PETROLOGY OF THE CROUSE LIMESTONE IN THE VICINITY OF MANHATTAN, KANSAS

by

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INTRODUCTION

Purpose of the Investigation

There is a need for most of the limestone units of Eastern Kansas, which were described nearly 30 years ago, to be restudied by more exact methods. Until recent years limestone units were identified by a few vague adjectives that had no definite or quantitative meanings.

This investigation was undertaken to determine the depositional environment of the Crouse Limestone by the analysis of petrographic data, the application of x-ray data, and the study of insoluble residues and field descriptions.

The Crouse Limestone was chosen for this study because of a lack of recent work on it and the availability of outcrops in the vicinity of Manhattan, Kansas.

Location of the Area

The area of this investigation includes parts of Riley, Pottawatomie, and Geary Counties, Kansas, and is within a radius of 10 miles of Manhattan, Kansas. During the early part of the investigation more than 30 outcrops of the Crouse Limestone were viewed and from these, six complete outcrops were selected; three north of Manhattan and three south. The location of the six outcrops are as follows:

Outcrop A (McDowell Creek section), NE$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$, Sec 27, T11S, R7E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.6 miles east of McDowell Creek.

Outcrop B (K-177 section), SW$\frac{1}{4}$ SW$\frac{1}{4}$ SW$\frac{1}{4}$, Sec 23, T9S, R7E, Riley County, Kansas, a road cut on K-177 one mile west of its junction with K-13.

Outcrop C (Spillway section), NW¼ SE¼ SW¼, Sec 18, T9S, R8E, Pottawatomie County, Kansas, in the spillway cut at Tuttle Creek Dam.

Outcrop D (McDowell Creek Road section), SW¼ SW¼ NE¼, Sec 28, T11S, R7E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.1 mile west of the McDowell Creek Road underpass.

Outcrop E (Clark's Creek section), SW¼ NE¼, SW¼, Sec 25, T11S, R6E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.6 mile west of Clark's Creek.

Outcrop F (Stockdale section), NE¼ SE¼ SW¼, Sec 33, T8S, R7E, Riley County, Kansas, a road cut on the access road to the Stockdale recreation area.

The approximate geographic locations of these outcrops are shown on Plate I.

The area is in the Flint Hills region of the Osage Plains. The Flint Hills extend from Nebraska south across eastern Kansas to Oklahoma and consist of gently rolling hills formed by the dissection of several prevalent beds of cherty limestone that dip approximately 15 feet per mile toward the west.

Stratigraphy and General Description

The Crouse Limestone is in the upper part of the Council Grove Group, Gearian Series (O'Conner, 1963), of the Permian System. The Council Grove Group consists of nearly 300 feet of thin beds of fossiliferous marine shale, and limestone intercalated with beds of non-marine sandstone and shale (Jewett, 1959). Most of the strata of the Council Grove Group are laterally persistent and nearly uniform in thickness.

The Crouse Limestone overlies the Easly Creek Shale and underlies the Blue Rapids Shale. Both of these shales represent very shallow marine deposition (Elias, 1937, p. 406).

EXPLANATION OF PLATE I

Index map of area showing approximate location of outcrops.

Outcrop A (McDowell Creek section), NE$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$, Sec 27, T11S, R7E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.6 mile east of McDowell Creek.

Outcrop B (K-177 section), SW$\frac{1}{4}$ SW$\frac{1}{4}$ SW$\frac{1}{4}$, Sec 23, T9S, R7E, Riley County, Kansas, a road cut on K-177 one mile west of its junction with K-13.

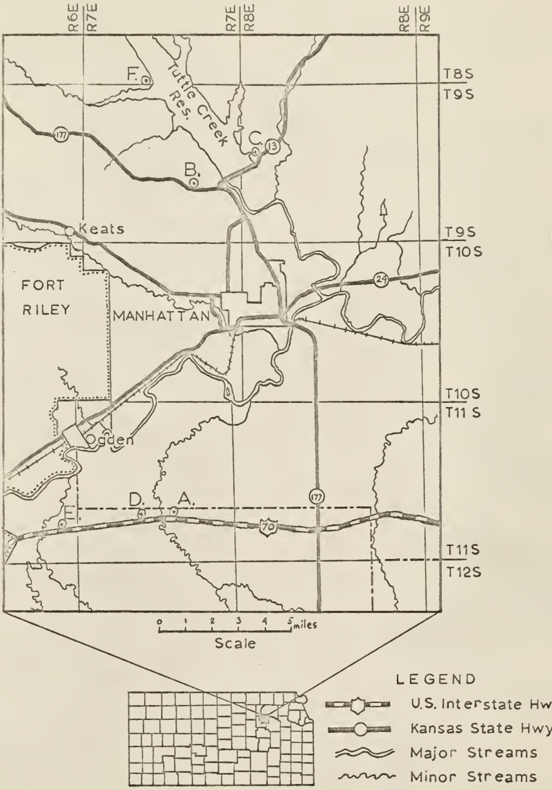
Outcrop C (Spillway section), NW$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$, Sec 18, T9S, R8E, Pottawatomie County, Kansas, in the spillway cut at Tuttle Creek Dam.

Outcrop D (McDowell Creek Road section), SW$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$, Sec 28, T11S, R7E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.1 mile west of the McDowell Creek Road underpass.

Outcrop E (Clark's Creek section), SW$\frac{1}{4}$ NE$\frac{1}{4}$ SW$\frac{1}{4}$, Sec 25, T11S, R6E, Geary County, Kansas, a road cut on U. S. Interstate 70, 0.6 mile west of Clark's Creek.

Outcrop F (Stockdale section), NE$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$, Sec 33, T8S, R7E, Riley County, Kansas, a road cut on the access road to the Stockdale recreation area.

PLATE I


R6E
R7E
R7E
R8E
R8E
R9E
T8S
T9S
T9S
T10S
T10S
T11 S
T11S
T12S
F.
Tuttle Creek Res.
C.
13
177
B.
Keats
24
FORT RILEY
MANHATTAN
Ogden
D.
A.
E.
177
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Scale
LEGEND
U.S. Interstate Hwy.
Kansas State Hwy.
Major Streams
Minor Streams
Outcrops

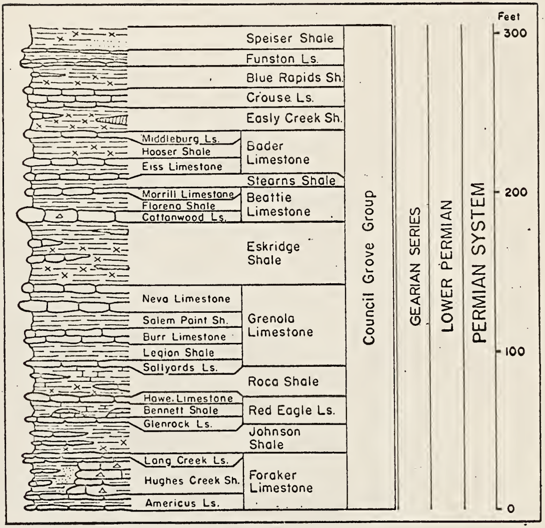


Fig. 1. Stratigraphic section of the Council Grove Group (after Jewett, 1960) and (O'Conner, 1963).

The alternation of beds of limestone and shale is typical of Upper Paleozoic rocks of the Mid-continent region and reflects the successive transgressions and regressions of the Permian Seas (Elias, 1937, p. 406). The stratigraphic position of the Crouse Limestone is shown in Figure 1.

The Crouse Limestone was named by Heald (1917, pp. 21-22) from an exposure at Crouse Hill in the northwest part of the Foraker quadrangle in Osage County, Oklahoma. The type locality is in the NE¼ of Sec 23, T29N, R6E, about 2¼ miles west of

Frankfort, Oklahoma (Condra and Upp, 1931, p. 21). In 1927 Condra (p. 234) named this limestone the Sabetha Limestone, and included it as one of three members in the Bigelow Limestone. The Bigelow consisted, in ascending order, of the Sabetha Limestone, the Blue Rapids Shale, and the Funston Limestone. The Bigelow Limestone was named for the town of Bigelow in Marshall County, Kansas. Later Condra and Upp (1931, p. 21) discarded the name Sabetha when they found that it was correlative with the Crouse Limestone.

In many exposures the Crouse Limestone can be divided into three units; lower, middle, and upper. The lower unit is a dense limestone that is resistant to weathering and contains an abundance of pelecypods, ostracodes, algae, and high-spired gastropods. This lower unit is from 1 to 4 feet thick and forms a bench. The middle unit is an argillaceous limestone that weathers like a shale and is from 3 to 8 feet thick; it grades into the unit above. The upper unit is from 3 to 10 feet thick and weathers to thin plates. The average total thickness is from 10 to 15 feet (Mudge and Burton, 1959, p. 82). The Crouse Limestone is easily identified on aerial photographs due to the covering of thin limestone plates on the surface of the ground.

PREVIOUS WORK

Limestones

A great deal has been written about limestones in general. The classification of them, however, has caused many problems because the rocks are essentially monomineralic, although they do have constituents which originated in a wide variety of ways such as by direct precipitation, as fragments of previous limestones, or by organic processes. Many of the earlier classifications were strictly genetic. One of the first attempts at classification was by Grabau (1904, 1913) who proposed that limestone should be classified according to calcite grain size and introduced the terms calcilutite, calcarenite, and calcirudite, all of which are still commonly used. Other genetic classifications have been proposed by Pettijohn (1957), Krumbein and Sloss (1951), Williams, Turner, and Gilbert (1954), and Carozzi (1960). Johnson (1951) recognized that fossils should be used in the classification of limestones and provided photographs and descriptions to help in identifying organic constituents.

Most of the newer classifications utilize a combination of descriptive and genetic parameters. Bramkamp and Powers (1958) in their work with Arabian carbonate rocks derived a classification which was primarily directed toward the clastic constituents of carbonate rocks and the diagenetic modifications of these rocks. Their four simplified classes are closely related in size to the Wentworth grade scale and they are; (1) aphanitic, (2) calcarenitic, (3) calcarenite, and (4) coarse clastic.

One of the most complete and practical limestone classifications was that of Folk (1959, 1962). It is basically descriptive, but has a definite genetic interpretation.

Folk's classification is based around three major members. These are (1) terrigenous constituents, (2) allochemical constituents, and (3) orthochemical constituents.

(1) Terrigenous constituents include materials which are

derived from the erosion of land outside of the basin of deposition and have been transported into the basin by streams, currents or wind. Common terrigenous materials are clay minerals, quartz sand, silt, etc.

(2) Allochemical constituents (allochems) are discrete particles that originated within the basin of deposition by chemical or biochemical precipitation, having undergone some transportation. These constituents include fossils, pellets, intraclasts (fragments of previously deposited carbonates from within the basin), and oolites. These allochems are similar to the sand grains of a sandstone and form the framework for the limestone.

(3) Orthochemical constituents include microcrystalline calcite and sparry calcite. These are formed within the basin of deposition by chemical precipitation, but unlike the allochems they show little or no evidence of transportation. Microcrystalline calcite (micrite) consists of calcite grains that are 1 to 4 microns in diameter and is deposited as a carbonate ooze. Sparry calcite (spar) is clear calcite which precipitates from solution in pores or voids. These orthochems form the matrix or cement for the allochemical constituents.

Folk also provided for recrystallization in his classification, and has given the name microspar to calcite grains 5 to 15 microns in diameter which have formed by the recrystallization of micrite. The names given the various limestone types are derived from a combination of the different constituent names depending on their relative abundance. He also used different suffixes to differentiate allochem grain size and added prefixes to the basic name to distinguish the predominant terrigenous and fossil material. A brief summary of Folk's classification is given on Table I.

Stauffer (1962), in his work on the carbonate rocks of the Caballo Mountains in New Mexico, added valuable information for the recognition of sparry calcite versus recrystallized calcite. The following is a list of these criteria:

Criteria directly indicative of sparry calcite:

1. Crystals in contact with a once free surface, such as oolites or the inside of shell chambers.
2. Crystals in the upper part of a former cavity which was partly filled with more or less flat-topped detrital sediment.
3. An increase in crystal size away from the wall of an allochem.
4. A decrease in the number of crystals away from the wall.
5. Preferred orientation of the optic axis of crystals normal to the wall.
6. Preferred orientation of the longest diameters normal to the wall.
7. Plane boundaries between crystals.

Criteria suggestive of sparry calcite:

8. Three dimensional packing of allochems.
9. Well sorted allochems.
10. Rounded allochems.
11. Presence of abundant oolites.
12. Size of crystals generally larger than 10 microns.
13. Clear, inclusion free, crystals.
14. Sharp contact between the crystal mosaic and the wall of an allochem.
15. A crystal mosaic entirely filling a more or less obvious cavity or, if only partly filling it, leaving an empty cavity or detritus in the center bounded by protruding crystal faces.

The following criteria are indicative of recrystallized calcite:

1. Irregular grain size of a crystal mosaic with no systematic variation.
2. Truncation by crystal mosaic of previously existing structures such as laminae

Table I. Classification of Carbonate Rocks

Volumetric Allochem Composition	Limestones, Partly Dolomitized Limestones, and Primary Dolomites (see Notes 1 to 6): >10% Allochems, Allochemical Rocks (I and II): Sparry Calcite Cement > Microcrystalline Ooze Matrix — Sparry Allochemical Rocks (I)	Microcrystalline Ooze Matrix > Sparry Calcite Cement — Microcrystalline Allochemical Rocks (II)	<10% Allochems, Microcrystalline Rocks (III): 1–10% Allochems (Most Abundant Allochem)	<1% Allochems	Undisturbed Bioherm Rocks (IV)	Replacement Dolomites[7] (V): Allochem Ghosts (Evident Allochem)	No Allochem Ghosts
>25% Intraclasts (i)	Intrasparrudite (Ii:Lr) Intrasparite (Ii:La)	Intramicrudite* (IIi:Lr) Intramicrite* (IIi:La)	Intraclasts: Intraclast-bearing Micrite* (IIIi:Lr or La)	Micrite (IIIm:L); if disturbed, Dismicrite (IIImX:L); if primary dolomite, Dolomicrite (IIIm:D)	Biolithite (IV:L)	Finely Crystalline Intraclastic Dolomite (Vi:D3) etc.	Medium Crystalline Dolomite (V:D4)
<25% Intraclasts; >25% Oölites (o)	Oösparrudite (Io:Lr) Oösparite (Io:La)	Oömicrudite* (IIo:Lr) Oömicrite* (IIo:La)	Oölites: Oölite-bearing Micrite* (IIIo:Lr or La)			Coarsely Crystalline Oölitic Dolomite (Vo:D5) etc.	Finely Crystalline Dolomite (V:D3)
<25% Intraclasts; <25% Oölites; Volume Ratio of Fossils to Pellets >3:1 (b)	Biosparrudite (Ib:Lr) Biosparite (Ib:La)	Biomicrudite (IIb:Lr) Biomicrite (IIb:La)	Fossils: Fossiliferous Micrite (IIIb: Lr, La, or Ll)			Aphanocrystalline Biogenic Dolomite (Vb:Dl) etc.	
<25% Intraclasts; <25% Oölites; Volume Ratio of Fossils to Pellets 3:1–1:3 (bp)	Biopelsparite (Ibp:La)	Biopelmicrite (IIbp:La)	Pellets: Pelletiferous Micrite (IIIp:La)			Very Finely Crystalline Pellet Dolomite (Vp:D2) etc.	etc.
<25% Intraclasts; <25% Oölites; Volume Ratio of Fossils to Pellets <1:3 (p)	Pelsparite (Ip:La)	Pelmicrite (IIp:La)					

NOTES TO TABLE I

* Designates rare rock types.

[1] Names and symbols in the body of the table refer to limestones. If the rock contains more than 10 per cent replacement dolomite, prefix the term "dolomitized" to the rock name, and use DLr or DLa for the symbol (e.g., dolomitized intrasparite, Li:DLa). If the rock contains more than 10 per cent dolomite of uncertain origin, prefix the term "dolomitic" to the rock name, and use dLr or dLa for the symbol (e.g., dolomitic pelsparite, Ip:dLa). If the rock consists of primary (directly deposited) dolomite, prefix the term "primary dolomite" to the rock name, and use Dr or Da for the symbol (e.g., primary dolomite intramicrite, IIi:Da). Instead of "primary dolomite micrite" (IIIm:D) the term "dolomicrite" may be used.

[2] Upper name in each box refers to calcirudites (median allochem size larger than 1.0 mm.); and lower name refers to all rocks with median allochem size smaller than 1.0 mm. Grain size and quantity of ooze matrix, cements or terrigenous grains are ignored.

[3] If the rock contains more than 10 per cent terrigenous material, prefix "sandy," "silty," or "clayey" to the rock name, and "Ts," "Tz," or "Tc" to the symbol depending on which is dominant (e.g., sandy biosparite, TsIb:La, or silty dolomitized pelmicrite, TzIIp:DLa). Glauconite, collophane, chert, pyrite, or other modifiers may also be prefixed.

[4] If the rock contains other allochems in significant quantities that are not mentioned in the main rock name, these should be prefixed as qualifiers preceding the main rock name (e.g., fossiliferous intrasparite, oölitic pelmicrite, pelletiferous oösparite, or intraclastic biomicrudite). This can be shown symbolically as Ii(b), Io(p), IIb(i), respectively.

[5] If the fossils are of rather uniform type or one type is dominant, this fact should be shown in the rock name (e.g., pelecypod biosparrudite, crinoid biomicrite).

[6] If the rock was originally microcrystalline and can be shown to have recrystallized to microspar (5–15 micron, clear calcite) the terms "microsparite," "biomicrosparite," etc. can be used instead of "micrite" or "biomicrite."

[7] Specify crystal size as shown in the examples.

(Folk, 1962, p. 70)

of oolites and fossil structures.
3. Ghosts of allochems in crystal mosaic.
4. Embayments by calcite crystals, which may have plane sides, into microcrystalline calcite or allochems.
5. Curved, serrated, or interlocking intergranular boundaries between crystals.

Criteria suggestive of recrystallized calcite:

6. Loosely packed allochems.
7. Poorly sorted allochems.
8. Angular allochems.
9. Gradational boundary between calcite mosaic and microcrystalline calcite.
10. Calcite crystal size never smaller than four microns and generally larger than seven microns.
11. Irregular patches of crystal mosaic in microcrystalline calcite.
12. Residual, irregular, floating patches of microcrystalline calcite in the midst of coarser calcite mosaic.

Leighton and Pendexter (1962) have derived a classification which is very similar to Folk's (1959). They used many of the same parameters but their classification is slightly more genetic and they use a different naming system.

In recent years there has been much work on the problem of the formation of limestones. The paleoecological work of Newell, and others (1953) on the Permian reef complex of the Guadalupe Mountains of Texas and New Mexico has added greatly to the understanding of environmental interpretation of limestones. They found that different fossils and limestone types could be used to distinguish fore reef, back reef, and lagoonal environments.

Illing (1954), Newell and others (1959), and Purdy (1960) have added considerable knowledge to the environment of limestone deposition with their studies on the Great Bahama Banks. They found several types of carbonate grains precipitated by physio chemical and bio-chemical action forming on a platform covered by a shallow sea. These grain types included oolites, grapestones, pellets, skeletal debris, and carbonate ooze. The controlling factor in the formation and distribution of the grain types was the tidal currents.

Areal Studies

Elias (1937) wrote one of the earliest papers dealing with the environment of deposition of the Lower Permian Rocks of Kansas. He noted the cyclic deposition and made certain assumptions concerning the depth of water and the marine life inhabiting these depths. In his work he indicated that the Crouse Limestone was deposited during one of the deeper phases at a maximum depth of approximately 110 feet (p. 406).

Jewett (1941) described the Crouse Limestone in Riley and Geary Counties as platy in the upper part, massive in the middle part, and ranging from gray to brown. He also stated that the Crouse Limestone is about 10 feet thick in this area. Jewett and O'Conner (1951, p. 22) described a section of the Crouse Limestone from Morris County that was approximately 20 feet thick and consisted of four major units.

Moore (1962, p. 91) restated and clarified the concepts of cyclic sedimentation of the Lower Permian in the Mid-continent region by discussing five generally accepted conclusions in regard to Pennsylvanian-Permian cyclic sedimentation: (1) the actuality of the cycles, (2) the recognition of regional variation in cyclothems, (3) the significance of the widespread distribution of cyclothems, (4) the significance of cyclic "phases" in terms of paleoecology, and (5) the unique aspect of late Paleozoic cyclic sedimentation.

Mudge and Burton (1959, p. 82) described the Crouse Limestone and gave several locations of outcrops in Wabaunsee County, Kansas. They recognized an upper and lower limestone with a shale between and noted the abundance of fossils in the lower limestone.

Insoluble Residue

An insoluble residue may be defined as the material remaining after a carbonate rock is digested in acid. McQueen (1931, pp. 102-181) published methods of preparation, terminology, and practical application of insoluble residues to problems of correlation. In his work dilute hydrochloric acid was used to digest the carbonates. The fine fraction was decanted, and the coarse fraction was then examined with a binocular microscope.

Ockerman (1931) used McQueen's methods in studying the insoluble residues of the Hunton and Viola Limestones. He found that insoluble residues could be used as a criteria for the identification of these beds and suggested that these characteristics persist throughout Kansas.

Schoewe and others (1937, pp. 269-281) studied the insoluble residue of some Lower Pennsylvanian Rocks in Kansas. They found that individual members within a formation could be distinguished by insoluble residues.

Ireland (1947) published the results of a conference which was held in Midland, Texas, to develop a standard terminology for insoluble residues. The terminology adopted was very similar to that previously used by McQueen.

Drake (1951) found no diagnostic residue in the members of the Grenola Limestone Formation. Parish (1952) and Wilbur (1956) in their studies of insoluble residues sampled the Crouse Limestone and found very low percentages of coarse residue. Most of the residue consisted of fossil casts of limonite, quartz, some shards of volcanic ash, and chalcedony.

Ireland (1958, p. 86) stated that the study of insoluble residues was to supplement not substitute for lithologic examination. In his article he reported that residues reflected clastic conditions, sea-bottom environment, current action, and adjacent land-mass conditions.

Clay Mineralogy

According to Grim (1953) the greatest expansion of interest and knowledge of clay minerals has occurred since 1920. This was brought about by the development of x-ray diffractometry and by the greater economic importance of clays.

Millot (Grim, 1951, p. 227) stated that illite is the dominant clay in calcareous marine sediments and that kaolinite is generally absent. He also noted that illite was usually dominant in lagoonal sediments, but montmorillonite could occasionally be the dominant clay.

Grim (1951, pp. 228-229) found that chlorite is common in marine sediments in small amounts. He also found that illite forms in an alkaline environment in which the potash content is high, that montmorillonite forms in an alkaline environment in which the content of magnesium is high, and chlorite forms in an alkaline environment where the concentration of magnesia is greater than that necessary for the formation of montmorillonite. Grim also noted that kaolinite forms in an environment where the pH is low, where leaching is active, and where alkalies are absent.

Robbins, and Keller (1952) were two of the first to note the effects of hydrochloric acid on some types of montmorillonites. They found that some varieties of montmorillonite were destroyed by hydrochloric acid.

Grim (1953, p. 356) stated that montmorillonite is generally absent in sedimentary rocks older than Mesozoic. He thought that any montmorillonite in a marine environment would take on potassium from the sea water and alter to another clay mineral, usually illite.

Bradley and Weaver (1956, p. 499) listed the x-ray diffraction data for a relatively pure chlorite-vermiculite clay from Moffat County, Colorado. They suggested that the clay was formed by alteration of an original chlorite.

Powers (1957, p. 362) suggested that a chloritic clay can be formed from a degraded illite and/or montmorillonite through a mixed layer vermiculitic stage. Weaver (1958, p. 858) thought that the montmorillonite in most marine sediments is not pure montmorillonite, but may contain from 10 to 30 percent illite layers and in places, chlorite. However, he stated that by substitution the brucite layer of the degraded chlorites will undergo gradual substitution by potassium; causing the illite to become pure. He concluded that; (1) no particular clay mineral is restricted to a certain environment, (2) illite, montmorillonite and interstratified illite-montmorillonite can occur in abundance, often as the only clay minerals, (3) kaolinite is dominant in fluvial environments, (4) chlorite is minor, but usually in sediments of all environments, and (5) many continental beds of shale contain large mixed layer assemblages along with individual clay mineral groups.

Work has been done by McPherron (1956), Asmussen (1958), Hargadine (1959), and Bryson (1959) on clay minerals of the Lower Permian Rocks near this area. The most common clay mineral is illite with smaller amounts of chlorite-vermiculite, montmorillonite illite, montmorillonite-chlorite-illite, montmorillonite-chlorite, and chlorite.

Pryor and Glass (1961, p. 38) in a study of the Cretaceous and Tertiary clays of the Mississippi Embayment found three distinct clay mineral assemblages. The clays in the fluviatile environment are dominantly kaolinite, those in the outer neritic environment are dominantly montmorillonite, and those in the inner neritic environments are composed of nearly equal amounts of kaolinite, illite, and montmorillonite. They believed these variations in clay mineralogy were caused by segregation of clay minerals rather than differences in diagenesis.

METHOD OF INVESTIGATION

Field Procedure

Several months of weekend driving were spent early in the investigation viewing more than 30 outcrops of the Crouse Limestone. Six sections were then selected for detailed study on a basis of their location to the Manhattan area and the completeness and quality of exposure. At each location the outcrop was given a designated letter and was described and measured with a metallic tape, a five foot staff, and a hand level. The color of fresh and weathered surfaces were described by the use of a rock color chart (Goddard, and others, 1951).

One hand specimen containing at least one fresh and one weathered surface was collected from each recognizable lithologic unit; the specimen was marked with an arrow to show the top, a letter corresponding to the outcrop location, and a number indicating its position in the formation. Samples were taken at approximately one foot intervals throughout each section. Fossils were also collected from several units. Photographs were taken of each outcrop and of each stratum.

The thicknesses of beds were assigned quantitative values proposed by McKee and Weir (1953, p. 382). The limestone was tentatively named according to Folk's (1959) Classification. This name was later verified or changed on the basis of the laboratory phase of the petrographic study.

Laboratory Procedure

A 200 gram part of each sample was scrubbed with a stiff brush and water to remove foreign material. This was then air dried and crushed with a mortar and pestle until the largest particle was approximately the size of a pea. This crushed sample was then placed in a jar and stored for use in the clay and insoluble residue study.

Thin sections were made from each unit of outcrop A (McDowell Creek section) and acetate peels were made from units of the remaining five outcrops. Specimens from outcrop A (McDowell Creek section) were cut into ½" x 1" x 1 3/4" slabs and sent to Rudolf von Huene, Pasadena, California, to have thin sections prepared. An additional slab that was 3/16 inch thick was cut for later x-ray determination of the relative proportions of calcite and dolomite.

Acetate Peels. The procedure used for preparing acetate peels was a combination of Lane's (1962, p. 870) and McCrone's (1960, p. 192). The rock specimens were first cut perpendicular to the bedding planes; the cut face was then polished on progressively finer lap wheels with number 120 grit and 320 grit used respectively. The final polishing was done with number 600 grit and water on a glass plate. After thorough washing with water, the polished surface was etched in one percent dilute hydrochloric acid for 15 to 30 seconds. The time required for etching was different for each limestone and had to be determined by trial and error. Generally the softer and more argillaceous limestone samples required less etching than the hard purer limestone ones. Hydrochloric acid was used rather than acetic acid because McCrone (1960) stated that acetic acid leaves a fine white deposit of calcium acetate on the surface which may interfere with the clarity of the peel. The etched surface was again washed and allowed to air dry.

While the rock was drying a piece of single-matte commercial acetate film (0.003 inches thick) was cut slightly larger than the polished face. The specimen was supported in a box of sand with the polished face up and level. The sand allowed even the most irregular specimen to be held in a level position. The etched surface was then covered with acetone with a small polyethelene squeeze bottle. Acetone was added until the entire surface was covered by a thin film. On porous rocks this took several applications, and on some more acetone had to be added as the acetate was applied. The acetate was then quickly placed, dull side down, on the rock surface by holding the acetate in the form of a "U" between the thumb and forefinger. Starting at one end, the acetate was then rolled on. This method pushed out any air bubbles and excess acetone.

The peel was allowed to dry for at least 30 minutes and was then carefully removed. It was not necessary to press the film against the rock as suggested by Grossnickle (1961) and Lane (1962) because this resulted in stretching the peel over the rock surface and caused severe buckling when dried. An arrow showing the top of the bed and sample number were placed on the peel with ink. The peels were trimmed and placed between 2" x 2" glass lantern slides. The peels proved to be very successful and were used for point-count studies with the petrographic microscope, were used as negatives for making photo prints, and were projected on a screen for further study.

Insoluble Residue. Insoluble residues were obtained by using a modification of the methods described by Ireland (1947) and McCrone (1963). Ten grams of the crushed limestone (which had been oven dried for 24 hours to remove the moisture) were placed in 250 cc glass containers. The "pea"-sized particles were used to prevent the possibility of destroying the larger grains of the residue by crushing. Water was added until the sample was immersed. Ten percent dilute hydrochloric acid was poured in very slowly allowing effervescence to cease before adding more. When no effervescence was noted additional acid was added and the sample allowed to stand for 24 hours. The supernatant acid was carefully siphoned off and the container refilled with water allowing it to stand until the water was clear and siphoned a second time. This process was repeated until litmus paper showed no acid. The residue was washed onto filter paper of known weight and allowed to air dry. The filter paper and residue were then reweighed and the weight percentage computed. At this time the residue was compared to the rock color chart (Goddard, and others, 1951) and the color and symbol were recorded. The insoluble residue from outcrop A (McDowell Creek section) was placed in a container and a 0.02 normal solution of sodium hexametaphosphate (Calgon) was added as a dispersing agent. After several hours of soaking, the residue was wet sieved through a 250 mesh sieve to separate it into a "coarse" fraction with a minimum particle diameter of 0.0625 mm and "fine" fraction with a maximum particle diameter less than 0.0625 mm. From this the weight percentages of "coarse" and "fine" fractions were computed by dividing their individual weights by the weight of the total sample and multiplying this quotient by 100.

The "fine" fraction which had been caught along with the dispersing solution was allowed to stand for two hours and the water and clay in suspension siphoned off. This process was repeated until only the silt fraction remained. The silt was washed onto filter paper and allowed to air dry.

The silt and coarse parts of the insoluble residue were examined with a binocular microscope where a preliminary description and identification of minerals was made. An oil immersion of a part of each sample was prepared and an accurate identification and determination of percentage was made with the petrographic microscope. An oil with an index of refraction of 1.53 was used which aided in distinguishing orthoclase from quartz. Quartz with its lowest index of 1.54 had positive relief whereas orthoclase with its highest index of 1.526 had negative relief. The percentage of each mineral was determined by counting as near to 100 grains as possible with the aid of a mechanical stage.

Petrographic Method. The composition of each sample of limestone was determined by point-count analysis of the thin sections and peels. The thin sections from the McDowell Creek outcrop were studied first to provide a "pilot suite" in which mineral identification could be made; the acetate peels of samples of other outcrops were then studied. The peels had several advantages over thin sections; they covered a much larger area than the thin sections, often showed the texture better, especially very fine textures which are lost due to the thickness of a thin section, and were cheaper and more quickly made. The principal disadvantage of peels is that some mineral grains could not be identified. It was noted, however, that a few mineral grains were removed from the rock and that these could be identified.

The point-count was made by the use of a mechanical stage that was moved along the x-axis in increments of one mm. At each point the grain under the cross hairs was identified and counted. If the particles were so small that the cross hairs obscurred them, the innermost particle in the northeast quadrant was identified and counted. At the end of each traverse along the x-axis (usually 20 mm) the stage was moved one mm on the y-axis and another traverse along the abscissa was made. With this method a grid of 300 total points were counted for each thin section or acetate peel. According to Behrens (1963, p. 9) this is near the minimum count that should be made. With 300 points the counting error would not exceed the variation in the limestone.

During the petrographic work the different types of calcite were noted, (Folk, 1959), the fossils were counted, and if possible identified, and the sizes of grains were determined. The measurements were made with a calibrated 10x micrometer ocular in which the width of the cross hairs and the distance between cross hairs had been determined for each objective. Most of the point counting was done with a 10x ocular and a 10x universal objective.

Calcite-Dolomite Ratio. The ratio of calcite to dolomite was determined by x-ray diffraction. Each of the 3/16" blanks cut earlier from the samples of the McDowell Creek outcrop was run from 35° two theta to 25° two theta to include the main calcite, dolomite, and quartz peaks (Grossnickle, 1961, p. 12). The position of the calcite and dolomite peaks, if present, were recorded, then converted to d-spacings. The ratio of calcite to dolomite could then be determined by a comparison of the ratio of the intensity of the calcite to the intensity of the dolomite with a conversion chart by Tennant and Berger (1957, p. 26).

Clay Mineralogy. The procedure for the separation of the clay sized material for x-ray analysis was essentially the same as that used by Asmussen (1958, p. 12) and Bryson (1959, p. 20). Five grams of the crushed limestone that passed through a 270 mesh sieve was placed in 150 ml of 0.02 normal solution of sodium hexametaphosphate (Calgon). The sample was then mixed for at least five minutes with a small malt mixer and transferred to 150 ml cylinders. The sample was shaken vigorously and after 24 hours of settling the upper 10 cm of suspension was siphoned off and placed in a four ounce glass bottle. Hydrochloric acid was not used to remove the carbonates because the acid often destroys certain types of montmorillonite and chlorite (Ostrom, 1961, p. 125). One disadvantage of this method is that colloidal-sized quartz and calcite may disrupt the preferred orientation of the clays (Watkins, 1957, p. 17).

Oriented slides were made by placing several eye droppers of the suspension on a glass slide and allowing the water to evaporate. Some samples required concentration by placing the clay suspension in a centrifuge for several minutes.

The slide was placed in a North American Phillips diffractometer with a proportional counter. The slides were exposed to nickel-filtered copper radiation at 18 milliamperes and 40 kilovolts with a one-degree soller slit system. The goniometer was rotated from 32° to $1\frac{1}{2}^\circ$ two theta for untreated slides. All slides which showed a peak in the 14 Å range were then lightly sprayed with ethylene glycol to expand the montmorillonite and vermiculite. These were run from 15° to 1½° two theta to include the (001) of illite, kaolinite, montmorillonite, and the (001) and (002) of chlorite and vermiculite. New slides were heated to 450° C for one-half hour and were run from 15° to 1½° two theta. They were then reheated to 600°C for one-half hour, and again run from 15° to 1½° two theta. Samples containing interlayered clay minerals were allowed to stand in warm concentrated hydrochloric acid for 24 hours. New slides from these samples were prepared and run from 15° to 1½° two theta to determine the amount of interlayering due to chlorite. The angles of peaks were then converted to kx-spacings by using the U. S. Bureau of Standards' conversion tables.

LITHOLOGY

General

The thickness of the Crouse Limestone ranged from 11.2 feet at the spillway outcrop to 13.5 feet at the Clark's Creek outcrop. In this small area the formation is thinner in the east. Three major units were noted at each outcrop. In general the lower unit is a hard resistant fossiliferous limestone. The middle unit is a laminated argillaceous limestone that weathers like a shale. The upper unit is similar to the argillaceous limestone below, but is more calcareous and weathers to plates. The contact between the middle and upper units is gradational and a definite break is lacking. In the uppermost part of the upper unit the laminations are highly contorted and calcite nodules are common; this could possibly be considered another unit. For reference in this paper these units will be known as the lower limestone, middle "shaly" unit, upper "platy" unit, and upper contorted unit. Plate II shows typical exposures of the Crouse Limestone.

The "shaly" and upper "platy" units weather easily and after a few years of exposure the outcrop becomes almost covered with platy slabs. The outcrops were difficult to correlate because of this and because breaks such as the one between the "shaly" and "platy" units did not show on fresh exposures. The difference in lithology becomes apparent only after the "shaly" unit weathers back at a faster rate than the upper "platy" one. Many of the contacts are gradational and arbitrary boundaries were set. Some of the thinner beds within the individual units are due to differences in the degree of weathering rather than in real lithologic changes. Detailed measured sections of each outcrop are included in the appendix.

Lower Limestone

The lower limestone is the most distinctive unit in the field. It is a resistant fossiliferous limestone that forms a good bench. The thickness of this unit ranges from 1.5 feet at the spillway outcrop to 3.5 feet at the McDowell Creek and Stockdale outcrops. At the spillway outcrop, which is the farthest east, the limestone consists of two beds; the lower is one foot thick and the upper is 0.5 foot thick. At the McDowell Creek and spillway outcrops this unit consists of several thin beds averaging 0.5 foot thick. These thin beds are separated by beds of shale most of which are less than one inch thick. Plate III shows some of the different

EXPLANATION OF PLATE II

Fig. 1. Typical outcrop of the Crouse Limestone at the Clark's Creek exposure (outcrop E) that occurs in a road cut 0.6 mile east of Clark's Creek on U. S. Interstate 70.

A Lower Limestone (partly covered)

B Middle "Shaly" Unit

C Upper "Platy" Unit

D contorted part of the Upper "Platy" Unit

Fig. 2. McDowell Creek outcrop of the Crouse Limestone showing the platy weathering. This exposure is in a road cut 0.6 mile east of McDowell Creek on U. S. Interstate 70.

PLATE II

Fig. 1.

Fig. 2.

EXPLANATION OF PLATE III

Differences in bedding of the Lower Limestone.

Fig. 1. Lower Limestone Unit at the Clark's Creek outcrop (outcrop E).

Fig. 2. Lower Limestone Unit at the McDowell Creek road outcrop (outcrop D).

PLATE III

Fig. 1.

Fig. 2.

bedding characteristics of the Lower Limestone.

The color of this Lower Limestone is influenced by the amount of limonite. Predominantly the fresh surface is pale yellowish brown (10 YR 6/2) and weathers to grayish orange (10 YR 7/4). Limonite is more abundant near the top of the unit and, therefore, the top is moderate brown (5 YR 4/4) where fresh, and dark yellowish orange (10 YR 6/6) where weathered.

Two zones of solution cavities occur at most outcrops (Plate IV). One occurs at about 0.5 foot and another at 2.5 feet from the top. These solution holes average one inch in diameter, but many are interconnected to form cavities up to one foot long and four inches wide. The solution holes are partly filled with a moderate yellowish brown (10 YR 5/4) residue of limonite. Also common are small clay balls and lenses within the limestone. The lenses average 0.25 inches thick and 3 to 4 inches long. The largest observed was at the K-177 outcrop where a lense one inch wide and 18 inches long was noted. The clay balls are generally elongated, average 0.5 inches long, and range from 0.25 inches to 1.5 inches in diameter.

Possibly the most distinctive feature of the Lower Limestone is the abundance of gastropods, ostracodes, pelecypods, and pelecypod fragments. The lower part of the unit contains some algae with a few brachiopod and bryozoan fragments. The most common pelecypods are Aviculopecten sp. and Pleurophorous sp. Perhaps other genera exist, but they were not recognized. Aviculopecten occidentalis, Newell, 1937, and Pleurophorous occidentalis, Meek and Hayden, 1858, were collected from the McDowell Creek Road outcrop. The gastropods

EXPLANATION OF PLATE IV

Fig. 1. Lower Limestone Unit at the McDowell Creek outcrop (outcrop A) showing the two zones of solution cavities.

Fig. 2. Top part of the Lower Limestone at the Stockdale outcrop (outcrop F) showing an abundance of solution cavities.

PLATE IV

Fig. 1.

Fig. 2.

were predominantly a small (2 mm x 1 mm) high-spired, smooth shelled variety. These are possibly small varieties of Holopea sp., according to Girty (1915, p. 185). Several Bellerophon sp. were collected at the McDowell Creek and K-177 locations. Also collected at the McDowell Creek outcrop was a small fragment of Rhombopora sp. and fragments of Derbyia? sp. and Hustedia sp. The ostracodes consist of several species of Hollinella sp., Bairdia sp., and Cavellina sp. The algae will be discussed later with the petrography because all identification was accomplished from peels and thin sections.

Middle "Shaly" Unit

The Middle "Shaly" Unit was originally described in the field as a calcareous shale because of its behavior to weathering. However, the unit contains an average of only 27.5 percent insoluble residue. According to Rodgers (1954, p. 226) any rock containing greater than 50 percent calcite would be classified as a limestone. The thickness ranges from 2.1 feet at the spillway (outcrop C) to 4.8 feet at Clark's Creek (outcrop E); the average thickness is 3.4 feet. This unit seems to be thinner in the east, similar to the Lower Limestone. The lower boundary of the Middle "Shaly" Unit is sharp, whereas the upper boundary with the platy limestone above is gradational. On fresh outcrops it was not possible to find this upper contact. At three locations (McDowell Creek, K-177, and Stockdale) there are thin more resistant limestones within this unit. These appeared identical to the Upper "Platy" Unit above and probably represented periods when smaller quantities of terrigenous material were deposited.

The Middle "Shaly" Unit is predominantly very pale orange (10 YR 8/2) and weathers yellowish gray (6 Y 7/2). At the McDowell Creek and Clark's Creek outcrops several streaks and mottled areas of light gray (N7) to medium gray (N5) were noted. A slight variation in color was noted at the McDowell Creek outcrop where the fresh surface is a grayish orange (10 YR 7/4). The unit is laminated with most laminae being four mm thick. Upon weathering the limestone splits along these laminae. According to McKee and Weir (1953, p. 382) a limestone that splits along laminae that are 2 mm to 1 cm thick would be called platy; whereas a shale would be called shaly. In this investigation the term shaly was used to describe the middle limestone unit in order to distinguish it from the more resistant limestone above.

Megafossils were not found in the Middle "Shaly" Unit. Microfossils consist predominantly of ostracodes, with some rounded echinoderm and brachiopod spines, and a few foraminifers. The ostracodes include several species of Hollinella sp., Bardia sp., Cavellina sp., and at least one species of Bythocypris sp. Several Tetrataxis sp. were collected from location E (Clark's Creek outcrop). Plate V shows typical outcrops of this unit.

Upper "Platy" Unit

The Upper "Platy" Unit is the thickest of the three units in the Crouse Limestone and averages about 6 feet thick. The thinnest section is at Stockdale (outcrop F) where it is 4.8 feet thick and the maximum is at the spillway exposure (outcrop C) where it totals

EXPLANATION OF PLATE V

Fig. 1. Middle "Shaly" Unit at the Stockdale section (outcrop F). Shovel is resting on the top of the Lower Limestone. This road cut is less than five years old.

Fig. 2. Middle "Shaly" Unit at the McDowell Creek section (outcrop A). The top of the Lower Limestone is visible at the bottom of the picture. This outcrop is less than one year old.

PLATE V

Fig. 1.

Fig. 2.

7.6 feet. There seems to be no definite trend in the thickness of this unit as there is with the middle "shaly" and lower one. This upper unit is a very fine-grained clayey limestone that is laminated, and weathers into many plates. Most of these plates average one cm, but with added time these continue to split into thinner plates. On a very fresh outcrop the limestone appears as one large massive unit, but with exposure this surface begins to take on the typical platy look. (Plate VI) This made measurement of beds difficult, and correlation between outcrops almost impossible. At the McDowell Creek and Stockdale outcrops (A and F) the top part of this unit has a sequence of interbedded "shaly" and resistant layers. In most outcrops this interbedded sequence was not noticeable and weathering was more consistent.

In the upper 1.5 feet of this "platy" unit the laminations become highly contorted and irregular. This may have been caused by numerous calcite nodules, and beds of nodules that are arranged along definite planes. The laminations arch over them and none of the laminations seemed to be truncated by the nodules. The nodules are somewhat flattened and are about 1.5 inches long and one inch thick (Plate VII). Tarr (1921, p. 383) stated that nodules arranged along planes and the arching of beds over the nodules indicated a syngenetic origin. This agrees with Twenhofel (1932, p. 713) who suggested that thickening and bending of laminae is indicative of a syngenetic origin. These nodules of relatively pure calcite were probably formed in young unconsolidated sediments and would show a large amount of surrounding and differential compaction (Weller, 1960, p. 116). Several of the nodules have radial cracks that are

EXPLANATION OF PLATE VI

Fig. 1. Upper "Platy" Unit at the McDowell Creek exposure (outcrop A). Notice the tendency for this somewhat massive unit to begin splitting along laminae. This outcrop is less than one year old.

Fig. 2. Upper "Platy" Unit at the Clark's Creek exposure (outcrop E). Notice contorted nodular zone at top.

PLATE VI

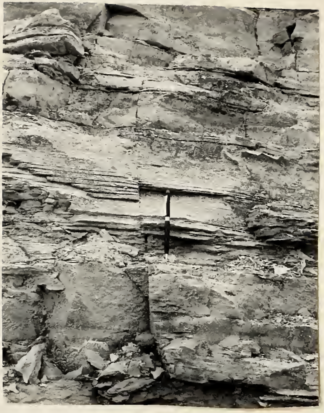


Fig. 1.

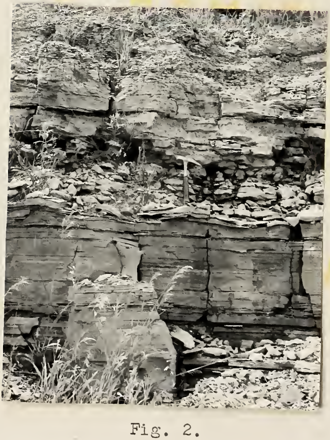


Fig. 2.

EXPLANATION OF PLATE VII

Fig. 1. View of the contorted nodular zone at the top of the "platy" unit. Notice laminae curving up over the nodule. Folds decrease toward bottom of the picture. Clark's Creek outcrop (E).

Fig. 2. Contorted, nodular zone showing several nodules arranged along a plane. Clark's Creek outcrop (E).

PLATE VII

Fig. 1.

Fig. 2.

filled by calcite that may have been caused by dehydration and shrinkage. Cracks of this type are also indicative of primary or syngenetic origin (Shrock, 1948, p. 168). The Upper "Platy" Unit grades into the Blue Rapids Shale above. The lower two feet of the Blue Rapids Shale also has many calcareous concretions.

Fossils in the upper unit are similar to those in the unit below. The most abundant are the ostracodes, Hollinella sp., Baridia sp., Cavellina sp., and Bythocypris sp. Small foraminifer including Tetrataxis and a few echinoderm spines are also found.

The platy nature of the upper unit makes it very distinctive. On hillside exposures the plates cover a wide area and are common as "float" for a considerable distance down the slope.

PETROGRAPHY

Lower Limestone

The limestone of the lower unit was classified according to Folk (Table I) and the following types found; ten recrystallized pelecypod biomicrites, two recrystallized gastropod biomicrites, two recrystallized fossiliferous micrites, two pelecypod biomicrosparrite, two fossiliferous micrites, and one recrystallized algal biomicrite. The percentages of the various consitutents are shown in Table 2.

Recrystallized Pelecypod Biomicrite. Samples A-1, A-5, C-1, D-1, D-3, E-1, E-2, F-1, F-3, and F-5 are all pelecypod biomicrites (Plate VIII, Fig. 1.). This is the major limestone type in the lower unit and is composed predominantly of micrite which comprises 42 percent of the total rock. Fossils comprise an average of 16

Table 2. Percentages of constituents in the samples from the Lower Limestone Unit of the Crouse Limestone.

Constituent	A1	A2	A3	A4	A5	B1	B2	C1	C2	D1	D2	D3	E1	E2	F1	F2	F3	F4	F5
Micrite	65	68	63	66	46	31	23	37	72	46	45	36	41	38	31	46	35	20	42
Microspar	11	8	11	22	19	28	35	30	8	21	23	29	20	25	21	35	27	38	20
Spar	5	5	9	1	14	15	24	9	5	14	15	15	16	18	17	4	12	15	12
Pellets								1			tr		tr		1	tr	2	tr	
Fossils	11	8	13	5	13	14	16	12	9	17	16	17	20	15	14	8	23	17	19
Pelecypods	6	4	3	2	8	3	9	3	2	9	4	9	10	8	4	1	10	8	11
Gastropods	tr	1	5	tr	2	tr	2	1	1	1	8	2	3	4	1	1	4	5	3
Ostracodes	2	2	1	1	1	1	tr	2	2	3	tr	1	2	1	2	4	2	1	tr
Foraminifers			tr			tr						tr	tr			tr			tr
Unidentified	2	1	5	2	2	1	3	6	4	4	4	5	5	2	4	2	4	3	3
Algae	1	1	tr	tr		9	2	tr		tr	tr	tr		tr	2	1	3	tr	2
Pores	3	9	1	4	2	12	tr	10	3	tr		1	1	1	16	2	tr	9	1
Other*	5	2	2	2	6	tr	2	1	3	2	1	2	2	3	1	3	1	1	6

tr = trace (less than one percent or noted but not found on point-count)
* = includes quartz, and fine dark material (algal dust, clay, etc.)

EXPLANATION OF PLATE VIII

Fig. 1. Positive peel print of the Lower Limestone (Pelecypod biomicrite). Black areas within gastropods are limonite. Notice poor orientation of fossils. Fossils include pelecypods, gastropods, ostracodes, and algae. (Sample F-5)

Fig. 2. Photomicrograph of peel D-2 showing typical high-spired gastropods found in the lower limestone. Notice all shell material is inverted to spar.

PLATE VIII

Fig. 1. 5 mm up

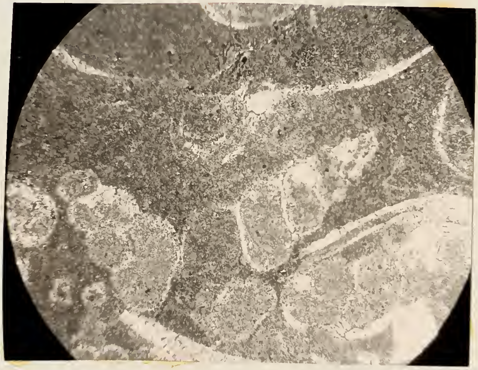


Fig. 2. 1 mm up

percent ranging from 11 to 20 percent with pelecypods being the most abundant. Recrystallization is quite extensive in these limestones with none having less than 10 percent microspar and a maximum of 30 percent in section C-1. Microspar averages 22 percent with an average grain size of 10 microns. Sample C-1 contains what appears to be large dolomite rhombs. However, x-ray analysis of identically the same surface from which the peel was prepared failed to show any dolomite. Crushed fragments of these rhombs were picked out of the sample and an oil immersion made. The oil used had an index of 1.66 which is higher than the highest index of calcite, but lower than the highest index of dolomite. The results of the oil immersion also showed only calcite and no dolomite. The spar is not abundant comprising an average of 13 percent; with a maximum of 17 percent in sample F-1. The spar occurs predominantly as a filling in cavities of fossils and as cement between fossils. In some areas it is in the upper part of a cavity formed by a curved shell lying with its concave side down. The spar averages 0.05 mm but some as large as one mm across were noted in sample F-1. Pores and non-carbonate grains comprised the remaining seven percent of the rock.

The micrite is quite uniform in size in each section. Most samples have micrite averaging 3 or 4 microns in size, except in sample D-1 where the size is nearer two microns. In most cases the micrite is directly in contact with the fossil fragments, but several specimens contain a layer of spar cyrstals that surround the fossils with the c-axes of the crystals normal to the shell. Samples D-3 and E-1 have thin concentrations of micrite within the biomicrite.

The pelecypod shells show no orientation parallel to the bedding and indicates a lack of sufficient wave action to turn the shells over to their most stable position (Lane, 1958, p. 147). The high percentage of micrite in these limestones also suggests a lack of wave action. All of the pelecypod and gastropod shells are composed of spar with a grain size ranging from 0.02 mm to 1 mm. The shells were originally aragonite that later inverted to calcite. Lowenstam (1954) stated that most pelecypod and gastropods from warmer water have shells composed of aragonite. The pelecypod shells range from 0.03 mm fragments to almost complete shells 25 mm long. Most of the pelecypods are possibly Aviculopecten sp. or Pleurophorous sp. Allee (1934) reported that certain pelecypods may become so abundant that they completely cover the sea bottom in littoral zones. The normal depths for pelecypods of this type are from 60 to 90 feet (Elias, 1937, p. 428).

Gastropods in the section were identified by the morphologic outline. All of the gastropods noted in the petrographic study are the small high-spired variety, (Plate VIII, Fig. 2.) that are possibly small forms of Holopea sp. according to Girty (1915, p. 185). These are usually filled with spar, or micrite, but some are filled with limonite and hematite. The size of the gastropods range from 2.51 mm to 0.75 mm and average 1.6 mm in length.

Ostracodes are abundant in all samples. These could be recognized by their unique shape and because most of them remain articulated (Stauffer, 1960, p. 24). In the acetate peels and thin sections the shells of the ostracodes are brown. The ostracodes, like the gastropods, have cavity fillings of spar, micrite, or limonite. The ostracodes include Hollinella sp., Bairdia sp., and Cavellina sp.; they range in size from 0.25 mm to 1 mm and average 0.57 mm. In several ostracodes that are filled with micrite the micrite inside the shell is less recrystallized than that outside the shell (Plate IX, Fig. 1.).

Seven of the pelecypod biomicrite samples have at least some algae, but in none is the percentage greater than three. An attempt was made to name the algae; however, all identification was based only on comparative pictures and brief descriptions by Johnson (1946, 1961, 1963). Therefore, the identification of the algae is somewhat uncertain. Several species of Anchicodium were noted, but specific identification was difficult because of recrystallization. The thalli on most are 0.1 mm wide. Some are nearly straight; others are wavy and the centers are filled with spar. Johnson (1946) described only one species from the Permian of Kansas, Anchicodium permianum, and stated that the diameter of the thallus of this species ranges from 0.27 to 0.32 mm. This is larger than those noted in this study which averaged 0.1 mm wide. Most of the Anchicodium sp. and several pelecypod shells are encrusted with Osagia sp. whose thickness ranged from 0.03 mm to 0.16 mm. On some the Osagia sp. completely surrounded all sides of the fossil fragment, but on others the encrustation was incomplete. The Osagia sp. appear under high power as a mass of fine laminae that are parallel to the surface with small areas of clear calcite that are 0.03 mm wide. Johnson (1963, p. 134) described Osagia sp. as being a mass of twisted tubes which form a laminated

EXPLANATION OF PLATE IX

Fig. 1. Photomicrograph of peel C-1 showing ostracodes filled with micrite in a highly recrystallized micrite matrix. Light areas with dark edges are voids.

Fig. 2. Photomicrograph of peel C-1 showing ostracodes filled with limonite. Matrix shows extensive recrystallization. Notice that the crystals of spar radiate from the shell surface; their long diameters normal to the shell.

PLATE IX

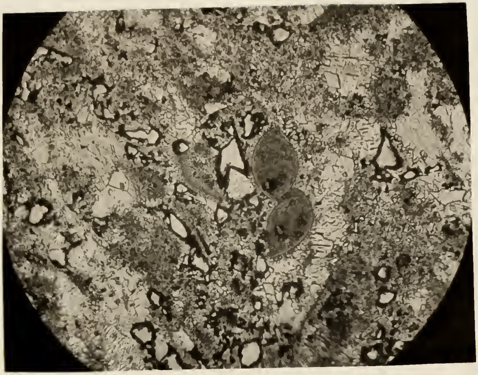


Fig. 1.

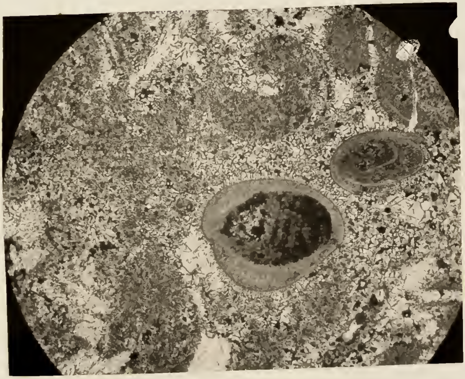


Fig. 2.

encrustation. He stated that _Osagia_ sp. is an intergrowth of algae and the foraminifer _Nubecularia_ sp. Although no definite tubes were seen the encrustation consisted of fine algal filaments and the areas of clear calcite are possibly the _Nubecularia_ sp. Lane (1958, p. 145) also reports the lack of definite tubes in _Osagia_ sp. from the Grenola Limestone.

Sample C-1 contains a fossil that could not be identified; it consisted of a series of twisted tubes and cells. The tube diameter is 0.1 mm and the walls of the tubes are 0.01 mm thick. The interior of the tubes are filled with sparry calcite. The walls of the tubes appeared darker than the surrounding calcite. It is thought that these are possibly _Serpula_ tubes. This assumption was made on the basis of the description and pictures by Johnson (1963, p. 99). Plate X, Fig. 1 shows a photo of this fossil.

Pelecypod Biomicrosparrite. Specimens B-2 and F-4 of the Lower Limestone are pelecypod biomicrosparrites. These are essentially the same as the previously discussed recrystallized pelecypod biomicrites except there has been more recrystallization and the percentage of microspar exceeds that of the micrite. In these samples the micrite averages 22 percent and the microspar 36 percent. Pelecypods are again the most abundant fossils, constituting 11 of the 17 percent of the fossils. Gastropods are next in abundance with three percent. The remaining three percent fossils are ostracodes and algae. The microspar in these limestones averages 15 microns in diameter with a range from 7 to 30 microns. The percentage of spar is slightly greater than in the

EXPLANATION OF PLATE X

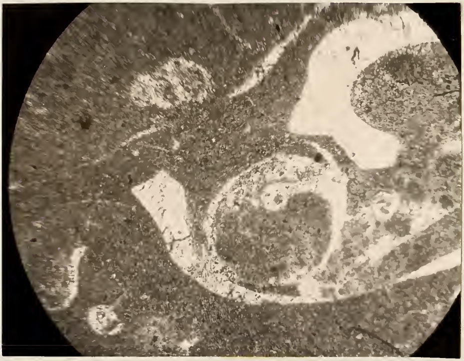
Fig. 1. Photomicrograph of peel C-1 showing possible Serpula? tubes in a recrystallized matrix. Notice the large rhombs in the lower part of the photo that appear to be dolomite; however, x-ray data and oil immersion showed no dolomite.

Fig. 2. Photomicrograph of peel D-2 showing gastropod and pelecypod shells inverted to clear sparry calcite, within a micrite matrix.

PLATE X

up

Fig. 1. 0.5 mm



up

Fig. 2. 1.mm

recrystallized pelecypod biomicrite with an average of 19 percent. It should be noted, however, that distinguishing between spar and microspar is often difficult, and in recrystallized limestones some microspar may have been wrongly identified as spar.

The fossils and their sizes are essentially the same as previously described for the pelecypod biomicrites. They include small high-spired gastropods, Hollinella sp., Cavellina sp., Bairdia sp., and Osagia sp. and Anchicodium permianum?.

Limonite again occurs inside cavities within fossils and associated with the algae; an association that seems to hold true throughout the limestone. Twenhofel (1919, p. 351) also noted this association of abundant limonite with Osagia sp. Carozzi (1960, p. 346) stated that this relationship of limonite and organic matter is common and indicates the iron oxides, hematite and limonite, are possibly derived from pyrite. He stated that the source for the sulfur in pyrite is from the nitrogenous component of the organic matter. The cavities of organisms with their high concentration of decaying organic matter form ideal conditions for bacteria growth which assist in the reduction of the sulfates from marine water.

Gruner (1922) attributed the origin of sedimentary iron primarily to the activity of bacteria and algae. According to Dana (1956, p. 249) certain bacteria can actually absorb iron from water and later deposit it as ferric hydroxide. Sverdrup and others (1942, p. 1032) emphasized the importance of bacteria and reducing conditions with the following statement:

> Iron is precipitated as sulphides in stagnant environments where hydrogen sulphide is produced.

Bacteria may be directly involved in the solution and precipitation of iron oxides and sulphides.

According to Zobell (1946, p. 510) an abundance of readily decomposable organic matter promotes reducing conditions. He also stated that fine sediments increase this effect. It is possible that the masses of algae and interior of fossils form micro-reducing environments where bacterial action and precipitation of iron can take place.

Recrystallized Gastropod Biomicrite. Specimens A-3 and D-2 of the lower limestone were classified as recrystallized gastropod biomicrites. In these limestones the percentages and sizes of micrite, spar, microspar, and total fossils are almost identical to the recrystallized pelecypod biomicrites. The main difference is that the gastropods are dominant over the pelecypods. In these the gastropod and pelecypod shells have also inverted to sparry calcite. The gastropods average 2.5 mm in length and one mm in width. All are the high-spired Holopea? sp. Most of the spar in the samples occurs in the cavities of gastropods and ostracodes. The ostracodes are not as well preserved in D-2 as in A-3. Also noted in D-2 was a small area that has undergone considerable recrystallization in which there are several ovoid to rounded pellets of micrite that are darker than the micrite of the matrix. These pellets range from 0.1 mm to 0.3 mm and average 0.19 mm. Folk (1959, p. 7) stated that pellets are much richer in organic material than the surrounding matrix and is the cause for their darker color. The darker color can also be due to a higher percentage of clay than in the matrix (Grossnickle, 1961, p. 25). Folk (1962, p. 64) considered pellets to be invertebrate fecal pellets due to the fairly constant size and shape. However, Thomas (1962, p. 198) indicated that they are possibly accretionary grains of algal material formed by the fragmentation of algal colonies. This idea agrees somewhat with that of Carozzi (1960, p. 209) who also suggested that they are possibly algal. The pellets in this limestone are thought to be fecal because of their fairly uniform size and shape. (Plate XI, Fig. 1.) The algae comprising less than one percent of samples A-3 and D-2 are Osagia sp. that have encrusted the pelecypod shells. With the greater amount of gastropod shells in these samples it would seem that at least some would also have an algal encrustation; however, no algae were found on any of the gastropods. All seemed to be restricted to the flatter pelecypod shells. The algal coatings average 0.15 mm in thickness.

Fossiliferous Micrite. Samples C-2 and A-2 are fossiliferous micrites. They average 70 percent micrite, 8 percent microspar, 9 percent fossils, 5 percent spar, and 8 percent pores and non carbonate grains. The micrite is uniform in size ranging from 3 to 4 microns. Most of the spar occurs beneath curved fossil shells and inside ostracodes and gastropods. All fossils except the ostracodes and algae are inverted to spar that have an average size of 15 microns; no preferred orientation of fossils was noted. Limonite is common in cavities within fossils and is associated with algae.

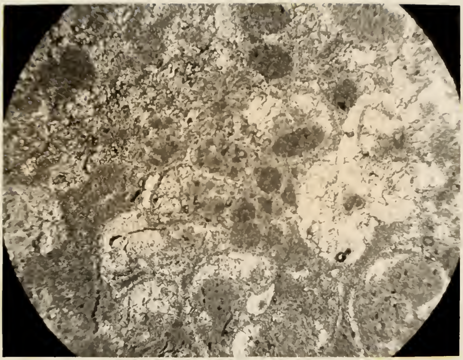
Pelecypod fragments are small with the largest being three mm long. Ostracodes are common and averaged 0.9 mm in length; they included Hollinella sp., and Cavellina sp. Algae are fairly

EXPLANATION OF PLATE XI

Fig. 1. Photomicrograph of peel D-2 showing dark ovoid pellets. Notice large amount of recrystallization of the matrix and inversion of the fossils to spar.

Fig. 2. Photomicrograph of thin section A-2 showing two fragments of *Anchicodium* sp. that are encrusted by *Osagia* sp. Small oval and rounded light areas within the *Osagia* sp. are possibly spar fillings in *Nubecularia* sp.

PLATE XI



up

Fig. 1. 0.5 mm

up

Fig. 2. 0.5 mm

abundant in sample A-2 totaling more than one percent of the rock; Anchicodium sp. and Osagia sp. are the only genera. The Anchicodium sp. measured 0.15 mm. This is small for Anchicodium permianum the only Permian algae of this type shown by Johnson (1946, p. 1100) for the Kansas area. Most of the specimens of Anchicodium sp. and some pelecypod shells are coated with 0.7 mm crust of Osagia sp. The encrustations appear continuous around the entire fossil (Plate XI, Fig. 2.).

Although classified as a fossiliferous micrite sample C-2 actually is a micrite that contains a biomicrite zone in it. The area covered by the point-count included enough micrite and biomicrite to average out to a fossiliferous micrite. It is possible small concentrations of fossils in a micrite could be caused by irregularities on the sea bottom where fossil fragments being moved about by the currents would become trapped (Plate XII, Fig. 1.).

Recrystallized Fossiliferous Micrite. Samples of limestone A-4 and F-2 are recrystallized fossiliferous micrites that contain 56 percent micrite, 29 percent microspar, 7 percent fossils, 2.7 percent spar, and 5 percent pores and non-carbonate grains. The grain size of the micrite is fairly constant at about 3 to 4 microns and the microspar about 10 microns. All spar occurs within the cavities of fossils, predominantly ostracodes. Sample F-2 is more highly recrystallized than A-4 containing 36 percent microspar as compared to 22 percent for A-4. The microspar occurs in small patches and thin bands. Some vague outlines of pellets (0.05 mm) that were partly destroyed by recrystallization were

EXPLANATION OF PLATE XII

Fig. 1. Positive peel print of sample C-2. A patch of biomicrite within a micrite. Black areas are limonite.

Fig. 2. Photomicrograph of peel B-1 (algal biomicrite) showing three sizes of *Anchicodium* sp. fragments with coatings of *Osagia* sp. X-ray data and oil immersion of rhombs similar to that in the lower right hand corner of the photo showed them to be calcite. The recrystallization in the lower right hand of the photo has possibly caused the break in the *Anchicodium* sp. fragment.

PLATE XII

up

Fig. 1. 5 mm

up

Fig. 2. 0.5 mm

noted in F-2.

The fossils in these samples consist of articulated ostracodes, small unidentifiable shell fragments that are smaller than 10 microns thick, and algae. The percentage of ostracodes is 2.3 and they range from 0.15 to 0.67 mm in length and average 0.44 mm. They include Hollinella sp., Bairdia sp., and Cavellina sp. The encrusting algae, Osagia sp., surrounds shell fragments and small (0.07 mm) unidentified foraminifers.

Recrystallized Algal Biomicrite. Sample B-1 is the only recrystallized algal biomicrite. This sample consists of 31 percent micrite, 28 percent microspar, 15 percent spar, 14 percent fossils, and 12 percent voids. The micrite in this rock averages 4 microns. The microspar ranges from 0.01 mm to 0.1 mm.

Algae make up 9 percent of the rock. Anchicodium sp. is the predominant type with the diameters of thalli ranging from 0.04 mm to 0.4 mm and lengths ranging up to one cm. Almost all specimens of Anchicodium sp. are encrusted by Osagia sp. (Plate XII, Fig. 2) The maximum thickness of the Osagia sp. is 0.15 mm. Several very small fragments of Mizzia? were noted. Other fossils are pelecypod fragments, ostracodes (Bairdia sp. and Cavellina sp.), small high spired gastropods, small fragments of foraminifers and a cross section of an echinoid spine. This spine is 0.68 mm in diameter and has radial symmetry (Plate XIII, Fig. 1).

Middle "Shaly" Unit

The Middle "Shaly" Unit contains only three types of limestone. Five of the samples are recrystallized clayey micrites,

EXPLANATION OF PLATE XIII

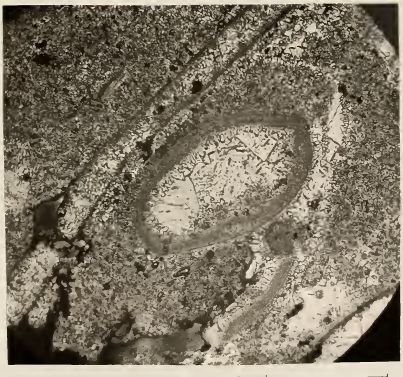
Fig. 1. Photomicrograph of peel B-1 showing cross section of an echinoid spine and *Anchicodium* sp. that is encrusted with *Osagia* sp. Very dark spots in the *Osagia* sp. are concentrations of limonite.

Fig. 2. Photomicrograph of peel B-1 showing an ostracode that is filled with clear sparry calcite and showing also, a long slender fragment of *Anchicodium* sp.

PLATE XIII

up

Fig. 1. 0.5 mm



up

Fig. 2. 0.5 mm

three are clayey micrites, and one is a recrystallized clayey fossiliferous micrite. The percentages of the constituents of the samples are listed in Table 3. The beds of limestone of this unit are fairly consistent with the various types defined only by slight differences in percentages of clay, fossils, and microspar.

Table 3. Percentages of constituents in the samples from the Middle "Shaly" Unit of the Crouse Limestone.

Constituent	A6	A7	B3	B4	C3	D4	E3	E4	E5	F6	6a
Micrite	74	75	81	85	80	75	63	64	65	68	73
Microspar	11	13	10	9	3	6	17	17	19	15	13
Spar		tr							tr	tr	
Fossils		4	tr	1				1	1	1	
Pelecypods											
Gastropods		1									
Ostracodes		1							1	1	
Foraminfers											
Unidentified		2	tr	1				1			
Algae											
Pellets											
Pores	2	1	3	tr	2	2		2	2		
Other*	13	7	6	5	15	17	20	16	13	14	14

tr = trace (less than one percent or noted but not found on point-count).
* = includes quartz, and fine dark material (algal dust, etc.)

Recrystallized Clayey Micrite. Samples A-6, F-6a, E-3, E-4, and E-5 are recrystallized clayey micrites that average 68 percent micrite, 15 percent microspar, less than 1 percent each of spar and fossils, and 16 percent pores and non-carbonate grains including clay. The greatest amount of recrystallization was found in E-3 and E-4, both containing 17 percent microspar. Sample A-6 has the least amount of microspar with 11 percent. The micrite in these samples is slightly smaller than in the lower unit, most of it being 1 to 2 microns with scattered grains of four microns. The average size of the microspar is 10 microns. The clay occurs as clots 0.05 to 0.08 mm across, as fine disseminated grains, and in very thin laminae. Probably the fine concentrations of clay within these limestones are the causes of the laminations and platy weathering of this unit. Several ostracodes are in E-5, E-3, and F-6a and are filled with micrite; there is no spar in these samples. Sample E-4 contains several recrystallized spines, 0.1 mm thick and 0.25 mm long. Small angular to subangular, 0.02 mm grains of quartz amounted to 6 percent of sample A-6. It is possible that quartz is in other samples, but was not identifiable in peels.

Clayey Micrite. Samples C-3, B-4, and D-4 are clayey micrites with an average of 80 percent micrite, 5 percent microspar, less than 1 percent fossils and spar, and 14 percent voids and non carbonate grains. The clayey micrites differ from the recrystallized clayey micrites in that the former have not been as extensively recrystallized. The clay occurs as small clots, as concentrations parallel to the stratification, and is disseminated throughout the micrite. Several ostracodes are in samples B-4 and C-3.

Recrystallized Clayey Fossiliferous Micrite. Sample A-7 is the only recrystallized clayey fossiliferous micrite in the "shaly" unit. This sample, however, was from a slightly more resistant bed within this unit. The limestone has 74 percent micrite and 13 percent microspar. The major difference from the clayey micrites is its 4 percent fossil content. The fossils consist of ostracodes, averaging 0.38 mm, several small high-spired gastropod fragments, and one foraminifer fragment. The gastropod fragments average 0.64 mm in diameter and are inverted entirely to spar. All ostracodes are articulated, and most of them contain spar as a cavity filling.

Upper "Platy" Unit

The Upper "Platy" Unit contains six types of limestone. Seven samples are recrystallized clayey micrites, 5 are recrystallized fossiliferous micrites, 4 are recrystallized micrites, 2 are clayey micrites, and 2 are micrites. Several types which are similar will be discussed together. Table 4 gives the percentages of the constituents.

Recrystallized Micrite and Recrystallized Clayey Micrite. Samples D-9, F-8, F-10, and C-5 are recrystallized micrites. Samples E-6, E-7, E-9, D-7, C-4, B-5, and A-8 are recrystallized clayey micrites. The only difference between the two types is that the percentage of clay is greater than 10 percent in the clayey micrites and less than 10 percent in the micrites. The average percentage of micrite amounts to 69 percent with a range from 52 to 87 percent. Microspar averages 22 percent with a range from 10 to 34 percent. The microspar in E-9 is somewhat concentrated in zones that are parallel to the bedding. The total of spar and fossils is less than 2 percent. Folk (1961, p. 141) stated that there must be a certain amount of allochems to support the growth of sparry calcite. This is well shown by these rocks; where the fossil content is less than one percent, the spar content is also very low. All spar occurs as cavity fillings in fossils. Most micrite is 2 microns in diameter whereas the micro-

Table 4. Percentages of constituents in the samples from the Upper "Platy" Unit of the Crouse Limestone.

Constituent	A8	A9	A10	B5	B6	B7	B8	B9	C4	C5	C6	C7	C8	C9	D5	D6	D7	D8	D9	E5a	E6	E7	E8	E9	F7	F8	F9	F10
Micrite	84	92	83	79	68	56	57	53	77	75	78	77	65	72	70	79	76	86	65	50	52	53	82	58	63	61	47	63
Micro-spar	11	3	6	11	27	24	31	35	10	22	10	12	25	10	13	18	11	9	23	19	30	34	8	24	27	34	15	28
Spar		tr			tr	tr	2	1	1	tr	5	3	2	1	2	tr		1	1	tr		tr	1	tr	7	tr	22	tr
Pellets																												
Fossils	1	1	tr		1	1	3	2	1	1	5	3	7	1	7	2	1	tr	1	2		1	1	1	2	1	9	1
P.											2	2	2												1			
G.											2	1													1			
O.		1							1	1	1	tr	3	1	tr	1	1	tr		1			tr		tr	1	5	
F.	tr						1	1						tr	2								tr				2	1
U.	1		tr		1		1	1		tr	tr	tr	2	tr	4	1			1	1		tr		1			1	tr
A.					tr	1	1	tr						tr	1	tr	tr					1	1	tr	tr		1	tr
Pores	1	tr	8	1			1	1		tr	1			3			tr		3	2	6	tr	3	5		tr	6	1
Other*	3	4	3	9	4	19	6	8	11	2	2	5	1	13	8	1	12	4	7	27	12	12	5	12	1	4	1	7

tr = trace (less than one percent or noted but not found on point-count)
* = includes quartz, and fine dark material (algal dust, clay, etc.)
P. = pelecypods
G. = gastropods
O. = ostracodes
F. = foraminifers
U. = unidentified
A. = algae

spar ranges from 7 to 20 microns. Samples D-9 and F-10 are from the contorted zone and the thin laminae of clay in the peels reflects this (Plate XIV, Fig. 1). Some of the laminae of F-10 are cross-bedded; this agrees with Folk's statement that micrite may be drifted about by the currents (Folk, 1961, p. 138). The predominant fossils are ostracodes about 0.3 mm in length. From the outlines these appeared to be *Cavellina* sp., *Bythocypris* sp., and *Hollinella* sp. Several fragments of foraminifer were also noted. The clay in these samples is concentrated in definite thin laminae.

Recrystallized Fossiliferous Micrite. This group of recrystallized fossiliferous micrites also includes the recrystallized clayey fossiliferous micrites which differ from the recrystallized micrites in that they contain from 1 to 10 percent fossils. Samples E-5a, D-5, B-6, B-7, B-8, B-9, D-6, F-7, F-9, C-6, C-7, and C-8 are of this type. The average percentage of micrite is 65 percent and non-carbonate grains and pores is 8 percent. The degree of recrystallization ranges from 10 to 31 percent. Many of these samples have alternating bands of micrite and biomicrite (Plate XIV, Fig. 2). In C-7 the biomicrite occurs as bands from 1 to 3 mm wide that are separated by bands of micrite 7 mm wide. Limonite is concentrated along the fossiliferous zones. These zones possibly were high in bacteria, and had a reducing environment during deposition. Samples C-6 and F-7 also have similar fossiliferous zones within the micrite. The ostracodes (0.4 mm long), *Bairdia* sp., *Hollinella* sp., and *Cavellina* sp. are the most abundant fossils. Other fossils are numerous high-spired

EXPLANATION OF PLATE XIV

Fig. 1. Positive peel print of a clayey micrite (sample F-10) from the upper contorted zone. Notice the laminae due to the concentration of clay.

Fig. 2. Positive peel print of sample C-7 showing the definite bands of fossils within a micrite. The black bands along the fossils are composed of limonite. Notice the small micrite intraclast in lower right hand corner.

PLATE XIV

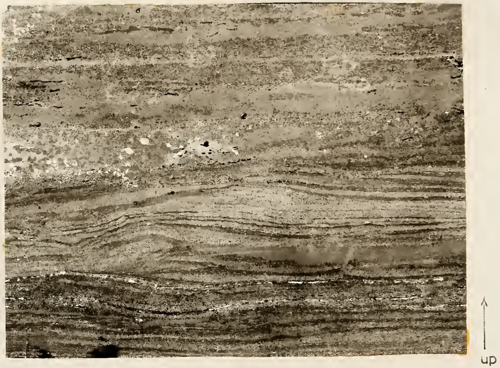


Fig. 1. 5,mm

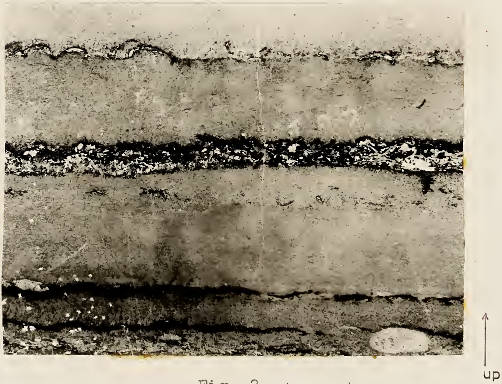


Fig. 2. 5.mm

gastropods, small unidentified pelecypods, and some algae and foraminifers (Tetrataxis sp.). Several fragments of Anchicodium sp. (0.1 mm wide and 2 mm long) that are coated with Osagia sp. are in sample F-9. Samples D-5, B-8, B-9, and F-9 contain two percent of a small unidentified cellular fossil; some are 0.75 mm long. The fossils consist of a series of cells with distinct calcareous walls that are 0.02 mm thick. The cell interiors are filled with sparry calcite. In most cases one side seems flattened and possibly indicates that the cells grew as an encrusting mass on a flat surface. These cellular fossils did not appear to be any of the algae described by Johnson (1963). The distinct boundaries of the cell walls seem also to indicate that the fossils are not algae. Most of the algae described by Johnson (1961, 1963) had fairly indistinct walls. The cellular fossil is possibly an encrusting form of foraminifer such as some species of Nubecularia sp. Hattin (1957, p. 73) reported that Nubecularia sp. in the Wreford Limestone occurred free in the limestone matrix without the normal association in Osagia sp. Johnson (1947, p. 41) described several species of Nubecularia sp. from the Lower Permian of Kansas that have walls 0.019 mm thick and colony lengths up to 20mm. Plate XV, Fig. 1 shows a photomicrograph of the possible Nubecularia sp. from sample D-5.

Sample D-5 contains numerous objects which are possibly fragments of organisms. These objects are rhomb-shaped, square, and several are long slender rectangles; they are filled with, or inverted to sparry calcite (0.01 mm). The objects were 0.15 mm wide and ranged from 0.1 mm to 0.3 mm long. An oil immersion of

EXPLANATION OF PLATE XV

Fig. 1. Photomicrograph of clayey fossiliferous micrite (D-5). Series of cells filled with spar is possibly a Nubecularia? sp. fragment. Rhomb shape at the right side of the photo is an unidentified object that was possibly organic in origin. Several similar objects occur in other parts of D-5 which are square or rectangular. An oil immersion study of some fragments from several of the rhomb-shaped objects showed no dolomite.

Fig. 2. Photomicrograph of typical clayey fossiliferous micrite containing ostracodes filled with clear sparry calcite (D-5).

PLATE XV

up

Fig. 1. 0.5 mm

up

Fig. 2. 0.5mm

fragments of the rhomb-shaped objects was made and no dolomite was found (Plate XV, Fig. 1).

Clayey Micrite and Micrites. Samples A-10 and E-8 are clayey micrites and A-9 and D-8 are micrites. The predominant constituent is micrite which averages 86 percent of the rock. The size of the micrite is from 1 to 2 microns. Microspar averages 7 percent and the pores and clay total 6 percent. Fossils and spar each amount to less than 1 percent. The only fossils are a few scattered ostracodes that have filled with spar. The grains of microspar are somewhat concentrated in small patches and are approximately 10 microns in diameter. Clay is concentrated parallel to the bedding.

Summary of Petrography

Recrystallized pelecypod biomicrite is the predominant limestone type in the lower unit. The samples that are not recrystallized pelecypod biomicrites differ because of fossil or microspar content. Fossils, other than the pelecypods, include gastropods, ostracodes, algae, and a few foraminifers. In several cases another fossil type is more abundant than the pelecypods.

The Middle "Shaly" Unit is predominantly a recrystallized clayey micrite; the only differences are less recrystallization and fewer fossils in some samples. Recrystallized clayey micrite and recrystallized fossiliferous micrite are the two predominant limestone types in the Upper "Platy" Unit. Several other limestone types in this unit have lesser amounts of microspar, clay, or fossils. Ostracodes are the most abundant fossils in the Upper "Platy" Unit.

INSOLUBLE RESIDUES

Mineral Identification

Quartz. Quartz is the most abundant mineral in both the silt and coarse residues. In some samples it composes as much as 98 percent; it never amounts to less than 10 percent. Quartz averages 59 percent of the coarse and 86 percent of the silt fractions. Quartz was identified by its uniaxial positive sign, its slightly positive relief in oil immersion (n = 1.53 @ 25°C), and its low birefringence. Most of the quartz was nearly free of inclusions. All grains are anhedral and are subangular to subrounded. The grain size ranged from 0.03 mm to 0.20 mm with an average of about 0.10 mm. Most of the quartz has undulose extinction.

Chert. Chert is the second most abundant mineral in the residue; however, it is completely lacking in the silt size fraction. Chert averages 26 percent, but in some samples amounts to 80 percent of the coarse fraction. All grains were identified as chert that showed the typical pinpoint extinction of a micro-quartz aggregate. The grains ranged from 0.04 mm to 0.24 mm with most grains approximately 0.20 mm.

Chalcedony. Chalcedony was identified by its fibrous or radial fibrous appearance, and by its undulatory or radial extinction. It occurs as a trace in several of the samples and amounts to four percent in sample A-10. The grain shape is quite irregular and averages 0.05 mm.

Limonite. Optically, limonite includes the mineral goethite

$FeO(OH)$ and the amorphous form, limonite $FeO(OH) \cdot nH_2O$. In most of the residue goethite and amorphous limonite occurs as aggregates and it was not possible to separate the two. Limonite was identified by its opaqueness, its rust red color in reflected light, and its form. It occurs as a trace in all samples, but it is most abundant in samples from the bottom and top of the Lower Limestone. In the top of the lower unit it amounts to as much as 86 percent of the insoluble residue. The form of the limonite is quite variable. It occurs as irregular earthy aggregates, as single grains (goethite), as wavy crusts, as the internal casts of gastropods and ostracodes, and as the framework for small hollow tubes.

Hematite. Hematite occurs as small aggregates of rhombohedral to nearly cubic crystals; also as the casts of gastropods. In most cases the hematite is surrounded by earthy limonite. It was identified by its reddish black color, its red streak, and its nearly opaque properties. The cubic crystals may be pseudomorphs of pyrite or magnetite. Only one sample of the silt size residue contained a trace of hematite. The coarse fraction of sample A-5 contains 10 percent hematite.

Gypsum. Gypsum occurs as a trace in three samples and amounts to two percent in another three samples. In all cases the gypsum is selenite and occurs as small platy crystals. It is distinguished from muscovite by its negative relief in oil with a refractive index of 1.53, its low birefringence, and by its positive biaxial sign. Most grains are about 0.04 mm in length.

Muscovite. Muscovite is absent from the coarse fraction but occurs at least as a trace in all but one of the samples of silt size residue. In sample A-6 it amounts to [illegible] percent of the total residue. This mineral was easily identified by its basal cleavage and high birefringence. The grains are generally rounded plates or subhedral laths that average 0.03 mm.

Volcanic glass. Volcanic glass occurs as a trace in five of the coarse samples (A-2, A-4, A-5, A-7, and A-10a) with a maximum of 1 percent in sample A-1. In all cases the glass is in the form of shards; however, a few shards have rounded edges. The glass was identified by its conchoidal fracture and its isotropism. The index of refraction of the glass is very close to the 1.53 index of the oil used for the immersion. The size of the shards averages 0.06 mm.

Orthoclase. Orthoclase occurs as a trace in the coarse fraction of sample A-9, but amounts to as much as 2 percent in several of the silt sized samples (A-2, A-7, and A-10a). It is identified by its low birefringence, its biaxial sign, and its negative relief in the 1.53 oil used. The grains range from 0.01 mm to 0.05 mm and average 0.03 mm in diameter.

Microcline. Microcline occurs as a trace in two samples (A-6 and A-7) of the silt sized material. It was determined by its typical polysynthetic grid twinning and low birefringence. The grains were 0.02 mm in diameter.

Quantity of Residue

The total weight percentage of the insoluble residue from the Crouse Limestone ranges from 2.2 to 45.7 percent. The proportion of the coarse residue is small, ranging from 0.01 to 0.12 percent. The weathering characteristics of the various lithologic units seems to be dependent on the percentage and composition of the residue. In most cases the color of the insoluble residue is very close to that of the limestone itself.

Table 5. Total weight percentage and mineral percentage of the coarse residue from the McDowell Creek Outcrop (A).

Mineral	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A10a
Quartz	62	75	82	72	10	94	88	20	70	71	13
Chert	10	20	16	25			10	80	27	20	80
Chalcedony	tr	tr		tr						4	
Orthoclase									tr		
Glass	1	tr		tr	tr		tr				tr
Gypsum	2	1	tr		1	2	2			1	1
Hematite	tr			1	3	1	tr	tr	tr	1	
Limonite	25	4	2	2	86	3		tr	3	3	6
Muscovite											
Coarse %	.08	.12	.07	.06	.02	.01	.04	.01	.05	.04	.08

tr = trace (less than one percent, or noted but not found on point-count)

Table 6. Mineral percentage of silt size insoluble residue from the McDowell Creek Outcrop (A).

Mineral	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A10a
Quartz	60	85	99	97	40	95	97	96	95	95	92
Chert											
Chalcedony	tr				tr			tr			
Orthoclase		2	tr	tr		1	2	tr	1	tr	2
Glass			1		tr			1			
Gypsum					tr						
Hematite										tr	
Limonite	40	13	tr	3	60	2	1	2	2	3	4
Muscovite	tr	tr	tr	tr		2	tr	1	2	2	2
Microcline						tr	tr				

tr = trace (less than one percent, or noted but not found on point-count)

Lower Limestone. The lowest unit in the Crouse Limestone contains the smallest amount of insoluble residue. The percentage ranges from 2.2 to 9.[illegible] percent with an average of 6.2 percent. The top of this unit generally contains less residue than the bottom; however, the spillway and Clark's Creek outcrops (C and E) show the reverse. The color of the insoluble residue ranges from moderate yellowish brown (10 YR 5/4) to dark yellowish orange (10 YR 6/6) and is caused by the high concentration of limonite. In the coarse residue the percentage of limonite is greater near the top and bottom of this limestone. The limonite occurs as crusts, earthy aggregates, and as casts of ostracodes and gastropods. Quartz is also abundant in this unit and in the middle part it exceeds the limonite. The quartz grains are subround to subangular and average 0.16 mm in diameter. The Lower Limestone also contains grains of chert, hematite, and traces of gypsum, volcanic glass, and chalcedony. The dominant mineral in the silt size part is quartz; smaller amounts of limonite and traces of chalcedony, orthoclase, and muscovite also occur.

Middle "Shaly" Unit. The middle limestone unit contains the greatest amount of insoluble residue of any unit in the Crouse Limestone. The total percentage ranges from 18.7 to 45.7 percent with an average of 27.5 percent. This high percentage of residue is approaching the 50 percent dividing line between shale and limestone, and is considered to be the cause of the shaly appearance of this unit. In all outcrops the percentage is generally greater at the bottom and less at the top. The color is a fairly consistent, yellowish gray (5 YR 7/2) with some variation to dusky yellow (5 Y 6/4) and light olive gray (5 Y 6/1). The percentage of "coarse" residue compared to that of the "fines" is lower than in the Lower Limestone. The percentage of coarse residue ranges from 0.01 to 0.04 percent.

Table 7. Total weight percentage and color of insoluble residue from the Lower Limestone Unit.

Outcrop	Sample No.	Color	Color Symbol	Percentage by weight
A	A5	Dark yellowish orange	10YR6/6	2.7
	A4	Pale yellowish brown	10YR6/2	6.7
	A3	Pale yellowish brown	10YR6/2	9.8
	A2	Moderate yellowish brown	10YR5/4	8.7
	A1	Dark yellowish orange	10YR6/6	9.4
B	B2	Moderate yellowish brown	10YR5/4	2.2
	B1	Grayish orange	10YR7/4	3.6
C	C2	Yellowish gray	5Y7/2	12.1
	C1	Moderate yellowish brown	10YR5/4	2.8
D	D3	Moderate yellowish brown	10YR5/4	2.2
	D2	Light olive gray	5Y5/2	5.3
	D1	Moderate yellowish brown	10YR5/4	9.8
E	E2	Grayish orange	10YR7/4	5.8
	E1	Moderate yellowish brown	10YR5/4	2.7
F	F5	Light brown	10YR5/6	3.5
	F4	Moderate yellowish brown	10YR5/4	3.0
	F3	Pale yellowish brown	10YR6/2	3.9
	F2	Yellowish gray	5Y7/2	13.1
	F1	Moderate yellowish brown	10YR5/4	7.0

Quartz is the dominant mineral in both the silt size and coarse residues. In the coarse fraction it ranges from 88 to 94 percent whereas in the silt size it is about 95 percent. The quartz occurs as subrounded to subangular anhedral grains. The coarse grains range from 0.08 to 0.25 mm and average 0.06 mm in diameter. In the coarse fraction chert, gypsum, limonite, and traces of volcanic glass and hematite also occur. The silt fraction contains some grains of orthoclase, limonite, muscovite, and traces of microcline.

Table 8. Total weight percentage and color of insoluble residue from the Middle "Shaly" Unit.

Outcrop	Sample No.	Color	Color Symbol	Percentage by weight
A	A7	Yellowish gray	5Y7/2	18.7
	A6	Yellowish gray	5Y7/2	29.3
B	B4	Yellowish gray	5Y7/2	20.3
	B3	Yellowish gray	5Y7/2	45.7
C	C3	Dusky yellow	5Y6/4	25.3
D	D4	Dusky yellow	5Y6/4	21.6
E	E5	Yellowish gray	5Y7/2	18.8
	E4	Yellowish gray	5Y7/2	26.6
	E3	Yellowish gray	5Y7/2	37.0
F	F6a	Light olive gray	5Y6/1	18.2
	F6	Yellowish gray	5Y7/2	31.3

Upper "Platy" Unit. The Upper "Platy" Unit, including the contorted zone at the top has a much more variable quantity of insoluble residue than the middle or lower units. In general the percentage of residue was less than in the "shaly" unit and greater than in the Lower Limestone. The insoluble residue ranges from 5.2 to 23.9 percent and averages 12.8 percent. The color is predominately yellowish gray (5 Y 7/2), like the "shaly" unit, but has much more variation. Olive gray (5 Y 4/1), light olive gray (5 Y 6/1), pale yellowish brown (10 YR 6/2), and moderate yellowish brown (10 YR 5/4) are other colors common in the Upper "Platy" Unit.

Table 9. Total weight percentage and color of the insoluble residue from the Upper "Platy" Unit.

Outcrop	Sample No.	Color	Color Symbol	Percentage by weight
A	A10a	Yellowish gray	5Y7/2	36.4
	A10	Pale yellowish brown	10YR6/2	10.9
	A9	Yellowish gray	5Y7/2	8.4
	A8	Yellowish gray	5Y7/2	16.4
B	B10	Yellowish gray	5Y7/2	13.5
	B9	Yellowish gray	5Y7/2	16.0
	B8	Yellowish gray	5Y7/2	13.0
	B7	Yellowish gray	5Y7/2	13.1
	B6	Light olive gray	5Y6/1	11.8
	B5	Dusky yellow	5Y6/4	13.5
C	C9	Yellowish gray	5Y7/2	7.3
	C8	Pale yellowish brown	10YR6/2	5.2
	C7	Moderate yellowish brown	10YR5/4	11.9
	C6	Pale yellowish brown	10YR6/2	7.2
	C5	Yellowish gray	5Y7/2	9.6
	C4	Light olive gray	5Y6/1	17.1
D	D9	Yellowish gray	5Y7/2	10.2
	D8	Olive gray	5Y4/1	7.8
	D7	Yellowish gray	5Y7/2	23.9
	D6	Light olive gray	5Y6/1	5.6
	D5	Yellowish gray	5Y7/2	15.8
E	E9	Yellowish gray	5Y7/2	16.9
	E8	Light olive gray	5Y6/1	10.8
	E7	Pale yellowish brown	10YR6/2	21.5
	E6	Yellowish gray	5Y7/2	20.1
F	F10	Pale yellowish brown	10YR6/2	7.9
	F9	Yellowish gray	5Y7/2	19.2
	F8	Pale yellowish brown	10YR6/2	6.8
	F7	Pale yellowish brown	10YR6/2	8.3

The coarse fraction of the insoluble residue from the Upper "Platy" Unit consists mainly of quartz and chert. In samples A-8 and A-10a the chert amounts to 80 percent and quartz equals 13 and 20 percent respectively. Samples A-9 and A-10 have approximately 70 percent quartz and 20 to 27 percent chert. The quartz consists of anhedral subrounded to subangular grains that average 0.08 mm and range from 0.06 to 0.16 mm in diameter. The chert occurs as subrounded to rounded grains and ranges from 0.08 mm to 0.25 mm with an average of 0.20 mm. Also in the coarse residue is less than 10 percent limonite and small quantities of orthoclase, chalcedony, gypsum, and hematite.

The silt size fraction consists of approximately 95 percent quartz. The quartz grains range from 0.01 to 0.05 mm and average 0.03 mm; most of them are subangular to subrounded. Also included in the silt size residue is 2 to 4 percent limonite, 1 to 2 percent muscovite, and traces of microcline, orthoclase, gypsum, hematite, and chalcedony.

X-RAY ANALYSIS

Clay Mineralogy

<u>Illite</u>. Poorly crystalline illite is by far the most abundant clay in all the samples of the Crouse Limestone. The illite was identified by its basal series of reflections of 10Å (001), 5Å (002), 3.33Å (003). The poorly crystalline nature of the illite was evident by the asymmetry of the (001) and (003) peaks. All illite reflections remained unchanged after treatment with ethylene

glycol. The first order intensity is larger than that of the third order and usually 3 to 5 times larger than the intensity of the second order. In some cases the (002) reflection was weak and somewhat broadened. This may indicate the presence of some iron substitution in the octahedral layer (Bryson, 1959, p. 26).

Illite-Montmorillonite. Illite-montmorillonite occurs as a trace in most samples. This mixed-layered clay is identified by the asymmetry it causes on the high angle side of the 3.33Å illite peak and on the low angle side of the 10Å illite peak. After treatment with ethylene glycol the montmorillonite expanded causing the 10Å illite peak to decrease in intensity and to become somewhat more symmetrical. The average reflection of this random interlayering gives a spacing that can vary from 12.4Å (pure montmorillonite) to 10Å (pure illite). The amount of expansion would be indicative of the relative amount of montmorillonite. In most samples there was only a slight variation in the illite peaks; therefore, the illite-montmorillonite was listed as a trace. Some asymmetry of the illite peak was also possibly due to the poorly crystalline nature of the illite.

Chlorite-Vermiculite. Regular interlayers of complex chlorite vermiculite (chlorite more abundant than vermiculite) occur as the second most abundant clay in four samples. This regularly interlayered clay was identified by its 28Å (001) superlattice peak, its 14Å (002) peak, its 7Å (004) peak, and a small shoulder on the high angle side of the 5Å illite peak. With glycolation the 14Å peak expanded to nearly 15Å and the 28Å superlattice reflection expanded to 31Å. After heating the sample to 450°C the

14Å peak collapsed to nearly 12Å and the superlattice from 28Å to 24Å. Heating the sample to 600°C caused little change. HCl-treated samples lost these characteristic peaks because the chlorite lattice is destroyed. Plate XVI shows a smooth line tracing of the x-ray data from a sample that contains illite and interlayered chlorite-vermiculite.

Vermiculite-Chlorite. Vermiculite-chlorite (vermiculite more abundant than chlorite) interlayered clay is the second most abundant clay in six samples. It occurs as both random and regularly stacked sequences. The regular sequence was determined by the superlattice peak of from 28Å to 29Å. This peak is from the added combination of the 14Å (001) chlorite peak and the 14Å (001) vermiculite peak. The most common sequence, however, is the random layered sequence in which the 28Å peak is absent. The 4.7Å and the 3.5Å peaks are very weak or non-existent in the vermiculite-chlorite clay; whereas, in the chlorite-vermiculite these higher order peaks are fairly strong. Glycolation caused some expansion of the 14Å peak to nearly 15Å and a reduction in the intensity of the 7Å (002). After heating the sample to 450°C the (001) reflection collapsed to nearly 12Å and the 10Å illite peak was intensified. Heating the sample to 600°C collapsed the (001) reflection slightly more. HCl treatment of this clay resulted in a loss of the (001) and (002) peaks. Plate XVII shows a smooth line tracing of the x-ray data from a typical illite and vermiculite chlorite sample.

Other Clay Size Minerals. Several other minerals are in the clay sized fraction. Calcite is a major constituent of several

EXPLANATION OF PLATE XVI

Smooth line tracings of the x-ray data from a typical illite and chlorite-vermiculite sample. (Sample A-7)

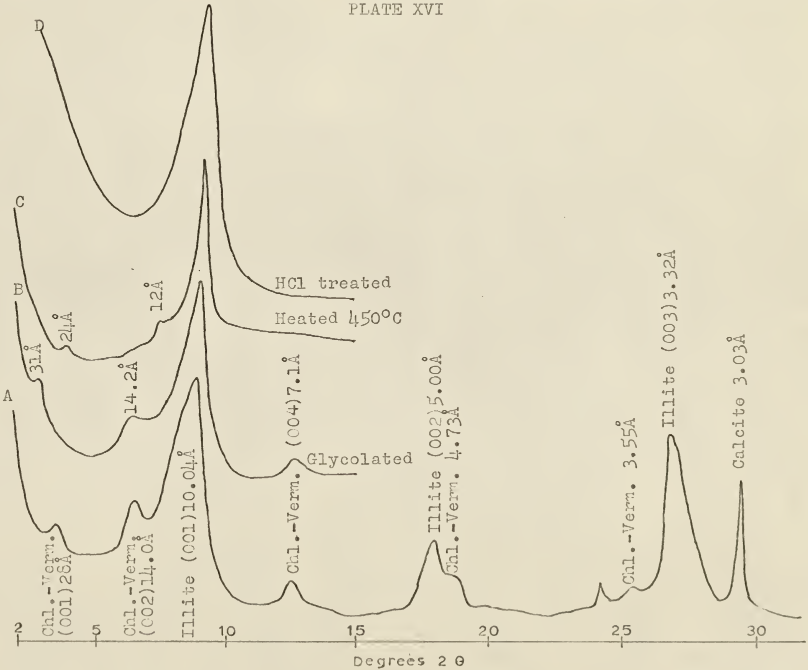
A. Untreated sample shows illite peaks at 10.04Å, 5.00Å, and 3.32Å; also chlorite-vermiculite peaks at 28Å (001)(superlattice), 14.0Å(002), 7.1Å(004), 4.73Å(006) (shoulder on (002) illite peak).

B. Glycolated sample shows no change in (001) illite peak, but chlorite-vermiculite (001)28Å expands to 31Å, and 14.0Å(002) expands only slightly.

C. After heating to 450°C the chlorite-vermiculite (001) collapses to 24Å and the 14.0Å to 12Å.

D. After treatment with hydrochloric acid the chlorite-vermiculite peaks are lost.

PLATE XVI


D
C
B
A
HCl treated
Heated 450°C
Glycolated
12Å
24Å
31Å
14.2Å
(004)7.1Å
Chl.-Verm.
(001)28Å
Chl.-Verm.
(002)14.0Å
Illite (001)10.04Å
Chl.-Verm.
Illite (002)5.00Å
Chl.-Verm. 4.73Å
Chl.-Verm. 3.55Å
Illite (003)3.32Å
Calcite 3.03Å
2
5
10
15
20
25
30
Degrees 2 Θ

EXPLANATION OF PLATE XVII

Smooth line tracings of the x-ray data from a typical illite and vermiculite-chlorite sample. (Sample F-11)

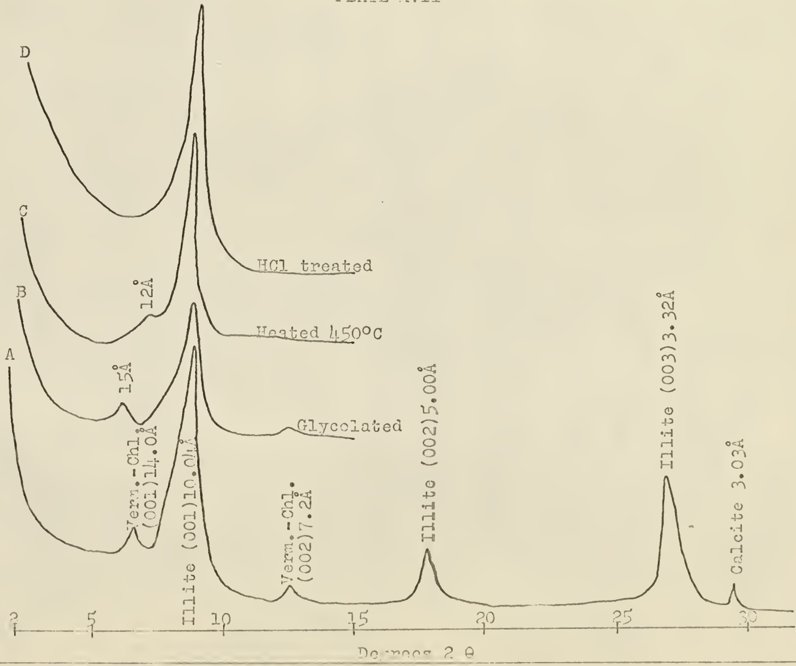
A. Untreated sample shows illite peaks at 10.04Å, 5.00Å, and 3.32Å; also vermiculite-chlorite peaks at 14.0Å(001), at 7.2Å(002), but has only a very weak (003) shoulder on the (002) illite peak. The (004) peak at 3.55Å which was with chlorite vermiculite is lacking the vermiculite-chlorite.

B. Glycolated sample shows no change in (001) illite peak, but the vermiculite-chlorite (001)14Å peak expands toward 15Å and the (002) peak is also expanded slightly.

C. After heating to 450°C the vermiculite-chlorite (001) peak collapses back to nearly 12Å; the chlorite prevents the peak from being completely destroyed as it would be in a pure vermiculite, and enhances the (001) illite peak. The 7.2Å(002) vermiculite-chlorite peak is almost destroyed.

D. After treatment with hydrochloric acid, the vermiculite-chlorite peaks are lost.

PLATE XVII



D
C
B
A
HCl treated
Heated 450°C
Glycolated
12Å
15Å
Verm.-Chl.
(001)14.0Å
Illite (001)10.04Å
Verm.-Chl.
(002)7.2Å
Illite (002)5.00Å
Illite (003)3.32Å
Calcite 3.03Å
2
5
10
15
20
25
30
Degrees 2 θ

samples; its major reflection occurs at 3.03Å. Goethite was also noted from a broad reflection at an interval of 4.18Å to 4.22Å.

Table 10. Summary of clay minerals from the Crouse Limestone.

Sample No.	Illite	Chlorite-Vermiculite	Vermiculite-Chlorite	Montmorillonite-Illite	Goethite
A1	Major	Minor		trace	P
A2	Major		Minor		P
A3	Major		Minor	trace	P
A4	Major	Minor		trace	P
A5	Major				P
A6	Major		Minor	trace	
A7	Major	Minor			
A8	Major		Minor	trace	P
A9	Major	Minor		trace	P
A10	Major		Minor		
F11	Major		Minor	trace	

Major = most abundant clay mineral
Minor = small peak but much less abundant than the major clay type
trace = shown only by slight expansion with glycolation of the asymmetrical illite peak
P = present as small broad peak

Calcite-Dolomite Determination

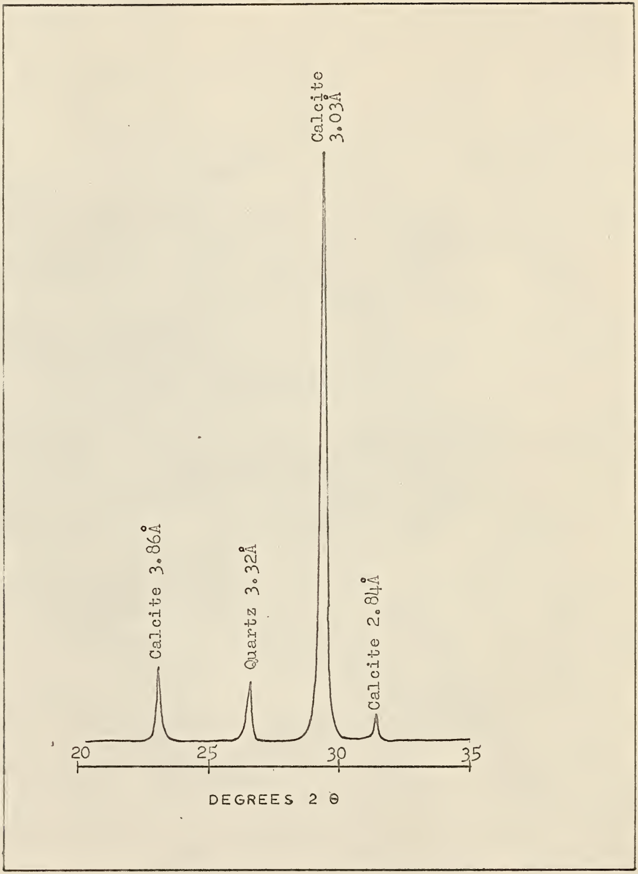
Samples A-1 through A-10, C-1, and F-11 were examined by x-ray diffraction to determine if dolomite occurs in the limestone. This was done before the petrographic work was started so that it would be known if dolomite was present prior to the thin section study.

The results of these determinations showed four major peaks that occur at intervals of 2.84Å, 3.03Å, 3.32Å, and 3.86Å. These correspond to the reflections of calcite and quartz. There was no evidence of any significant amount of dolomite which should have

EXPLANATION OF PLATE XVIII

A characteristic smooth line tracing of the results of the x-ray data for calcite and quartz. (Sample A-7)

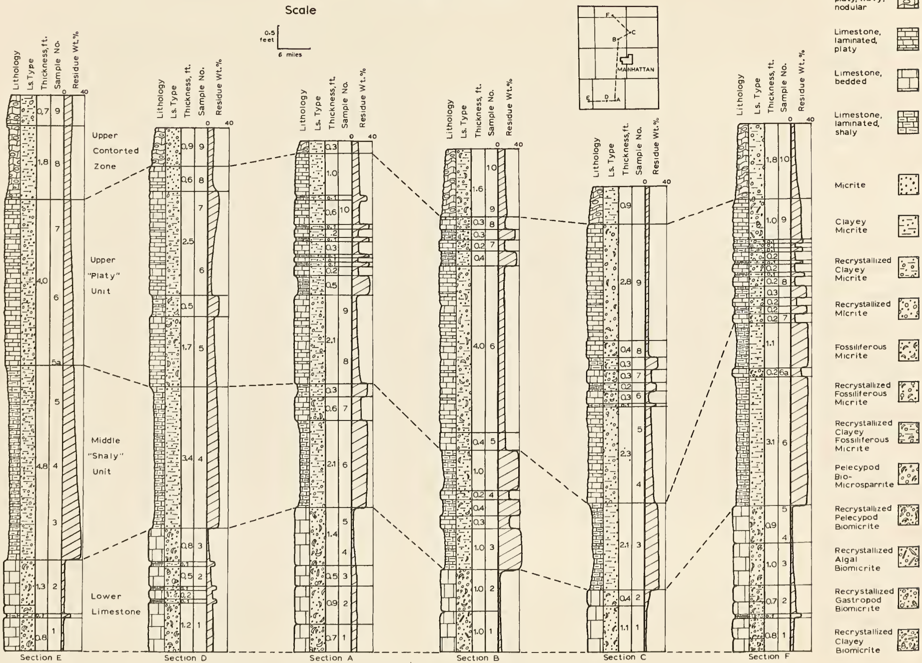
PLATE XVIII


Calcite 3.03Å
Calcite 3.86Å
Quartz 3.32Å
Calcite 2.84Å
20
25
30
35
DEGREES 2 θ

EXPLANATION OF PLATE XIX

Lithology of the Crouse Limestone in the vicinity of Manhattan, Kansas, showing the correlation of individual sections, the limestone types according to Folk's (1959) Classification, and the insoluble residue percentages.

PLATE XIX



LITHOLOGY OF THE CROUSE LIMESTONE IN THE VICINITY OF MANHATTAN, KANSAS shown a peak at 2.9Å. Plate XVIII shows a characteristic smooth line tracing of the results of the x-ray data for calcite and dolomite.

ENVIRONMENT OF DEPOSITION

The Crouse Limestone was deposited in shallow marine waters that spread over the Mid-continent region during Gearian time. Imbrie and others (1959, p. 70) postulated an elongate seaway from northeast Wyoming to Arkansas and Oklahoma that separated the low-lying continent to the north from tectonically active lands to the south and west. Water of this continental sea was connected to the open sea by the Arkansas Embayment. The seaway in Kansas was subdivided, by a shoal in western Kansas, into two partly restricted sedimentary basins (shelf lagoons). The area included in this study of the Crouse Limestone is in one of these shelf lagoons. This lagoonal area is separated from the Arkansas Embayment by a narrow shoal that Imbrie named the Greenwood Shoal. These seaways and shoals were present during the deposition of the Beattie Limestone; similar conditions could have persisted during deposition of the Crouse Limestone (Plate XX). Further study of the Crouse Limestone over a larger area would be needed to support the presence of these shoals and lagoons in the Crouse Sea.

Weller (1960, p. 199) stated that pelecypods are common in shallow, near shore water of normal salinity. The pelecypods of the lower Crouse Limestone suggest deposition in a similar environment. The Lower Limestone Unit corresponds with the molluscan phase of Elias' ideal Permian cyclothem (1937, p. 411). He stated

EXPLANATION OF PLATE XX

Extent of the Beattie Limestone sea that was postulated by Imbrie and others (1959, p. 71).

Fig. 1. Map view of the extent of the Beattie Limestone sea showing the location of shoals and lagoons.

Fig. 2. Cross section from A to A' of Figure 1 showing the high land area in Oklahoma and the sea level in relation to the shoals and lagoons.

PLATE XX

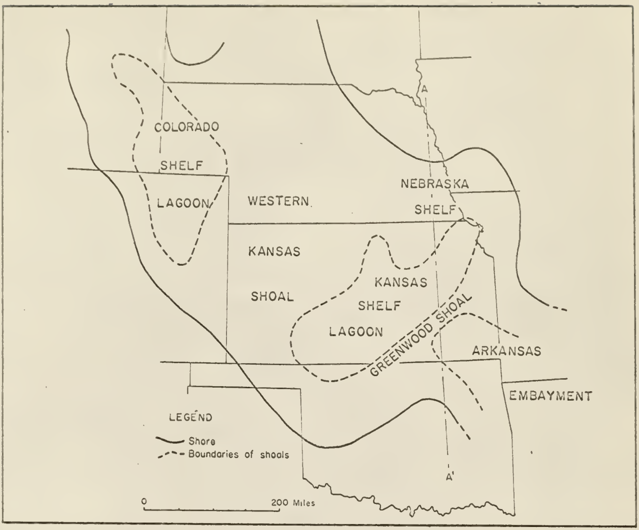


Fig. 1.

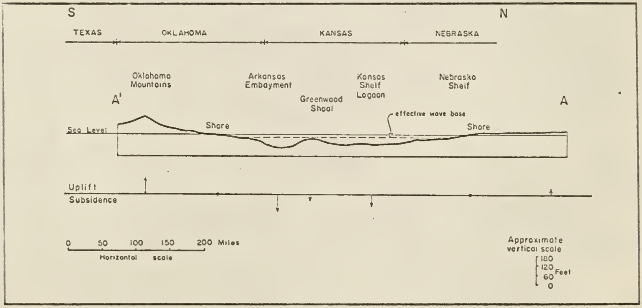


Fig. 2.

that the molluscan phase is typified by pelecypods, gastropods, and calcareous encrusting algae which may occur in a bedded limestone. Elias placed the depth of deposition of this phase between 60 and 90 feet. According to Hattin (1957, p. 54) some typical fossils from the molluscan phase are; Osagia sp., Nubecularia sp., Aviculopecten sp., small high-spired gastropods, ostracodes, and worm tubes.

The random orientation of the pelecypods and the dominance of microcrystalline calcite in the Lower Limestone is indicative of calm currents and a low energy environment (Lane, 1958, p. 147). Folk (1961, p. 149) stated that ineffective winnowing and calm currents occur in four major ways: (1) in protected lagoons with shallow water, (2) on broad shallow platforms on the lee side of barriers, (3) in moderately deep water, and (4) around organic baffles, such as marine grasses or algal growth. Folk suggested that pelecypods are criteria of a shallow or lagoonal area rather than deeper water. Some algae are mucilaginous and have the ability to hold fine silt and clay size particles that normally would not be deposited (Ginsburg and Lowenstam, 1958).

Several origins can be postulated for the microcrystalline calcite which are; (1) by direct precipitation of calcite from sea water, (2) by precipitation of aragonite and later inversion to calcite, (3) by abrasion of fossils, or (4) fine organic (algal) material (Stauffer, 1960, p. 29). It is probable that several of these origins were responsible for the microcrystalline calcite in the Crouse Limestone.

The small percentage of insoluble residue in the Lower Limestone unit could have been caused by: (1) a deepening sea that raises the base level, (2) arid climatic conditions that lessen runoff, (3) low relief of the land areas, and (4) lack of insoluble rocks in the source area.

The Easly Creek Shale, which underlies the Crouse Limestone, is a red, green, and gray shale that has an abundance of gypsum in the basal part (Moore and others, 1952, p. 46). This shale is indicative of deposition in very shallow water with a high salinity in a restricted basin. The gypsum probably formed in a semi-arid climate where the evaporation rate was high (Folk, 1961, p. 150). Imbrie and others (1959, p. 76) stated that shallowing conditions prevailed after Morrill time. The restrictive Greenwood Shoal could have caused a nearly isolated lagoon in which the gypsum of the Easly Creek Shale was deposited. The pelecypod biomicrite of the Crouse Limestone could possibly indicate a deepening of the sea and a restoration of normal circulation and salinity. The sharp contact between the Easly Creek Shale and the Crouse Limestone suggests rapid deepening of the sea. A continuation of arid conditions and a rising base level could have been the cause of the low quantity of insoluble residue in the Lower Limestone.

Ager (1963, p. 276) reported that when a Dutch island was flooded for a period of one year, only the most rapid colonizers among the marine fauna were able to establish themselves. The most abundant animals were pelecypods, whereas the slower moving gastropods did not arrive. Many Pectinacea pelecypods, which are common in the Lower Crouse Limestone, are free swimming, (Moore and others, 1952, p. 423) and would possibly be some of the first organisms to move into an area of recent inundation.

Laporte (1962, p. 540) stated, in the case of the Beattie Limestone, that depth difference alone is not responsible for environmental conditions. He listed three other factors equally important: (1) rate and amount of terrigenous material which is related to relief and nearness of the source, (2) turbulence which is inversely related to depth, and (3) salinity which is related to circulation, climate, and basin geometry.

The Middle "Shaly" Unit has more insoluble residue and fewer fossils, except ostracodes, than the lower unit. The increase in terrigenous material and the dominance of ostracodes could possibly have been caused by a more humid climate. Greater rainfall would increase the stream flow into the basin; therefore, increasing the inflow of terrigenous material, and at the same time cause the water to become slightly brackish. Brackish water could cause the decrease in organisms other than ostracodes. Weller (1960, p. 200) stated that ostracodes are most common in brackish shallow water and can withstand conditions often unfavorable to most other marine invertebrates. Newell (1942, p. 16) indicated that certain mytilid pelecypods are also tolerant of wide ranges in salinity; however, no pelecypods of this type were noted in the study of the Crouse Limestone. The terrigenous material in the Crouse Limestone was probably derived from land areas to the northeast and south. An increase in terrigenous material could also be attributed to an uplift of these source areas or a slow regression of the sea causing a lowering of base level.

The environment of deposition of the Upper "Platy" Unit seems to be very much the same as for the Middle "Shaly" Unit. The only lithologic difference is a gradual decrease in insoluble residue. This decrease in insoluble residue could have been caused by drier climatic conditions or a lowering of the land areas by erosion. The concentration of the clay into laminae, which is common in the Middle "Shaly" and Upper "Platy" Units, possibly represent seasonal changes much like that in varved clays. The concentrations of clay would correspond to the wetter seasons; during the drier seasons carbonate deposition would be dominant. According to Cloud (1942, p. 373) the major cause for laminations is fluctuation in atmospheric conditions.

The contorted laminations and the alternation of shaly and less shaly beds near the top of the Crouse Limestone possibly suggest a shallowing of the sea in late Crouse time. Small irregular concentrations of fossils and the orientation of fossils parallel to bedding planes suggest possible periodic disturbances by waves. The overlying Blue Springs Shale is a gray, green, and red shale that contains a thin coal bed in Geary County (Moore and others, 1951, p. 46). This shale is indicative of a very shallow or possibly continental environment and seems to support the possibility that during late Crouse time the sea was regressing.

Although the significance of color in limestones is not too well known, it is thought that in well-oxygenated shallow water bacteria can thrive and eat decaying organic matter, resulting in light-colored rocks (Folk, 1961, p. 150). If this is true, then the predominance of shades of yellowish-gray and other light colors throughout the Crouse Limestone seem to indicate the water was fairly shallow and well-oxygenated.

CONCLUSIONS

The following conclusions were drawn from the results of this investigation:

1. The Crouse Limestone is about 12 feet thick in the vicinity of Manhattan, Kansas, and can be subdivided into three units that include a lower resistant pelecypod limestone, a middle "shaly" limestone, and an upper "platy" limestone.

2. The most abundant clay throughout the Crouse Limestone is illite with minor amounts of interlayered chlorite-vermiculite and vermiculite-chlorite.

3. The Lower Limestone unit seems to represent deposition in shallow quiet water where terrigenous influx was low; currents and wave actions were not sufficient to remove the microcrystalline calcite matrix or cause orientation of the fossils. In this area during early Crouse time, the sea probably deepened and returned to normal salinity after deposition of the Easly Creek Shale.

4. The Middle "Shaly" and Upper "Platy" Units contain more terrigenous material and were possibly deposited in shallow quiet water that was more brackish than that of the Lower Limestone.

5. It is proposed that the laminations in the Middle "Shaly" and Upper "Platy" Units may have been caused by seasonal climatic changes; the deposition of clay increased during wetter periods and decreased during drier seasons.

6. Important factors in the deposition of the Crouse Limestone

are; depth of water, changes in salinity, differences in the influx of terrigenous material, turbulence, and climate.

7. Further study of the Crouse Limestone over a larger lateral extent is needed to determine whether the lagoons and shoals postulated by Imbrie and others (1959, p. 69) continued until Crouse time.

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APPENDIX

Section A

This section occurs in a road cut on U. S. Interstate 70 just west of the crest of a hill 0.6 mile east of McDowell Creek. Exposed in the section is five feet of the Easly Creek Shale, the Crouse Limestone, and the Blue Rapids Shale.

Legal Description: NE$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$ Sec 27, T11S, R7E, Geary County, Kansas.

Measured June 9, 1964, with metallic tape, hand level, and five foot staff.

	Thickness in feet	Thickness above base
Blue Rapids Shale		
Crouse Limestone		
21. Limestone - very pale orange (10 YR 8/2) clayey micrite, irregular wavy laminations with calcite nodules, weathers yellowish gray (5 Y 7/2) and platy, grades into shale above	.3	12.0-12.3
20. Limestone - very pale orange (10 YR 8/2) clayey micrite, alternating resistant and non-resistant laminae, weathers yellowish gray as alternating platy and shaly zones	1.0	11.0-12.0
19. Limestone*- grayish orange (10 YR 7/4) clayey micrite, laminated, with ostracodes and spines, weathers very pale orange (10 YR 8/2) and shaly	.1	10.9-11.0
18. Limestone - very pale orange (10 YR 8/2) clayey, micrite, laminated, with ostracodes, weathers gray (5 Y 7/2) and platy	.6	10.3-10.9
17. Limestone*-grayish orange (10 YR 7/4) clayey micrite, laminated, with ostracodes and spines, soft, weathers very pale orange (10 YR 8/2) and shaly	.1	10.2-10.3
16. Limestone - very pale orange (10 YR 8/2) clayey micrite, medium hard, laminated and platy, weathers yellowish gray (5 Y 7/2)	.2	10.0-10.2
15. Limestone*- grayish orange (10 YR 7/4) clayey micrite, laminated, weathers shaly to very pale orange (10 YR 8/2) . .	.1	9.9-10.0
14. Limestone - very pale orange (10 YR 8/2) clayey micrite, laminated and platy, weathers yellowish gray (5 Y 7/2), grades into "shaly" limestone above	.3	9.6-9.9

13.	Limestone - (same as unit 20)	.1	9.5-9.6
12.	Limestone - very pale orange (10 YR 8/2) clayey micrite laminated and platy, weathers yellowish gray (5 Y 7/2)	.1	9.4-9.5
11.	Limestone*-grayish orange (10 YR 7/4) clayey micrite, laminated, contains <u>Hollinella</u> sp. and <u>Cavellina</u> sp., weathers like shale to a very pale orange (10 YR 8/2)	.1	9.3-9.4
10.	Limestone - very pale orange (10 YR 8/2) micrite, medium hard, weathers yellowish gray (5 Y 7/2), a single bed	.2	9.1-9.3
9.	Limestone*- grayish orange (10 YR 8/2) micrite, soft, laminated, with ostracodes, weathers like a shale to very pale orange (10 YR 8/2)(Sample A-9)	.5	8.6-9.1
8.	Limestone - very pale orange (10 YR 8/2) recrystallized clayey micrite, laminated, distinct limonite stain 8 inches from base, weathers platy to yellowish gray (5 Y 7/2)	2.1	6.5-8.6
7.	Limestone*- grayish orange (10 YR 7/4) clayey micrite, laminated and soft, weathers like a shale to very pale orange (10 YR 8/2)	.3	6.2-6.5
6.	Limestone - very pale orange (10 YR 8/2) recrystallized clayey fossiliferous micrite, with ostracodes, pelecypod fragments, and gastropods, laminated, horizontal dark yellowish orange (10 YR 6/6) limonite streaks, breaks out into blocks but splits platy, weathers very pale orange (10 YR 8/2) (Sample A-7)	.6	5.6-6.2
5.	Limestone*- grayish orange (10 YR 7/4) recrystallized clayey micrite, non fossiliferous, laminated, soft and weathers like a shale to a very pale orange (10 YR 8/2). Several thin bands of light gray (N7)(Sample A-6)	2.1	3.5-5.6
4.	Limestone - moderate brown (5 YR 4/4) recrystallized pelecypod biomicrite in upper part to pale yellowish brown (10 YR 6/2) recrystallized fossiliferous micrite in lower part, with <u>Aviculopecten</u> sp., <u>Pleurophorus</u> sp., small high-spired gastropods, ostracodes, <u>Osagia</u> sp., <u>Anchicodium</u>? and fossil fragments, abundant limonite in upper part, hard resistant, weathers yellowish gray (5 Y 7/2), solution cavities 0.5 and 1.0 feet down from top, a single bed (Samples A-4 and A-5) . . .	1.4	2.1-3.5

3. Limestone - pale yellowish brown (10 YR 6/2) recrystallized biomicrite, with pelecypods, ostracodes, high-spired gastropods, <u>Osagia</u> sp. and <u>Nubecularia</u>?, very thin-bedded, weathers flaggy and vuggy to grayish orange (10 YR 7/4)(Sample A-3)	.5	1.6-2.1
2. Limestone - pale yellowish brown (10 YR 6/2) fossiliferous micrite, with pelecypod fragments, ostracodes, <u>Osagia</u> sp. and <u>Anchicodium</u> sp. Limonite stains on surface, small clay lenses common, a single bed, weathers yellowish gray (5 Y 7/2) and vuggy with solution holes filled by moderate yellowish brown (10 YR 5/4) residue (Sample A-2)	.9	0.7-1.6
1. Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod biomicrite, with <u>Aviculopecten</u> sp., <u>Pleurophorus</u> sp., pelecypod fragments, high-spired gastropods, ostracodes, <u>Anchicodium</u>? and <u>Osagia</u> sp. A single bed, hard resistant and weathers yellowish gray (5 Y 7/2) separated from bed above by $\frac{1}{4}$ inch shale. Makes sharp contact with yellowish gray (5 Y 7/2) shale below (Sample A-1) . . .	.7	0.0-0.7
Total	12.3	

Easly Creek Shale

Section B

This section occurs in a road cut on the north side of highway K-177, one mile west of its junction with K-13, north of Manhattan, Kansas. The lowermost part of the section occurs 500 feet east of this location. The entire outcrop includes most of the Easly Creek Shale, up to, and including, the lower part of the Threemile Limestone.

Legal Description: SW$\frac{1}{4}$ SW$\frac{1}{4}$ SW$\frac{1}{4}$ Sec 23, T9S, R7E, Riley County, Kansas.

Measured June 6, 1964, with metallic tape, hand level, and five foot staff.

Blue Rapids Shale	Thickness in feet	Thickness above base
Crouse Limestone		
14. Limestone - very pale orange (10 YR 6/2) recrystallized clayey fossiliferous micrite, with ostracodes, fossil fragments, foraminifers, algae?. laminated, weathers platy to yellowish gray (5 Y 7/2) top 4 inches thinly laminated, lower part appears brecciated due to collapse structure? solution holes 2 to 4 inches wide are common; gradational into nodular shale above (Samples B-9 and B-10)	1.6	10.5-12.1
13. Limestone - yellowish gray (5 Y 7/2) recrystallized clayey fossiliferous micrite with ostracodes and foraminifers; has a thin band of brown (5 YR 5/6) limonite. A single bed, weathers yellowish gray (5 Y 7/2) (Sample B-8)	.3	10.2-10.5
12. Limestone*- yellowish gray (5 Y 7/2) clayey fossiliferous micrite, with <u>Cavellina</u> sp. and brachiopod? spines, laminated, weathers shaly to yellowish gray (5 Y 7/2)	.3	9.9-10.2
11. Limestone - yellowish gray (5 Y 7/2) recrystallized clayey fossiliferous micrite, with high-spired gastropods, and foraminifers? a single bed with thin light brown (5 YR 5/6) banding, weathers yellowish gray (5 Y 7/2) (Sample B-7)	.2	9.7-9.9
10. Shale - calcareous, yellowish gray (5 Y 7/2) fossiliferous, with <u>Cavellina</u> sp. and brachipod? spines. Laminated, weathers shaly to yellowish gray (5 Y 7/2)	.4	9.3-9.7
9. Limestone - medium light gray (N6) recrystallized clayey fossiliferous micrite, with ostracodes and brachiopod? spines. Laminated to thinly laminated, weathers yellowish gray (5 Y 7/2) and platy (Sample B-6)	4.0	5.3-9.3
8. Limestone - dusky yellow (5 Y 6/4) recrystallized clayey micrite, soft and porous, weathers light brown (5 YR 5/6) is distinguished from limestone above only by color change (Sample B-5)	.4	4.9-5.3
7. Limestone*- yellowish gray (5 Y 7/2)		

	clayey fossiliferous micrite, laminated with Hollinella sp., Bythocypris sp., Bairdia sp., Cavellina sp., and spines, weathers yellowish gray (5 Y 7/2) and shaly	1.0	3.9-4.9
6.	Limestone - yellowish gray (5 Y 7/2) clayey micrite, a single bed, weathers yellowish gray (5 Y 7/2) (Sample B-4)	.2	3.7-3.9
5.	Limestone*- yellowish gray (5 Y 7/2) clayey fossiliferous micrite, laminated, with Hollinella sp., Bythocypris sp., and Cavellina sp. Weathers yellowish gray (5 Y 7/2)	.4	3.3-3.7
4.	Limestone - yellowish gray (5 Y 7/2) clayey micrite, a single bed, weathers yellowish gray (5 Y 7/2)	.3	3.0-3.3
3.	Limestone*- yellowish gray (5 Y 7/2) clayey fossiliferous micrite, with ostracodes, and spines, laminated, weathers same color and shaly (Sample B-3)	1.0	2.0-3.0
2.	Limestone - very pale orange (10 YR 5/2) pelecypod biomicrosparrite, with Aviculopecten sp., Pleurophorus sp., pelecypod fragments, Bellerophon sp., small high-spired gastropods, ostracodes, Osagia sp., and Anchicodium sp. Hard, resistant, a single bed, small clay lenses (up to 18 inches long and 2 inches wide). Abundant limonite, weathers moderate brown (5 YR 4/4) (Sample B-2)	1.0	1.0-2.0
1.	Limestone - very pale orange (10 YR 8/2) recrystallized algal biomicrite with Anchicodium sp., Osagia sp., Mizzia?, Bairdia sp., Cavellina sp., small high-spired gastropods, pelecypods, and foraminifers? a single hard resistant bed, weathers yellowish gray (5 Y 7/2)	1.0	0.0-1.0
	Total	12.1	

Easly Creek Shale

Section C

This section is located on the east bank of the spillway cut at Tuttle Creek Dam, just north of the spillway gates. The entire cut exposes the stratigraphy from the Eskridge Shale up to the Funston Limestone. A vertical fault cuts through the south end of this exposure with a total displacement of approximately 30 feet. The Crouse Limestone is partly covered at this location by limestone plates from its upper unit.

Legal Description: NW¼ SE¼ SW¼ Sec 18, T9S, R8E, Pottawatomie County, Kansas.

Measured June 12, 1964, by metallic tape, hand level, and five foot staff.

Blue Rapids Shale	Thickness in feet	Thickness above base
Crouse Limestone		
11. Limestone - very pale orange (10 YR 8/2) clayey micrite contorted and wavy laminations, with ostracodes, and shell fragments. Weathers yellowish gray (5 Y 7/2) and platy, gradational into nodular shale above	.9	10.3-11.2
10. Limestone - yellowish gray (5 Y 7/2) recrystallized fossiliferous micrite, with ostracodes, foraminifers, and algae?, laminated, weathers yellowish gray (5 Y 7/2) and platy (Sample C-9)	2.8	7.5-10.3
9. Limestone - yellowish gray (5 Y 7/2) recrystallized fossiliferous micrite, with *Hollinella* sp. and shell fragments, laminated; weathers yellowish gray (5 Y 7/2) and platy (Sample C-8)	.4	7.1-7.5
8. Limestone*- yellowish gray (5 Y 7/2) clayey fossiliferous micrite, with *Hollinella* sp. and spines; weathers same color and shaly	.3	6.8-7.1
7. Limestone - yellowish gray (5 Y 7/2) recrystallized fossiliferous micrite, with ostracodes and foraminifers?, laminated with 2 mm wide dark yellowish orange (10 YR 6/6) biomicrite zones. Biomicrite zones have ostracodes, small pelecypods and a few high-spired gastropods. Yellowish orange color due to limonite concentration. Weathers yellowish gray (5 Y 7/2) and platy (Sample C-7)	.3	6.5-6.8
6. Limestone*- yellowish gray (5 Y 7/2) clayey micrite laminated and soft, weathers yellowish gray (5 Y 7/2) and shaly	.2	6.3-6.5

5.	Limestone - yellowish gray (5 Y 7/2) recrystallized fossiliferous micrite, with high-spired gastropods, ostracodes, pelecypods and shell fragments. Laminated and has some yellowish brown (10 YR 4/2) limonite stains. Small concentrations of biomicrite common. Weathers yellowish gray (5 Y 7/2) and platy (Sample C-6)	.3	6.0-6.3
4.	Limestone*- very pale orange (5 YR 8/2) clayey micrite, soft, laminated, weathers yellowish gray (5 Y 7/2) and shaly	.1	5.9-6.0
3.	Limestone - yellowish gray (5 Y 7/2) recrystallized micrite near top grades into recrystallized clayey micrite near bottom, rare ostracodes, some fossils replaced by limonite, laminated. Weathers yellowish gray (5 Y 7/2) and platy (Samples C-4 and C-5)	2.3	3.6-5.9
2.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite, laminated, weathers same color and shaly (Sample C-3)	2.1	1.5-3.6
1.	Limestone - very pale orange (5 YR 8/2) fossiliferous micrite near top to recrystallized biomicrite in lower part with pelecypods, small high-spired gastropods, ostracodes, and some <u>Osagia</u> sp. Much limonite replacement and fossil fillings. Upper part has irregular areas of biomicrite in a micrite; a single hard resistant bed, upper part weathers light brown (5 YR 5/6) due to limonite, lower weathers grayish orange (10 YR 7/4). Solution holes common in upper part . . .	1.5	0.0-1.5
	Total	11.2	

Easly Creek Shale

Section D

This outcrop occurs in a road cut on Interstate 70, 0.1 mile west of the McDowell Creek road underpass. The Crouse Limestone is exposed in the ditch on the north side of the road. The complete outcrop includes 10 feet of the Easly Creek Shale up to and including 3 feet of the Threemile Limestone Member.

Legal Description: SW¼ SW¼ NE¼ Sec 28, T11S, R7E, Geary County, Kansas.

Measured June 10, 1964, with metallic tape, hand level, and five foot staff.

Blue Rapids Shale	Thickness in feet	Thickness above base
Crouse Limestone		
13. Limestone - yellowish gray (5 Y 7/2) recrystallized micrite, wavy to contorted laminae, upper 6 inches thinly laminated, abundant calcite nodules, weathers grayish orange (10 YR 7/4) and platy, grades into nodular shale above (Sample D-9)	.9	11.7-12.6
12. Limestone - yellowish gray (5 Y 7/2) micrite with scarce ostracodes, laminated (slightly wavy). Weathers yellowish gray (5 Y 7/2) and platy; grades into limestone below (Sample D-8)	.6	11.1-11.7
11. Limestone - yellowish gray (5 Y 7/2) recrystallized clayey micrite in upper part, grades into recrystallized micrite in lower, laminated to thinly laminated, scarse ostracodes; weathers same color and platy (Samples D-6 and D-7) . .	2.5	8.6-11.1
10. Limestone*- yellowish gray (5 Y 7/2) clayey fossiliferous micrite, with ostracodes (<u>Hollinella</u> sp., <u>Cavellina</u> sp.) soft, laminated, weathers grayish orange (10 YR 7/4) and shaly, grades into limestone below	.5	8.1-8.6
9. Limestone - yellowish gray (5 Y 7/2) recrystallized clayey fossiliferous micrite, with ostracodes (<u>Hollinella</u> sp., <u>Cavellina</u> sp., <u>Bythocypris</u> sp.) echinoid? spines, <u>Nubecularia</u>? laminated, weathers grayish orange (10 YR 7/4) and platy (Sample D-5) . . .	1.7	6.4-8.1
8. Limestone*- yellowish gray (5 Y 7/2) clayey micrite, non-fossiliferous, soft, laminated two less clayey zones at 2.3 and 3.1 feet from base. Weathers yellowish gray and shaly (Sample D-4) . .	3.4	3.0-6.4
7. Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod biomicrite, with <u>Aviculopecten</u> sp., <u>Pleurophorus</u> sp., pelecypod fragments, small high-spired gastropods, <u>Bellerophon</u> sp., ostracodes, <u>Hustedia</u> sp., foraminifers		

	and Osagia sp. Abundant limonite fossil fillings, in upper part, a single hard resistant bed; upper part weathers dark yellowish orange (10 YR 6/6) due to limonite, lower weathers grayish orange (10 YR 7/4)(Sample D-3)	.8	2.2-3.0
6.	Shale - calcareous, yellowish gray (5 Y 7/2) laminated, weathers same color and shaly	.1	2.1-2.2
5.	Limestone - pale yellowish brown (10 YR 6/2) recrystallized gastropod biomicrite, with abundant small high spired gastropods, pelecypods, ostracodes, Osagia sp., a single hard resistant bed, weathers grayish orange (10 YR 7/4) (Sample D-2)	.5	1.6-2.1
4.	Shale - calcareous, yellowish gray (5 Y 7/2) soft and laminated, weathers same color and shaly	.1	1.5-1.6
3.	Limestone - pale yellowish brown (10 YR 6/2) biomicrite with high-spired gastropods, pelecypod fragments, ostracodes, a single resistant bed, weathers grayish orange (10 YR 7/4)	.2	1.3-1.5
2.	Shale - calcareous, yellowish gray (5 Y 7/2) soft, laminated, weathers same color and shaly	.1	1.2-1.3
1.	Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod biomicrite with high-spired gastropods, pelecypods, ostracodes, thin-bedded hard and resistant, weathers grayish orange (10 YR 7/4) and slabby (Sample D-1)	1.2	0.0-1.2
	Total	12.6	

Easly Creek Shale

Section E

This section occurs in a road cut on U. S. Interstate 70, south of Manhattan, just west of the crest of a hill 0.6 mile east of Clark's Creek. The Crouse Limestone is exposed on the north and south sides of the road. The complete section includes the Crouse Limestone up to and including four feet of the Havensville Shale Member of the Wreford Limestone.

Legal Description: SW½ NE¼ SW¼ Sec 25, T11S, R6E, Geary County, Kansas.

Measured June 12, 1964, with metallic tape, hand level, and five foot staff.

Blue Rapids Shale	Thickness in feet	Thickness above base
Crouse Limestone		
7. Limestone - medium light gray (N6) recrystallized clayey micrite, wavy to contorted laminae, some calcite nodules, weathers yellowish gray (5 Y 7/2) and platy; nodules weather loose, grades into nodular shale above (Sample E-9)	.7	12.8-13.5
6. Limestone - medium light gray (N6) clayey micrite non-fossiliferous, very irregular to controted laminations, abundant calcite nodules, less resistant than limestone above and below, weathers yellowish gray (5 Y 7/2) and platy. Nodules weather out and form loose rubble (Sample E-8)	1.8	11.0-12.8
5. Limestone - yellowish gray (5 Y 7/2) recrystallized clayey micrite, with recrystallized clayey fossiliferous micrite zone in center, with _Bairdia_ sp., _Bythocypris_ sp., _Tetrataxis_ sp., _Anchicodium_ sp., and _Osagia_ sp., laminated, weathers grayish orange (10 YR 7/4) and platy	4.0	7.0-11.0
4. Limestone*- yellowish gray (5 Y 7/2) recrystallized clayey micrite, with scarce ostracodes, and brachiopod? spines, soft, laminated, some large medium gray (N5) mottled areas and horizontal streaks, weathers very pale orange (10 YR 8/2) and shaly (Samples E-3, E-4, E-5)	4.8	2.2-7.0
3. Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod biomicrite, with _Aviculopecten_ sp., _Pleurophorus_ sp., small high-spired gastropods, _Bairdia_ sp., and shell fragments, most ofssils concentrated in upper four inches, abundant limonite in fossil cavities, two hard resistant beds, upper one 1.1 feet thick, lower 0.2 feet thick, weathers dark yellowish orange (10 YR 6/6) due to limonite (Sample E-2)	1.3	0.9-2.2

2.	Shale - calcareous, yellowish gray (5 Y 7/2) with ostracodes, is laminated, weathers pale yellowish brown (10 YR 6/2) and shaly	.1	0.8-0.9
1.	Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod fragments, small high-spired gastropods, ostracodes, foraminifers, and *Osagia* sp. A single hard resistant bed, weathers dark yellowish orange (10 YR 6/6) due to abundant limonite; makes sharp contact with yellowish gray (5 Y 7/2) shale below (Sample E-1)	.8	0.0-0.8
	Total	13.5	

Easly Creek Shale

Section F

This section occurs in a road cut on an access road to the Stockdale Recreation Area boat ramp at Tuttle Creek Lake. It is located 100 yards up the road from the boat ramp. The complete exposure includes five feet of the Easly Creek Shale and continues up the hill through the Havensville Shale Member of the Wreford Limestone Formation.

Legal Description: NE¼ SE¼ SW¼ Sec 33, T8S, R7E, Riley County, Kansas.

Measured June 18, 1964, with metallic tape, hand level, and five foot staff.

Blue Rapids Shale		Thickness in feet	Thickness above base
Crouse Limestone			
22.	Limestone - very pale orange (10 YR 8/2) recrystallized clayey micrite, with algal threads? wavy to contorted laminations, abundant calcite nodules. Common lateral bands of dark yellowish orange (10 YR 6/6) limonite; weathers yellowish gray (5 Y 7/2) and platy, grades into pale olive (10 Y 6/2) nodular shale above (Sample F-10)	1.8	10.9-12.7

21.	Limestone - very pale orange (10 YR 8/2) recrystallized clayey biomicrite, with <u>Bairdia</u> sp., <u>Hollinella</u> sp., <u>Cavellina</u> sp., <u>Anchicodium</u> sp., and <u>Osagia</u> sp., medium hard, weathers yellowish gray (5 Y 7/2) and breaks out into blocks but then weathers platy (Sample F-9)	1.0	9.9-10.9
20.	Limestone*- very pale orange (10 YR 6/2) recrystallized clayey micrite, laminated, soft, weathers yellowish gray (5 Y 7/2) and shaly	.1	9.8-9.9
19.	Limestone - very pale orange (10 YR 7/2) recrystallized micrite, medium hard, and laminated; weathers yellowish gray (10 YR 7/2) and platy	.1	9.7-9.8
18.	Limestone*- very pale orange (10 YR 8/2) recrystallized clayey micrite, laminated and soft; weathers yellowish gray (5 Y 7/2) and shaly	.1	9.6-9.7
17.	Limestone - very pale orange (10 YR 8/2) recrystallized micrite, medium hard and laminated; weathers yellowish gray (5 Y 7/2) and platy	.2	9.4-9.6
16.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite soft and laminated; weathers yellowish gray and shaly	.1	9.3-9.4
15.	Limestone - very pale orange (10 YR 8/2) recrystallized micrite, medium hard and laminated; weathers yellowish gray (5 Y 7/2) and platy	.2	9.1-9.3
14.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite soft and laminated, weathers yellowish gray and shaly	.1	9.0-9.1
13.	Limestone - very pale orange (10 YR 8/2) recrystallized micrite, medium hard and laminated, with scarce ostracodes, weathers yellowish gray (5 Y 7/2) and platy (Sample F-8)	.2	8.8-9.0
12.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite, soft and laminated, weathers yellowish gray (5 Y 7/2) and shaly	.3	8.5-8.8
11.	Limestone - yellowish gray (5 Y 7/2) recrystallized micrite, medium hard and laminated, weathers yellowish gray (5 Y 7/2) and platy	.2	8.3-8.5
10.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite soft and laminated, weathers yellowish gray (5 Y 7/2) and shaly	.2	8.1-8.3

9.	Limestone - very pale orange (10 YR 8/2) recrystallized fossiliferous micrite, with pelecypod fragments, and small high-spired gastropods, consists of micrite with zone of biomicrite 1 cm thick, limonite common in biomicrite zone, medium hard and laminated, weathers yellowish gray (5 Y 7/2) and platy (Sample F-7)	.2	7.9-8.1
8.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite, laminated and soft, weathers yellowish gray (5 Y 7/2) and shaly	1.1	6.8-7.9
7.	Limestone - very pale orange (10 YR 6/2) recrystallized clayey micrite, scarce ostracodes, medium hard and laminated, weathers yellowish gray (5 Y 7/2) and platy	.2	6.6-6.8
6.	Limestone*- yellowish gray (5 Y 7/2) clayey micrite with scarce ostracodes, soft and laminated, weathers yellowish gray (5 Y 7/2) and shaly	3.1	3.5-6.6
5.	Limestone - pale yellowish brown (10 YR 6/2) recrystallized pelecypod biomicrite in upper part to pelecypod biomicrosparrite in lower part, with _Aviculopecten_ sp., _Pleurophorus_ sp., pelecypod fragments, small high-spired gastropods, _Cavellina_ sp., _Bythocypris_ sp., and some _Osagia_ sp. Upper part has much limonite in fossil cavities, a single hard resistant bed, weathers dark yellowish orange (10 YR 6/6) in upper part to grayish orange (10 YR 7/4) in lower, makes sharp contact with limestone above (Samples F-4 and F-5)	.9	2.6-3.5
4.	Limestone - light gray (N7) recrystallized pelecypod biomicrite with _Aviculopecten_ sp., _Pleurophorus_ sp., pelecypod fragments, small high-spired gastropods, _Cavellina_ sp., foraminifers and _Osagia_ sp. concentration of fossils in upper 6 inches and lower 5 inches of bed, a single hard resistant bed, weathers yellowish gray (5 Y 7/2) with abundant solution cavities	1.0	1.6-2.6
3.	Limestone - very pale orange (10 YR 8/2) recrystallized clayey fossiliferous micrite, with pelecypod fragments abundant ostracodes (_Hollinella_ sp., _Bairdia_ sp., _Cavellina_ sp.) and some algae. Thin bedded, weathers grayish orange (10 YR 7/4) and slabby (Sample F-2)	.7	0.9-1.6

2. Limestone*- very pale orange (10 YR 8/2) clayey micrite, soft and laminated, weathers yellowish gray (5 Y 7/2) and shaly	.1	0.8-0.9
1. Limestone - very pale orange (10 YR 8/2) recrystallized pelecypod biomicrite, with *Pleurophorus* sp., pelecypod fragments, small high-spired gastropods, *Bairdia* sp., and *Anchicodium* sp., consists of two hard resistant beds (0.3 and 0.5 feet thick), weathers grayish orange (10 YR 7/4) and slabby, some solution holes filled with light brown (5 YR 5/6) limonite residue, makes sharp contact with yellowish gray (5 Y 7/2) shale below (Sample F-1)	.8	0.0-0.8
Total	12.7	

Easly Creek Shale

*These appear as shales in the field, however, insoluble residue results on all studied showed approximately 30 percent residue. Therefore, these should be classified as limestones.

Table 11. Number of points counted for each constituent out of a total of 300.

Sample No.	Micrite	Microspar	Spar	Pelecypods	Ostracodes	Gastropods	Algae	Unidentified Fossils	Foraminifers	Pellets	Pores	Other*
A1	195	33	14	19	5	1	3	6	-	-	10	14
A2	201	25	16	11	6	2	4	4	-	-	26	5
A3	188	33	27	10	2	15	1	14	-	-	4	6
A4	197	65	4	6	3	1	-	7	-	-	12	5
A5	138	57	42	24	1	7	-	7	-	-	7	17
A6	222	32	-	-	-	-	-	-	-	-	6	40
A7	224	39	-	-	4	2	-	6	-	-	4	21
A8	253	33	-	-	-	-	-	2	-	-	4	8
A9	277	9	-	-	2	-	-	-	-	-	1	11
A10	249	17	-	-	-	-	-	1	-	-	23	10
B1	93	83	44	9	3	-	29	-	2	-	35	2
B2	70	105	71	27	-	5	7	9	-	-	1	5
B3	244	29	-	-	-	-	-	1	-	-	9	17
B4	255	26	-	-	-	-	-	2	-	-	1	16
B5	237	33	-	-	-	-	-	-	-	-	2	28
B6	202	82	1	-	-	-	2	2	-	-	-	11
B7	167	73	1	-	-	-	1	2	-	-	-	56
B8	170	93	7	-	-	-	4	4	3	-	2	17
B9	160	103	4	-	-	-	1	3	3	-	2	24
C1	112	91	26	10	5	3	-	18	-	2	30	3
C2	217	22	14	7	6	4	-	12	-	-	9	9
C3	239	10	-	-	-	-	-	-	-	-	7	44
C4	232	31	2	-	2	-	-	-	-	-	-	33
C5	226	67	-	-	2	-	-	-	-	-	-	5
C6	235	30	15	6	2	5	-	-	-	-	2	5
C7	231	36	9	5	1	2	-	1	-	-	-	15
C8	195	75	6	7	10	-	-	5	-	-	-	2
C9	215	30	4	-	2	-	1	1	-	-	8	39
D1	137	64	41	28	10	2	-	12	-	-	1	5
D2	134	69	46	11	1	25	1	11	-	-	-	2
D3	108	86	44	27	4	5	2	14	-	-	3	7
D4	225	17	-	-	-	-	-	-	-	-	6	52
D5	208	40	5	-	1	-	2	12	7	-	-	25
D6	238	54	-	-	2	-	1	2	-	-	-	3
D7	228	33	-	-	2	-	-	-	-	-	1	36
D8	257	27	4	-	1	-	-	-	-	-	-	11
D9	196	69	4	-	-	-	-	2	-	-	8	21
E1	122	59	48	28	6	9	2	15	1	-	4	6
E2	113	76	54	23	3	13	-	6	-	-	3	9
E3	188	51	-	-	-	-	-	-	-	-	-	61

Table 11 (cont.)

Sample No.	Micrite	Microspar	Spar	Pelecypods	Ostracodes	Gastropods	Algae	Unidentified Fossils	Foraminifers	Pellets	Pores	Other*
E4	192	50	-	-	-	-	-	4	-	-	5	49
E5	196	58	-	-	1	-	-	-	-	-	6	39
E5a	149	58	1	-	2	-	-	4	-	-	6	80
E6	156	90	-	-	-	-	-	-	-	-	18	36
E7	159	102	-	-	-	-	1	1	-	-	1	36
E8	245	25	3	-	-	-	-	2	-	-	9	16
E9	174	73	-	-	-	-	-	2	-	-	16	35
F1	94	64	51	12	5	2	6	13	-	3	47	3
F2	139	109	12	3	11	2	4	6	-	1	5	8
F3	106	80	36	31	5	11	8	13	-	6	2	2
F4	59	113	45	23	2	16	1	8	-	2	27	4
F5	125	59	36	32	1	10	5	9	-	-	3	20
F6a	182	83	-	-	-	-	-	-	-	-	-	14
F7	190	80	20	2	1	3	1	-	-	-	-	3
F8	184	102	-	-	2	-	-	-	-	-	1	11
F9	143	39	67	-	15	-	6	3	7	-	17	3
F10	188	83	1	-	-	-	1	1	2	-	3	21

*non-carbonate material including quartz, clay, silt, iron oxides, etc.

Table 12. Lengths of fossil constituents in millimeters.

Sample No.	Ostracodes
A1	.60, .30, .50
A2	.42, .40, .35, .50
A4	.15, .50, .40
A5	.30
A7	.40, .25, .40, .64, .34
A9	.40, .42
B1	.30, .45
C1	.63, .50, .50, .60
C2	.80, .80, .70
C4	.16
C7	.32, .25, .25, .50
C8	.38, .50, .50, .40, .37, .50, .30, .50, .60

Table 12 (cont.)

Sample No.	Ostracodes
D1	.35, .25, 1.00, .60, .50, .50
D2	.40
D3	.50, .60, .87
D5	.26, .20, .32, .36, .30, .40
D6	.56, .24
E1	.40
E5	.37
F1	.70, .80, .60, .55
F2	.37, .45, .50, .45, .45, .45, .51, .67, .38
F3	.70, .30, .45
F4	.50, .45
F5	.30
F9	.60, .80, .75

Sample No.	Gastropods
A1	.75
A3	4.50, 6.00, 3.00
A4	1.00
A5	2.00, 2.25
A7	.64, .60, .65, .67
B2	1.60, .88, 1.00
C1	1.15, 2.25, 2.78, 1.20
C2	1.75
C6	2.50, 1.75, 1.50
C7	1.30, 1.40
D1	1.20, .85
D2	2.60, 1.75, 2.50, 2.00, 3.50, 2.50, 2.50, 2.50
D3	1.25, 1.00
E1	2.00, 1.75, 1.80, 2.10, 2.00, 1.60, 1.50
F1	.87, 1.40
F2	1.50
F3	2.50, 1.80, .85
F4	2.50, 2.40, 1.50, 2.70
F5	2.00, 2.00, 2.51

Sample No.	Pelecypods and Pelecypod Fragments
A1	5.00, 1.50, 4.00, 2.50, 2.00, 2.00, 2.10, .80, .60, .30, .20, .10, .40
A2	1.60, 2.00, 4.00, .50, .60, 1.00
A3	4.50
A5	5.00, .40, .20, 3.00, 1.50, 2.40, 1.80, .50, .30, 1.20, 1.50, .60, 3.00, 2.00

Table 12 (cont.)

Sample No.	Pelecypod and Pelecypod Fragments
B1	2.00, 1.50, 3.00, 4.00, .50, 1.00
B2	5.00, 4.00, 1.50, 2.10, 1.50, 2.00, 1.80, 1.40, 2.40, 2.20, 1.60, .50, .20, 4.00
C1	1.50, .80
C2	1.00, .40, .60, 3.00, 5.00, .20
D1	3.30, 2.50, 2.00, 1.50, .60, .80, .40
D2	6.00, 5.00, 4.00, 1.20, .40
D3	3.50, 5.00, 6.00, 2.50, 1.20, .40, .80, .60, .50, 1.10, 1.30, 2.00
E1	4.00, 4.10, 2.30, 5.00, 1.40, 2.40, 1.40, .30, .20, .60, .40
F1	2.60, 6.00, 3.50, 4.00, .40, .80, 1.20, 2.40
F3	3.50, 1.00, 2.60, 3.50, .70, 4.00, .80, 1.10

Table 13. Insoluble residue weight in grams.

Sample No.	Weight of limestone sample	Weight of residue and filter paper	Weight of filter paper	Weight of insoluble residue
A1	10.000	2.202	1.267	0.935
A2	10.000	2.141	1.269	0.872
A3	10.005	2.249	1.267	0.982
A4	10.000	1.936	1.265	0.671
A5	10.002	1.972	1.700	0.272
A6	10.002	4.628	1.701	2.927
A7	10.000	3.500	1.635	1.865
A8	10.003	3.340	1.696	1.644
A9	10.000	2.475	1.636	0.839
A10	10.000	2.726	1.635	1.091
A10a	10.000	5.270	1.634	3.636
B1	10.001	1.996	1.633	0.363
B2	10.001	1.854	1.635	0.219
B3	10.000	6.210	1.645	4.565
B4	10.000	3.665	1.640	2.025
B5	10.000	2.980	1.632	1.348
B6	10.004	2.811	1.635	1.176
B7	10.005	2.950	1.636	1.314
B8	10.000	2.933	1.634	1.299
B9	10.000	3.233	1.635	1.598

Table 13 (cont.)

Sample No.	Weight of limestone sample	Weight of residue and filter paper	Weight of filter paper	Weight of insoluble residue
C1	10.003	1.919	1.635	0.284
C2	10.001	2.847	1.641	1.206
C3	10.002	4.234	1.700	2.534
C4	10.001	3.343	1.635	1.708
C5	10.001	2.589	1.630	0.959
C6	10.000	2.353	1.634	0.719
C7	10.004	2.826	1.641	1.185
C8	10.000	2.220	1.702	0.518
C9	10.000	2.396	1.635	0.731
D1	10.005	2.622	1.640	0.982
D2	10.000	2.169	1.635	0.534
D3	10.003	1.850	1.632	0.218
D4	10.004	3.788	1.625	2.163
D5	10.000	3.215	1.635	1.580
D6	10.004	2.200	1.636	0.564
D7	10.004	4.031	1.643	2.388
D8	10.002	2.411	1.634	0.777
D9	10.000	2.222	1.704	0.518
E1	10.002	1.901	1.635	0.266
E2	10.001	2.280	1.697	0.583
E3	10.002	4.969	1.267	3.702
E4	10.000	3.925	1.267	2.658
E5	10.001	3.510	1.633	1.877
E5a	10.001	4.350	1.635	2.715
E6	10.004	3.645	1.639	2.006
E7	10.000	3.780	1.628	2.152
E8	10.005	2.710	1.635	1.075
E9	10.005	3.323	1.638	1.685
F1	10.000	1.965	1.268	0.697
F2	10.001	3.011	1.700	1.311
F3	10.007	1.650	1.260	0.390
F4	10.000	1.563	1.267	0.296
F5	10.000	1.620	1.266	0.354
F6	10.001	4.830	1.699	3.131
F6a	10.005	3.520	1.705	1.815
F7	10.002	2.093	1.268	0.825
F8	10.004	2.379	1.700	0.679
F9	10.006	3.617	1.698	1.919
F10	10.001	2.052	1.267	0.785

Table 14. Weight in grams of the insoluble residue coarse (plus 250 mesh) and fine fractions (from the McDowell Creek outcrop)(A).

Sample No.	Weight of Capsule and Coarse	Capsule Weight	Coarse fraction weight	Total residue weight	Fine fraction weight
A1	0.1716	0.1638	0.0078	0.935	0.9272
A2	0.1825	0.1708	0.0117	0.872	0.8603
A3	0.1770	0.1700	0.0070	0.982	0.9750
A4	0.1860	0.1800	0.0060	0.671	0.6650
A5	0.1945	0.1720	0.0225	0.272	0.2495
A6	0.1734	0.1724	0.0010	2.927	2.9260
A7	0.1720	0.1683	0.0037	1.865	1.8613
A8	0.1485	0.1474	0.0011	1.644	1.6429
A9	0.1462	0.1408	0.0654	0.839	0.8336
A10	0.1520	0.1476	0.0044	1.091	1.0866
A10a	0.1555	0.1480	0.0075	3.636	3.6285

Table 15. Point-count of the coarse fraction of insoluble residue (McDowell Creek outcrop)(A).

Mineral	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A10a
Quartz	62	75	82	72	10	46	88	10	67	71	13
Chert	10	20	16	25	--	--	10	40	24	20	80
Chalcedony	--	--	--	--	--	--	--	--	--	4	--
Orthoclase	--	--	--	--	--	--	--	--	1	--	--
Glass	1	--	--	--	--	--	--	--	--	--	--
Gypsum	2	1	--	--	1	1	2	--	--	1	1
Hematite	--	--	--	1	3	1	--	--	1	1	--
Limonite	25	4	2	2	86	2	--	2	2	3	6
Muscovite	--	--	--	--	--	--	--	1	--	--	--
Total count	100	100	100	100	100	50	100	53	95	100	100

Table 16. Silt size fraction point-count data of the insoluble residue (McDowell Creek outcrop)(A).

Mineral	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A10a
Quartz	60	85	99	97	20	95	97	96	95	95	92
Chert	--	--	--	--	--	--	--	--	--	--	--
Chalcedony	--	--	--	--	1	--	--	--	--	--	--
Orthoclase	--	2	--	--	--	1	2	--	1	--	2
Glass	--	--	1	--	1	--	--	1	--	--	--
Gypsum	--	--	--	--	1	--	--	--	--	--	--
Hematite	--	--	--	--	--	--	--	--	--	--	--
Limonite	40	13	--	3	30	2	1	2	2	3	4
Muscovite	--	--	--	--	--	2	--	1	2	2	2
Microcline	--	--	--	--	--	--	--	--	--	--	--
Total count	100	100	100	100	50	100	100	100	100	100	100

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PETROLOGY OF THE CROUSE LIMESTONE
IN THE VICINITY OF MANHATTAN, KANSAS

by

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The Crouse Limestone, a laterally persistent marine limestone in the vicinity of Manhattan, Kansas, was examined in order to determine the environment of deposition. Six outcrops, from more than 30, were selected for their completeness and quality of exposure to be studied in detail. Each section was measured and samples were collected at approximate one foot intervals.

Samples from one outcrop were selected for point-count analysis of thin sections, determination of clay minerals, insoluble residue mineral studies, and determination of the ratio of calcite to dolomite. This outcrop was then used as a "pilot suite" and the remaining five outcrops were studied by point-count analysis of acetate peels, and by percentage determinations of insoluble residues. Fossils were also collected and identified from all outcrops.

Three distinct units were recognized in the Crouse Limestone; a lower resistant pelecypod limestone, a middle "shaly" limestone, and an upper "platy" limestone. According to Folk's (1959) Classification the dominant limestone type in the Lower Limestone Unit is a recrystallized pelecypod biomicrite, in the Middle "Shaly" Unit a recrystallized clayey micrite, and in the Upper "Platy" Unit a recrystallized clayey micrite and a recrystallized fossiliferous micrite.

Illite is the most abundant clay with minor quantities of interlayered chlorite-vermiculite and vermiculite-chlorite. The insoluble residue averages 6 percent in the Lower Limestone, 27 percent in the Middle "Shaly" Unit, and 13 percent in the Upper "Platy" Unit; quartz is the most abundant mineral and limonite is common in the lower unit. No dolomite was found in any samples.

The Crouse Limestone was probably deposited in a warm shallow continental sea that extended across Kansas during the Permian Period. The water was apparently without strong currents, circulation was good, and salinity was near normal to slightly brackish. The Lower Limestone Unit possibly represents deposition in a deepening sea of normal salinity and the Middle "Shaly" and Upper "Platy" units represent deposition in a slowly regressing slightly brackish sea.