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CLAY MINERALOGY AND DEPOSITIONAL ENVIRONMENTS
OF UPPER CHEROKEE (DESMOINESIAN) MUDROCKS,
EASTERN KANSAS, WESTERN MISSOURI, AND
NORTHEASTERN OKLAHOMA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Geology
in the Graduate College of
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May, 1982

Thesis supervisor: Assistant Professor Robert L. Brenner

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CERTIFICATE OF APPROVAL

MASTER'S THESIS


This is to certify that the Master's thesis of

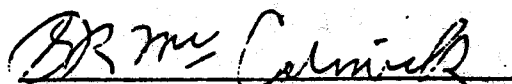
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Science degree in Geology at the May, 1982
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ABSTRACT

The "Lagonda interval" (Desmoinesian) principally consists of interstratified shales and sandstones with minor thin limestones and coals. Clay mineralogy, sediment-size analysis, and microfossil distribution were examined in 8 outcrop sections. Clay mineralogy was studied in selected samples from six subsurface cores west of the outcrop belt. The lithologies exposed in these sections can be divided into three recognizable facies of deltaic deposition: 1) a prodeltaic mud facies characterized by high total mud percentages, high illite crystallinity values, low kaolinite percentages, and low mixed layer clay percentages with some carbonate beds and marine fossil fragments; 2) a deltaic progradation facies characterized by gradual upward decrease in total mud percentages, illite crystallinity, and abundance of marine fossils, and gradual upward increase in mixed-layer clay percentages and kaolinite percentages; and 3) a shoreline-coastal facies characterized by low total mud percentages, high kaolinite percentages, high mixed layer clay percentages, coals and fluvial sandstones.

Mudrocks in the "Lagonda interval" represent deltaic lobes which prograded westward into the Cherokee and Forest City basins during stillstands of sea level, and during regressive phases of cyclic sedimentation. Intermittant minor transgressions of the Pennsylvanian sea shifted shorelines east of the study area. Lagonda sedimentation then progressed through another series of deltaic progradation and regression.

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INTRODUCTION

The Middle Pennsylvanian in Kansas comprises alternating units of limestones and shales with lenticular sandstones. The Cherokee Group constitutes the lower part of the Desmoinesian Series, and principally consists of interstratified shales and sandstones with minor thin limestones and coals, which taken together are common as part of a regressive sequence of Pennsylvanian cyclic sedimentation.

This study concentrates upon the mudrocks in the upper portion of the Cherokee Group, called the Lagonda Formation by Howe (1956). This interval used herein extends from the top of the Verdigris Limestone Member (defined by Smith, 1914; fide Woodruff and Cooper, 1930; described by Clayton, 1965) upward to the Breezy Hill Limestone Member (Pierce and Courtier, 1937; Howe, 1956) where the latter is present. Where the Breezy Hill is not present, the upper boundary of this interval is the base of the Excello Shale (Figure 1).

Preliminary outcrop and subsurface analysis of this formation indicates that the Breezy Hill Limestone in Crawford County is not continuous outside the type area, and the Verdigris Limestone is often too thin to be detected by geophysical well logs (R. L. Brenner, personnel communication, 1981). For these reasons, an informal term, the "Lagonda interval" is used to designate the stratigraphic column from a black shale below the Verdigris Limestone

Figure 1: Stratigraphic column of Cherokee group. (Modified from Zeller, 1968).

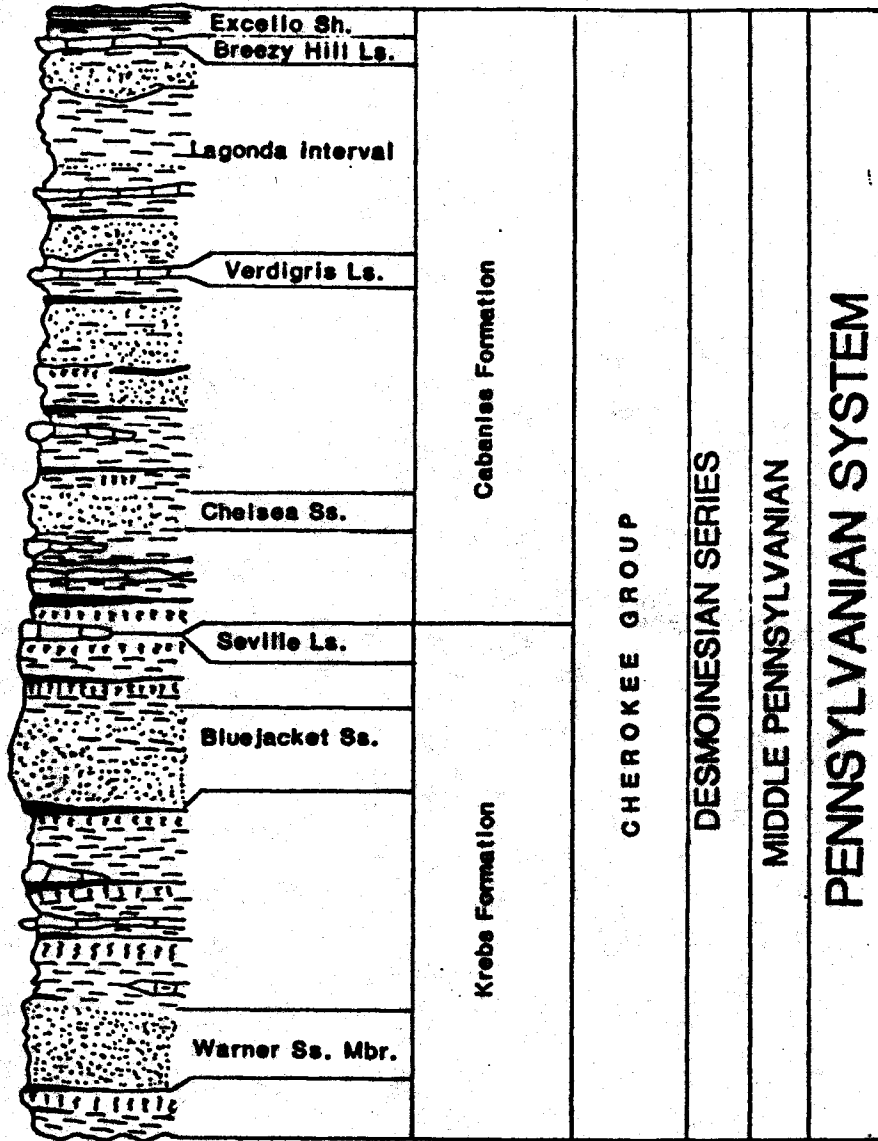


Figure 1

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Figure 2: Limits of Lagonda interval in this study. Note inconsistent nature of Breezy Hill Limestone. No vertical scale.

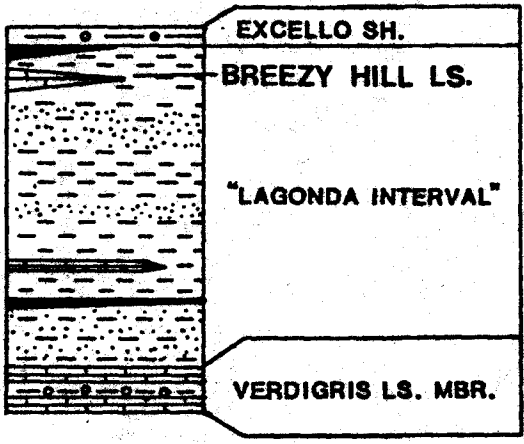


Figure 2

to the Excello Shale (Figure 2). The scope of this study includes all of the Lagonda interval above the Verdigris Limestone.

The geographic scope of this study includes outcrops in Bates and Vernon Counties, Missouri, Crawford and Labette Counties, Kansas, and Craig County, Oklahoma (Figure 3). In addition, well log information and core samples from Allen and Anderson Counties, Kansas, were used to study the section in the subsurface (Figure 3).

Purpose of Study

The principle objectives of this research are to: 1) determine vertical and lateral trends in the clay mineralogy, lithology, and paleontology of the mudrocks of the Lagonda interval; and 2) interpret the depositional environments represented by the mudrocks in the Lagonda interval. The combination of these two objectives, when considered within a time-stratigraphic framework, sheds light upon the potential siliciclastic source areas and the diagenetic history of these rocks. This information, when coupled with the depositional and diagenetic histories of the sandstones of the Lagonda interval (e.g. P. N. Reinholtz thesis, in preparation, Univ. of Iowa), can be used to formulate predictive depositional models for the entire Lagonda.

Previous Work

Regional stratigraphy and petroleum geology of the Forest City and Cherokee basins (Figure 4) have been studied by Weller (1930, 1958), Moore (1931, 1964), Lee (1943), Searight et al. (1953), Weirich (1953), Anderson and Wells (1968), and van Dyke (1975).

Figure 3: Desmoinesian outcrop and core localities. (•) indicate sample localities. Lagonda exposures crop out within a NE-SW trending belt. Core samples were obtained from wells in Allen and Anderson Counties, Kansas.

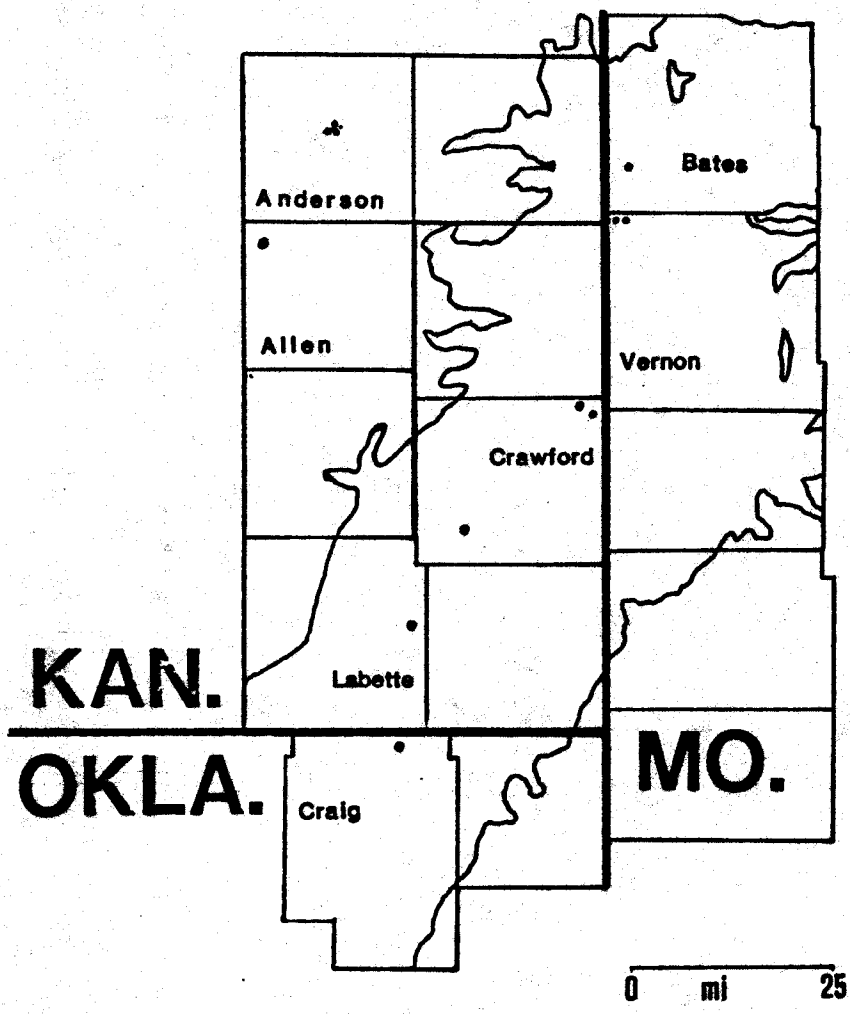


Figure 3

Figure 4: Structural provinces of the southern mid-continent. Study area (from Figure 3) includes Cherokee Platform (on figure) and south end of Forest City basin.

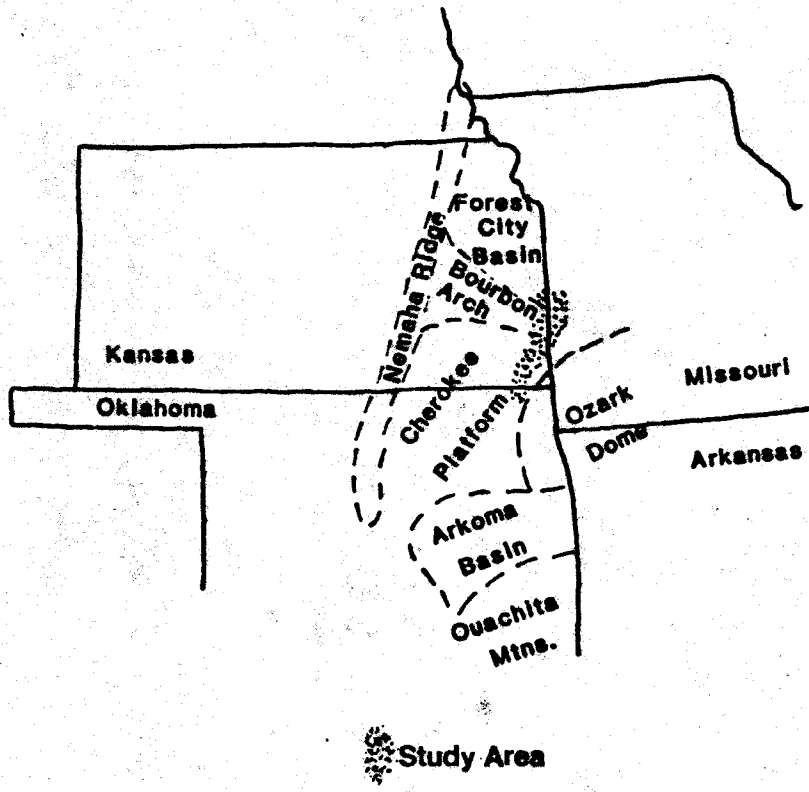


Figure 4

Formal stratigraphy of Middle Pennsylvanian rocks in the mid-continent area has been established by Condra (1949), Moore et al. (1951), Howe (1956), Howe and Koenig (1961), and Zeller (1968). Geology of the Cherokee Group in southeastern Kansas has been studied by Abernathy (1937), Howe (1956), and Ebanks and James (1975).

Two studies were completed on stratigraphic sections used in this study. Gentile (1976) described the NE Foster section in Bates County, Missouri, and the shaliest portion of that section was sampled for this study. Jungmann (1964) described the Neosho River Park section at Oswego, Kansas, and the entire exposure was sampled for this study. Detailed work on Cherokee sediments has been restricted, in most cases, to the sandstones, limestones, and coals in the group.

Stratigraphy of the Cherokee Group

The Cherokee Group shales were first described by Haworth and Kirk (1894), and were given formational rank in Iowa by Keyes in 1896 (Searight, 1955). Oakes (1953) divided outcropping Cherokee rocks in eastern Oklahoma into the Krebs and Cabaniss Groups. Howe (1956) recognized 18 formations within the Cherokee Group in southeastern Kansas, assigning the lower 6 formations to the Krebs Subgroup, and the remaining 12 to the Cabaniss Subgroup. The Cherokee Group in Kansas is presently divided into the Krebs and Cabaniss Formations (Zeller, 1968). The boundary between these formations is formally situated at the top of the Seville Limestone Member (Figure 1).

Regional Structure and Paleogeography

In western Missouri, southeastern Kansas, and northeastern Oklahoma, rocks of the Cherokee Group were deposited on the Cherokee Platform, a shelf-like extension of the Arkoma Basin of Oklahoma (Figure 4). The Ozark Uplift forms the eastern boundary of the basin and the Nemaha Uplift forms the western boundary. The Cherokee Basin was separated from the Forest City Basin during the early Pennsylvanian by low-relief paleotopographic feature known as the Bourbon Arch (Figure 4; Merriam, 1963).

Inspection of well log traverses extending across both the Cherokee and Forest City basins (Figure 5) reveals that both basins had essentially been filled up by the time Lagonda sediments were being deposited. The Bourbon Arch likewise had been covered prior to Lagonda deposition. As a result, the Bourbon Arch is not considered a depositional barrier in the context of this study.

Figures 6 and 7 are isopach and sand isolith maps of the Lagonda interval in southeastern Kansas. The isopach map reveals three thicker areas of accumulation. The sand isolith map reveals increased sand thicknesses which tend to coincide with these thicker sequences. This relationship suggests that these accumulations represent locations connected with source areas. Anderson and Wells (1968) reported that movements along the Nemaha Uplift may have begun as early as the late Early Ordovician, but it was definitely active between the Early Mississippian through at least the Early Permian. This evidence indicates that the Nemaha Uplift is a viable clastic

Figure 5: Well-log traverse across eastern Kansas from north to south. Thicknesses obtained from well-log information. Note fluctuations in thickness of lower Cherokee group sediments. Also note that Lagonda sediments are uniform in thickness even across Bourbon Arch (From R. L. Brenner, unpublished work, 1982).

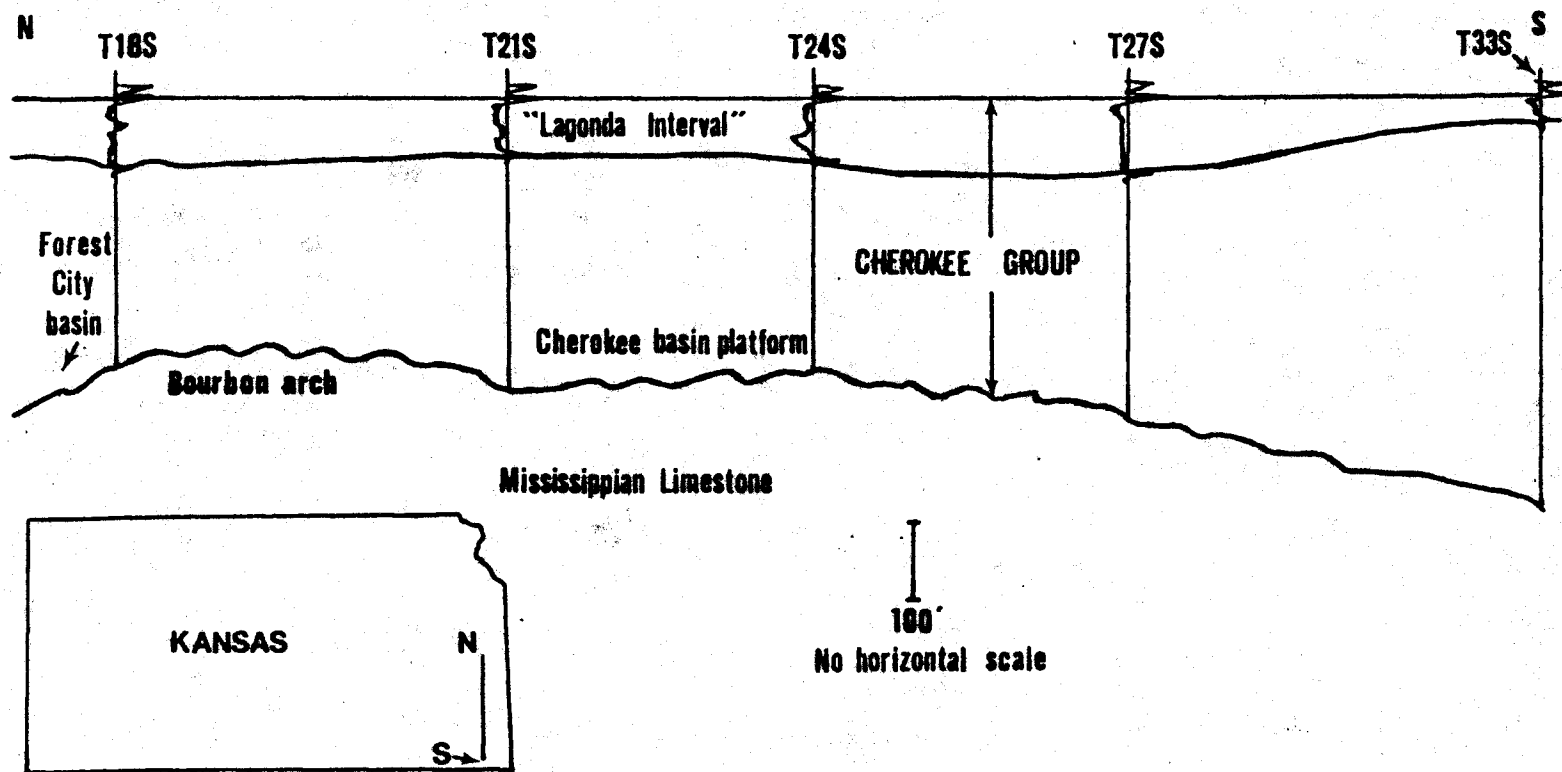


Figure 5

Figure 6: Isopach map of Lagonda interval in southeast Kansas. Note thicker areas of accumulation extending east from Nemaha Uplift and west, presumably from Ozark Dome area. Numbers along map border represent south townships and east ranges. Contour interval 10 feet. Dots (•) indicate well data points.

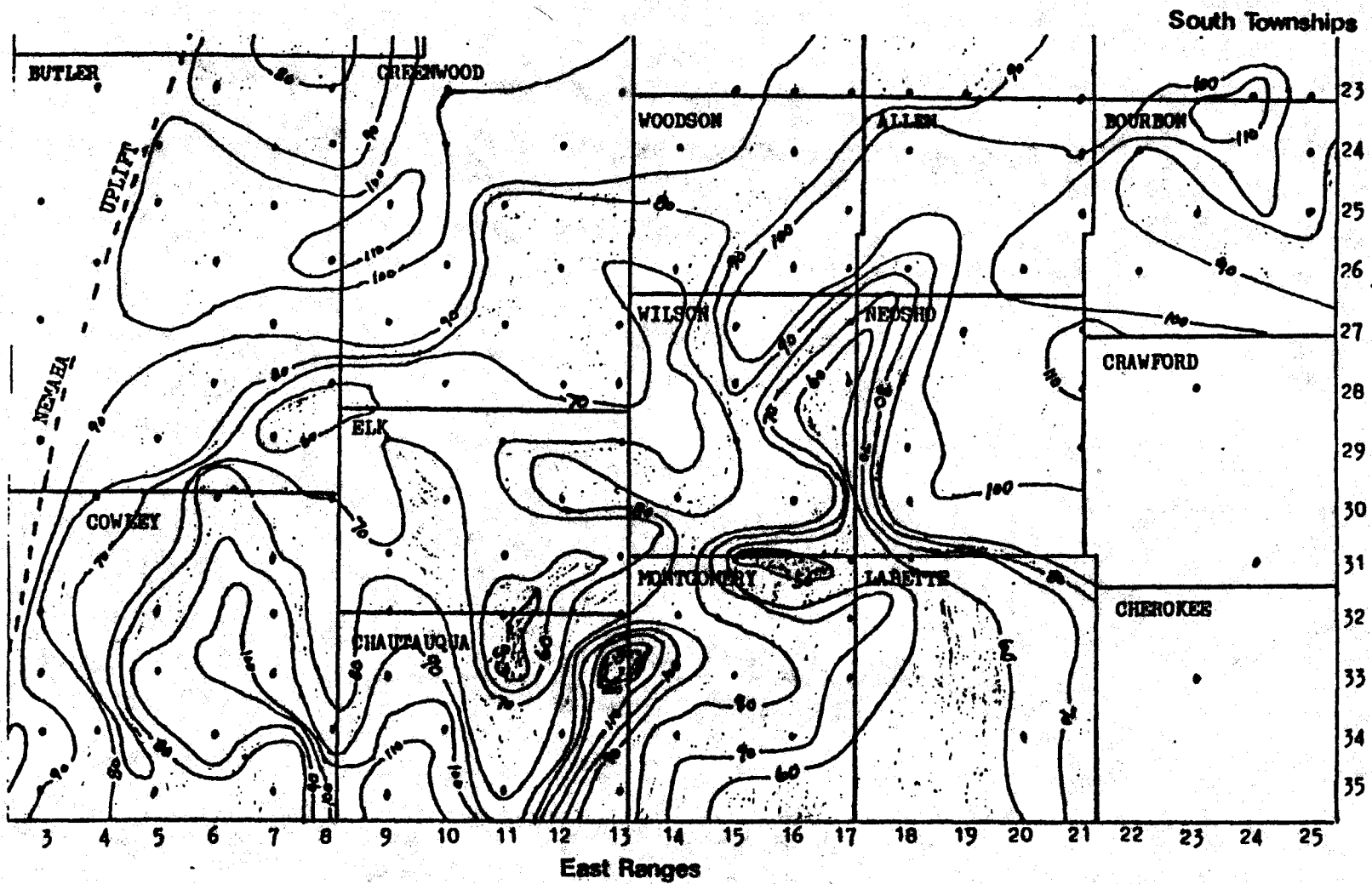


Figure 6

Figure 7: Sand isolith map of Lagonda interval in southeast Kansas. Thick areas of sand accumulation tend to coincide with thick areas of entire interval in Figure 6 (from R. L. Brenner, unpublished work, 1982). Contour interval 20 feet. Dots (•) indicate well data points.

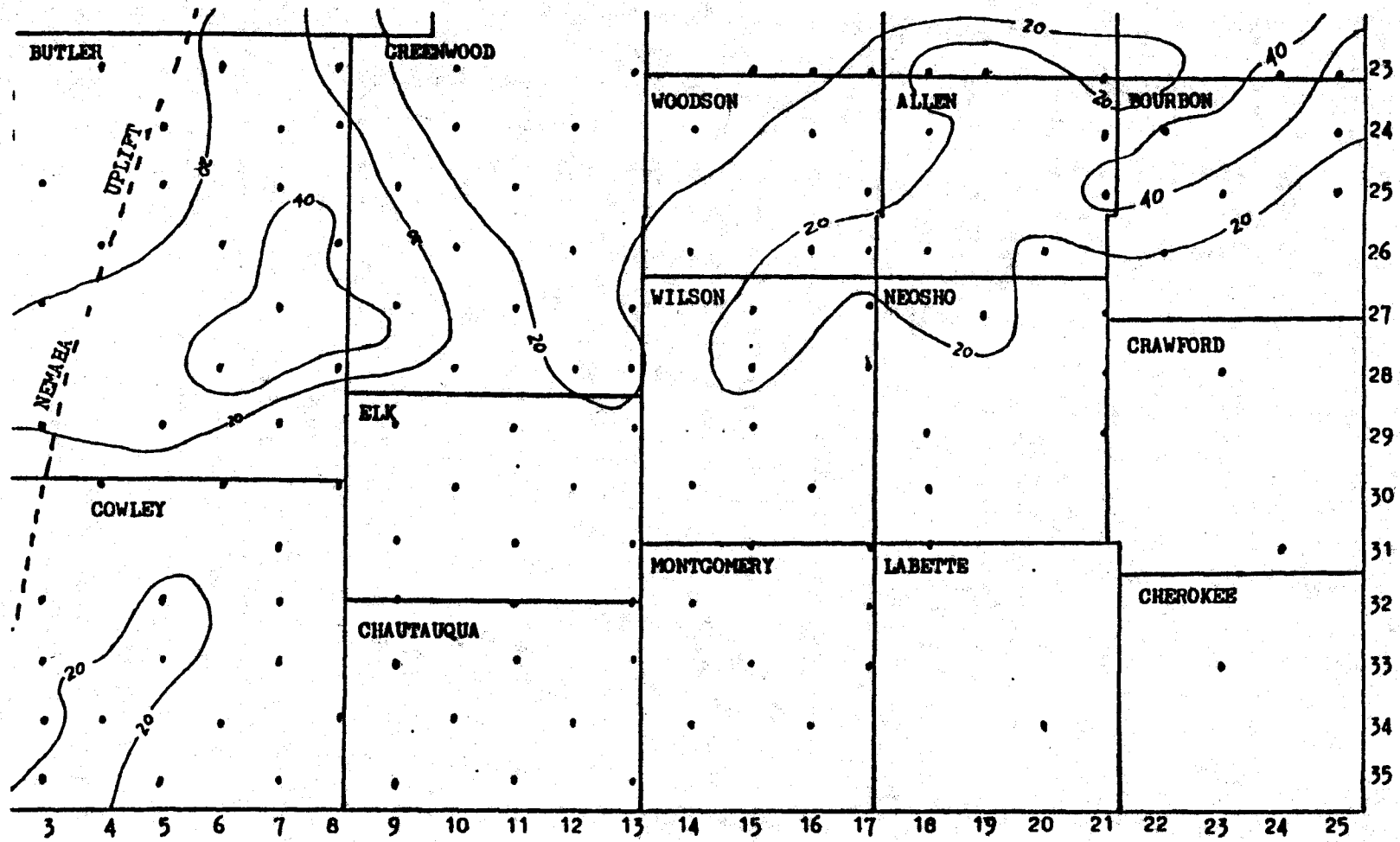


Figure 7

source during the Pennsylvanian, and explains the thicker sand accumulations near it.

Figure 8 illustrates Pennsylvanian paleogeography of North America (modified after Heckel, 1977, Figure 6). The Cherokee Basin and Forest City Basin are situated about 6 to 7 degrees north of the paleoequator. During Desmoinesian time period when the Lagonda interval was deposited, much of the Mid-Continent was intermittently inundated, and marine conditions alternated with deltaic advances (Moore, 1979). These deltaic advances prograded southwestward during regressive periods (Merriam, 1963, and Visher et al., 1971), exposing large areas of swampy coastal area. Greater inundations during subsequent transgressions became episodes of carbonate deposition.

Figure 8: Pennsylvanian paleogeography of North America. Study area highlighted with stippled pattern (modified from Heckel, 1977, (Figure 6).

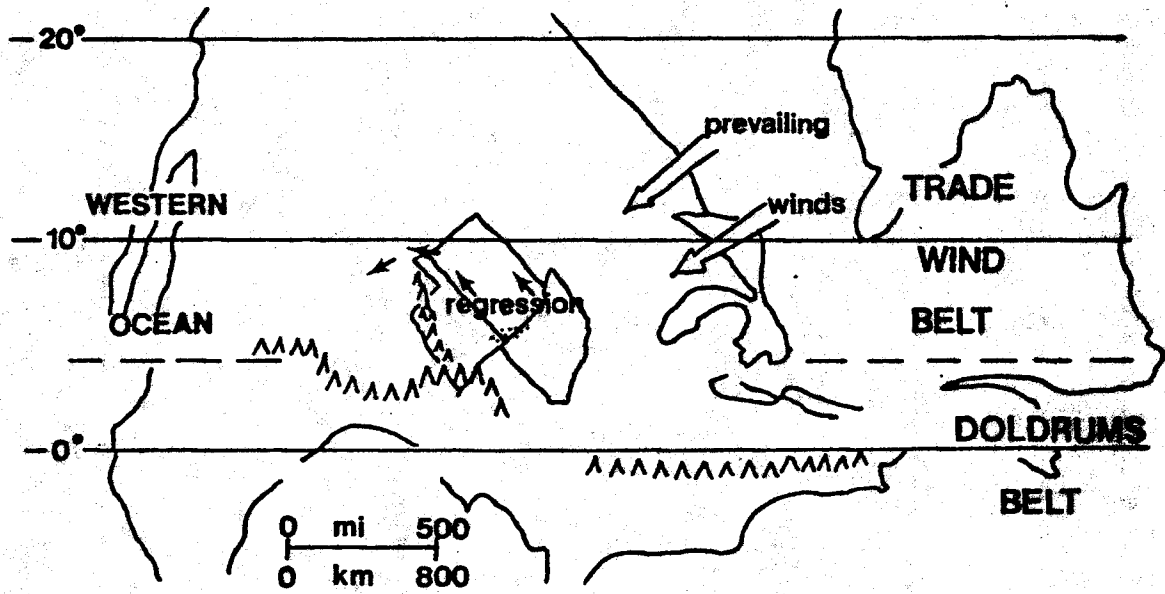


Figure 8

STUDY METHODS AND TOOLS

Sample Collection

Eight outcrops and cores from six wells, which includes all or parts of the Lagonda interval, were measured, sampled, and described (Figure 3). Sampling procedure involved collecting shale samples at an interval which ranged between 1.0 and 1.5 m (depending upon accessibility) throughout each section. In addition, samples were collected upon encountering any major lithologic variations.

Ninety-four unweathered outcrop samples and twenty-four core samples were used in determining the clay minerals present. Closely spaced, regular sampling intervals provided detailed sample suites from which variations in the clay mineralogy were demonstrated.

Seventy-four outcrop samples were used for sediment analysis, which illustrated variations in grain size and microfossils throughout each section. Carbonate samples were thin-sectioned and analyzed for major skeletal and non-skeletal grain types. The sandstones within the Lagonda are undergoing petrographic analysis in separate studies (e.g., P. N. Reinholtz, MS thesis in preparation, Univ. of Iowa).

Shale Processing

The laboratory procedure for sample breakdown was limited to shales and silty shales. Five hundred grams of each air-dried sample

were placed in a container. (Due to the siltiness of most shales, larger samples, would have provided an unmanageable supply of residue.) The samples were covered by Stoddard's solvent for approximately 24 hours, after which the Stoddard's solvent was decanted off and immediately replaced with water. This procedure disaggregated the shales during immersion in the water for another 24 hour period before further processing. For certain siltier samples, the above procedure had to be repeated in order to ensure more complete disaggregation.

The resulting slurry was then sieved through a series of three screens, a #18 (1mm) screen, a #120 (0.125 mm) screen, and a #230 (62.5 microns) screen. These residues were oven-dried, packaged, and weighed.

Each #120 residue was divided into two-thirds/one-third portions using a sample splitter, in order to reduce the amount of residue to a reasonable, yet unbiased quantity. The amount of residue picked for each sample ranged between 5 and 30 grams, depending upon the amount of original sample present. The residue was examined under a binocular microscope at 20x magnification, and microfossils were picked and identified as precisely as possible.

Sediment size data were obtained at the time the weighing of the samples took place. Wentworth's scale defines anything smaller than 63 microns to be the mud (silt and clay) fraction. As a result, the difference between the original sample weight and the total amount of residue after washing became the total mud percentage of each sample.

This value represents the portion of the entire sample that was smaller than 63 microns.

A small error was introduced in some of the coarser samples. Stoddard's solvent was ineffective in breaking extremely silty samples apart, even after several washings. Thus, a large portion remained as large rock fragments in the 1mm sieve. X-ray diffraction demonstrated that these fragments were composed of quartz, feldspars, and clays. Petrographic analyses of these fragments revealed silt-sized quartz and feldspar grains with a maximum of 3-5% clay dispersed between these grains. Therefore, the clay percentages recorded could be as much as 5% low in the siltier samples. Rather than use absolute values for the percentage of silt particles present, a ratio of the percentages seems more accurate when considering the randomness of particles which broke down during processing.

This "problem" actually aided the stratigraphic analysis because many of these very silty shales were, in actuality, silt stringers surrounded by more clay-rich laminations, a relationship not noticed during the collection and description of the sections.

Clay Mineralogy Sample Preparation

The laboratory procedure for clay preparation included the processing of clay-rich shales, calcareous shales, normal shales, silty shales, and argillaceous sandstones. The air-dried samples were gently tamped with a mortar and pestle in order to reduce the rock material into its component parts without straining clay crystal

lattices. This powder was then dry-sieved through a 63 micron screen. Material which fell through the sieve was thus the mud-sized fraction of the sample.

Carbonate material effectively dilutes the amount of clay minerals present, reducing the x-ray intensities of the clay. In order to obtain reproducible data from calcareous samples, it was necessary to acidize them. Calcareous samples were powdered following the method described above. They were then placed in 50 ml beakers and allowed to sit in spent formic acid for 24 hours. The formic acid was pipetted off and replaced with water, changing the water several times over a 2 day period to remove any excess formic acid. These samples were air dried, and were ready for further processing.

At this point, all powdered samples were placed in glass containers to which distilled water and a few grains of sodium hexametaphosphate (antiflocculent agent) were added. This mixture was stirred until all particles were in suspension. After allowing the coarser, non-flaky particles to settle, a portion of the remaining suspended material was pipetted off and placed onto porous ceramic tiles. A vacuum from beneath drew the water through the tile, orienting the clay's (00 ℓ) dimension parallel to the flat upper surface. A relatively thick layer of clay material was placed upon the tiles. This allowed the clays in contact with the porcelain to fill in the microscopic pores, allowing the material in contact with the x-ray beam to be oriented with less deviation from parallel. Subjecting the clays to a vacuum increased the randomness of clays

that would be x-rayed. The vacuum did not allow differential settling of different sized clays, increasing the representitiveness of the sampled clay mineralogy.

It should be noted that the suspended material was allowed to settle for only 35-40 seconds before pipetting. This procedure separated most of the clay minerals from most of the quartz silt, and provided a clay sample representing the bulk mineralogy of detrital clays, thus more closely reflecting the bulk mineralogy of the rock sample. Baker (1973) found that less-than-2-micron fractions were not as representative of clays in the Columbia River as the 62-micron fraction. In addition, Gibbs (1977) noted that clay sizes in the Amazon River range from 0.4 microns to 10 microns. These studies suggest increased settling times would have missed the larger size fractions.

Data were obtained by running the oriented samples on Philips APD 3500 Automated Powder Diffraction System, with a peak search program. The samples were exposed to monochromatic CU K α radiation, and were run at 40 kilovolts and 20 milliamps. Numerical data were obtained by runs described in the following section.

Semiquantitative Analysis

The semiquantitative analysis used to determine the clay mineralogy is based on a procedure described by Austin (1973). Four runs on the diffractometer were necessary for each sample: 1) The oriented air-dried samples were run between 2 and 38 degrees 2θ at a fixed time of 0.5 seconds per 0.2 degrees. This run was used to

identify the dominant clay-sized minerals in each sample, and to attain values at 12.4 degrees 2θ (Kaolin 001 and Chlorite 002), at 17.8 degrees 2θ (Illite 002), and at 18.4-18.9 degrees 2θ (Chlorite 003). Since quartz was present in all samples, its characteristic peaks at 20.85 degrees 2θ and 26.66 degrees 2θ served as excellent controls over the amount of variance in the location of peaks. These variances are due to deviations from a perfectly parallel upper surface of the porcelain chips upon which the samples were mounted.

2) The second run was again air-dried and run between 24 degrees 2θ and 28 degrees 2θ at a fixed time of 2.5 seconds per 0.2 degrees. This slow speed enabled a visual separation of the kaolin 002 and chlorite 004 peaks at 24.9 degrees 2θ and 25.1 degrees 2θ respectively. The slow speed also provided a more precise quantitative determination of peak intensities. The 3.43 Å quartz peak (26.66 degrees 2θ) was again used as the control. 3) The third run was completed after the sample had been exposed to an ethylene glycol-saturated atmosphere for 24 hours, which expands the expandable clays. This allows a more precise measurement of the illite 001 peak at 8.8 degrees 2θ and also provides an opportunity to detect smectites by measuring the peak found at 5.2 degrees 2θ . No smectite was observed in any of the samples processed in this study. Since kaolinite was present in all samples, its peak at 12.4 degrees 2θ was used as the control in this run. 4) After heating the sample to 375 degrees C for 1 hour, the sample was run from 2 degrees 2θ to 18 degrees 2θ at a fixed time of 0.5 seconds per 0.2 degrees. The illite 001 peak at 8.8 degrees 2θ was again measured.

Heating the sample at this temperature was effective in separating mixed layer clays from the low-angle side of the illite 001 peak (Figure 9). The kaolinite 001 peak at 12.4 degrees 2θ was again used as control. Percentage values were then calculated using the following formulas:

If chlorite was not present:

$$T = I_{1H} + K_1$$

If chlorite was present:

$$T = I_{1H} + \frac{C3 \times I_{1G}}{I2} + \frac{K2 \times C3 \times I_{1G}}{2 \times C4 \times I2}$$

"T" was then inserted into the following equations to arrive at the percentage of different clay minerals present:

$$\% \text{ Illite} = \frac{I_{1G}}{T} \times 100$$

$$\% \text{ Chlorite} = \frac{I_{1G} \times 100 \times C3}{T \times I2}$$

If no chlorite was present, the following formula was used to complete the percentage of kaolinite present:

$$\% \text{ Kaolinite} = \frac{K_1}{T} \times 100$$

If chlorite was present, the following formula was used to compute the percentage of kaolinite present:

$$\% \text{ Kaolinite} = \frac{I_{1G} \times 100 \times C3 \times K2}{T \times I2 \times 2 \times C4}$$

$$\% \text{ Mixed Layer Clays} = \frac{I_{1H} - I_{1G}}{T} \times 100$$

Figure 9: X-ray pattern and peak identification. Peak locations for the various clay minerals are identified.

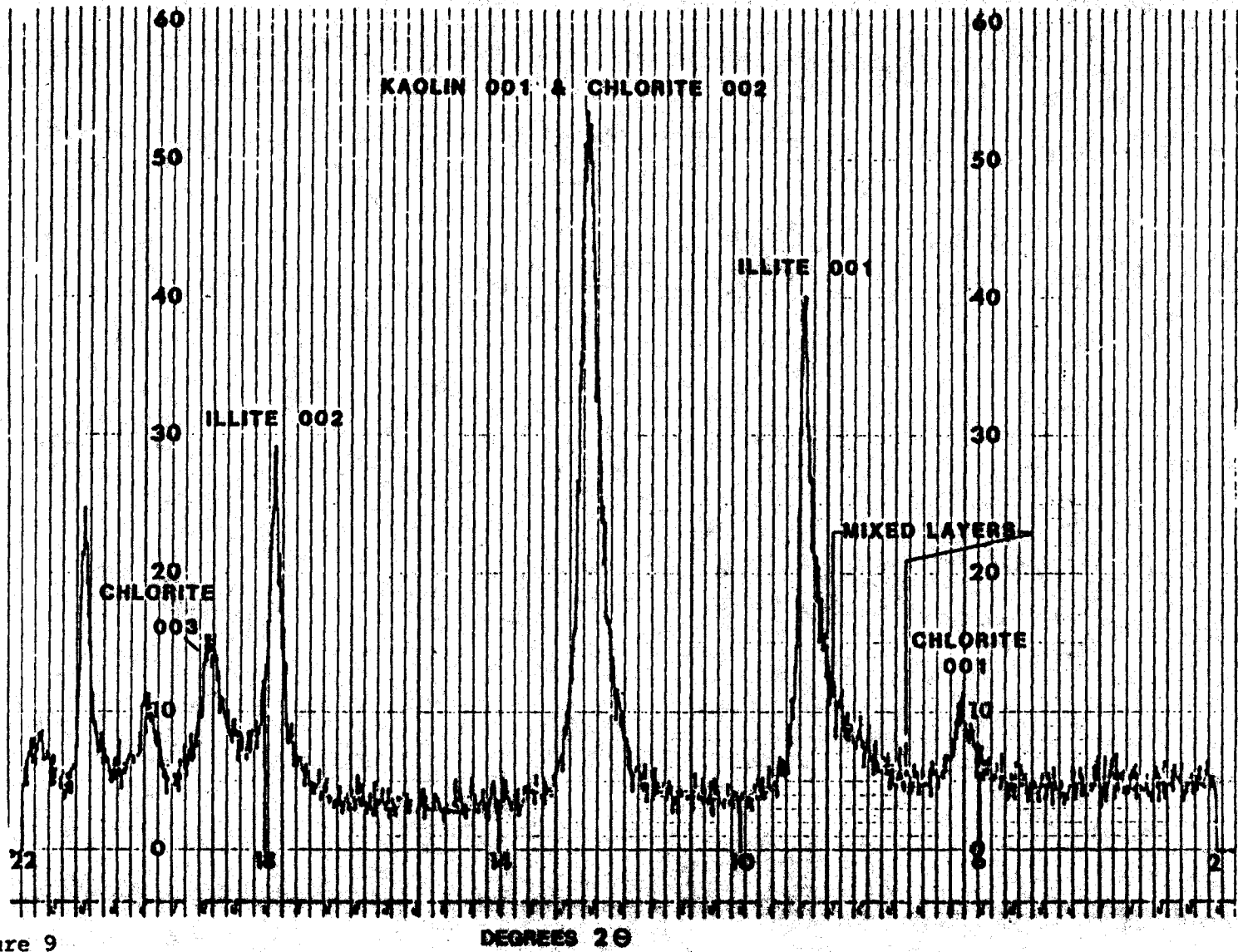


Figure 9

Few parameters in this semi-quantitative analysis are not subject to at least some degree of uncertainty. Measurement errors are introduced by problems associated with samples (e.g. too many quartz grains, which prevent many clay flakes from lying parallel to the porcelain chip, thereby reducing intensities), problems associated with hardware, and problems associated with relative reflecting abilities of the various clay minerals. For a complete discussion concerning these problems, the reader is referred to S. R. Schutter (Ph.D. dissertation, in preparation, Univ. of Iowa).

Illite Crystallinity Index

Calculation of the illite crystallinity index was accomplished using the method of Weaver (1965). The illite crystallinity index was attained by measuring a ratio of the untreated 001 peak height to the height of the subordinate peak $\frac{1}{2}$ degree 2θ to the lower angle side of the illite peak used (Figure 10).

Figure 10: Illite 001 peak and position of subordinate peak used for computing illite crystallinity. The value is obtained by dividing the height of the illite 001 peak by the height of the peak $\frac{1}{4}$ degree to the lower-angle side.

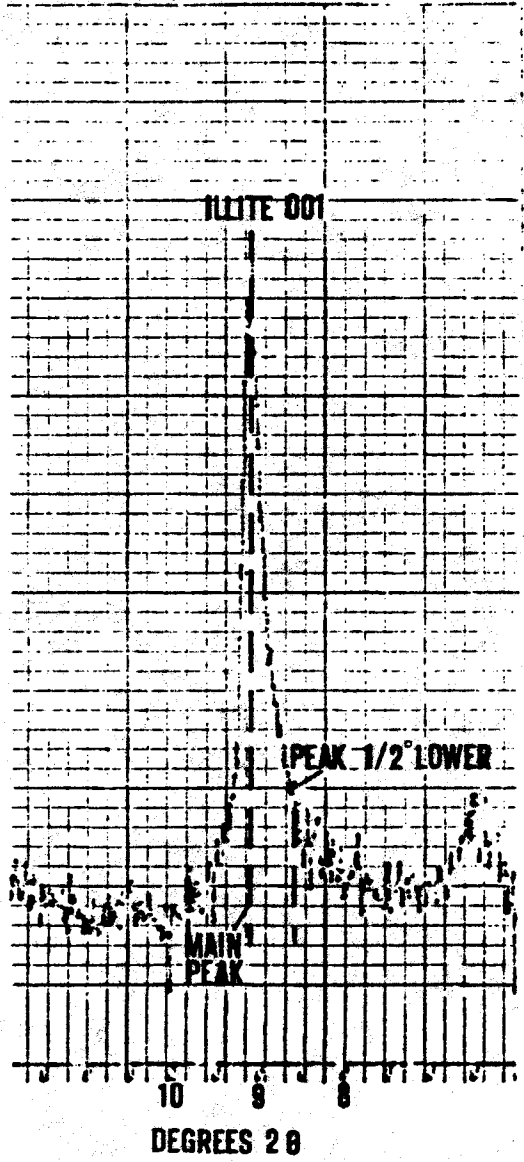


Figure 10

OUTCROP AND SAMPLE OBSERVATIONS

NE Foster (SE $\frac{1}{4}$ Sec. 6T39N, R32W, Bates Co. Mo.)

The sampled interval at NE Foster (Figure 11) consists of 20.3m of shale and silty shale. The base of the section chosen for sampling was a coal seam. Unit 1 (Figure 11) is 2.5m of sparsely fossiliferous silty (46.5% silt) shale, with a 0.1m wavy-bedded fossiliferous limestone bed between 0.5m-0.6m above the coal. Illite crystallinity values in the lower 2.5m range from 0.9-1.4, randomly fluctuating between samples. Mixed layer clays uniformly constitute 20% of the clay minerals within this interval. Total mud percentages fluctuate, initially decreasing upward, then reversing their trend. Several irregular, discontinuous lenses and beds of carbonate concretions are present between 0.7-2.0m (Figure 11).

Unit 2, comprising mudrocks in the interval between 2.5m-10.4m, is more mud-rich (averaging about 77% mud), and is interstratified with laterally continuous 0.1m thick siltstone beds. These siltstone beds display irregular-wavy to faintly cross-laminated stratification. Total mud percentages within these siltstone stringers are in sharp contrast with the clay-rich muds surrounding them (Figure 11). Mixed layer percentages range between 2%-10% in the lower 4.5m of this unit, and gradually increase upward, abruptly

Figure 11: Data acquired from NE Foster section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. "mf" denotes marine fossils at indicated horizons. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

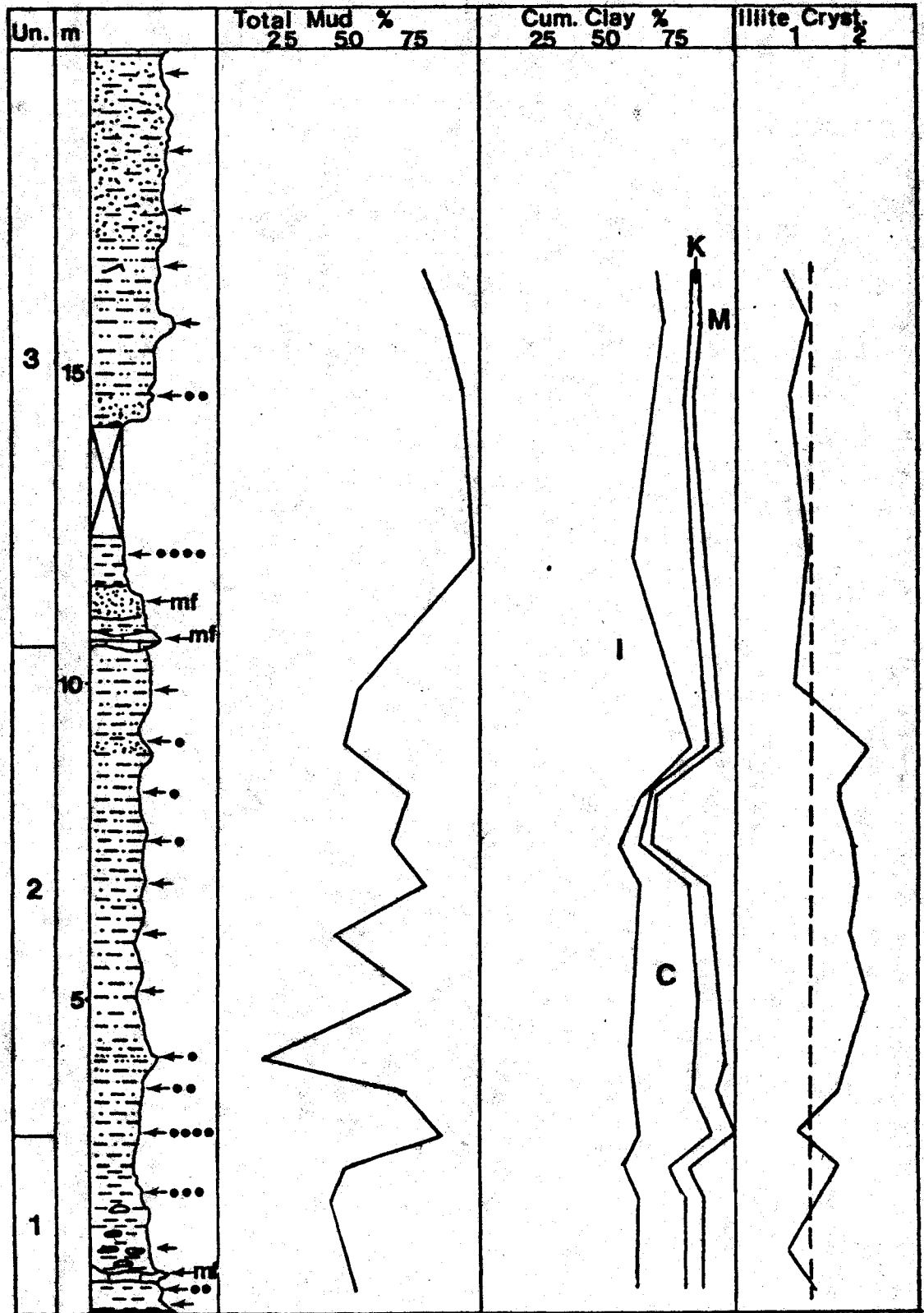


Figure 11

increasing to 25%-35% at the top of this unit (Figure 11). Illite crystallinity values for this interval are high, ranging between 1.7-2.1. Faunal evidence is restricted to poorly preserved productid brachiopod spines. These are most abundant at the base of this unit, and disappear upward (Figure 11).

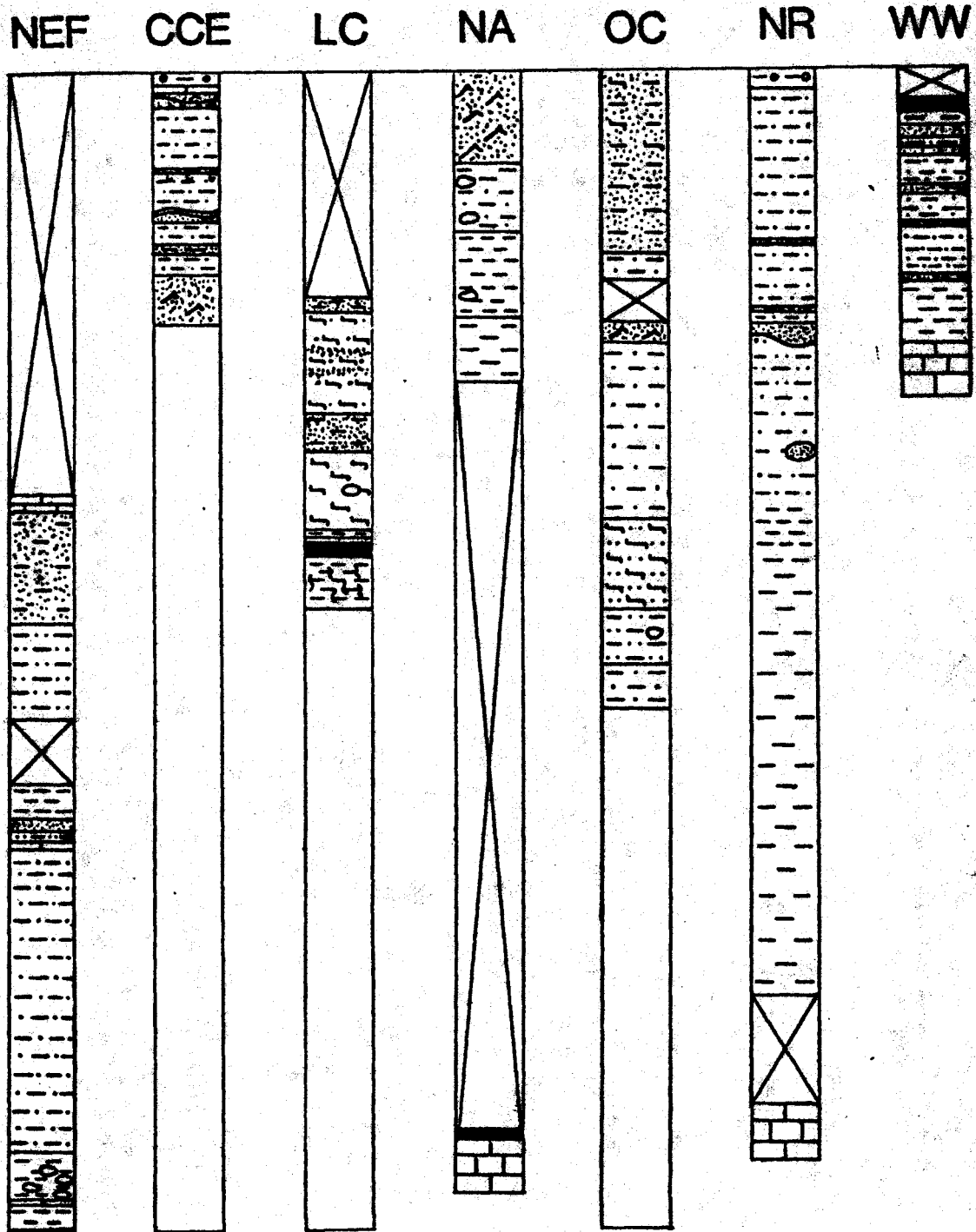
Lithologies present in unit 3 (Figure 11) include an open marine fossiliferous limestone bed between 10.4m-10.6m above base of section, and a 0.3m fossiliferous sandstone above the limestone. From 11.2m-12.2m, an extremely mud-rich (98.8% mud) fossiliferous mudrock is present. Well-preserved ostracodes and productid brachiopod spines and shells are abundant throughout this interval. These mudrocks grade into interstratified rippled sandstones and siltstones 17.5m above base of section. Total mud percentages and faunal abundances between 11.2m-17.5m (top of sampled interval) also decrease upward. Illite crystallinity values in unit 3 (10.4m-17.5m) are low, ranging between 0.9-1.1. Mixed layer clay percentages display a gradual increase upward throughout unit 3.

The silt consists of subangular-subrounded quartz grains throughout the entire sampled section. Muscovite flakes are common and are especially noticeable along bedding planes within sandstones.

Lawrence Cemetery (SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 5,
T37N, R33W, Vernon Co., Mo.)

The base of the Lawrence Cemetery section is stratigraphically equivalent to the sandstones that cap the sampled interval at NE Foster (Figure 12). A second section (Cemetery Creek East in this

Figure 12: Stratigraphic correlation of outcrops. Datum is base of Fort Scott Limestone. No horizontal scale. Note NE Foster (NEF), Neosho River Park (NR), and West Welch (WW) represent entire section. Cemetery Creek East (CCE), Lawrence Cemetery (LC), North Arma (NA) (and West Croweberg), Osage Cemetery (OC), Neosho River Park (NR), and West Welch (WW) represent upper portions of the Lagonda interval. This Figure illustrates the stratigraphic relationships of all the sections, particularly the relationship between the top of the NE Foster section and the base of the Lawrence Cemetery section.



Datum: Base of Ft. Scott Ls.

Figure 12

study) is located across the road from Lawrence Cemetery. The base of the Cemetery Creek East section is stratigraphically equivalent to the sandstone unit that caps the Lawrence Cemetery section and extends upward to the Fort Scott Limestone. A composite section, Figure 13, has been constructed for these two outcrops.

Unit 1 consists of 1.5m of mottled, unfossiliferous underclay overlain by 0.4m of coal. The underclay is mud-rich (79.2% mud), and the clay mineral assemblage is composed entirely of illite (57.5%) and mixed layer clays (42.5%). Illite crystallinity values for the underclay are anomalously low (0.6).

Unit 2 consists of a thin (0.1m) fossiliferous limestone and 2.4m of calcareous shale containing echinoderm fragments. Irregular, discontinuous beds of carbonate concretions are present within this shale at two different stratigraphic levels (Figure 13). Illite crystallinity values remain anomalously low throughout this unit. Mixed layer clay percentages fluctuate markedly, entirely disappearing in the sample (LC-4) that contains the echinoderm pieces (Figure 13).

Unit 3 is interstratified calcareous clayey shales (averaging 75.5% mud), siltstones, and fine-grained sandstones. Illite crystallinity values remain low, while mixed layer clay percentages rapidly decrease upward, totally disappearing in the upper half of this unit (Figure 13). Faunal assemblages consist of well-preserved ostracodes within the shales.

Figure 13: Data acquired from Lawrence Cemetery section including Cemetery Creek East. Arrows indicate sample points. Dots (•) indicate relative abundance of probably eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. "mf" denotes marine fossils at indicated horizons. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Dotted line in illite crystallinity column indicates a value of 1.2.

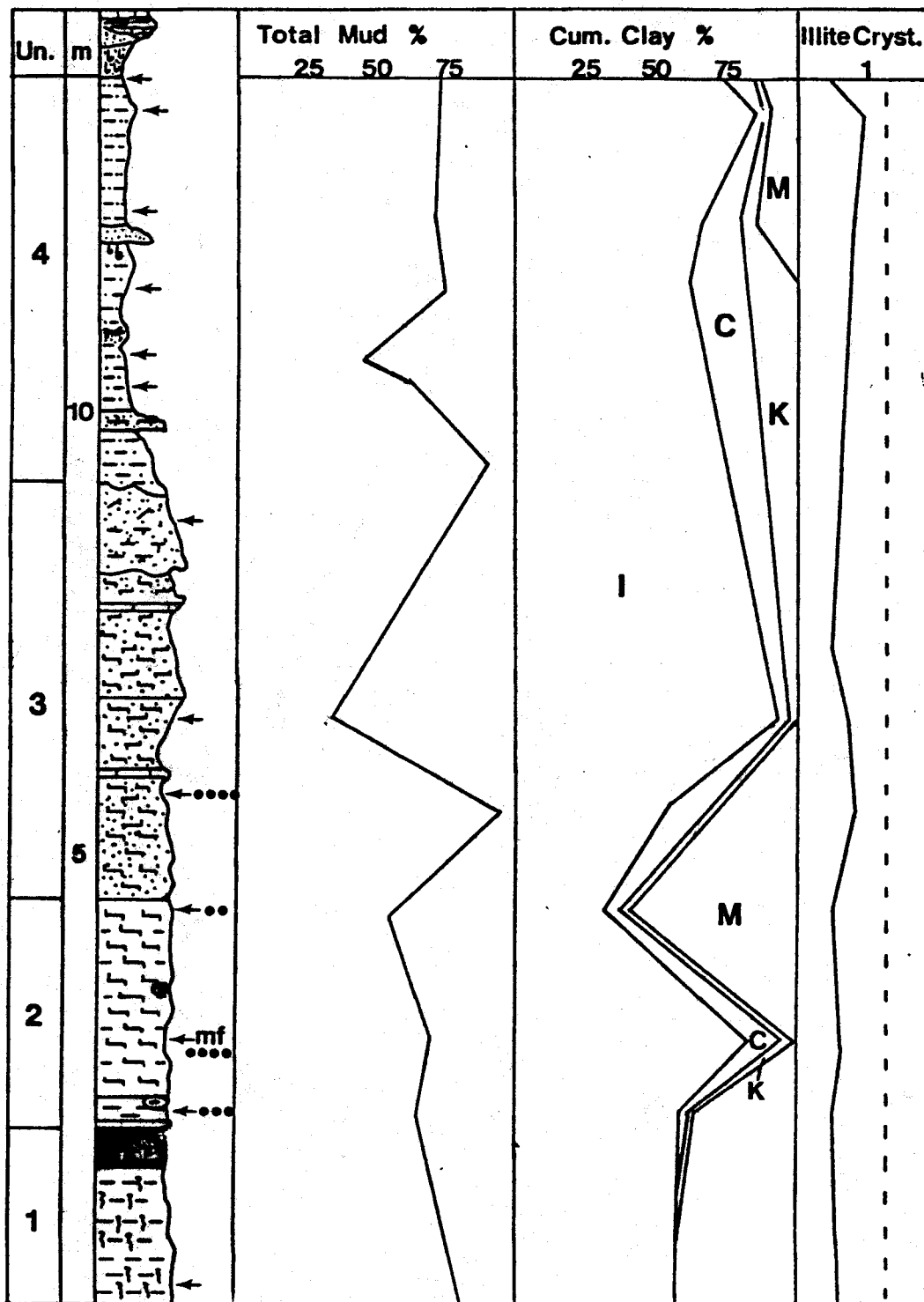


Figure 13

Unit 4 comprises clayey shales (averaging 70% mud) interstratified with calcite-cemented quartzarenites (sandstone classification of Dott, 1964). Illite crystallinity values remain low. The upper 2m of this unit displays a return of mixed layer clays (Figure 13).

Above the sampled interval are burrowed and rippled sandstones overlain by a mottled, unfossiliferous limestone, the Breezy Hill, and eventually the Excello Shale and Fort Scott Limestone.

North Arma (SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 32,
T27S,R25E, Crawford, Co., Ks.) and
West Croweberg (SW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 9,
T28S,R25E, Crawford, Co., Ks.)

The North Arma outcrop and the West Croweberg outcrop are located approximately 2.5 miles apart (see Figure 14). Both sections occupy the same stratigraphic levels, and as a result, facies relationships on a more local scale were investigated.

The North Arma highway 69 section consists (Unit 1) of 4.2m of mud-rich (averaging 82.1% mud) shale which grades into 1.9m of siltstone (Unit 2). The lower 3.7m of shale (Figure 15) displays high illite crystallinity values (1.3-1.7), gradually upward-increasing mixed-layer clay percentages (from 4.3% to 16.8%), and gradually upward-decreasing total mud percentages. Productid spines were recovered from the next to lowermost sample (Figure 15). The upper 0.7m of shale displays lower illite crystallinity values and a substantial increase in kaolinite percentage with an associated

Figure 14: Location of North Arma (NA) and West Croweberg (WC) outcrops.

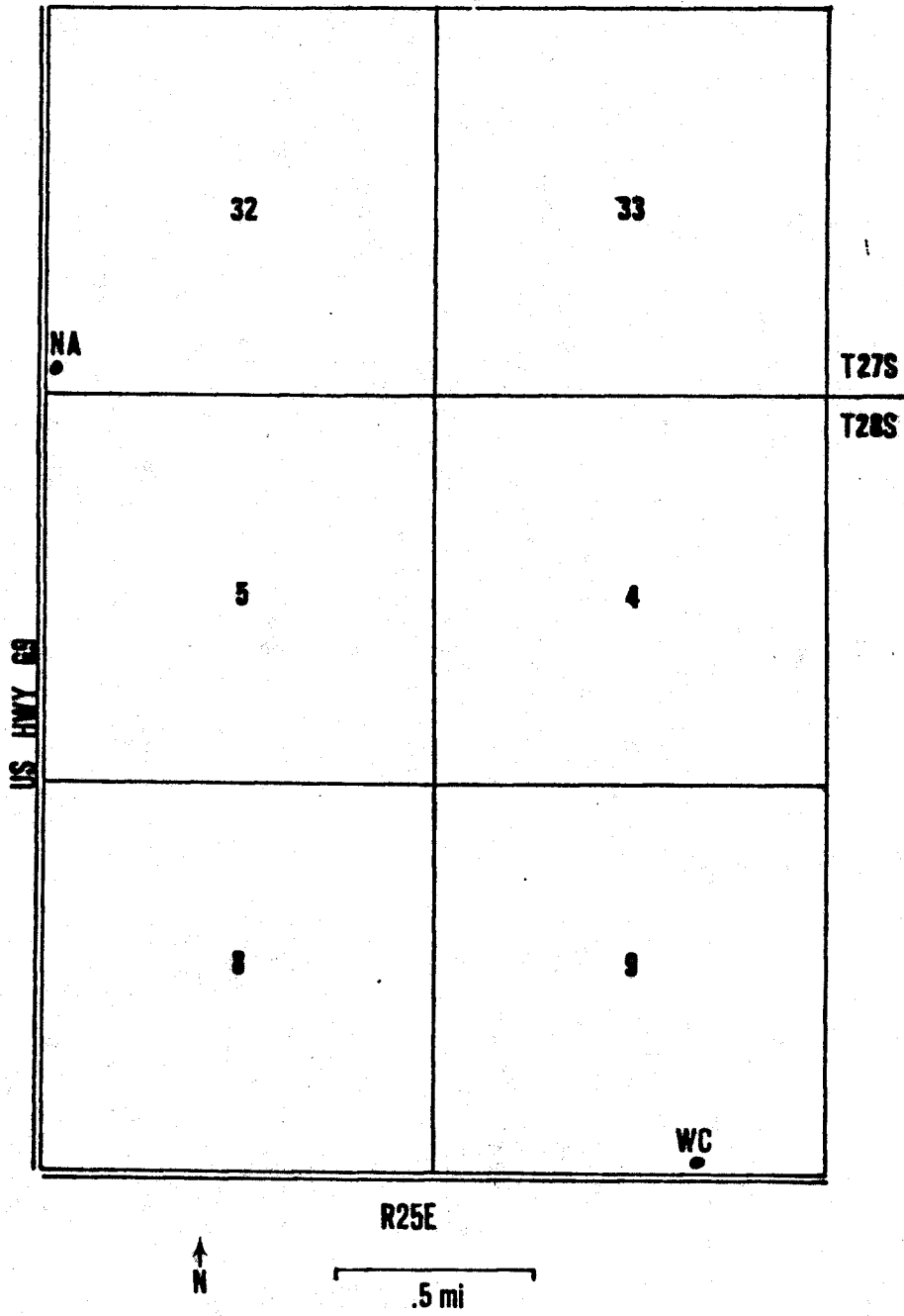


Figure 14

Figure 15: Data acquired from North Arma section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

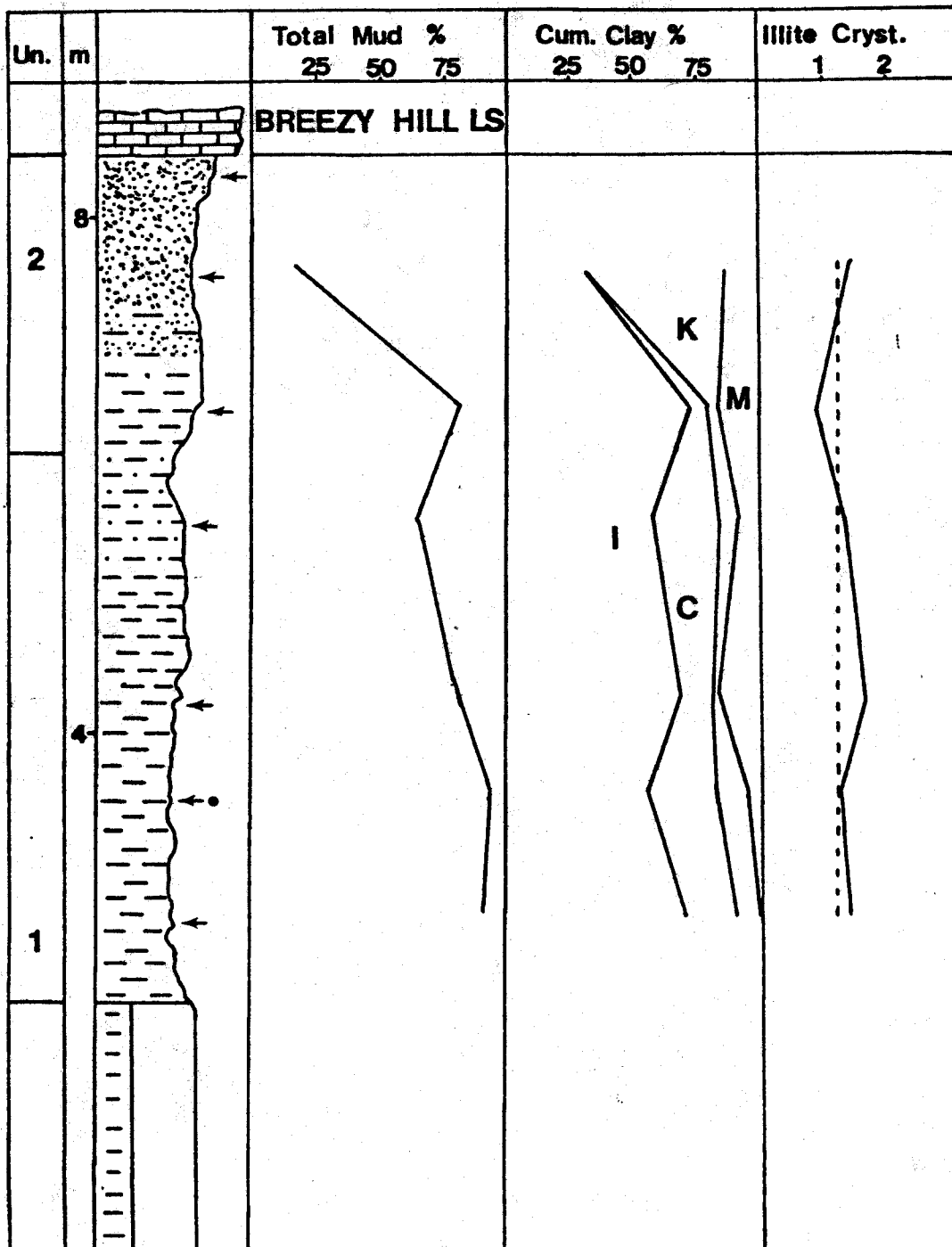


Figure 15

decrease in total mud percentages (Figure 15). No microfossils were recovered from this interval. The siltstones that overlie these shales continue these same trends.

The West Croweberg section is composed of 5m of shale (Units 1 and 2) overlain by 1.2m of sandstone. The lower 2m of shale (Unit 1) are mud-rich (93% mud). These mudrocks abruptly become sandier (61% mud) within the upper 3m of shale present. Poorly preserved brachiopod spines were recovered from the lowermost sample (Figure 16). Sand in these shales consist of subangular-subrounded quartz grains and pink feldspathic rock fragments. The sandstones overlying these mudrocks (Unit 3) display sharp, erosional basal contacts and bedding surfaces with current ripple marks. Illite crystallinity values for this entire section are low (0.5-1.2). Mixed-layer clay percentages display great variability, fluctuating between 0.7%-47.6% (Figure 16). The uppermost shale sample displays a very low illite crystallinity value of 0.5. Kaolinite is present throughout the section, increasing abruptly near the top of the sampled interval (Figure 16).

Osage Cemetery (NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 25,

T30S, R22E, Crawford Co, Ks)

The Osage Cemetery section is 19.7m thick, with the base of the section beginning at the water level of Lightning Creek. The lower 14.7m (Unit 1) is silty shale (ranging between 13.7% and 69.2% mud) with a 1m interval of clayey shale (82.8% mud) between 5.0m-6.0m

Figure 16: Data acquired from West Croweburg section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

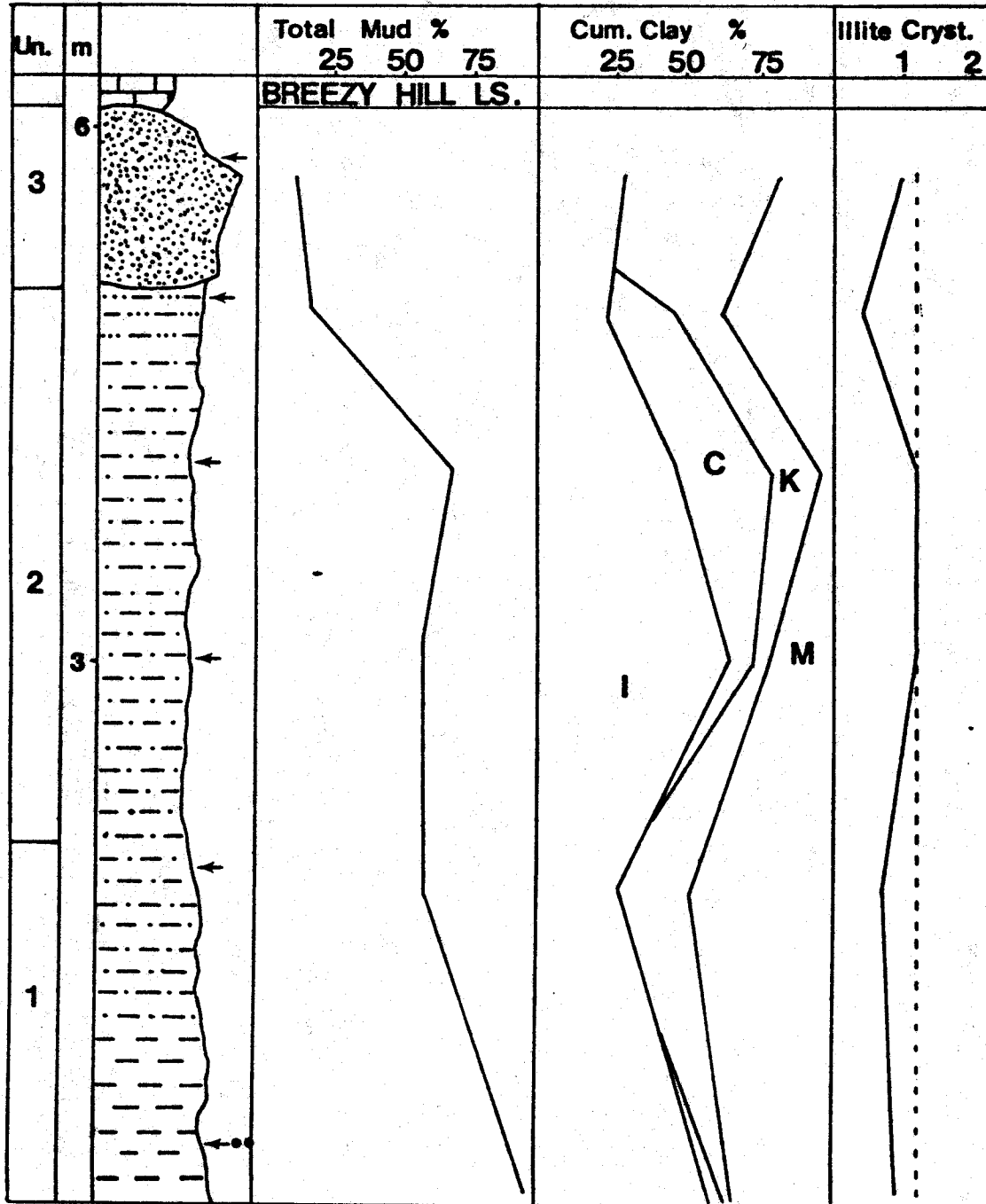


Figure 16

above base of section (Figure 17). Small (0.05mm diameter) hematite-stained concretions occur throughout the lower 14m.

Siltstone stringers occur in thin (1-3 cm) beds consisting of subrounded-rounded quartz grains and pink feldspathic rock fragments. Mud-sized material is interstratified with these siltstone stringers in 0.5-1.5 cm beds.

Unit 2 lies above this shale, and comprises approximately 5m of slabby, wavy-bedded very fine-grained, micaceous sandstone. Immediately overlying this sandstone is a small covered interval and the Fort Scott Limestone.

Clay mineral percentages at Osage Cemetery vary more than those in other sections sampled. The lower 10.5m of this section is uniform in clay composition, dominated by illite (Figure 17). The interval between 10.5m and 14.7m displays a complete lack of chlorite, a great reduction in illite, and an equally large increase in kaolinite (Figure 17). Mixed layer clay percentages display a more gradual upward reduction.

Illite crystallinity values are above 1.2 mainly near the base, and are low (0.7-1.2) throughout most of the section, especially within the zones of high kaolinite. Only samples 1,2,3 and 10 have crystallinity values of 1.2 or greater.

Neosho River Park (SW $\frac{1}{4}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 15,

T33S,R21E, Labette Co., Ks)

The Neosho River Park section consists of 25.2m of mudrocks overlain by 0.5m of black, phosphatic shale (Excello Shale) and the

Figure 17: Data acquired from Osage Cemetery section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

base of the Fort Scott Limestone. Approximately 3 miles southeast of this section, the Verdigris Limestone outcrops near the Overman Bridge in the SW $\frac{1}{4}$ Sec. 35, T33S, R21E. Assuming no structural displacement, the location of the Verdigris Limestone can be extrapolated to the measured section, using the regional dip of 30 feet per mile to the west. As a result, nearly a complete thickness of the Lagonda interval is represented at this section.

The extremely mud-rich (averaging 82.5% mud) section is interstratified with three intervals of fine-grained sandstone. These are located between 18.2m-18.8m, 19.1m-19.2m, and 10.8m-10.85m above the base of the measured section (Figure 18). All the sandstones display sharp but non-erosional basal contacts, with the lowest sandstone exhibiting load structures. Upper contacts with intervening mudrocks are also sharp, demonstrated by the immediate return to mud-dominated sediments with no evidence of gradation.

Silt in the mudrocks is subangular-subrounded quartz. Mica is common throughout the section.

The Neosho River Park section displays little variation in illite, chlorite, or kaolinite percentages throughout Unit 1. Unit 2 illite percentages increase as mixed layer clay percentages decrease (e.g. samples 14A and 17), while higher mixed layer clay percentages appear at the expense of chlorite and kaolinite (e.g. samples 13A, 16 and 18). Illite crystallinity values are moderate to high (1.2-2.2) with low values of 1.1 encountered mainly in samples with higher mixed layer clay percentages (e.g. samples 5, 14, and 16).

Figure 18: Data acquired from Neosho River Park section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

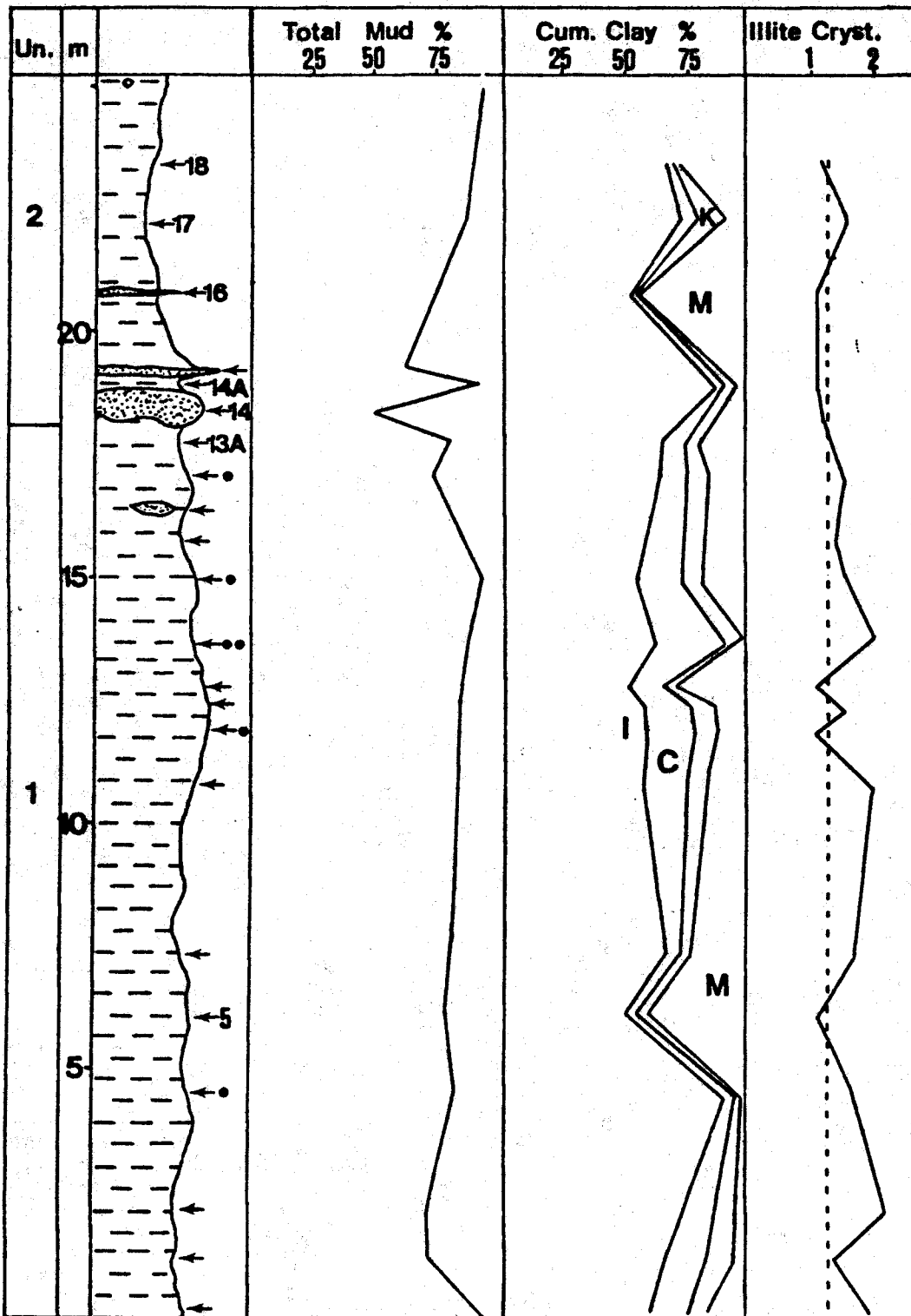


Figure 18

Fossils are sparse throughout this section. In the lower half, a low abundance of well-preserved ostracodes and phosphatic fragments, possibly fish plates were recovered.

West Welch (SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 30,
T28N,R20E, Craig Co., Ok.)

The West Welch exposure includes a complete section of the Lagonda interval, which has thinned to only 9m. The upper contact of the Verdigris Limestone is abrupt and perhaps erosional. Approximately 1.75m of muddy, sparsely fossiliferous shale with productid brachiopods overlies the contact (Unit 1). The muddy shale grades upward into 4m of unfossiliferous silty shale (Unit 2). This silty shale is interstratified with 0.1m beds of laterally continuous siltstones. Unit 3 consists of silty shale and siltstones interstratified with 0.4m beds of very fine-grained sandstones. These sandstones are rippled in 1-5 cm beds, dip 8-10 degrees west, grade laterally towards the east into silty shales, and display an overall channel-like geometry with sharp erosional bases. Above this sequence of sandstone, 1m of coal and underclay occur.

Clay mineralogy data are illustrated in Figure 19. Illite crystallinity values are low throughout the sampled interval, with only the shale between the upper two sandstones demonstrating a value that is greater than 1.2 (Figure 19). Mixed-layer clay percentages are high in samples 4, 5, 6, 8, and 9 (Figure 19). Low mixed layer clay percentages occur at samples 3, 7, and 10. A large increase in kaolinite occurs in the upper 1.5m of the sampled interval.

Figure 19: Data acquired from West Welch section. Arrows indicate sample points. Dots (•) indicate relative abundance of probable eurytopic fossils (productids and ostracodes); 0 dots = barren sample, 1 dot = 1-10 specimens, 2 dots = 11-20 specimens, 3 dots = 21-30 specimens, and 4 dots = more than 30 specimens for each sample examined. I = illite; C = chlorite; K = kaolinite; M = mixed-layer clays. Values to the right of dotted line in illite crystallinity column indicate illite crystallinity values greater than 1.2.

Fossils (productid brachiopods) were recovered only from the lowest shale sample processed.

Core Samples (Location in Appendix D)

The cores used in this investigation (some of those used by P. N. Reinholtz, MS thesis, in preparation, Univ. of Iowa) are located northwest of the outcrop belt (Figure 3). Core intervals consist of interstratified shales and silty shales, which become gradationally sandier upward. The core samples chosen for clay mineralogic examination were somewhat biased as shales were extracted from only the more mud-rich areas in the lower sections of the cored interval due to drilling biases. As a result, no clay mineralogy data was available to analyze vertical changes as the shales became sandier.

The mud-rich samples examined were all similar. Kaolinite percentages were low (0%-10.9%), illite percentages ranged from 41.5%-57.9%, chlorite percentages ranged from 21.8%-36.2%, and mixed-layer clays varied between 8.6%-33.9%. Illite crystallinity values were extremely high, never falling below 1.8.

It is conceivable that the consistently high illite crystallinity values found in these samples reflect the unweathered nature of the core material. As a result, it is also conceivable that the low crystallinity values encountered in some outcrop samples are the results of weathered rocks, even though care was taken to collect only fresh samples. I believe that differential weathering between outcrops and cores is present but not a problem for

depositional interpretations. The illite crystallinity values attained from both outcrop and core samples reflect relative trends, and trends seen on outcrop represent valid relative values which can be incorporated into depositional interpretations.

ENVIRONMENTS OF DEPOSITION

Clay Mineralogical Considerations

A wealth of data has been published in the past few decades dealing with what clay mineralogy can indicate about depositional environments (e.g. Biscaye, 1965, Grim and Johns, 1954, Milne and Schott, 1958, Milne and Earley, 1958, Johns and Grim, 1958, Taggart and Kaiser, 1960, Griffin and Ingram, 1955, Powers, 1957, Grim, 1951, Pryor and Glass, 1961, Degens, et al., 1957, Weaver, 1958). From these studies, a few generalizations can be made concerning both modern and ancient marine sediments.

All types of clay minerals have been identified in recent marine sediments. Illite and chlorite are abundant components, with kaolinite commonly abundant in local nearshore areas (Grim, 1968). It appears that in marine sediments, kaolinite is very slowly altered to illite or chloritic mica (Grim, et al. 1949). It also appears that any of the major clay minerals can occur in any ancient depositional environment. Clay minerals seem not to be restricted to particular environments. However, either illites, smectites, or mixed layer clays can occur as the only clay minerals present in any of the major depositional environments, while kaolinite appears to be dominant only in fluvial and nearshore environments.

Depositional interpretations are further complicated by the extreme variability of the structures of the clay minerals and their

ion-exchange capacities. These properties allow atomic substitutions within clay lattices, thereby introducing diagenetic alterations between source and depositional areas.

The facts cited above suggest that definitive statements concerning depositional environments can not be inferred solely from the clay mineralogy present in any sample. However, upon careful inspection of certain parameters of clay minerals, depositional models can be suggested.

Use of Semi-quantitative Clay Percentages

The value of individual clay percentages throughout a sequence of rocks lies in large percentage fluctuations, which occur both abruptly and gradually throughout a complete sequence of strata. Abrupt changes are used in this study to suggest rapid fluctuations in some aspect of source area or depositional rate. Since diagenetic studies (e.g. Grim, 1958) suggest that all clay minerals can alter to illite and chlorite, the percentage values for these two clay types may be reflecting actual differences in source areas, or they may be reflecting differing diagenetic histories. These two possibilities result in vastly different geologic interpretations, and the inability to adequately conclude which process was dominant casts doubt on the reliability of interpretations based solely on the percentage values obtained for these two clay minerals.

Weaver (1958) and Pryor and Glass (1961) showed that kaolinite is dominant mainly in fluvial and nearshore environments. Variations in kaolinite thus should reflect relative nearness to

terrestrial sources with greater amounts of kaolinite present nearest the source. This is especially true in equatorial regions (as the Pennsylvanian mid-continent) where leaching produces large amounts of kaolinite. This relationship is used to aid in the evaluation of distance from shoreline in marine environments.

Mixed layer clay structures are of two different types. The interstratification of individual clay types may be regular, with stacking along the c axis due to a regular repetition of the differing layers. In such cases, the unit cell is equivalent to the sum of the component layers, and regular 001 x-ray reflections are obtained. Since this unit cell is a combination of more than one clay type, a "super-cell" is picked up on the x-ray diffraction pattern. The location of the peak of this super-cell is the sum total of all the 001 dimensions present in the mixed layers. This results in characteristic peaks larger than 20 \AA .

Another kind of mixed layer structure is due to a random irregular interstratification of layers in which there is no uniform repetition of layers. Gruner (1934), Bradley (1945), and Weaver (1956) emphasized the occurrence and importance of random mixed layers. Due to their lack of repetition, no characteristic x-ray diffraction peak exists to aid in identification.

Clay mineral grains range in size from 0.4 microns to 10 microns (Gibbs, 1977). As no super-cell x-ray peaks were identified, the randomness of the clays encountered in this study suggests lack of sorting and rapid deposition. This relationship is related to the percentage of mixed layer clays present in a sample, with higher

values suggesting more rapid sedimentation. Additionally, more rapid sedimentation insulates the sediments from marine diagenetic processes, allowing less alteration of the mixed layers to highly crystalline illites and chlorites. In this study, high mixed layer percentages (20%-50%) are inferred to represent higher sedimentation and burial rates, while lower percentages (0%-20%) represent slower sedimentation and burial rates where marine diagenetic processes have altered the clays.

The degree of crystallinity (sharpness of x-ray diffraction peaks) of each clay mineral is an indirect way of evaluating how well-ordered a clay mineral is. As a result, variations in peak shapes are useful in the interpretation of weathering profiles and diagenetic alterations.

Use of Illite Crystallinity Indexes

Another parameter that was employed was the illite crystallinity index, which is dependent on a shape parameter of the illite 001 peak. This variable can be related to the degree of leaching illite has undergone. During the leaching process (e.g. in a weathering profile), loss of potassium ions occurs, increasing the amount of expanding clays present (Weaver, 1965). This affects the illite by lowering its crystallinity, and is represented on x-ray patterns as a broader, less intense peak. The illite crystallinity index is plotted in a vertical arrangement, illustrating crystallinity gradations through time. Low values, representing broad, flat peaks and ranging from 0.5-1.2, suggest degraded illites (Weaver, 1960).

They are interpreted in this study to represent weathering horizons if the mudrocks are massive (without bedding), or materials derived from weathering horizons if the mudrocks are bedded. Values of 1.2 or greater, representing sharper peaks, demonstrate more highly crystalline structures (Weaver, 1960), and are inferred to represent slower, marine sedimentation where illite regains K^+ , if mixed-layer percentages are low. Values of 1.2 or greater are inferred to represent unweathered bedrock sources of illite if mixed layer percentages are high.

Paleontological Considerations

Fossil data were sparse, and consisted of low diversity faunal assemblages. Productid brachiopods were the most abundant fossils encountered and frequently made up the entire faunal assemblage. Although poorly preserved in most cases, several examples of ?Desmoinesia were identified (Figure 20). The ostracode Cavellina (Figure 21) was also present in several samples. In view of the low diversity of these assemblages, the organisms apparently were eurytopic, able to withstand broad salinity and turbidity fluctuations.

One sample (LC-4) contained an abundant normal marine assemblage of sea-cucumber sclerites and crinoid columnals in addition to the brachiopods and ostracodes normally encountered. Unidentified phosphatic plates, possibly fish plates, were occasionally recovered from residues in the Neosho River Park section. The carbonate

Figure 20: Productid brachiopod ?Desmoinesia. Bar scale equals .5
mm.

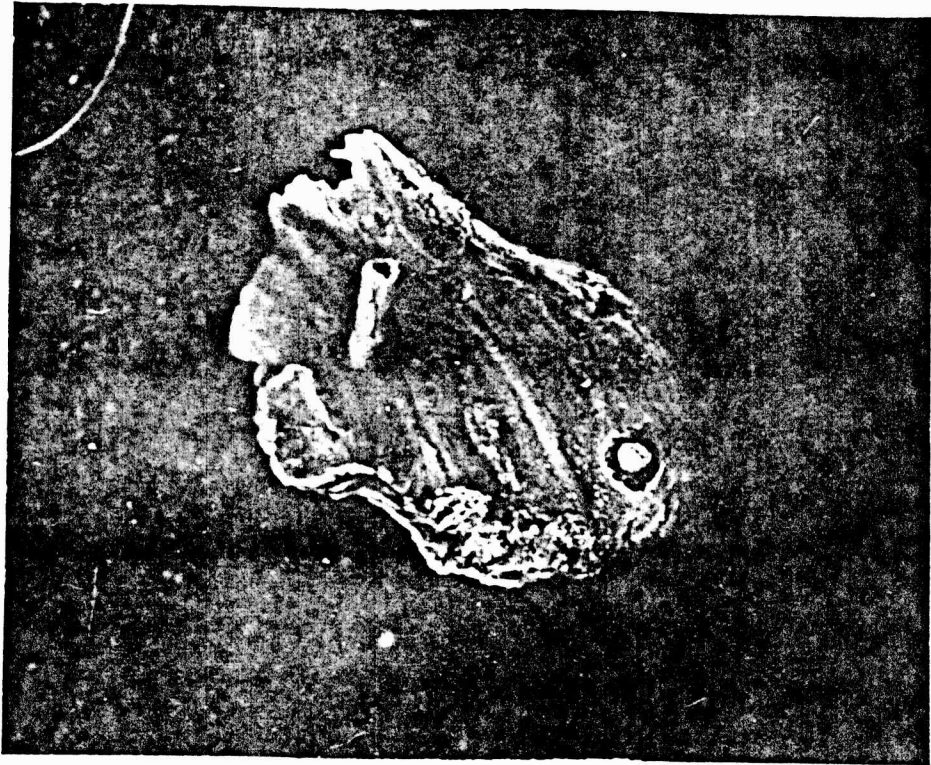


Figure 20

Figure 21: Ostracode Cavellina and one productid spine. Bar
scale equals .5 mm.

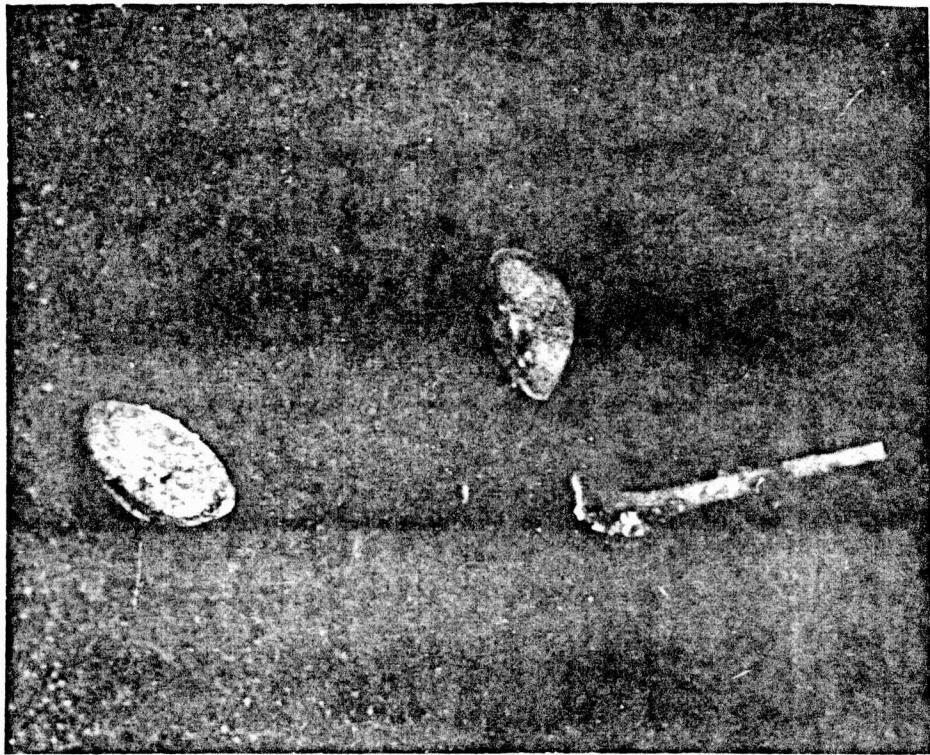


Figure 21

concretions encountered consist of mud-sized carbonate grains surrounding a nucleus of brachiopods and snails.

The general low diversity in conjunction with lack of open marine fauna (except LC-4) and the presence of organisms known today to be adaptable to restricted conditions suggests an overall restricted depositional environment of fluctuating salinities and turbidities.

Fluctuations in depositional rates were reflected in the abundances of fossils found. During periods of increased sedimentation rates, clastic material diluted faunal abundances. Specimens were also poorly preserved in these intervals. Intervals of slower sedimentation rates exhibited increased abundance and better preservation.

Reliability of Data

The key to the usefulness of the preceding observations is that internal consistency was strictly maintained in attaining this data. This was accomplished by always using the same peak locations in the quantitative analysis of clay minerals, and identical sample preparation for both the clay mineral samples and the shales which were processed for fossils and sediment size data. As a result, the variations between and within the samples studied are comparable to one another, and depositional interpretations can be made with a greater degree of confidence.

Previous work (mentioned earlier) has adequately described the geologic history underlying the deposition of Pennsylvanian cyclic

deposits in the mid-continent. The intent of this study is not to test or challenge these observations and interpretations, but rather to observe relationships and interpret depositional facies within the Lagonda deltaic sediments deposited during an overall regressive phase of Pennsylvanian cyclic sedimentation. Interpretations and observations formulated in this study concur with the previous interpretations of regression, and will be the basis for further interpretations concerning source areas, sedimentation rates, and fossils.

FACIES RECOGNITION

The integration of all parameters discussed in the preceding paragraphs has led to the development of three recognizable facies of Lagonda sedimentation: 1) a slowly deposited prodeltaic mud facies, 2) a shoreline coastal facies, and 3) a prograding delta front facies (Figure 22).

Prodeltaic Mud Facies

High illite crystallinity values (1.2 or greater), high total mud percentages (75% or greater), low kaolinite percentages (0%-10%), and low mixed-layer clay percentages (0%-20%) are characteristic of the prodeltaic mud facies. These values suggest a depositional environment which: 1) was not close to a terrestrial source, 2) was receiving mostly mud-sized material, and 3) was experiencing slow sedimentation rates.

The characteristics of this facies are best displayed in the Neosho River Park section (Figures 18 and 23), the lower 5m of shale in the North Arma highway 69 section (Figures 15 and 24), and the core sections sampled. Within these samples, decreases in illite crystallinity values and total mud percentages are directly related to co-existing increases in mixed layer clay percentages (refer to sandstone intervals in Figure 18 in particular). These fluctuations suggest a temporary increase in sedimentation rates,

Figure 22: Location of three facies recognized in the Lagonda interval. Prodeltaic muds are located beyond the reaches of active deltaic sedimentation . Active sedimentation deposits silty shales just landward of the prodelta mud facies. Shoreline coastal environments include fluvial systems that empty into the basin, providing sediments for deltaic progradation.

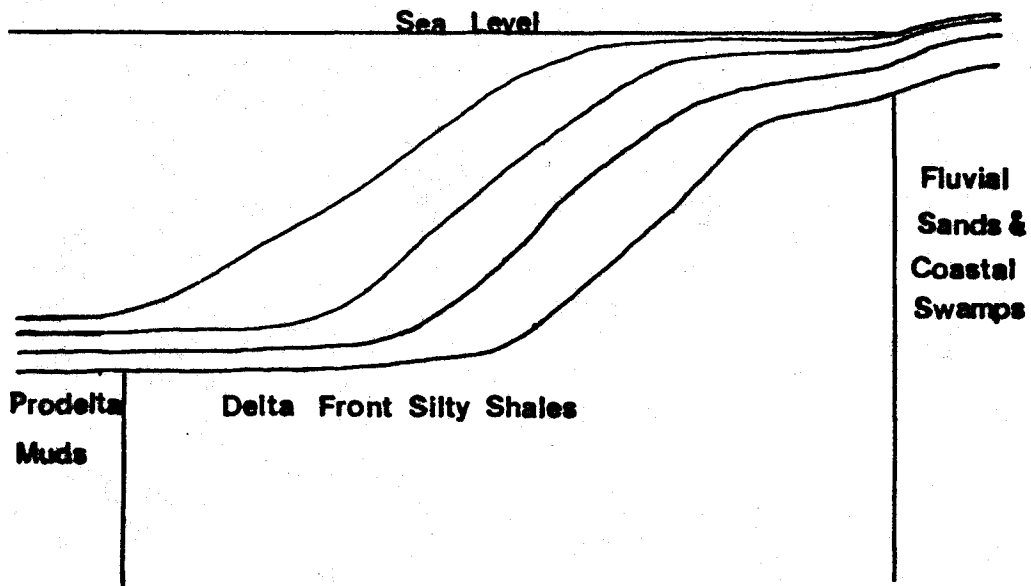


Figure 22

**Figure 23: Depositional environments represented in Neosho River
Park section.**

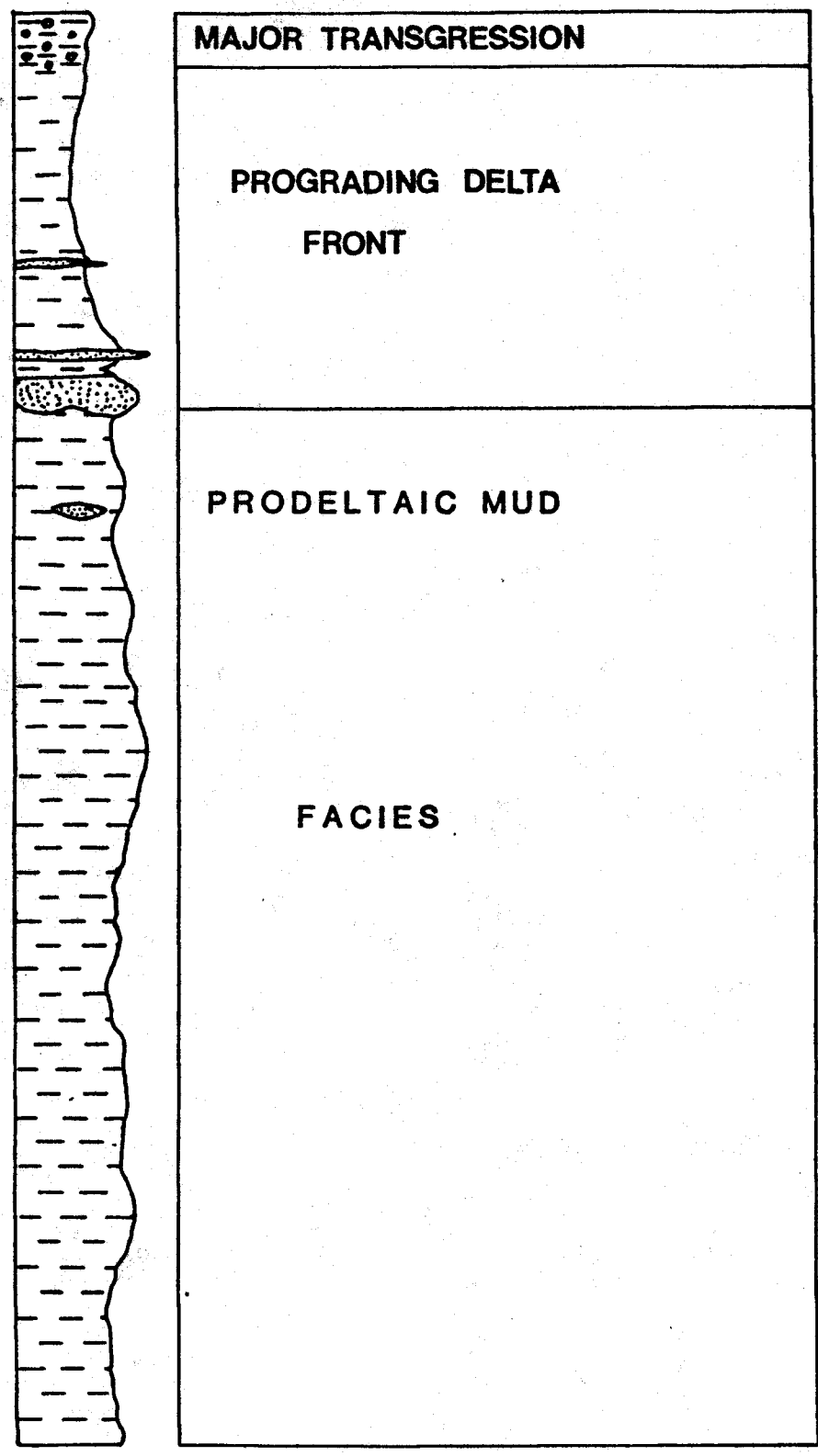


Figure 23

Figure 24: Depositional environments represented in North Arma section.

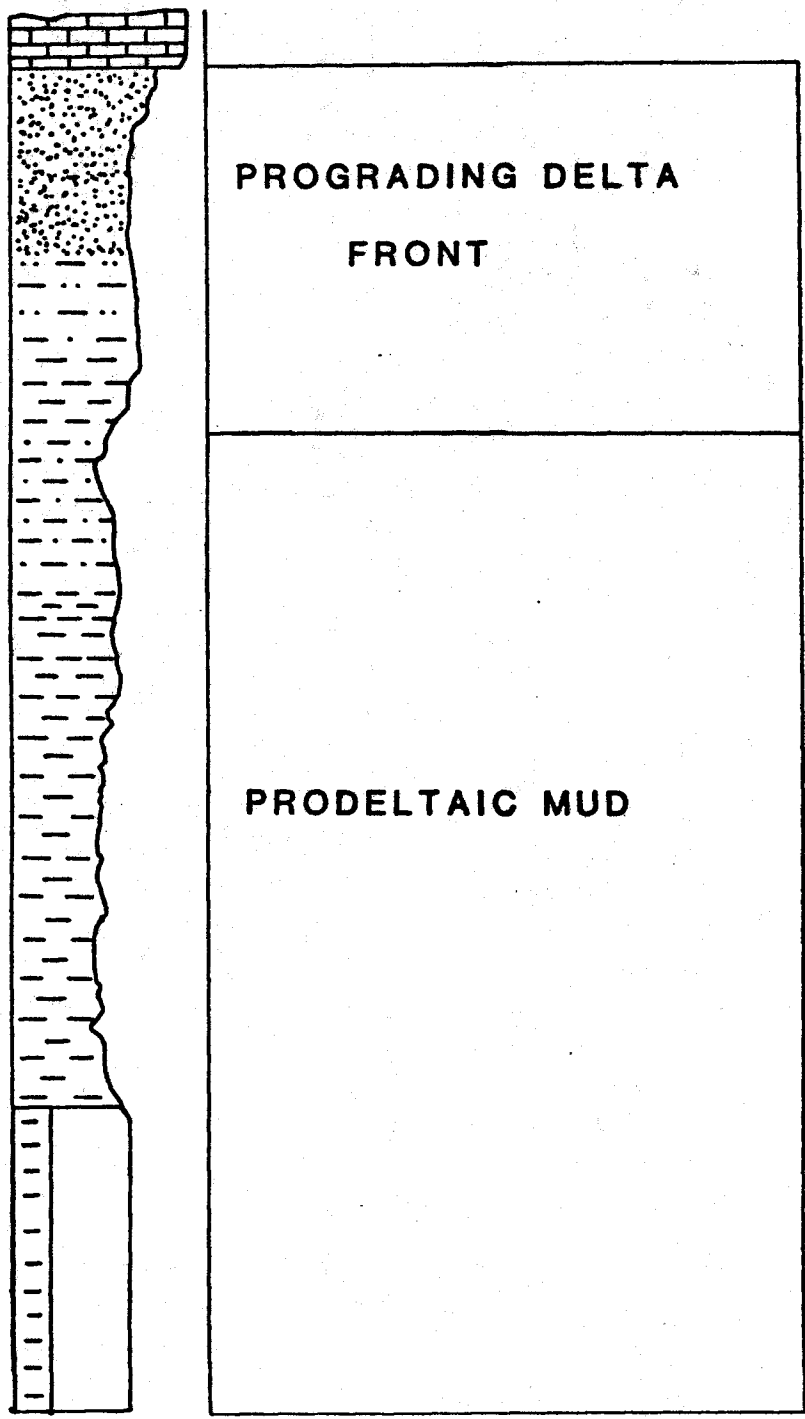


Figure 24

and probably represent extensions of delta front sedimentation during peak periods of sediment supply.

Shoreline-coastal Facies

The shoreline-coastal facies is characterized by the presence of coal beds and seat earths with stratigraphically equivalent sandstones and siltstones. Shales and silty shales are subordinate lithologies, represented in this facies as underclays and soils where illite crystallinity values are very low (0.5-0.8) and bedding is massive. Sandstones and siltstones display sedimentologic features characteristic of fluvial environments, such as unidirectional current ripple marks, convex downward geometries, and erosional bases, and also display high kaolinite percentages (15%-55%), low total mud percentages (0%-30% clay), and an absence of fossil evidence. Mixed layer clay percentages are moderate to high (20%-60%). These criteria support a fluviially dominated environment where sedimentation rates fluctuated in response to changing flow regimes and sediment supplies.

Sections in this study that demonstrate these criteria are the basal coal at the NE Foster section (Figures 11 and 25), and sandstone-coal intervals at the NE Foster and Lawrence Cemetery sections (Figures 11, 12 and 26), the upper 1.5m at the West Croweberg section (Figures 16 and 27), the coal-underclay and sandstone interval (Unit 3) at the top of the West Welch section (Figures 19 and 28), and Unit 2 at Osage Cemetery section (Figures 17 and 29). Fluctuations in illite crystallinity values reflect the

Figure 25: Depositional environments represented in NE Foster section.

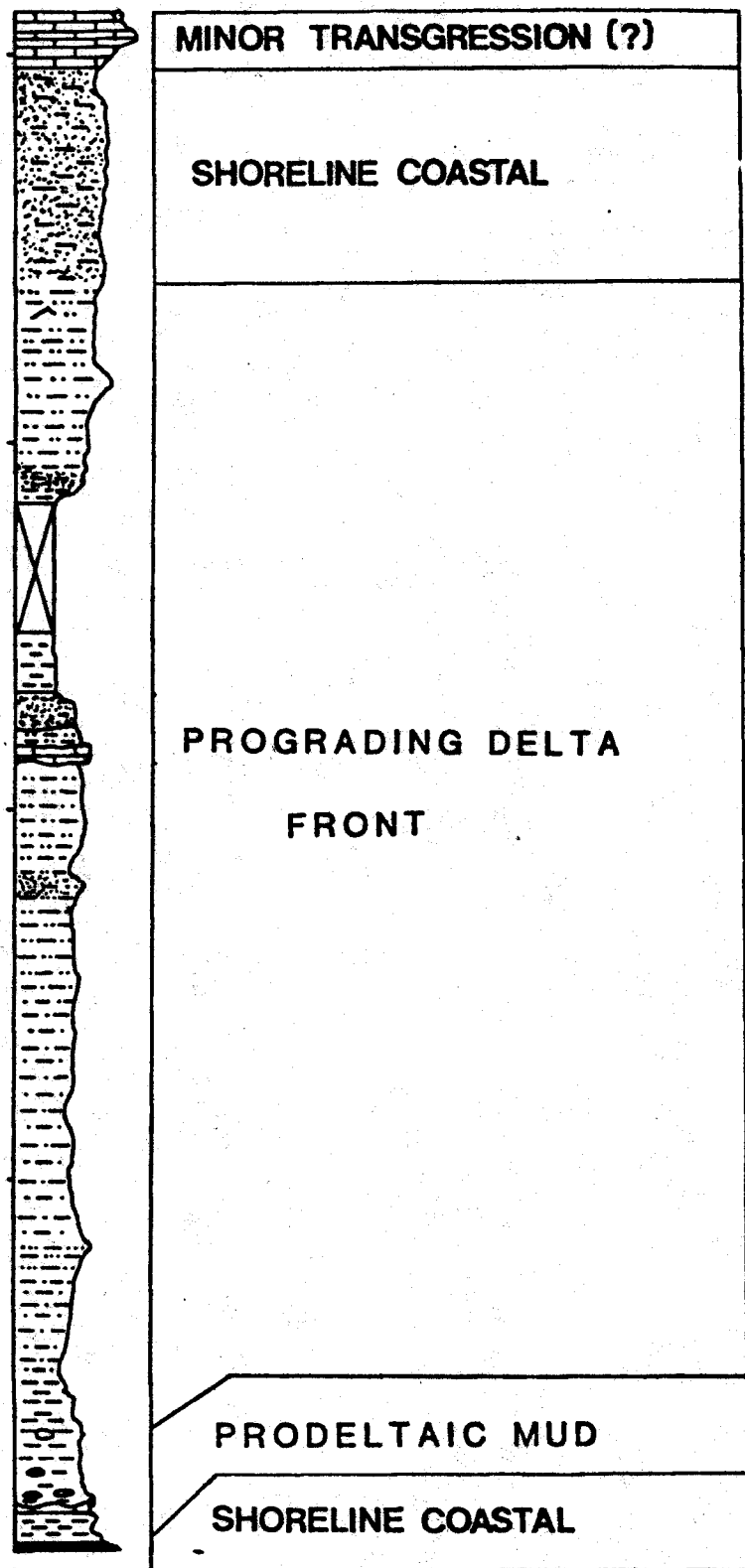


Figure 25

Figure 26: Depositional environments represented in Lawrence Cemetery section.

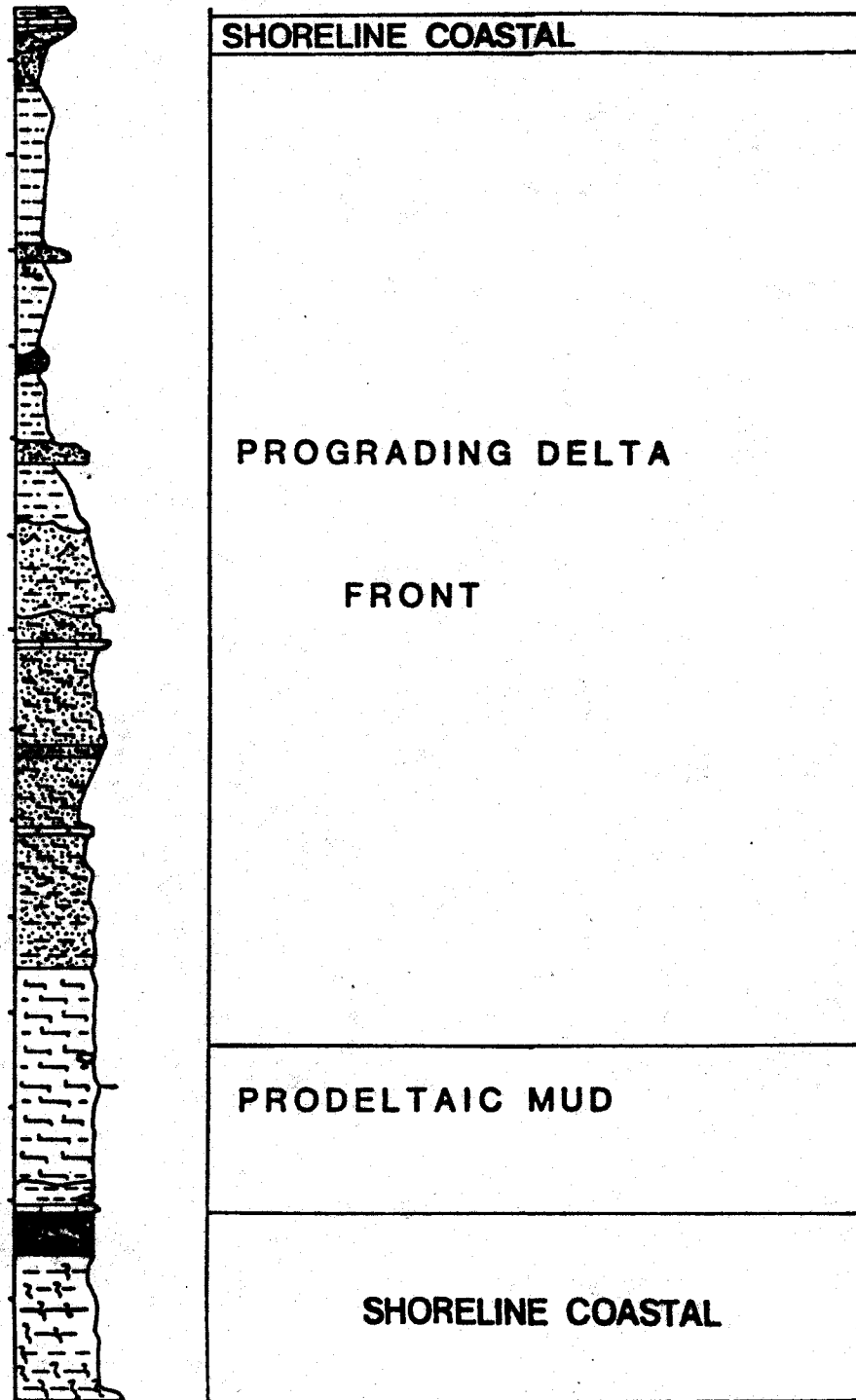


Figure 26

Figure 27: Depositional environments represented in West Croweberg section.

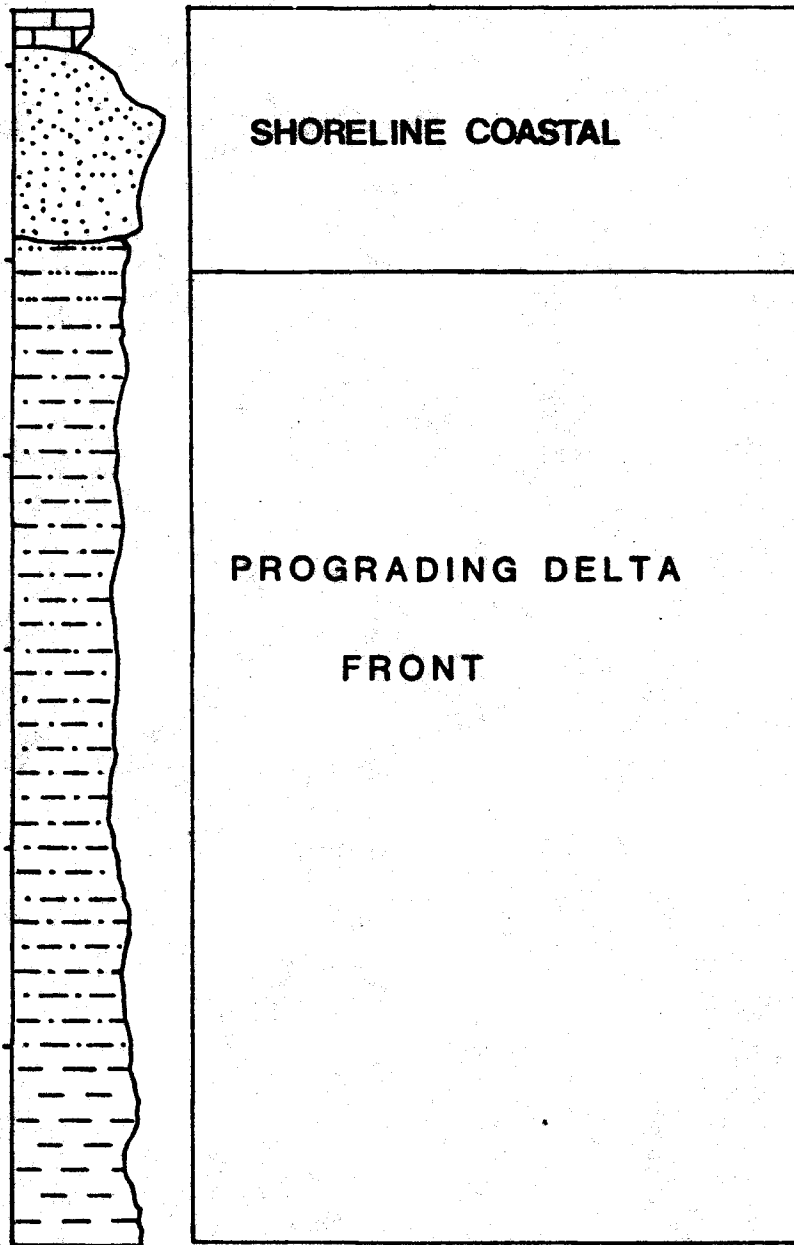


Figure 27

Figure 28: Depositional environments represented in West Welch section.

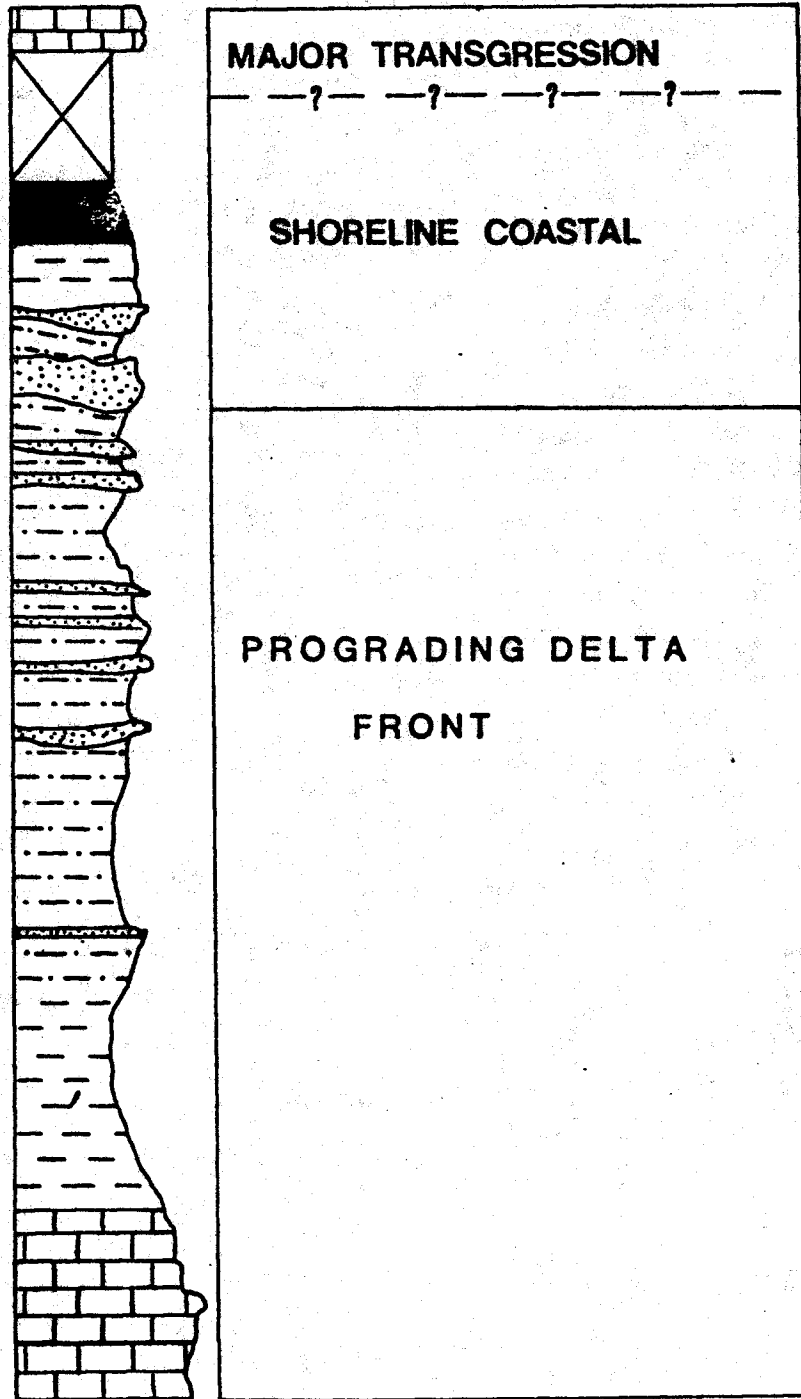


Figure 28

Figure 29: Depositional environments represented in Osage Cemetery section.

variations in source material being eroded, with values less than 1.2 representing eroded soil profiles and values greater than 1.2 representing eroded bedrock.

Delta Front Facies

The prograding delta front facies is transitional between the prodeltaic mud facies and the nearshore-coastal facies. As a result, the delta front facies can be recognized only by identifying gradual changes in parameters. These changes will grade from "more prodeltaic mud facies" to "more shoreline-coastal facies," as delta lobes prograde over an area.

Progradation of deltaic lobes occurred: 1) during sea level stillstands as fluvial systems built their way into the basin, or 2) during regression where shifting coastlines forced these deltaic lobes to migrate toward the basin. In either case, fluvial influences were shifting across the area of progradation through time. This would result in greater kaolinite percentages upward, greater mixed layer clay percentages upward, decreased faunal abundance upward, and decreasing total mud percentages upward. Illite crystallinity values in this facies reflect which type of source material was being provided.

Sections in this study which display these gradational changes are the lower 4m of shale at the West Welch section (Figures 19 and 28), Unit 1 at Osage Cemetery section (Figures 17 and 29), the upper 2m of shale and siltstone at the North Arma highway 69 section (Figures 15 and 24), the West Crowberg section (Figures 16 and 27),

units 3 and 4 at the Lawrence Cemetery section (Figures 13 and 26), units 2 and 3 at the NE Foster section (Figures 11 and 25), and Unit 2 at Neosho River Park (Figures 18 and 23).

This facies is obviously the most widespread of the three facies recognized in this study. Combinations of parameters within this facies provided evidence for the recognition of 3 types of depositional events within the overall generally regressive Lagonda sequence.

Minor transgressive events were recognized by a change in illite crystallinity values, an associated increase in mixed-layer clay percentages, but no change in total mud percentages. At the NE Foster section (Figure 11), the base of unit 2 marks the onset of a transgressive event. This transgression shifted the shoreline to an area where unweathered, highly crystalline source material was being provided to the depositional basin. The shifting shoreline moved the main area of delta front deposition away from the NE Foster area, allowing less turbid, slower sedimentation rates in this area. This interpretation is supported by a shift to higher illite crystallinity values, lower mixed layer clay percentages, and abundant productid spine remains in the lower few meters of unit 2 (Figure 25). Deltaic progradation began working its way over the NE Foster area throughout the rest of unit 2, increasing the turbidity and burial rates. This is supported by gradually increasing mixed layer clay percentages and decreasing occurrences of productid spines upward (Figure 11).

Regressive events were recognized by upward-decreasing illite crystallinity values, decreasing total mud percentages, and/or increasing kaolinite percentages. At the NE Foster section (Figure 11), unit 3 reflects a change to soil derived sediments, suggested by decreasing illite crystallinity values. As regression occurred, unconsolidated delta front muds and sands which had been deposited during higher sea level stands became subaerially exposed, resulting in degraded and reworked clay minerals. Plant growth on these unconsolidated sediments would have begun developing soil profiles, and erosion of these sediments provided the low illite crystallinity values encountered in unit 3.

Decreasing total mud percentages upward (North Arma and West Croweberg sections—Figures 15 and 16) demonstrate an increasing supply of sand-sized grains. This suggests a regressive event where shifting shorelines and higher energy fluvial environments were providing larger siliciclastic grains to the delta front. Upward-increased kaolinite percentages (North Arma section Figure 15, West Croweberg section Figure 16, Osage Cemetery section Figure 17, and West Welch section Figure 19) also support shifting of terrestrial source areas closer to these areas as regression continued.

Fluctuations in sediment supply were recognized by periodic decreases in total mud percentages associated with increases in mixed layer clay percentages. These fluctuations suggest temporary increases in sedimentation rates, and probably represent extensions of fluvial deposition during periods of peak sediment supply.

The areal extent of the deltaic lobe in northeastern Crawford County, Kansas (refer to Figure 14) can also be recognized. The North Arma section (Figures 15 and 24) is characterized by prodeltaic muds at the base of the sample interval. At the West Croweberg section (Figures 16 and 27), prograding delta front sediments with more direct influence from fluvial environments are present within the same stratigraphic interval. This relationship helps outline the extent of active delta front sedimentation. The deltaic lobe evolved through time by prograding over a larger geographic area. This resulted in the gradual westward shift of the prograding delta front facies, which is displayed higher in the sampled interval at the North Arma section to the northwest.

DEPOSITIONAL INTERPRETATION: LAGONDA INTERVAL

The following discussion is based upon the recognition of the three facies summarized in Figures 23-29. Figure 30 illustrates a cross-section of the lithologies present in outcrop, and together with Figures 23-29 will serve as the basis for facies reconstructions of Lagonda sediments across the study area. The cross section has been hung on the base of the Fort Scott Limestone, and displays the stratigraphic position within the Lagonda interval of each outcrop used in this study. Rock types between outcrops have been inferred, based upon facies interpretations made on the sampled areas.

Early during Lagonda sedimentation, the sea that had deposited the Verdigris Limestone regressed to the southwest. This interval of sedimentation is represented by rocks present at NE Foster, West Croweberg, Neosho River Park and West Welch (Figure 30). Coal deposits at NE Foster and West Croweberg suggest swampy, shoreline-coastal environments at these localities while time equivalent rocks interpreted as prodeltaic muds are represented at Neosho River Park (Figure 23). The abrupt contact between the top of the Verdigris Limestone and the base of the overlying silty shales at West Welch possibly suggests a period of non-deposition prior to Lagonda sedimentation in northeastern Oklahoma. Proposed facies distributions during this time period are illustrated in Figure 31.

Figure 30: Cross-section of inferred facies relationships of outcrop sections. The three time slices illustrated in Figures 31-33 are shown at their stratigraphic positions. The coal at the base of the North Arma (NA) and West Croweburg section is no longer exposed due to strip mine reclamation.

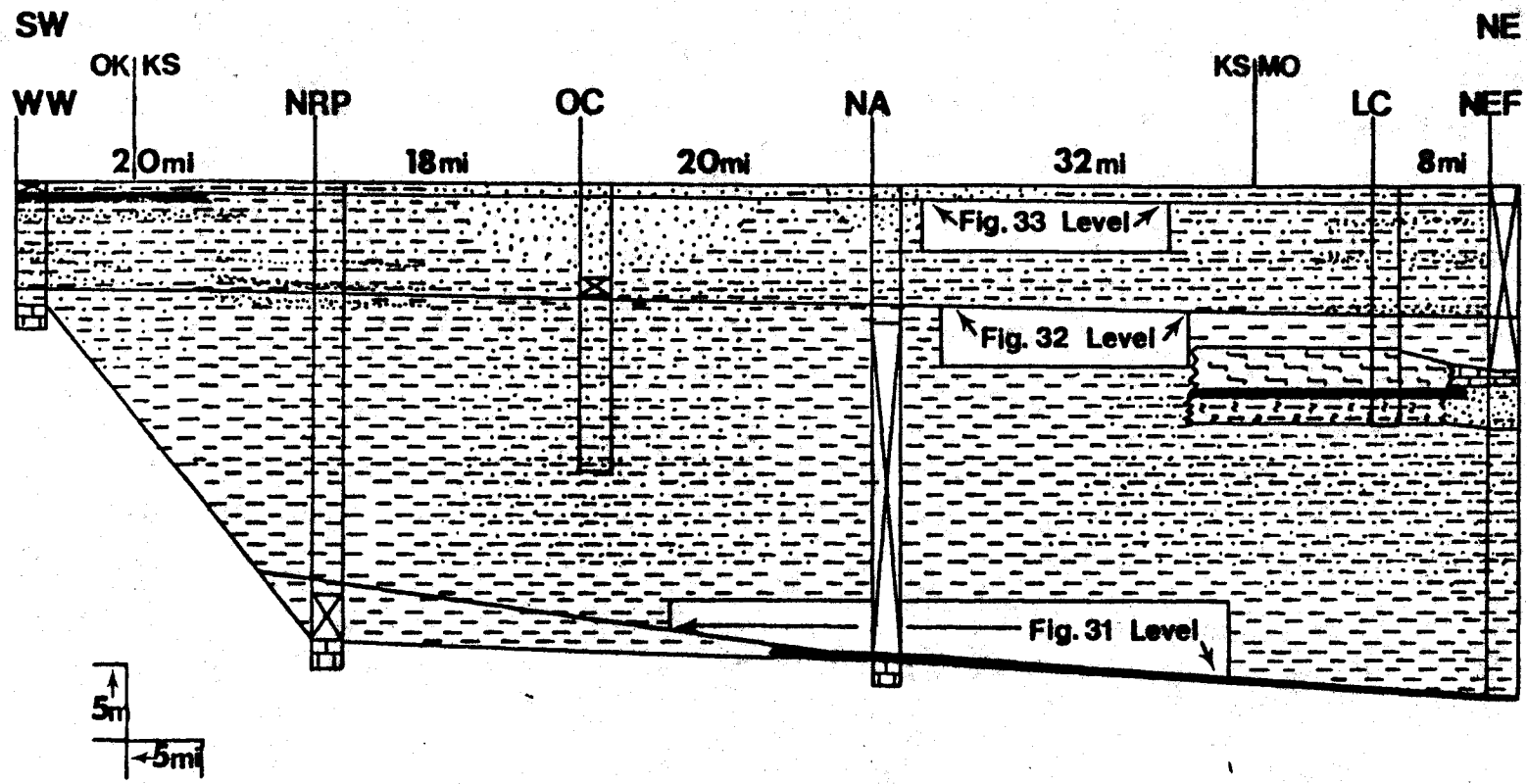
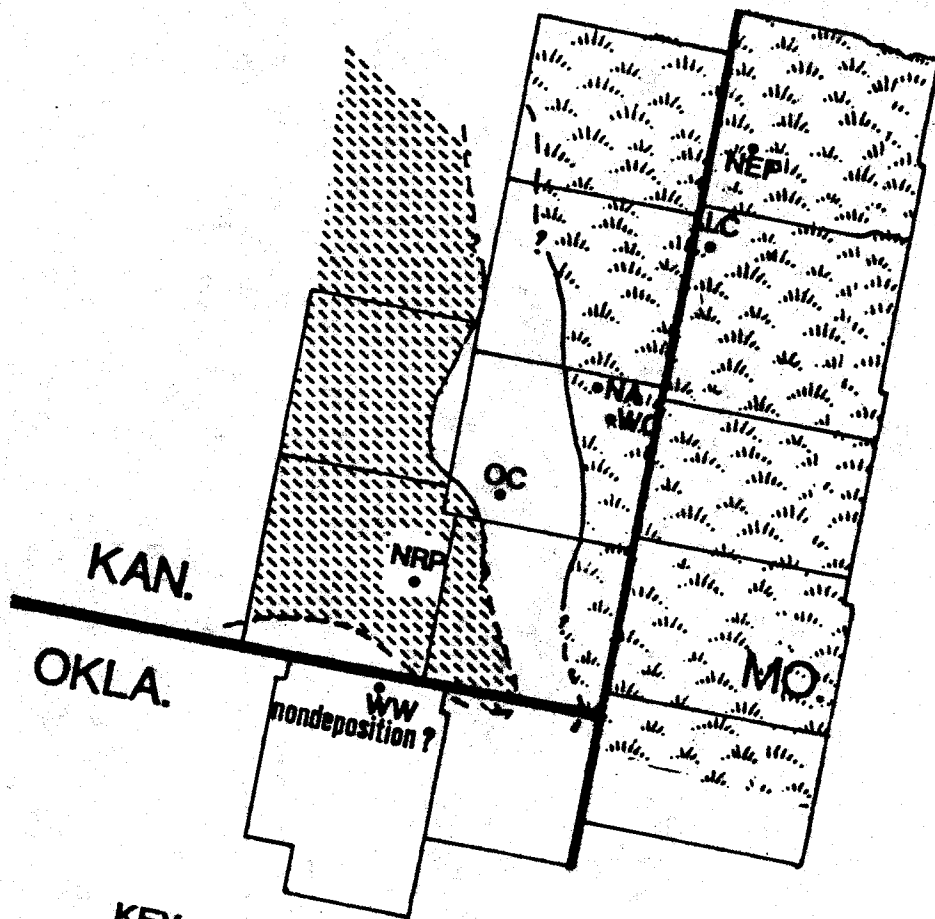


Figure 30

Figure 31: Paleogeographic reconstruction of early Lagonda sedimentation.






- KEY**
-  Swamps & fluvial channels
 -  Prograding delta lobes
 -  Prodelta muds

Figure 31

Subsequent transgression extended across the entire study area, suggested by the presence of the prodeltaic facies at both Neosho River Park and NE Foster (Figures 23 and 27). Thin, fossiliferous limestone beds found within this facies record brief periods of reduced clastic influx and/or turbidity, allowing temporary carbonate production. Discontinuous lenses and beds of carbonate concretions which consist of clay-sized carbonate grains, surrounding a nucleus of brachiopods and snails also record temporary intervals of diagenetic carbonate migration on a local scale.

As sea level stabilized, deltaic progradation began dominating sedimentation in NE Foster (Figure 25), Osage Cemetery (Figure 29), and West Welch (Figure 28). Continued prodeltaic mud sedimentation at Neosho River Park and in Allen and Anderson Counties, Kansas, suggests that areas westward of these localities were still beyond the reaches of prograding delta lobes.

After sea level stabilization, the sea regressed (based on changes in illite crystallinity), shifting the eastern shoreline into southwestern Bates County and northwestern Vernon County, Missouri. This shoreline-coastal environment is represented by fluvial sands at the top of the sampled section at NE Foster (Figure 25) and coals at the base of the stratigraphically equivalent Lawrence Cemetery section (Figures 26 and 30).

This regression was followed by another transgression or delta lobe abandonment, suggested by the open marine fauna present above the coal at Lawrence Cemetery (Figures 13 and 26). As sea level again stabilized, two identifiable deltaic lobes began prograding in a

west-southwest direction (Figure 32). A northern delta lobe provided quartz dominated sediments to the NE Foster/Lawrence Cemetery area, while a southern delta lobe provided quartz and pink feldspathic fragments to the West Croweberg and Osage Cemetery areas. Stratigraphically equivalent rocks in Allen, Anderson, and Labette Counties, Kansas, suggest continued prodeltaic mud deposition from these counties westward. These facies relationships are represented in Figure 32.

Late Lagonda sediment distribution suggests a final regression of the Cherokee sea. This is represented by swamps and fluvial channels at West Welch (Figure 28), West Croweberg (Figure 27), and Lawrence Cemetery (Figure 26), and active prograding deltas at Osage Cemetery (Figure 29) and North Arma (Figure 24). Equivalent sediments deposited at Neosho River Park were also beginning to display characteristics of the deltaic progradational facies (Figure 23). These facies relationships are illustrated in Figure 33.

Figure 32: Paleogeographic reconstruction of middle Lagonda sedimentation.

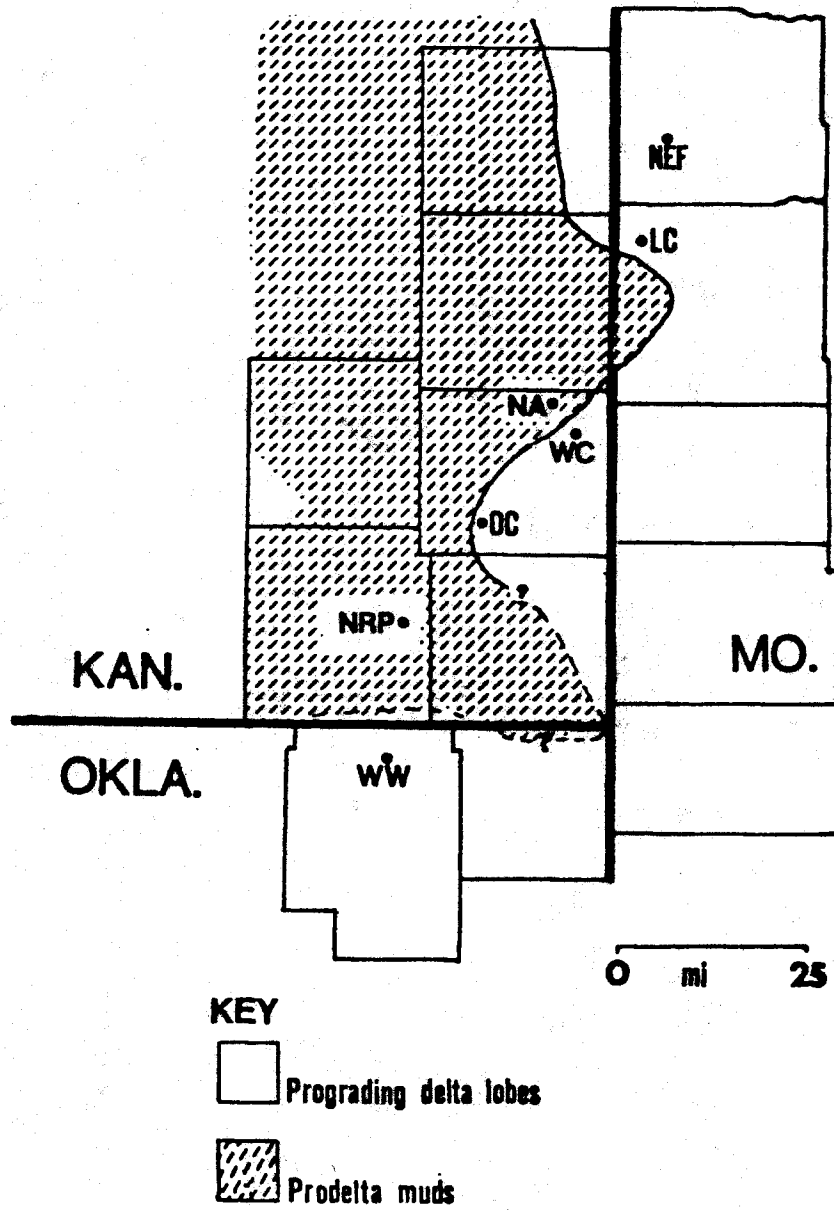


Figure 32

Figure 33: Paleogeographic reconstruction of late Lagonda sedimentation.

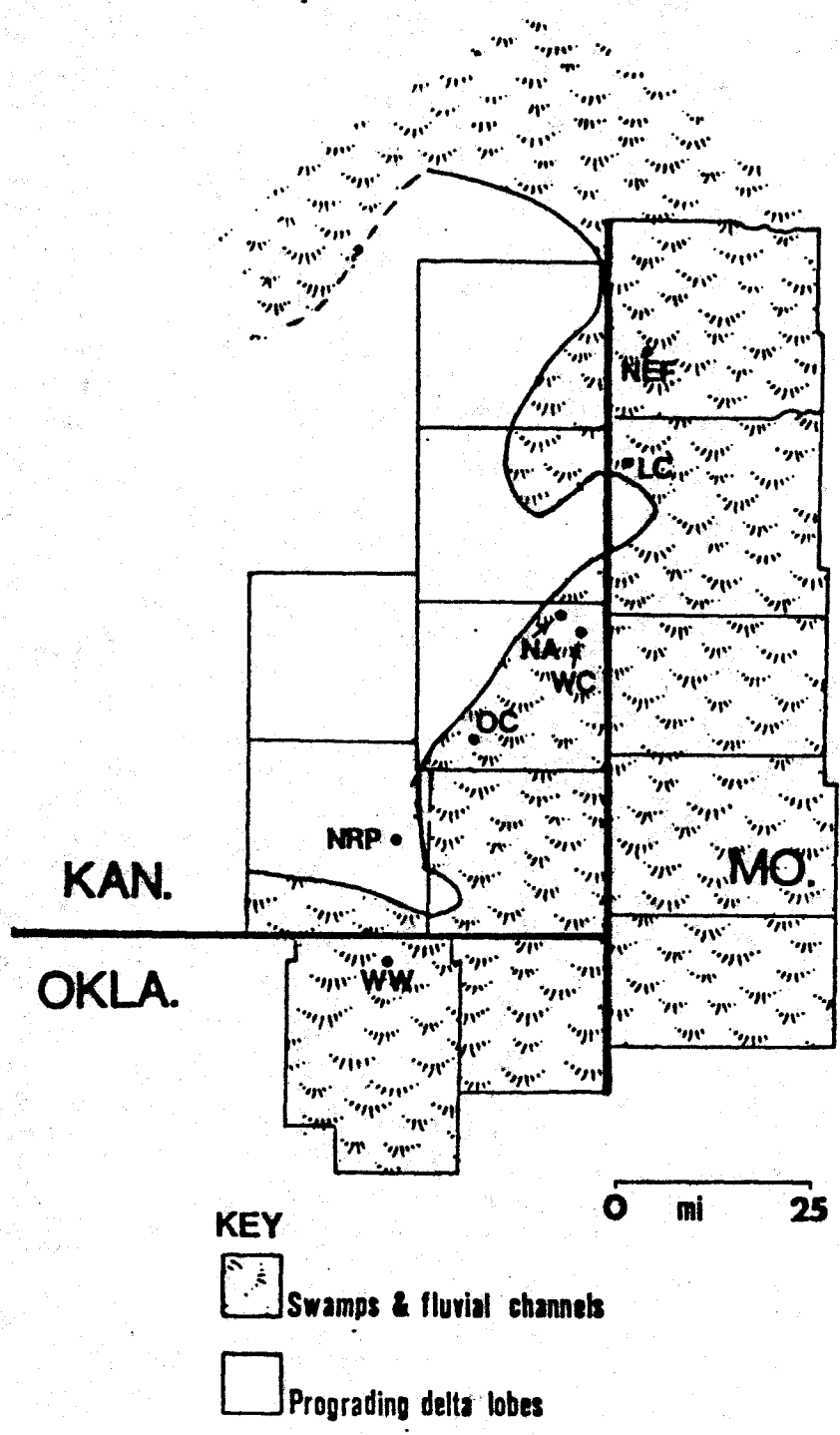


Figure 33

CONCLUSIONS

Study of the clay mineralogy and micropaleontology of the Lagonda interval has led to the following statements concerning the depositional environments of the Lagonda interval:

- 1) High illite crystallinity values, low kaolinite percentages, low mixed layer clay percentages, and high total mud percentages reflect slow sedimentation in an area removed from terrestrial influences; e.g. a prodeltaic mud facies.
- 2) High kaolinite percentages, moderate to high mixed layer clay percentages, low total mud percentages, and fluvial characteristics on outcrop reflect rapid sedimentation in an area in close contact with continental influences; e.g. a shoreline-coastal, swampy distributary stream environment.
- 3) Gradational changes in a vertical sequence in clay mineralogical parameters from characteristics of prodeltaic muds to characteristics of shoreline-coastal environments suggests deltaic progradation through time.
- 4) High illite crystallinity values and high mixed layer clay percentages reflect rapid sedimentation of unweathered source rocks.

- 5) Pulses of sediment influx suggesting higher flow velocities of fluvial streams can be recognized by abrupt fluctuations in total mud percentages and mixed layer clay percentages.
- 6) Where paleontologic data is available, well-preserved specimens of more diverse faunal assemblages suggest prodeltaic mud facies. Decreasing diversities and abundances, and poorer preservation of specimens suggest the more fluctuating turbid and eurytopic environments related to deltaic progradation.

APPENDIX A

SEDIMENTOLOGY DATA FOR

PROCESSED SHALES

	Sieve Sizes			%Mud
	#18	#120	#230	
West Welch				
WW-3		11.6	9.0	
WW-4		3.0	1.2	
WW-5		11.2	5.6	
WW-6		2.0	0.8	
WW-7		15.2	9.2	
WW-8	18.4	34.8	12.4	34.4
Neosho River Park				
NR-1	0.0	6.8	2.0	91.2
NR-2	2.0	13.2	12.2	72.6
NR-3	2.4	13.2	12.2	72.2
NR-4	0.0	7.8	8.9	83.3
NR-5	0.2	11.4	10.0	78.4
NR-6	0.0	10.8	8.4	80.8
NR-7	0.2	8.4	7.8	83.6
NR-8	1.6	6.0	8.5	83.9
NR-9	0.2	5.0	9.2	85.6
NR-10	0.2	5.2	7.0	87.6
NR-11	0.0	3.8	6.4	89.8
NR-12	5.2	5.6	7.8	81.4
NR-13	2.6	17.4	6.6	73.4
NR-13A	1.0	10.5	8.0	80.5
NR-14A	1.0	6.1	2.6	90.3
NR-17	6.4	6.0	2.0	85.6
Osage Cemetery				
OC-1	80.9	3.6	1.8	13.7
OC-2	71.1	6.9	3.2	18.8
OC-3	46.6	13.9	7.1	32.4
OC-4	1.6	11.0	4.6	82.8
OC-5	13.0	18.6	12.0	56.4
OC-5A	21.7	10.7	7.3	60.3
OC-6	56.0	7.1	6.1	30.8
OC-7	45.3	10.4	6.3	38.0
OC-8	11.0	21.0	8.6	59.4
OC-9	43.5	14.4	6.1	36.0
OC-10	9.8	13.8	7.2	69.2
OC-12	33.6	13.4	6.0	47.0

Kansas Geological Survey

Open File Report 1982-31

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	Sieve Sizes			%Mud
	#18	#120	#230	
West Croweburg				
WC-4	1.0	3.6	2.4	93.0
WC-5	5.8	18.5	16.1	59.6
WC-6	11.8	15.5	14.3	58.4
WC-7	0.5	13.9	21.3	64.3
WC-8	70.4	10.9	4.0	14.7

APPENDIX B

ILLITE CRYSTALLINITY INDEXES
OF OUTCROP SAMPLES

Sample	Illite Crystallinity
Neosho River Park	
NR-1	2.0
NR-2	1.4
NR-3	2.2
NR-4	1.7
NR-5	1.1
NR-6	1.7
NR-7	2.0
NR-8	1.1
NR-9	1.5
NR-10	2.0
NR-11	1.6
NR-12	1.4
NR-13	1.5
NR-13A	1.3
NR-14A	1.1
NR-16	1.1
NR-17	1.6
NR-18	1.2
West Welch	
WW-3	1.2
WW-4	1.0
WW-5	0.9
WW-6	1.1
WW-7	0.9
WW-8	0.8
WW-9	9.2
WW-10	0.7
Osage Cemetery	
OC-1	1.3
OC-2	1.5
OC-3	1.3
OC-4	1.2
OC-5	0.9
OC-5A	1.0
OC-6	0.8
OC-7	1.2
OC-8	1.0
OC-9	0.9
OC-10	1.4
OC-11	1.0
OC-12	1.1
OC-13	0.7

Sample	Illite Crystallinity
OC-13A	0.9
OC-14	0.9
North Arma	
NA-1	1.4
NA-2	1.3
NA-3	1.7
NA-5	1.3
NA-6	0.9
NA-7	1.4
West Croweburg	
WC-4	1.0
WC-5	0.8
WC-6	1.2
WC-7	1.2
WC-8	0.5
WC-9	1.0
NE Foster	
NEF-2	1.3
NEF-5	1.4
NEF-5A	0.9
NEF-6	1.6
NEF-7	1.1
NEF-8	1.7
NEF-9	1.8
NEF-9A	2.1
NEF-9B	1.8
NEF-9C	1.9
NEF-9D	1.8
NEF-10	1.6
NEF-11	2.1
NEF-11B	1.0
NEF-11D	1.2
NEF-12	0.9
NEF-13	1.2
NEF-14	0.8
Lawrence Cemetery	
LC-1	0.6
LC-3	0.5
LC-4	0.6
LC-5	0.5
LC-6	0.8
LC-10	0.7

Sample	Illite Crystallinity
Cemetery Creek East	
CCE-8	0.7
CCE-9	0.8
CCE-10	0.9
CCE-12	0.5

APPENDIX C

SEMIQUANTITATIVE CLAY PERCENTAGES

	%Illite	%Chlorite	%Kaolinite	%Mixed layer
West Welch				
WW-3	70.1	18.3	9.9	1.7
WW-4	58.1	11.6	7.8	22.5
WW-5	58.1	12.5	7.0	22.4
WW-6	57.7	9.7	1.9	30.7
WW-7	82.5	9.3	6.6	1.6
WW-8	57.7	4.4	4.4	33.5
WW-10	12.8	0.0	83.1	4.1
Neosho River Park				
NR-1	55.3	18.7	6.2	19.8
NR-2	66.3	16.5	8.2	9.0
NR-4	91.4	5.9	2.7	0.0
NR-5	52.2	3.9	2.6	41.3
NR-6	67.0	6.3	3.5	23.2
NR-7	57.7	17.3	7.1	17.9
NR-8	60.7	18.5	8.5	12.3
NR-9	57.9	19.3	7.7	15.1
NR-10	52.3	11.3	2.9	33.5
NR-11	62.8	28.1	9.1	0.0
NR-12	54.6	19.0	8.4	18.0
NR-13	64.7	11.3	8.7	15.3
NR-13A	65.3	9.2	5.4	20.1
NR-14A	87.6	3.9	2.7	5.8
NR-16	52.0	0.7	0.4	46.9
NR-17	74.1	9.5	6.7	9.7
NR-18	67.1	1.1	1.8	30.0
Osage Cemetery				
OC-3	69.6	22.4	7.1	0.9
OC-4	65.0	17.3	3.8	13.9
OC-5	89.6	3.8	2.5	4.1
OC-5A	59.2	11.5	3.4	25.9
OC-6	66.4	13.6	2.8	17.2
OC-7	75.8	8.9	2.7	12.6
OC-8	86.5	3.0	1.0	9.5
OC-9	53.1	8.9	2.8	35.2
OC-10	36.3	0.0	48.3	15.4
OC-11	37.0	0.0	48.7	14.3
OC-12	47.8	0.0	47.9	4.3
OC-13	45.9	0.0	51.3	2.8
OC-13A	36.0	0.0	54.3	9.7
OC-14	37.8	17.4	7.0	37.8

	%Illite	%Chlorite	%Kaolinite	%Mixed layer
Cemetery Creek East				
CCE-8	62.6	20.9	16.5	0.0
CCE-9	68.8	12.2	4.7	14.3
CCE-10	84.3	3.9	1.9	9.9
CCE-12	78.2	6.1	2.6	13.1
Lawrence Cemetery				
LC-1	57.5	0.0	0.0	42.5
LC-3	59.5	1.3	0.5	38.7
LC-4	85.7	10.9	3.4	0.0
LC-5	36.8	1.8	0.2	61.2
LC-6	56.1	13.9	5.5	24.5
LC-10	92.4	4.4	3.2	0.0
LC-11	88.7	7.5	3.8	0.0
NE Foster				
NEF-2	60.8	9.3	6.3	23.6
NEF-5	61.4	15.6	5.9	17.1
NEF-6	56.2	17.8	6.0	20.0
NEF-7	61.5	26.3	9.7	2.5
NEF-8	59.5	21.9	7.8	10.8
NEF-9	58.7	22.5	11.7	7.1
NEF-9A	58.2	24.0	8.5	9.3
NEF-9C	61.3	17.9	6.5	14.3
NEF-9D	53.3	7.7	3.7	35.3
NEF-10	61.8	2.6	1.4	34.2
NEF-11	79.3	8.1	3.2	9.4
NEF-11D	57.8	21.5	2.8	17.9
NEF-12	65.8	10.8	3.6	19.8
NEF-13	69.5	10.4	3.5	16.6
NEF-14	67.2	13.8	3.7	15.3
North Arma				
NA-1	71.9	21.0	7.1	0.0
NA-2	55.6	29.9	10.2	4.3
NA-3	69.4	11.5	3.4	15.7
NA-5	60.1	24.8	9.3	5.8
NA-6	73.8	6.9	2.5	16.8
NA-7	35.3	0.0	52.2	12.5

	%Illite	%Chlorite	%Kaolinite	%Mixed layer
West Croweburg				
WC-4	59.8	2.8	4.0	28.0
WC-5	28.3	0.0	24.1	47.6
WC-6	64.8	8.5	7.7	19.0
WC-7	46.9	33.8	18.6	0.7
WC-8	22.0	26.4	14.2	37.4
WC-9	28.2	0.0	55.7	16.0

APPENDIX D

CORE LOCATIONS

Well	Approx. Depth Below Excello Shale	Location
H-8	50-55	W $\frac{1}{2}$ E $\frac{1}{2}$ SE $\frac{1}{4}$ Sec 13, T21S, R20E, Anderson Co., Ks.
H-20	50-55	SW $\frac{1}{4}$ Sec 13, T21S, R20E, Anderson Co., Ks.
J-22	45-50	SW $\frac{1}{4}$ Sec 13, T21S, R20E, Anderson Co., Ks.
L-36	?	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec 14, T21S, R20E, Anderson Co., Ks.
H-B	?	SW $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec 14, T21S, R20E, Anderson Co., Ks.
M.C. Colt 18AO Keown	?	Sec 22, T23S, R18E, Allen Co., Ks.

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