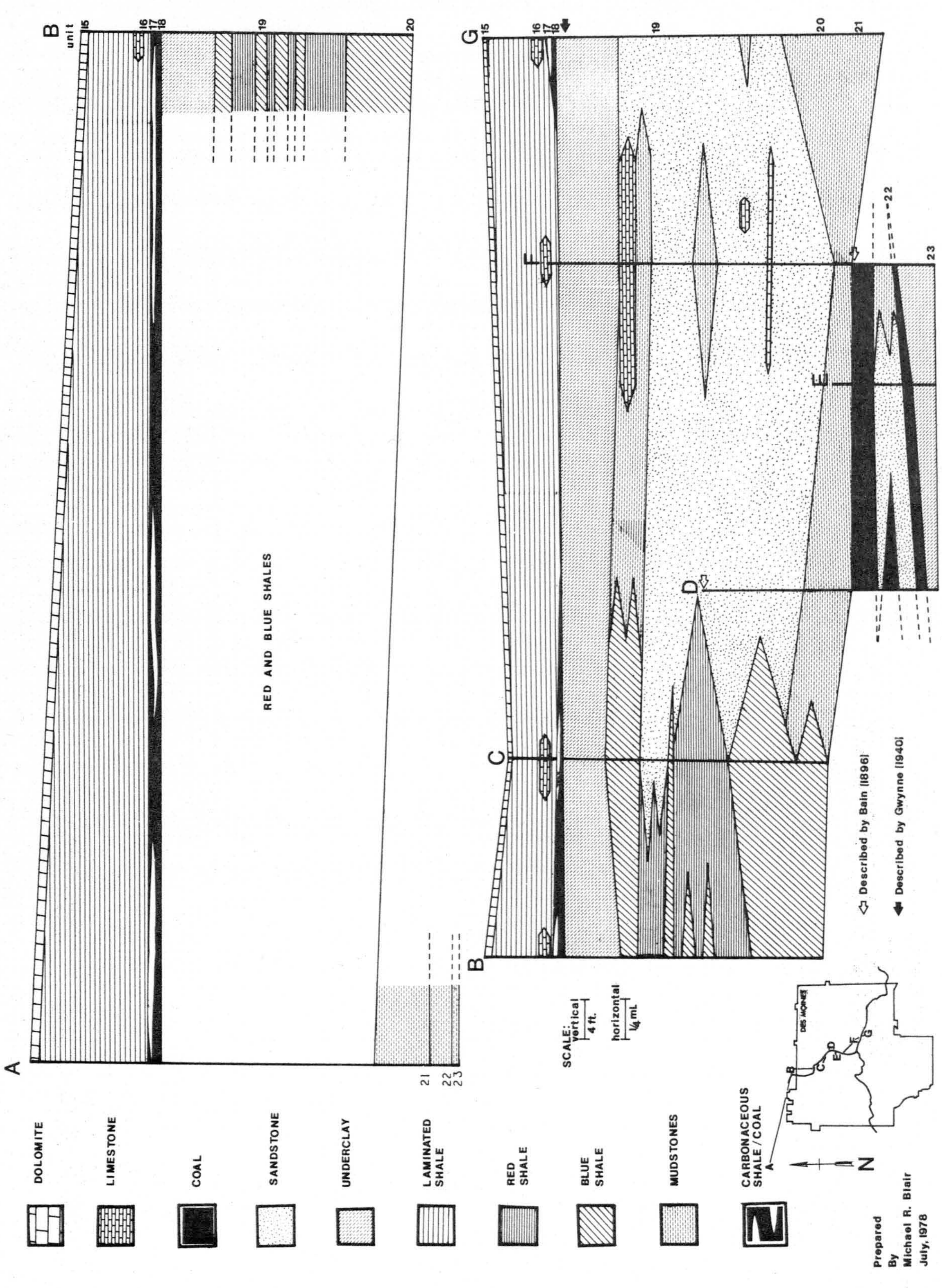
Additional lithologic units, that can be correlated to CP-47, are present at the Thomas Beck Road exposure. At that location, units 10 to 14 occur as mudstones with two coal layers, units 9 and 13. Similar strata occur in CP-47.

Stratigraphy of the core section and outcrop exposures

CP-47 The core section, located northwest of the city, contains the most complete record of the stratigraphic section available. All the units studied are present in CP-47, although the carbonate lenses of unit 16 are absent, and the distinction between the contact of the upper and lower portions of unit 19 is not as clear as between those displayed in the outcrops (see Appendix C for a more detailed description of the strata and location of the core section and outcrop exposures).

Can-Tex quarries These quarries are located on the northern edge of the City of Des Moines, along the east and west sides of the Des Moines River Valley. At this location, units 15 and 20 are exposed. The carbonate lenses of unit 16 are best exposed here, and units 19 and 20 are

Figure 1. Cross section of lithofacies of the Des Moines Series in the City of Des Moines. A-CP-47; B-Can-Tex quarries; C-Hickman Road; D-described by Bain (1896); E-2nd Avenue outcrop; F-Capitol ground outcrop; G-Goodwin Brick and Tile quarries


A
B
unit
15
16
17
18
19
20
21
22
23
RED AND BLUE SHALES
G
F
E
D
C
B
Described by Bain (1896)
Described by Gwynne (1940)
DOLOMITE
LIMESTONE
COAL
SANDSTONE
UNDERCLAY
LAMINATED SHALE
RED SHALE
BLUE SHALE
MUDSTONES
CARBONACEOUS SHALE / COAL
SCALE:
vertical
4 ft.
horizontal
1/4 mi.
DES MOINES
N
Prepared
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present as siltstones. Other units above 15 are present but are difficult to correlate with other exposures.

Hickman Road outcrop   One and seven-tenths of a mile to the south of the quarries, on Hickman Road, there are a series of outcrops approximately one-half mile long. At the western edge of the exposure, units 13 to 20 are exposed. At the eastern edge of the exposure, a facies change occurs. At this location, approximately 5 ft. of sandstone outcrop at the same elevation as the alternating blue and red mudstone beds (units 19 and 20) in the exposure to the west and are similar in appearance to the sandstone outcroppings at the Capitol grounds. Although exposures exhibiting the exact relationship are not present, lithological similarity of the two sandstones and similar distance of the Capitol grounds sandstone and Hickman Road mudstones from units 17 and 18 indicate that the mudstones and sandstones are stratigraphically equivalent. The intertonguing of sandstones and mudstones and a gradation into one another laterally, rule out a channel cut.

Second Avenue outcrop   Six-tenths of a mile to the south of the Hickman Road exposure, units 21 to 23 outcrop along Second Avenue. They consist of coals, a fossiliferous sandstone, and an underclay.

Capital grounds outcrop   Two miles to the south and east of the Second Avenue outcrop, units 16 to 20 are exposed at the southern edge of the Capitol grounds. An anticline brings the younger units to the surface in the western part, while older sandstone units are progressively exposed to the east. Units 19 and 20 are present as sandstones and siltstones.

Goodwin Brick and Tile One and one-half miles to the south of the Capitol grounds, at the Goodwin Brick and Tile quarries, units 15 to 18 and a portion of 19 are currently exposed. Gwynne (1940) described another 28 ft. of siltstones and argillaceous sandstones below the present exposure which probably are equivalent to units 19 and 20.

Thomas Beck Road outcrop Two and three-tenths of a mile west of Goodwin Brick and Tile, on Thomas Beck Road, an abandoned quarry poorly exposes units 8 to 20. In no place is the complete section exposed, and it was only until the stratigraphy of CP-47 was known that the different outcrops could be pieced together. Units 8 to 14 are best exposed along the walls of the quarry, while units 15 to 20 occur in the hills to the east as scattered outcrops.

LITHOLOGY OF UNITS

Introduction

The section is composed primarily of mudstones, although sandstones comprise a large percentage of the strata in the southern portion. Even in the sandstones and carbonates, clay and silt-size particles are present in appreciable quantities. The mudstones vary from highly fissle, argillaceous shales to nonlaminated sandy siltstones. At the Capitol grounds outcrop a transition from an argillaceous shale to a sandy siltstone is well-displayed between the sandstone beds. The sandstones are fine-grained and argillaceous. The carbonates are calcilutites to fossiliferous, argillaceous micrites, but a medium-grained, fossiliferous dolomite unit also occurs.

Description of Units

Lower units

Units 21 to 23 Units 21 to 23 occur in CP-47 and at the 2nd Avenue outcrop (Figure 1). At the 2nd Avenue outcrop, the units are composed of two coals, an underclay, and a sandstone. Bain (1896) was able to trace these units from the Capitol grounds outcrop, north past the 2nd Avenue outcrop, because of several outcrops not now exposed. He was able to demonstrate that the two coal beds, which are separated by a sandstone lens, combine to form a single bed to the north. In CP-47 units 21 to 23 are present as mudstones. Correlation of these dissimilar strata is based on their stratigraphic position beneath unit 20, lack of evidence for erosion between units 20 and 21 and a similar depositional environment, as suggested by fossil plants.

In CP-47 unit 23 consists of an 11 in. thick, dark gray to black, highly fractured, slickensided shale. Kaolinite is the major mineral, while mica-clay and quartz are present in minor quantities. Unit 22 is a green-gray, mottled yellow, slickensided shale that darkens with depth and is 2 ft., 9 in. thick. Kaolinite is also the major mineral, while mica-clay and quartz are minor minerals. The contact between the two units is sharp and regular. Unit 21 is composed of gray-green to gray, argillaceous, fossiliferous siltstones interbedded with sandy siltstones and is 5 ft., 5 in. thick. Quartz is the major mineral, while kaolinite and mica-clay are minor minerals. The lower and upper contacts are sharp and irregular.

At 2nd Avenue the oldest bed is a light gray, fossiliferous, slickensided underclay that is approximately 5 ft. thick. The lower 3 ft. are poorly exposed and have not been sampled. The upper 2 ft. contain gypsum, pyrite and other sulfides, and are rich in kaolinite, with only minor amounts of mica-clay and quartz. Above the underclay is a bituminous coal 1 ft., 1 in. thick. It is dull to semi-shiny black, banded and breaks with a blocky fracture.

The next youngest bed exposed at 2nd Avenue is a 1 ft., 1 in. thick cycle of light gray, sandy siltstones and dark gray, argillaceous siltstones. The sandy siltstones are ½ in. thick and contain fossillized lycopod roots. The argillaceous siltstones are 1/8 to 3/4 in. thick and contain more pyrite and gypsum than the sandy siltstones. At the southern edge of the outcrop, the sandstone unit from above cuts into the siltstones to a depth of less than 1 ft. (Plate 1, Figure 1). The sandstone above the siltstones is a light to medium gray and is 2 ft., 4 in. thick. The upper

1 ft., 1 in. are less resistant than the lower portion of the unit. The sandstone displays little internal structure, but many fossil rhizomes and rhizoids of Lycopodia are present, which influence fracturing of the rock. The rock is poorly cemented and moderately friable, breaking easily around the grains. The sand grains are rounded and of approximately a +3 phi size (.12 to .25 mm). The surface of the grains is also pitted (Plate 1, Figure 2). Quartz is the major mineral, while kaolinite and mica-clay are minor minerals. Above the sandstone is a dull to semi-shiny black, banded, bituminous coal that is 2 ft. thick. It breaks with a blocky fracture.

Units 19 and 20 Units 19 and 20 are present as silty shales and siltstones in CP-47 and at the Can-Tex quarries. At the Hickman Road exposures, to the south, the siltstones are more sandy and finally become sandstones at the eastern most outcrop. At the Capitol grounds, in the southern section, units 19 and 20 are present as sandy siltstones and silty sandstones. The combined units range in thickness from 21 ft., 7 in. in CP-47 to 27 ft., 5 in. at the Capitol grounds (Figure 1).

Unit 20 is comprised of alternating cycles of silty shales and siltstones in the northern section. The silty shales are finely parallel-laminated, uniformly thick, brick red to brown minor subunits, while the siltstones are laminated to very thinly-bedded, occasionally wedge-set to tabular-crossbedded, light blue to gray, shaley major subunits. Both break with a conchodial to blocky fracture.

The mineralogy of the two subunits is similar. Kaolinite, mica-clay, and quartz are present in relatively equal proportions, but the shaly siltstone also contains visible, mica flakes and siderite nodules (.1 to 1 mm in diameter) which increase in number towards the lower portion of unit 20.

The contact between the shaly siltstones and the silty shales is difficult to distinguish because it is gradational. Although the shaly siltstones and silty shales are often differently colored with a sharp color boundary between the lithologies, color is independent of bedding to some extent and does not always distinguish the contact (Plate 1, Figures 3 and 4).

The second shaly siltstone from the top contains a carbonate bed. The bed is composed of a medium-grained, argillaceous, light blue-gray rock that is primarily calcite with minor amounts of dolomite, kaolinite, mica-clay, quartz, and siderite. It varies in thickness from 1/8 in. to 2 ft., and the contact between the siltstone and carbonate is sharp but irregular. Three types of ichnofaunas are present on the surfaces of the bed and will be described later.

At the Hickman Road exposure, the siltstones contain several sandstone layers. They are pale green, micaceous, silty, and are similar to the Capitol grounds sandstones. They also contain microscopic, euhedral, calcite crystals.

In the southern section, units 19 and 20 are predominately sandstones, being occasionally interrupted by siltstones that grade into them and by carbonate beds. The sandstones are lithologically homogeneous throughout the section. They are a pale yellow, that weather to a dark yellow, moderately friable, fine-grained, tabular to wedge-set crossbedded, micaeous, argillaceous, lithic graywackes (Pettijohn, 1957) that range in thicknesses from 2 ft. to 7 ft. (Plate 1, Figure 5). The individual sand grains are rounded and of a +3 or less phi size (0.12 to 0.25 mm) and have pitted surfaces similar to the grains at 2nd Avenue. The crossbedding alternates in thickness from a few mm. to approximately 3 cm. with the foresets facing a southerly direction (Plate 1, Figure 6). Accurate foreset measurements were not obtained because exposures permitting such measurements were not present. The sandstones are predominately quartzose with minor amounts of mica, kaolinite, siderite (in the form of nodules up to 1 mm.), mica-clay, calcite, and gypsum.

Between the sandstones are buff to light gray, fissiled to blocky, argillaceous shales to sandy siltstones that grade upward into the sandstones. They range in thickness from 1 ft., 3 in. to 2 ft., 8 in. and are composed primarily of kaolinite, but minor amounts of mica-clay and quartz, which increases upward, are also present. The upper contact is gradational and regular while the lower contact is sharp and regular.

The carbonate beds associated with the sandstones consist of two types. The first is a light gray, resistant, medium-grained, laterally-persistent calcilutite (Folk, 1959). The second is a light gray, resistant, medium-grained, lenticular calcilutite. The thickness of the laterally persistent calcilutite varies from 10 in. to 2 ft., and three beds can be traced most of the length of the exposure. The lenticular beds range from 4 ft. to 30 ft. in length and 1 ft. to 6 ft. in thickness. The number of lenticular beds is not known, but they tend to be concentrated in the middle to upper portion of the units. Both types of beds contain minor amounts of kaolinite, mica-clay, quartz, and siderite. The upper-most, laterally-persistent calcilutite also contains oscillation and interference ripple marks (Plate 2, Figure 1). The oscillation ripple marks, which strike N 45° E, are dominant while other ripple marks, which strike N 45° W, interfere with the dominant ones. The contacts between the sandstones and both types of calcilutites are sharp and regular (Plate 2, Figures 2 and 3).

The upper portion of unit 19 is a light to medium gray, mottled red, purple, and dark yellow, blocky to conchoidal fractured, weakly slickensided underclay (Huddle and Patterson, 1961). It varies in thickness from 4 ft. to 5 ft., 6 in. The upper 1 ft. contains small black streaks (less than 1 cm. long), whereas the lower 4/5 of the unit is mottled red, purple, and dark yellow and contains small, red, circular stains (usually less than 2 cm. in diameter) that have dark purple centers. The upper 3 ft. to 4 ft. of the unit contain slightly more quartz than kaolinite while the lower 1 ft. to 2 ft. contain minor amounts of mica-clay. Limestone nodules occur in CP-47. The contact with the lower portion of unit 19 is gradational while the contact with unit 18 is sharp and regular.

Upper units

Unit 18 Unit 18 is exposed at each outcrop and consists of a dark gray, laminated to thinly-bedded, fossiliferous, slickensided, carbonaceous shale and/or coal. The thickness varies greatly within the outcrops and can range from 0 in. to 7 in. within a single outcrop. The coal and carbonaceous shale grade laterally into each other within a short distance (1 ft. to 2 ft.). Occasionally, the coal contains euhedral crystals of pyrite and pyritized, small plant parts. The contact between units 18 and 17 is sharp but irregular.

Unit 17 Unit 17 is exposed at each outcrop and consists of a dark gray, slickensided, laminated, fossiliferous, carbonaceous shale that varies in thickness from a trace to 9 in. It is composed primarily of kaolinite and quartz but contains minor amounts of mica-clay. Pyrite is present as nodular aggregates of small crystals and as pyritized, small plant fossils. The contact between the shale and unit 16 is sharp and irregular.

Unit 16 Unit 16 is exposed at all of the outcrops and consists of a medium blue-gray, mottled red to brown and dark yellow, finely parallel laminated, moderately fractured, highly fissile, slickensided, slightly silty shale that weathers to a light blue-gray. It varies in thickness from 10 ft., 7 in. to 5 ft., 5 in. Two sets of polygonal desiccation cracks are present in the shale. The largest is 6 inches to several feet wide and has olive-brown, metallic-lustered slickensides on the walls of the cracks. Bedding is occasionally vertically offset, 1 in. to 2 in., by small-scale normal faulting along the cracks. This set of cracks cuts across all other primary and secondary features in the shale and consequently is the most recent in age. The cracks of the second set rest directly on the bedding plane. They are 6 in. or less in width and extend less than 1/8 in. vertically into the bedding. The shale contains twice as much kaolinite as quartz, and a third of the rock is composed of mica-clay. Occasionally, imprints of brachiopods and driftwood are present on the bedding surface. Dark, linear stains are also present on the surface. The shape and regularity of internal design suggest that the stains are fossilized plants instead of being the result of inorganic processes.

Also present in the lower portion of unit 16 are carbonate lenses, and under one lens, at the Can-Tex quarry, a phosphate layer occurs. The number of lenses is unknown, but at least one lens can be found in each outcrop. The phosphate layer is a dark purple, medium-grained, 1 ft., 6 in.

thick layer that is composed primarily of apatite. The carbonate lenses are dark gray, silty, thinly-lenticular laminated, fossiliferous biomicrites that weather to a chocolate brown (Folk, 1959). Kaolinite, mica-clay, and quartz are present in large amounts. The size of the lenses ranges from 40 ft. to 100 ft. in width (in an east-west direction) and 6 in. to 1 ft. in thickness (Plate 2, Figure 4). The north-south dimension is unknown, but in the quarry walls, several lenses can be traced for over ¼ mi. in a north-south direction. The lower contact with the shale is gradational, while the upper contact is sharp and regular.

Unit 15 Unit 15 is a light gray, weathering to a chocolate brown, medium-grained, crystalline, fossiliferous dolomite that varies in thickness from 8 in. to 1 ft. The dolomite contains a minor amount of calcite and only a trace of clay minerals. Many of the dolomite crystals are euhedral in shape (Plate 2, Figure 5). The fossils contained in unit 15 are similar to those found in the biomicrite lenses of unit 16 except that they are poorly preserved. The lower contact with unit 16 is sharp and regular. The upper contact is sharp but irregular due to a knobby surface texture (Plate 2, Figure 6).

PALEONTOLOGY OF THE SECTION

Introduction

The majority of the section is devoid of fossils, but in a few subunits they occur in abundance. The lower section contains many land plant fossils while the upper section is dominated by marine fossils. Except for unit 15, most of the fossils are well-preserved. In unit 15 dolomitization has destroyed much of the detail normally preserved in the other units.

Fossils of the Plant Kingdom

Few types of plants are preserved in the strata, but at 2nd Avenue many large, fossil rhizomes and rhizoids of Lycopodium are present (Plate 3, Figure 1). They are best preserved in the sandstone lens but can also be found in the underclay. Compressed plant matter can be recognized in the coal beds above and below the sandstone lens. In units 17 and 18, small, fossil plants are present, and nodes on their stems suggest that they belong to the division Sphenophyta. Fossil Sphenophyta stems can occasionally be found in unit 16. Most of them are preserved in the biomicrite lenses.

Fossils of the Animal Kingdom

Many types of animal fossils are preserved in the strata, but brachiopods are the most numerous. Brachiopods dominate the fossil community in the carbonate lenses of unit 16 and in unit 15 while inchnofossils are present locally in units 19 and 20.

The carbonate bed in units 19 and 20 contains three types of inchnofaunas on its surfaces. They consist of concave epireliefs and repichnias and convex hyporeliefs that extend into the siltstone below (Plate 3, Figures 2 and 3).

In the shaly siltstone, below the carbonate bed, exists two types of burrow casts. The first type is long, tubular-shaped and tapered at the basal ends (Plate 3, Figures 4 and 5). It is more resistant to weathering than the surrounding siltstones and project from the sides of the quarry walls at a 0 to 45 degrees angle, with the basal ends pointing in a northerly direction. The casts range in length from 2 in. to 8 in. and from ½ in. to 1 in. in diameter. The second type of burrow casts are similar to the first type, except that it has the same resistance to weathering as the surrounding sediments. The casts tend to cut across bedding and streaks of red coloration extend into the bedding along the walls of the tubes (Plate 1, Figure 3).

Fossils from 11 subclasses and at least 20 genera are commonly found in unit 16. They are primarily preserved in the biomicrite lenses and calcareous shales but can occasionally be found in the surrounding shales.

The lower invertebrate animals are represented by the phyla Protozoa, Bryozoa, and Coelenterata. Protozoa is represented by Fusulina, which is most common in the calcareous shale. Bryozoa is represented by encrusting, lacy, and branching types. The branching types are more common in the calcareous shale while the lacy and encrusting types are more common in the biomicrite. Coelenterata is represented by the rugose coral, Lophophyllidium. This genus is present in the calcareous shale but in reduced numbers as compared to the biomicrite. The corals are usually small and broken in the shale but large and complete in the biomicrite.

The higher invertebrates are represented by the phyla Brachipoda, Mollusca, and Echinodermata. Of the 12 species of articulate brachiopods present, nine have been identified. Desmoinesia muricatina is the most abundant brachiopod in the calcareous shale, and at the Capitol grounds outcrop the shale is replaced by a coquina of D. muricatina pedicle valves. In the biomicrite D. muricatina is almost completely replaced by Antiquatonia portlockiana. Neospirifer cameratus is the second most abundant brachiopod in the biomicrite and calcareous shale. Composita subtilita is the third most abundant brachiopod while less abundant brachiopods include Derbyia crassa, Welleralla tetrahedra, Punctospirifer kentuckensis, and Hustedia mormoni. Only three specimens of Mollusca (two Cephalopoda and one Gastropoda) have been found by the author; all have been abraded and crushed and therefore are unidentifiable. Echinodermata is represented by crinoids and echinoids. Crinoids are present as disarticulated stems, plates, and spines, while the echinoids are present as spines and occasionally plates.

Chordates are represented by the classes Chondrichthyes and Osteichthyes. Chondrichthyes are represented by numerous dermal denticles of the elasmobranch Petrodus and teeth with enamel-like outer coatings, while the holocephalans are represented by pieces of spine material from Listracanthus. Other vertebrate material is present but is largely identifiable only to classes. They include various bony plates and scales that, because of their size, undoubtedly belong to the class Osteichthyes. The remaining vertebrate material is spherical to tubular coprolites. Many of the coprolites contain other vertebrate material (i.e., teeth, scales, and bony material) and are composed primarily of apatite and other phosphate minerals and calcite (Plate 3, Figure 6).

CLAY AND QUARTZ TRENDS IN THE SECTION

Quantitative analysis of mudstone samples, based on a method developed by Cody and Thompson (1976), reveals four general trends in mineral assemblages. Two interunit trends consist of the following:

1. An increase in quartz, a decrease in mica-clay, and a stability in kaolinite from units 20 to 19 (Figure 2).
2. An increase in kaolinite and mica-clay and a decrease in quartz from units 19 to 16 (Figure 2).

Two intraunit trends consist of:

1. A decrease in kaolinite and an increase or stability in mica-clay and quartz to the north in units 16 and 17 (Figures 3, 4, and 5).
2. An increase in kaolinite and a decrease in mica-clay and quartz to the north in units 19 and 20 (Figures 3, 4, and 5).

The exception to these generalizations occurs in the upper portion of unit 19. Quartz increases and kaolinite decreases to the north until they reach a quartz maximum and a kaolinite minimum at the Can-Tex quarries. North of the quarries quartz decreases and kaolinite increases (Figures 3 and 5).

The sandstone portion of units 19 and 20 and the carbonates were not included in the analysis of mineral trends for various reasons. Scanning electron microscopy showed that the sandstones and their carbonate lenses contained euhedral (and therefore presumably authegenic) crystals of clay between the quartz grains which might have obscured primary depositional trends in the mineral assemblages. Units 15 and 18 did not contain enough clay minerals for analysis, and mineral trends in the carbonate lenses of unit 16 were similar to those of the surrounding shales.

Figure 2. Ternary diagram of the average percentage of kaolinite (K), mica-clay (M) and quartz (Q) in the lithologic units

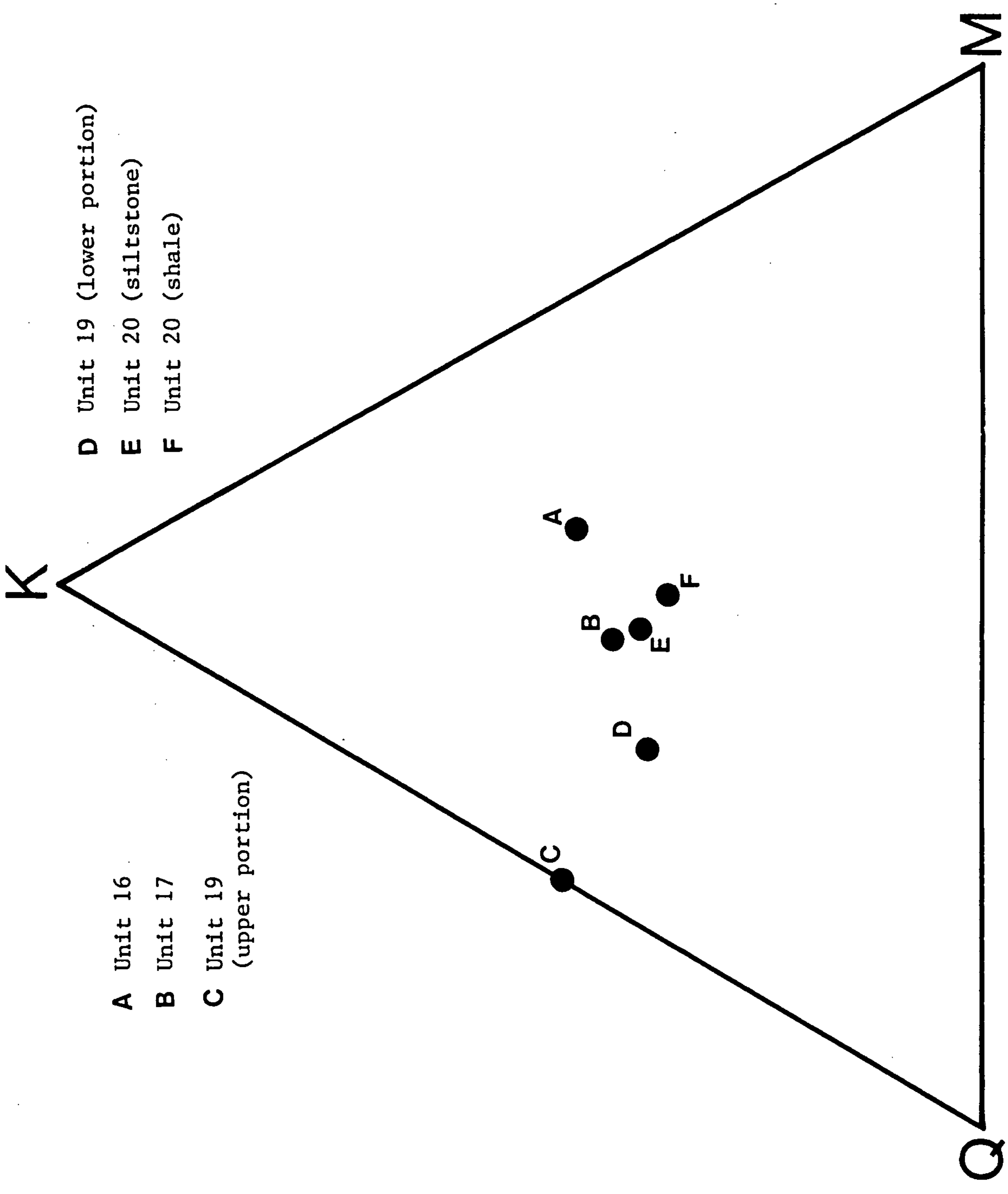

K
M
Q
A
B
C
D
E
F
A Unit 16
B Unit 17
C Unit 19
(upper portion)
D Unit 19 (lower portion)
E Unit 20 (siltstone)
F Unit 20 (shale)

Figure 3. Distance versus percent kaolinite

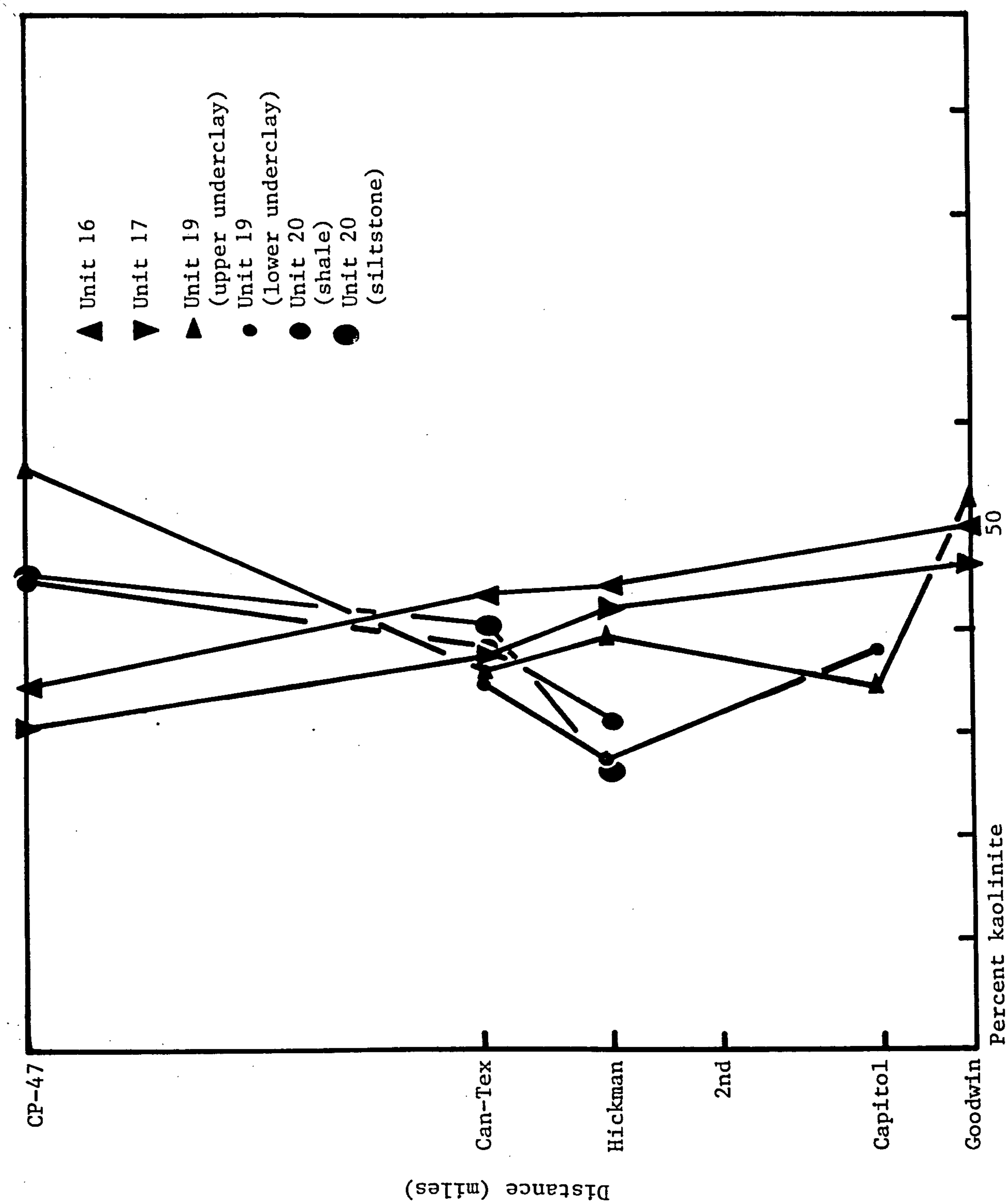

Unit 16
Unit 17
Unit 19
(upper underclay)
Unit 19
(lower underclay)
Unit 20
(shale)
Unit 20
(siltstone)
50
Percent kaolinite
CP-47
Can-Tex
Hickman
2nd
Capitol
Goodwin
Distance (miles)

Figure 4. Distance versus percent mica-clay

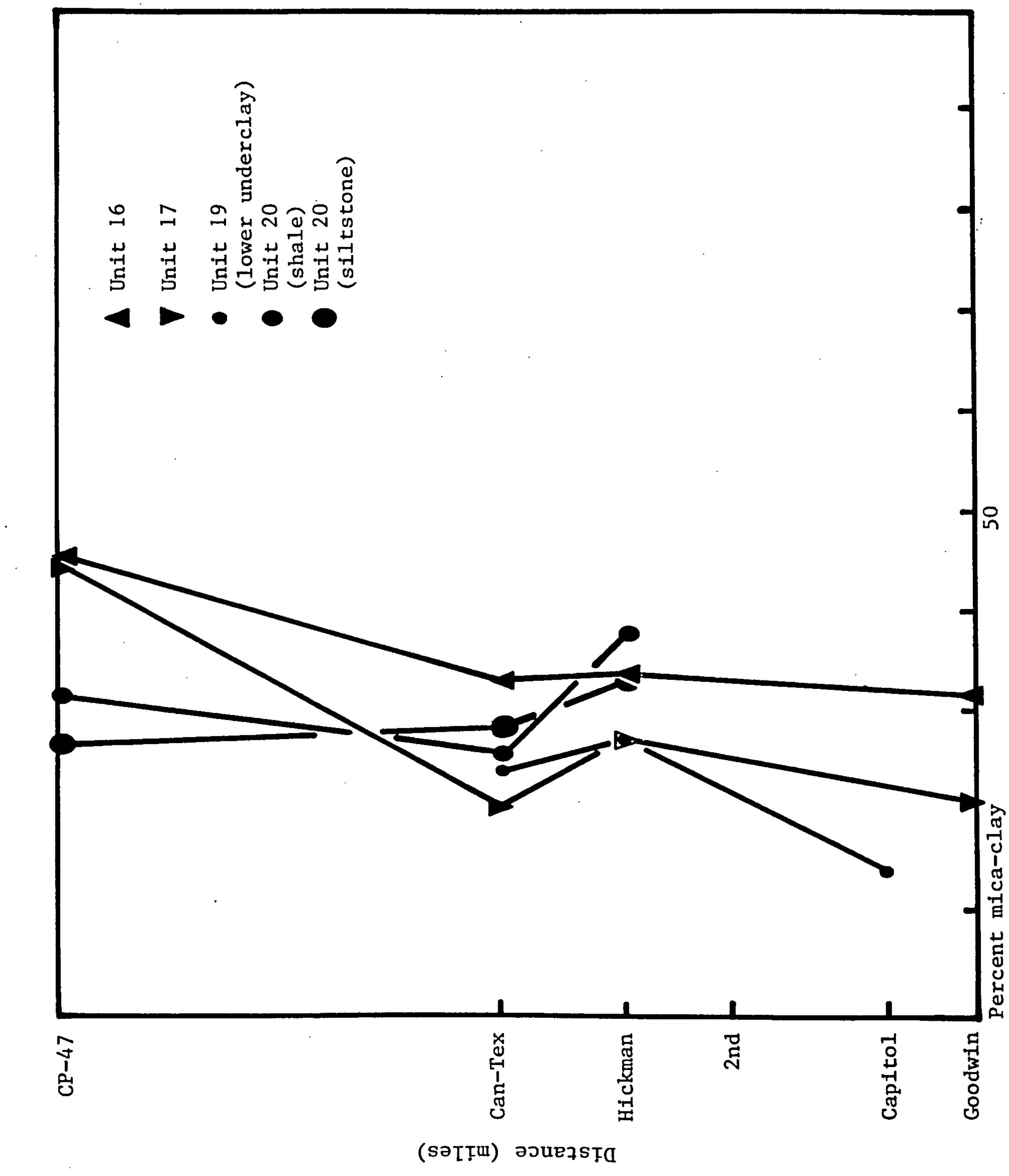
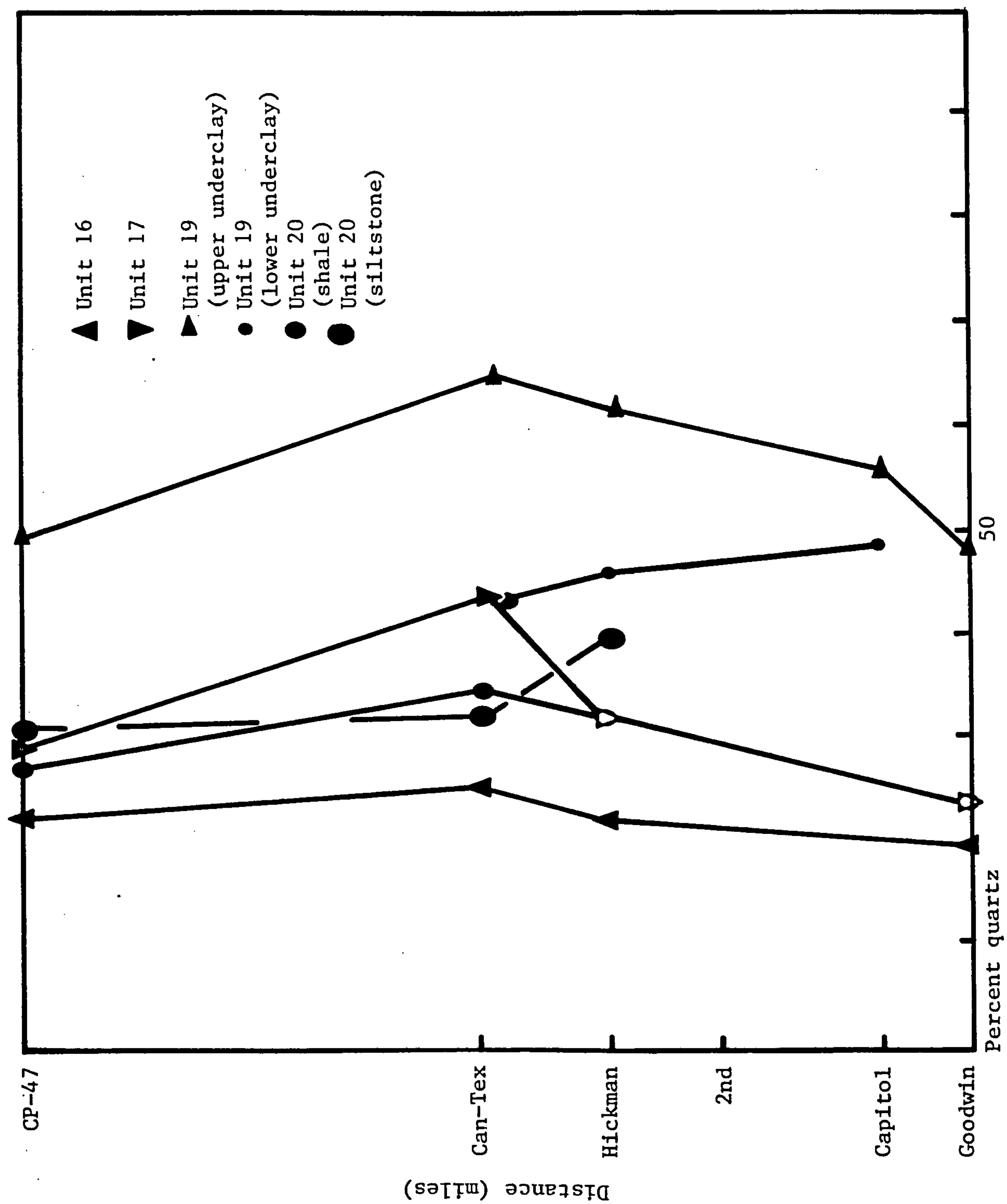

Unit 16
Unit 17
Unit 19
(lower underclay)
Unit 20
(shale)
Unit 20
(siltstone)
50
Percent mica-clay
CP-47
Can-Tex
Hickman
2nd
Capitol
Goodwin
Distance (miles)

Figure 5. Distance versus percent quartz



Unit 16
Unit 17
Unit 19
(upper underclay)
Unit 19
(lower underclay)
Unit 20
(shale)
Unit 20
(siltstone)
50
Percent quartz
CP-47
Can-Tex
Hickman
2nd
Capitol
Goodwin
Distance (miles)

Random mixed-layered clays and chlorite were detected in many mudstone samples but did not occur in any noticeable pattern. The chlorite may have been related to the weathering of montmorillonite in the mixed-layer clays after burial and not have been detrital.

DEPOSITIONAL ENVIRONMENTS

Introduction

The inferred depositional history indicates that the type section was a site for deltaic-interdeltaic deposits. The lower units were deposited on a fluvial plain, which later submerged to form a tidal flat landward of a barred coastline. The sea then regressed and a marsh formed, depositing thin uneven layers of coal and clay. A transgression of the ocean occurred next, forming a lagoon. As the sea regressed and clastic sediments became reduced, carbonate sediments were deposited on a supratidal flat. This became a site for dolomitization and was later buried by silts and clays that were deposited in mixed marine environments.

Units 21 to 23

Features found in these units indicate that the sediments were deposited in a fluvial environment. The cyclic deposits, above the lower coal and below the base of the sandstone wedge, at the 2nd Avenue outcrop are interpreted to have been deposited during floods in a fluvial environment, the sandy siltstone layers being deposited when a stream overspread its bank and the argillaceous siltstone layers being deposited as the flood water became stilled. Fisk (1958), Frazier and Osanik (1964), and Frazier (1967) have reported wedge-shaped flood sediments in peat deposits along stream channels in the Mississippi River Delta that compare well to the sandstone wedges exposed at 2nd Avenue and described by Bain (1896) (Figure 1). At the southern edge of the 2nd Avenue outcrop, the cut into the cyclic sediments (Plate 1, Figure 1), from the sandstone above, suggests cut-and-fill deposition, which is typical of fluvial environments. The abundance of large, fossil, lycopod rhizomes in the sandstone and underclay indicate that many large plants existed. This is comparable to the forest-type community that Frazier and Osanik (1964) found in fresh water swamp-land basins separated by natural levees. They also noted that peat is replaced towards the ocean by clayey peat, peaty clay, and/or an organic muck. This is similar to the lateral changes that occur between the 2nd Avenue outcrop and CP-47.

The depth to which fossil roots penetrate into the beds, lack of bedding, and mineral composition of the underclay below the coal indicate that soil development occurred (Hodson, 1923; MacMillan, 1956; Huddle and Patterson, 1961; Williams et al., 1968; Hosterman, 1972). The presence of fossil roots throughout the units contradict Weller's (1930) and O'Brien's (1963) conclusion that the majority of roots do not penetrate deeply enough to influence the formation of underclays. The lack of bedding throughout the units also suggests that roots were able to penetrate deeply into sediments. Williams et al. (1968) have concluded that swamp waters were unable to alter clay minerals in Pennsylvanian shales but were sufficient to remove soluble bases and organics from sediments. McGowen (1968), however, has shown that kaolinite is concentrated, due to leaching, in overbank fluvial facies near pointbar meanderbelt sand bodies which act as conduits for leaching fluids. The absence of mica-clay in the upper portion of the underclay and sandstone units studied here seems to support McGowen's conclusion that leaching by acid swamp water through sandstone conduits was sufficiently reactive to alter clay minerals.

Mineral trends

Analysis of mineral trends shows that kaolinite is constant in abundance, but mica-clay decreases and quartz increases from CP-47 to 2nd Avenue. Based on the conclusion of Weaver (1967), Keller (1970), and other others, that kaolinite increases and mica-clay decreases landward, mineralogical trends of these units suggest a landward mass south and east of CP-47.

Units 19 and 20

Introduction

Horizontal sedimentation patterns in these units are similar to those observed in the Mississippi Delta Front (Fisk and others, 1954; Fisk, 1961; Frazier, 1967). However, the presence of fine clastics, dominance of parallel laminations and small-scale crossbedding, and absence of high energy features, indicate that deposition of the siltstones occurred in a low energy environment.

Siltstone facies

Primary and secondary depositional features in this facies suggest that the sediments were deposited in a tidal/supratidal flat environment. Several environments, such as alluvial flood plains, tidal flats, and lagoons, favor the formation of low energy features, but carbonate subunits, inchnofossils, and alternating coloration of the siltstones suggest a marine deposition. The alternating thick and thin parallel laminations of the siltstones, that are occasionally crossbedded, are indicative of tidal flats but not lagoons.

Several primary features indicate a low energy environment. Harms and Fahnestock (1965) and McBride, Shepherd, and Crawley (1975) have shown that parallel laminations in siltstones result from suspension in almost quiet waters or from migration of bed forms in small flumes. The occurrence of carbonate subunits, the inchnofossils within them, and the gradation of mudstones into sandstones suggest the environment was intermittently interrupted by minor increases and decreases in energy levels. The presence of thin and thick mud layers that contain sandy cross-laminations in the siltstones compares well to those features reported to be common in modern tidal flat sediments (van Straaten, 1954; Reineck and Wunderlick as cited in Blatt et al., 1972; Blatt et al., 1972).

Alternation of red and blue pigmentation in the siltstones indicates deposition in an aqueous/subaqueous environment. Van Houten (1973) has suggested red pigmentation may be due to a concentration in iron oxide during deposition, but because the color in the siltstones of the present study is independent of bedding, another mechanism is needed to explain the color boundary. Braunagel and Thompson (1970) and McBride (1974) suggest that post-depositional, partial bleaching may be a mechanism for alternating coloration. They suggest that dissolved iron will migrate when the siltstones are saturated with water but before they are buried below the ground water table. The iron will then move upward from the lower portion of the sediments by diffusion or capillary action, as a result of repeated wetting and drying of sediments. In this zone iron will become oxidized, while below it iron will remain reduced. This type of mechanism will produce an irregular and cross-cutting color (oxidation-reduction) boundary (Plate 1, Figure 3).

Sandstone facies

Grain size in this facies suggests that the sandstones were deposited in a higher energy environment than the siltstones, but the presence of clay and silt-size particles, small-scale crossbedding, and the interbedding of mudstones that grade into sandstones, suggest that the energy level was not much higher than the siltstones. Small-scale ripple marks in the upper carbonate subunit also indicate an energy regime that corresponds to the lower flow regime (Allen, 1963). Tanner (1971) has shown that ripple marks, similar to those in the carbonate subunit, are formed only within very shallow and restricted bodies of water with limited fetch.

The presence of carbonate subunits and the absence of plant fossils in the sandstones suggest a marine deposition. The lenticular shape and sharp contact between the carbonate and sandstone subunits further suggest that these carbonates were deposited in rip-current channels extending from the open ocean into the sand body. This compares well with modern examples of barred coastlines (Krumbein, 1939; Evans, 1970; Davidson-Arnott and Greenwood, 1974).

Until the extent of the sandstone body and its lateral stratigraphic relationships to the surrounding sediments are known, only a general interpretation is possible, but Davidson-Arnott and Greenwood (1974) have shown that crossbedding, similar to those found in the sandstones, is produced in swash slopes behind sand bars along barred coastlines. The crossbedding in the slopes will be oriented seaward. Crossbedding and ripple mark directions and a similar occurrence of sandstone bodies in the Marmaton group of central Iowa (Brown and others, 1977) suggest that longshore current direction was to the north, and oceanward direction was south and west of the Capitol grounds outcrop.

Upper portion of unit 19

Strong soil development, that altered the upper portion of unit 19, is suggested by a gradational contact with the strata below, gradual enrichment of kaolinite and quartz upward, concentration of iron oxides, absence of bedding, blocky texture, and superposition of a thin coal above unit 19 (Hodson, 1923; MacMillan, 1956; Huddle and Patterson, 1961; Williams and others, 1968; Hosterman, 1972). In marsh environments, many roots of plants do not penetrate into the sediments below. This explains why there is an absence of fossil plant roots in the upper portion of unit 19, even though an abundance of plants in unit 18 is indicated by the presence of plant fossils.

Mineral trends

Mineralogical trends of these units suggest a landward mass north of the section. Kaolinite increases and mica-clay decreases to the north. Quartz increases to the south, which is to be expected with the existence of a sand body to the south of the tidal flat area. An explanation is lacking for the quartz maximum and kaolinite minimum at the Can-Tex quarries in the upper portion of unit 19, but any explanation of this trend must take into account the effects of weathering (i.e., the absence of mica-clay) upon the sediments and not deposition trends.

Units 17 and 18

The presence of small plant parts, the absence of large fossil roots in the upper portion of unit 19, and their position above the tidal flat sediments of units 19 and 20 indicate that units 17 and 18 were deposited in a marsh environment, similar to those of the recent Chenier Plain of the Gulf Coast (Frazier and Osanik, 1964). A marsh environment is also suggested by the abundance of plant debris. Evans (1965) has concluded that salt marshes contain a high proportion of plant debris. This is in contrast to other delta subenvironments, which are deficient in these materials.

Mineral trends

Mineralogical trends in unit 17 indicate that sediments are depositionally related to unit 16. Analogous to unit 16, kaolinite decreases, quartz is constant and mica clay increases in abundance to the north. The significance of this trend will be discussed in the next unit.

Unit 16

Shale facies

The absence of high energy features and the dominance of low energy, marine features suggest that the sediments were deposited in a lagoon and/or tidal flat. Although sediments in several other environments are characterized by parallel laminations, the existence of marine fossils in the carbonate lenses exclude all but those environments dominated by tides. Lagoonal and tidal flat deposits are difficult to separate because they resemble each other, and lagoons may eventually fill to become tidal flats (Dunbar and Rodgers, 1957, p. 73). Because the smallest set of desiccation cracks extends only a short distance into the bedding, this would suggest that they were formed shortly after deposition, possibly by the drying of sediments during periodic emergence.

The cross-cutting relationship of the largest set of desiccation cracks, to other features, indicates they were formed later than the other features. This suggests that they were formed during compaction and lithification of shales and not shortly after deposition.

Carbonate and phosphate facies

The origin of the carbonate lenses in unit 16 appears to be analogous to that of modern carbonate bodies in terrigenous muds. In modern analogues epibiont growth on marine grass beds produce in situ accumulations of carbonate sediments. The grasses also serve as sediment traps and bindings to produce sharp, distinct carbonate areas in terrigenous muds (Petta and Gerhard, 1977). Although angiosperms were not present during the Pennsylvanian period, other plants that served similar functions were probably present. The length of the north-south direction suggests that the form of the carbonate lenses may also have been influenced by other factors such as currents and topography.

An interpretation of the origin of the phosphate layer under the carbonate lens at the Can-Tex quarry is difficult because recrystallization has destroyed most of the primary features. The large amount of vertebrate material present in the carbonate lens suggests that sufficient quantities of dissolved organic phosphate could have been present to accumulate by precipitation (McKelvey et al., 1953; Gulbrandsen, 1966). The medium-grained texture of the layer and the lack of primary structures indicate that recrystallization has occurred and that replacement of calcium carbonate by calcium phosphate may have taken place (Ames, 1959).

Mineral trends

A reversal in mineral trends, as compared to those found in units 19 and 20, suggests that a major source for sediments into the lagoon existed to the south. Kaolinite increases and mica-clay decreases to the south while quartz is constant in unit 16 but increases to the south in unit 17.

Unit 15

Dolomitization of unit 15 has destroyed most of the primary features, making an interpretation of the original depositional environment difficult. The original carbonate was probably deposited on a supratidal flat, where most evaporitic dolomites are being formed today (Illing and others, 1965), and dolomitization later occurred by evaporative reflux (Adams and Rhodes, 1960). The absence of halite and gypsum deposits are evidence of a humid, tropical climate (Milliman, 1974). The knobby top surfaces on the carbonate unit indicate that shrinking and cracking into polygonal forms and subsequent erosion of them occurred, as described by Shinn (1972), or that the surface resulted from algal mat growth, with algal laminations being subsequently destroyed by dolomitization.

SUMMARY AND CONCLUSIONS

Although the third dimension of the strata is unknown, primary and secondary structures along with clay trends and fossils have aided in the interpretation of sediment transport directions and the depositional history of the section. The basal units were deposited in a fluvial environment, which was favorable for the accumulation of peat. Chemical and physical actions, caused by forest vegetation, modified these sediments. This environment was then encroached upon by a minor north and eastward transgression of the sea. This transgression led to the development of a tidal/supratidal flat area which was protected from the open ocean by sandbars formed during northwestward transportation of sediment by longshore currents. Later, when the sea regressed, a salt marsh covered the area leaving thin, uneven deposits of peat and modifying the upper portion of the tidal flat sediments. A transgression of the ocean to the north led to the development of a lagoon and/or tidal flat. As the lagoon filled and the influx of terrigenous sediments was reduced, carbonate sediments accumulated and covered the entire area which had become a supratidal flat and a site for later dolomitization. This was finally buried by classic sediments deposited in mixed and marine environments.

Other studies, in which regional depositional systems of Pennsylvanian sediments have been interpreted, give an indication of regional environmental patterns and sediment transport directions in central Iowa during Des Moinesian times. Brown et al. (1977) have given an interpretation to sediments of the Marmaton group in south-central Iowa and northeastern Missouri which is analogous to the one given for the strata in this study. Wanless

(1964) and Wanless et al. (1963) have interpreted the regional environment of southern Iowa, Illinois, and northern Missouri during Des Moinesian times. Their studies and this study indicate that the shore line in central Iowa was northwest/southeast and that the longshore current was to the north. Central Iowa during Des Moinesian times was a deltaic-interdeltaic area with the type region being an interdeltaic area that derived most of its sediments, transported by longshore currents, from a delta complex to the south.

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EXPLANATION OF PLATES

Plate 1

Figure 1. Cut-and-fill structure (A) in the cyclic sediments of sandy and shaly siltstones below and around the sandstone subunit

Figure 2. Sand grain from the sandstone subunit in Figure 1. Scale represents 30 micron

Figure 3. Close-up of color boundary in the siltstones of units 19 and 20. The dark areas tend to be silty shales while the light areas tend to be shaly siltstones. View of rock A is normal to bedding while rocks B and C are parallel to bedding. Note tubular structure to the right of the nickel in rock A

Figure 4. Color boundary of the siltstones in units 19 and 20 exposed at Can-Tex quarries. The dark area is a silty shale while the light area is a shaly siltstone

Figure 5. Clay size particles in unit 20 at the Capitol grounds outcrop. Scale represents 30 micron

Figure 6. Tabular crossbedding in sandstone exposed at the Capitol grounds. Approximately 3 cm. exist between sets

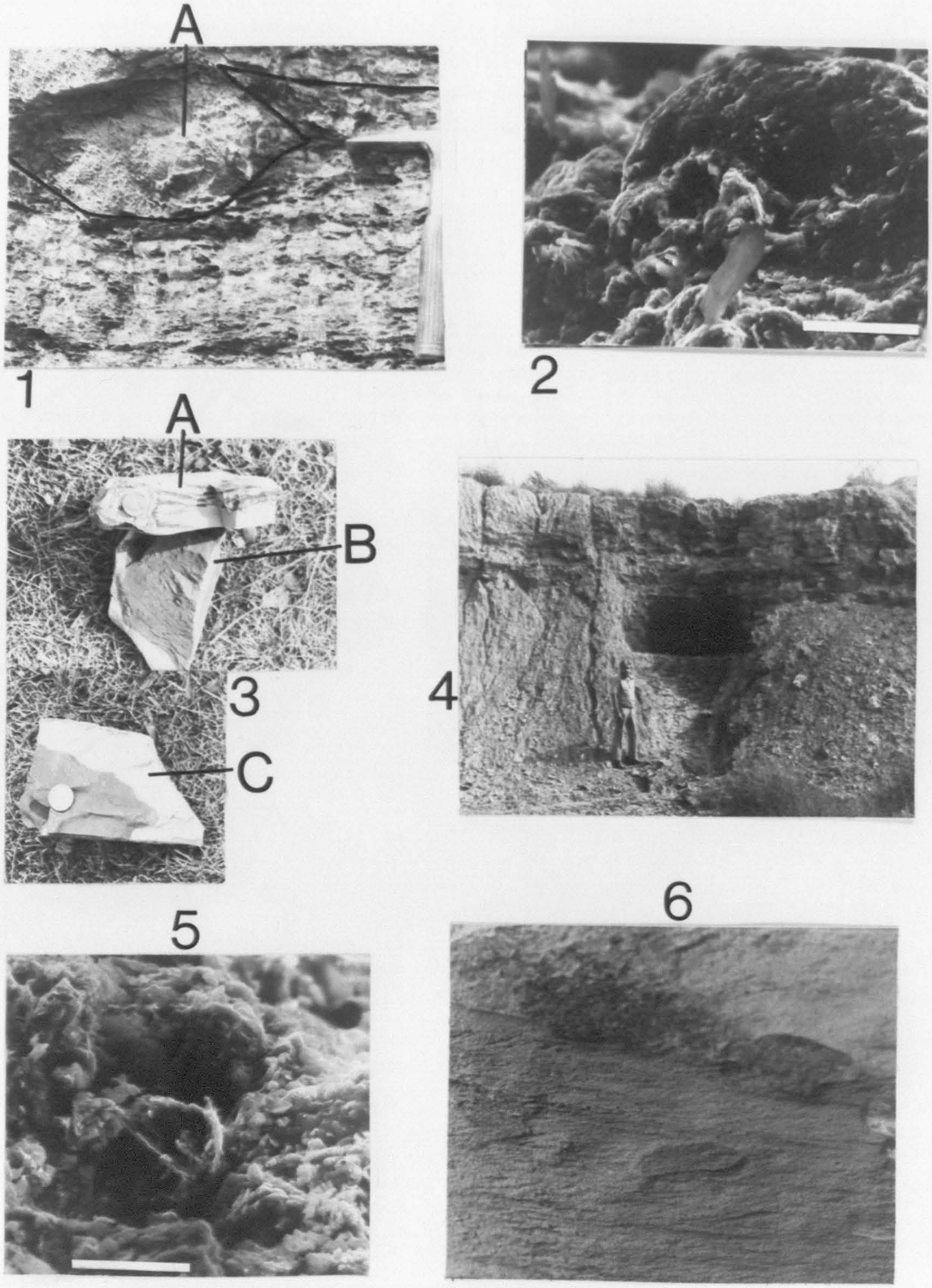

A
1
2
A
B
3
C
4
5
6

Plate 2

Figure 1. Oscillation and interference ripple marks in the upper laterally-persistent carbonate bed exposed at the Capitol grounds outcrop. Ruler is 15 cm. long

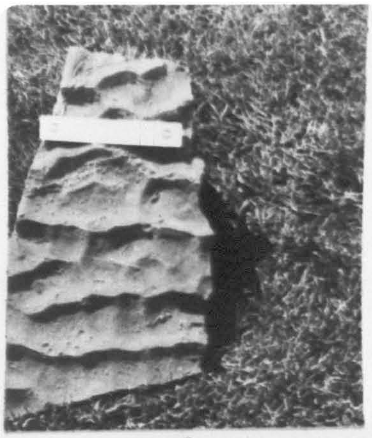
Figure 2. Laterally-persistent carbonate beds in sandstone facies at the Capitol grounds outcrop

Figure 3. A lenticular carbonate bed at the Capitol grounds exposure. Length and height are 30 ft. and 6 ft., respective

Figure 4. Carbonate lens (center lines) in unit 16 (between outer lines). Outcrop is at the western Can-Tex quarry

Figure 5. Dolomite crystals in unit 15. Scale represents 30 micron

Figure 6. Top surface of unit 15. Ruler is 15 cm. long



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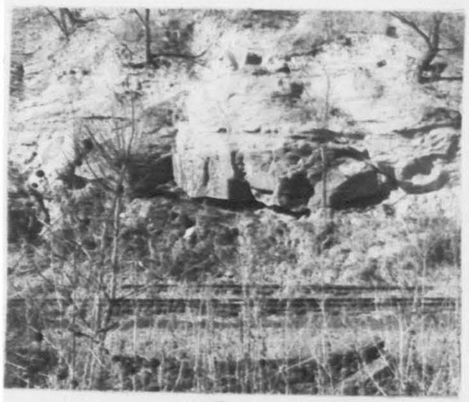

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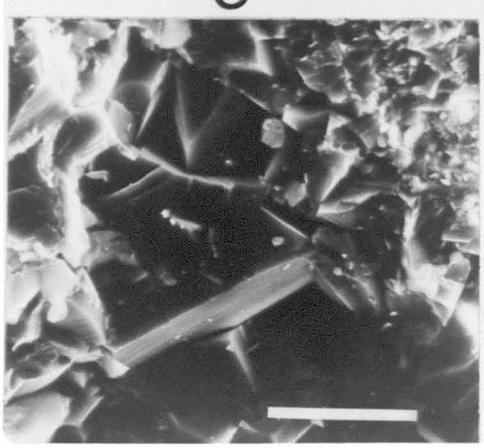
4

5



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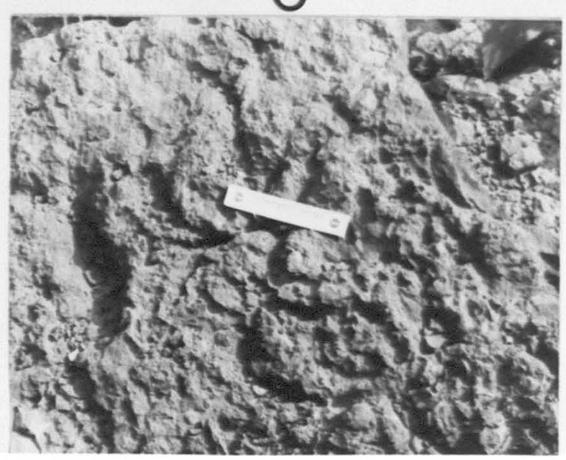


Plate 3

Figure 1. Rhizome and rhizoids of *Lycopodium* in sandstone at the 2nd Avenue outcrop

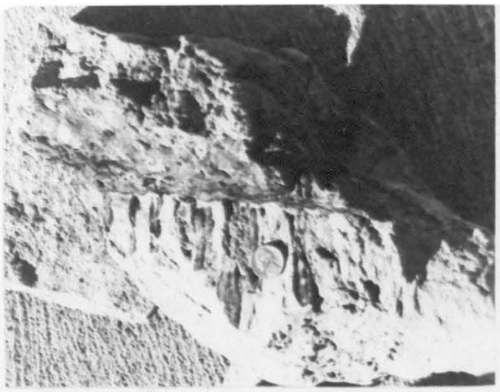
Figure 2. Convex hyporeliefs on the under surface of the carbonate bed in units 19 and 20

Figure 3. Concave epireliefs and repichnias on the upper surface of carbonate bed in units 19 and 20

Figure 4. Burrow casts in units 19 and 20 at the eastern Can-Tex quarry

Figure 5. Close-up of lower set of casts in Figure 2

Figure 6. Coprolite (light areas in upper left corner) and surrounding matrix in biomicrite lens in unit 16. Scale represents 30 micron



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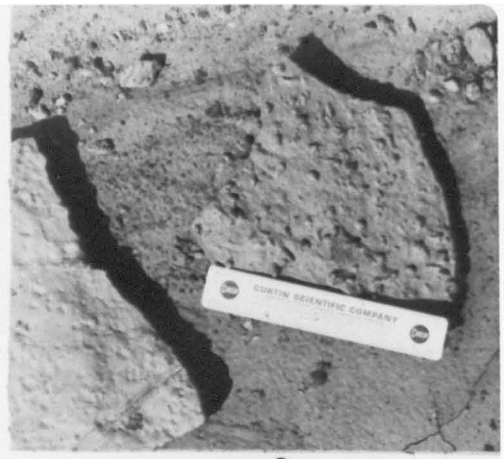
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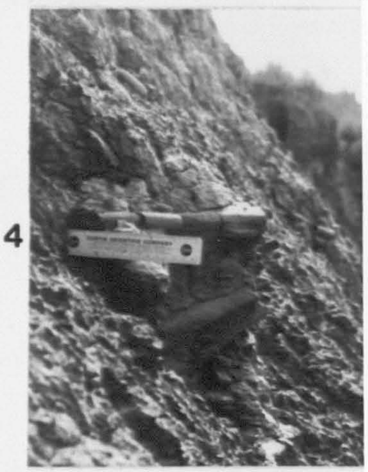

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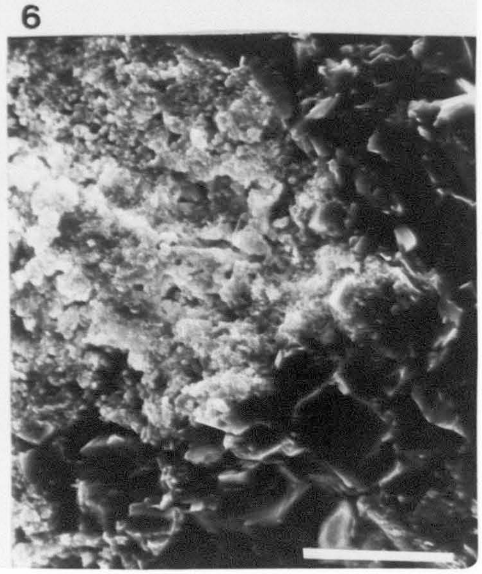

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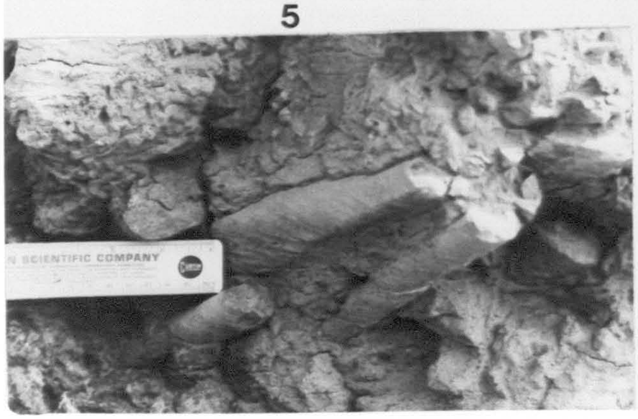
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APPENDIX A. MINERAL PERCENTAGES

Symbols Used in Appendix A

D-dolomite main constituent
P-pyrite present
G-gypsum present
Ca-calcite present
Ch-chlorite present
S-small amount of mixed-layer clay present
M-medium amount of mixed-layer clay present
*-insufficient clay for analysis

Unit 18 was not included in analysis because of its carbonaceous nature.

Exposure: CP-47

Location: SE, NE, NE, of Section 4, Township 79 N., Range 25 W.

Depth of sample from the surface (in feet)	Unit	Mineralogy of samples (in percentage) Mica-clay	Kaolinite	Quartz	Other minerals
115.5	15	*	*	*	D
121.0	16	35.5	41.1	23.4	S
127.0	16	54.2	28.0	17.8	S
128.0	17	44.0	30.0	26.0	S P
128.3	19	0.0	44.6	55.4	S P
132.0	19	0.0	61.4	38.6	S
136.4	19	32.3	46.2	21.5	M
138.0	19	30.0	42.0	28.0	S
141.0	20	23.0	46.0	31.0	S
145.5	20	22.0	51.0	27.0	S
149.5	20	34.1	37.5	28.4	S
152.7	21	17.0	34.0	49.0	S
153.8	22	19.6	44.0	36.4	M
155.8	22	23.5	32.5	44.0	M
157.0	22	32.0	46.0	22.0	S
157.8	22	30.5	52.5	17.0	S
159.0	23	32.0	46.0	22.0	S

Exposure: Can-Tex Quarry on the east side of the Des Moines River

Location: SW, SW, NW, of Section 22, Township 79 N., Range 24 W.

Depth of sample from the top of unit 15 (in feet)	Unit	Mineralogy of samples (in percentage)			Other minerals
		Mica-clay	Kaolinite	Quartz	
0.5	15	*	*	*	D
0.7	16	26.8	52.4	20.7	Ca S Ch
4.7	16	33.8	50.0	16.2	S
5.8	16	32.6	47.8	19.6	S
6.6	16	32.9	30.3	36.8	S
6.7	16	30.0	43.0	27.0	S
6.7	16	24.1	48.3	27.6	S
6.8	16	30.8	35.4	33.8	S
6.9	16	38.8	48.3	22.4	S
7.0	17	20.0	37.8	42.2	S
7.1	19	0.0	28.1	71.9	S
9.0	19	0.0	44.9	55.1	S
12.0	19	20.7	36.4	42.8	S
12.7	19	25.7	33.9	40.4	Ch S
12.8	19	26.2	34.3	39.4	S
14.2	20	21.1	27.8	51.1	S
14.3	20	26.6	36.7	36.7	S
17.0	20	25.5	46.8	27.7	Ch S
17.1	20	26.8	57.3	15.8	Ch S
21.1	20	24.4	32.2	43.3	S
21.2	20	23.4	29.8	46.8	S
23.2	20	23.3	50.0	26.7	S
25.3	20	36.9	47.7	15.4	Ch S
25.4	20	29.8	44.8	25.4	Ch S
32.9	20	26.2	31.8	42.0	S

Exposure: Hickman Road

Location: SW, SW, SW, of Section 27, Township 79 N., Range 24 W.

Depth of sample from the top of unit 15 (in feet)	Unit	Mineralogy of samples (in percentage)			Other minerals
		Mica-clay	Kaolinite	Quartz	
0.6	15	*	*	*	D
0.7	16	32.0	49.5	18.5	S
3.0	16	33.5	44.0	22.5	S
5.2	16	27.0	39.0	34.0	S
5.4	16	34.0	40.0	26.0	S
6.3	17	26.7	42.5	22.8	M
6.4	19	0.0	39.5	60.5	M
12.0	19	27.3	27.3	45.4	S
16.7	20	28.0	36.0	36.0	S
17.7	20	25.0	33.0	42.0	M
17.8	20	28.2	34.9	36.9	M
20.7	20	34.5	41.7	23.8	M
23.1	20	38.5	41.5	20.0	M
23.2	20	25.0	37.5	37.5	S

Exposure: 2nd Avenue

Location: NW, NE, SE, of Section 34, Township 79 N., Range 24 W.

Depth of sample from the top of exposure (in feet)	Unit	Mineralogy of samples (in percentage)			Other minerals
		Mica-clay	Kaolinite	Quartz	
4.7	21	13.7	35.9	50.4	S P
4.8	t	17.1	33.3	48.8	S P
6.7	o	0.0	41.0	59.0	S G
7.0	23	20.8	54.6	24.6	S G

Exposure: Capitol Grounds

Location: SE, SE, of Section 3, Township 78 N., Range 24 W.

Depth of sample from the top of unit 18 (in feet)	Unit	Mineralogy of samples (in percentage) Mica-clay	Kaolinite	Quartz	Other minerals
0.2	19	0.0	40.0	60.0	S
2.0	19	0.0	45.3	54.7	S
2.2	19	0.0	38.9	61.1	S
3.2	19	0.0	51.6	48.4	M
4.4	19	9.6	41.9	48.6	M
4.9	19	9.1	34.3	56.6	M
5.0	19	20.8	37.5	41.6	S
5.4	19	16.0	31.9	52.1	M
6.3	20	13.9	44.3	41.7	S
7.9	20	9.9	34.6	55.5	Ca S
8.7	20	17.7	43.0	39.2	S
9.1	20	35.3	41.2	35.3	S
13.2	20	19.0	40.0	41.0	Ch S
14.7	20	24.3	35.3	40.5	Ch S
15.7	20	20.2	26.9	53.0	Ch S
27.0	20	19.2	39.8	41.0	Ch S Ca
28.0	20	24.2	43.2	43.2	Ch S

Exposure: Goodwin Brick and Tile

Location: NW, NE, of Section 14, Township 78 N., Range 24 W.

Depth of sample from the top of unit 15 (in feet)	Unit	Mineralogy of sample (in percentage) Mica-clay	Kaolinite	Quartz	Other minerals
0.5	15	*	*	*	D
0.8	16	30.9	44.7	24.4	S
3.5	16	33.3	48.1	18.5	S
5.5	16	22.4	55.0	22.4	S
7.4	16	34.4	52.2	13.4	S
7.5	17	25.5	51.1	23.4	S P
8.2	17	15.7	41.4	42.8	S P
8.3	19	0.0	50.9	49.1	M
11.1	19	0.0	53.1	46.9	S

APPENDIX B. AVERAGE MINERAL PERCENTAGE OF LITHOLOGIC UNITS

Average Mineralogy of the Units

Number of samples Location		Mineral percentage Mica-clay	Kaolinite	Quartz
Unit 16				
2: CP-47		44.8	34.6	20.6
5: Can-Tex		32.1	43.9	24.0
3: Hickman Road		33.2	44.5	22.3
4: Goodwin		30.3	50.0	19.7
Total 14	Average:	33.6	44.4	21.9
Unit 17				
1: CP-47		44.0	30.0	26.0
1: Can-Tex		20.0	37.8	42.2
1: Hickman Road		26.7	42.5	30.8
2: Goodwin		20.6	46.2	33.1
Total 5	Average:	26.4	40.5	33.0
Unit 19 (upper portion of underclay)				
2: CP-47		00.0	53.0	47.0
2: Can-Tex		00.0	36.5	63.5
1: Hickman Road		00.0	39.5	60.5
4: Capitol		00.0	43.9	56.1
2: Goodwin		00.0	52.0	48.0
Total 11	Average:	00.0	45.3	54.7
Unit 19 (lower portion of underclay)				
2: Can-Tex		23.2	35.1	41.7
1: Hickman Road		27.3	27.3	45.4
5: Capitol		13.9	38.0	48.1
Total 8	Average:	17.9	35.9	46.2
Units 19 and 20 (silty shales)				
2: CP-47		31.1	44.1	24.8
5: Can-Tex		25.0	38.2	33.5
4: Hickman Road		37.8	31.6	30.6
Total 11	Average:	31.7	36.9	30.9
Units 19 and 20 (siltstone)				
3: CP-47		26.4	44.8	28.8
6: Can-Tex		27.6	40.7	31.7
3: Hickman Road		33.6	26.8	39.6
Total 12	Average:	28.8	38.2	33.0

Average mineralogy of units 21 to 23 was not included because of the small number of samples taken and lack of a third outcrop to varify clay mineral trend.

APPENDIX C. DESCRIPTION OF LITHOLOGIC UNITS

Location: CP-47

Unit	Thickness ft.	in.	Description
1	4	2	Sandstone: light grayish green; contains mica and pyrite; contact sharp and irregular.
2	3	3	Shale: green, darkening with depth; calcareous towards base; fossil plants; contact sharp and irregular.
3	0	4	Limestone: greenish gray; fossiliferous; 1 in. compacted mud at top and base; contact sharp and irregular.
4	0	9	Shale: dark gray to black with some mottling of lighter colors; slickensided; 1.5 in. fossil zone 3 in. above base; pyritic; contact sharp and irregular.
5	0	9	Limestone: greenish gray; fossiliferous; contact sharp and irregular.
6	7	6	Shale: dark gray to black; silty, laminated, fissile; fossil plants and pyrite; calcareous; contact sharp and irregular.
7	0	11	Limestone: medium gray; fossiliferous; contact sharp and slightly irregular.
8	1	9	Shale: dark gray to black; fissile, laminated; contains phosphate nodules (coprolites); calcareous at top, base smutty; contact sharp and irregular.
9	1	1	Coal.
10	5	2	Mudstone: medium grayish green; silty; calcareous with abundant limestone nodules; slickensided; plant parts in upper part; contact sharp and irregular.
11	9	0	Siltstone: grayish green; calcareous with interbedded sands; limestone nodules; decreases in grain size with depth; pyritic and micaeous; contact gradational.
12	18	0	Shale: mudstone and limestone; top grayish green, silty shale becoming mottled red, gray, green, yellow, grading to a mudstone; unit has several gray, fine-crystalline limestone nodules; slickensided; pyritic; several smut layers are present.

Unit	Thickness ft.	Thickness in.	Description
13	0	4	Coal.
14	16	6	Mudstone: grayish green to green, mottled yellow and maroon; slickensided; silty; limestone nodules; calcareous at top, shaly at bottom; few fossils; contact sharp and irregular.
15	0	9	Limestone (Dolomite): light greenish gray, mottled yellow; fine-crystalline; contact sharp and irregular.
16	10	9	Shale: grayish green, mottled yellow and red; silty; slickensided; fissile and laminated; contact sharp and irregular.
17	0	9	Shale: dark gray; slickensided; abundant pyrite and plant parts; contact sharp and irregular.
18	0	7	Coal.
19	11	6	Mudstone-shale: dark gray; silty; slickensided; limestone nodules; few plant parts at top; grades to a greenish gray shale and red shale; contact sharp and irregular.
20	10	1	Mudstone-siltstone: gray, mottled with yellow and green and finally green with vertical mixing of pyritic silt; contact sharp and irregular.
21	5	5	Siltstone and mudstone: grayish green to gray muddy siltstone with interbedded silts, grades to a silty mudstone; (fossil plants); contact sharp and irregular.
22	2	9	Mudstone-shale: greenish gray, darkens with depth, mottled yellow; slickensided; slightly silty; contact sharp and regular.
23	0	11	Shale: black to dark gray; slickensided, highly fractured; contact sharp and regular.

For log records below unit 23, contact the Iowa Geological Survey. Description of units are based on Survey's log; information in parentheses is author's own.

Location: Can-Tex Quarries

Unit	Thickness ft.	in.	Description
15	0	8	Dolomite: light gray; fine crystalline; contact sharp and irregular.
16	6	5	Shale: light grayish green, darkening with depth, mottled reddish brown and yellow; slickensided; fissile and laminated; contains fossiliferous lenses of limestone; contact sharp and irregular.
17	0	8-0	Shale: dark grayish green; fossiliferous smut.
18	0	2-0	Coal: contact sharp and irregular.
19	5	5	Underclay: light gray, mottled red, purple, and yellow; blocky; contact gradational.
	1	6	Siltstone: light blue-gray; finely laminated, sandy and crossbedded in places; breaks with a conchodial fracture; sharp and irregular.
20	2	4	Siltstone: dark brick red; finely laminated; breaks with a conchodial fracture; contact sharp and irregular.
	1	0	Siltstone: light blue-gray, same as above, but contains a thin limestone layer and burrow casts.
	1	1	Siltstone: dark brick red, same as above.
	1	3	Siltstone: light blue-gray, same as above.
	0	9	Siltstone: dark brick red, same as above.
	1	0	Siltstone: light blue-gray, same as above.
	4	2	Siltstone: dark brick red, same as above.
	7	0	Siltstone: light blue-gray, same as above.

Shales and carbonates exist above the dolomite but are scattered in outcrops that are difficult to correlate.

Location: Hickman Road

Unit	Thickness ft.	in.	Description
13	0	9	Shale: black; highly fissile; contact sharp and regular.
14	3	0	Mudstone: light gray, mottled yellow; blocky; contact sharp and regular.
	1 to 3	0	Mudstone: light blue, mottled red and yellow; blocky; contact gradational and irregular.
	8	0	Mudstone: red, purple, yellow and dark gray; contains a resistant smut layer ¼ to ½ in. thick; fissile towards bottom; contact sharp and irregular.
15	0	7	Dolomite: light gray; fine crystalline; contact sharp and regular.
16	4	10	Shale: light to medium gray, darkening with depth, mottled red and brown; highly fissile; metallic luster on slickensides; contains fossiliferous, silty limestone lenses; contact sharp and irregular.
17/18	0	3	Coal and smut: contact sharp and regular.
19	4	0	Underclay: light gray, mottled with red and yellow; blocky; slickensided; gradational contact; unit mostly covered.
	3	7	Siltstone: white to light blue; sandy; contact somewhat gradational.
20	2	8	Sandstone: light greenish white; micaceous; silty; contact sharp and regular.
	1	0	Siltstone: light blueish gray; sandy; shaley upon weathering; contact sharp and irregular.
	5	5	Siltstone: dark red; finely laminated; contact sharp and irregular.
	10	0	Siltstone: light blue; sandy; contains sandstone lens 3 in. thick at top.

The quarry at the western end of the exposure contains units 13 to 20. The hills facing Hickman Road contain units 16 to 20. A sandstone layer in the outcrop to the east of the siltstones correlates to the siltstones of unit 20.

Location: 2nd Avenue

Unit	Thickness ft.	in.	Description
20	2	0	Siltstone: light gray; calcareous; weathers to a shale; contact sharp and regular.
	2	2	Coal: dull black to semi-metallic; banded; blocky; contact sharp and regular.
t o	3	4	Sandstone: upper 1.5 ft. are medium gray, fine-grained, fossiliferous, with little internal structure. Middle section is white, fine-grained, massive, fossiliferous, that weathers to a rust color; more resistant than upper part. Lower 13 in. are cyclic gray, sandy beds ½ to 1 in. thick to dark gray, clayey layers 1/8 to 3/4 in. thick with abundant pyrite nodules and plant fossils; upper portion composed of cut and fill sediments.
	1	1	Coal: dull black to semi-metallic; banded; blocky; contact sharp and regular.
23	approximately 5 ft.		Underclay: light gray; blocky; mottled yellow; very plastic; fossiliferous; lower portion not exposed except for a sandstone at base.

Location: Capitol Grounds

Unit	Thickness ft.	in.	Description
16	0	3	Coquina-shale: light gray; silty; fossiliferous with mostly *Desmoinesia muricatina* pedicle value; contact sharp and regular.
17/18	0	.5	Shale: dark gray to dull black; contact sharp and regular.
19	6	1	Shale: light gray, becoming buff and sandy with depth, in places mottled yellow; 2 to 3 ft. below contact a dark layer 4 to 6 in. thick occurs; 1 in. mottled dark red layer occurs 4 ft., 8 in. below contact; contact gradational.
	1	6	Limestone: light blue that weathers to a reddish brown; sandy and silty; crossbedded in places; siderite nodules present; ripple marks occur; contact somewhat gradational and regular.
20	1	3	Siltstone: buff passing downward to a light gray; sandy at top, grading downward to a shale; contact gradational and regular.
	4	0	Sandstone: dull medium yellow; crossbedding from ½ to 4 in. thick; fine-grained; contains large amounts of clay, mica, and siderite; contact gradational and regular.
	2	8	Siltstone: dull yellow, passing to a blue-gray clay; sandy and blocky; contact gradational and regular.
	0	10	Sandstone: buff to a dull yellow; fine-grained; crossbedded; contains large amounts of clay, siderite, and mica; resistant limestone layers and lenses present; contact gradational and regular.
	2	0	Sandstone: same as above except less resistant.
	2	1	Sandstone: same as above except more resistant.
	7	0	Sandstone: same as above except less resistant.
	2	0	Siltstone: light gray; sandy; calcareous; crossbedded; contact gradational and regular.

Unit	Thickness ft.	in.	Description
21	2	0	Coal.[1]
to	2	0	Shale:[1] sandy.
	0	3	Coal.[1]
23	2	0	Shale:[1] light gray.

[1]Beds described by Bain (1896).

Location: Goodwin Quarry

Unit	Thickness ft.	in.	Description
14	10	0	Shale:[1] wide range of colors, but upper few feet are dull purple, red, and gray below; argillaceous.
15	0	8	Dolomite: light gray; fossiliferous; fine crystalline; knobby top surface; contact sharp and irregular.
16	6	8	Shale: light gray, darkening with depth, streaked with red, yellow; slickensides polished to a high metallic luster; highly fissile; contact gradational.
17	0	8	Shale: dark gray; slickensided; fossiliferous; contains pyrite nodules; contact sharp and irregular.
18	0	2	Coal: dull black; contact sharp and irregular.
19	4-6	0	Underclay:[1] light gray; blocky; slickensided.
20	12	0	Shale:[1] light gray; silty, finely straticulate with a tendency towards shaly parting; contains small sandy calcareous concretions.
	1	2	Shale:[1] dark gray brown; fissile and argillaceous.
	3	0	Sandstone or siltstone:[1] light gray; jointing prominent; resembles 12 ft. unit.
	10	0	Shale:[1] light gray; silty or sandy; resembles 12 ft. shale but is possibly more indurated.

[1]Beds described by Gwynne (1940).

Location: Thomas Beck Road

Unit	Thickness ft.	in.	Description
8	5-7	0	Shale: dark black; fissile, laminated; phosphatic coprolites, fossil "shark" material and gypsum crystals present; contact sharp and regular.
9	1	5	Coal: dark black; contact sharp and regular.
10	4	0	Underclay: light gray; blocky; contact gradational.
11/12	4	0	Mudstone: light blue-gray; blocky; contact sharp and regular.
13	2	0	Shale-coal.
	5-10	0	Covered.
14	1	0	Shale: purple, red, gray.
15	0	8	Dolomite: light gray that weathers to a brown; fine crystalline; contact sharp and regular.
16	6	0	Shale: light grayish green; fissile; mottled with yellow and red; contact sharp and regular.
17/18	0	2	Coal-smut: contact sharp and regular.
19	4	0	Underclay: light gray; blocky; contact gradational and regular.
	3	0	Siltstone: light blueish gray; weathers to a shale; contact sharp and regular.
20	2	0	Siltstone: dark red; similar to siltstone above but is less silty.
	5	0	Siltstone: light blueish gray.

The strata is poorly exposed in the quarry and outcropping just east of the quarry. Only a brief description of the rocks was taken, and actual thickness may vary from recorded thickness because of the difficulty in locating the contact.