PETROLOGY OF THE FORT RILEY LIMESTONE FROM FOUR KANSAS QUARRIES

by

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INTRODUCTION

Purpose of Investigation

The purpose of this investigation was to describe and classify the Fort Riley Limestone in East Central Kansas and to determine the environment of deposition. This study was part of a research program by the State Highway Commission of Kansas, designed to reveal the vertical and lateral ranges of the basic mineralogical and physical properties of individual ledges of the Fort Riley Limestone. This program was in turn, part of a more extensive Highway Commission investigation of soft limestone aggregates. Also of importance in this study was the applicability of Folk's (1959) classification of limestones to the Fort Riley Limestone.

Location of Quarries

During the preliminary phase of this investigation by the State Highway Commission, a total of 24 quarries were given special attention, of which twelve were selected for more detailed study. C. F. Crumpton and W. A. Badgley, research geologists, Kansas State Highway Commission, sampled and made laboratory studies of four quarries selected on the basis of completeness of the Fort Riley section and availability of crushed stone for applied study. Location of the four quarries is as follows:

NE¼ NW¼, Sec. 10, T12S, R5E, Geary County, Kansas
(one mile west of Junction City.)

NW¼ NW¼, Sec. 32, T14S, R7E, Morris County, Kansas (two miles east of White City.)

SE¼ NE¼, Sec. 6, T21S, R5E, Marion County, Kansas (one mile northeast of Florence.)

SE¼ NE¼, Sec. 9, T28S, R4E, Butler County, Kansas (three miles southwest of Augusta.)

For convenience and simplicity these quarries shall hereafter be referred to as Junction City or J.C., White City or W.C., Florence or F., and Augusta or A.

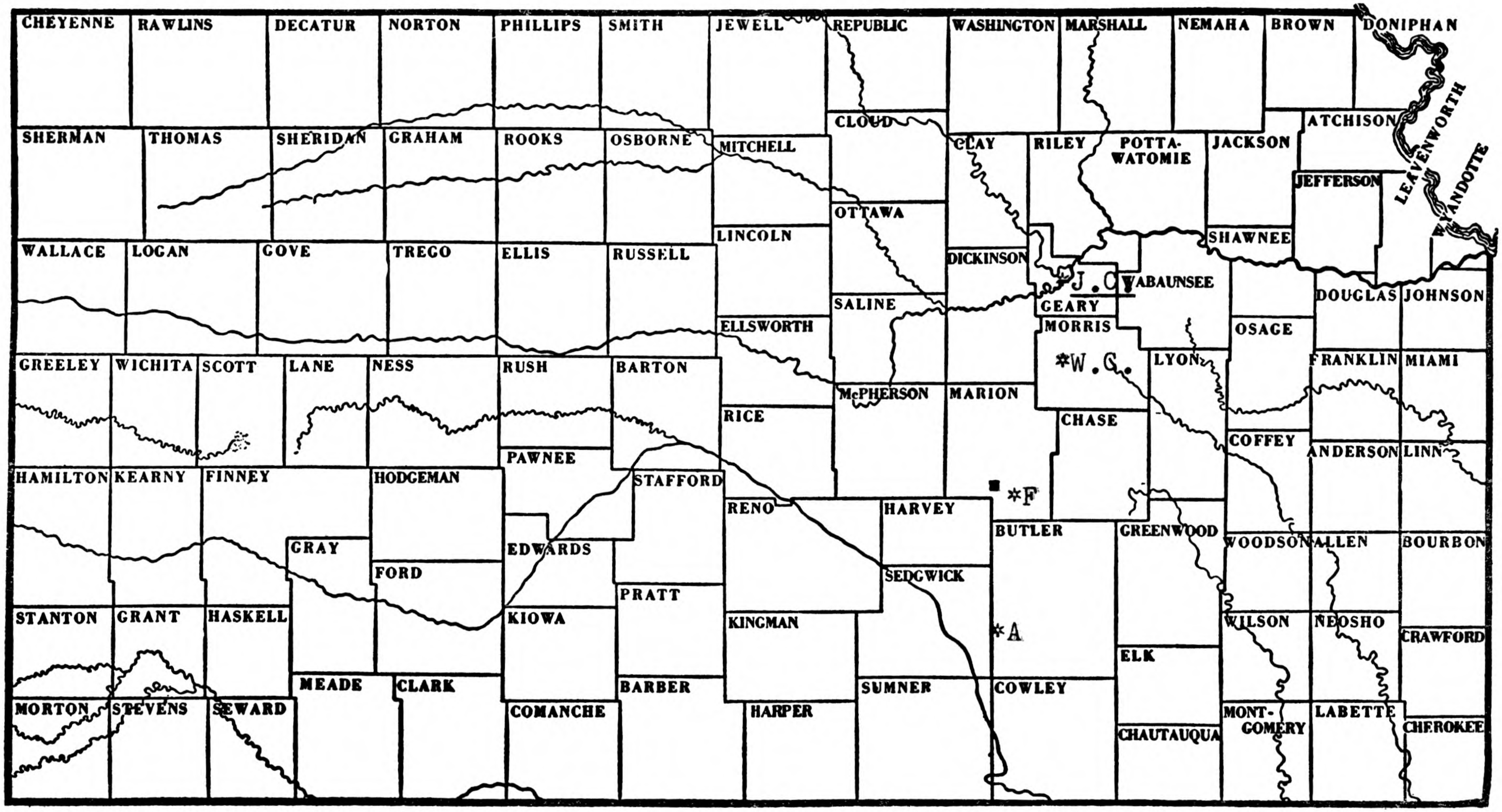
Approximate geographic locations of the four quarries are shown in Figure 1, and a graphic section of each of the four quarries with probable correlative beds and respective bed numbers are shown in Plate I.

General Stratigraphy and Lithology of Fort Riley Limestone

The Fort Riley Limestone is a member of the Barneston Limestone, Chase Group, and belongs to the Wolfcamp Series of the Permian System (Jewett, 1959, p. 44). The groups of the Wolfcamp Series and the divisions of the Chase Group are summarized in Table 1.

Table 1. Groups of the Wolfcampian Series and the divisions of the Chase Group.

- Chase Group
    - Doyle Shale
    - Barneston Limestone
        - Fort Riley Limestone member
        - Oketo Shale member
        - Florence Limestone member
    - Matfield Shale
        - Blue Springs Shale member
        - Kinney Limestone member
        - Wymore Shale member



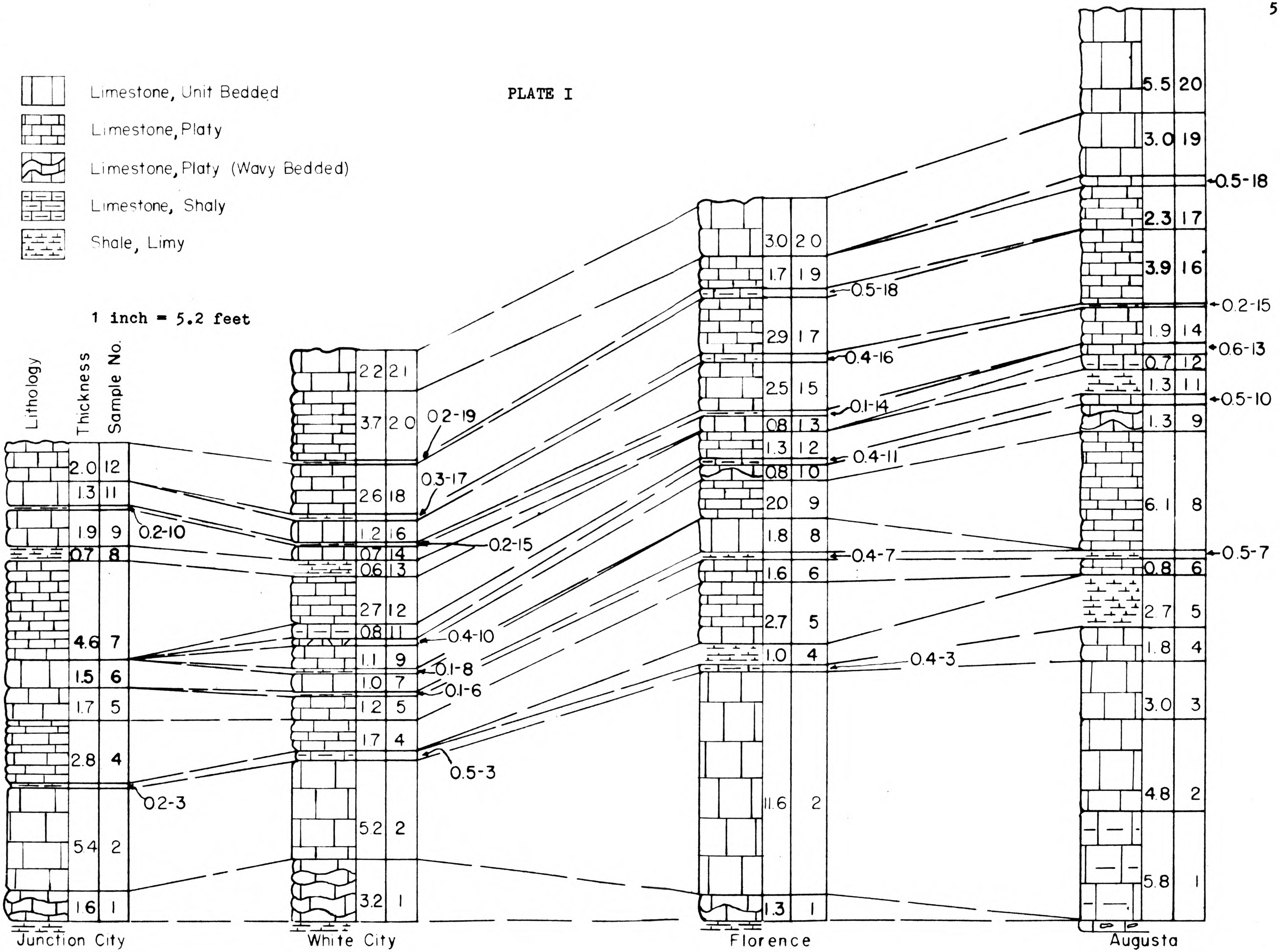
J.C. = Junction City, W.C. = White City, F. = Florence, A. = Augusta

Fig. 1. Index map of Kansas showing approximate location of quarries investigated.

EXPLANATION OF PLATE I

Graphic sections showing each of the four quarries. Broken lines between sections show beds of the same lithology and corresponding samples.

PLATE I



Limestone, Unit Bedded
Limestone, Platy
Limestone, Platy (Wavy Bedded)
Limestone, Shaly
Shale, Limy
1 inch = 5.2 feet
Lithology
Thickness
Sample No.
Junction City
White City
Florence
Augusta

Table 1 (concl.)

Wreford Limestone
Schroyer Limestone member
Havensville Shale member
Threemile Limestone member
Council Grove Group
Admire Group

The Fort Riley Limestone, named by Swallow (1866, p. 14), underlies the Holmesville Shale member of the Doyle Shale in northern Kansas. According to Moore, (1951, p. 45), the Oketo Shale is absent in sourthern Kansas, and the Fort Riley lies directly on the Florence Limestone. The Fort Riley Limestone extends from southern Nebraska into north-central Oklahoma. Although the thickness of the Fort Riley is variable, the average thickness in Kansas, according to Moore (1951, p. 45), ranges from 30 to 45 feet. The thickness of the Fort Riley Limestone increases southward from 22 feet at Junction City to approximately 50 feet at Augusta. These values represent only the thickness measured in the quarries and may not be the true total thickness of the Fort Riley Limestone. Even so the values do serve as a basis for comparison with the thickness of 5 feet reported in Noble County (north-central Oklahoma) by Tanner (1959, p. 327).

The Fort Riley consists of thick beds of limestone separated by thin beds of calcareous shale. Two "rimrock" ledges, a persistent one near the base and another in the upper part, characterize the limestone at most locations. Local connotation has designated the lower of these two thick beds as the "rimrock," and "upper rimrock" is used for the upper bed. The term "rimrock" stems from the conspicuous rim the Fort Riley forms on many hillsides because of its resistance to weathering and erosion. This rim forms a narrow white line on hillsides and supports a natural "bush line," characteristics that combine to make the "rimrock" easily recognizable at considerable distance and also on aerial photos. On natural slopes, only the "rimrock" ledges are exposed; the platy beds in middle and upper part of the Fort Riley are usually covered by a foot or more of soil.

PREVIOUS WORK

The literature on limestones is extensive. Unfortunately this array dwindles considerably when limestone classifications are considered, even more so for petrographic classifications. One of the earliest and more elaborate attempts to classify sedimentary rocks was that of Grabau (1904). This classification divided rocks into two types: authigenic and allogenic. Grabau's system is probably the most logical and complete classification yet designed, but his extensive use of unfamiliar terms proved to be its downfall. After this initial attempt men such as Trowbridge (1914), Krynine (1948), and Pettijohn (1957), continued to propose classifications of sedimentary rocks. As a result of the great amount of attention directed toward this subject in recent years, many classifications of sedimentary rocks are now competing for acceptance. Of the sedimentary rocks, sandstones were the first to receive much attention, possibly because of their close mineralogical resemblance to igneous rocks. This is not to imply that the battle has been won for an acceptable classification for either sedimentary or igneous rocks, but tremendous strides have been made.

Until now little has been said regarding petrographic classifications. Many classifications are applied to field work only, especially those used for limestone. Limestones are composed dominantly of calcite; therefore the one property usually identifiable in the field, mineral composition, is of little use. Folk (1959, p. 2) has summarized most limestone investigations in a manner that is sad but true; "---- if the rock fizzes in acid, that is normally the terminus of the investigation."

The first practical classification of limestones was that of Folk (1959). This classification is based upon the identification of three general constituents in limestones; terrigenous, allochemical, and orthochemical constituents. A more detailed discussion of this subject is included later.

Thomas and Glaister (1960, p. 477), while working with carbonates in the Western Canada Basin, have concluded that clear crystalline calcite was introduced into open pores during diagenesis and the micrograined matrix suggest quiet water deposition.

Moore's (1959) conclusions on the origin of orthochemical constituents in carbonates of the Ozark region are similar. However, both papers fail to standardize the terms used in describing limestones. It is in this respect that Folk's paper proves its excellence.

Although Folk's work has undoubtedly spurred limestone studies more than has any single contribution, many men not in direct contact with Folk have helped to solve the limestone problem. Newell (1957), Rigbey (1957), and Illing (1954) have studied the submerged limestone plains southeast of Florida, the Great Bahama Banks. Here the conditions of sedimentation favorable for limestone deposition can be observed. Newell and Rigbey (1957) reported that no other area affords the opportunity for such excellent studies on the origin of marine limestones. In this area these men found carbonate deposits forming under a variety of conditions; 1) direct precipitation of aragonite ooze in considerable quantities, 2) sediments being formed by the accumulation of skeletal remains, and 3) newly formed coral reefs.

Newell, et al. (1953), have completely described the Permian reef complex of the Guadalupe Mountains Region of Texas and New Mexico. Their paleoecological studies of the great Capitan barrier reef and associated rocks are classics and are invaluable to the sedimentary petrologist.

METHOD OF INVESTIGATION

Field Procedures

Oriented blocks were collected from each limestone unit sampled for this study by personnel of the Kansas Highway Research Staff. Each block was marked in the field showing the bedding plane and a plane perpendicular to it.

Each of the four quarries were visited by the author and John W. McGonigle under the supervision of Mr. Crumpton;

(Mr. McGonigle is a member of the Kansas Highway Research Staff and is currently completing work on limestone units not included in this investigation.) Exposures of the Fort Riley Limestone were measured and described. Because all trips were made after the petrographic investigation had begun, laboratory findings and postulations were checked in the field.

Laboratory Procedures

The oriented blocks were sent to the State Highway Commission where each block was cut into 2 inch cores, both parallel and perpendicular to the bedding plane. Subsequently each core was sawed into discs approximately one-quarter of an inch thick; these were used to make acetate peels and thin sections.

Acetate peels were prepared first because the discs are not harmed during this process. The sawed surfaces of each disc were polished and then etched by immersing them in an 8 per cent solution of hydrochloric acid for approximately 45 seconds. The discs were then washed in water to remove acid and impurities and dried on paper towels.

The equipment for preparing acetate peels consists of a size #13 smooth rubber stopper, draftsman's acetate (cut into approximately 4 inch squares), acetone, and a 10 pound weight. First the acetate was placed on the smooth rubber stopper, the stopper serving as a cushion to premote uniform contact between the acetate and the blank. Next the acetate was softened by adding a sufficient amount of acetone to cover the disc. The disc was pressed against the softened acetate and weights were placed on the disc. The acetate sheet hardened quickly and was peeled away from the rock surface after about 5 minutes. The acetate peels were placed between 2 X 2 inch lantern slide glass plates.

At least two peels were prepared from each limestone unit, one perpendicular to the bedding plane, the other parallel to it. The peels were scanned to determine which units would be studied, and to determine whether there were any distinct differences between peels made from discs taken parallel to the bedding plane or those made from discs taken normal to the bedding plane. As a result of this preliminary investigation samples from 30 ledges were selected for further study. Additional samples from two shaly beds were added on the advice of Professor A. B. Sperry, Department of Geology, Kansas State University.

Early in this investigation, while the acetate peels were being examined, thin sections were made from the same discs used in preparing the peels. It was realized at the time that the thin sections should have been used as the "pilot suite" to acquaint the writer with the mineralogy of the rocks, but because both peels and thin sections were obtained from the same discs this was physically impossible.

Petrographic examination of the thin sections included identification, percentage determinations, and grain size determinations of the rock constituents (the types of limestone constituents are discussed in the following section). Using the mechanical stage and the point-count method a traverse of 200 points was made. To count by this method the mechanical stage was moved in increments of one millimeter and each constituent under the intersection of the cross hairs was recorded. For general counting a 10 X ocular and 30 X universal stage objective were used. The 10 X calibrated ocular was used to determine grain size, greatly reducing the chance for error. The cross hairs in an ordinary ocular may be used quite satisfactorily, if the width of the cross hairs have been accurately measured. This method was used by the author early in the investigation; however, serious problems arose when a very minor point was forgotten: when cross hair widths are measured it must be remembered that although the actual cross hair width does not change when using different powered objectives, the area covered by the cross hair does increase as the magnification increases.

The percentage of calcite and dolomite in each sample was determined by X-ray diffraction, using a method devised by C. F. Crumpton (personal communication, 1960). Each disc was run from 31° 2θ to 29° 2θ to include the main calcite and dolomite peaks. If dolomite was found on one side of the disc, the reverse side was then run and an average value used. Calcite-dolomite percentages were determined by multiplying the peak height of each curve by the vertical mid-height width of each curve; thus the area under each curve was obtained. The areas were then converted to percentages by adding the two areas and dividing the total into each respective area value. This value X 100 gave the percentages of calcite and dolomite. Figures obtained by this method represent only the calcite-dolomite ratio, but because calcite and dolomite do comprise the bulk of the sample the figures approximate the true percentages of calcite and dolomite.

Three methods have been used to determine the percentages of dolomite in thin sections in an attempt to obtain results that are comparable to those obtained by X-ray methods.

1. Several staining techniques have been used in an attempt to distinguish calcite from dolomite, namely those outlined by Fairbanks (1952), and Heeger (1913). Only Fairbanks' method using hematoxylin as a staining agent, gave results which could be seen and those were far from satisfactory. The dolomite did change to light purple (calcite remained white), but most of the dolomite was too fine-grained and highly disseminated to obtain satisfactory results. Freidman (1959) has reviewed staining techniques for carbonate minerals.

2. Dolomite rhombs were counted while making a point count of each thin section.

3. Because dolomite rhombs had been observed in thin sections, an attempt was made to crush, not grind, small limestone fragments and then observe the resulting powder under the microscope. For this method an oil with a refractive index of 1.670 was used. Both indices of calcite are below this figure, while one dolomite index is above and one below 1.670. This provides an easy method for differentiating between cleavage fragments of calcite and dolomite rhombs. Dolomite rhombs were then counted and sizes of each were noted.

DEFINITION OF LIMESTONE CONSTITUENTS

Definitions of geological terms are omitted from most investigations, but because Folk's terms (1959) are new, such a discussion seems necessary. All terms and definitions are those used by Folk; the present author's comments are indicated. For further information the reader should consult the original article by Folk (1959).

The three end members of Folk's classification of limestones are as follows: (1) terrigenous constituents, (2) allochemical constituents, and (3) orthochemical constituents. The classification of limestones using these three end members is shown in Table 2.

Terrigenous Constituents. Included under terrigenous constituents are clay minerals, quartz sand, silt, etc. These materials have been derived from outside the basin of deposition and subsequently transported to the site of deposition in solid form.

Allochemical Constituents. Allochemical constituents have formed by chemical or biochemical precipitation within the basin of deposition but have been transported within this basin. The four types of "allochems" are: oolites, fossils, pellets, and intraclasts. The first three terms have been widely used, but the last term, "intraclast," was introduced by Folk to describe a fragment of carbonate sediment that was torn from the sea bottom, reworked, and then redeposited.

Orthochemical Constituents. These constituents, "orthochems,"

Table 2

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	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	<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 (1959, p. 14)

are the chemical precipitates and, like the "allochems," have formed within the depositional basin or even within the sediment itself. Unlike the allochems, these constituents show little or no evidence of transportation. In this category Folk includes three members, "microcrystalline calcite ooze, sparry calcite, and other replacement or recrystallization minerals."

Microcrystalline Calcite Ooze. Calcite of this type forms grains ranging from 1-4 microns in diameter and shall hereafter be called "micrite" (pronounced "mick-rite" by Folk) in this report. Individual grains characteristically show a faint brownish cast in thin sections and are equant and irregularly rounded. Folk considers micrite to have been formed by rapid chemical or biochemical precipitation in sea water with subsequent settling to the bottom.

Sparry Calcite. Sparry calcite, which shall be called "spar," is distinguished from micrite by its larger crystal size (10 microns and over in diameter) and by clarity. Folk noted two rather serious difficulties in distinguishing between micrite and spar. First of all, clarity is definitely a function of grain size. The larger crystals of spar should be clearer than the micrite because of size alone. Secondly, Folk mentioned that considerable difficulty arose when trying to fix limits on the maximum and minimum grain size of the two types of calcite. Morphology is probably the key, as Folk suggested. Morphology, crystal size, and clarity are used to distinguish between sparry calcite and micrite. Sparry calcite forms mainly as a simple pore-filling cement.

Recrystallized Calcite. Folk noted several types of recrystallization in limestones; but only one, the formation of "microspar," is regarded by the author as being important in this investigation. Microspar supposedly forms by the recrystallization of micrite into grains ranging from 5 to 15 microns. Some confusion has arisen as to whether material in the 10 to 15 micron range should be called microspar or spar, because anything over 10 microns had previously been placed in the sparry calcite category. For this report all calcite grains ranging in size from 5 to 10 microns have been designated as microspar. A few grains larger than 10 microns have been called microspar, but only after it was clear that microspar was dominant over all other constituents. Reasons for this breakdown and the problems pertaining to microspar terminology are discussed later (p. 30).

The terms applied to orthochemical constituents by Folk are new, but their presence and interpretation are already scattered throughout the literature. Sievers (1952, p. 59) in discussing the Pennsylvanian carbonate rocks of Illinois reported calcite ranging in size from 40 to 100 microns (spar according to Folk) which he said was the result of recrystallization or replacement of the original matrix. Thomas and Glaister (1960, p. 477), in discussing the cemented skeletal and non-skeletal carbonate rocks in western Canada noted that echinoderm ossicles and plates form the major part of the rocks and ossicles and plates are in turn cemented with "clear crystalline calcite." They explained that, "the cement was probably introduced into open pores in the course of diagenesis, being precipitated as crystal growths derived from carbonate-saturated waters." Conversely, the skeletal limestone with a micrograined matrix (undoubtedly micrite) "all suggest sheltered, quiet water conditions of deposition," exactly the same as Folk (1959, p. 26) proposed. R. C. Moore's (1959) observations on the Mississippian carbonate rocks of the Ozarks also agreed with the previous hypothesis.

PETROGRAPHY OF THE FORT RILEY LIMESTONE

Junction City Location

The Fort Riley Limestone section at Junction City has been divided into nine limestone units and three limy shale units (table 4). The distinction between limestone and shale was made entirely on the basis of weathering characteristics of the rocks. As can be seen from table 5, the "so-called shales" may not be shales, but actually limestones. This problem and findings of the present investigation are presented later in this section. The remaining nine* limestones have been classified according to Folk (table 2) and the following results were obtained: one algal biomicrite, three algal fossiliferous micrites, two dolomitic algal biomicrites, three dolomitic micrites, and one microsparite. The percentages of the constituents of the twelve units are shown in Table 3 .

*One unit included within the nine limestones, JC 7 has been divided into two beds, JC 7B and JC 7M, making a total of ten divisions.

Table 3. Percentages of constituents in the samples of Fort Riley Limestone from Junction City, Kansas.

Constituent	JC1	JC2	JC4	JC5	JC6	JC7B** 1	JC7B** 2	JC7M	JC8	JC9	JC10	JC11	JC12
Micrite*	54	36	59	44	39	56	48	59	44	31	22	53	49
Microspar	21	18	25	25	23	34	16	36	31	64	46	28	39
Spar	10	14	9	13	19	6	9	5	19	4	31	12	9
Quartz	6		2	1	2				1	1	1	2	2
Organic (?)***			4		5	4	20		4				
Pellets		18										t	
Fossils (total)	5	10	t	16	11		6		1			4	
Brachiopods	(1)			(7)	(2)		(4)						
Echinoderms	(1)	(8)		(6)	(3)		(1)		(1)				
Pelecypods	(2)	(2)	(t)	(2)	(5)							(3)	
Ostracodes													
Foraminifers	(1)			(1)	(t)							(1)	
Bryozoans	(t)												
Algae	p	p		p	p		p					p	p
Osagia sp.[o]	4	4					1					p	p

t= trace (less than 1 per cent).
p= present (no per cent determined).
*= fine algal material included in micrite category.
o==represents percentage of Osagian colonies, i.e., algae surrounding fossils and as structureless masses.
**= part 1 is micrite.
part 2 is fossiliferous seams.
***= maybe algal dust (?).

Table 4. Field description of the Fort Riley Limestone, NE¼ NW¼, Section 10, T12S, R5E, Geary County, Kansas, Junction City location.*

Unit No.	Thickness in feet.	Description
12.	2.0	Limestone: yellowish tan, quite similar to underlying unit but a thin bed separates the two.
11.	1.3	Limestone: yellowish tan, fossiliferous, porous and solution pitted aspect denotes mealy appearance.
10.	0.2	Shale: limy, dark blue gray to gray.
9.	1.9	Limestone: bluish gray, called the "dense zone" because of fine-grained, hard, dense appearance.
8.	0.7	Shale: gray, fine thinly bedded.
7.	4.6	Limestone: gray to blue gray, composed dominantly of fine-grained calcite with sparsely scattered horizontal dark bands.
6.	1.5	Limestone: orange brown, highly fossiliferous, mealy texture, "mealy unit."
5.	1.7	Limestone: light gray, pelecypod burrows more numerous than in unit 2, referred to as the "burrow zone."
4.	2.8	Limestone: gray to light gray, unit bedded.
3.	0.2	Shale: tan to gray, limy.
2.	5.4	Limestone: light tan to light gray, somewhat porous, unit-bedded, pelecypod burrows approximately 1 inch in diameter present in upper 1.5 feet; designated as the "rimrock."
1.	1.6	Limestone: dark bluish gray, weathers to tan gray, thin-bedded with uneven curved plates.
	21.9	Total Thickness

*Measured: by C. F. Crumpton and W. A. Badgley, using steel tape and hand level, August, 1958.

Algal fossiliferous micrite. Units JC1, JC 11, and JC 12 are algal fossiliferous micrites, being composed dominantly of micrite and averaging about 5 per cent fossils. Spar is subordinate in these rocks and in sample JC1 spar is confined to one area. This small area in the thin section is rather unique, not only because of the abundance of spar, but because it consists of an abundance of algal material, and 16 per cent fossils (this figure represents an increase of 14 over the percentage of fossils in the "non-sparry" area). Probably this sharp change represents the transition between a micrite and an algal biosparite. The other two samples, JC 11 and JC 12, are composed dominantly of micrite but did not resemble JC1 mainly because of the different role assumed by the algal material.

Algae. An accurate determination of the percentage of orthochems in slides JC 11 and JC 12 was diffficult because of the "dirty" appearance of some parts of the slides. This "dirty" appearance can best be described as crusted or clotted, very closely resembling thin sections that are thicker than the normal .03 mm. The cause of this appearance is not definitely known but Carozzi (1960, p. 209) has suggested that incipient recrystallization or a primary algal origin may account for the clotted texture in fine-grained limestones. Carozzi's explanation of the two possibilities is as follows.

> The first process is an incipient recrystallization which gradually isolates clots displaying typically hazy and irregular boundaries (Cayeux, 1935). The recrystallized portions looking like a matrix appear light in thin section and are formed by a water-clear crystalline calcite. The clots have kept the original composition of the sediment and

appear as dark, dense, fine-grained calcite, often showing the features of algal dust (Wood, 1941). The reasons for this pervasive recrystallization are not very clear. Organic action has been involked to explain the breakdown of the fine-grained sediment; algal action, at least, does not seem to be apparent, since clotting can begin in sediments partly filling the interior of mollusk shells.

According to a second concept (Hadding, 1958a), the clotted texture is considered as being of primary algal origin and the even-grained texture might have evolved out of it. It has been noticed that algal crusts on fossil fragments building intraformational conglomerates and algal balls (Gashe, 1956) in similar deposits typically display a clotted texture which is identical to that found in numerous fine-grained limestones. In other words, the conclusions may be drawn that the diffused clots of the fine-grained limestones may also have been formed by calcareous algae (Hadding, 1958a).

The second hypothesis seemingly best explains the appearance of units JC 11 and JC 12. Clots and pellet-like aggregates are in close association with various algae types that have been recognized in other units. Although the presence of algae in these two beds was not proven, rounded pellet-like bodies similar to those found in other beds were conspicuous. In slide JC 11 a few round-to-elliptical masses were observed. These objects range in size from 0.45 mm. to 1.5 mm. in diameter and are darker than the surrounding micrite. Some of the bodies which are lighter in color are almost impossible to distinguish from the surrounding micrite except for a thin rim of clear calcite which marks the boundary between the bodies and matrix. It is unlikely that these discrete, isolated masses represent algae but the possibility does exist.

The algae in JC1 were much easier to identify than in the other two samples. Epimastopora kansasensis Johnson, (top view) is associated with echinoid spines, Epimastopora jewetti Johnson (fig. 2), and Osagia sp. form encrustations on many fossils. On one brachiopod, Osagia sp. conforms to the crenulations of the shell; the thickness of the crust being greater on the crenulated side than on the flat side. Another similar brachiopod, about ½ inch from the encrusted brachiopod, has little if any coating of algae. The remaining algal-encrusted fossils are all pelecypods with equal thickness of crust surrounding the long dimensions of the valves and smaller amounts on the anterior and posterior ends. In a few areas several fossils (usually small, 0.3 mm. and less) are within a large semi-rounded mass of algae. Seemingly the algae grew outward from the fossils and finally formed a larger mass. The end result is a semi-rounded object suggestive of intraclasts. Upon first contact with these encrusted fossils the writer was inclined to call them intraclasts, partly because of this "rolled up" appearance, and also because of their occurrence in "spar-rich" areas such as in JC1. Sparry calcite forms in pore spaces, probably as a secondary precipitate. The pore space is caused by the action of currents which remove the microcrystalline calcite. A high energy environment such as this could cause "rolled up" intraclasts incorporating the fossils in the process. The objections to the intraclast theory are as follows:

1. Many intraclasts are stratified because of having been torn up while partly concolidated; no stratification was found in the algae.

2. Further evidence condemming the intraclast theory is that algae surrounding the fossils is dark brown. Had the

surrounding algae been microcrystalline calcite, as it should have been if these bodies were intraclasts, the algae would have looked like the surrounding micrite.

Other fossils. Brachiopod shells, ranging from small fragments to specimens nearly 7½ mm. long, are in the sparry area of thin section JC 1. Many of these shells have large crenulations and are composed of columnar calcite. Gilbert (in Williams, Turner, and Gilbert, 1955, p. 343) stated that: "The shells that consist of granular calcite have been recrystallized; fibrous ones are probably original calcite."

A few fragments of bryozoans (one nearly 6 mm. in length) are in JC 1. The largest bryozoan is elongate with a well preserved "cellular structure." The main body is composed of columnar calcite while the small tear-shaped areas, which are responsible for the cellular appearance, are dark areas of micrite. The delicate structure is well preserved.

The other fossils are ostracodes, crinoid columnals, pelecypods, and foraminifers. The size of the foraminifers is uniform (0.36 to 0.40 mm.); their tests are well preserved and the chambers are filled with sparry calcite. In axial sections most of the foraminifers display a dark brown outline. A few dark brown foraminifers are in algal encrustations around other fossils. Most of the ostracodes consist of a central cavity filled with spar similar to the foraminifers.

<u>Algal</u> <u>Biomicrite</u>. As compared with the micrites previously discussed, sample JC 2B has a lower percentage of micrite and a

higher percentage of spar and fossils. Micrite and microspar form the matrix of this rock and are dispersed throughout the sample. Spar occurs as crystals that project into pores and as radial fringes or encrustations around pellet-like masses.

The most diagnostic microscopic characteristic of this rock is the fuzzy mottled appearance caused by small dark bodies resembling pellets. The possibility that these bodies are pellets has not been disproved, but they are probably clots of algal material. These bodies are nearly uniform in size (the majority of them ranging from 0.10 to 0.36 mm.) and are round, ovoid, ellipsoidal, rod-like, kidney-bean shaped, and dumbell-shaped. Under reflected light these masses are yellowish-brown which clearly distinguishes them from the surrounding micrite. Several possibilities could account for this distinct shape and color.

Folk (1959, p. 7) stated that generally pellets are much richer in organic material than the surrounding matrix, and therefore impart a distinct, brownish color. Undoubtedly this is true, but the yellowish brown of the pellets does not resemble the dark brown organic material in some of the shales in the Junction City section.

The yellowish brown is also somewhat suggestive of clay, indicating that these bodies might be discrete patches of clay or possibly aggregates of dirty calcite that contain only a small amount of clay. It seems unlikely that clay is very abundant in these samples because the insoluble residue in this rock is only 2.9 per cent by weight.

The most probably explanation is that the bodies are clots or masses of algal material, or algae in the colonial form. Johnson (1951, p. 170), and Carozzi (1960, p. 209) reported occurrences of clay quite similar to those observed in JC 2B. Most of these bodies lack internal structure and are indistinct in outline. Carozzi (1960, p. 208) has attributed this lack of transparency to "a loss of light by total internal reflection at junction of crystals in the thickness of the slide." A few round masses contain large crystals of spar near their centers; possibly the spar crystals are nuclei.

Algae. Several algal fragments of Epimastopora kansasensis were found. This species has been described by Johnson (1946, p. 1096), and his illustrations were responsible for the present conclusions. Only top views of this species were observed; irregular rows of closely spaced pores were clearly seen (fig. 3). The pores are about 0.12 mm. in diameter and quite uniform in size and shape. Most of the small round pores are easily discernable because they are surrounded by clear calcite crystals that extinguish as units. These two properties, clarity and extinction, characterize fossils belonging to Phylum Echinodermata, i.e., all fossils of this phylum possess the unique characteristic of single extinction. Johnson (1946, p. 1096) noted that Epimastopora kansasensis is usually associated with fossil ecinoderm spines, other invertebrate fossils, and another fossil algal form, Osagia sp., that was also found in unit JC 2B.

The rich brown colonies of Osagia sp. consist of an intergrowth of algal filaments and dark threads. Primarily Osagia sp.

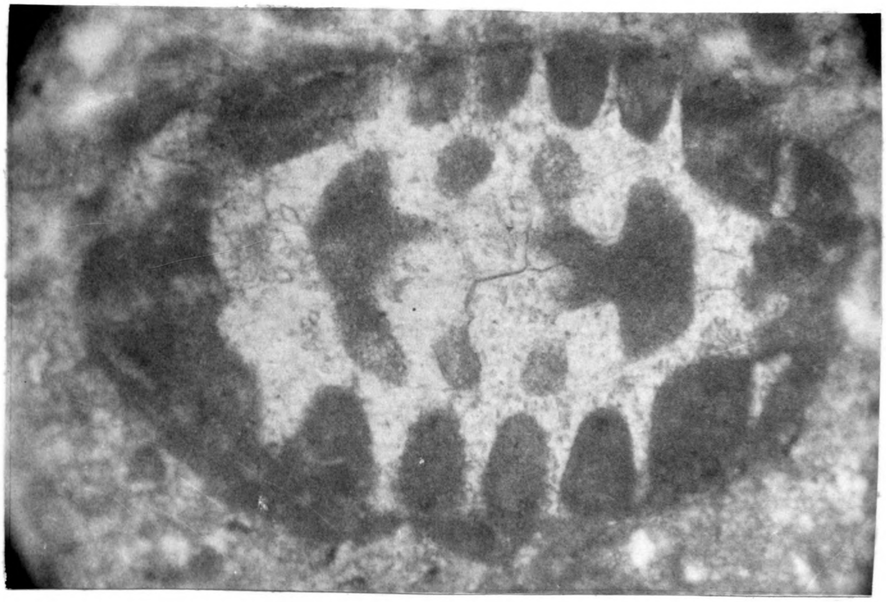


Figure 2. Photomicrograph showing pores (top view) of algae, *Epimastopora jewetti*, X 120, plane polarized light. Sample no. JC 1.

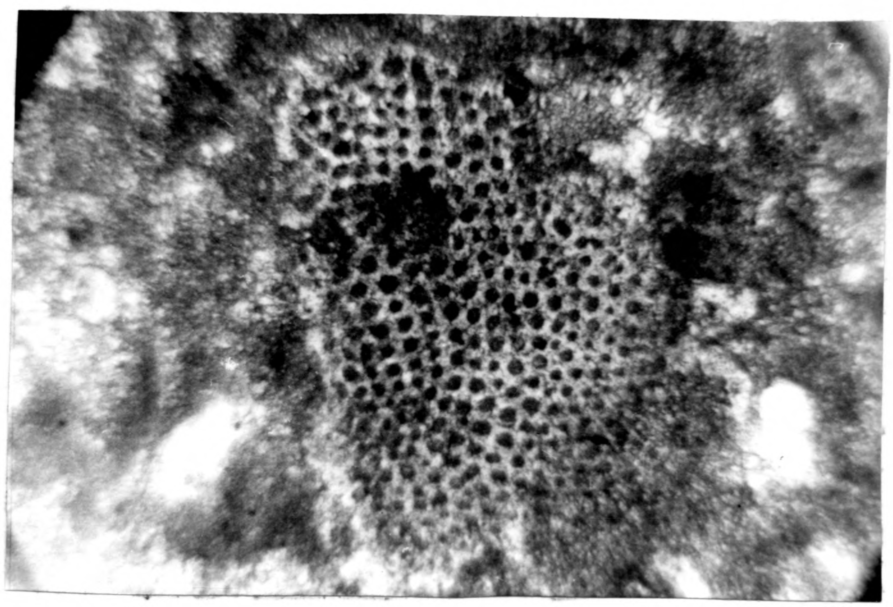


Figure 3. Photomicrograph showing small-pored variety of *Epimastopora kansasensis*, X 120, plane polarized light. Sample no. JC 2B.

forms encrustations around fossil fragments. These crusts completely surround the fragments, although the thickness of encrusting algae varied from fossil to fossil. Commonly the thickness averaged between 0.06 mm. and 0.12 mm; the encrustation is thinner on the anterior and posterior parts of the brachiopods and thicker on the dorsal and ventral parts. (One echinoderm fragment possessed a crust 0.12 mm. thick on one side and only 0.01 mm. thick on the opposite side). These crusts were almost structureless, even growth lines were absent.

Other fossils. Crinoids are the dominant invertebrates; their sizes range from 0.3 mm. to 3.75 mm.; the larger fragments are transverse cross sections of columnals. Conversely, the smaller fossils are commonly round, indicating that they were cut normal to the length of the column.

Dolomitic Micrite. According to Folk (1959, p. 26), the term "micrite" should be restricted to rocks that consist almost entirely of microcrystalline calcite. The units classified as dolomitic micrites in the Junction City section, namely JC 4, JC 7B, and JC 7M, did not fulfill this requirement where only the percentage of microcrystalline calcite was considered. In general, the percentage of micrite ranged from 49 to 58 per cent, clearly dominant over the other constituents, but probably not as much as required by Folk's definition. This deficiency of micrite was offset by increased percentages of microspar, commonly about 30 per cent. If, for example, approximately 55 per cent of the sample is micrite and 30 per cent microspar (recrystallized micrite), a total percentage would indicate the rock was originally composed of 85 per cent micrite, about the percentage that would be expected in rocks of this type.

The dolomitic micrites in the Junction City section are structureless and homogeneous. Sample JC 7B is an exception; in the field unit JC 7B contains seams of fossiliferous material about an inch thick. Luckily, the thin section of this unit contained two of these fossiliferous seams. Had this rock not been observed in the field, it would have been difficult to distinguish whether the fossiliferous area or the area of microcrystalline calcite was more representative of the rock unit.

Microscopically, the fossiliferous seams are probably best classified as algal biolithite. The contact between seams and micrite is sharp (fig. 4). Laminae are conspicuous only within the seams. Brown lenses stained by iron, quartz grains, and most of the fossils are crudely alligned. Dark wavy stringers of algae (probably Osagia sp.) contributed most to the laminated character. In several places individual laminae and stringers of algae are shaped similar to large crinoid fragments, possibly because of differential compaction. In addition to the algal mattes, Osagia sp. formed crusts around a few fossil fragments, generally echinoderm plates. A few fragments of algal crust apparently had broken off and now are angular fragments (0.24 to 0.48 mm. in size) in the micrite portion of the rock near the micrite-seam contact. The other alga in this rock, are a few fossil fragments of Epimastopora kansasensis Johnson.

The percentages of orthochemical constituents in each area is similar, the chief difference being a greater quantity of fossils and algae in the seams. The fossils in the seams are interpreted as a "death assemblage,"that is they probably died as a result of a toxic effect of the water (or some other mechanism) and subsequently dropped into the calcite ooze. Any interpretation involving increased current activity to transport the fossils into this area is without merit because such conditions would also cause an incresed quantity of spar; this increase was not indicated.

Microsparite. Unit JC 9 is a microsparite. Orthochems compose approximately 95 per cent of the sample; 64 per cent is microspar and 31 per cent is microcrystalline calcite. The rock is similar to a micrite, i.e., uniform grain size and no allochems, but the average grain size of 10 to 20 microns excludes this rock from the microcrystalline variety. Folk, (1959, p. 32) gave no limits for the distinction between a micrite and a microsparite but instead said:

> 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."

The recognition of microspar was essential, then the distinction between micrites and microsparites would depend upon the dominant constituent in the rock, i.e., if microcrystalline calcite was dominant (greater than 50 per cent), the term "micrite" was used. If microspar was dominant, "microsparite" was used.

Many of the grains in JC 9 (fig. 5) are greater than 15 microns and would be called "spar" according to Folk (1959, p. 32) who placed the size limits of microspar from 5 to 15 microns.

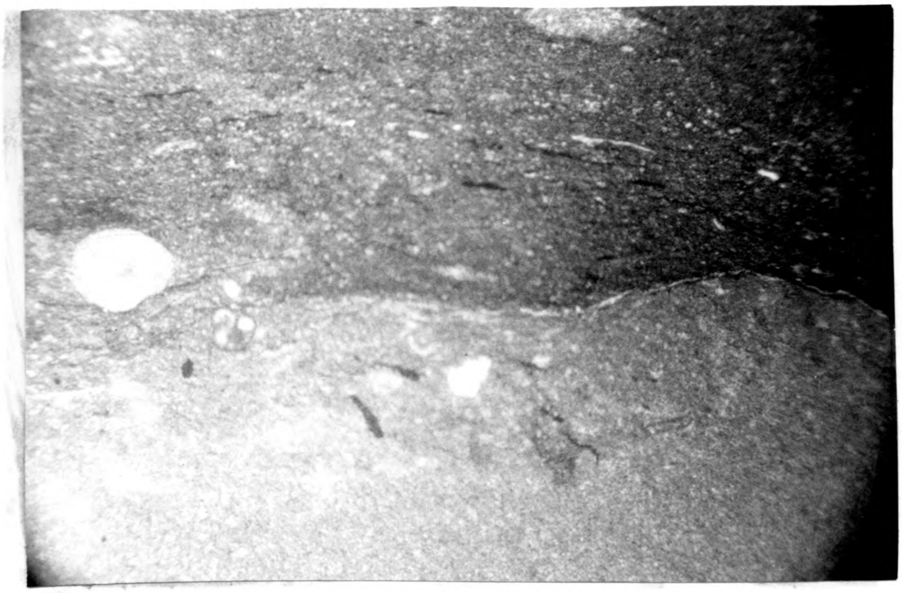


Figure 4. Photomicrograph showing contact between micrite (upper half) and seam composed of fossils and algae (seam is about ½ inch wide). X 24, plane polarized light. Sample no. JC 7B.

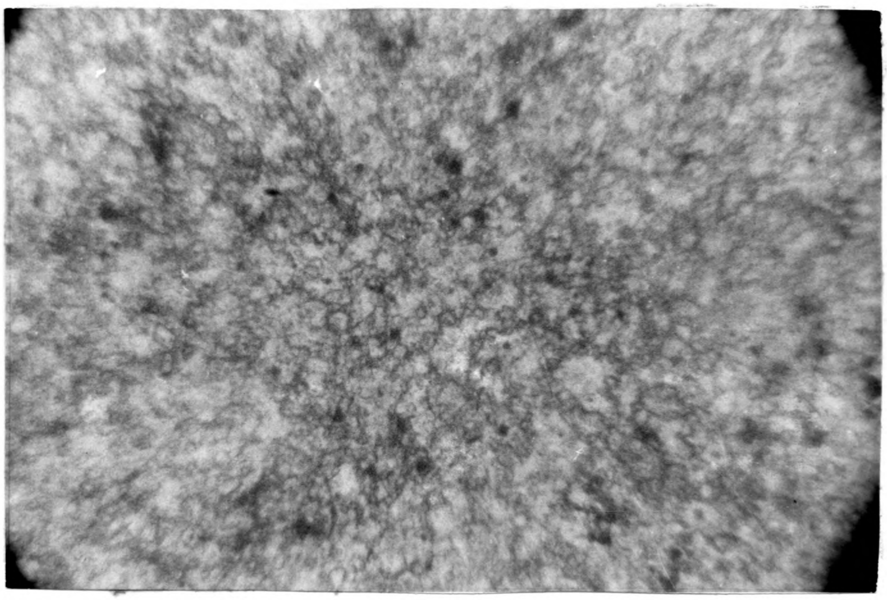


Figure 5. Photomicrograph of microsparite. Average grain size between 10 and 20 microns. X 240, plane polarized light. Sample no. JC 9.

If the grains in JC 9 are called "spar," the resulting rock would be one in which spar forms part of the supporting framework. Folk (1959a, p. 141) stated the following:

> There must be a certain minimum amount of allochems present in order to support the structure---sparry calcite cement grows only in pore spaces and in general cannot form a rock in its own right unless recrystallization occurs.

Fossils, that would act as a supporting structure, are absent, so open space filling by spar was impossible. Isolated areas of spar and micrite were not observed so incomplete washing could not have been responsible for the large grains of calcite. One explanation is that the calcite has recrystallized; the writer agrees with Folk (1959, p. 32) on the origin of microspar. Also if primary pores in a poorly consolidated lime ooze were filled with spar a similar rock would result.

Dolomitic Biomicrite-Biosparite Transition. Units JC 5 and JC 6 have received the transition terminology because both samples contain large areas of homogeneous micrite that are surrounded by spar-rich areas. Actually, JC 5 contains only one small area of homogeneous micrite (2.85 mm. in the longest dimension). Such rocks supposedly are the result of "poor washing," the micrite having been partly winnowed out (figs. 6 and 7). Possibly the greater area of micrite in JC 6 is due to less complete washing than the washing that occurred to JC 5.

Poor Washing. Some of the micrite areas in JC 5 and JC 6 are string-like, others are more equant with an irregular outline. These two characteristics, irregular outlines and the stringy appearance, prevented these areas of micrite from being

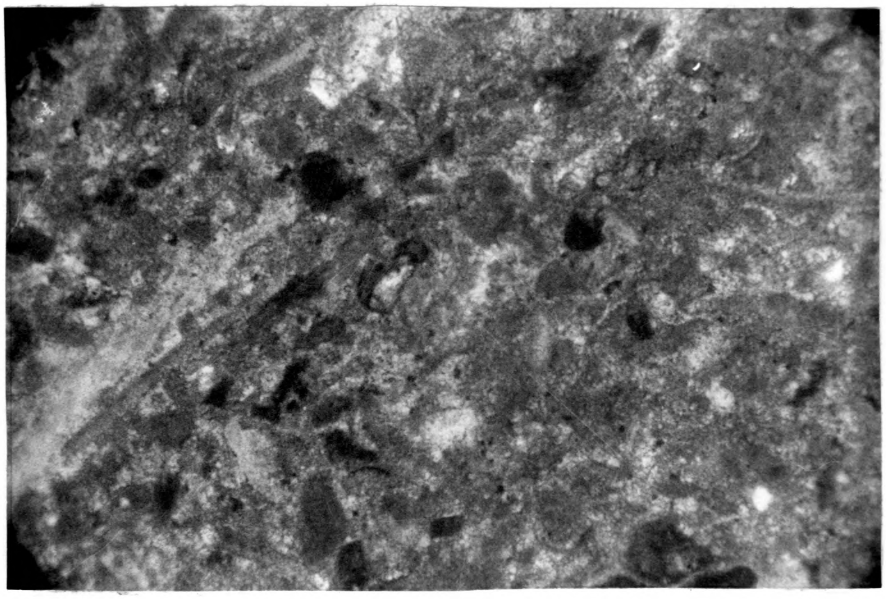


Figure 6. Photomicrograph showing the "poorly washed" appearance of unit JC#5. X 120 plane polarized light.

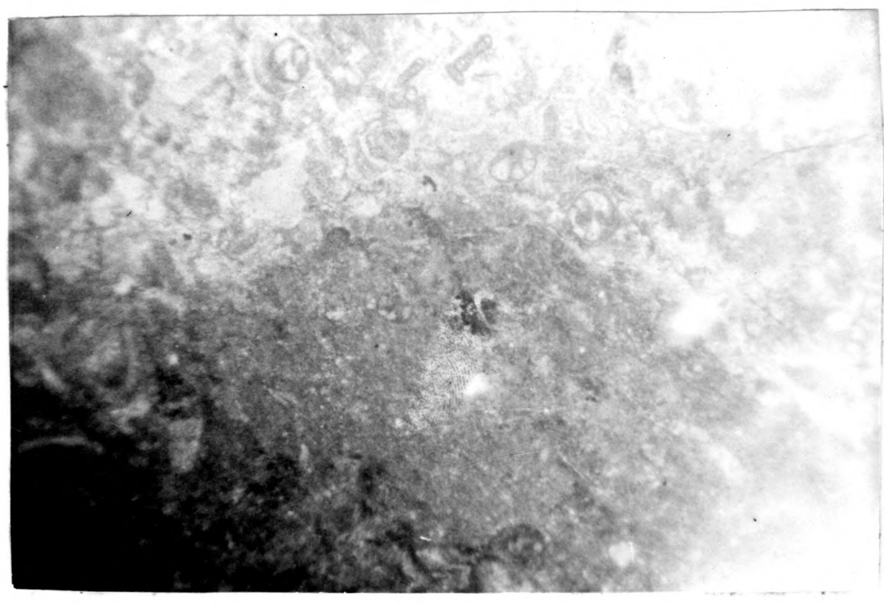


Figure 7. Photomicrograph showing large area of residual micrite (bottom) and spar rich area where micrite has been winnowed out, JC#6. Note abundance of forams. X 120, plane polarized light.

called "intraclasts." Intraclasts should show some effects of rounding and would be discrete bodies, not stringers of micrite. These areas resemble residual micrite that was the sole survivor to incomplete washing. Two occurrences favor the theory of "poor washing" in samples JC 5 and JC 6; the abundance of invertebrate fossils and algae in the washed, sparry area and their corresponding absence in the homogeneous areas of micrite.

Fossils, dark strings that may be algal threads and filaments, scattered grains of micrite, microspar, and an abundance of spar are in the "washed areas" surrounding the homogeneous micrite. The distribution of spar and micrite was controlled by the distribution of fossils, i.e., in areas of fossil concentration micrite was removed; where fossils were absent the micrite remained intact. The selective removal of the micrite was probably caused by loose packing of the micrite around the fossils.

The algae in the spar-rich areas suggest that algae may enhance the removal of micrite. If a rock is composed of micrite and algae, it seems that the effects of sediment-binding by algae suggested by Pettijohn (1957, p. 221) are probably in operation. But, if a third component, fossils, is added to the rock, the writer feels that sediment-binding effects of algae are no longer as important. The fossils seemingly would serve as crude supports for the threads, stems, and filaments of algae. As a result the algae probably could not encompass and bind the micrite and the micrite would be easily removed.

Other Fossils. Echinoderms, brachiopods, and foraminifers constitute the majority of the invertebrate fossils. The remaining fossils are so broken that identification is difficult, if not impossible. Crinoids range from 2.0 to 0.15 mm. in diameter and a few are surrounded with crusts of Osagia sp. The boundaries between some well-rounded crinoid columnals and surrounding micrite are distinct; other fossils have ragged and obscure outlines which are suggestive of corrosion by recrystallization. A few longitudinal sections of crinoid columnals are rounded on the corners, but most of the fossils apparently have not been extensively abraded because many of the fragments are still quite angular. Only some of the many small fragments of fossils are oriented.

A few pelecypod fragments, about ½ mm. in diameter, are composed of aragonite. The low interference colors and feathery extinction of this mineral are distinct from the calcite found in most shells; the biaxial negative figure served to distinguish the aragonite from celestite. Several smaller fossils have feathery extinction but the interference colors are that of calcite, suggesting that aragonite has inverted to calcite. The occurrence of aragonite in fossils is common in Cenozoic rocks (A. B. Sperry, Kansas State University, personal communication) but in Permian rocks such as the Fort Riley it is rather unusual.

Shale. Because units JC 8 and JC 10 are thin and platy and are easily weathered they were described in the field as shales; but, the percentages of insoluble residue (table 5) for both units are lower than would be expected for shale.

Under the microscope unit JC 10 has a uniform, coarse-grained texture. The average grain size is in the microspar range; scattered euhedral rhombs and the coarse grain size indicate that dolomite is abundant.

Two samples from unit UC 8 were examined; one from the shaly part of the unit, and the other from a dolomite-like part. Petrographic examination revealed that the first sample was laminated micrite (fig. 8), and the second was dolomite (fig. 9). In hand specimens the micrite part of this unit is banded, the light areas composed of microcrystalline calcite and the dark bands probably of organic material. This banding was not seen in thin sections possibly because the organic material was too fine. As can be observed from fig. 8., the only apparent cause of laminations is the alignment of quartz grains and crystals of spar. Removal of the organic bands by weathering would result in thin layers of calcite no longer separated by organic bands; hence, the platy nature of units JC 8 and JC 10.

The two samples of unit JC 8, micrite and dolomite, were taken about 35 feet apart along strike. This wide range in the calcite-dolomite ratio was noted on a much smaller scale when different calcite-dolomite values were obtained from opposite sides of the discs analyzed in the X-ray. Chilingar (1956, p. 64) mentioned that secondary epigenetic dolomites can be easily recognized by the wide variation of Ca/Mg ratios over short distances both horizontally and vertically; quite likely the dolomite in the Fort Riley is of this type. Underground water

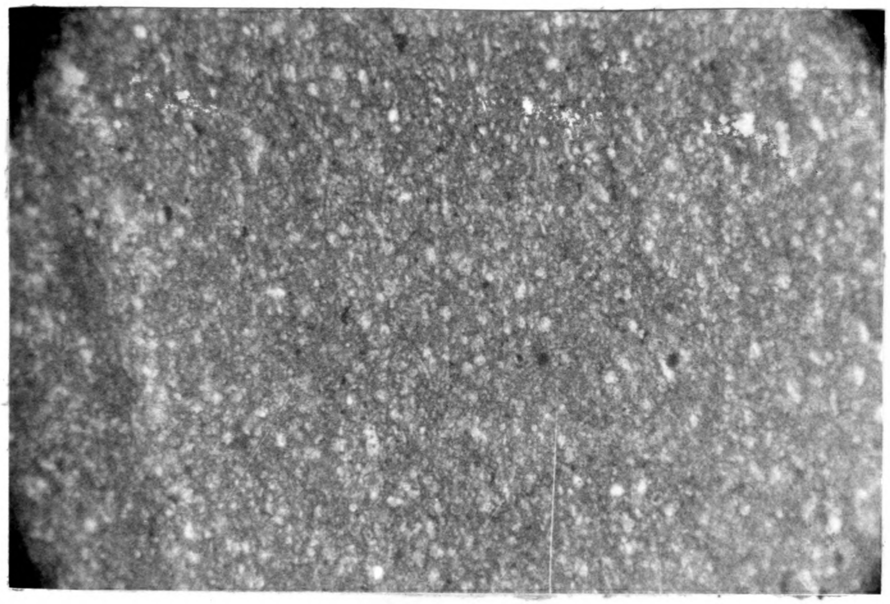


Figure 8. Photomicrograph showing laminated micrite of JC#8. X 120, plane polarized light.

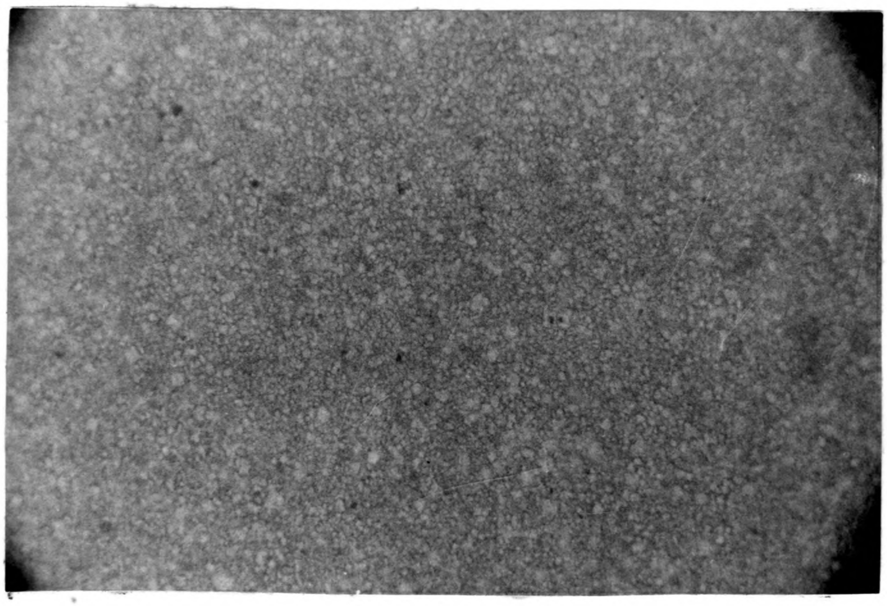


Figure 9. Photomicrograph showing coarse-grained dolomite of unit JC#8. X 120, plane polarized light.

percolating through the limestone may have had a high concentration of magnesium ions that were derived from leaching and selective precipitation of pre-existing limestone. Chilingar (p. 64) also noted that secondary solutioning and dolomitization increases the percentage of insoluble residue of carbonate rocks. Some units such as JC 7 and JC 8, seem to confirm Chilingar's conclusion. Conversely, unit JC 1 has the highest percentage of insoluble residue in the Junction City section but has only a trace of dolomite (table 5). Discrepancies such as this tend to contradict Chilingar's conclusion although it is realized that any such inference is based only on the Fort Riley rocks and undoubtedly is not representative of carbonates as a whole.

White City Location

Only seven units from the White City location were selected for study. Field descriptions of the entire section are in table 7 and results of the petrographic examination of the seven units are in table 6.

Biomicrite and Algal Biomicrite. Unit WC 16 has been classified as a biomicrite; micrite and fossils are the dominant constituents. The grain size of the micrite is uniform (3 to 4 microns). Although 20 per cent microspar and some spar were found, these constituents are limited to one part of the slide where fossil fragments are smaller than in adjoining areas in the slide.

The matrix of WC 1 differs from the matrix of WC 16 because the grain size is coarser and not as uniform and the percentages

Table 5. Percentages of insoluble residue and dolomite in units of the Fort Riley Limestone.

J.C.	Insoluble* Residue % by weight	Dolomite	W.C.	Insoluble Residue % by weight	Dolomite
1	24.7	t	1	20.1	t
2 "rimrock"	2.9	t	2 "rimrock"	3.2	t
4	10.7	49	5	5.9	t
5	11.8	19	12	18.7	t
6	6.9	13	16	5.8	t
7	17.5	26	18	9.5	t
8 "shale"	23.8	23	21	0.9	t
9	8.8	9			
10 "shale"	12.7	80			
11	4.3	17			
12	6.6	25			
F.			**A.**		
1	28.7	t	1 "rimrock"	4.4	t
2 "rimrock"	5.1	t	2 "rimrock"	5.0	t
6	9.4	t	3 "rimrock"	7.0	t
12	11.4	12	6	12.5	t
15	15.6	16	14	9.3	t
17	17.2	43	16	20.1	t

t= trace (less than five per cent).
*= insoluble residue values obtained by Carl Crumpton and Wm. Badgley (1960).

of spar and microspar are greater in WC 1. Some sparry calcite surrounds the fossils in WC 1 whereas micrite generally surrounds the fossils in WC 16.

Table 6. Percentages of constituents in the Fort Riley Limestone from White City, Kansas.

Constituents	WC1	WC2	WC5	WC12	WC16	WC18	WC21**
Micrite*	36	49	38	59	49	56	
Microspar	22	29	52	24	20	30	
Spar	15	11	6	13	8	8	66
Quartz	2	1	t		t		
Organic					2		
Pellets	4	7					
Fossils (total)	17	2	4	4	21	6	
Brachiopods	(2)	(t)				(1)	
Echinoderms	(9)	(t)	(2)	(1)	(t)	(t)	
Pelecypods	(3)	(1)			(21)	(5)	
Ostracodes	(t)		(1)	(1)			
Forams	(2)	(t)	(1)	(1)			
Bryozoans							
Algae	p	p	p			p	34**
Osagia sp.[o]	4		t				

t= trace (less than 1 per cent).
p= present (no percentage determined).
*= fine algal material included in micrite category.
o= percentage of Osagian colonies, i.e., algae surrounding fossils and structureless masses.
**= *Cryptzoon sp.*

Algae. Algal encrusted fossil fragments composed about 2 per cent of WC 1. Brachiopods, ostrocodes, pelecypods, and algae that resemble *Anachicodium permianum* Johnson, are nuclei for encrusting *Osagia sp*. The encrusting algae generally conform to the shape of the nucleus and range from 0.12 mm. to 0.30 mm. in thickness. A few quartz grains (maximum 18 microns) are entrapped in the fibrous microcrystalline algal mat. Two possible members of Class Chlorophyta (green algae) were found; Epimastopora jewetti and Epimastopora kansasensis. Both side and top views of the latter were observed. Epimastopora jewetti was identified on the basis of pore size. The pores average 0.12 mm. in diameter, well within the limits of 0.11 mm. and 0.14 mm. reported by Johnson (1946, p. 1097).

Table 7. Field description of the Fort Riley Limestone, NW¼ NW¼, Section 32, T14S, R7E, Morris County, Kansas, White City location.

Measured: by C. F. Crumpton and W. A. Badgley, using steel tape and hand level, August, 1958.

Unit No.	Thickness in feet.	Description
21.	2.2	Limestone: light gray, unit bedded, quite hard, weathers to a highly porous almost "mealy"-appearing surface.
20.	3.7	Limestone: yellowish tan, many small black specks on surface of fresh fractures, finely porous.
19.	0.2	Limestone: brown, intensely weathered and iron-stained, pitted surface.
18.	2.6	Limestone: gray to brownish gray, fine-grained.
17.	0.3	Shale: gray, calcareous.
16.	1.2	Limestone: ranges from gray to yellow, weathers to tan, fossiliferous, numerous small pelecypods stand out in relief on fractured surface.
15.	0.2	Shale: gray, calcareous.
14.	0.7	Limestone: gray, dense, hard and fine-grained, "dense zone."
13.	0.6	Shale: gray, calcareous, platy-bedded.

Table 7 (continued)

Unit No.	Thickness in feet.	Description
12.	2.7	Limestone: bluish gray, weathers to light blue-gray, very fine-grained.
11.	0.8	Limestone: bluish gray, shaly, weathers to gray.
10.	0.4	Limestone: dark blue gray, weathers to gray, nodular irregular surface, commonly called the "nodular zone."
9.	1.1	Limestone: dark blue gray, weathers light blue gray, exceedingly fine-grained.
8.	0.1	Shale: dark blue gray, calcareous, weathers to gray.
7.	1.0	Limestone: gray brown, weathers to orange brown, highly fossiliferous with a mealy texture, denoted as the "mealy zone."
6.	0.1	Shale: gray, calcareous.
5.	1.2	Limestone: light gray, weathers to white, unit-bedded, pelecypod burrows more numerous than unit 2, called the "burrow zone."
4.	1.7	Limestone: light gray, weathers to yellowish tan, unit-bedded.
3.	0.5	Limestone: gray shaly appearance, thin stylolitic partings separate this bed from units above and below.
2.	5.2	Limestone: light gray, tan-stained, unit-bedded, pelecypod burrows in upper two feet, designated as the "rimrock."
	30.7 feet	Total thickness

Other Fossils. Crinoids are the dominant invertebrates in WC 1. Cross sections of crinoid columnals are round, elliptical, and rectangular indicating various degrees of orientation. The sizes range from 0.24 mm. to 2.25 mm.; the larger plates and columnals are partly alligned.

Two bryozoan colonies, each cut transverse to the tubes, are in WC 1. The amalogomate wall is micrite and each autopore contains sparry calcite.

The percentage of fossils (21 per cent) in WC 16 is not unusual for a biomicrite, but the occurrence of a faunal assemblage consisting almost entirely of pelecypods (fig. 10) was observed in only one other unit. In general, the shells range from fragments less than 0.03 mm. to complete shells about 5.4 mm. in length. The shell thickness of the larger pelecypods ranges from 0.03 mm. to 0.3 mm. (measured from inner to outer surface). All of the shells are composed of a mosaic of interlocking crystals of spar ranging from 10 microns to 0.84 mm. in diameter. Most shells in this sample were observed in cross section and are alligned.

Microcrystalline calcite surrounds the pelecypods in this sample whereas most of the samples have some sparry calcite surrounding the fossils. This alone marks this unit as an oddity.

Significance of Pelecypod Fauna. The implications of a pelecypod fossil assemblage are unknown to the writer. Allee (1934, p. 542) reported that under favorable conditions the pelecypod Modiola modiolus may become so abundant in the littoral zone that the entire bottom may be covered with a layer of living mollusks. The conclusion then arises "that gregarious pelecypods prefer water down to a depth of 120 feet" (Elias, 1937, p. 149.).

Although the genera of pelecypods in WC 16 was not recognized, gregarious groups of pelecypods have been found and even though the conditions responsible for this assemblage are not known, the depth limits at which they are common is a clue to the depth of sedimentation for the surrounding matrix.

Microsparite. Unit WC 5 has been designated as a microsparite. The micrite and microspar are patchy as compared to the White City section. The average grain size of the microspar is 12 microns.

In addition to several echinoderm fragments and one dark algal (?) mass, a "ghost" fossil was noted. "Ghost" fossils have been interpreted by Folk (1959, p. 34) as being recrystallized fossils. This "ghost" fossil is approximately 1.20 mm. long and is biconvex (fig. 11) when seen under low power. The calcite crystals of the "ghost" fossil are larger (15 to 45 microns) than the microspar that surrounds the fossil. Folk (1959, p. 34), noted that ordinarily the formation of microspar leaves the allochems unaffected and only when the entire rock has been recrystallized to coarse spar are the allochems obliterated. The "ghost" fossil in WC 5 probably was caused by one of the following processes: (1) the fossil could have originally been composed of aragonite and as the microcrystalline matrix recrystallized the fossil inverted to calcite; or (2) calcite may have originally formed the fossil and as the matrix recrystallized the calcite in the fossil also recrystallized.

Cryptozoon microsparite. The upper unit at the White City location, WC 21, was described because it contains a type of

Figure 10. Photomicrograph showing pelecypod biomicrite WC#16. Pelecypod shells have been entirely recrystallized and are surrounded by microcrystalline calcite. X 120, plane polarized light.

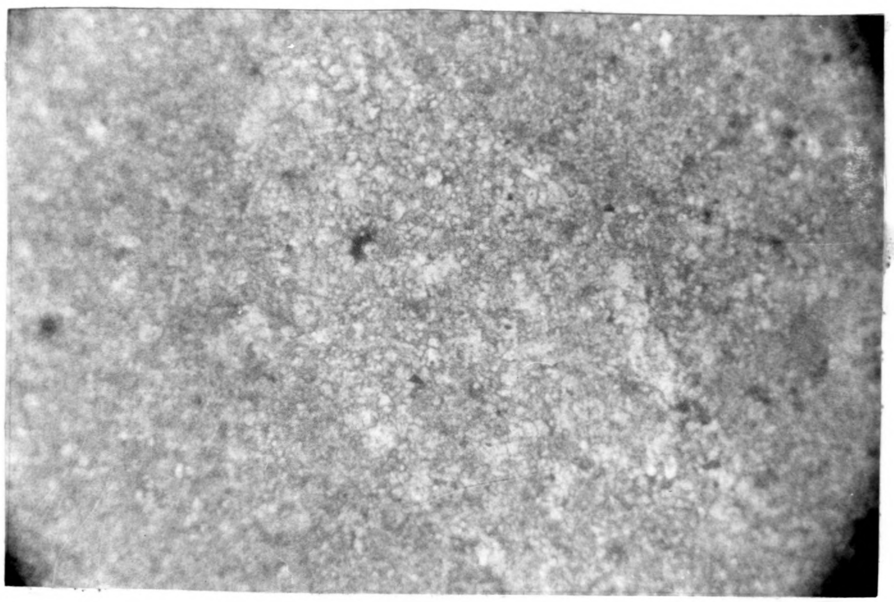


Figure 11. Photomicrograph of microsparite WC#5. Note "ghost" fossil in center and coarser grain size in fossil as compared to the surrounding microspar. X 120, plane polarized light.

algae not found in other slides. This rock consists of microspar (averaging 25 to 30 microns) and algae resembling Cryptozoon kansasensis (fig. 12). The author's identification of this genus was based primarily on the illustrations by Johnson (1946, p. 1118).

The question has arisen as to the origin of the calcite in this slide. The grain size of the calcite is coarse and uniform, apparently much too coarse for direct chemical or biochemical precipitation. Dolomite has a coarse texture similar to that in Fig. 12 but X-ray determinations showed only a trace of dolomite in this rock. The answer probably lies in recrystallization as suggested by Johnson, (1946, p. 1106).

> Laminae are composed of fine, mostly branching threads of simply organized algae, probably Cyanophyaceae. Originally these formed a spongy mass. Very fine-grained calcium carbonate was deposited around algal filaments. When the plants die, molds of thread were left, forming a very porous calcareous mass that was easily dissolved by percolating waters and often recrystallized. As a result, details of the algal threads are discernable but are seldom clearly shown.

The author agrees with Johnson; recrystallization apparently accounts for the coarse crystals of calcite and the obscure appearance of the dark wavy algal threads.

Florence Location

Six units from the Florence location were studied. A detailed analysis of these units and field descriptions of the entire section are given in tables 8 and 9 respectively. Description of individual units were shortened and references to similar units were made.

Micrite. Three units in the upper part of the Florence section, F 12, F 15, and F 17, are dolomitic micrites. The matrix of these rocks is dominatly micrite, but F 12 contains nearly an equal amount of microspar. The three samples are remarkably similar, each having a fine-grained matrix and poorly developed laminae. Laminae in these rocks consist of an alignment of grains that average about 30 microns in diameter. The shape of these large grains range from euhedral dolomite rhombs, to sharp angular quartz grains (clear, no inclusions, no overgrowths), to equant or shapeless crystals of sparry calcite.

Table 8. Percentage of constituents in the Fort Riley Limestone at Florence, Kansas

Constituent	F1	F2	F6	F12	F15	F17
Micrite*	30	28	38	50	48	54
Microspar	23	15	56	42	34	24
Spar	19	17	5	6	14	14
Quartz				1	1	4
Organic					2	4
Pellets	4	15				
Fossils (total)	13	24	1	t	1	
Brachiopods		(8)				
Echinoderms	(8)	(t)	(1)		(t)	
Pelecypods	(3)	(16)	(t)			
Ostracods	(1)		(t)		(t)	
Forams						
Bryozoans	(1)					
Algae	p	p				
Osagia°	11	1				

t= trace (less than 1 per cent).
p= present (no percentage determined).
*= fine algal material included in micrite category.
o= percentage of Osagian colonies, i.e., surrounding fossils and structureless masses.

Table 9. Field description of the Fort Riley Limestone, SE¼, NE¼, Section 6, T21S, R6E, Marion County, Kansas, Florence location.

Measured: by C. F. Crumpton and W. A. Badgley, using steel tape and hand level, August, 1958.

Unit No.	Thickness in feet.	Description
20.	3.0	Limestone: gray to blue gray, weathers light gray, solution effects quite conspicuous.
19.	1.7	Limestone: gray to blue gray, a few solution pits.
18.	0.5	Shale: limy, gray, platy bedded.
17.	2.9	Limestone: gray, very fine-grained.
16.	0.4	Limestone: gray, very fine-grained, shaly.
15.	2.5	Limestone: gray, very fine-grained.
14.	0.1	Shale: brown partly due to abundant iron staining, limy, many solution pits.
13.	0.8	Limestone: gray, very fine-grained, hard and dense, "dense zone."
12.	1.3	Limestone: gray, very fine-grained.
11.	0.4	Shale: limy, gray to brown.
10.	0.8	Limestone: gray, breaks with curved irregular nodular surface, "nodular zone."
9.	2.0	Limestone: gray, very fine-grained, unfossiliferous.
8.	1.8	Limestone: tan brown to gray, weathers to orange brown, called the "mealy zone" because of bands and streaks of small brown fossils which impart a "mealy" appearance.
7.	0.4	Shale: gray, several thin brown horizontal fossiliferous seams.

Table 9. (continued).

Unit No.	Thickness in feet.	Description
6.	1.6	Limestone: yellow gray to light gray, characterized by pelecypod burrows, "burrow zone."
5.	2.7	Limestone: dark gray to gray on unweathered surface, weathers to tan, horizontal dark gray streaks, breaks into thin units varying from 0.2 to 0.7 feet in thickness.
4.	1.0	Shale: limy, tan, weathers yellowish tan, fossiliferous.
3.	0.4	Limestone: shaly, tan to gray, numerous large brachiopods.
2.	11.6	Limestone: light gray, several stylolitic seams and horizontal carbonaceous partings, fossiliferous, pelecypod burrows in upper four feet, "rimrock."
1.	1.3	Limestone: dark blue, fine-grained, fossiliferous, fossils are orange or brown in fresh surfaces.
	37.2 feet	Total Thickness

Laminae. Laminae are formed by: a change in the rate of sedimentation, a change in the type or quantity of sediment being deposited, or a change in grain size. Alternating layers of calcite and quartz silt are not unusual in limestones and have been seen in other thin sections. The sparry calcite and dolomite that form the laminae in units F12, F15, and F17 are unusual because both minerals are secondary and were absent when the laminae were developed. Laminae in these three units may have formed by one of two possibilities.

1. Both minerals may have filled voids that were originally occupied by quartz grains or may have replaced other minerals that originally occupied the space.

2. Carozzi (1960, p. 201) has discussed a group of algal limestones with so-called "bird's eye" texture. This texture, according to Carozzi, looks like "irregular flecks and masses of clear calcite" (in a fine-grained matrix) "that reflect light as isolated sparkles." Carozzi noted that the flecks of calcite resemble the calcite found in the interior of molluscan shells (see fig. 15), in interstices between fossil fragments, and in the irregular spaces within the calcite precipitated as encrustations of blue-green algae (Cryptzoon sp. found in WC21 is a blue-green algae, see fig. 12). Carozzi implied that the flecks of calcite look like isolated crystals of sparry calcite. Actually, these flecks of calcite are recrystallized fragments of algae and are not pore fillings of sparry calcite. The author is unfamiliar with limestones of this type but this origin for the sparry calcite should not be discounted. Note, that Carozzi's description of a "bird's eye" texture, i.e., irregular flecks and masses of clear calcite in a fine-grained matrix, seems to adequately describe unit F12 (fig. 13).

Microsparite. Unit F6 is a microsparite as was WC5 which occupies the same stratigraphic position. If grain size is an indication of the degree of recrystallization, unit F6 is in the initial stage of being converted from a micrite to a microsparite. Not only is micrite abundant, but only a few microspar grains exceed 10 microns in diameter. Other microsparites examined

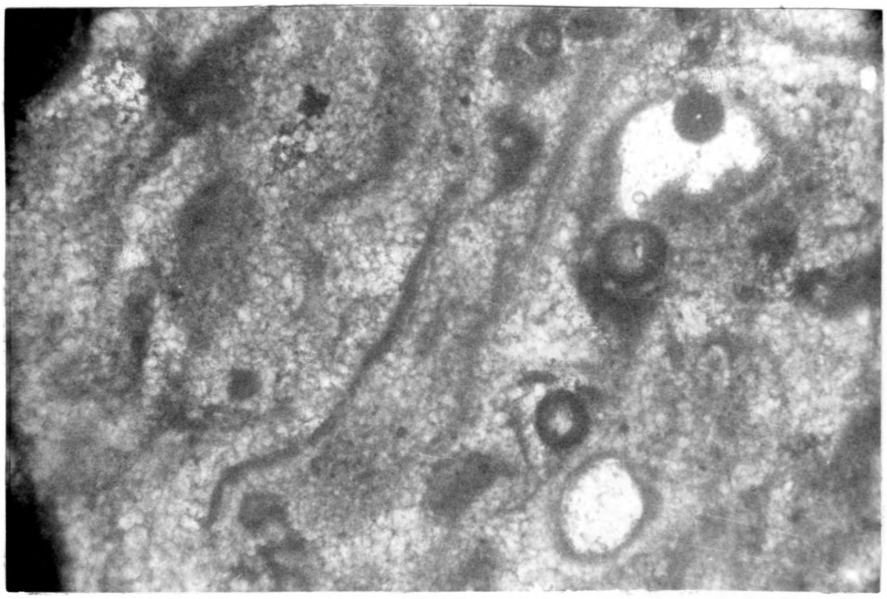


Figure 12. Photomicrograph of Cryptzoon microsparite WC#21. Note dark wavy nature of algae and matrix of clear microspar. X 120, plane polarized light.

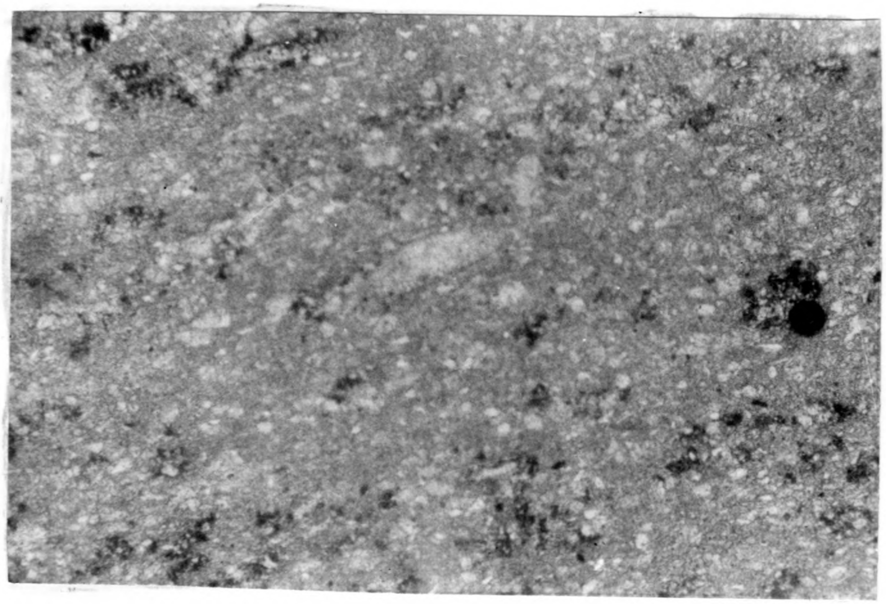


Figure 13. Photomicrograph of unit F#12 showing fine-grained matrix and crude alignment of quartz grains and spar crystals. Note fusulinid in center. X 120, plane polarized light.

commonly have an average grain size of 15 microns and more.

A few scattered, clear areas were seen with plane polarized light. Commonly the isolated areas are: (1) angular quartz grains with an average size of 12 to 22 microns; (2) crinoid fragments with single extinction and with corroded and vague outlines; or (3) crystals of spar, 20 to 50 microns.

Algal Biomicrite. The two lower beds in the Forence section are distinctive because they contain approximately 10 per cent more spar than the average unit and an abundance of allochems. Orthochemical constituents are dispersed throughout the sample although some sparry calcite fills the pores around and between fossils and pellets. A few crystals of spar in the maxtrix are approximately 160 microns in diameter (most noticeable in F2B). These crystals are not recrystallized fossil fragments, but cement. The clarity of the spar grains and their occurrence in clusters are characteristic of cement.

Algae. Several types of algae were found in F1 and F2B but algae were more abundant in F1. In this unit many crusts of *Osagia sp.* were found on *Anchicodium permianum* Johnson, echinoderms, and pelecypods. These crusts are composed of dark algal filaments (?) and threads and a few white chamber walls of an unidentified foraminifer (?) are scattered within the darker mass of algae.

A species resembling *Epimastopora kansasensis* is also in F1 (same as fig. 3). The top view of this algae consists of small, nearly spherical pores approximately 0.03 mm. in diameter. Johnson (1946, p. 1096) who originally described the species

Espimastopora kansasensis, noted that two types of this species exist; the first type (called Epimastopora kansasensis by Johnson) with pores that range from 0.07 to 0.11 mm. in diameter, and the second type with pores that range from 0.03 to 0.04 mm. in diameter (called the small-pored type of Epimastopora kansasensis by Johnson). A side view, presumably of the same species, is 1.08 mm. in length and 0.11 mm. wide (fig. 14).

A side view of Epimastopora kansasensis was also noted in unit F2B. This stem fragment, which is nearly 6.3 mm. in length, is unusual because the stem is not of uniform thickness, but is tapered to a point at one end. Johnson (1946, p. 1097) noted that stems of Epimastopora kansasensis characteristically are of uniform thickness throughout their length. The thicker part of this fragment is fibrous or columnar calcite (similar to the calcite in fig. 14), but the small tapered end is composed of equant grains of calcite.

Pellets. Nearly one-third of the allochems in F2B are pellet-like bodies that form dark patches over much of the slide (fig. 15). Some of the bodies are rounded to elliptical and only a few exceed 0.12 mm. in diameter (Folk, 1959, p. 7, noted size boundaries of 0.03 and 0.15 mm. for pellets). The dark bodies with identifiable outlines may well be pellets but the remaining opaque matter is probably recrystallized micrite. Some pellet-like objects, according to Folk (1959, p. 7), may form by recrystallization, "a sort-or auto-agglutination of once homogeneous calcareous mud." The indistinct boundaries and irregular outlines of the dark matter and the fine-grained microspar that

Figure 14. Photomicrograph showing side view of Epimastorpora kansasensis F#1. X 120, plane polarized light.

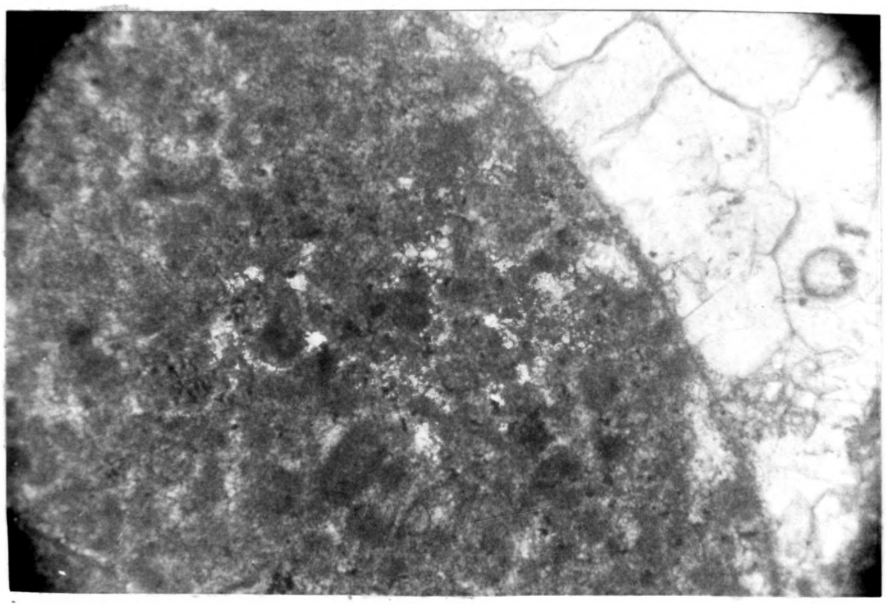


Figure 15. Photomicrograph of unit F#2B. Note large pelecypod in upper right corner and patchy appearance of the remaining slide. A few pellet-like bodies can be observed. X 120, plane polarized light.

occupies the interstices between these bodies seemingly support the theory of recrystallization.

Other Fossils. Crinoids and pelecypods were the most important fossils in unit F1 and F2B respectively. An important fact to note in F2B is the large size of the pelecypods. One pelecypod is nearly 13½ mm. in length, and shells averaging 5½ mm. are common.

Several large brachiopods (approximately 3 to 4 mm. in length) in F2B retained their original laminated calcite except for a few patches of secondary chalcedony.

Augusta Location

Six units from the Augusta location were studied. Field descriptions of the entire section are presented in Table 11 and results of the petrographic examination are shown in Table 10.

Micrite. Although unit A6 is lithologically similar to units F6 and WC5 which are microsparites, it contains only 32 per cent microspar and is dominatly micrite.

Table 10. Percentages of constituents in the Fort Riley Limestone at Augusta, Kansas.

Constituents	A1	A2	A3	A6	A14	A16
Micrite*	42	22	12	51	46	50
Microspar	26	11	6	32	22	24
Spar	17	17	20	14	18	9
Quartz					t	
Organic		10	20	2	2	4
Pellets		10	20			
Fossils (total)	14	15	12	1	12	13
Brachiopods	(2)	(1)	(2)		(2)	
Echinoderms	(2)	(6)	(6)	(t)	(2)	(t)

Table 10. (continued).

Constituents	A1	A2	A3	A6	A14	A16
Pelecypods	(8)	(8)	(4)		(7)	(13)
Ostracods	(1)		(t)			
Forams					(1)	
Bryozoans						
Algae	p	p	p		p	p
Osagia°	1	25	30			

t = trace (less than 1 per cent).
p = present (no per cent determined).
* = fine algal material included in micrite category.
o = percentage of Osagian colonies, i.e., surrounding fossils and structureless masses.

One end of the slide has an average grain size of 8 to 10 microns, whereas the grain size in the other end is 4 microns, but no transition of micrite to microspar was observed. Echinoderms with irregular and ragged boundaries in the coarse-grained area seemingly suggest that micrite has recrystallized.

Biomicrite. Unit A16 resembled WC 16 although these beds are not correlative (Plate 1). Pelecypods and micrite form most of the fabric as they do in WC16. The main difference between the two units is that the average size of pelecypods in A16 is from 0.03 to 3.6 mm. whereas, the average shell size in WC16 is 5.4 mm. Again no alignment of the shells was noticed.

Most of the shells are surrounded by microcrystalline calcite although a few small patches of spar are intermingled with fine fragments of disarticulated shells. The association of spar with fragmented fossils and the corresponding absence of spar with intact shells indicates that in places currents were vigorous enough to wash away micrite and wash in broken, rounded fossils.

Table 11. Field description of the Fort Riley Limestone, SE¼, NE¼, Section 9, T28S, R4E, Butler County, Kansas, Augusta location.

Measured: by C. F. Crumpton and W. A. Badgley, using steel tape and hand level, August, 1958.

Unit No.	Thickness in feet.	Description
20.	5.5	Limestone: tan, weathers brown, porosity appears quite high because of many small pores, fossiliferous.
19.	3.0	Limestone: gray to cream with yellow to orange mottling, weathers light gray, unit-bedded, fossiliferous, weathered surface has many small pores.
18.	0.5	Limestone: gray with brown mottling, yellow-tan on weathered surface.
17.	2.3	Limestone: gray, weathers tan, separates into five nearly equal units, fossiliferous, "mealy" at some locations.
16.	3.9	Limestone: gray to light gray, weathers yellow-tan, platy-bedded, burrow fillings. Echinoids, crinoids, and large brachiopods are abundant.
15.	0.2	Shale: gray, calcareous, a few fossils, scattered, hard, elongate, calcareous nodules.
14.	1.9	Limestone: light gray to tan gray, separates into three nearly equal units all containing pelecypod burrows. Many burrows filled with fretwork of small fossils.
13.	0.6	Limestone: gray, weathers tan brown, exceedingly fine-grained, "dense zone."
12.	0.7	Limestone: gray, shaly, weathers tan brown, platy-bedded.
11.	1.3	Shale: blue gray, limy, fossiliferous, numerous elongate hard calcareous nodules.

Table 11. (continued).

Unit No.	Thickness in feet.	Description
10.	0.5	Limestone: gray, weathers to brown, very fossiliferous, fossils mostly exposed in cross section.
9.	1.3	Limestone: gray to tan gray, weathers tan brown, fossils are clustered, uneven nodular surface, "nodular zone."
8.	6.1	Limestone: dark blue gray, weathers to light blue gray, sparsely fossiliferous, dark horizontal bands.
7.	0.5	Shale: blue gray, calcareous, weathers light blue gray, platy-bedded.
6.	0.8	Limestone: blue-gray on fresh surface, weathers light blue-gray, very fine-grained, sparsely fossiliferous.
5.	2.7	Shale: blue gray, calcareous, weathers light blue gray, fossiliferous, minute gypsum crystals glisten in sunlight. A few hard limy nodules.
4.	1.8	Limestone: yellowish tan color, splits into irregular uneven plates, fossils including echinoids and crinoids abundant in middle part.
3.	3.0	Limestone: gray to tan-gray, weathers light tan, upper 1.5 feet contains many pelecypod burrows 1 inch in diameter. Upper unit of "rimrock."
2.	4.8	Limestone: gray, unit-bedded, fossiliferous, surface marked with numerous fine pits.
1.	5.8	Limestone: dark bluish gray, mottled with small elongate to round soft white inclusions, several thin carbonaceous partings impart a false shaly appearance. Stylolitic parting separates this unit from overlying unit. Base of the "rimrock."
	53.2 feet	Total Thickness

Crystals of spar are dispersed throughout the sample. The larger crystals, 180 to 200 microns, resemble recrystallized fossil fragments with ragged outlines whereas the smaller grains, averaging about 60 microns, are rhombic crystals of dolomite.

An unusual seam of micrite (?) surrounded on both sides by a fossiliferous micrite matrix almost traverses the thin section. Toward one end of the slide the seam pinches out; the seam resembles the matrix of micrite and isolated crystals of spar in A14.

Algal Biomicrite. Units A1 and A14 are classified as algal fossiliferous micrites. The matrix of A1 consists primarily of micrite with an abundance of dark, nearly opaque algae, several fragments of other fossils, and scattered crystals of spar (some of these crystals may be recrystallized algal fragments.)

The matrix of A14 consists mainly of micrite but spar crystals are more abundant and algae less abundant than in A1. A1 is one of three units of the "rimrock" at Augusta and grades into the upper two units which are algal biosparites.

Algae in A1 are the small-pored type (0.02 to 0.036 mm.) of *Epimastopora kansasensis* and encrustations of *Osagia sp.* on several large pseudopunctate brachiopods. Only a few crusts are thicker than 0.1 mm. but all surround the incorporated nucleus. A few dark structureless masses of *Osagia sp.* were noted; these are discussed with algal biosparites in the following section.

Algae in unit A14 consist of encrusting *Osagia sp.* and the large-pored member of Family Dasycladaceae, *Epimastopora jewetti*.

Algal Biosparite. Units A 2 and A 3, the upper units of the Augusta "rimrock," are algal biosparites. Both units contain approximately 25 per cent Osagian-encrusted fossils. The encrusting algae in these rocks have grown around fossil nuclei that were frequently moved to permit algal growth on all sides.

In units A 2 and A 3 sparry calcite fills many of the interstices although scattered patches of residual micrite were noted in units A 2. The remaining constituents are largely of algal origin and are dominant in these two rocks.

Algae. Osagia sp. is the most abundant type of algae in A 2 and A 3 and several crusts are nearly 1.0 mm. thick. The thickness may seem insignificant, but when compared to an average thickness of 0.1 to 0.3 mm. in other rocks studied, it is somewhat more impressive. Growth lines are conspicuous (fig. 16) in most of the encrustations of Osagia sp. although a few crusts are completely structureless.

Nuclei for the Osagian colonies are shells of crinoids and pelecypods and another type of algae, Anchicodium permianum. One echinoderm, broken into two pieces, is completely surrounded by Osagia sp. Although the two halves are in optical continuity, Osagia sp. fills the area between the halves possibly forcing apart the crack in the echinoderm.

Pellets. Pellet-like bodies in samples A 2 and A 3 are of two types; round bodies composed of very fine-grained calcite, and bean-shaped bodies that are somewhat darker.

1. The bodies composed of fine-grained calcite may be true pellets. Many explanations have been postulated for the origin of pellets but the writer believes that these are current-laid fecal pellets. Invertebrate fossils are quite abundant in units

A 2 and A 3 so fecal pellets would be expected. The abundance of sparry calcite is indicative of a high energy environment; similar to that responsible for the current-laid pellets.

2. The darker bodies are larger than the true pellets, some reaching 2½ mm. in diameter. These larger objects are probably colonies of Osagia sp. that have been cut during grinding of the thin section near the outer part of the colony. An overall view of an Osagian colony would probably be elliptical in outline. A thin section cut near the end of the elliptoid would produce a cross section of almost any size. This cross section would not contain a nucleus but would be spherical in outline and still retain its laminated character.

Other Fossils. Fossils are abundant (12 and 16 per cent) in units A 2 and A 3; some of them are surrounded by Osagia sp. Although some echinoderms are untouched, most of them are encrusted with Osagia sp. or associated with Epimastopora kansasensis (small pore variety).

Many echinoderm fragments contain patches of chalcedony and one crinoid columnal has been entirely replaced by chalcedony. Spherulites composed of chalcedony were found in a fine-grained brachiopod shell (fig. 17). These spherulites are round, average 0.21 mm. in diameter, and possess radial extinction. Pettijohn (1957, p. 202) has also reported spherulites of chalcedony in some limestones. According to Pettijohn the spherical form may be due to primary precipitation as collodial gel, and the internal radial structure to crystallization of the gel. The author believes that these spherulites are probably secondary replacement of calcite or dolomite.

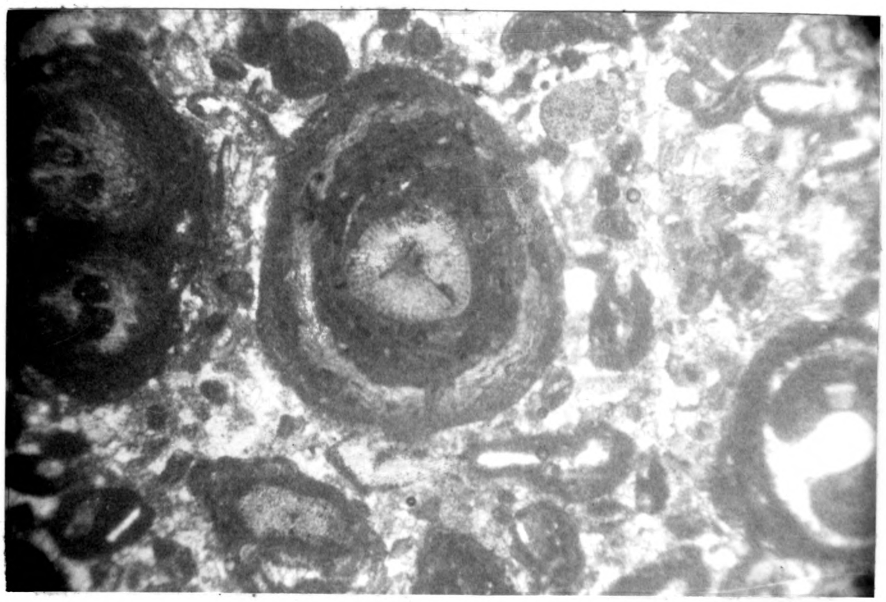


Figure 16. Photomicrograph showing Osagian colonies surrounding fossils, A#2. Note growth lines in colony surrounding echinoderm in center. Matrix is composed predominately of spar. X 24, plane polarized light.

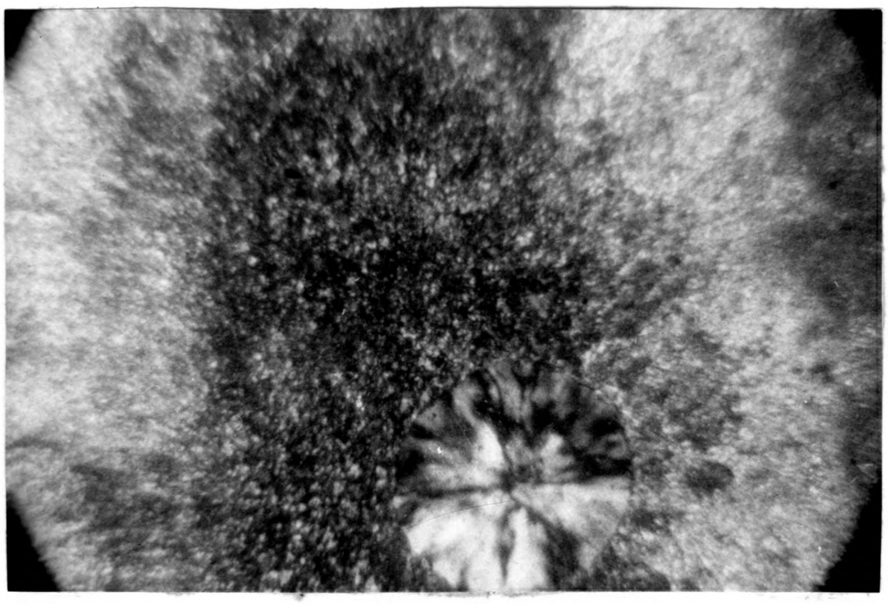


Figure 17. Photomicrograph showing spherulite surrounded by dark patch of chalcedony (?), A #3. X 120, plane polarized light.

DEPOSITIONAL ENVIRONMENT OF THE FORT RILEY LIMESTONE

Conclusions about the conditions of deposition have been limited to the general area of the four quarries. Only the Junction City section was studied in its entirety. As a result, this was the only location in which the sequence of geologic events could be determined. The other three quarries were used to supplement evidence found in rocks of the Junction City location. Inasmuch as all four quarries are approximately along the strike of the Fort Riley, observation of lateral changes of the limestone member was limited to changes in a north-south direction.

Early Fort Riley Time

Three important components characterize the lower units of the Fort Riley Limestone, i.e., "rimrock;" an abundance of green algae (about 15 per cent) and sparry calcite, and gypsum crystals at the Augusta location. All are seemingly indicative of a general depositional environment.

The following green algae have been identified in the "rimrock;" _Epimastopora_ _sp_., _Anchicodium_ _nodesum_?, _Osagia_ _sp_.* Pearse and Gunter (1957, p. 139) have noted that some green algae have internal concentrations of dissolved salts, etc. twice as great as sea water. Algae with high internal concentrations of dissolved salts would have an advantage in a medium with a high

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*Class Chlorphyto (green algae) does not include _Osagia_ _sp_. which belongs to class Cyanophyta, but Johnson (1957, p. 1094) suggests that a combination of the two classes might be advisable.

osmotic pressure, i.e., a hypersaline medium. Equalizing pressures would exist on the internal and external sides of the plant because salt concentrations within the algae and of the surrounding medium (sea water) would be nearly equal.

Gypsum has been identified in the Augusta section by C. F. Crumpton. Initial recognition was made using the X-ray diffraction method. Later these minute crystals were observed in the outcrop by Mr. Crumpton and Mr. Badgley. The author has not observed these crystals so it is not known if they are primary or secondary. Until further study confirms the origin of the gypsum, the proof of hypersalinity by the occurrence of gypsum can only be postulated. In spite of scanty evidence, the author believes that the abundance of green algae indicates hypersaline conditions.

Hypersaline Environment. The hypersaline environment of early Fort Riley times was probably caused by a regression and evaporation of the sea. During regression of the sea, circulation of landward moving waters is at a minimum (or even nonexistent, Hattin, 1957, p. 96). Lack of circulation would lead to evaporation of shallow near-shore water, and without replenisment, would increase the salinity slightly causing a hypersaline environment.

The salinity of the Great Salt Lake is 203.49 parts per thousand; sea water is approximately 35 parts per thousand. The postulated hypersaline waters existent during "rimrock" deposition had a salinity between these two values, probably more closely approximating normal sea water.

Characteristics of Hypersaline Sea. The following constituents of the "rimrock" greatly aid in interpreting the characterists of the hypersaline sea of early Fort Riley Time:

1. Large quantities of algae (nearly 50 per cent at Augusta).

2. Fossils encrusted by (*Osagia sp.*).

3. Abundance of sparry calcite (the percentage of spar in the "rimrock" averaged about 10 per cent more than in other units.)

Illing (1954, p. 21) has shown that encrusting algae on the Bahama Banks were essentially absent at depths less than 60 feet, while at the outer edges of the Banks (approximately 60 feet deep) calcareous algae made up 39 per cent of one sample. Newell (1953, p. 201) has suggested depth limits of 10-30 meters as the optimum depth for the growth of Permian algae. The writer believes that the "rimrock" sediments were probably deposited in water no deeper than 60 feet and possibly even less.

In order that *Osagia sp.* completely encrust fossils, Lane (1958, p. 153) suggested that the fossil nuclei must have been turned over from time to time to permit algae growth on all sides. The part of the nucleus imbedded in micrite would not be exposed to sunlight; hence, photosynthesis could not occur and the algae would not develop.

King (1951, p. 134) has stated that the depth of disturbance in deep water is much less than in shallow water because turbulence decreases as water depth increases. According to King: "Heavy wave currents produced by storms would agitate particles down to a depth of 6 inches or less." Lane (1958, p. 153) has applied this limit of disturbance to the Osagite limestone (Grenola Limestone, Council Grove Group, Lower Permian) which are 2 to 3 feet thick and contain algal encrustations distributed evenly throughout the bed from top to bottom. He has concluded that:

> ----------shell fragments must have accumulated slowly, for once an encrusted particle was buried under six inches of material, it probably could not be brought back to the surface by wave aggitation, and the algae would die. Therefore, the entire 2 to 3 feet of small shell fragments could not have been deposited at or nearly at the same time but must have accumulated slowly.

These conclusions are readily applicable to the "rimrock" because encrusting algae are found in all units of the "rimrock" at all four locations.

The high percentage of sparry calcite (18-20 per cent) in the "rimrock" further attests to turbulent waters. Sparry calcite forms by secondary precipitation in pore spaces and voids. Before spar can form, pore space must be created by the removal of micrite, i.e., removal by currents. This assumes that micrite was originally in the rock. If primary pore space is already existent, removal of micrite is not necessary.

Middle Fort Riley Time

A decrease in the abundance of algae in the units overlying the "rimrock" and the appearance of burrowing pelecypods (in JC 5), indicate that hypersaline conditions characteristic of "rimrock" deposition were not existent in mid-Fort Riley time.

The decreased abundance of algae in units overlying the "rimrock" probably best indicates the changed conditions.

Pearse and Gunter (1957, p. 140) have noted that algae can survive the transition from one environment to another providing the change is slow. The percentage of algae decreases upward from the "rimrock." An average of 5 per cent and less was noted in overlying units indicating that although the percentage of algae did decrease, complete disappearance did not occur. Inasmuch as green algae seem to favor hypersaline water, a decrease in the amount of algae is suggestive of decreased salinity. Highly saline conditions (salinity of approximately 200 parts per thousand, i.e., Great Salt Lake) could also cause a decrease in the amount of algae, however, a salinity of 200 parts per thousand would be unfavorable for growth of any kind. The numerous pelecypod burrows in unit JC 5 indicates that highly saline conditions were not existent.

According to Hattin (1957, p. 98):

> Burrowing clams such as _Barnea_, _Ensis_, _Solen_, and _Mya_, which resemble in form the burrowers of the Late Paleozoic, are abundant in the bottom muds of the near-shore brackish-water environments of the present-day seas.

Hattin notes that these modern forms may be regarded as homeomorphs of Late Paleozoic burrowing clams. The author is well aware that burrowing pelecypods are not limited to brackish-waters but their presence in middle Fort Riley units along with decreased amounts of algae certainly cannot be discredited entirely as evidence of brackish-water conditions, i.e., decreased salinity as compared to the hypersaline environment of early Fort Riley time.

Decreased salinity. Two conditions may have been responsible for freshening the water in the Junction City and surrounding areas in mid-Fort Riley time: (1) enclosure by a reef, or (2) the influx of fresh water from near shores.

Reefs. No positive evidence of a reef has been found; however, the following two facts are suggestive of a reef in the Florence area (south of Junction City): (1) An unusual thickening of the "mealy unit" at the Florence location, and (2) the absence of the "mealy unit" at Augusta.

Within the Florence quarry the normal thickness of the mealy zone (1.6 feet, see unit F 8, Plate II) is continuous over much of the area but in the northern part of the quarry an unusual thickening of the "mealy unit" (12 feet) was found (fig. 18 and 19). At present it is not known if this greater thickness was caused by a reef or by greater sedimentation. According to Newell (1953, p. 108) an important characteristic of reefs is that true organic reefs represent continuous deposition; therefore, reefs lack stratification. Examination of figure 19 quickly reveals that the "mealy unit" at Florence cannot be called a reef according to Newell's limitations because stratification is quite evident. Little is known of the lateral extent of this unit because it has been observed in only one part of the quarry. Because of this limitation, it can only be postulated that this structure might have acted as a barrier in mid-Fort Riley time, separating the Junction City and Augusta areas.

The absence of the "mealy unit" at Augusta suggests that the greater thickness at Florence may have acted as a barrier. The "mealy unit" has been identified north of Florence, so something

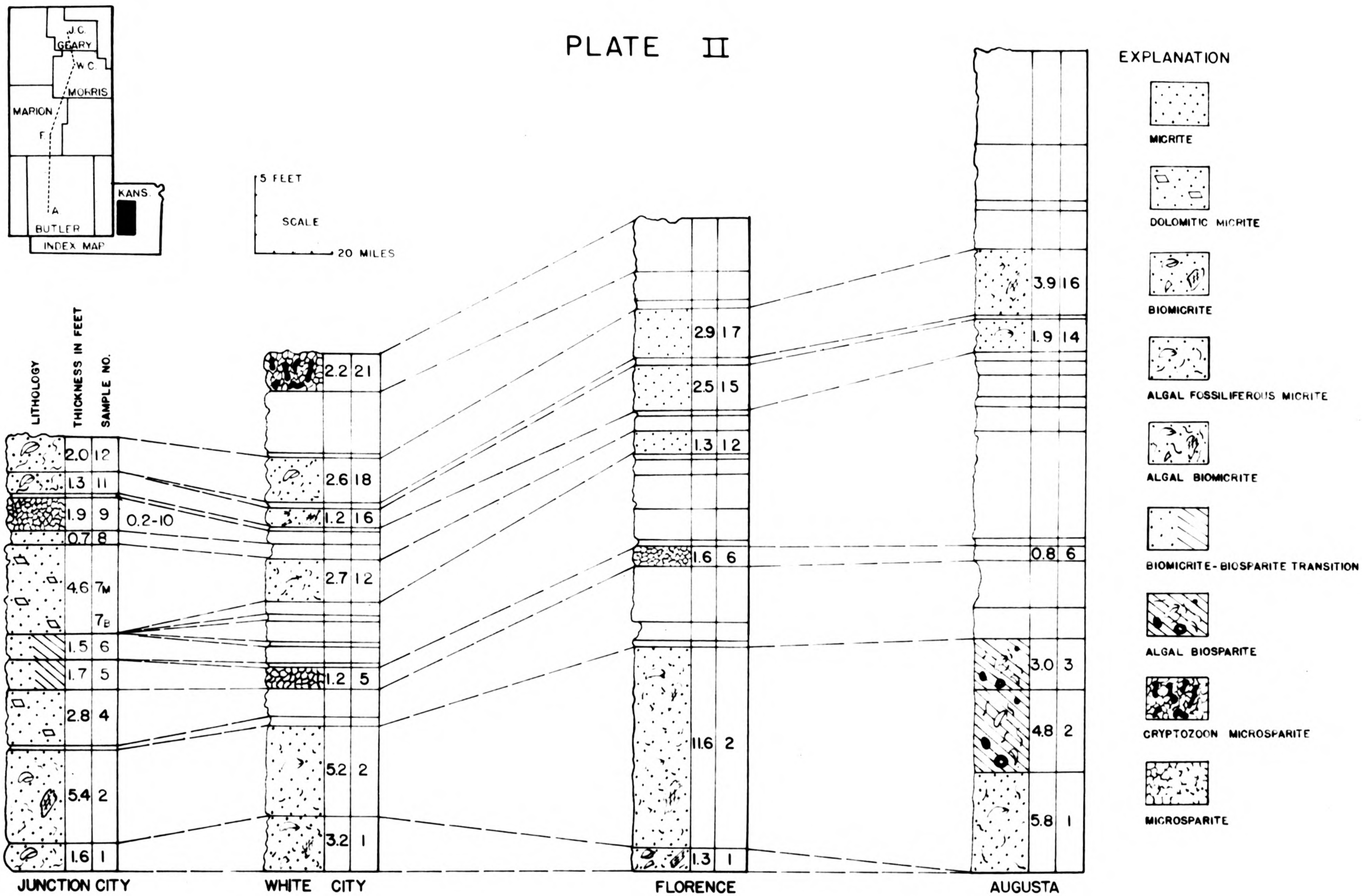
Figure 18. Northward View of "mealy zone" at Florence quarry. NW¼, NW¼, Sec. 32, T14S, R7E, Morris County, Kansas.

Figure 19. Close up, of same thickened "mealy zone" at Florence. The rod is 4½ feet long and is standing on the bottom of the mealy zone (F#8). Looking northward.

EXPLANATION OF PLATE II

Graphic section showing individual units of each of the four quarries. Only units studied in this investigation are numbered and correlated. Lithologic types are those determined by petrographic examination.

PLATE II


J.C.
GEARY
W.C.
MORRIS
MARION
F
A
BUTLER
KANS.
INDEX MAP
5 FEET
SCALE
20 MILES
LITHOLOGY
THICKNESS IN FEET
SAMPLE NO.
0.2-10
JUNCTION CITY
WHITE CITY
FLORENCE
AUGUSTA
EXPLANATION
MICRITE
DOLOMITIC MICRITE
BIOMICRITE
ALGAL FOSSILIFEROUS MICRITE
ALGAL BIOMICRITE
BIOMICRITE-BIOSPARITE TRANSITION
ALGAL BIOSPARITE
CRYPTOZOON MICROSPARITE
MICROSPARITE

must account for the absence of this unit at Augusta. Inasmuch as the thickness of the units decreased to the north of Junction City and thickened to the south, the shoreline during middle Fort Riley time was to the north of Junction City. The geologic setting at Junction City during the deposition of JC 6 was as follows: (1) shoreline to the north, (2) reef-like structure at Florence, and (3) an open basin to the south of Florence. Because Augusta was south of the enclosing reef-like structure a "mealy unit" with burrowing pelecypods could not develop.

Influx of fresh water. If the thickening at Florence is not a reef or in no way acted as barrier between the Junction City and Augusta areas, an alternate theory can account for the near marine conditions at Junction City.

The shallow sea that covered east-central Kansas during Fort Riley time was undoubtedly a retreating sea. Newell (1958, p. 183) states that the Wellington Salt in Kansas (Leonardian in age) and the salt deposits of southwest Texas (Guadalupian in age) are indicative of the progressive migration of the sea to the southwest during Permian time. In a basin occupied by a regressive sea, all parts of the basin would at sometime be subjected to near-shore conditions (providing regression was nearly continuous) and would receive fresh water from inflowing rivers.

Late Fort Riley Time

Any attempt to theorize how long these conditions existed in the Junction City area is beyond the realm of this investigation. Probably, these conditions were terminated by a re-entry of the sea. The laminated limestone units at Junction City (JC 8 and JC 10) may mark the initial part of this transgressive phase.

Units JC 11, WC 16, and A 14 (see Plate II) are peleypod limestones and are composed of micrite and pelecypods (approximately 25 per cent pelecypods). The lack of orientation of the fossils and the dominance of microcrystalline calcite are indicative of a low energy environment. Apparently the last phase of Fort Riley time was a period of calm conditions.

APPLICABILITY OF FOLK'S CLASSIFICATION

One purpose of this investigation was to determine the applicability of Folk's (1959) classification to the Fort Riley Limestone. The Fort Riley is a uniform, microcrystalline limestone in the field and one of the early apprehensions of the author was whether the entire limestone section would be composed of one or two of Folk's limestone types. The early anxiety of the author has since been satisfied; ten distinct litologic units have been recognized in the Fort Riley Limestone.

According to Folk, micrite and spar are indicative of calm and turbulent environments, respectively. This conclusion has been verified many times throughout the investigation. Sparry calcite and algal encrusted fossils are common associates in the Fort Riley; both suggestive of turbulent waters. Likewise, micrite is seldom found with a high percentage of allochems. One important exception is unit WC 16. The genetic importance of micrite and spar are well illustrated by this unit. In the field this unit was described as containing abundant pelecypod shells enclosed in a fine-grained matrix of calcite. The abundance of shells might be attributed to current activity and hence the rock would be the product of a high energy environment. However, petrographic examination revealed that the matrix surrounding the shells was entirely micrite. Inasmuch as micrite precipitation and calm conditions are closely associated, current activity was lacking in this environment.

Of the units examined from the Fort Riley Limestone, three are microsparites and all other units contain microspar. The evidence of recrystallization suggested by Folk, i.e., presence of "ghost fossils" and coarse-grained rocks lacking a supporting framework of allochems was confirmed in this study. Disparity of grain size also indicated recrystallization in most units.

SUMMARY AND CONCLUSIONS

This investigation was instigated in order to describe and analyze the Fort Riley Limestone in East Central Kansas and to determine the environment of deposition. Four quarries were studied and oriented block samples were collected from each limestone unit in the quarries. Later these blocks were cored by the State Highway Commission and discs from the cores were used to make acetate peels and thin sections for petrographic examination. It was found that the acetate peels preserved detail very well but could not replace the thin sections for detailed petrographic work. In several cases identical areas from a thin section and peel were compared and certain discrepancies were found. Areas that seemed to be spar in the acetate peel were found to be clusters of very small micrite grains in the thin section so all point-counting was done on thin sections.

Petrographic examination of the thin sections included identification, percentage determinations, and grain size determinations of the rock constituents. Calcite and dolomite percentages were obtained by X-ray defraction and an attempt was made to obtain comparable results from the thin sections. Staining techniques, outlined by Fairbanks (1952) and Heeger (1913), were used but the results were unsatisfactory. The need for a method to distinguish calcite from dolomite in thin section is very great. A satisfactory ratio of dolomite to calcite can be obtained by crushing the sample and observing the powder under high power while immersed in oil with a refractive index of 1.670. However, this does not permit observation of texture as can be seen in thin section.

Thirty-one units from the four quarries have been classified according to Folk's (1959) classification. The following limestone types have been recognized; algal fossiliferous micrite, algal biomicrite, algal biosparite, micrite, biomicrite, dolomitic micrite, microsparite, dolomite, biomicrite-biosparite transition, and Cryptozoon microsparite. No correlation of units between quarries was possible on the basis of rock constituents alone. The petrographic work did reveal one possible mistake in the field correlations. Initially units JC 11, WC 16, and A 14 had been correlated on the basis of stratigraphic position in the field. However, the close microscopic similarities between

Units JC 11, WC 16, and A 16 suggest that these units rather the previous ones are actually correlative.

The writer has relied rather heavily on algae to establish characteristics of the depositional environment of the Fort Riley Limestone. Green algae (which are quite abundant in the "rimrock") commonly have internal concentrations of dissolved salts twice as great as sea water (Pearse and Gunter, 1957). Algal growth would be favored by a hypersaline medium because equilizing osmotic pressures would exist on the internal and external sides of the plant. The algae seem to indicate a hypersaline environment for Early Fort Riley time.

Water depths during "rimrock" deposition were probably less than 60 feet. Newell and Illing have suggested that such a depth seems to be favorable for algal growth.

An abundance of Osagian encrusted fossils in the "rimrock" suggests that waters were turbulent during the deposition of the lower Fort Riley units. In order for algae to completely encrust the fossils, turbulence was necessary so the fossils could be turned over periodically so that algae could grow on all sides of the fossil nucleus. A high percentage of sparry calcite intermixed with micrite is also indicative of turbulence.

A decrease in the amount of algae in the units overlying the "rimrock" indicates that the salinity changed from hypersaline to more nearly that of sea water. The discovery of a thickened unit (F 12) at Florence has caused speculation on the author's part that the lower salinity was due to enclosure by a reef-like structure. Such a theory definitely needs further evidence and as a result has found little support from people associated with the author.

The pelecypod limestones in the upper part of the Fort Riley section may mark the beginning of a marine transgressive phase. A high percentage of micrite is characteristic of these limestones and probably represents a calm depositional environment.

Diagenesis by replacement, recrystallization, and inversion is common in the Fort Riley Limestone. Non-uniformity of grain-size, "ghost fossils," lack of a supporting framework in rocks of coarse-grained calcite, and crystals of microspar protruding into patches of micrite indicate that recrystallization has been important. Calcareous shells of crinoids and brachiopods have been replaced by spherulites of chalcedony and dolomite has replaced micrite. Pelecypod shells of a mosaic of sparry calcite indicate that aragonite has inverted to calcite.

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PETROLOGY OF THE FORT RILEY LIMESTONE FROM FOUR KANSAS QUARRIES

by

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The purpose of this investigation was to describe and analyze the Fort Riley Limestone in East Central Kansas and to determine the environment of sedimentation. Four quarries were studied and oriented samples were collected from each limestone unit. Acetate peels and thin sections were prepared from each unit and examined to determine mineral composition and texture of the rock.

The units of the Fort Riley Limestone were classified according to Folk's (1959) classification and the following rock types are dominant; (1) algal and fossiliferous micrite, (2) recrystallized microcrystalline calcite (microspar), and (3) secondary dolomite. Correlation of the units of the Fort Riley between quarries was difficult because of the differences in petrography, both laterally and vertically.

Algal encrusted fossils are abundant and have been used as environmental indicators. The gradual decrease in the abundance of algae from the lower units upward, as well as the concurrent increase in burrowing pelecypods, may indicate that the environment changed from hypersaline in Lower Fort Riley time to normal marine in Upper Fort Riley time.