

A PETROGRAPHIC STUDY OF INSOLUBLE RESIDUES FROM  
FOUR FORT RILEY LIMESTONE QUARRIES IN KANSAS

by

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## INTRODUCTION

### Purpose of the Investigation

The purpose of this investigation is to describe the insoluble residue of the Fort Riley limestone in four Kansas quarries. The investigation constitutes one portion of an investigation of soft limestone aggregates by the State Highway Commission of Kansas. Determination of the vertical and lateral variations of the basic mineralogical and physical properties of individual ledges of the Fort Riley limestone is the objective of the phase which includes this investigation. Also of importance in this study is the variation of insoluble residue from quarry to quarry and variation within each quarry both mineralogical and percentage wise.

### Quarries Studied

Selection of four quarries to be used for various studies of the Fort Riley limestone was made on the basis of the completeness of the Fort Riley section and availability of crushed stone for an applied studies phase of investigation.

The location of these quarries are as follows:

NE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec 10, T12S, R5E, Geary County, Kansas (one mile west of Junction City).

NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec 32, T14S, R5E, Morris County, Kansas (two miles east of White City).

NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec 6, T21S, R5E, Marion County, Kansas (one mile northeast of Florence).

SE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec 9, T28S, R4E, Butler County, Kansas (three miles southwest of Augusta).

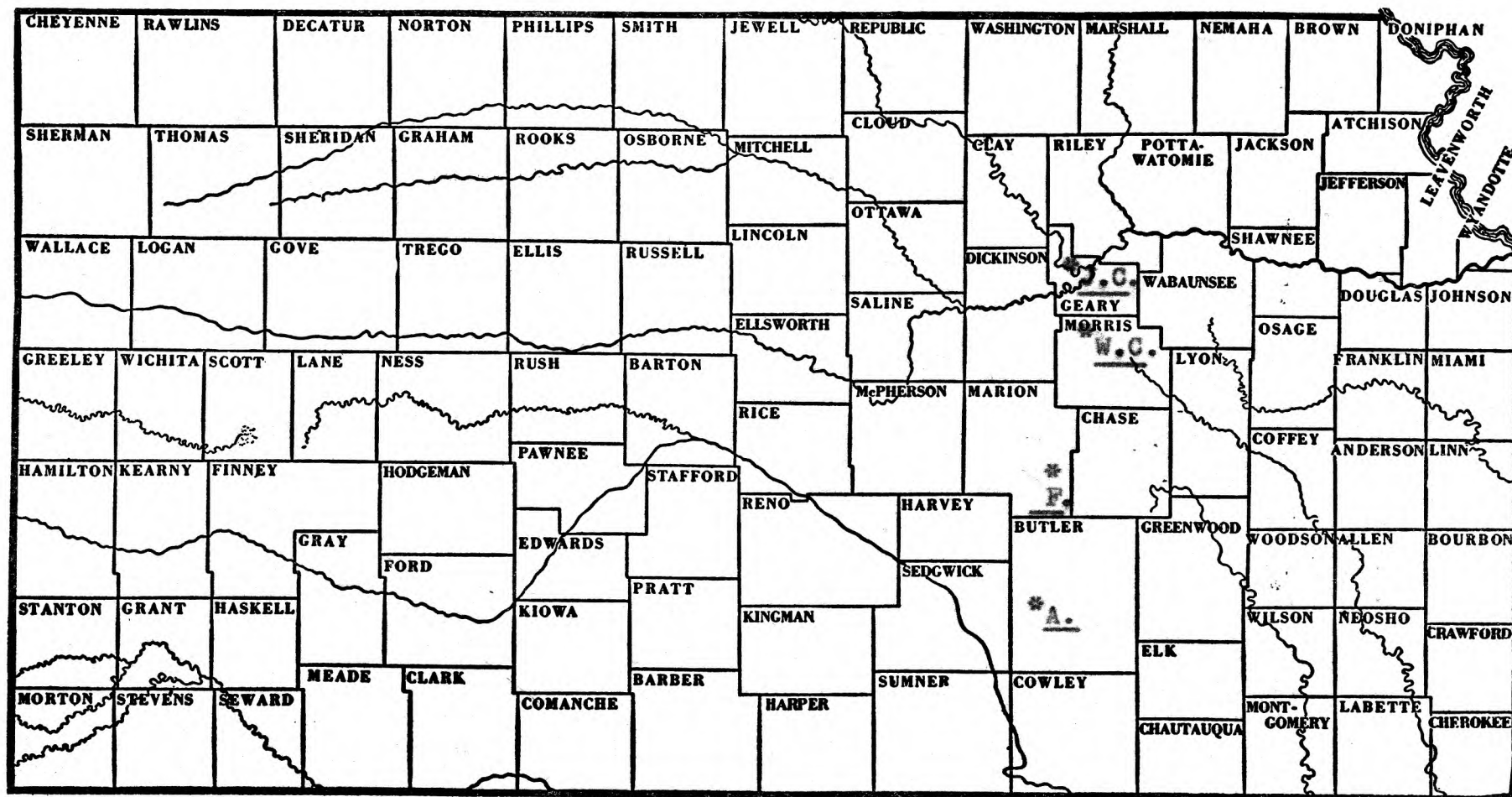
For simplicity these quarries shall be referred to as Junction City or J.C., White City or W.C., Florence or F., and Augusta or A.

Figure 1 gives the approximate location of the quarries sampled and a graphic representation and field correlation between quarries is shown in Plate I.

### General Discussion of the Fort Riley Limestone

The Fort Riley limestone member of the Barneston limestone, Chase group has been placed in the Wolfcampian stage (Jewett, 1959) of the Permian system. The unit was named by Swallow (1866), p. 14. The type locality is at Fort Riley, Geary County, Kansas (Condra and Upp, 1931, p. 42). Prosser (1895), pp. 771-798, described the Fort Riley as including the Florence limestone. The Fort Riley was redefined (Prosser, 1902, p. 714) to include the noncherty units now comprising the Barneston limestone. The Fort Riley limestone and the Florence flint was included in the Barneston limestone when the Barneston was named by Condra and Upp (1931), p. 42. The terminology of the unit was revised by Moore, Elias, and Newell (1934) to include the Fort Riley limestone as the upper member of the Barneston limestone.

The Fort Riley limestone underlies the Holmesville shale member of the Doyle shale and in northern Kansas it overlies the Oketo shale member of the Barneston limestone. In southern Kansas the Oketo shale member is absent and the Fort Riley lies directly on top of the Florence limestone.



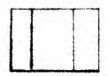
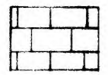
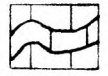
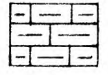
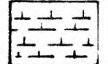
J.C. = Junction City, W.C. = White City, F. = Florence, A. = Augusta.

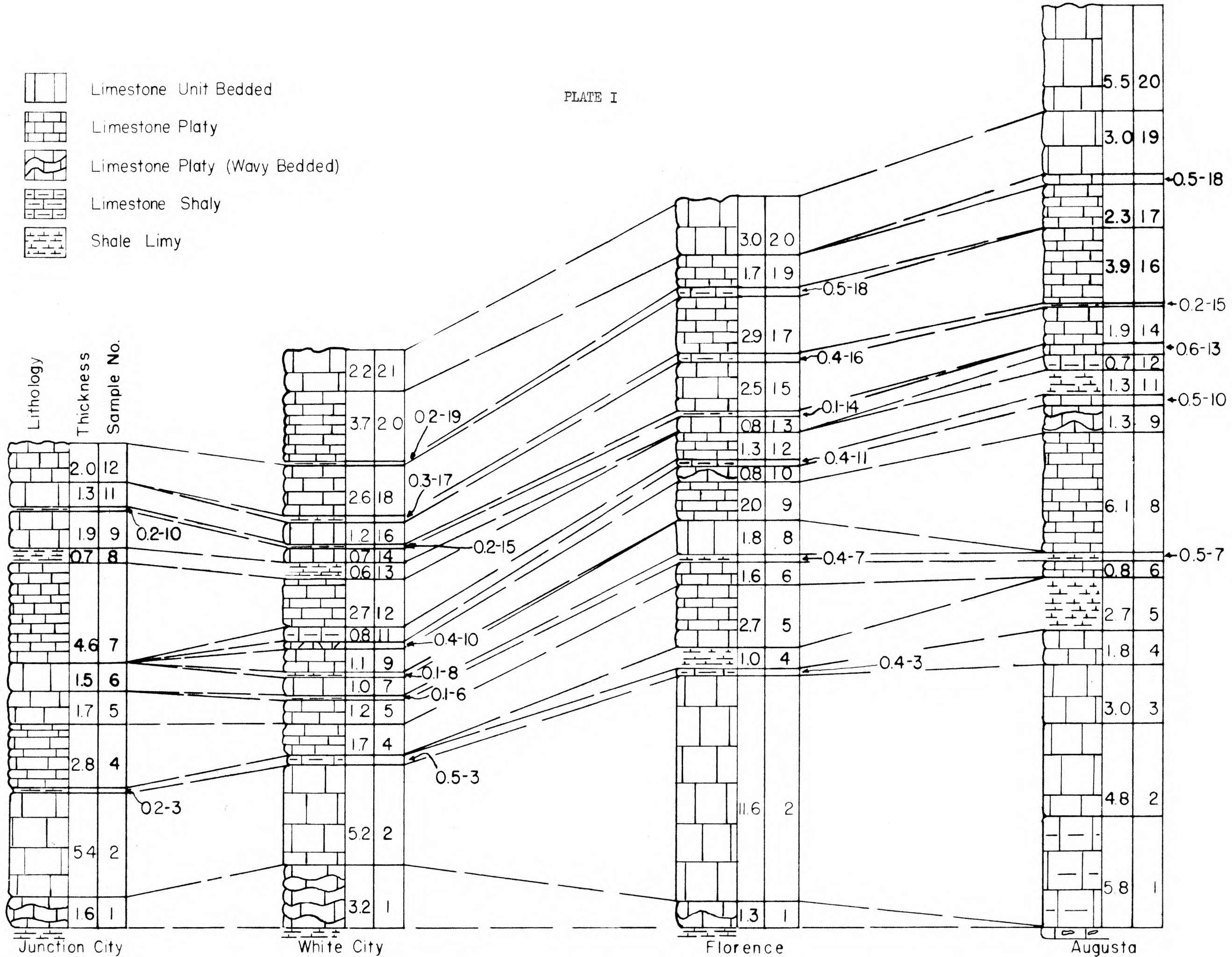
Fig. 1. Index map of Kansas showing approximate location of quarries investigated.

### EXPLANATION OF PLATE I

Graphic sections representing each of the four quarries. Broken lines between sections show correlating zones and corresponding samples.

PLATE I

-  Limestone Unit Bedded
-  Limestone Platy
-  Limestone Platy (Wavy Bedded)
-  Limestone Shaly
-  Shale Limy



Massive and thin-bedded limestone separated by thin partings of calcareous shale characterize the Fort Riley limestone. Two rimrock ledges, one a persistent ledge near the base and another in the upper part occur in most of the outcropping area of the Fort Riley. Local terminology designates the lower ledge as the "upper rimrock". Several other local or lay terms have been attached to certain other zones within the unit. The rimrock is a massive limestone that is especially resistant to weathering and erosion and forms a distinct rim on the shoulders of many hillsides. The rimrock is conspicuous at a distance and shows up as a narrow white line on aerial photographs. The Fort Riley limestone occurs as an extensive dip slope that crops out as a steep escarpment extending from north to south across Kansas. The rimrock ledges are usually the only portions of the unit exposed on natural slopes. The platy zones of the middle and upper part are generally covered by a foot or more of soil.

#### PREVIOUS WORK ON INSOLUBLE RESIDUES

Insoluble residue has been defined as that material remaining after fragments of limestone have been dissolved in acid (Ireland, 1950). Hydrochloric acid is usually used for insoluble residue work. Glacial acetic acid may be used for preservation of fossils or other delicate structures. The unaltered material or residue consists of various forms of silica, feldspars, clay minerals, micas, amphiboles, pyroxenes, several iron oxides, zircon, tourmaline, celestite, and several other less abundant



minerals.

At the present time insoluble residues are used primarily for subsurface correlation purposes by the petroleum industry. Various state highway departments study insoluble residues, mainly the clay minerals, to determine their effect on the engineering properties of limestones used for road building purposes.

Work on insoluble residues has been going on for some 70 years with the publishing of the first paper on the subject by Wethered in 1888 (Ireland, 1936, p. 1087). Laboratory and examination techniques have undergone steady development since that time.

Trager (1920) p. 170, in examining well cuttings, ground the sample fine enough to pass through an 80-mesh screen, measured out a unit volume, dissolved the carbonates in hydrochloric acid, and centrifuged the material in a water medium to separate sand and shale. In the resulting examination the percentages of sand, shale, and carbonates were recorded.

Total insoluble residue was used in an analysis of some Mississippian limestones by Lamar (1926), p. 578-585. He separated the residue into fractions of clay, silt, sand, and oversize. The data were then plotted as graphs indicating constituent percentages in each fraction. Heavy mineral studies were made of the silt- and sand-size fractions.

The content of calcite, dolomite, and magnesite was used by Claypool and Howard (1928), pp. 1147-1152, to classify limestones in well cuttings. The sample was ground and sieved

through an 80-mesh screen and the light, medium, and heavy fractions were separated by centrifuging in liquids of varying specific gravities. Hydrochloric and nitric acid were used to treat each fraction, dissolving the calcite from the light fraction, dolomite from the medium fraction, and magnesite from the heavy fraction. Sand and shale volumes were measured subsequent to removal of calcite from the light fraction.

Merritt (Ireland, 1936, p. 1087) undertook studies of insoluble residues from the Arbuckle limestone in 1928 and from the Simpson formation in 1931. The samples he used were from outcrops in the Arbuckle Mountains of Oklahoma.

McQueen (1931), pp. 102-131, proposed a system of terminology, methods of preparation, and applications of insoluble residues to correlation of carbonate rocks. Dilute hydrochloric acid was used to digest the carbonates from well cuttings. The fine residue was decanted and the coarse residue examined under the binocular microscope to determine diagnostic characteristics. This method has been used with some modification by the United States Geological Survey and by a number of state surveys.

McQueen's methods were used by Ockerman (1931), pp. 42-46, in studies of the Unton and Viola limestone well cuttings from oil wells drilled near Topeka, Kansas. Insoluble residues were used by Martin (Ireland, 1947, p. 1749), in 1931 to correlate Mississippian limestones in Indiana and Kentucky. Mitchell (1935), p. 412, used insoluble residues as a basis for his study of correlation and deposition of some Pennsylvanian limestones in Ohio. Burpee and Wilgus (Ireland, 1936, p. 1087) studied

insoluble residues of Permian rocks in New Mexico in 1936. Ireland (1936), pp. 1086-1121, found insoluble residues a definite criteria for identification of the Hunton and Viola limestones in Oklahoma.

A preliminary study of the insoluble residues of some lower Pennsylvanian limestones in Kansas by Schoewe, Kercher, and Kercher (1937), pp. 269-281, indicated that the insoluble residues are diagnostic of formations and members of formations.

In 1946, Ireland (1947), pp. 1479-1490 called for a conference in Midland, Texas to work on standardization of insoluble residue terminology. The terminology adopted by the conference followed closely that of the Missouri Geological Survey which was proposed by McQueen in his earlier reports.

In some recent work, Wilmoth (1958), p. 181, studied insoluble residues from some Conemaugh limestones in West Virginia. The insoluble residue and light and heavy mineral data indicated that there were enough characteristic ranges in proportions of the principle constituents to aid considerably in distinguishing between several of the Conemaugh limestones.

## METHOD OF INVESTIGATION

### Sampling Procedure

Each quarry was sampled in a vertical column in order to assure uniformity of samples. Rock for each sample was collected by breaking pieces from the entire thickness of each zone.

### Laboratory Procedure

Field samples from each zone were broken down in a laboratory jaw crusher to pass through a four mesh seive. The minus four mesh material was split and 200 grams were retained for insoluble residue studies. The 200 gram fraction was oven dried at 105 degrees centigrade for 24 hours. After drying the material was placed in a one gallon wide mouth laboratory jar and enough distilled water was added to completely cover each sample. The sample was then treated with concentrated hydrochloric acid in 50 ml increments until effervescence had ceased upon addition of fresh acid. After the last portion of acid was added the sample was allowed to stand for 18 hours with frequent swirling to assure digestion of the carbonates.

When the acid treatment had been completed each sample was transferred to a buchner funnel containing a Whitman No. 42 filter paper. A vacuum pump was connected to the filtering flask to facilitate removal of the liquid. Distilled water was used to wash each sample and the filtrate was tested with silver nitrate until all of the free chlorine was removed from the sample. The washed residue was transferred to a drying dish and was allowed to dry for 24 hours in an oven at 105 degrees centigrade.

After drying the insoluble residue was weighed and the percent of insoluble residue calculated. The sample was then sieved through a 270-mesh screen and each sieved fraction was weighed for percentage determination. The plus 270 fraction was

sealed in small storage bottles for heavy mineral separation, examination under the binocular microscope, and for microscope slide preparation.

Heavy mineral separation was carried out on only a few samples. In general, the amount of plus 270 material was too small to make a satisfactory heavy mineral separation.

The apparatus for heavy mineral separation consisted of two steep sided funnels, funnel holder, watch glass, rubber tubing with a pinchcock, and a bottle to collect washing. The procedure was modified from Twenhofel and Tyler (1941), p. 78.

The top or separatory funnel was fitted with a short rubber tube and pinchcock and was placed directly over the second funnel, which contained a filter paper. The collecting bottle was placed below the second funnel. Bromoform (tribromomethane, specific gravity 2.72) was poured into the separatory funnel and was covered with a watch glass to reduce evaporation.

The plus 270 insoluble residue was heated in an oven to remove atmospheric moisture. The presence of such moisture tends to buoy up the mineral grains in the bromoform. Also, grains containing moisture tend to adhere to the side of the funnel. When drying had been completed the material was poured slowly into the bromoform. During the first half hour of separation the bromoform was stirred frequently, then it was allowed to stand for several hours to allow complete settling of the heavy minerals.

Upon completion of settling the pinchcock was released slowly to allow the heavy fraction to pass into the funnel

containing the filter paper. The bromoform passed into the collecting bottle and the heavy minerals were retained on the filter paper.

Ethyl alcohol was used to remove the bromoform from the filter paper and heavy mineral grains. Three washings were sufficient to effect removal. After washing the filter paper was removed and dried in an oven.

A second filter paper was placed in the bottom funnel, and the light fraction was collected in the same manner as the heavy fraction. This last operation completed the separation of the insoluble residue into two groups of differing specific gravity.

A microscope slide of each sample was made using caedax as a mounting medium. Caedax was chosen because of its refractive index (1.54), handling ease, and the speed with which it can be used to make slides. Other mounting mediums may involve a rather lengthy procedure, including one or two heatings. On the other hand caedax may be used directly from the container with no extra preparation.

To assure a clean mounting surface each slide was washed successively in soap and water and alcohol. Drying was accomplished over a bunsen burner. After the slide had been thoroughly cleaned two drops of caedax were placed on the slide by means of a glass dropper. The liquid was allowed to spread without external force for several minutes. A small amount of the plus 270-mesh material was then picked up with a small spatula and sprinkled evenly on the mounting medium. A cover glass was then

placed over the sample and was allowed to settle under its own weight. After a very short settling period the slide was ready for microscope examination.

Two types of microscope examinations were made of each zone sampled. The first examination consisted of a study of the prepared slides under the petrographic microscope. This study consisted of mineral identification, percentage determination of minerals present, and characteristics of the mineral grains. Approximately 200 grains were counted on each slide, using a mechanical stage to assure a systematic traverse. Doubtful identification of some minerals were corrected or confirmed by the oil immersion method in which the refractive indices were determined. In a few isolated cases the x-ray diffraction method was used as an additional identification aid.

The second examination utilized the binocular microscope. The insoluble residue was placed in a small rectangular black cardboard container for binocular microscope study. The prime purpose of this examination was to determine the type of fossils which had undergone silicification.

Carbonate and clay mineralogy studies were carried out by Mr. Carl Crumpton and Mr. William Badgley of the Kansas Highway Commission. Unpublished results of these studies have been made available to the author for use in this thesis. Portions of these investigations are presented in the sections on description of insoluble residues. The x-ray diffraction method was used for carbonate and clay determination.

## ANALYSIS OF THE FORT RILEY LIMESTONE

## Junction City Location

Clay and Carbonate Mineralogy. The most abundant clay mineral in the Junction City section was illite, comprising from 70 to 87 percent of the samples analyzed. In order of descending abundance, the other clay minerals included interlayered chlorite-vermiculite, chlorite, interlayered vermiculite-chlorite, montmorillonite, and vermiculite. Table 1 lists the percentage occurrence of the clay minerals.

Table 1. Percentage of clay mineral constituents in the clay fraction of the Junction City samples. (after Crumpton, 1960).

Sample : number :	Illite	Montmor- illonite	Vermic- ulite	*V-C	*C-V	Chlorite
JC12.	82	*t				15
JC11.	81	t				16
JC10. shale	83	5				12
JC9.	82	5			5	3
JC8. shale	84	t		16		
JC7.	86	t				14
JC6.	87	t	13			
JC5.	80	t		10		10
JC4.	76	t			24	
JC3. shale	79	8			13	
JC2.	72	t			24	
JC1.	70	t			15	15

\* V-C = vermiculite-chlorite interlayer

C-V = chlorite-vermiculite interlayer

t = trace (less than five percent)

Calcite was the predominant carbonate constituent, comprising from 20 to 100 percent of the carbonate fraction. Dolomite constituted from a trace to 80 percent of the carbonate fraction. Table 3 gives the constituent percent of the carbonate fraction.



Table 2. Field description of the Fort Riley limestone section measured in NE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec 10, T12S, R2E, Geary County, Kansas. (Junction City)

Zone :	Description	:Thickness :in feet
12.	Limestone, yellowish tan; porous surface; looks similar to zone 11 but separated from zone 11 by a very thin parting.	2.0
11.	Limestone, yellowish tan; slightly porous and solution pitted; fossiliferous; mealy appearance.	1.3
10.	Shale, calcareous, dark blue to gray in color.	0.2
9.	Limestone, bluish gray; very fine grained; dense and hard; called "dense zone".	1.9
8.	Shale, gray; fine platy bedding.	0.7
7.	Limestone gray to blue gray; very fine grained; contains a few dark horizontal bands.	4.6
6.	Limestone, orange brown; highly fossiliferous; mealy texture, called "mealy zone".	1.5
5.	Limestone, light gray; pelecypod burrows, called "burrow zone".	1.7
4.	Limestone, gray to light gray; unit bedded.	2.8
3.	Shale, calcareous, tan to gray color.	0.2
2.	Limestone, light tan to light gray; unit bedded; slightly porous; pelecypod burrows appear in upper 1.5 feet; commonly referred to as "rimrock".	5.4
1.	Limestone, dark bluish gray weathering to tan gray; platy with curved uneven plates.	1.6
Total Thickness		21.9 feet

Table 3. Percentage of calcite and dolomite in the carbonate fraction of the Junction City samples. (after Crumpton, 1960)

Sample number	Calcite	Dolomite
JC12.	56	44
JC11.	56	44
JC10. shale	20	80
JC9.	94	6
JC8. shale	77	23
JC7.	76	24
JC6.	94	6
JC5.	60	40
JC4.	78	22
JC3. shale	100	*t
JC2.	100	t
JC1.	100	t

\*t = trace (less than one percent)

Insoluble Residue. The percentage of total insoluble residue and plus 270-mesh material is as follows:

Sample number	Total Insoluble Residue	Plus 270 Residue
JC12.	6.6	0.03
JC11.	4.35	0.02
JC10. shale	12.75	0.06
JC9. "dense zone"	8.85	0.01
JC8. shale	23.85	0.02
JC7.	17.51	0.14
JC6. "mealy zone"	6.92	0.02
JC5. "burrow zone"	11.8	0.03
JC4.	7.55	0.04
JC3. shale	6.7	0.16
JC2. "rimrock"	2.88	0.02
JC1.	24.7	0.78

Detrital quartz was present in all zones of the Junction City section. Quartz comprised 36 percent of the plus 270-mesh insoluble residue in zones one and two and as little as three percent in zone seven. The grain size varied from 0.05mm to 0.15mm in diameter with an average of about 0.1mm. Most of

the grains were subangular in shape and a few were subrounded. Rounded grains were not present in the section. Quartz types were described under the classification of Folk and Krynine (Folk, 1959). All grains exhibiting straight extinction were placed in the plutonic or common category of Krynine's genetic classification and all grains exhibiting undulatory extinction or containing microlites, vacuoles, and other inclusions were placed in Folk's empirical classification. The majority of the quartz in the Junction City section were those of the plutonic type. Grains with slightly undulose extinction (empirical, by extinction, type 2) occurred in zones one, five, and 10. Quartz exhibiting strongly undulose extinction (empirical, by extinction, type 3) were present in small amounts in zones 11 and 12. Grains containing inclusions of other minerals (empirical, by inclusion, type 2) occurred in three zones. Zone one contained quartz with abundant rutile needles. Quartz with zircon needles occurred in zones two and three. In addition, zone two contained a few quartz grains with inclusions of short, stubby apatite crystals.

Chert was the major constituent of most samples in the section. Sample JC7 contained the smallest amount of chert (35 percent) and sample JC12 the largest amount (93 percent). Chert was identified by its microcrystalline character and aggregate extinction. The average grain size in the Junction City section was about 0.15mm in diameter. The grains were generally irregular in shape but a few grains were somewhat rounded or roller shaped. A very small amount of brachiopod fragments were silicified in the form of chert or chalcedony.

Table 4. Percentage of mineral constituents in the Junction City samples.

Mineral	JC1	JC2	JC3	JC4	JC5	JC6
<u>Light Minerals</u>						
Quartz	36	36	30	11	6	12
Chert	41	39	69	84	58	47
Chalcedony	*t	t	t		t	t
Opal	t	t	t	t	t	
Glass, Volcanic	t	t	t	t	t	t
Orthoclase	10	13	1	2	1	t
Microcline						
Albit	1	1	t	t		
Oligoclase	1	4	t	1		
Andesine						
<u>Heavy Minerals</u>						
Chlorite	1	t				
Muscovite	10	7	t	2	t	
Biotite						
Hornblende						
Goethite				t	35	41
Hematite	t		t	t		t
Magnetite	t		t			t
Zircon	t	t	t		t	t
Garnet						
Tourmaline	t	t				
Celestite				t	t	
Apatite						
Corundum						
Total	100	100	100	100	100	100

Table 4. (concl.)

Mineral	JC7	JC8	JC9	JC10	JC11	JC12
<u>Light Minerals</u>						
Quartz	3	7	10	8	16	6
Chert	35	87	78	92	81	93
Chalcedony						
Opal	*t	t	t	t	t	t
Glass, Volcanic	t	t	1		t	t
Orthoclase	t		t	t	1	
Microcline						
Albite						
Oligoclase	t		t		1	t
Andesine						
<u>Heavy Minerals</u>						
Chlorite						
Muscovite	t		6		1	1
Biotite				t		
Hornblende						
Goethite	57	t	4	t		
Hematite	5		1	t	t	
Magnetite	t		t		t	t
Zircon		t		t		
Garnet				t		
Tourmaline						
Celestite	t	6			t	
Apatite	t		t	t		
Corundum					t	
Total	100	100	100	100	100	100

\*t = trace (less than three grains)

Sample JC9 contained a few silicified brachiopod fragments and sample JC10 contained a relatively abundant amount of fragments.

Chalcedony, a fibrous form of chert, was present in traces in five samples. The chalcedony was characterized by a fibrous or radial fibrous appearance. Under crossed nichols the grains exhibited extremely undulatory or radial extinction. Grain size averaged about 0.1mm in diameter and grain shape was irregular.

Opal occurred as a trace in every sample except JC6. Opal may be confused with volcanic ash if care is not taken in examination. Glass may be differentiated from opal mainly by the difference in index of refraction and grain characteristics. Glass grains are usually quite angular in shape and usually have a lower index of refraction. Opal grains frequently exhibit shrinkage cracks caused by a loss of water. The opal in the Junction City section was usually irregular in shape with a few grains tending to be subhedral. Grain size was about 0.12mm in diameter. Many of the grains had shrinkage cracks and were recrystallizing to quartz around their outer edges. Much of the opal in this section had a faint green color.

Volcanic glass occurred in all samples except JC10. Glass comprised one percent of zone nine and occurred as a trace in the remainder of the zones. Grain size ranged from 0.02mm to 0.15mm in diameter. The most common occurrence of glass was in shard form.

Orthoclase was the most abundant feldspar in the section comprising a trace of the plus 270 residue in four zones and as

much as 13 percent of zone two. All but a very small amount of the orthoclase was detrital in origin. Authigenic feldspar, having the same general optical properties as orthoclase was counted as orthoclase. The detrital grains varied from 0.07mm to 0.5mm in diameter with an average grain size of about 0.11mm. The majority of the grains were subangular in shape and a few were subrounded. Authigenic feldspar occurred as a trace in zones one, two, four, five, and six. The authigenic grains averaged about 0.15mm in diameter and ranged from irregular to sub-equant in shape, showing no effects of transportation.

Other feldspars present were the plagioclases, albite and oligoclase. Albite comprised one percent of zones one and two and occurred as a trace in zones three and four. Oligoclase was present in eight zones in amounts ranging from a trace to four percent. The grains of both minerals averaged about 0.09mm in diameter and were subangular to subrounded in shape.

Goethite was the most abundant heavy mineral, occurring in seven zones in amounts ranging from a trace to 57 percent of the plus 270 residue. Zones five, six, and seven were comprised of 35, 41, and 57 percent goethite respectively. The goethite occurred as irregularly shaped grains ranging from 0.1mm to 0.6mm in diameter.

Hematite occurred as a trace in six zones and comprised one percent of zone nine and five percent of zone seven. The grains varied from 0.15mm to 0.6mm in diameter. Grain shape was elongate, rounded, and irregular. Magnetite occurred as a trace in seven samples. The magnetite grains were subequant to

irregular in shape and averaged about 0.12mm in diameter.

Muscovite was present in nine zones in amounts up to 10 percent of the sample. The muscovite grains averaged 0.12mm in diameter and were subrounded in shape. Zones one and two contained muscovite grains with inclusion of tourmaline and needles of zircon. In one grain the zircon needles were oriented subparallel to one another. Another grain was encountered in which one tourmaline inclusion was in the process of being released from the grain. A grain of biotite was found in zone 10. The grain was elongate and subangular, and exhibited pleochroic haloes. Chlorite comprised one percent of zone one and a trace of zone 10. The chlorite grains were massive and irregular in shape and averaged 0.1mm in diameter.

Zircon occurred as traces in seven zones. The zircon was needle shaped with the grains having a length of 0.02mm to 0.03mm. Tabular shaped tourmaline was encountered in zones one and two. The grains were 0.4mm long and showed only a small amount of rounding. Garnet occurred as a single grain in one sample. Apatite was found in three samples in trace amounts.

Celestite comprised six percent of sample JC8 and was found in trace amounts in four other samples. The celestite occurred as tabular shaped grains about 0.13mm in diameter. Most of the grains were highly corroded.



## White City Location

Clay and Carbonate Mineralogy. The most abundant clay mineral in the White City section was illite, comprising the greatest percentage of all but one sample (Table 5). Significant amounts of montmorillonite were present in the upper and lower portions of the section, while the middle portion contained only traces of montmorillonite. Vermiculite also occurred in the lower and upper part of the section and was absent in the middle. The middle part of the section was characterized by a significant amount of interlayered chlorite-vermiculite and chlorite. Interlayered vermiculite-chlorite was present in only one sample.

Table 5. Percentage of clay mineral constituents in the clay fraction of the White City samples. (after Crumpton, 1960)

Sample number	Illite	Montmorillonite	Vermiculite	*V-C	*C-V	Chlorite
WC21.	57	32	11			
WC20.	37	42		21		
WC19.	60	8	16			
WC18.	69	20	11			
WC17. shale	80	8	12			
WC16.	79	5	16			
WC15. shale	87	*t	13			
WC14.	73	t			27	
WC13. shale	93	t			7	
WC12.	86	t			5	9
WC11.	82	t			10	8
WC10.	81	t			9	10
WC9.	88	t			6	6
WC8. shale	75	t			15	10
WC7.	93	t			7	
WC6. shale	90	t			10	
WC5.	58	18			24	
WC4.	50	24	26			
WC3.	70	14	16			

Table 5. (concl.)

Sample number :	Illite	Montmorillonite	Vermiculite	*V-C	*C-V	Chlorite
WC2.	54	7	39			
WC1.	73	*t			27	

\*t = trace (less than five percent)

V-C = Vermiculite-chlorite interlayer

C-V = Chlorite-vermiculite interlayer

Of the carbonate minerals, calcite was the most predominate throughout the section (Table 6). Dolomite occurred in significant amounts in the middle of the section and as traces in the remainder of the section.

Table 6. Percentage of calcite and dolomite in the carbonate fraction of the White City samples. (after Crumpton, 1960)

Sample number :	Calcite	Dolomite
WC21.	100	*t
WC20.	100	t
WC19.	100	t
WC18.	100	t
WC17. shale	100	t
WC16.	97	3
WC15. shale	100	t
WC14.	98	2
WC13. shale	75	25
WC12.	81	19
WC11.	98	2
WC10.	97	3
WC9.	96	4
WC8. shale	94	6
WC7.	100	t
WC6. shale	100	t
WC5.	100	t
WC4.	100	t
WC3.	100	t
WC2.	100	t
WC1.	100	t

\*t = trace (less than one percent)

Table 7. Field description for the Fort Riley limestone section measured in NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec 32, T14S, R7E, Morris County, Kansas. (White City)

Zone :	Description	: Thickness : in feet
21.	Limestone, light gray; unit bedded; very hard; weathers with a highly porous almost mealy appearing surface.	2.2
20.	Limestone, yellowish tan, many small black specks on surface of fresh fracture; finely porous.	3.7
19.	Limestone, brown; intensely weathered and iron stained; pitted surface.	0.2
18.	Limestone, gray to tan gray; fine grained.	2.6
17.	Shale, calcareous, gray	0.3
16.	Limestone, gray to yellow gray, weathers tan; highly fossiliferous, abundant small pelecypods stand out in relief on fractured surfaces.	1.2
15.	Shale, calcareous, gray color.	0.2
14.	Limestone, gray; very fine grained; dense and hard. "dense zone"	0.7
13.	Shale, calcareous, gray; platy.	0.6
12.	Limestone, bluish gray, weathers light blue gray; very fine grained.	2.7
11.	Limestone, argillaceous, bluish gray, weathers gray.	0.8
10.	Limestone, dark blue gray, weathers gray; nodular uneven surface. "nodular zone"	0.4
9.	Limestone, dark blue gray, weathers light blue gray; very fine grained.	1.1
8.	Shale, calcareous, dark blue gray, weathers gray.	0.1
7.	Limestone, gray brown, weathers orange brown; highly fossiliferous; mealy texture. "mealy zone"	1.0

Table 7. (concl.)

Zone :	Description	: Thickness : in feet
6.	Shale, calcareous, gray color.	0.1
5.	Limestone, light gray, weathers nearly white; unit bedded; numerous pelecypod burrows. "burrow zone"	1.2
4.	Limestone, light gray, weathering to a yellowish tan; unit bedded.	1.7
3.	Limestone, argillaceous, gray; separated from zones above and below by thin stylitic partings.	0.5
2.	Limestone, light gray, stained tan; unit bedded; upper two feet contains pelecypod burrows. "rimrock"	5.2
1.	Limestone, tan brown color; platy.	3.2
Total Thickness		30.7 feet

Insoluble Residue. The percent of total insoluble residue and plus 270-mesh residue is given as follows:

<u>Sample number</u>	<u>Total Insoluble Residue</u>	<u>Plus 270 Residue</u>
WC21.	0.99	0.01
WC20.	3.25	0.03
WC19.	4.58	0.03
WC18.	9.46	0.02
WC17. shale	26.48	0.03
WC16.	5.78	0.02
WC15. shale	22.27	0.06
WC14. "dense zone"	8.3	0.02
WC13. shale	25.18	0.05
WC12.	18.71	0.04
WC11.	19.09	0.05
WC10. "nodular zone"	9.58	0.01
WC9.	15.36	0.03
WC8. shale	35.45	0.09
WC7. "mealy zone"	10.71	0.02
WC6. shale	19.85	0.24
WC5. "burrow zone"	5.94	0.02
WC4.	5.11	0.05
WC3.	12.57	0.41
WC2. "rimrock"	3.25	0.03
WC1.	20.14	1.6

Quartz was present in every sample of the White City section (Table 8). The mineral comprised as little as two percent of the plus 270-mesh material in one sample and as much as 71 percent in another. Quartz was more abundant in the seven lower most zones than in the rest of the section. The size of the quartz grains ranged from slightly less than 0.01mm to 0.4mm in diameter. Zones 12, 15, 17, 19, and 20 contained an abundance of grains in the minus 0.03mm range. The largest grains (0.4mm) were found in zone 11. The average grain size throughout the section was about 0.1mm in diameter. Grain shape was quite varied, ranging from rounded to subangular. Rounded grains were relatively abundant in samples WC9 and WC10 but were sparse in the remainder of the



Table 8. (concl.)

Mineral	:WC11:	:WC12:	:WC13:	:WC14:	:WC15:	:WC16:	:WC17:	:WC18:	:WC19:	:WC20:	:WC21:
<u>Light Minerals</u>											
Quartz	7	6	3	10	3	9	9	2	4	6	19
Chert	55	93	93	89	96	81	91	98	80	94	81
Chalcedony											
Opal	*t	t	t	t	t	1	t	t	t	t	t
Glass, Volcanic	t	t	t			t	t			t	t
Orthoclase		t		t	t	3		t		t	t
Microcline						2			t	t	
Albite											
Oligoclase				t	t					t	t
Andesine											
<u>Heavy Minerals</u>											
Chlorite					t	t					
Muscovite		1		t		3	t	t	t		
Biotite				t							
Hornblende										t	
Goethite	32	t	3	t		1			16		
Hematite					1			t	t		
Magnetite	2			t	t	t				t	t
Zircon					t				t	t	
Garnet											
Tourmaline							t				
Celestite	4		1	1	t	t		t	t		t
Apatite			t			t			t		
Corundum						t					t
Total	100	100	100	100	100	100	100	100	100	100	100

\*t = trace (less than three grains)

section. Most of the grains in the section were subrounded. Grains less than 0.1mm in diameter were frequently subangular in shape. Several quartz types were encountered in the samples, the most predominant being the plutonic or common variety. The common quartz exhibited straight extinction under the microscope and contained few vacuoles. Quartz with slightly undulose extinction was present in zones five, 16, and 20. Zone 21 contained grains with strong undulatory extinction. Samples WC1, WC5, and WC16 contained quartz with abundant inclusion of zircon needles. Quartz with apatite inclusions was present in zone three. Sample WC21 contained one or two quartz grains with secondary overgrowths of silica.

The most abundant constituent of the White City section was chert. This form of silica was found in amounts ranging from 12 to 98 percent of the samples examined. Chert comprised over 50 percent of all samples except WC1. The upper 10 zones were composed of more than 80 percent chert. Grain size varied from 0.05mm up to 0.3mm in diameter. The average grain size was about 0.15mm in diameter. Most of the grains were slightly rounded in shape with irregular shaped grains occurring frequently. Brachiopod fragments, silicified in the form of chert, were very sparsely scattered in the section. Fragments of silicified foraminifera tests were found in sample WC9.

The hydrated form of silica, opal, occurred persistently throughout the section. Opal was present as a trace in 15 samples and constituted one percent of sample WC16. Grain size was generally less than 0.06mm except in sample C16 which



contained opal up to 0.23mm in diameter. Some of the grains were sub-equant but the majority exhibited irregular shapes. Recrystallization of opal to quartz occurred very infrequently. A few of the grains seemed to be reverting to quartz or chalcedony on their outside edges.

Volcanic glass also occurred persistently in the section. Traces of glass were found in 14 zones. Grain size was generally less than 0.05mm. The majority of the grains were angular in shape with shards being quite common in all samples.

Orthoclase was the most abundant feldspar in the White City section. Of the 21 samples examined, 15 contained orthoclase. The amount of orthoclase present varied from a trace in seven samples to 14 percent of the insoluble residue from zone one. Grain size varied from 0.05mm to 0.15mm in diameter with an average grain size of about 0.1mm. Most of the grains were sub-rounded in shape. A minor number of grains exhibited little surface alteration.

Other feldspars present were microcline and the plagioclases, albite, oligoclase, and andesine. Microcline occurred as a trace in zones six, 19, and 20 and comprised two percent of zone 16. The microcline grains averaged 0.1mm in diameter and were subangular in shape. Albite constituted one percent of sample WC1 and occurred as a trace in samples WC5 and WC8. Grains of albite were subrounded and averaged 0.08mm in diameter. Oligoclase comprised one percent of sample WC6, three percent of WC2, and occurred as a trace in eight other samples. Oligoclase

grain shape was subrounded. Andesine occurred as a trace in zone one, having a size of 0.08mm and a subangular shape.

Iron oxides were the most abundant minerals in the heavy fraction. Goethite occurred as a trace in five zones and made up from one to 32 percent of four other zones. The goethite grains varied from 0.07mm to 0.5mm in diameter and occurred primarily in irregular shapes. Zone 19 contained an abundance of rounded goethite grains. Hematite was present as a trace in six zones. Zone 15 contained one percent hematite, zone nine contained five percent, and zone 10 contained 12 percent hematite. The average grain size was about 0.15mm in diameter and the grains were irregularly shaped. Magnetite was present as a trace in eight zones and comprised from two to 22 percent of the insoluble residue in four other zones. Most of the magnetite had a subrounded shape and occurred in sizes averaging about 0.15mm in diameter.

Muscovite was a rather persistently occurring mica. The mineral was present in sixteen zones in amounts ranging from a trace to three percent. Most of the muscovite was sub-equant in shape and averaged about 0.1mm in diameter. Another mica, biotite, occurred as a trace in zone 14 and was absent in the remainder of the section.

Zircon needles averaging about 0.03mm in length were present as traces in six zones. Tabular shaped tourmaline occurred as a trace in six samples. The average size of the tourmaline grains was about 0.03mm. Apatite was present in trace amounts in seven zones. The apatite grains occurred as stubby,

rounded prisms averaging about 0.02mm in length. Zones 16 and 21 contained subrounded grains of corundum with a grain size of about 0.07mm.

Traces of celestite were found in six zones of the section. Zones seven, 10, 13, and 14 contained one percent celestite and zone 11 contained four percent celestite. The celestite grains varied from 0.05mm to 0.2mm in diameter. The average grain size was about 0.12mm. Most of the grains were tabular shaped and a small amount of grains were subrounded. The tabular grains were highly corroded and the subrounded grains were generally free of surface alteration.

## Florence Location

Clay and Carbonate Mineralogy. Illite is the most abundant clay mineral in the Florence quarry (Table 9). Also present in descending order of abundance are interlayered chlorite-vermiculite, vermiculite, interlayered vermiculite-chlorite, chlorite, and a very minor amount of montmorillonite.

Table 9. Percentage of clay mineral constituents in the clay fraction Florence samples. (after Crumpton, 1960)

Sample number :	Illite	Montmorillonite	Vermiculite	*V-C	C-V	Chlorite
F20.	88	*t				12
F19.	71	5				24
F18. shale	80	t		20		
F17.	84	t		16		
F16.	82	t	18			
F15.	79	t		15		
F14. shale	75	t		25		
F13.	80	t		20		
F12.	79	t		21		
F11. shale	87	t	13			
F10.	73	t		27		
F9.	83	t	17			
F8.	86	t		14		
F7. shale	89	t		11		
F6.	61	t			36	
F5.	71	t			14	15
F4. shale	71	t	29			
F3.	78	t			22	
F2.	77	t		23		
F1.	64	t	36			

\*V-C = Vermiculite-chlorite interlayer

C-V = Chlorite-vermiculite interlayer

t = trace (less than five percent)

In the lower part of the section calcite is the most predominant carbonate (Table 11). Dolomite appears in a significant amount in the middle of the section and increases to 100 percent of the carbonate fraction in the two upper most zones (F19 and

Table 10. Field description of the Fort Riley limestone section measured in SE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec 6 T21S, Marion County, Kansas. (Florence)

Zone :	Description	: Thickness : in feet
20.	Limestone, gray to blue gray, weathers light gray; contains many cavities and solution pits.	3.0
19.	Limestone, gray to blue gray; contains some solution pits.	1.7
18.	Shale, calcareous, gray color; platy.	0.5
17.	Limestone, gray; very fine grained.	2.9
16.	Limestone, argillaceous, gray; very fine grained.	0.4
15.	Limestone, gray color; very fine grained.	2.9
14.	Shale, calcareous, brown; iron stained; much solution.	0.1
13.	Limestone, gray; very fine grained; hard and dense. "dense zone".	0.8
12.	Limestone, gray; very fine grained.	1.3
11.	Shale, calcareous, gray to brown color.	0.4
10.	Limestone, gray; nodular, breaks with curved irregular nodular surface. "nodular zone"	0.8
9.	Limestone, gray color; very fine grained.	2.0
8.	Limestone, gray to tan brown, weathers orange brown; contains bands and streaks of small brown fossils giving an overall mealy texture. "mealy zone"	1.8
7.	Shale, gray with several thin brown horizontal streaks and bands of very small fossils.	0.4
6.	Limestone, yellow gray to light gray; contains abundant pelecypod burrows. "burrow zone"	1.6

Table 10. (concl.)

Zone :	Description	: Thickness : in feet
5.	Limestone, dark gray to gray, weathers tan; contains a few horizontal dark gray streaks; unit breaks into several thin beds ranging from 0.2 to 0.7 feet in thickness.	2.7
4.	Shale, calcareous, tan, weathers to a yellow tan; fossiliferous.	1.0
3.	Limestone, argillaceous, tan to gray color; abundant fossils including large brachiopods.	0.4
2.	Limestone, light gray; horizontal carbonaceous partings and styolytic seams are present; fossiliferous; pelecypod burrows occur in upper four feet. "rimrock".	11.6
1.	Limestone, dark blue color; fine grained; fossiliferous, fossils show an orange or brown color on fresh exposure.	1.3
Total Thickness		37.2 feet

Table 11. Percentage of calcite and dolomite in the carbonate fraction of the Florence samples (after Crumpton, 1960)

Sample number	Calcite	Dolomite
F20.	*t	100
F19.	t	100
F18.	59	41
F17.	57	43
F16.	75	25
F15.	84	16
F14. shale	90	10
F13.	87	13
F12.	82	18
F11. shale	89	11
F10.	96	4
F9.	90	10
F8.	98	t
F7. shale	98	t
F6.	98	t
F5.	100	t
F4. shale	100	t
F3.	98	t
F2.	100	t
F1.	98	t

\*t = trace (less than two percent)

F20).

Insoluble Residue. Total insoluble residue percentage and percentage of plus 270 mesh material in the Florence samples is as follows:

Sample number	Total Insoluble Residue	Plus 270 Residue
F20.	7.0	0.02
F19.	10.5	0.03
F18. shale	23.7	0.04
F17.	17.2	0.06
F16.	14.9	0.04
F15.	15.6	0.04
F14. shale	9.1	0.11
F13. "dense zone"	11.2	0.03
F12.	17.2	0.02
F11. shale	17.3	0.01
F10. "nodular zone"	7.2	0.03

<u>Sample number</u>		<u>Total Insoluble Residue</u>	<u>Plus 270 Residue</u>
F9.		18.4	0.02
F8.	"mealy zone"	5.5	0.94
F7.	shale	32.7	0.2
F6.	"burrow zone"	9.4	0.02
F5.		9.6	0.13
F4.	shale	38.4	0.48
F3.		12.2	0.69
F2.	"rimrock"	5.1	0.7
F1.		28.7	0.8

In general the plus 270-mesh material decreases in amount in the middle and upper zones of the section. Zone six is the only significant exception, possibly due to the great number of burrows in that zone (Table 10).

The most predominant light minerals in this set of samples were chert and quartz (Table 12). In the lower half of the section quartz was relatively abundant but the upper nine zones contain only small percentages of quartz. Grain sizes ranged from 0.03mm to 0.15mm in diameter with an average grain size in most samples of 0.1mm. Zones one and two contained a great abundance of grains in the minus 0.005mm size range. The shape of the detrital quartz varied only slightly. In general, grain shape can be correlated with grain size. Grains under 0.1mm in diameter were usually subangular and those over 0.1mm were subrounded. Deviations from this rule were not uncommon however. A number of quartz types were encountered with the most abundant being the common or plutonic type showing straight extinction. Minor amounts of quartz exhibiting slightly undulose extinction were found in zones 18 and 20. Strongly undulose quartz was absent. Quartz containing abundant microlites and vacuoles was found in zone three. Zone four contained a few





Table 12. (concl.)

Mineral	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
<u>Light Minerals</u>										
Quartz	10	5	5	5	2	1	1	1	2	5
Chert	82	52	94	85	98	89	96	84	98	98
Opal	1	t	t		t	t			t	1
Glass, Volcanic	1	t	t	t	t	t	t	1		1
Orthoclase	*t	1						1		1
Microcline						t				
Albite										
Oligoclase										
Chalcedony	t	t			t				t	
<u>Heavy Minerals</u>										
Chlorite		t								t
Muscovite	t	t					1	t	t	1
Biotite	t									
Hornblende										
Goethite	2	41	t				1			
Hematite										t
Magnetite			t		t		t	t	t	
Ilmenite					t					
Zircon					t				t	t
Garnet										
Tourmaline						t				
Celestite		1	t	15		10	1	15		
Apatite										
Total	100	100	100	100	100	100	100	100	100	100

\*t = trace (3 grains or less)

quartz grains with microlites only. Quartz containing tourmaline inclusions occurred in zones two and 15. In addition, zone 15 contained quartz with inclusions of zircon needles. Quartz with a secondary overgrowth was present in zone 14.

Chert was the most abundant constituent throughout the entire Florence section. The lower half of the section contained from five to 88 percent chert in each sample. Upper zones contained extremely high percentages, ranging from 52 to 98 percent. The chert grains ranged in size from 0.05mm to 0.3mm in diameter. The majority of the grains were rounded. Some grains were irregular, tabular, elongated, and roller shaped. Zone 13 contained an unusually large number of roller shaped grains. Most of the chert was rather massive but a few grains with a fibrous appearance were scattered about the section. These fibrous grains probably represent silicified brachiopod fragments. Examination under the binocular microscope indicated that silicification of brachiopod fragments was frequent throughout the section. Several samples, especially zones eight, 13, and 19, contained silicified tests of foraminifera. Samples F11, F12, and F13 contained chert grains with inclusions of calcite and some elongate apatite (?) grains. None of the apatite (?) grains could be isolated so positive identification was not possible. An organic origin might be postulated for such an occurrence of apatite.

Chalcedony was present in amounts ranging from a trace to 49 percent. Grains averaged about 0.2mm in diameter and were characterized by fibrous and radial structure with extremely

undulatory extinction.

Opal was present in 13 samples. Only three zones contained more than a trace of opal. The opal grains were generally less than 0.05mm in diameter. Most of the grains were irregular in shape with only a few being somewhat rounded. A very small number of the opal grains were partially recrystallized to chalcedony and quartz.

Volcanic glass occurred in all samples except zone 19. Zones five, 10, 11, 12, 18, and 20 contained glass in relative abundance (more than three grains). The size of the glass grains was usually less than 0.03mm in diameter. Sample F16 had several grains with a diameter of 0.1mm. Nearly all of the grains were quite angular in appearance, commonly occurring as shards.

The feldspars occurred in all but four zones of the section. Orthoclase was the most abundant, comprising from slightly more than a trace in zone 15 to 45 percent in zone three. The lower half of the section contained most of the orthoclase. The mineral occurred as subangular to subrounded grains ranging from 0.06mm to 0.7mm in diameter. Grains in the 0.7mm range were thought to be authigenic feldspars, occurring in all zones from one to eight, and zones 10, 12, 15, and 20. Authigenic feldspar occurred in nearly all samples which contained chalcedony. The average grain size was about 0.1mm. Most of the detrital grains were free of surface alteration. Microcline occurred as traces in only three samples: F3, F7, and F16. The plagioclases, albite and oligoclase, were present in small amounts. Traces of albite

occurred in zones four and six while two percent of zone one was made up of albite. Albite grains were subrounded and averaged 0.09mm in diameter. Oligoclase comprised six percent of sample F2 and two percent of F3. The mineral occurred as a trace in zones one and 10, and four grains were counted in zone 15. The oligoclase grains were subrounded and averaged 0.1mm in diameter.

The heavy minerals were characterized mainly by an abundance of iron minerals, muscovite, and celestite. Goethite occurred in significant amounts in seven zones and as a trace in three additional zones. Zones eight, nine, 10, 11, 12, and 13 contained from two to 41 percent goethite. Sample F9 contained an abundance of goethite grains with an elongated tabular shape. In all other samples the grains were mostly irregularly shaped. Grain size varied from 0.07mm to 0.25mm in diameter with an average size of about 0.09mm. Most of the grains were subequant in shape.

Muscovite appeared quite consistently throughout the section. Of the samples containing muscovite, eight contained only traces while eight other samples were made up of one to 11 percent muscovite. The grains ranged from 0.01mm to 0.25mm in diameter with an average size of about 0.09mm. Most of the grains were subequant in shape.

Biotite occurred as a trace in zone eleven. The grain size was 0.01mm in diameter and the shape was subrounded. Chlorite was relatively abundant in two zones (F1 and F5) and was present as traces in zones four, six, 12, and 20. The chlorite occurred as massive, irregular shaped grains about 0.5mm

in diameter. A trace of hornblende was found in zone six.

Zircon was present as traces in seven samples and was relatively abundant in samples F5 and F8. The zircon occurred most commonly as small needles about 0.008mm long. A trace of tabular shaped tourmaline was found in six zones. Samples F5 and F6 contained a trace of garnet. Apatite occurred as a trace in zones one and two.

Celestite occurred in 11 zones of the Florence section. It was present in amounts ranging from a trace to 15 percent. The grain size ranged from slightly less than 0.1mm to 0.8mm in diameter. The average grain size was about 0.15mm. The grains were rather elongate with corroded edges and a few grains were somewhat rounded. The elongate grains had a corroded surface as well as the edges. The rounded grains were clear with a smooth surface.

## Augusta Location

Clay and Carbonate Mineralogy. Illite was the most abundant clay mineral in the Augusta section, appearing in all samples in amounts ranging from 53 to 88 percent (Table 13). Also present in order of descending abundance were interlayered vermiculite-chlorite, vermiculite, chlorite, interlayered chlorite-vermiculite, and montmorillonite.

Table 13. Percentage of clay mineral constituents in the clay fraction of the Augusta samples. (after Crumpton, 1960)

Sample number	Illite	Montmorillonite	Vermiculite	*V-C	*C-V	Chlorite
A20.	69	11		20		
A19.	58	13		29		
A18.	53	20	27			
A17.	59	*t		41		
A16.	62	t	38			
A15. shale	78	t	22			
A14.	74	t	26			
A13.	72	t		28		
A12.	67	t		33		
A11. shale	87	t				13
A10.	67	t	33			
A9.	74	t	26			
A8.	83	t				17
A7. shale	87	t				13
A6.	88	t				12
A5. shale	87	t				13
A4.	79	t			21	
A3.	67	t		33		
A2.	71	t			29	
A1.	88	t				12

\*V-C = Vermiculite-chlorite interlayer

C-V = Chlorite-vermiculite interlayer

t = trace (less than five percent)

Table 14. Field description of the Fort Riley limestone section measured in SE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec 9, T8S, R4E, Butler County, Kansas. (Augusta)

Zone	Description	Thickness : in feet
20.	Limestone, tan, weathers brown; highly porous with small pores; fossiliferous.	5.5
19.	Limestone, gray to cream color, yellow to to orange mottling; weathers light gray; unit bedded; fossiliferous; weathered surface shows many small pores.	3.0
18.	Limestone, gray with brown mottling, weathers yellowish tan.	0.5
17.	Limestone, gray, weathers tan, separates into five units of equal thickness; highly fossiliferous; has a "mealy" appearance in places.	2.3
16.	Limestone, gray to light gray, weathers to yellowish tan; platy; fossiliferous, fossils include crinoids, echinoids, and large brachiopods, contains burrow fillings.	3.9
15.	Shale, calcareous, gray color; sparsely fossiliferous; scattered hard elongate calcareous nodules.	0.2
14.	Limestone, tan gray to light gray in color; made up of three units of about equal thickness; contains numerous pelecypod burrows throughout, a fretwork of small fossils fills many burrows.	1.9
13.	Limestone, gray, weathers tan brown; extremely fine grained. "dense zone"	0.6
12.	Limestone, argillaceous, gray, weathers tan brown; platy.	0.7
11.	Shale, calcareous, blue gray; contains numerous hard elongate calcareous nodules; fossiliferous.	1.3
10.	Limestone, gray, weathers brown; highly fossiliferous; fossils generally exposed in cross section.	0.5



Table 14. (concl.)

Zone :	Description	: Thickness : in feet
9.	Limestone, gray to tan gray, weathers to a tan brown; fossils present in clusters; nodular uneven surface. "nodular zone"	1.3
8.	Limestone, dark blue gray, weathers light blue gray; few fossils; contains dark horizontal bands.	6.1
7.	Shale, calcareous, blue gray, weathers light blue gray; platy.	0.5
6.	Limestone, blue gray color, weathers to a light bluish gray; few fossils; very fine grained.	0.8
5.	Shale, calcareous, blue gray color; weathers to a light bluish gray; contains scattered hard calcareous nodules; minute gypsum crystals present.	2.7
4.	Limestone, yellowish tan; breaks into irregular plates; middle portion contains abundant small fossils including echinoids and crinoids.	1.8
3.	Limestone, gray to tan gray, weathering to light tan; pelecypod burrows one inch in diameter frequent in upper 1.5 feet. (Top zone of rimrock)	3.0
2.	Limestone, gray color; unit bedded; fossiliferous; surface finely pitted.	4.8
1.	Limestone, dark bluish gray in color; numerous elongate and rounded soft white inclusions give a mottled appearance; several thin black carbonaceous partings tend to give a false shaly appearance to the lower part of the bed; upper and lower zone separated by a brown stylolitic parting.	5.8
Total Thickness		47.2 feet

Calcite comprised from 98 to 100 percent of the carbonates in all but two samples. Zones four and five contained 19 percent dolomite while all other zones contained less than two percent dolomite.

Table 15. Percentage of Calcite and dolomite in the carbonate fraction of the Augusta samples. (after Crumpton, 1960)

Sample number	Calcite	Dolomite
A20.	100	*t
A19.	100	t
A18.	100	t
A17.	100	t
A16.	100	t
A15. shale	100	t
A14.	100	t
A13.	100	t
A12.	100	t
A11.	100	t
A10.	100	t
A9.	100	t
A8.	98	t
A7. shale	98	t
A6.	98	t
A5. shale	81	19
A4.	81	19
A3.	98	t
A2.	98	t
A1.	98	t

\*t = trace (less than two percent)

Insoluble Residue. Total insoluble residue percentage and percent of plus 270-mesh residue is given as follows:

<u>Sample number</u>	<u>Total Insoluble Residue</u>	<u>Plus 270 Residue</u>
A20.	2.98	0.03
A19.	3.31	0.01
A18.	4.66	0.01
A17.	8.72	0.03
A16.	20.07	9.56
A15. shale	23.11	0.12

<u>Sample number</u>	<u>Total Insoluble Residue</u>	<u>Plus 270 Residue</u>
A14.	9.32	0.02
A13. "dense zone"	12.13	0.02
A12.	31.51	0.19
A11. shale	23.66	0.46
A10.	12.96	0.05
A9. "nodular zone"	10.59	0.03
A8.	14.41	0.01
A7. shale	22.86	0.10
A6.	12.47	0.03
A5. shale	21.05	0.31
A4.	13.43	0.19
A3. "rimrock"	6.97	0.27
A2. "rimrock"	4.97	0.39
A1. "rimrock"	4.38	0.37

Quartz was present throughout the Augusta section. The quartz content varied from one to 51 percent. Only two zones contained over 20 percent quartz and 10 zones contained less than 20 percent quartz. Grain size varied from 0.09mm to 0.3mm in diameter. The average grain size in most samples was about 0.12mm. Subrounded and subangular grains were very abundant in all samples. Only a few samples contained angular grains. Rounded grains were not present in the section. Quartz in most of the samples exhibited a moderately high degree of sorting. Quartz types were quite varied with common quartz being the most abundant. Grains exhibiting slightly undulatory extinction occurred in zones five, 15, and 17. Samples A12 and A17 contained abundant quartz having strong undulatory extinction. Zones 10, 13, and 14 contained a few strongly undulatory quartz grains. Quartz grains containing inclusions of short apatite crystals occurred in samples A7, A13, and A19. Sample A17 contained grains with tourmaline inclusions. Quartz with microlites was present in zones five and 16.



Table 16. (concl.)

Mineral	: A11:	A12:	A13:	A14:	A15:	A16:	A17:	A18:	A19:	A20
<u>Light Minerals</u>										
Quartz	5	12	18	17	7	3	6	45	51	11
Chert	40	69	54	66	87	97	94	50	39	89
Chalcedory	2		t	t		t		t	t	t
Opal	*t	t	t		t	t	t	t	t	t
Glass, Volcanic	t	t	t	t	t	t	t	t		t
Orthoclase	10	2	1	t		t		2	6	
Microcline			t	t	t				2	
Albite	1	1					t	t	1	
Oligoclase			t	t	t			1	t	t
Andisine										
<u>Heavy Minerals</u>										
Chlorite										
Muscovite	2	t	t	t	1			t		
Biotite					t					
Hornblende								t	t	
Goethite	40	7	10	7	4	t	t	t	t	
Hematite		t			t					
Magnetite	t	9	17	10	1		t	1	1	t
Zircon	t									
Garnet										
Tourmaline							t	t		
Celestite		t	t					t	t	
Apatite										
Corundum							t			
Total	100	100	100	100	100	100	100	100	100	100

\*t = trace (less than three grains)

Chert was present in all zones in the Augusta section. However, this section contained less chert than the other three sections studied. The amount of chert present varied from eight percent in zone six to 97 percent in zone 16. The size range of the grains was from 0.08mm to 0.5mm in diameter. The average grain size was about 0.15mm in diameter. Most of the chert occurred as irregularly shaped masses. A smaller number of grains were slightly rounded in shape. Zones six, 12, 13, and 18 contained a few grains of chert with inclusion of small tabular calcite crystals. Silicified fossil fragments were present in several samples. Brachiopod fragments were found in zones 10 and 17 and tests of foraminifers were present in zones two, three, 10, and 14.

Opal was found in small amounts throughout the Augusta samples. A trace of opal was found in 12 samples and zones seven and 10 contained five and one percent opal respectively. The opal grains varied from 0.1mm to 0.23mm in diameter. Most of the opal occurred as irregular masses having a rough surface texture. All of the opal found in zone seven was of this type. Minor amounts of opal were sub-equant in shape. Shrinkage cracks were evident in many of the opal grains. A very small amount of the opal had recrystallized to quartz along the outer edges of the grains.

Volcanic glass or ash fragments was present as traces in 11 samples and comprised one percent of another sample (A9). The glass grains were generally smaller than 0.05mm. One sample contained several glass grains about 0.3mm in diameter which may

represent laboratory glass rather than naturally occurring glass. All of the glass grains were very angular in shape. Shard forms were not abundant, occurring in only four samples.

Chalcedony was present in 15 zones of the Augusta section. Traces of chalcedony were found in seven samples and the eight other samples were comprised of one to six percent chalcedony. The grains averaged about 0.15mm in diameter. Grain shape was irregular to rounded. Most of the chalcedony exhibited extremely fibrous structure and somewhat radial extinction.

Orthoclase comprised a significant amount of 13 samples and occurred as a trace in three other samples. Only a small amount of the orthoclase is detrital in origin. All of the authigenic feldspar in the section was counted as orthoclase, giving a relatively high percentage occurrence for this mineral. Zones one through six and zones nine through 11 contained high percentages of authigenic feldspar with only very small amounts of detrital orthoclase. Detrital orthoclase predominated over authigenic feldspar in zones seven, 13, and 18. The authigenic grains varied from 0.1mm to 0.6mm in diameter with an average grain size of about 0.2mm. Most of the grains were anhedral with a small number being subhedral. The grain surfaces had a slightly mottled appearance under crossed nichols. Detrital orthoclase occurred as grains ranging from 0.08mm to 0.17mm in diameter. A subrounded grain shape predominated over a subangular grain shape.

Microcline was present in trace amounts in six zones and comprised two percent of zone 19. The microcline grains averaged

0.1mm in diameter and varied from subangular to subrounded in shape. Albite made up one percent of five samples, two percent of one sample, and occurred as a trace in three other samples. Oligoclase was present as a trace in nine samples and comprised one percent of two other samples. The albite and oligoclase grains were identical in size and shape. The grains averaged 0.09mm in diameter and were subrounded in shape. Many of the grains appeared to be weathered or altered to a small extent.

The Augusta section contained a very abundant amount of goethite. This mineral was present in all samples except A2 and A20. Goethite occurred as a trace in four samples and comprised from one to 63 percent of the remaining samples. There were seven samples in the section that were comprised of more than 30 percent goethite. The goethite occurred as irregular masses ranging from 0.1mm to 0.7mm in diameter.

Hematite was present in nine samples, occurring as a trace in six samples and comprising from two to 12 percent of three other samples. The grains were irregular in shape and averaged about 0.15mm in diameter. Magnetite was found in 12 samples in amounts ranging from a trace to 17 percent. The magnetite grains varied from 0.1mm to 0.18mm in diameter. Most of the grains were irregularly shaped but a small amount were somewhat subhedral in shape.

Muscovite comprised two percent of sample A11, one percent of samples A15 and A4, and occurred as a trace in nine other samples. The muscovite grains averaged about 0.1mm in diameter and were predominantly sub-equant in shape. Zones two and five



contained a few equant muscovite grains. Biotite occurred as a trace in zone 15. The grain size was 0.07mm in diameter and the shape was subrounded. Massive, irregular shaped chlorite comprised one percent of sample A6 and occurred as a trace in sample A9. Hornblende was present as a trace in zones five, 18, and 19, occurring as subrounded grains averaging 0.15mm in diameter.

Needle shaped zircon crystals were present as traces in four zones. The needles were about 0.02mm long. Tourmaline occurred as a trace in four samples. The tourmaline grains were 0.15mm in diameter and had a tabular shape with rounded edges. Samples A1 and A9 contained subrounded grains of garnet about 0.09mm in diameter. Apatite grains were found in trace amounts in zones one and three. Zones one, five, and 15 contained traces of corundum.

Celestite occurred as a trace in eight samples and comprised from one to 25 percent of four other samples. The average grain size was about 0.15mm in diameter. Most of the grains were tabular in shape and were highly altered on the grain surfaces.

## DISCUSSION OF THE RESULTS

In this study little would be accomplished in a lengthy discussion on the origin and transportation of the common detrital minerals found in the limestone samples examined. The reason for this lies in the geographic distribution of the quarries sampled for study. All of the quarries lie essentially on a north-south line, allowing little chance in locating the source of the detrital minerals. Also, unusual occurrences and characteristics in the detrital fraction were very uncommon.

Of particular interest, however, was the occurrence of tourmaline and zircon inclusions in muscovite grains found in zones one and two of the Junction City section. One tourmaline grain was found to be in the process of being released from its muscovite host, indicating a possible additional source of tourmaline and zircon found in the insoluble residues. The primary source would be direct transportation of the individual tourmaline and zircon grains from the provenance area, as the percentage occurrence of muscovite containing such inclusions was too small to be significant in this line of reasoning.

The primary objective of this discussion is the evaluation of certain relationships and variations found in the amount of insoluble residue, clay minerals, carbonate minerals, and minerals found in the plus 270-mesh residue (especially authigenic minerals). Such an evaluation should lead to postulations on the reason for variations in and between quarries and on the origin of some important authigenic minerals.

Wide variation in the carbonate mineralogy of the upper Pennsylvanian and lower Permian limestones of Kansas is a common occurrence. A number of workers have found that the ratio of calcite to dolomite may change abruptly over very short distances in certain limestones. Such a variation was found to occur in the quarries examined in this project. In the Junction City section the calcite-dolomite ratio was relatively low (abundant dolomite) in zones four through 12. The reverse was true at White City. Only two zones in the White City section contained dolomite in amounts comprising over six percent of the carbonate content. Dolomite was again relatively abundant in the Florence section, being concentrated in the upper 11 zones. The upper two zones at Florence contained 100 percent dolomite. The Augusta quarry reflected another abrupt change, with only two zones containing more than a trace of dolomite. A possible explanation of the spotty occurrence of dolomite may be found in a consideration of the configuration of the sea bottom following deposition of the carbonates. If the sea floor was undulatory rather than flat then in an extremely shallow sea small basin-like areas may act as a site of concentration of magnesium ions. Such concentrations might form primary dolomite, but more than likely it will increase the availability of magnesium for replacement of calcite (dolomitization).

The occurrence of dolomite in the sections studied is also related in a general way to the occurrence of chlorite. The total amount of chlorite present may be obtained by allotting three-quarters of the chlorite-vermiculite interlayer clays and

Table 17. Summary of some important data pertaining to the samples studied.

Junction City Samples	Important Characteristics	White City Samples	Important Characteristics
1.	a, f, c	1.	
2.	a, f, c	2.	a, c, m
3.	s, a, c	3.	a, m
4.	a, f, ce, d, c	4.	a, m
5.		5.	s, a, c, m
6.		6.	a, c
7.	a, ce, d, c, g	7.	s, ce, c
8.	s, a, ce, d, c	8.	a, d, c, g
9.	a, d, c, m	9.	ce, d, c, g
10.	s, d, c, m	10.	a, ce, d, c, g
11.	a, ce, d, c	11.	s, a, ce, d, c, g
12.	a, d, c	12.	a, d, c
		13.	a, ce, d, c
		14.	ce, d, c
		15.	s, ce
		16.	a, ce, d, m
		17.	a
		18.	ce, m
		19.	a, ce, m, g
		20.	a, m
		21.	a, ce, m

Irregular lengths of sections indicate relative thickness of sections.

s=shale; a=volcanic ash or glass; f=authigenic feldspar; ce=celestite; d=dolomite; c=chlorite percent greater than vermiculite percent; m=montmorillonite; g=abundant iron oxides (goethite, etc.).

Table 17. (concl.)

Florence Samples	Important Characteristics	Augusta Samples	Important Characteristics
		20.	a, m
20.	a, f, d, c	19.	ce, m
19.	d, c, m	18.	a, f, ce, m
18.	s, a, ce, d, c	17.	a
17.	a, ce, d, c	16.	a
16.	a, f, ce, d, c	15.	s, a
15.	a, f, ce, d, c	14.	a, g
14.	s, a, ce, d, c	13.	a, f, ce, g
13.	a, ce, d, c	12.	ce, g
12.	a, f, ce, d, c, g	11.	s, a, c, g
11.	s, a, d	10.	ce, g
10.	a, f, d, g	9.	a, ce, g
9.	a, d, g	8.	a, ce, d, c, g
8.	a, f, ce	7.	ce, d, c, g
7.	s, a, f, g	6.	a, f, ce, d, c, g
6.	a, f, ce	5.	s, a, f, ce, d, c, g
5.	a, f, c	4.	a, f, d, c
4.	s, a, f	3.	f, ce, d, g
3.	a, f, c	2.	f, ce, d, c
2.	a, f, ce	1.	f, d, c, g
1.	a, f, ce,		

one-quarter of the vermiculite-chlorite interlayers to the amount of chlorite present. The same type of calculations may be applied to the vermiculite present. When the resulting amounts of vermiculite and chlorite in each zone containing dolomite were compared it was found that the chlorite percentage was higher than the vermiculite percentage. There were 37 zones containing dolomite and chlorite was more abundant than vermiculite in 29 of these zones. Vermiculite content was greater than the chlorite content in only six zones and two of the 37 zones contained no vermiculite or chlorite. The predominance of chlorite in the dolomitic zones might be explained in the same manner as the occurrence of dolomite was explained. Areas in the sea having a high magnesium content would be favorable for the formation of chlorite as well as dolomite, with the magnesium contributing to a predominantly chloritic rather than a vermiculitic type clay lattice structure.

A problem of special interest in the clay mineral suite of the quarries studied is the occurrence of montmorillonite in significant amounts. Only three zones in the Junction City and Augusta quarries and one zone in the Florence quarry contained pure montmorillonite. However, in the White City section, 10 zones contained pure montmorillonite in amounts ranging from five to 42 percent of the clay minerals present. Although the total amount of montmorillonite in all of the sections is small as compared to illite, there is a decided contrast between data from the present study and material presented by other workers. Pettijohn (1957), p. 137, stated that montmorillonite is usually

rare in older sediments and Grim (1953), p. 356, found montmorillonite to be usually absent in his analyses of ancient sediments from many localities. The reverse was true in Mesozoic and Cenozoic sediments, in which montmorillonite was more abundant than illite. In addition, Grim (1953), p. 356 believes that montmorillonite will alter to illite in the course of geologic time. Potassium and magnesium would be released during the disintegration of ferromagnesian minerals and feldspars and added to the montmorillonite lattice by percolating ground waters. Absorption of potassium and magnesium and dehydration due to compaction would, in time, alter montmorillonite toward a mica type mineral.

The author agrees with the statements of Grim and Pettijohn and believes that the illite in the Fort Riley limestone was actually derived from montmorillonite and/or degraded illite subsequent to deposition. Twiss (1955), p.53, drew similar conclusions in a study of some upper Pennsylvanian and lower Permian limestones in Kansas.

From the foregoing discussion it is possible that the montmorillonite present was not an original constituent of the Fort Riley limestone, but must have formed some time after deposition and lithification. A possible explanation of the origin of the montmorillonite might be derived from studies by Bryson (1959) on the upper Wolfcamp and lower Leonard series in east and north central Kansas. Bryson found that under subaerial weathering processes the chlorite in his samples appeared to be changing to montmorillonite through an intermediate vermiculite stage.

He also found illite randomly interlayered with montmorillonite, indicating the development of an occasional water layer in the clay structure in place of potassium leached from the illite. If an appreciable amount of illite leaching were to take place then a relatively abundant amount of montmorillonite would show up in an analysis of the leached sample.

Crumpton (1960), in describing the clay minerals of the Fort Riley limestone, stated that most of the illite contained some layers transitional to montmorillonite. Non-interlayered montmorillonite was found in significant amounts in 17 of the 73 samples examined in this study. Chlorite was present in only three of the samples containing montmorillonite and the remainder of the 17 samples contained either vermiculite, vermiculite-chlorite interlayers, or chlorite-vermiculite interlayers. Porosity studies by the State Highway Commission of Kansas Research Laboratory in Topeka and by Mr. William Grossnickle (personal communication) indicate that enough pore space is present to allow ground water to pass through the limestone in question, allowing alteration of the other clay minerals to montmorillonite to take place.

The foregoing relationships would indicate a multiple source of the montmorillonite. The most important source would be from the alteration of vermiculite and the interlayer varieties of vermiculite and chlorite in those zones now containing no chlorite. Minor amounts of montmorillonite could be derived from weathering of the illite present.



Volcanic ash will alter to montmorillonite (Grim, 1953, p. 357), and ash widely was distributed in these samples but not enough ash was present to contribute significant amounts of montmorillonite.

The most abundant constituent in the insoluble residue from the Fort Riley limestone was authigenic silica. This silica was present in the form of chert, chalcedony (essentially the same as chert), and subordinately as opal, a hydrated form of silica. All of the silica was microscopic in size and was not evident in the limestone outcrops. Under the microscope the silica grains were found to occur in sizes usually less than 0.5mm in diameter. The grains were generally irregular in shape, with a few rounded and roller shaped grains being widely scattered throughout the samples. The fibrous chalcedony grains occurred in relatively small amounts compared to the occurrence of the micro-crystalline aggregates classified as chert.

The origin of authigenic silica has long been a problem to geologists. A great deal of work has been done on the subject and several hypotheses have been advanced as to transportation and precipitation of silica. However, dissention still exists among workers and many of the facts related to authigenic silica are incompletely understood.

In summarizing some of the geochemical relationships of silica in sedimentary environments Krauskopf (1959), p. 4, states that:

Amorphous silica dissolves in either fresh or marine water to the extent of 100-140 ppm at ordinary

temperatures. This is true solution, not colloidal dispersion, most or all of the silica being in the form of monosilicic acid,  $H_2SiO_4$ . Crystalline forms of silica have lower solubilities, quartz least of all. The solubility increases as temperature rises, but is little affected by changes of pH in the range 0-9.

Silica ordinarily does not precipitate at once from supersaturated solution, but forms a colloid. In concentrated solutions the colloid may eventually set to a gel or precipitate as flocculent masses, but in fairly dilute solutions the dispersed sol is very stable. At equilibrium the sol contains dissolved silica in amounts given by the figures above, in addition to the colloidal particles. The reactions of forming and disaggregating the sol particles are slow, so that supersaturated solutions of molecularly dispersed silica and very dilute solutions of colloidal silica can persist for days or weeks.

Colloidal silica may be precipitated by evaporation, by cooling, or by addition of electrolytes, but if the solution is at equilibrium the dissolved part of the silica does not precipitate. Precipitation of dissolved silica may be brought about by organisms, by adsorption, by reaction with cations to form silicates, and probably by slow approach to equilibrium with a crystalline form of silica.

In natural waters silica is mostly in true solution. Its concentration is less than the amount at equilibrium with amorphous silica, both because it is derived largely from materials less soluble than amorphous silica and because it is removed from solution by the processes described above. Most precipitated silica is disseminated widely through sediments. To form chert requires an unusually abundant supply, diagenetic redistribution of freshly precipitated silica, or later replacement.

The most common source of nonclastic silica is probably the silica carried to the sea by river waters. Smaller amounts may be provided by volcanic ash falls, with the partial solution and alteration of the ash fragments. Another possibility has recently been advanced by Walker (1960), p. 145. Walker found that carbonate replacement of detrital crystalline silicate minerals was an important source of authigenic silica in some formations in Texas and Colorado.

In the Fort Riley limestone the amount of volcanic ash present is quite small but widely distributed and the detrital silicates show no effect of replacement, indicating that most of the authigenic silica was provided by river waters. The chalcedony and opal were probably formed by silica replacement of calcareous organic remains such as brachiopod fragments and foraminifera tests. The non-fibrous form of silica, chert, presents a problem as to origin. Chert has commonly been reported to be derived from accumulation of silica by diatoms, radiolaria, and siliceous sponge spicules, and subsequent reorganization of the siliceous material into chert (Cressman, 1955). Such an origin of chert in the Fort Riley is unlikely because the remains of organisms having siliceous skeletons were absent. The irregular shape of the chert grains and the presence of some calcite within a few of the grains indicate that replacement of calcite by silica is one mode of origin of the chert. Solutions containing silica (possibly derived from organic remains in formations other than the Fort Riley) could effect such replacement as they moved through the rock after deposition. It is important to note that silica could not have been very abundant in the sea water at the time of deposition. Although authigenic silica is the most abundant constituent of the residue studied, the total amount of residue is small and only a very small percentage of such silica occurs in the limestones sampled.

Authigenic feldspar is common in marine sediments, the Fort Riley limestone being no exception. The Florence and Augusta

sections contained significant amounts of authigenic feldspar and the Junction City and White City sections contained a very small amount of authigenic feldspar. The abundance of such feldspar in any given sample is indicated by a quartz-feldspar ratio of less than one. In normal limestone deposition the amount of detrital quartz present should be greater than that of detrital feldspar. The grains were characterized by their irregular to subhedral shape and by an absence of a nucleus. The optical properties were nearly identical to those of orthoclase and the percentage occurrence was added to that of detrital orthoclase. The mode of origin and time of formation of authigenic feldspar is not completely understood. Folk (1959), p. 83, states that authigenic feldspars develop in limestone by replacing carbonates under low temperatures and probably low pressures. The authigenic feldspar in the Fort Riley may have occurred as a carbonate replacement, but there is little evidence to either confirm or rule out such an occurrence. An important consideration is the availability of potassium needed to complete the orthoclase lattice. This, however, is not a problem because enough potassium was present to effect alteration of montmorillonite and degraded illite to illite and would be available for the formation of authigenic feldspar as well. The silica needed to form orthoclase can be precipitated from true solution by reaction with aluminum ions (Krauskopf, 1959, p. 18).

Authigenic celestite was a common constituent of the Fort Riley limestone in the four quarries examined. Several other workers (Hargadine, 1959; Hartig, 1954; and Twiss, 1955) have

reported the occurrence of celestite in a number of upper Pennsylvanian and lower Permian limestones of Kansas. The diagnostic characteristics under the microscope included moderately high index of refraction, tabular shape, and corroded grain surfaces.

According to Noll (Rankama and Sahama, 1949) aragonite may contain up to four percent strontium. Celestite is often associated with marine organisms which have originally constructed exoskeletons consisting of aragonite. Aragonite is not as stable as calcite and given time will usually convert to calcite or go into solution. In the conversion process the strontium is released and precipitated in the fossils as strontium sulfate. If part of the original calcium carbonate had been precipitated as aragonite then a similar mode of origin is probably responsible for the formation of celestite in the Fort Riley limestone, however, a detailed thin section study would be needed to substantiate the presence of primary aragonite.

The middle part of each section studied contained a relative abundance of iron minerals. These minerals included goethite, hematite, and magnetite, with goethite being the most abundant. The grains of these minerals were characterized by highly irregular shapes with no apparent rounding, indicating a secondary origin for these minerals. The source of iron for these oxides and hydrated oxides is not apparent from the insoluble residue constituents. It is possible that weathering of the chlorite would free enough iron to form these minerals. Most of the chlorite present was of an iron rich variety (Crumpton, 1960).

Another possibility is introduction of iron from an outside source. The upper zones in each section show effects of solution and any iron brought in would tend to collect directly below zones which have undergone solution.

From the study of the insoluble residue of the Fort Riley limestone the author has concluded that individual zones within the Fort Riley cannot be correlated on the basis of insoluble residues alone. Zones that can be correlated in the field may vary a great deal from quarry to quarry with respect to amount and mineral constituents of the insoluble residue. The presence of unusual amounts of iron minerals may be used as an indicator for a group of zones in the middle part of each quarry but not for individual zone correlation. Several workers have studied residues from limestones below the Fort Riley in the stratigraphic column. Comparison of these residues with the Fort Riley residue indicates that the Fort Riley limestone as a unit could be distinguished on the basis of its residue. Work on the Florence limestone by Hartig (1954), p. 26, shows a marked difference in chert content between the two units, with the Florence limestone containing extremely high chert percentages in the insoluble residue. Also, comparison with some other lower Permian and upper Pennsylvanian residues indicates a higher chert content in the Fort Riley than in those limestones.

## SUMMARY

In this investigation the plus 270-mesh insoluble residues from four Fort Riley limestone quarries in Kansas were studied under the petrographic microscope. A total of 73 different samples were examined and their mineral constituents described. The percentage occurrence of each mineral in each sample was also calculated. Other data utilized to a great advantage included clay and carbonate mineralogy, total amount of insoluble residue, and amount of plus 270-mesh insoluble residue. From the data gathered it was possible to explain the reasons for occurrences of some of the minerals and to discuss their origins.

The most abundant mineral found in the insoluble residue was chert. Other minerals occurring in the light fraction included abundant quartz and less abundant opal, chalcedony, volcanic ash, authigenic feldspar, and detrital feldspars. The heavy minerals were characterized by an abundance of iron oxides and hydrated oxides, and smaller amounts of celestite, muscovite, chlorite, zircon, and tourmaline.

Analyses of the clay minerals by the State Highway Commission of Kansas indicated that illite was the most abundant clay mineral present. Other clay minerals present included vermiculite, chlorite, two varieties of vermiculite and chlorite interlayers, and montmorillonite. The illite was thought to be derived from alteration of original montmorillonite and/or degraded illite. The montmorillonite present may have been formed by leaching of the other clay minerals.

The parallel occurrence of dolomite and chlorite led to a postulation that small basin-like areas on the sea floor may act as a site of magnesium ion concentration resulting in either the primary deposition or secondary formation of dolomite.

Several other constituents were thought to be of secondary origin. Chert was believed to have formed by silica replacement of calcite, and chalcedony and opal by silica replacement of fossil fragments. Authigenic feldspar was formed by reaction of potassium with aluminum and silica present, possibly replacing calcite. Celestite originated from a process involving the release of strontium during recrystallization of aragonite to calcite and its subsequent redosition as a sulfate. A definite postulation as to the origin of the iron minerals was not advanced, however, it was thought that an outside source was a possibility.

Correlation of individual zones between quarries was deemed impossible but a general location of the middle part of each section could be made on the basis of the iron oxides present. The insoluble residue mineral suite from the Fort Riley limestone as a whole was found to differ slightly from that of other lower Permian and upper Pennsylvanian limestones.



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The purpose of this investigation was to describe the insoluble residue of the Fort Riley limestone in four Kansas quarries. Important aspects of the study included a critical evaluation of the variation in insoluble residue from quarry to quarry and variations within each quarry.

The samples used in this study were crushed and treated with hydrochloric acid to remove the carbonates. After complete digestion of the carbonates the remaining material (insoluble residue) was dried and sieved through a 270-mesh screen. The portion retained on the 270-mesh screen was used for insoluble residue study. The study consisted of a petrographic microscope examination of mounted grains from the insoluble residue.

Data derived from the study enabled the author to postulate origins for several of the minerals present. Chert was authigenic in origin, occurring as a silica replacement of calcite. Chalcedony, a fibrous form of chert, was formed by silica replacement of fossil fragments. Authigenic feldspar in the form of orthoclase was relatively abundant in the Fort Riley and was formed by the reaction of potassium with aluminum and silica in pore solutions, possibly replacing calcite. Celestite was derived from a process involving the release of strontium during recrystallization of aragonite to calcite and the subsequent precipitation of the strontium as a sulfate. The middle zones of each quarry contained abundant secondary iron oxides which may have been derived from weathering within the unit or by introduction of iron from some outside source.

Illite, the dominant clay mineral, was derived from the alteration of originally deposited montmorillonite and/or degraded illite by potassium fixation. The montmorillonite present was thought to be formed by leaching of the other clay minerals present. The spotty occurrence of dolomite and its parallel occurrence with chlorite led the writer to believe that small basinlike areas on an undulatory sea floor may act as zones of magnesium ion concentration, causing much of the irregularly distributed dolomitization found in the Fort Riley and other Permian limestones of Kansas.

It was concluded that correlation of zones within the Fort Riley limestone is impossible on the basis of insoluble residue alone. The variations in insoluble residue are too great to attempt to draw similarities on a zonal basis. However, the presence of abundant iron oxides may be used as an indicator to locate the middle part of each section examined. Taken as a whole, the Fort Riley insoluble residue was found to differ slightly from residues of limestones stratigraphically lower than the Fort Riley.