

**KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 59-10**

**STRATIGRAPHY OF THE ZEANDALE LIMESTONE
(UPPER PENNSYLVANIAN) IN SHAWNEE, OSAGE, AND LYON
COUNTIES, KANSAS**

By

R. L. Wood

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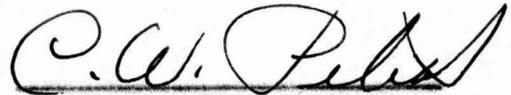
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(UPPER PENNSYLVANIAN) IN SHAWNEE,
OSAGE, AND LYON COUNTIES, KANSAS

by

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B.S., University of Kansas, 1957

Submitted to the Department of
Geology and the Faculty of the
Graduate School of the University
of Kansas in partial fulfillment
of the requirements for the degree
of Master of Science.


Instructor in charge


For the department

May, 1959

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ABSTRACT

The Zeandale Limestone (Virgilian Series, Wabaunsee Group) contains three generally recognized members. Both the upper (Maple Hill) and lower (Tarkio) limestone members pinch out to the south in the area of study. A locally prominent limestone bed (Stormont) divides the middle shale member (Wamego) into two parts in Osage and Lyon Counties, but this limestone cannot be traced into Shawnee County.

Several distinctive microlithologies are recognized from acetate peels and insoluble residues. These lithologically and texturally similar units are not always coextensive with recognized stratigraphic members.

The fauna of the upper and lower limestone members is characterized by an abundance of fusulinids which indicate a far-from-shore depositional environment. The clastics contain a normal near-shore assemblage. The limestones contain a greater percentage of clastics to the south suggesting a possible approach to a southern shore.

The Zeandale interval reflects a cyclic sequence of sedimentation, containing the transgressive phase of one cyclothem and the regressive phase of a second. The complete succession of the "ideal" Wabaunsee cyclothem is never observed in a single exposure.

INTRODUCTION

Purpose of Investigation

A study of the Zeandale Limestone in northeastern Kansas was undertaken for the purpose of obtaining a more complete understanding of the formation--its variations in thickness and lithology, and the relationships between the units of which it consists. On the basis of gross lithology, microlithology, insoluble residues, and paleontology, an attempt is made to explain these relationships more fully. The probable depositional environments are discussed.

This report is one of four which are currently being completed on upper Wabaunsee limestone formations in northeastern Kansas. Studies such as these will add greatly to our present knowledge of the detailed stratigraphy in this area. It is hoped that detailed work on these formations will aid future workers in the understanding of the conditions and processes of sedimentation in this part of the column.

Location of Area

The outcrop belt of the Zeandale Limestone can be traced through Shawnee, Osage and Lyon Counties, Kansas to the vicinity of Eaporia. The areal extent of this report as originally proposed included outcrops in these

counties between the Kansas River in the north, and Neosho River in the south. However, during the course of field study, interesting relationships were discovered north of the Kansas River which I felt should be included in this report. In addition, outcrops of Zeandale Limestone were located in Riley, Jefferson, and Wabaunsee Counties, Kansas. Some of these localities are also discussed. Figure 1 is an index map showing the location of described sections in the major area of study.

Previous Investigation

Stratigraphic units in the upper Wabaunsee Group of the northern Midcontinent region have been subject to extensive and repeated miscorrelation and name revision. For this reason there has been much confusion in the literature concerning the members of the Zeandale Limestone and other Wabaunsee formations. The Zeandale did not receive its name until 1956 when considerable revision of old nomenclature was proposed by R. C. Moore and M. R. Mudge. The details concerning correlation and nomenclature of Zeandale members are discussed within the text of this report.

G. E. Condra and N. A. Bengtson were active in the early studies of the Wabaunsee in Nebraska. E. Haworth, J. W. Beede, C. S. Prosser, and M. Z. Kirk were early workers in Kansas. R. C. Moore and G. E. Condra have made the most notable contributions to the knowledge of the Wabaunsee

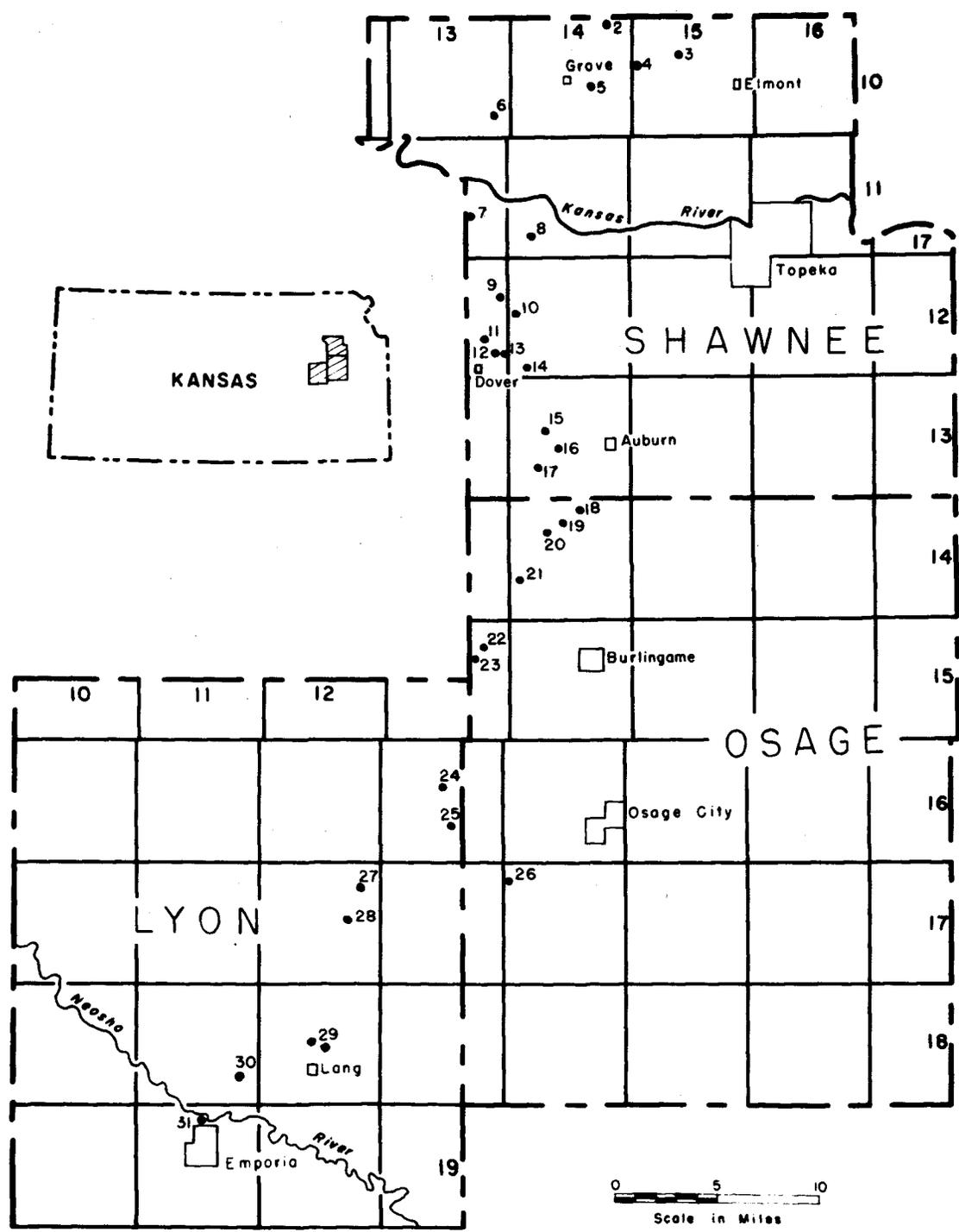


Fig 1 Index map and location of described Zeandale sections

in the past thirty years. L. Wahrhaftig (1952) studied the insoluble residues of the Wabaunsee Group including the Tarkio and Maple Hill Limestones.

The area covered in this report is extensively mapped. The United States Geological Survey is presently completing a geologic map of Shawnee County. Lyon and Osage Counties were mapped for the State Geological Survey of Kansas by O'Connor in 1953 and 1955, respectively. The name Stormont was proposed by O'Connor for a prominent arenaceous limestone found within the Wamego Shale of those counties. The relationship of the Stormont Limestone is discussed in detail within this report.

W. B. Howe of the State Geological Survey of Missouri is presently completing field work on the upper Wabaunsee Group in northwestern Missouri and southeastern Nebraska.

No detailed study of the Zeandale Limestone has been previously made in the State of Kansas.

Topographic Expression

The stratigraphic relationship of the recognized Zeandale Limestone members may be seen in the generalized column on p.12. In Shawnee County, where the Wamego shale is thin, the Tarkio Limestone forms a prominent escarpment (Fig. 2), and generally good exposures of the formation are available.



FIG. 2. Typical topographic expression of the Tarkio Limestone in Shawnee County. (Locality 5, SE NE Sec. 22, T. 10 S., R. 14 E.)

Southward into Osage County, the thickness of the Tarkio rapidly decreases to a feather-edge, and the Wamego Shale thickens. The Maple Hill Limestone, youngest member of the Zeandale Limestone, is neither thick enough nor resistant enough to form a significant topographic expression. As a result, natural exposures of the Zeandale are rare.

The Stormont Limestone, which is definitely recognized in only Osage and Lyon Counties is non-resistant to weathering. However, numerous road cuts provide ample coverage of the Stormont and Maple Hill limestones in the south. The Wamego Shale is generally poorly exposed.

Acknowledgements

I would like to express appreciation to my supervisor, Dr. Charles W. Pitrat, who offered helpful suggestions and corrections on this paper during its preparation. My thanks also are given to Dr. H. A. Ireland and Dr. W. Kenneth Hamblin for their critical reading of this report, and to the State Geological Survey of Kansas for financial assistance with the field expenses incurred during this study. The time spent in the field by Dr. J. M. Jewett and Mr. Stanton Ball of the State Survey staff is appreciated. I am especially grateful to my wife, Lou Ann, for the typing of this manuscript.

TECHNIQUES

Field Techniques

Approximately 45 sections or partial sections were measured in detail. Thickness measurements were made with a steel tape. A hand-level was used to measure covered intervals and thicknesses not available in a vertical section along the outcrop. Approximately 140 limestone specimens were collected for later laboratory analysis. Samples were taken at each lithologic change; massive, lithologically similar units were sampled at intervals of approximately 1.5 feet. Specimens were marked for locality, position in section, and orientation as to top and north. Shale samples

were obtained from the upper part of the Willard Shale formation and the Wamego Shale member of the Zeandale Limestone. Descriptions of measured sections may be found in Appendix A. Appendix B lists the outcrop location of partial Zeandale sections; description of these localities has been omitted.

Laboratory Techniques

The laboratory study of the Zeandale Limestone included the study of acetate peel sections, insoluble residues, etched-block surfaces, and thin-sections. A few representative shales were washed and examined.

Acetate Peel Sections

Approximately 130 acetate peels were made from the limestone samples. The specimens were cut parallel to the bedding plane, and vertically along the east-west direction and the north-south direction. The latter surface was generally selected for the peel. A detailed discussion of the preparation techniques can be found in Sternberg and Belding (1942), and Brown (1958, p. 10).

The work of the writer differed from that of Brown only in the type of acetate used. It was found that light-weight frosted acetate has less tendency to curl, and that the print definition is superior to that obtained with heavy, clear acetates.

Insoluble Residues

Insoluble residues have been discussed at length by several authors (McQueen, 1931; Ireland, 1947) and the methods of preparation have become somewhat standard (Ireland, 1936, 1958). The procedures employed in this study closely parallel those of Ireland (1958) and Fisher (1957 p. 10), to whom the reader is referred for a detailed description of technique.

After the soluble materials were completely digested, the residues were divided into coarse and fine fractions. Each fraction was weighed and converted into percent of total residue, (Appendix D). The constituents of the coarse fraction are described in Appendix C. The fine fraction was not retained for study.

Etched-Block Surfaces

The use of acid etched-blocks for describing texture, grain size, and orientation of insoluble material was first employed extensively by J. E. Lamar. For a detailed discussion of preparation technique the reader is referred to Lamar (1950, p. 2) or Ives (1954, p. 5).

Some of the surfaces previously used in the preparation of acetate peels were re-etched and studied under the binocular microscope. Etched surfaces were found to be superior to peels in the identification of the insoluble material, but the blocks are inconvenient to study and require

considerable storage space. However, orientation of insoluble material is easily observed on the etched surfaces, an advantage over insoluble residue study in which this is not possible.

Thin-sections

Although a number of thin-sections were prepared, study of them did not appreciably add to the knowledge of lithology obtained by previously described techniques.

Axial sections of the large, robust fusulinids from the Tarkio Limestone were prepared for purposes of identification.

Shale Studies

Shale samples from 12 representative sections were prepared for study of fossil content and mineral associations.

STRAIGRAPHY

Wabaunsee Group

The "Wabaunsee formation" was first defined by Prosser (1895) from exposures in Wabaunsee County, Kansas. It constitutes the top of the Pennsylvanian System in the Midcontinent, and consists of approximately 465 feet of shale and thin persistent limestones. The lower limit of the Wabaunsee as originally defined was indefinite, however;

Prosser redefined the "Wabaunsee stage" in 1902, and recognized eight formations extending from the Burlingame Limestone to the Cottonwood Limestone. Fath (1921) first referred to the Wabaunsee as a group.

In 1931 Moore extended the lower boundary of the Wabaunsee Group to the top of the Topeka Limestone. The upper limit has been progressively lowered with the redefinition of the Pennsylvanian-Permian boundary. The present position at the top of the Brownville Limestone was set by Moore and Moss in 1934.

Three major subdivisions of the Wabaunsee Group are recognized. In descending order they are, the Richardson Subgroup (Condra, 1935) Nemaha Subgroup (Condra and Bengtson, 1915) and Sac Fox Subgroup (Condra, 1935). Figure 3 is a graphic section of the upper Wabaunsee Strata. The Zeandale Limestone is the basal formation in the Richardson Subgroup.

Willard Shale

The beds between the "Chocolate" limestone (Tarkio) and the Elmont Limestone were called Willard Shale by Beede (1898) from exposures near the town of Willard on the Kansas River. The literature for some 30 years following Beede's classification erroneously referred to the thick shale between the Emporia Limestone and Burlingame Limestone, as Willard Shale. Condra (1927) brought attention to this error in nomenclature. The name Willard has since been applied to the shale interval between the Elmont and Tarkio

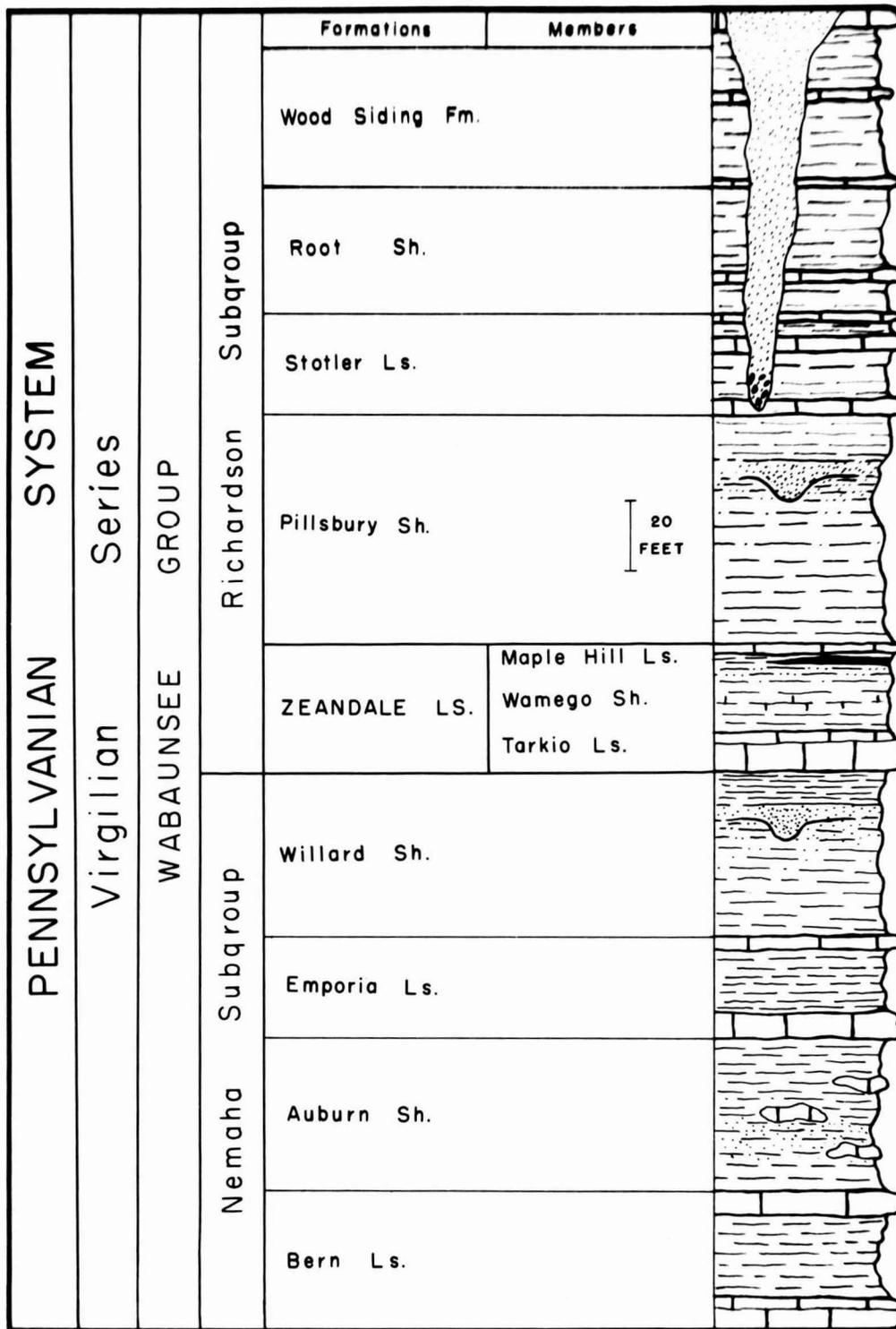


Fig. 3. Generalized columnar section of upper Wabaunsee strata.

limestones as originally defined.

Exposures of Willard Shale were studied at measured localities of Zeandale Limestone. Few complete sections were observed. The Willard ranges in thickness from about 65 feet to 12 feet. Maximum development is in the vicinity of the Kansas River. In general, the thickness decreases toward the south averaging 18 to 24 feet in Osage County and 12 to 15 feet in Lyon County. Locally, however, the thickness changes are irregular. The Willard interval increases from 17.6 feet to 39.4 feet between Locality 16 and Locality 18. It is not possible to separate the Willard from the Wamego or Pillsbury shales south of Emporia in Lyon County.

The lower half of the Willard is a gray to gray-green, blocky, clayey shale; it is generally thin-bedded, gray, silty-clayey shale in the upper half. Large and small ironstone concretions are found in most exposures. Locally, thin siltstone layers characterize the upper part. The contact between the Tarkio and Willard is irregular, but sharp throughout most of Shawnee County. In the southern exposures the contact is more gradational and calcareous nodules are common in the top 6 inches. Figure 4 shows a complete section of Willard Shale at Locality 18.

Cyclic development is most easily observed in exposures north of the Kansas River. Locally a soft, massive, micaceous, brown sandstone represents the basal unit of the Tarkio cyclothem. At Locality 6 a well-developed underclay and abundant plant remains were observed 2.6 feet below the Tarkio Limestone.

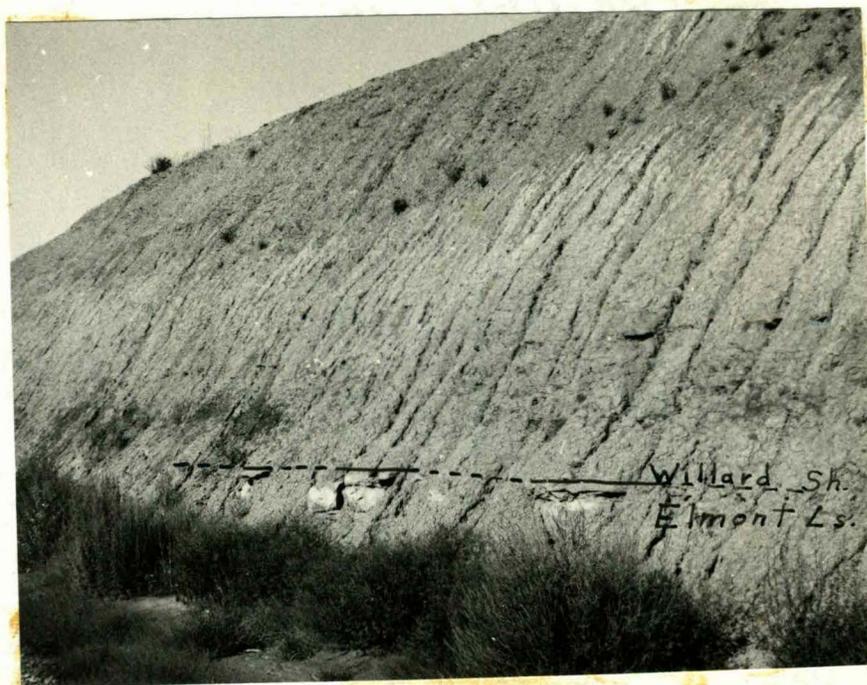


FIG. 4. Thin-bedded Willard Shale. (Locality 18, C Sec. 3, T. 14 S., R. 14 E.)

Fossils are uncommon, but in some exposures the upper 1.5 feet is calcareous and contains abundant Dietyoclostus, Chonetes, Hustedia, fenestrate Bryozoa, and crinoid columnals. The upper 5 feet at Locality 16 contains abundant marine fossils including Nuculana, Derbyia, Chonetes, and very small planispiral gastropods.

Zeandale Limestone

General

The Zeandale Limestone (Moore and Mudge, 1956) is the basal formation of the Richardson Subgroup, in the northern Midcontinent region. The Zeandale has been traced from southwestern Iowa through northwestern Missouri and southeastern Nebraska to central Lyon County, Kansas. Some

of the members are recognized in the southern part of Kansas.

The Zeandale Limestone is composed of three generally recognized members. In descending order they are: Maple Hill Limestone, Wamego Shale, and Tarkio Limestone. The Stormont Limestone, a locally persistent arenaceous lime in the Wamego Shale, was named from exposures in Osage and Lyon Counties by O'Connor (1953).

The type locality (Fig. 5) of the Zeandale Limestone is located in the SE NE NE NE Sec. 28, T. 10 S., R. 9 E., Riley County, Kansas. A detailed description of this section (Locality 1) is found in Appendix A. The thickness of the Tarkio Limestone member is greater than normal at this exposure.

The thickness of the Zeandale Limestone ranges from 14 feet to 50 feet in the area under consideration. The average thickness is about 25 feet. The Zeandale is bounded above and below by shale sequences which normally are 30 to 50 feet thick. As noted previously, these shales locally become quite thin.

Tarkio Limestone

History and type locality.

Tarkio Limestone was first described by Swallow (1866) from exposures along Mill Creek southwest of Maple Hill, Kansas. Swallow called this thick, massive, brown weathering rock the "Chocolate" limestone. Calvin (1900) referred to the "Tarkio limestone series" from exposures on Tarkio

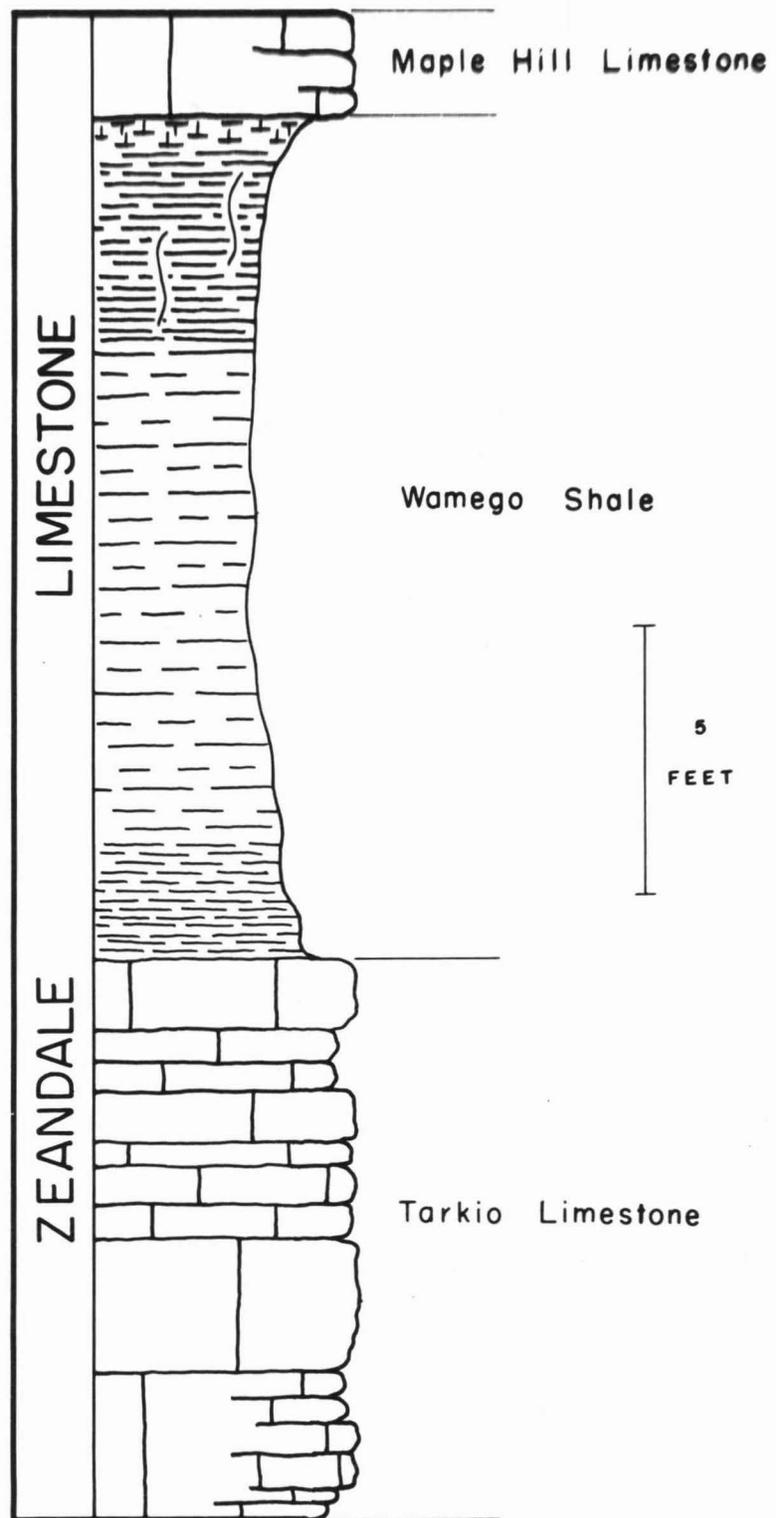


Fig. 5. Zeandale Limestone at type locality.

Creek in Page County, Iowa. Early work by Condra incorrectly correlated Swallow's "Chocolate" limestone with Calvin's Tarkio section. The name Tarkio was officially applied to the "Chocolate" limestone by Condra and Bengtson in 1915.

It was the belief of Hinds and Greene (1915) that detailed work would show that the Tarkio of Iowa was equivalent to the Burlingame Limestone of Missouri, Nebraska, and Kansas. However, subsequent work, chiefly by Condra, established that the strata named Tarkio by Calvin were correlative with the Emporia Limestone of the present classification. This relationship was not recognized until 1934. By that time the name Tarkio had become firmly associated with the thick, brown fusulinid-bearing lime in Kansas and Nebraska. Under the circumstances it seemed unwise to propose a new name for this distinctive unit. Since the names applied to the members of the Emporia Limestone had priority over Calvin's "Tarkio series", that name could not be used for the Emporia interval which he described.

Inasmuch as the unit designated Tarkio by Condra and Bengtson was previously unnamed, and to avoid further confusion, the name Tarkio was retained on the basis of usage in Kansas and Nebraska. Swallow's locality on Mill Creek was recognized as the new "type" locality (Moore, 1936).

Distribution and thickness.

The Tarkio Limestone represents the basal member of the Zeandale Limestone. The Tarkio is recognized from south-

eastern Iowa to west-central Osage County, Kansas. In the area of study a maximum thickness of 12.3 feet is attained at Locality 11 northwest of Dover in Shawnee County. At this exposure 3.7 feet of shale divides the two dominant limestone units. The upper unit, called "Tarkio Osagite" for purposes of this report is not lithologically similar to typical Tarkio Limestone. It is included within the Tarkio, however, because it can definitely be correlated with the upper beds of this unit at the "type" locality on Mill Creek in Wabaunsee County. The "Tarkio Osagite" is recognized only from U.S. Highway 40 to the vicinity of Dover in Shawnee County. The thickest exposure of continuous limestone is found at Locality 10 where 11.8 feet of Tarkio Limestone is exposed. Locality 18 in northern Osage County exhibits 8.4 feet of Tarkio. The preceding maximum figures are far above the average of about 3.1 feet for the member in exposures north of the Kansas River, and 4.2 feet in southern Shawnee and northern Osage Counties.

The Tarkio Limestone thins rapidly southward from Locality 21 in northern Osage County. Total thickness at Locality 23 west of Burlingame is 2.5 feet and only 2 feet are exposed at Locality 25. At the most southerly exposure of Tarkio Limestone 5 miles southwest of Osage City (Locality 26) the total thickness is less than one foot. Seemingly the Tarkio pinches to a feather edge in this area as no limestones are recognized in this interval to the

south. Figure 6 illustrates the southernmost exposure of Tarkio Limestone.



FIG. 6. Tarkio Limestone at southernmost exposure (Locality 26, SW Sec. 6, T. 17 S., R. 14 E.). The very abundant fusulinids characterize this unit in all exposures.

Lithology and paleontology.

The Tarkio Limestone in the area of study can be divided into two distinct lithologic units; the typical fusulinid bearing Tarkio and the overlying "Tarkio Onagite".

"Fusulinid Tarkio". The "Fusulinid Tarkio" is characterized by persistence of lithology and faunal assemblage. The

yellow-brown weathered color, massive bedding, and profusion of very large, robust, Triticites ventricosus mark the Tarkio as the most distinctive and easily recognized member in the Wabsunsee Group. These fusulinids are generally weathered to relief as shown in Figure 7.



FIG. 7. Profusion of fusulinids in relief on weathered surface of Tarkio Limestone. (Locality 18, C Sec. 3, T. 14 S., R. 14 E.)

Fresh samples of the Tarkio Limestone range in color from light gray or gray-brown to dark gray. Weathered surfaces are generally dark yellow-brown to orange-brown. Results of insoluble residue analysis show that the deeper color is found in sections containing a high percentage of iron oxide. The weathered color in southern exposures is

often lighter ranging from light tan-brown to light yellow-brown.

The Tarkio is usually exposed as a single massive ledge. Prominent widely spaced vertical joints transect the unit. Along creek banks and in other natural exposures the non-resistant shale is eroded from beneath the Tarkio ledge. Large boulders of Tarkio Limestone are scattered down the slope of the Willard Shale. Figure 8 shows a typical natural exposure in central Shawnee County. In badly weathered localities the massive-bedded Tarkio breaks up into irregular wedges as illustrated in Figure 9. The limestone is fine to very finely crystalline in all exposures.

Basal contacts are irregular, but sharp in Shawnee County exposures. In Osage County, however, the Tarkio contact is gradational. The upper 6 inches of Willard Shale is calcareous and commonly contains limestone nodules. The upper Tarkio contact is generally well defined. A gradational contact into the overlying Wamego Shale was noted at Localities 19, 22, and 23 in Osage Counties.

The abundance of Triticites has been previously mentioned. These very large fusulinids comprise the vast majority of the Tarkio fauna. Crinoid columnals are found in varying quantity in all exposures. Productid brachiopods are also common throughout the area. Dictyoelostus is most abundant, but occasional specimens of Echinoconchus and Chonetes are noted. The brachiopods Meekella, Composita,



FIG. 8. Weathering characteristic of massive Tarkio Limestone in typical exposure, (Locality 9, CSL SE Sec. 12, T. 12 S., R. 13 E.)



FIG. 9. Wedge-like appearance of Tarkio Limestone in highly weathered exposure. (Locality S, SW Sec. 24, T. 15 S., R. 13 E.)

Enteletes, Hustedia and Dielasma are found in a few exposures. In all exposures, however, unidentified brachiopod shell fragments are more or less abundant.

Small horn corals, chiefly Lophophyllidium, are present in about one-third of the exposures. Ramose bryozoans are found in about one-half of the Tarkio sections, but they are never abundant. Occasional fenestrate bryozoans are noted.

The algae Osagia and Ottonosia are commonly found in the Tarkio Limestone. Ottonosia is usually found at or near the top of the unit, but the occurrence is apparently random. The linear algae (?) called "Marksia", for purposes of reference, are noted from exposures in central Shawnee County. Small high-spined gastropods are found in the general vicinity of the Kansas River, but they are rare.

Fusulinids, crinoid columnals, and the brachiopod Dictyoclostus are the dominant faunal elements in the "typical" Tarkio Limestone.

"Tarkio Osagite". The lithology of the so-called "Tarkio Osagite" differs markedly from the previously described limestone. This clastic limestone consists of coarse, broken shell fragments, crinoid columnals, and fenestrate bryozoans. Occasionally robust fusulinids are found. All fragments are heavily coated with the encrusting algae, Osagia.

The osagite is soft and porous in most exposures. Figure 10 shows the unusual type of weathering that is

characteristic of this massive unit. The "pit and cusp" appearance is especially prominent at Locality 10. Other exposures exhibit an uneven, vuggy weathered surface. Weathered color ranges from medium gray to light gray-tan, but fresh samples are light gray to light reddish-gray or brown-gray. The sub-collitic texture is most easily observed in thin-section.

The writer has visited exposures on the Missouri River bluffs near Fairfax, Missouri, where about 0.8 foot of osagite material also appears at the top of the Tarkio. However, exposures of osagite were not found in Shawnee County north of the Kansas River, and the bed cannot be definitely extended south from Locality 14. At Localities 8, 9, and 10 the unit is developed at the top of the "typical" Tarkio Limestone. At both the Tarkio type locality in Wabaunsee County and the Zeandale type locality in Riley County this distinctive unit is also developed in direct contact with the "typical" Tarkio, and by definition is a part of the Tarkio Limestone (Fig. 11). The irregular contact and variable thickness of a medium-bedded limestone at Locality 8 suggests the presence of a disconformity between the two units at that locality. Elsewhere the contact is gradational.

In Localities 11, 12, 13, and 14 east of Dover varying amounts of green-gray silty shale separate the osagite strata from the fusulinid-bearing limestone. The basal portion of the osagite limestone becomes progressively more arenaceous



FIG. 10. "Pit and cusp" weathering characteristic of the "Tarkio Osagite". (Locality 10, C Sec. 18, T. 12 S., R. 13 E.)



FIG. 11. Tarkio Limestone. Contact between the algal and fusulinid limestones is marked by the change in bedding and weathering characteristics near the center of the bed. (Locality 1, SE NE NE Sec. 28, T. 10 S., R. 9 E.)

from north to south. In Localities 13 and 14 the algal bed is separated from this relatively soft, arenaceous base by sandy to silty shale.

The basal arenaceous beds at Localities 11, 12, and 14 contain abundant Neospirifer. Marginifera, Dictyoclostus, Juresania, and Chonetes are less abundant. Well preserved shells of Myalina, Aviculopecten small high-spired gastropods, and productid brachiopods are rather abundant in the thin-bedded, shaly interval shown in Figure 12. This interval is recognized only at Locality 10.

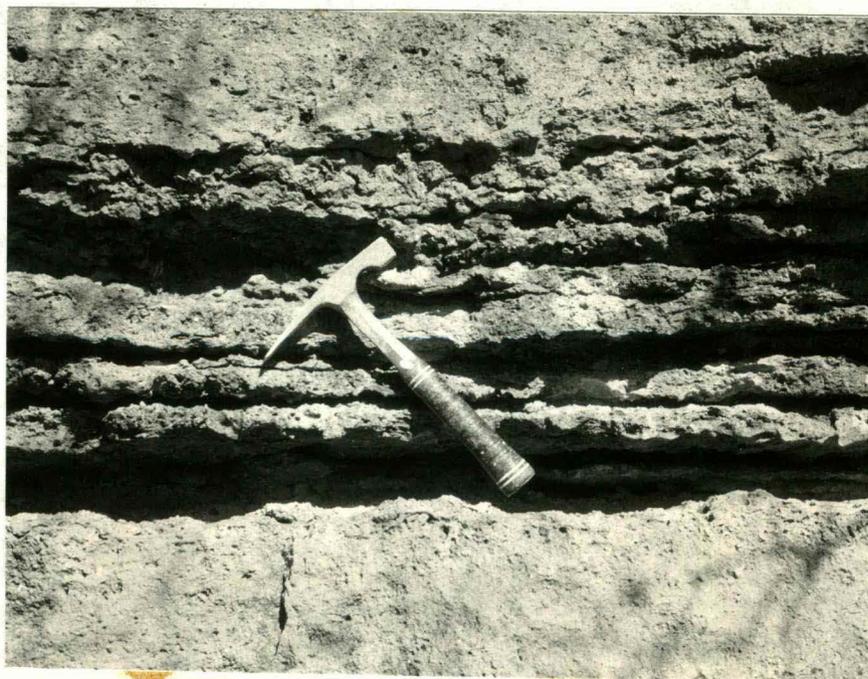


FIG. 12. Thin-bedded, shaly interval in "Tarkio Osagite" at Locality 10. (C Sec. 18, T. 12 S., R. 13 E.)

Environment of deposition.

Inasmuch as the many environmental factors are complexly interrelated, it is not known with certainty which controls were most important in the determination of an ancient environment. Probably depth, distance from shore, and character of sea bottom were most important, but salinity, temperature, currents and food supply cannot be ignored.

Much of the early work on Pennsylvanian and Permian deposits in the Midcontinent area was concentrated on the interpretation of the fauna as an indicator of depth. The most notable of these studies is that of Elias (1937) on the Big Blue Series (Lower Permian) of Kansas. He postulated that the fusulinid zone denotes maximum transgression, during which sea ranged from about 160 to 180 feet maximum depth. Elias stated that the Pennsylvanian seas were slightly deeper, but probably did not exceed 200 feet in depth. Moore (1929), and Wanless (1948) agree that distance from shore may have been a more dominant factor than depth. In their opinion the sea may have been less than 100 feet deep in time of maximum transgression. Regardless of absolute depth values, however, the faunal assemblage of a given bed is a valid indicator of environment.

The texture and faunal assemblage of the "Fusulinid Tarkio" limestone clearly indicate deposition at maximum depth. Fusulinids, markers of maximum transgression, comprise nearly all of the fauna at most exposures. The

remaining fauna, chiefly brachiopods, are also considered to be inhabitants of relatively deep water. A high percentage of argillaceous material, and general lack of coarse clastics, indicate that the source was a considerable distance from the depositional site. Irregularity of sea bottom may account for the range in thickness. On the other hand, variation of any environmental factor or factors such as temperature, salinity or currents, could cause deposition at varying rates in the area of sedimentation.

Sharp basal contacts in the north suggest rapid transgression in Shawnee County. The gradational basal contacts and decided thinning in the southern area may indicate a more gradual transgression in that area, an approach to shore, and/or a change to more shallow water. The increased percentage of fine-fraction residue and apparent lack of lime deposition south of Locality 26 seem to corroborate this suspicion. Whether the increase in clay material and the rapid thickness change represents the gradual approach to a distant shore line or only an extensive shallowing on the sea floor cannot be determined from this localized study. Absence of Tarkio Limestone in southern Kansas, however, indicates that the change from the lime depositing conditions present in Shawnee County was widespread. This change may well indicate the gradual approach to a southeastern shore.

A relatively rapid change of environment from the fusulinid "deep water" conditions in Shawnee County is indicated by the occurrence of the so-called "Tarkio Osagite". The conditions under which "osagite" limestone is deposited have been discussed in detail by Lane (1954) and Brown (1958). Based largely on Illing's (1954) observations in the Bahama Banks, they have concluded that the Osagia beds developed at depths of approximately 60 feet. Moore (1929) and others have indicated that the algae thrive in clear, warm, shallow water. The association of Myalina and Aviculopecten at Locality 10 indicate that the "Tarkio Osagite" was deposited in either a near-shore or "shallow" water environment. The high percentage of arenaceous foraminifers also suggests a shallow depth of the sea. Studies by Ireland (1956, p. 836) indicate that arenaceous foraminifer apparently prefer the shallow water environment of a regressive sea.

Oolites are often associated with the "Tarkio Osagite". Pettijohn (1957) states that oolites probably "indicate accumulation in a turbulent medium". Moore (1929) postulated the formation of oolites in shallow water with appreciable current action and association of bacteria.

All evidence seems to indicate a clear, shallow water environment with a certain amount of turbulence. The broken shell fragments which form the nucleus for the encrusting algae are even more positive proof of rather vigorous wave or current action. Because the algae completely

cover all sides of the fragments, it is certain that they were occasionally overturned and moved about. Inasmuch as the algae could not survive if they were buried beneath a layer of fragments, the heavy coatings indicate slow accumulation of the deposit.

Because of the marked size difference in the fragments of the "Tarkio Osagite", it may be possible to establish the approximate source for the broken shell fragments. It seems logical to assume that the coarser material will be found nearest the point of breakage, or near the area of maximum current and that the finer debris will be deposited away from this point. The maximum coarseness is observed at Locality 9, 4 miles north of Dover and in the lower beds of Locality 10. The osagite texture is considerably more fine at Locality 11, and is hardly recognizable at Localities 8, 12 and 13, 2 miles northeast of Dover. This seemingly places the maximum breakage zone or area of strongest current in the vicinity of Locality 9.

Whether the osagite is related to the regressive phase of the Tarkio cyclothem is not definitely known. It should again be emphasized that many factors other than depth can be responsible for a change in environment.

Summary

The two Tarkio Limestone lithologies are easily distinguished on the basis of gross lithology. Results of the acetate peel and insoluble residue studies indicate that these two units can also be distinguished on the basis of microtexture and insoluble constituents. The insoluble residues of the osagite bed are characterized by an abundance of arenaceous foraminiferal fragments while the fusulinid-bearing Tarkio contains few arenaceous foraminifers.

Because the osagite strata are included in the "type" Tarkio Limestone on Mill Creek, the name Tarkio is applied to the sandy shale, arenaceous limestone, and the osagite limestone in Localities 11 to 14, as well as to the more typical fusulinid-bearing beds.

Wamego Shale

History and type locality.

The Wamego Shale as defined by Condra and Reed (1943), is limited by the Maple Hill Limestone above and the Tarkio Limestone below. Its type locality is in the bluffs north of U.S. Highway 24, 4 miles west of Wamego, Kansas. There has been considerable revision of nomenclature involving this unit.

The name Pierson Point was applied to shale supposedly in the interval between the Tarkio and Maple Hill limestones by Condra (1927, 1949) from exposures found at Pierson's Point southeast of Falls City, Nebraska. It has since been

proved, however, (Moore and Mudge, 1956, letter from Reed) that the strata Condra has called Pierson Point lie between the Tarkio Limestone and an argillaceous limestone in the Wamego Shale. Therefore, the name Pierson Point has been abandoned, and the name Wamego is officially recognized by the state geological surveys in the northern Midcontinent region.

Distribution and thickness.

The Wamego is recognized from southeastern Iowa to west-central Osage County, Kansas. In the area of study the thickness ranges from 9.6 feet at Locality 8 to 44.2 feet at Locality 23. The average thickness in Shawnee County is 13.5 feet. From Locality 18 in northern Osage County the Wamego thickens rapidly to the south, reaching its maximum observed thickness at Locality 23.

Since the Tarkio cannot be recognized southward from Locality 26, it is not possible to separate the Wamego Shale from the Willard Shale in Lyon County. The combined interval is called the Willard--Wamego Shale. Inasmuch as the Maple Hill Limestone also disappears in the vicinity of Emporia, the strata between the Dover Limestone and the Elmont Limestone are called the Willard-Pillsbury Shale south of Emporia. This interval attains a thickness of 50 to 60 feet.

The Wamego Shale member is divided into two parts by the Stormont Limestone in Osage and Lyon Counties. For

purposes of this report the lower shale interval between the Tarkio Limestone and the Stormont Limestone is recognized as Wamego₁ and the upper shale unit between the Stormont and the Maple Hill Limestone is called Wamego₂.

Through the courtesy of Dr. Wallace B. Howe of the State Geological Survey of Missouri, the writer has visited exposures of the Zeandale interval in northwestern Missouri. There is no doubt that the bed previously identified as Maple Hill in this area by the Geological Survey of Nebraska is a poorly developed argillaceous limestone within the lower Wamego Shale.

Dr. Howe believes that this unit corresponds to the Stormont Limestone of Osage and Lyon Counties Kansas (personal communication March 19, 1959). Inasmuch as the Stormont cannot be traced northward into Shawnee County, the writer believes that this equivalence cannot be proved. However, if this supposition is correct, the Wamego₁ Shale of this report should be called Pierson Point Shale (see Wamego Shale history p. 31). In the meantime, the use of Wamego₁ and Wamego₂ seems preferable to the alternative of introducing new member names in an interval already cluttered with obsolete nomenclature.

The thickness of Wamego₁ ranges from 0 to 23 feet, while that of the Wamego₂ ranges from 10 feet to 27 feet. Thicknesses increase to the south.

Lithology and paleontology.

The lithology of the Wamego Shale is variable across the area of study. Underclay and associated carbonaceous material or thin coal within the upper 3 feet of the Wamego are the most persistent features. Coal or lignite is found from Locality 18 to Locality 27 in Osage and Lyon Counties. The underclay-like material persists further to the north, but the coal is absent in observable exposures throughout most of Shawnee County.

Wamego in Shawnee County. The lower portion of the Wamego in Shawnee County is generally green-gray to green-brown, blocky, to clayey shale. This blocky shale becomes more fissile and micaceous in Localities 16 and 17. Lingula is occasionally observed in these strata. Several apparently discontinuous calcareous zones containing abundant Juresania, fenestrate and ramose bryozoans, Nyalina, Promytilus, crinoid columnals and ostracods are noted in this interval (Fig. 13).

North of the Kansas River a prominent, wavy-bedded, arenaceous limestone is found in exposures of Wamego Shale. This unit has been called the "Grove Arenite" in the sedimentary analysis section of this report. The weathered color ranges from medium to dark yellow-brown but fresh surfaces are gray-brown to light tan-brown. Figure 14 illustrates the weathering character of this unit. Fossils are abundant near the top. Dictyoclostus, Derbyia,

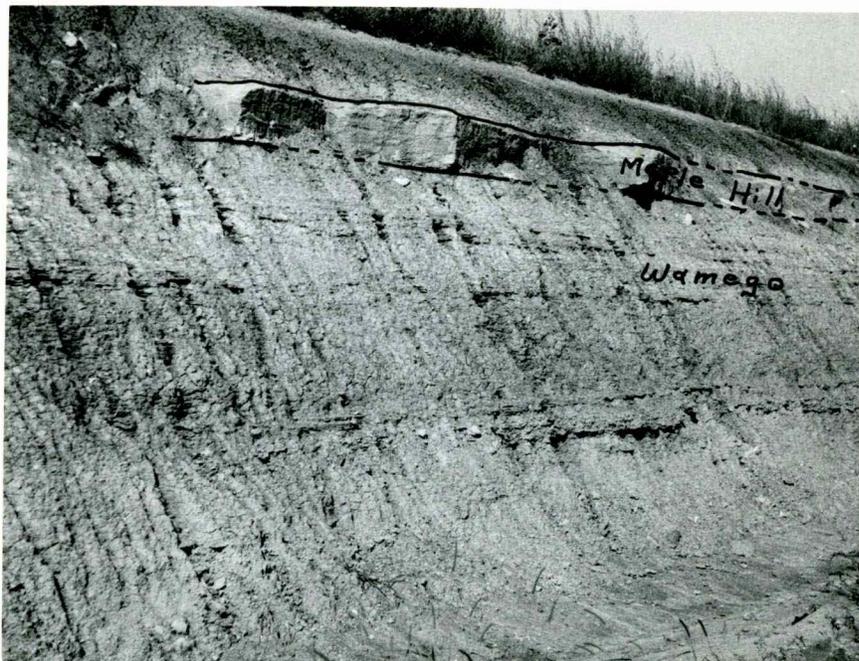


FIG. 13 Wamego Shale and Maple Hill Limestone members.
 Note the more resistant calcareous layers in the shale.
 (Locality 8, SW SW Sec. 29, T. 11 S., R. 14 E.)



FIG. 14. Typical weathering character of the "Grove
 Arenite". (Locality 4, CWL Sec. 18, T. 10 S., R. 15 E.)

Linoproductus, Juresenia, and abundant brachiopod fragments comprise the majority of the fauna. Large crinoid columnals are occasionally found. The "Grove Arenite" is best developed in Localities 4 and 5.

A similar arenaceous limestone is present at Localities 15, 16, and 17 in southern Shawnee County. For convenience this bed will be called the "South Shawnee Arenite".

From the discussion of "Tarkio Osagite" at Localities 11 to 14, it will be recalled that the lower beds become arenaceous to the south and are separated from the Osagia bearing strata in Localities 13 and 14. An attempt was made to determine the true relationship between the "Grove Arenite", the "South Shawnee Arenite", and the geographically intermediate "Tarkio Osagite".

Neospirifer is abundant in the arenaceous beds below the "Tarkio Osagite" and in two exposures of the "South Shawnee Arenite", but at Locality 17 the "South Shawnee Arenite" is unfossiliferous. Other fossil forms are neither abundant nor persistent. Peel-prints of the three sandy units indicate that the microlithologies are closely similar and seemingly indicate the possibility of correlation. However, conflicting results are obtained from the insoluble residue study. The total residue percent is higher in the arenaceous beds of the "Tarkio Osagite", but the coarse fraction percent is much larger in the "South Shawnee Arenite". On the other hand, the constituent percentages

of the coarse fraction agree closely in the two samples.

The most significant observations from field data are the marked change in the thickness and lithology of the subjacent shale. The interval of 1.1 feet from top of "Fusulinid Tarkio" to base of arenite at Locality 14 east of Dover is composed of blue-gray, micaceous, silty, shale, while at Locality 15, 10 feet of hard, blocky, green-gray to light-gray, clayey shale are exposed beneath the "South Shawnee Arenite". Ostracods were found in the washed shale samples below the "Tarkio Osagite" at Locality 14, but none were observed in samples below the "South Shawnee Arenite" at Locality 15.

The writer suggests the possibility that the lithologically similar arenaceous beds discussed above may be correlative, but the evidence is inconclusive. Owing to the absence of conclusive proof of correlation, I have chosen to include the "South Shawnee Arenite" in the Wamego Shale. The "Grove Arenite" is similarly placed in the Wamego interval.

Wamego₁ in Osage and Lyon Counties. The interval recognized as the Wamego₁ Shale in Osage and Lyon Counties is largely covered. Calcareous green to gray shale with abundant limestone nodules at the top and bottom characterize this interval at Locality 19. Spines and shell fragments are found in the upper foot. In southern exposures, the lower one-half to two-thirds of the Wamego₁ is generally blocky

and the color ranges from green-gray to brown. Brachiopods are occasionally found in the lower few feet, but fossils are not observed elsewhere. The upper 5 to 7 feet become silty and micaceous. The color ranges from medium gray to gray-green. The contact with the Stormont Limestone is gradational.

Wamego₂ in Osage and Lyon Counties. Two fossiliferous, calcareous zones are generally recognized within the Wamego₂ Shale interval. The lowermost of these units is best developed at Locality 18 in northern Osage Counties. One and five-tenths feet of thin-bedded, moderately hard, arenaceous limestone containing very abundant near-shore invertebrates is exposed. Moderately high-spired and small planispiral gastropods, Septimyalina, Myalina, Dictyoelostus, fenestrate bryozoans, and abundant broken shell fragments comprise the fauna. In other exposures Dielasma, Composita, and Aviculopecten are recognized. The lithology is variable, ranging from hard, oolitic, limestone to calcareous siltstone. The abundance of fossil fragments persists.

The upper calcareous zone is generally represented by 0.3 to 0.7 feet of limy shale or argillaceous limestone. Productid brachiopods, pelecypods, gastropods, and crinoid columnals are found in varying abundance from section to section. O'Connor, (1953) described the pelecypods Leda, Yoldia, and Myalina; the gastropods Pharkidonotus Euphenus,

and Worthenia from these units.

These calcareous zones cannot be recognized northward from Locality 18. However, similar calcareous strata are exposed at Locality 8 near the Kansas River. It is impossible to determine their relationship to the southern exposures.

The presence of underclay and coal in the Wamego₂ have been previously discussed. Plant remains and smooth, unornamented ostracods are often found in this interval and in southern exposures a fine, gray to brown, micaceous, sandstone is common below the underclay.

Environment of deposition.

Deposition in early Wamego time took place in a marine environment which differed widely from that of the underlying Tarkio Limestone. Except in Localities 19, 22, and 23, the basal contact is sharp. Gradational contacts at the above localities may represent masking of the calcium carbonate deposition in late Tarkio time by a large local influx of argillaceous material.

The rare occurrence of Lingula in this interval coupled with the occasional presence of thin fossiliferous, calcareous strata indicates that these strata were deposited in shallow marine water. The calcareous zones contain abundant Juresania, Myalina, Promytilus, bryozoans, and ostracods. Although ostracods can adapt to any kind of environment, Elias (1937) observes that they are most often

associated with the so-called molluscan phase in the Midcontinental Permian cyclothems. Other forms are more indicative, however. The presence of Juresania, and the thick-shelled clams indicates that the water deepened only slightly during the deposition of these calcareous zones.

These calcareous strata may indicate minor transgressions of the sea. On the other hand, if turbulence were reduced because of local restriction or current change, the seas would become more clear. The absence of masking clastics would result in the appearance of calcareous zones in the sedimentary record. Thus, a change in sea level is not necessary to explain these minor irregularities in the shale deposition. Deposition far from the sediment source is suggested by the fine-grained, blocky appearance of the shale.

Deposition of clay particles was temporarily interrupted by the advance of the Stormont sea in the south. The environment of Stormont time is discussed in the following section.

The Wamego₂ shale contains sparse marine fossils and is characterized by two extremely fossiliferous limestone and limy shale units. Although the increase in abundance of organisms and the deposition of calcium carbonate may be the result of the shoreline being more distant because of a transgressing sea, it seems more likely that variation of one or more of the environmental factors has brought about this change.

The micaceous sandstone and silty shale often found beneath the underclay in southern exposures is probably non-marine. There is no glauconite in the sand, and no fossils have been observed. Moore (1929, 1957) suggests that this type of deposit is probably laid down by very low gradient streams meandering across a broad floodplain. The particles are transported, sorted and resorted by the waves and currents in the shallow water at the margins. Weller (1956) postulates deposition by subaerial streams with a gradient on the order of one foot per mile. Sheet wash is also suggested as a possible origin.

Underclay and coal are found within the upper 3 feet of the Wamego Shale. There is considerable controversy as to the origin of underclay or "fireclay". Often poorly preserved leaves and plant stems are found associated with the clay. Twenhofel (1932) believes that they were deposited in coastal swamps or in poorly drained areas. Stout (1931), Abernathy (1936) and others believe that underclay is subject to weathering and leaching prior to swamp formation and subsequent plant accumulation. Grim and Allen (1938) conclude that underclays were formed in an aqueous environment, but whether they are marine or nonmarine in origin is not determinable. The environment suitable for the formation of underclay was not everywhere present in the area of study. In exposures where no underclay is found the shale which occupies the same stratigraphic interval is apparently unfossiliferous, but it was not

definitely identified as nonmarine.

The scope of this paper does not allow space for presentation of the various theories of coal formation. It is generally believed that vegetable matter was deposited in swampy lands or broad delta and coastal plain areas under humid conditions. Vast quantities of material are required as only a small percentage is preserved and converted into coal.

The thin shale above the Wamego coal is marine. Inasmuch as the fossils observed are brachiopod spines and shell fragments, a rapid transgression over the coal forming swamp is indicated. The thinness of these strata and the appearance of calcareous nodules indicates steady transition toward deeper and more clear water which culminated with the deposition of the Maple Hill Limestone.

Summary

The Wamego Shale of Shawnee County contains prominent arenaceous beds in some exposures. These units may be equivalent to the arenaceous beds of the "Tarkio Osagite", but results of this study neither confirm nor deny this possibility.

The Wamego Shale interval is divided into two parts by the Stormont Limestone in Osage and Lyon Counties. These units are recognized as Wamego₁ and Wamego₂. The Wamego₂ Shale is characterized by two fossiliferous, calcareous zones.

Stormont Limestone

History and type locality.

The name Stormont was applied to an arenaceous limestone within the Wamego Shale of Osage and Lyon Counties by O'Connor (1953). The type locality was established as NW Sec. 9, T. 14 S., R. 14 E., Osage County, Kansas. The Stormont has been occasionally misidentified as Tarkio Limestone south of the point where that fusulinid-bearing bed pinches out. In at least one previous study the Stormont Limestone was identified as Maple Hill Limestone (Wahrhaftig, 1952).

Distribution and thickness.

In the area of study the Stormont Limestone is recognized southward from Locality 19 in northern Osage County. It is found in the Lyon County exposures south of Emporia, (O'Connor, 1953) and is reported in some southern Kansas sections. Beds of similar lithology are locally observed in Shawnee County and along the Missouri River bluffs. It is doubtful that these units are correlative with the type Stormont of central and southern Kansas. The thickness averages 2.5 feet, ranging from 1.5 to 3.6 feet.

Lithology and paleontology.

The Stormont Limestone at the type locality is represented by 2.2 feet of hard, medium to finely crystalline, thick-bedded, arenaceous limestone. Color of the fresh limestone ranges from light gray to buff-tan. Small shell fragments, crinoid columnals, fusulinids, and ramose bryozoans characterize the fauna.

Lithology of the Stormont is variable, but the arenaceous texture is always present. At Locality 25 six miles west of Osage City, the Stormont is actually a calcareous siltstone or sandstone as the insoluble fraction is over 50 percent. Because of the variation in lithology, the weathering characteristics vary from outcrop to outcrop. However, the bed is non-resistant to weathering in all exposures (Fig. 15). As a result, few sections are available for study. In more weathered exposures the slabby or wedge-like type weathering illustrated in Figure 16 is observed in the Stormont. The Stormont upper unit is generally better consolidated than the lower bed or beds, and forms a more resistant ledge.

The Stormont is always very fossiliferous. Mollusks including the pelecypods Myalina, Orthomyalina and Aviculopecten; and the gastropods Bellerophon, and Pharkidonotus are abundant. The brachiopods Neospirifer, Dietyoclostus, Derbyia, and Composita are common and crinoid columnals, ramose and fenestrate bryozoans, sparse fusulinids, Osagia-



FIG. 15. Non-resistant weathering character of Stormont Limestone member. Note prominent calcareous strata in Wamego₂ Shale above. (Locality 19, NE Sec. 9, T. 14 S., R. 14 E.)



FIG. 16. Stormont Limestone showing slabby, wedge-like appearance of weathered exposure. (Locality C, south side Sec. 2, T. 15 S., R. 13 E.)

type algae and "Marksia" complete the faunal assemblage.

The arenaceous texture, the presence of Neospirifer, and the high percentage of insoluble residue is suggestive of the arenaceous units in the Wamego Shale of Shawnee County ("South Shawnee Arenite"). Because of the impossibility of "walking out" these beds, their exact relationships are difficult to determine in the field. The problem is rendered more difficult by the rapid thinning of the Wamego₁ Shale in Localities 19 and 20. At Locality 18 the Stormont Limestone is included in an abnormal thickness of Tarkio, and the Wamego₁ is not represented.

Results of the sedimentary analysis are more conclusive. The constituents of the insoluble residues from the Stormont and the "South Shawnee Arenite" are basically similar, but there are no arenaceous foraminifers in the Shawnee County sections. In addition, the total and coarse fraction percentages do not agree. Acetate peels illustrate a similarity of texture, but close examination reveals minor differences such as the greater percentage of argillaceous material in the "South Shawnee Arenite".

In view of the evidence obtained by sedimentary analysis, it is probable that the arenaceous units in Localities 15, 16, and 17 ("South Shawnee Arenite") are a local development within the Wamego Shale, as previously indicated. In the opinion of the writer, it would be unwise to correlate these units with the Stormont solely

on the basis of lithologic similarity and position in section. Therefore, the name Stormont is not extended north from Locality 16 where the Stormont Limestone merges with the Tarkio.

Some workers may insist that Stormont is a useful term, and at the risk of referring to non-equivalent beds by the same name, will suggest that the name Stormont be applied to lithologically similar units in this interval. By following this practice, the shale units will be entirely shale, and all of the limestone units will have names. However, confusion in nomenclature would likely result in areas where the so-called "Stormont" is not present.

Environment of deposition.

A vigorous transporting medium is indicated by the arenaceous texture of the Stormont Limestone. The character of the basal contact is everywhere gradational indicating gradual transition toward an environment more favorable for limestone deposition. Lime content increases toward the top of the bed.

Few fossils are present in the basal portion of the Stormont, but diverse faunal elements are abundant in the upper units. It seems likely that the lack of organisms may be attributed to the excessive turbulence in the seas of early Stormont time. The accumulation of fine sand was probably very rapid. In middle and late Stormont time

the increasing depth of water and/or decrease in the amount of turbulence created more favorable conditions for the growth of organisms. Abundant Myalina, Aviculopecten, ramose and fenestrate bryozoans, common gastropods, and scattered brachiopods characterize the fauna. This assemblage suggests a shallow-water environment. Furthermore, the lack of clay in the insoluble residues and rather abundant percentages of arenaceous foraminifers indicates that the water may have been relatively clear, and more quiet than in earlier Stormont time. Sharp upper contacts indicate a rapid change from lime-forming conditions as Stormont sedimentation ended.

Inasmuch as the percentage of coarse-fraction of the residue increases in a southerly direction, the source of these sediments is inferred to be in the south or southeast. Such an assumption is risky considering the limited area studied in this report. However, there is general agreement (Moore, 1931; Dott, 1928) that a shoreline lay to the south. The source area may have been in the position of the Ouachita and Arbuckle Mountains.

Summary.

The possible correlation of arenaceous beds in southern Shawnee County with "Tarkio Osagite" of the Dover area was discussed in the stratigraphy of the Wamego Shale. In this section, these same arenaceous beds have been suggested as Stormont equivalents. If each of the above

relationships were valid, the Stormont Limestone of Osage and Lyon Counties would be equivalent to the "Tarkio Osagite" in Shawnee County. Furthermore, because the osagite can be traced into the Tarkio at the type section, the Stormont Limestone would be a facies or tongue of the Tarkio Limestone. This relationship has been previously suggested. There is marked similarity of the "blotched" peels from these units at two widely separated localities. (See Figs. 29 and 31.) However, it is the conclusion of the writer that the results of field work and sedimentary analysis do not favor the above interpretation. The possibility is not entirely eliminated but the conclusions previously presented seem most probable.

Maple Hill Limestone

History and type locality.

The Maple Hill Limestone was named as a subdivision of the McKissick formation by Condra (1927). The type locality is on Mill Creek, southwest of Maple Hill, Kansas.

The Maple Hill Limestone was recognized as a formation by Moore (1920). It was reduced to member rank and defined as the top unit in the Zeandale by Moore and Mudge (1956).

The Geological Survey of Nebraska has incorrectly applied the name Maple Hill to an argillaceous limestone within the Wamego Shale. As a result, the nomenclature in parts of the northern Midcontinent region needs revision.

The upper Wabaunsee strata as recognized and defined by the State Geological Survey of Kansas are apparently correct and should be used as a basis for revision.

Distribution and thickness.

The Maple Hill Limestone is exposed throughout the area studied. It is absent outside the area south of Emporia in central Lyon County, but apparently is present in southern Lyon County sections (O'Connor, 1953). Exposures of Maple Hill average 1.4 feet in thickness ranging from 1.1 feet at Locality Y to 2.0 feet at Locality 7.

Lithology and paleontology.

The Maple Hill Limestone is easily recognized. It is generally exposed as a single bed with widely spaced vertical joints (Fig. 17). Large, rectangular blocks are often weathered out along the outcrop. Weathered exposures break down into shelly slabs as shown in Figure 18.

The fresh color of the Maple Hill is light to medium gray. Weathered colors range from gray to light buff-brown, and the upper surface commonly has an unmistakable reddish cast. Unlike the members previously discussed, the lithology of the Maple Hill varies only slightly in the area under consideration, everywhere being hard and fine to very finely crystalline.



FIG. 17. Maple Hill Limestone member showing widely spaced vertical joints and typical rectangular blocks. (Locality Y, SE Sec. 26, T. 17 S., R. 12 E.)



FIG. 18. Slabby character of badly weathered exposure of Maple Hill Limestone. (Locality 28, CWL Sec. 14, T. 17 S., R. 12 E.)

The basal contact of the Maple Hill Limestone is gradational into the Wamego Shale. A thin fissile, calcareous shale with abundant calcareous nodules is found in most exposures. Because of the poor Maple Hill exposures generally available, the upper contact was not observed in detail.

The faunal assemblage is characterized chiefly by an abundance of small, slender fusulinids. Crinoid columnals and brachiopod fragments also are abundant. The brachiopod genera Dictyoclostus, Juresania, Composita, and Punctospirifer are recognized. Unidentified broken shell fragments are abundant. Gastropods, ramose bryozoans, the algae "Marksia" and Ottonosia are occasionally found. Ottonosia is chiefly confined to the upper one-quarter of the bed. Pelecypods and horn corals are rare in the Maple Hill.

Ireland, (1956) identified the arenaceous foraminifers from the Shawnee and Wabaunsee groups in northeastern Kansas. Glomospira monogranula, Glomospira pusilla, and Ammonovertella inclusa were described from the Maple Hill.

Environment of deposition.

The uniformity of lithology and faunal content in the Maple Hill Limestone has been shown, indicating that environmental conditions were similar over a widespread area. Abundant fusulinids attest that the Maple Hill was

deposited during maximum sea depth. The common association of organisms generally considered to indicate shallower water or closer proximity to shore suggests that the depth may have been less than that attained in the Terkio cycle.

The basal contact is gradational, indicating a less rapid rate of transgression. Commonly the basal part of the bed contains abundant brachiopods, and fewer fusulinids than the upper part. Many shells are abraded indicating that relatively strong currents were present in the area.

The texture indicates that the Maple Hill was probably deposited at a considerable distance from shore. Moore (1929) suggests that sea-bottom scavengers through continual working and reworking of limy material may modify the sediments considerably. However, the presence of unbroken microfossils implies that the texture probably is due to original deposition.

Otonosia is commonly found in the upper one-quarter of the bed. According to Elias (1937) calcareous algae are poor indicators of depth. Generally they are confined to the shallower seas. Therefore, their presence may indicate shallowing of the sea or an advance of the shore connected with the initiation of the regressive phase.

Summary.

There are no problems connected with the identification or correlation of the Maple Hill Limestone in the area of study. Sedimentary analysis indicates that the lithology

and microtexture of this unit are essentially uniform north to south.

Pillsbury Shale

The Pillsbury Shale includes the strata between the Dover Limestone member of the Stotler Limestone, and the Maple Hill Limestone member of the Zeandale Limestone. (Moore and Mudge, 1956) The type locality is Pillsbury Crossing on Deep Creek in Riley County, Kansas.

First study of the Pillsbury Shale interval was by Beede (1898). He referred to the strata between the Dover Limestone and "Chocolate" (Tarkio) limestone as the Dover Shale and Sandstone. The name Table Creek Shale was proposed by Condra in 1927 for the interval between the Dover and Maple Hill members of the McKissick formation. This name was changed to Langdon when study at the type locality by Condra and Reed (1943) indicated that the Maple Hill Limestone was not present, and what had been identified as Tarkio was the Elmont Limestone member of the Emporia formation. The name Pillsbury was adopted when it was discovered by W. Searight that type Langdon as identified by Condra and Reed was actually equivalent to the Wamego Shale member of the Zeandale Limestone (Moore and Mudge, 1956).

Exposures of the Pillsbury Shale were not examined in detail during the course of this study. However a pronounced range in thickness was observed. The Pillsbury

attains a thickness of about 50 feet in the vicinity of the Kansas River thinning irregularly to about 3.6 feet at Emporia. It is impossible to differentiate the Willard Shale from the Pillsbury Shale south of Emporia. The combined thickness of the interval designated Willard-Pillsbury is between 50 and 60 feet.

In most exposures the Pillsbury contains a tan or buff sandstone near the top. This represents the basal unit of the Dover cyclothem. The lower portion of the Pillsbury is generally a blue-gray, blocky, shale characterized by abundant ironstone concretions. O'Connor, (1953, 1955) reported scattered plant remains near the center.

SEDIMENTARY ANALYSIS

Acetate Peel Study

A comprehensive study of limestone units in the Zeeland Limestone was facilitated by the preparation of acetate peel-prints. Knowledge gained from a study of acetate peels is similar to that obtained from normal thin-sections except that insoluble constituents are not readily identified in the peel-prints. However, this disadvantage is offset by the speed of preparation and ease of study of acetate peel-prints.

Inasmuch as insoluble residues were also studied extensively in this report, it is doubtful that the time required for preparation, study, and photography of a

comparable number of thin-sections would be justified by more complete and accurate data.

In the course of this study several definite lithologies were noted. Since they were not always coextensive with named units in the Zeandale, it seemed desirable to establish an artificial nomenclature for the lithologically and texturally similar units as noted from the acetate peels. These are: "Fusulinid Tarkio", "Tarkio Osagite", and "Grove Arenite", in addition to the Stormont, Wamego and Maple Hill.

A summation of the data compiled from peel studies of the Zeandale Limestone is found below. The individual units are discussed under their assigned headings, but the actual stratigraphic position is noted.

"Fusulinid Tarkio"

The massive yellow-brown weathering Tarkio Limestone forms the base of the Zeandale Limestone. Typically, this distinctive unit is characterized throughout by a profusion of the large, very robust fusulinid Triticites ventricosus. To distinguish it from other Tarkio lithologies, this unit will be referred to as the "Fusulinid Tarkio". It thins to a feather edge at Locality 26 in central Osage County.

Figure 19 illustrates the typical argillaceous texture and abundance of fusulinids in this limestone. Figure 20 is from the southernmost exposure of "Fusulinid Tarkio". Note that the texture and fauna are similar in both places.

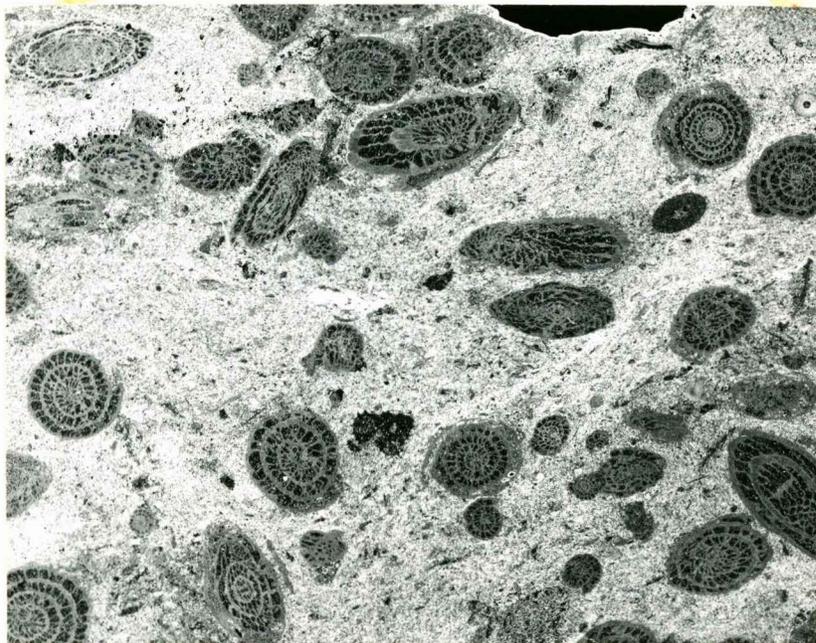


FIG. 19 Peel-print of "Fusulinid Tarkio" (X4) showing argillaceous texture and abundant fusulinids. (Locality 20, CWL Sec. 9, T. 14 S., R. 14 E.)

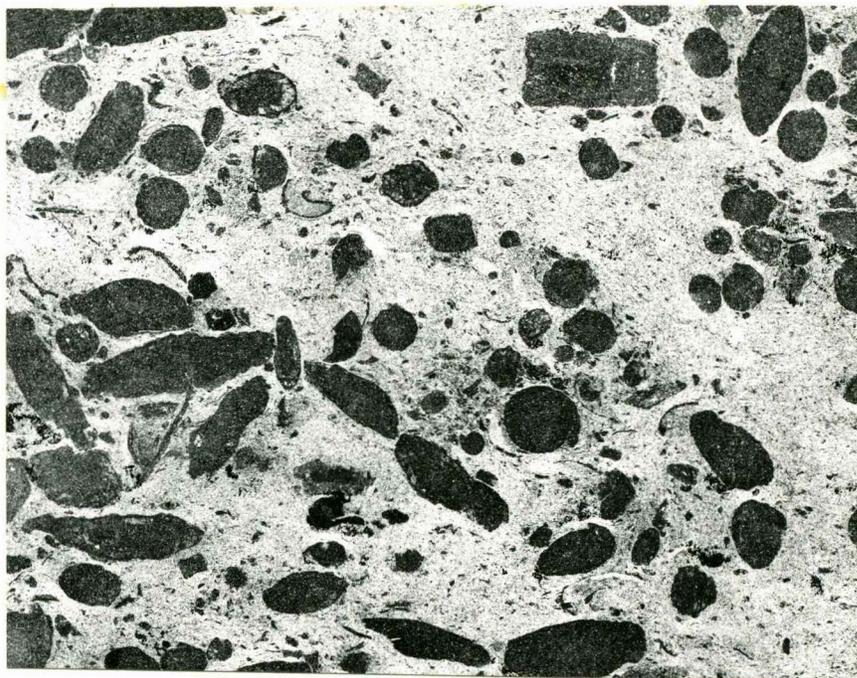


FIG. 20. Peel-print (X4) from last recognized exposure of "Fusulinid Tarkio". Intense weathering has destroyed most of the fusulinid structure. (Locality 26, SW Sec. 6, T. 17 S., R. 14 E.)

Although this unit remains essentially uniform in gross lithology and microlithology, minor changes are interesting to note. The basal contact of the Tarkio Limestone is sharp and well defined in the exposures of Shawnee County. In the south, however, the contact becomes gradational and limy nodules are not uncommon in the upper 6 inches of the Willard Shale. Figure 21 shows that such a gradational contact is reflected in the acetate peels. The "banded" appearance in this basal sample is caused by a variation in quantity of argillaceous material. This characteristic feature is common in the basal samples from Osage County.

Ottonosia is more or less common in the "Fusulinid Tarkio". In southern Shawnee County Ottonosia is found in the lower part of the unit. It is localized near the top in Osage County exposures, and is rare in northern Shawnee County sections. The relationships noted above are general, and the stratigraphic occurrence of this alga is apparently random. Figures 22 and 23 are peel-prints of Ottonosia.

At Localities 8 and 18 the typical "Fusulinid Tarkio" grades upward into a dense, very finely crystalline, algal (?) zone, characterized by an absence of Triticites (Fig. 24).



FIG. 21. Peel-print of "Fusulinid Tarkio" (X4) showing "banded" appearance in basal sample of Locality 19. (NE Sec. 9, T. 14 S., R. 14 E.)



FIG. 22. Ottonosia algae from upper part of "Fusulinid Tarkio". X4. (Locality 22, NE Sec. 11, T. 15 S., R. 13 E.)

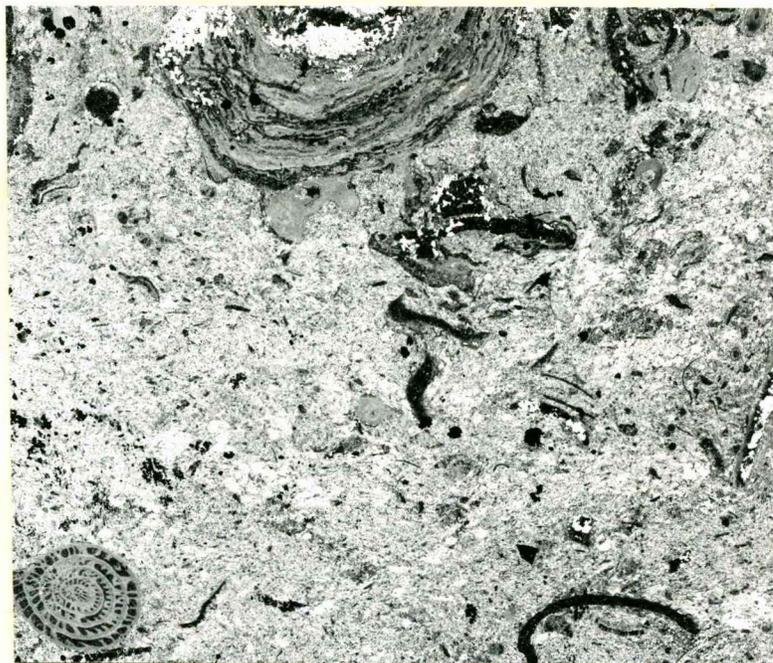


FIG. 23. Peel-print of *Ottonosia* algae, X4. Note association of fusulinids, shell fragments, and spines. (Locality 20, NE Sec. 30, T. 14 S., R. 14 E.)

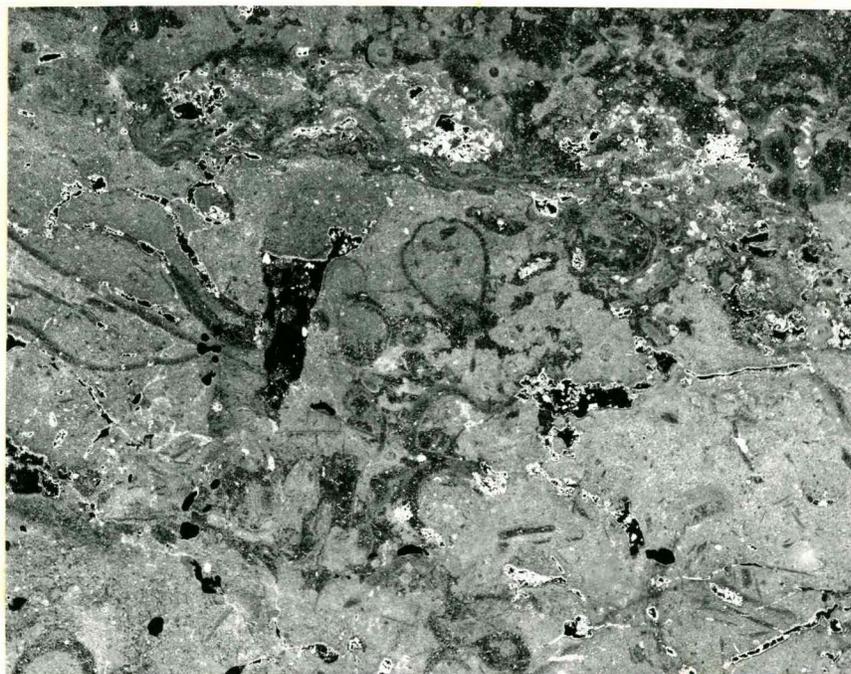


FIG. 24. Peel-print of dense algal limestone at top of Tarkio. X4. This unit is characterized by an absence of fusulinids. (Locality 18, C Sec 3, T. 14 S., R. 14 E.)

"Tarkio Osagite"

The "Tarkio Osagite" can be traced from Locality 8 at the Kansas River into Locality 14 near the town of Dover. In the north it is in direct contact with the underlying "Fusulinid Tarkio". To the south, however, it is separated by sandy shale which attains a thickness of 3.7 feet at Locality 11. Maximum osagite thickness is observed at Locality 10, where over 8 feet of algal-oolitic limestone is exposed above the "Fusulinid Tarkio". Figure 25 shows the sub-oolitic texture, and Osagia-coated shell fragments, which characterize this unit.

The "Tarkio Osagite" at Locality 9 (Fig. 26) is coarser and more porous than normal. The sub-oolitic texture is less obvious due to the presence of abundant detrital fragments which are heavily coated with Osagia. Encrusted fusulinids are common in this exposure. Coarse-textured osagite of a similar nature comprises the lower 3 feet in Locality 10.

The "Tarkio Osagite" is represented at Locality 8 (Fig. 27) by 1 foot of sub-oolitic limestone interspersed with very small Osagia-encrusted fragments. The osagite is not recognized further north, but it apparently has considerable areal extent in an east-west direction. Thirty miles to the west, at the type section of Zeandale Limestone in Riley County, 5.2 feet of Osagia-coated

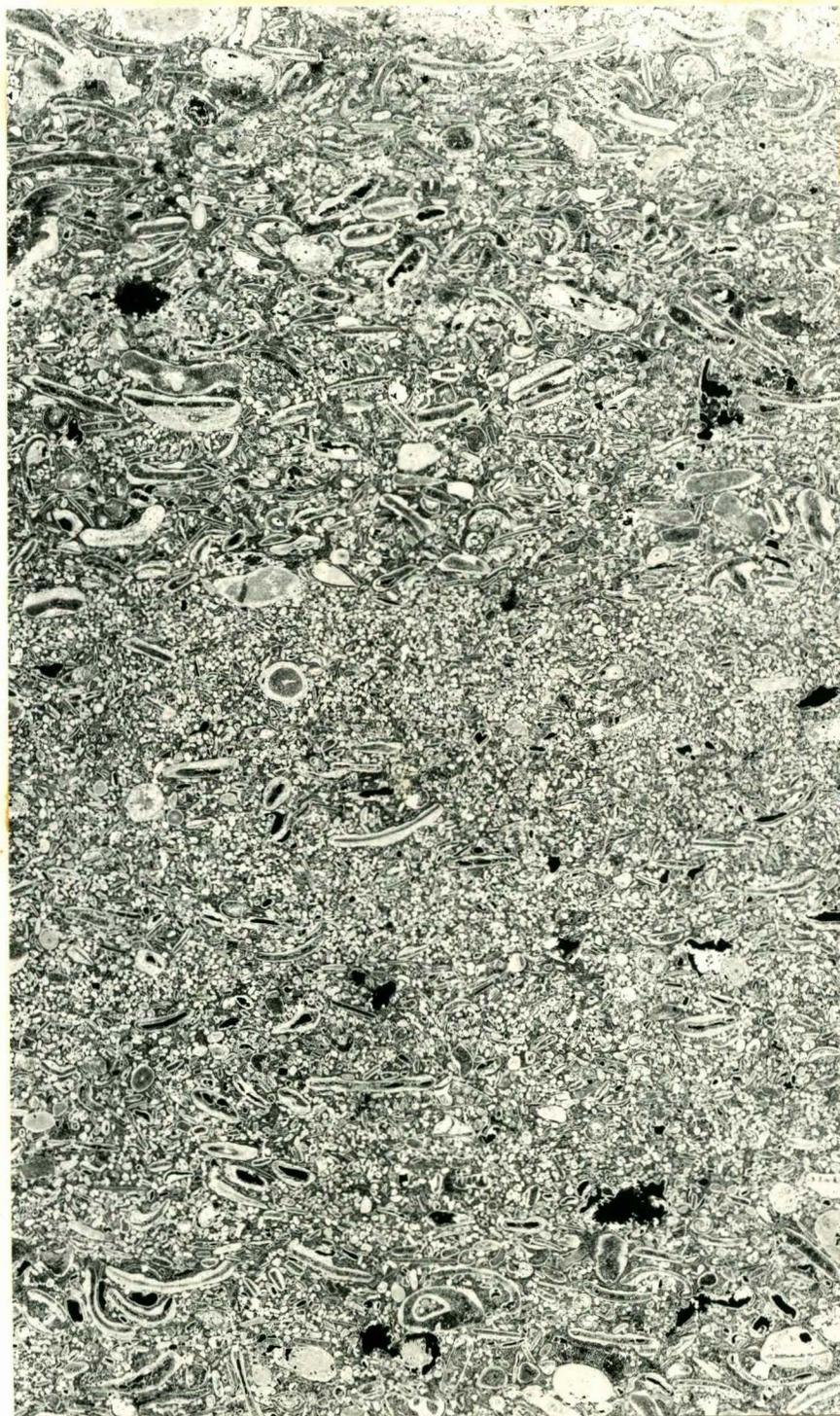


FIG. 25. Peel-print of "Tarkio Osagite" (X4) showing sub-oolitic texture and Osagia-encrusted shell fragments. (Locality 10, C Sec. 18, T. 12, S., R. 13 E.)



FIG. 26. Peel-print of "Tarkio Osagite" (X₄) from Locality 9. (CSL T. 12 S., R. 13 E.) Note coarser texture and abundance of heavily coated fusulinids.

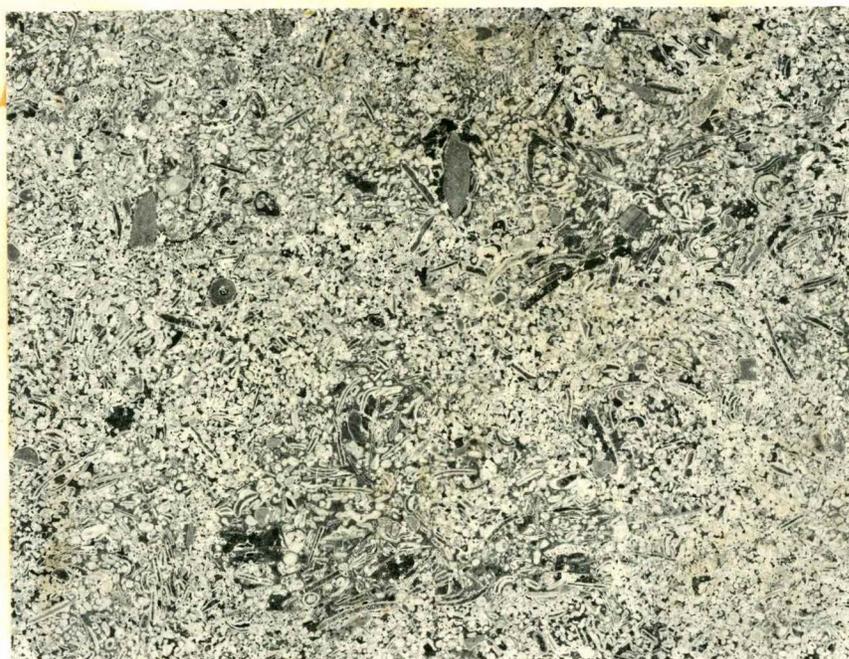


FIG. 27. Fine textured, sub-collitic appearance of "Tarkio Osagite" at northernmost exposure. X₄. (Locality 6, SW SW Sec. 29, T. 11 S., R. 14 E.)

detrital limestone is present. Figure 28 shows the similarity of texture. Locality 1, 3 miles east of Locality 8 exhibits 5.1 feet of "Tarkio Osagite" above the "Fusulinid Tarkio".

The lower 1.2 feet of the osagite bed at Locality 11 is quite sandy and generally unlike previously cited exposures. However the porous, detrital character is retained in the upper 2.2 feet. Figure 29 is a print of the "Tarkio Osagite" horizon from Locality 12, only 1.4 miles from Locality 11. The osagite character is completely lacking. This "blotched" texture is discussed more thoroughly in connection with Stormont correlation problems.

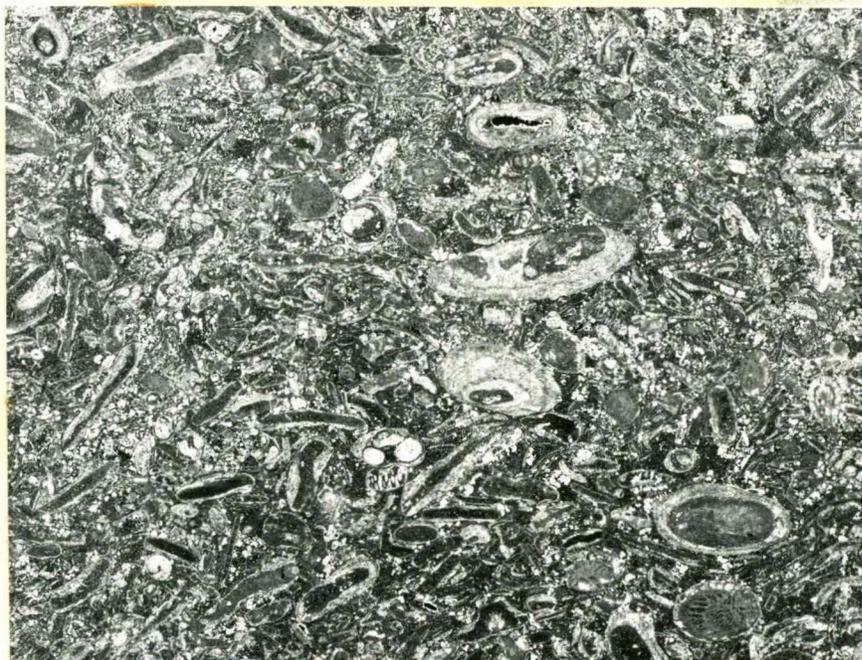


FIG. 28. Peel-print of "Tarkio Osagite" (X₄) from Zeandale type locality in Riley County. Coarse texture and Osagia-encrusted fragments are similar to Shawnee County exposures.

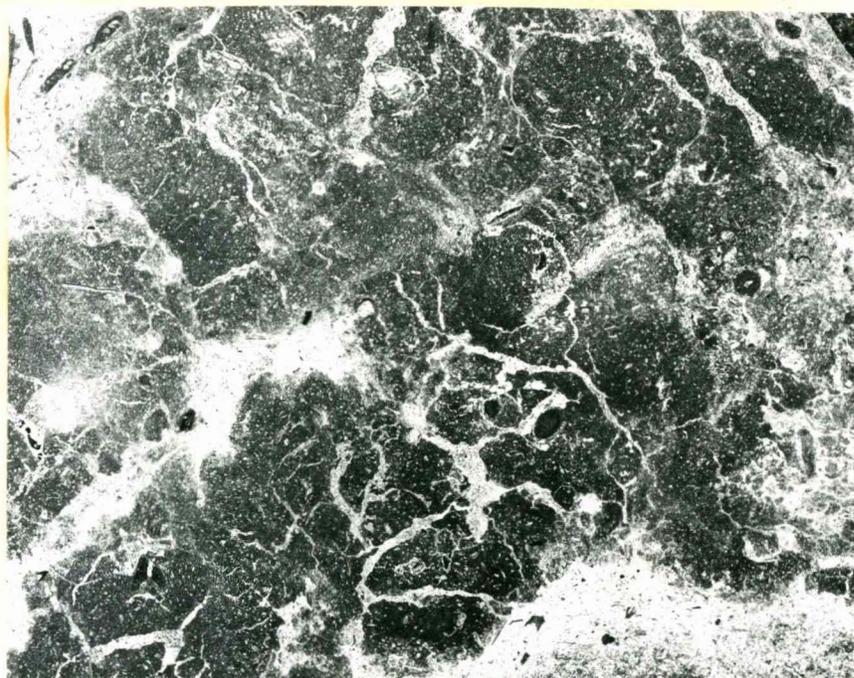


FIG. 29. "Blotched" texture of argillaceous to arenaceous basal beds of "Tarkio Osagite" at Locality 12. X₄. (CSL, Sec. 25, T. 12 S., R. 13 E.)

Stormont Limestone

Throughout Lyon and most of Osage Counties the Stormont Limestone is easily recognized on the basis of gross lithology and stratigraphic position. As previously described by O'Connor (1953, 1955), the base of the horizon ranges from 10 to 28 feet above the Tarkio Limestone. Results of this study indicate that in at least one exposure the Stormont is in direct contact with and grades into the Tarkio Limestone.

Peel-prints show moderate local variation in texture, but the microlithologies observed remain essentially constant. Figure 30 illustrates the fine, arenaceous texture typical of the upper beds of the Stormont. The lower Stormont is characterized by the "blotched" appearance shown in Figure 31.

At Locality 18 the Stormont Limestone is apparently incorporated in an abnormal thickness of Tarkio Limestone. Study of peel-prints at this exposure reveals the typical "blotched" texture of Stormont Limestone at the top of the Tarkio (Fig. 32). It is also interesting to note the similarity of the "blotching" in Figures 29, 31, and 32. Since the unit from which Figure 29 was obtained can be definitely traced into the "Tarkio Osagite", the possibility of correlation between these two apparently dissimilar lithologies is suggested. It seems inadvisable to assume such correlation on this basis alone, however.

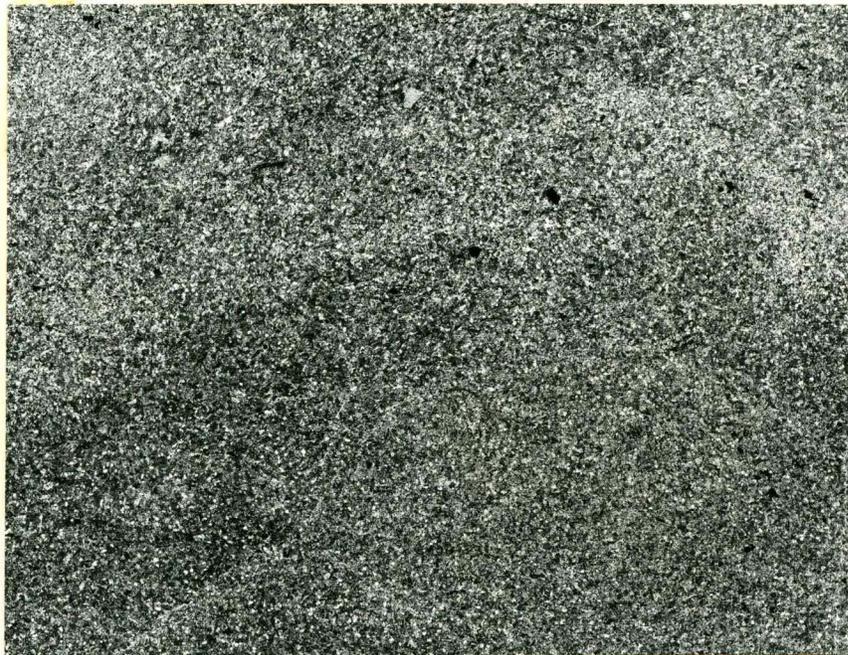


FIG. 30. Peel-print of upper bed of the Stormont Limestone (X4) showing uniform very fine arenaceous texture of the unit. (Locality 23, SW SW Sec. 11, T. 15 S., R. 13 E.)

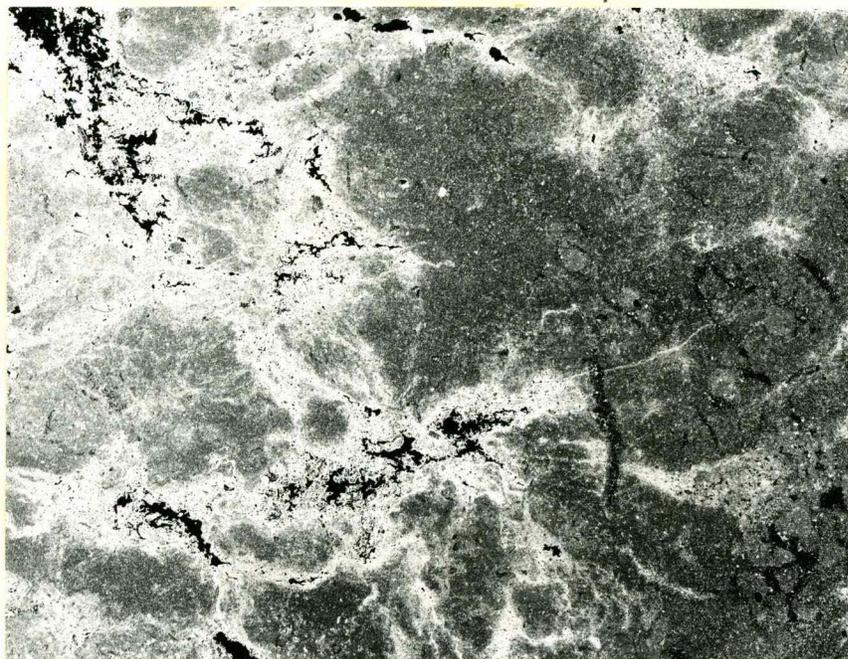


FIG. 31. Peel-print of basal bed of the Stormont Limestone showing the "blotched" texture exhibited by this unit. X4. (Locality 23, SW SW Sec. 11, T. 15 S., R. 13 E.)

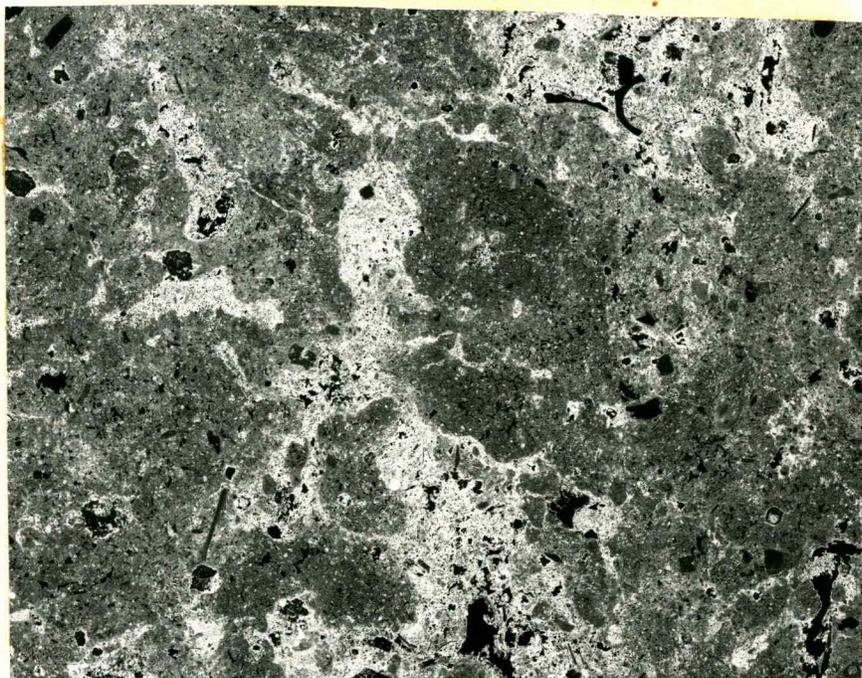


FIG. 32. Peel-print showing "blotched" texture characteristic of Stormont Limestone. Sample obtained from top of the Tarkio Limestone at Locality 18 where the Stormont is incorporated into Tarkio. (X₄)

"Grove Arenite"

North of the Kansas River in the general vicinity of Grove, Kansas, a wavy-bedded, arenaceous limestone is locally well-developed. The shale interval between top of Tarkio and base of arenite ranges from 3 to 9 feet.

The texture of this unit closely resembles upper Stormont Limestone. Figure 33 shows the typical concentration of argillaceous material in layers, resulting in a banded appearance. This banding contrasts with the irregular, spotty, concentrations of argillaceous material in the Stormont.



FIG. 33. Peel-print of "Grove Arenite" illustrating the typical concentration of included argillaceous material in layers. X4. (Locality 4, CWL, Sec. 18, T. 10 S., R. 15 E.)

The marked similarity of peel-prints suggests that the "Grove Arenite" in the north may be correlative with the Stormont Limestone in the south. These two beds occur in the same stratigraphic interval, but it is impossible to substantiate this similarity of appearance with positive proof of correlation. Nor can the "Grove Arenite" be correlated with the "Tarkio Osagite". The 5-mile wide area between critical exposures of the two units lies in the floodplain of the Kansas River and the beds have been removed by erosion.

Wamego Shale

No persistent microlithologies in the few well-consolidated strata of the Wamego Shale were found in the acetate peel study. Consolidated calcareous zones were sampled and studied in an attempt to establish some basis for correlation by microlithology. A typical peel-print of a fossiliferous limy zone is illustrated in Figure 34. Occasionally these strata could be definitely correlated between two sections, but the irregularity of the lithology resulted in marked difference in the appearance of the acetate peels.



FIG. 34. Calcareous zone Wamego Shale. Note concentration of argillaceous material within the brachiopod shells. X4
(Locality 19, NE Sec. 9, T. 14 S., R. 13 E.)

Maple Hill Limestone

The texture and lithology of the Maple Hill Limestone is essentially uniform from north to south. However, the content of argillaceous material increases toward the pinch out near Emporia. The basal contact is transitional in almost every exposure. The high percentage of argillaceous material and the abundance of brachiopod shell fragments and spines near the base are clearly shown in Figure 35.

Fusulinids and crinoid remains dominate the faunal assemblage above the basal 6 inches in the Shawnee County area (Fig. 36). A localized microlithology was discovered in sections 8 and 9 near the Kansas River. Figure 37 shows the dense, fine-grained texture and dark algal (?) circles and bands. This microlithology could not be identified at other localities.

Argillaceous texture along with a reduced quantity of fusulinids and an abundance of encrusting algae is typical of the southernmost exposures (Fig. 38). Algae are common in the upper part of the bed throughout most of Lyon and Osage Counties. Ottonosia is more or less abundant at the top of this unit.

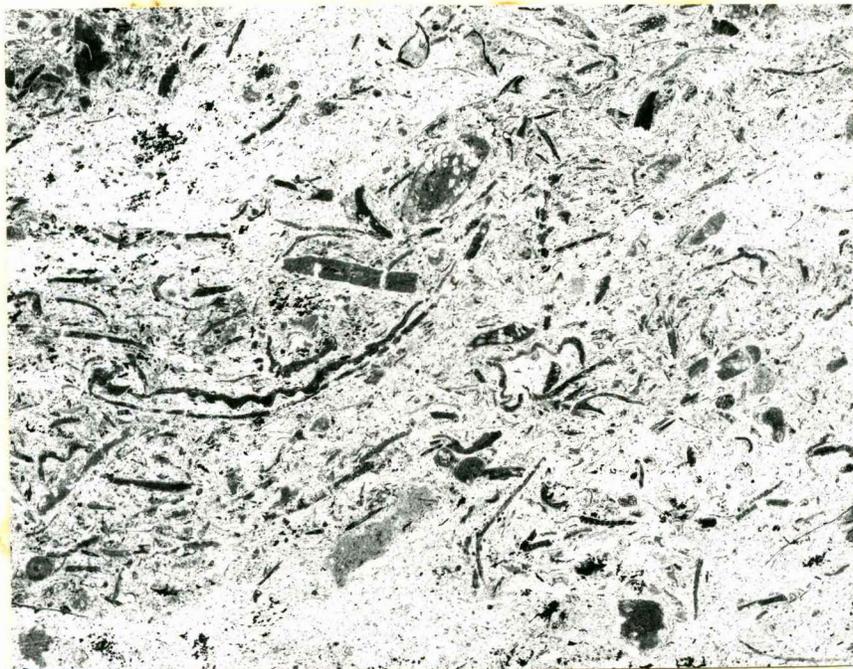


FIG. 35. Peel-print of Maple Hill Limestone showing abundance of brachiopod fragments and spines near the base. X4. (Locality 21, NE Sec. 30, T. 14 S., R. 14 E.)



FIG. 36. Typical texture of Maple Hill Limestone in northern exposures showing abundant fusulinids, gastropods, crinoid columnals, spines and shell fragments. X4. (Locality 8, SW SW Sec. 29, T. 11 S., R. 14 E.)



FIG. 37. Localized development within Maple Hill member. Dark circles and bands are algal (?). Occasional fusulinids and brachiopods are found. X4. (Locality 9, CSL SE Sec. 12, T. 12 S., R. 13 E.)

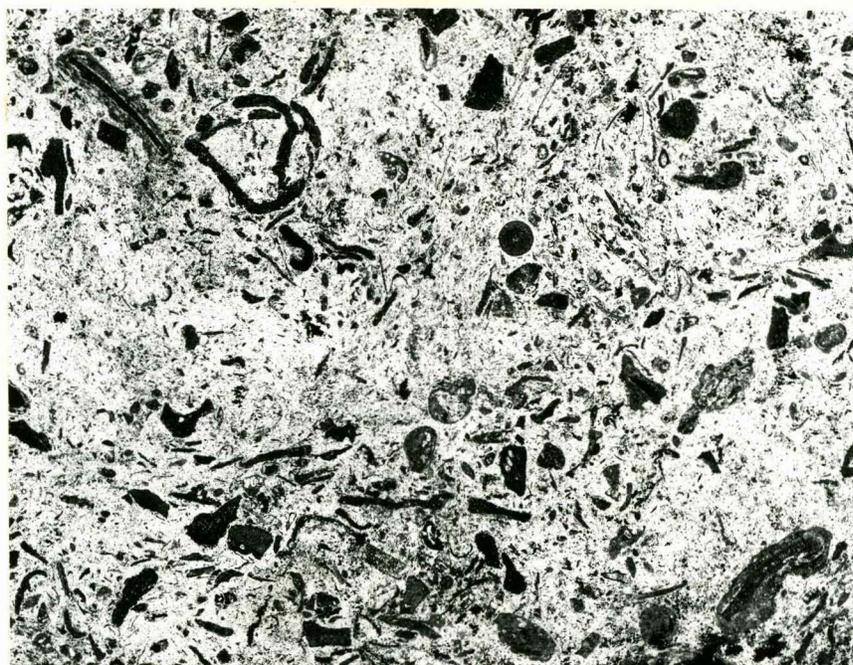


FIG. 38. Peel-print illustrating argillaceous texture of Maple Hill near the last recognized exposure at Emporia. X4. (Locality 31, CSL Sec. 3, T. 19 S., R. 11 E.)

Insoluble Residue Study

Insoluble residues are the materials remaining after the digestion of calcareous rock in acid. Hydrochloric acid was used in this study because of its relatively rapid digestion time. Wahrhaftig, (1952, p. 20) compared samples prepared with both acetic and hydrochloric acid and noted no difference in the quality or quantity of the residue. However, Ireland (personal communication, May, 1959) has discovered that phosphatic remains which are destroyed in hydrochloric acid can be obtained by using an acetic acid treatment.

Table 1 shows a classification of the insoluble residues of the Zeandale Limestone. Each of the constituents is discussed under its proper heading. Appendix D is a tabulation of the percentages of all the insoluble residues prepared in this study. The weights from which percentages were computed have been omitted from Appendix D for the sake of simplicity. Generally weight of the original sample was 20 grams, but occasionally as much as 30 grams was used.

The percentage of coarse-fraction constituents from each sample is tabulated in Appendix C using the descriptive terminology of Ireland, et. al. (1947).

A summary of results from the residue study for each member of the Zeandale Limestone is included following Table 1.

Table 1. Classification of the insoluble residues of the Zeandale Limestone. *

I. Allogenic--Constituents derived from previous sediments.

1. Quartz sand
2. Feldspar
3. Mica flakes, chiefly muscovite
4. Silt, clay, and argillaceous material

II. Authigenic--Constituents formed contemporaneous with or subsequent to deposition of the sediments.

A. Syngenetic--Contemporaneous constituents

1. Fossils
2. Glauconite
3. Carbonaceous material

B. Epigenetic--Subsequent constituents

1. Secondary quartz
2. Silicified fossils
3. Beekite

C. Syngenetic or Epigenetic

1. Pyrite
2. Magnetite
3. Limonite
4. Chert
5. Gypsum
6. Celestite

*Classification modified from Ireland (1936).

Tarkio Limestone

The total insoluble residues in the Tarkio Limestone range from 2.7 percent at Locality 1 to 48 percent at Locality 12, averaging approximately 10 percent. It is interesting to note that the average percentage of total residue increases to the south. In the Kansas River area the average is 7 to 8 percent. At the most southerly recognized exposure of Tarkio (Locality 26) the residue percent is 18.6.

Iron oxide was removed from samples of Tarkio Limestone by boiling the residue in hydrochloric acid. Percentages computed from representative sections revealed that iron oxide composed as much as 13.7 percent of the original sample and 66.7 percent of total residue. The average iron oxide content is 30 percent of the residues prepared from fresh samples. Greatest amounts of iron oxide are found in southern Shawnee County and in the vicinity of the Kansas River.

The coarse fraction ranges from 0.1 percent to 28.7 percent, averaging about 3.5 percent. Wahrhaftig (1952, p. 57) suggests that the very low percentage of coarse residue and the high iron oxide content can be used to distinguish the Tarkio Limestone from other Wabaunsee limestone formations.

Dominant constituents of the coarse fraction are very fine, subangular to subround, frosted quartz sand, arenaceous

foraminifers and clay aggregates; the remaining constituents are chiefly pyrite, celestite, mica flakes, and silicified fossil fragments. In a given sample, one or more of these minor constituents may comprise a majority of the total residue.

It is possible to distinguish the well-developed "Tarkio Osagite" in the Kansas River area on the basis of insoluble residues. The 5.7 percent average total residue is smaller than the 10 percent average noted in the typical Tarkio. A more significant observation is the marked increase in the average percentage of the coarse constituents. The average from the "Tarkio Osagite" is 23.7 percent as compared with 3.5 percent in the typical Tarkio. In addition, arenaceous foraminifers, which are less abundant in the fusulinid bearing Tarkio, become the dominant constituent of the coarse fraction in the "Tarkio Osagite". They commonly form 70 percent of the total residue, and average over 55 percent.

Stormont Limestone

The insoluble residues of the Stormont Limestone range from 9.5 to 66.2 percent of the original sample. The Stormont lithology is variable and as a result the residue percentages are not uniform. However, the percentage of total residue is almost always much higher than other beds studied, averaging about 22.7 percent. The residue content increases irregularly from north to south.

The coarse fraction averages 38.8 percent of total residue, ranging from 11.2 percent at Locality 19 to 93.8 percent at Locality 29. The coarse-fraction constituents of the Stormont Limestone are characterized by an abundance of very fine, subangular to subround, loose, sand grains composed chiefly of feldspar and quartz. Stormont residue is occasionally composed of 90 percent sand. Arenaceous foraminifers and muscovite are always present, but amounts vary. Clay aggregates make up a large proportion of the residue in some samples, but are not characteristic of the unit.

One of the primary objectives of this insoluble residue study was to establish with more certainty the stratigraphic relationship of the Stormont and the arenaceous beds of southern Shawnee County ("South Shawnee Arenite"). Analysis of the residue from Locality 17 shows that both the total residue and the coarse-fraction (34.8 and 48.3 percent respectively) are higher than the Stormont average, and considerably above the Stormont at Localities 18, 19, and 20. In addition, there are no arenaceous foraminifers in the arenaceous beds at Locality 17. Known Stormont samples contain an average of 17 percent arenaceous foraminifers. It should be pointed out, however, that the size, shape, and composition of the sand from the "South Shawnee Arenite" is similar to those of Stormont residues.

Analysis of the residue from the "Grove Arenite" in Localities 4 and 5 show that insoluble residue comprises

52.9 percent of the original sample. The coarse fraction forms 74.2 percent of the total residue. The situation here is similar to that described for Locality 17. Although the constituents are comparable except for a complete lack of arenaceous foraminifers, the percentages of total and coarse-fraction residues are even further from the average of Stormont insoluble residues.

Maple Hill Limestone

The percent of total residue in samples of Maple Hill Limestone ranges from 5.5 at Locality 7 at the Kansas River to 20.6 at Locality 19 in northern Osage County, averaging about 12.7 percent. The residue percent of Maple Hill Limestone as noted by Wahrhaftig (1952, p. 59) ranges from 23 percent in sample B-M24 to 36 percent in sample B-M1. These figures are considerably higher than those for any samples of Maple Hill collected for this study.

The writer has visited the exposure described by Wahrhaftig (op. cit.). There is no doubt that the rocks identified as Maple Hill Limestone at this locality are actually Stormont Limestone. This explains the unusually high residue percentages previously reported.

The average of the coarse fraction of the insoluble residues in the Kansas River area is 14.9 percent. However, throughout the remainder of the area of study the average is only about 7 percent. The unusually high residue percent in the vicinity of the Kansas River is due to the high percentage

of the heavy minerals celestite and pyrite. Fine subangular to subround, frosted sand, foraminiferal fragments, and muscovite commonly form the dominant constituents of the coarse residue. Minor amounts of beekite, carbonaceous material, and clay aggregates are often present.

The insoluble residues of the Maple Hill Limestone do not possess any unique characteristic on which correlation could be based.

Acid Etched-Block Study

In the present study, only a limited number of limestone blocks were prepared according to the techniques set forth by Lamar (1950) and Ives (1955) for etched-block observation. However, each of the partially etched blocks used for the preparation of acetate peels was studied in detail under the binocular microscope.

Etched-blocks contributed little information on texture, grain-size, and arrangement of non-carbonates which may not be obtained by previously described techniques.

The nature and arrangement of coliths in the porous "Tarkio Osagite" was more readily distinguished on the etched surface than from the acetate peels. However, more compact units were described with equal accuracy from the peel surface.

It was observed that although the orientation of insoluble material is readily determined on the etched block, it is difficult to estimate the percentage of this material.

Thin-Section Study

The sub-collitic nature of the "Tarkie Osagite" was well illustrated in the thin-sections. The details of the encrusting Osagia could be best observed in this method of analysis. Note the successive layers coating the shell nucleus in Figure 39.

The higher magnifications of the polarizing microscope reveal a very thin algal coating around some of the sand grains in the Stormont Limestone at Locality 23. Thin-sections of the "Grove Arenite" do not exhibit this feature. Possibly a more detailed study would present more evidence concerning possible correlation of these units. The abbreviated study here completed, however, will neither confirm nor deny this possibility.

In the opinion of the author, results of this study indicate that detailed sampling and preparation of thin-sections would not significantly add to the knowledge obtained by other methods with the possible exception noted above.

Inasmuch as a considerably larger area can be observed on both the acetate peels and the etched-block surfaces, these methods of analysis are judged to be superior to thin-sections for ordinary micro-texture description. In addition, the time required for their preparation and study is considerably less.

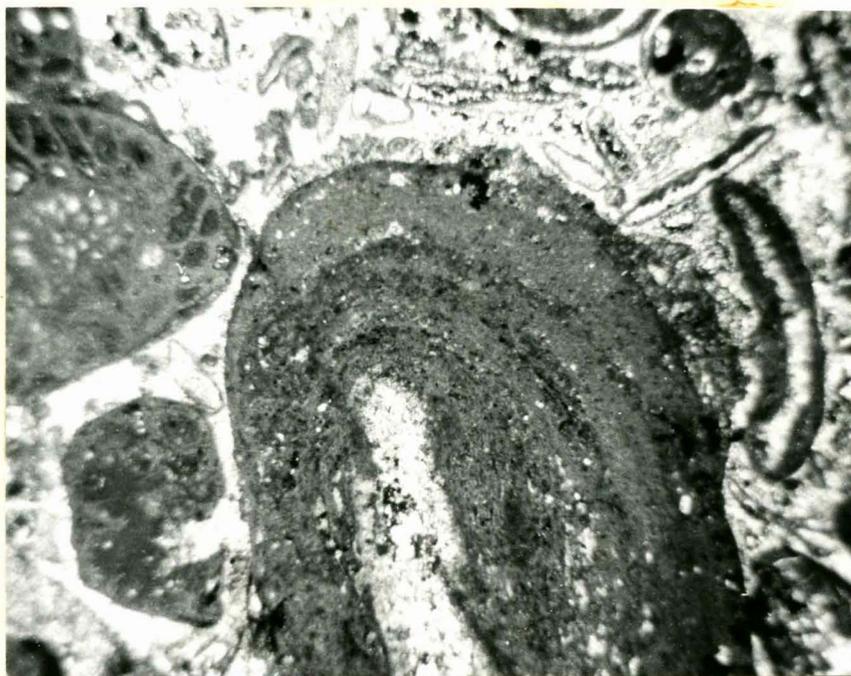


FIG. 39. Photomicrograph of *Osagia*-encrusted shell fragment. Approximately X70 (Locality 1, SE NE NE Sec. 28, T. 10 S., R. 9 E.)

Shale Study

In an effort to determine the correct relationship between Stormont, "Tarkio Osagite", "South Shawnee Arenite", and "Grove Arenite", the shale samples between the Tarkio and the above units were examined.

The washed residue from Localities 5 and 17 are found to be remarkably similar. Lithologically and mineralogically Locality 11 is also similar, but abundant ostracods characterize the unit at this exposure. Further to the south, beneath beds definitely identified as Stormont, the shale is silty and contains poorly preserved spines and shell fragments.

This problem was discussed more thoroughly with the stratigraphy of the Stormont Limestone.

Abundant marine fossils were found in the lower 3.5 feet of the Wamego Shale at Locality 8. These were mainly shallow-water invertebrates including Juresania, ramose and fenestrate bryozoans and abundant ostracods. On the other hand, no fossils were found in the lower Wamego at Localities 5, 15, and 17.

Ostracods and plant fragments were found associated with the underclay-like material just below the Maple Hill Limestone in Locality 19. At Locality 5, plant fragments alternating with underclay material are abundant 1.7 foot below the Tarkio Limestone.

The value of this shale study lies in the information obtained pertaining to the interval between the Tarkio and arenaceous units in the general Stormont position.

ZEANDALE CYCLOTHEMS

Introduction

Moore (1950) has classified the strata of the northern Midcontinent region into simple and complex sedimentary cycles. The complex cycles are characterized by megacyclothems, that is, regular sequences of incomplete cyclothems. Cycles of the Wabauensee Group are much more simple, exhibiting a regular succession of beds from nonmarine sandstone to shale, underclay, coal, marine shale and lime-

stone. Moore, (1935, p. 25) describes the members of a typical Wabaunsee cyclothem as shown in Table 2.

Table 2. Members of typical Wabaunsee group cyclothem.
(after Moore, 1935)

- .8--.9 Shale, mostly unfossiliferous, marine or nonmarine.
- .7 Limestone, light-gray, algal, in many cases sandy to conglomeratic, or coquinoid, locally oolitic, may contain numerous mollusks, marine.
- .6 Shale, commonly somewhat sandy, marine.
- .5 Limestone, blue to gray, weathers brown, granular to dense, massive, contains more or less abundant fusulinids, less commonly brachiopods, bryozoans, and crinoid remains, marine.
- .4 Shale, clayey, in many cases with rich molluscid fauna, marine.
- .3 Limestone, blue-gray, dense to shelly, contains numerous mollusks, especially pelecypods, and some brachiopods, crinoid remains, etc., marine.
- .2 Shale, clayey, commonly contains Myalina and other pelecypods, Derbyia, Chonetes, Lincolproductus, and bryozoans, marine.
- .1c Coal, continental
- .1ab Shale, sandy to clayey, top few inches in some cases constituting underclay of the coal, may contain plant fossils, continental.
- .0 Sandstone, shaly to massive, may contain fragments of plants, continental.

Wabaunsee cyclothem are characterized by a dominance of clastics over limestone, however, in general, the thin limestones and coals persist over a wide area.

The Zeandale Limestone includes the regressive phase of the Tarkio cyclothem and the transgressive phase of the

Maple Hill cyclothem, but the complete sequence of the ideal cyclothem is seldom, if ever, observed at a single exposure. A more detailed discussion of individual members follows.

Maple Hill Cyclothem

Moore, (1935, 1950, 1957) cites the Maple Hill Cyclothem as the typical Wabaunsee cyclic sequence. Figure 40 illustrates the relationship between the cyclothem units and the stratigraphic units (after Moore, 1950). Phases .0 through .2 are found in the Wamego Shale member, phases .3 through .7 in the Maple Hill Limestone member, and the thick .8 and .9 phases in the Pillsbury Shale.

In the area covered by this report, no exposures were found in which all of the ideal units are represented. For example, the basal sandstone was recognized only at Locality 28, but the silty shale and underclay of the .1ab phase are almost always present. The .1c or coal phase is found in varying degrees of development in southern exposures, but it is not recognized north of Locality 20 in Osage County.

The molluscan .3 member of the Maple Hill Cyclothem is definitely recognized only at Locality 21. A more abundant molluscan fauna in the base of the Maple Hill Limestone in other sections is interpreted as representing this phase. Likewise the presence of encrusting algae in the upper one-quarter of the bed may signify the regression of Maple Hill seas. The algae may be interpreted as being related to the

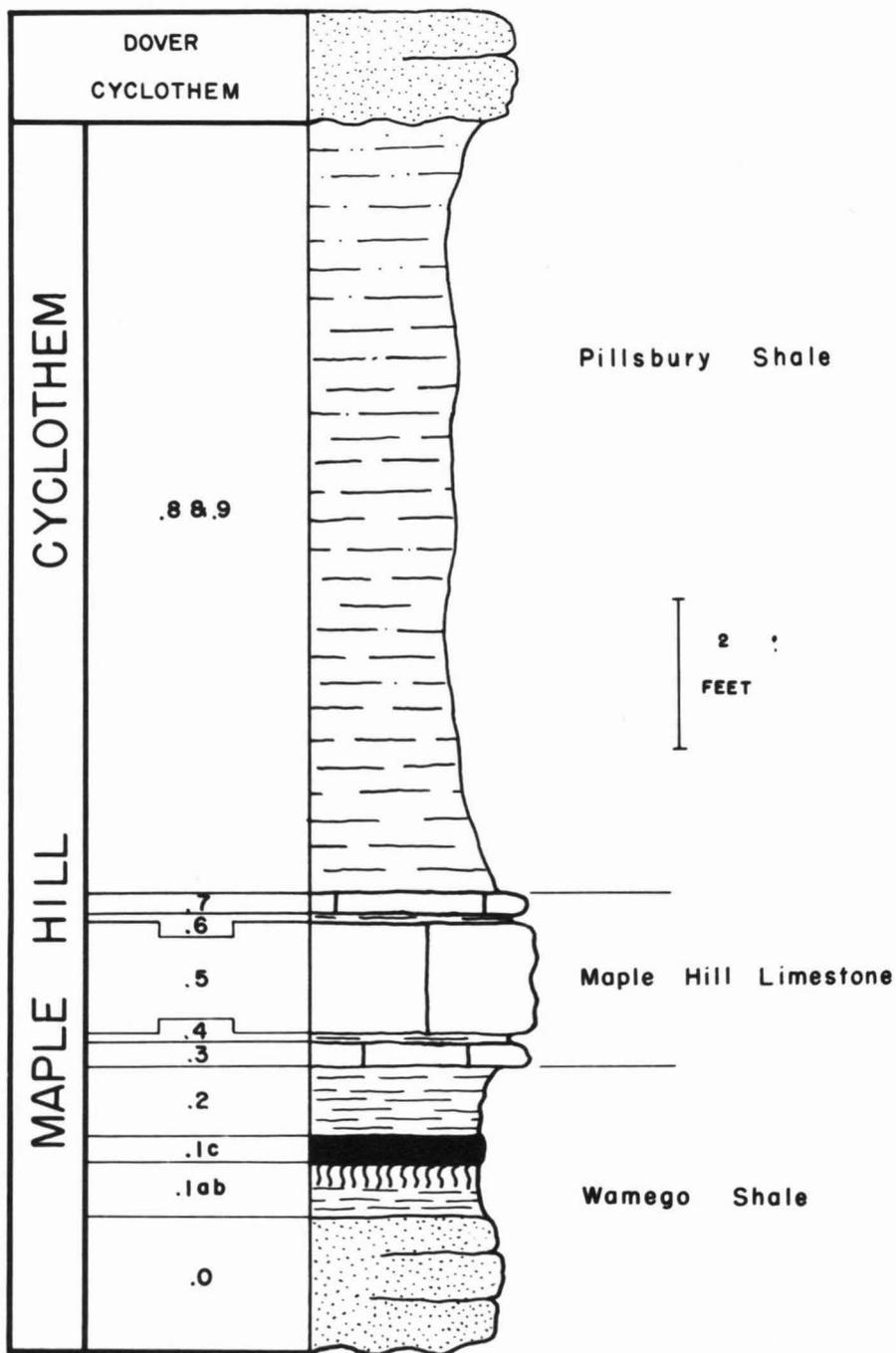


Fig. 40. Graphic section of Maple Hill Cyclothem showing ideal succession of cyclic phases (after Moore, 1950).

.7 phase, but if this is true, the .6 phase is not present. The .8 and .9 members in the Pillsbury Shale were not studied in detail.

Tarkio Cyclothem

Figure 41 is a graphic representation of selected exposures of Zeandale Limestone showing the relationship between the cyclic members and the stratigraphic members in the Tarkio Cyclothem. Cyclic members .0 through .2 are found in the Willard Shale, and the Tarkio Limestone represents the .5 and possibly the .3 members. The remaining cyclic members are found in the Wamego Shale.

The nonmarine sandstone, phase .0 of the typical cyclothem, is seen only at Locality 3. However, silty strata identified as the .1ab nonmarine phase are always present. The underclay is rarely developed in the Tarkio cycle. It was observed only at Locality 5. Plant imprints and carbonaceous streaks are found within the clay.

The initiation of marine conditions is theoretically marked by the appearance of phosphatic inarticulate brachiopods, but shale identified as the .2 phase is generally unfossiliferous in the Tarkio Cyclothem. Molluscan faunas are observed only at Locality 21. Elsewhere the boundary of the .2 member was placed at the first appearance of calcareous shale.

Inasmuch as the .3 and .4 phases are not definitely recognized, the transgression to maximum sea depth was

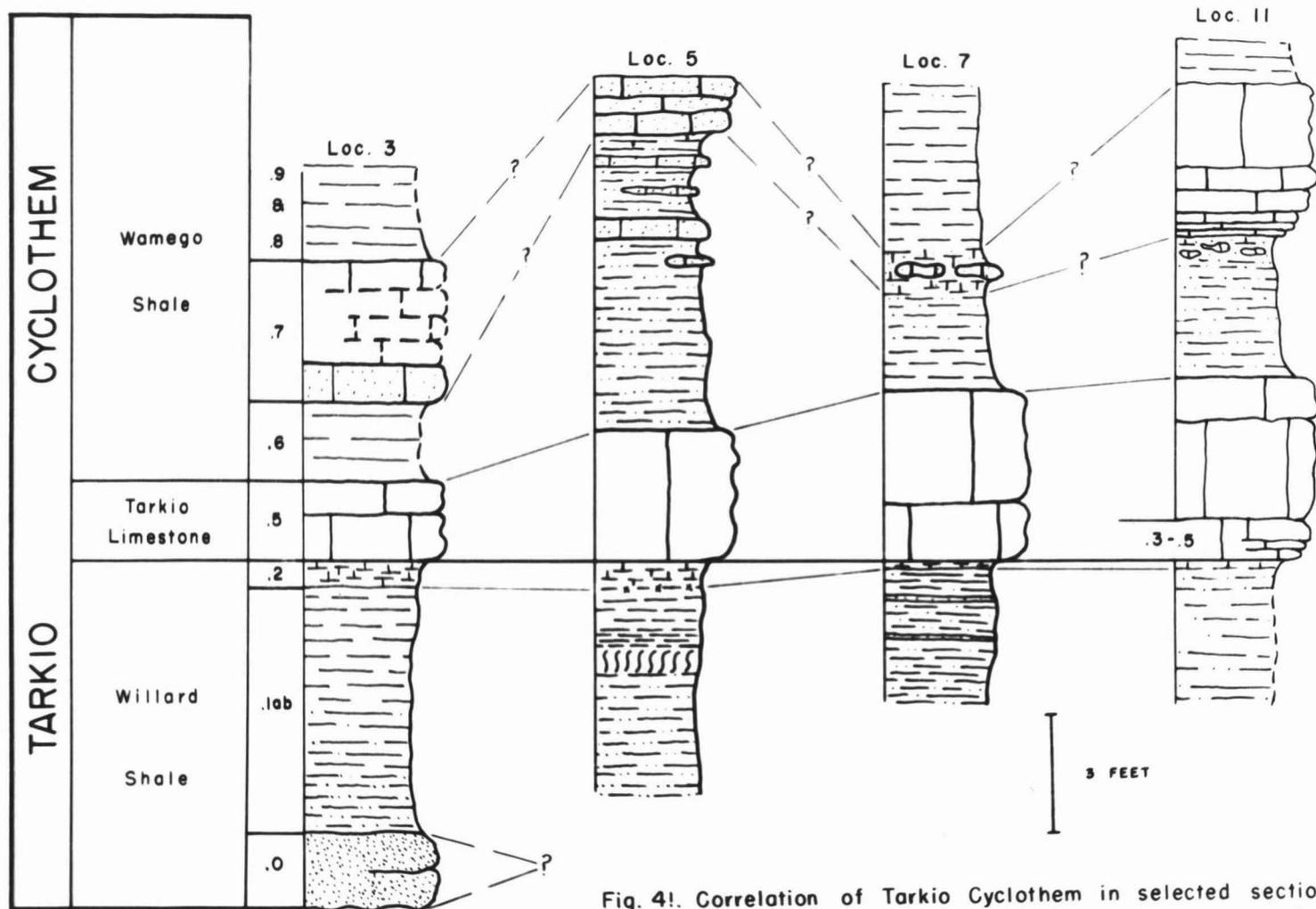


Fig. 4!. Correlation of Tarkio Cyclothem in selected sections.

apparently very rapid. Numerous brachiopods and crinoid remains occur in the basal part of the Tarkio Limestone at some localities and are interpreted as probably representing the short-lived .3 phase. The .5 member indicating maximum transgression is always well-developed.

Members .6 through .9 of the regressive phase are well represented in the vicinity of the Kansas River. The cyclic significance of the arenaceous limestones at Locality 5 is uncertain. Although the position and general lithology correspond to the description of the .7 member, there are no algae in the bed (Fig. 40). Nevertheless this bed is tentatively assigned to the algal-molluscan .7 position. No fossils are observed in .8--.9 shale which is generally brown-green to yellow-gray. It was not possible to determine the marine or nonmarine origin of these phases.

The members of the Tarkio cyclothem are generally well-developed in the vicinity of the Kansas River. They are poorly-defined and difficult to recognize in Osage County.

Summary

The existing literature emphasizes the remarkable uniformity of the cyclic units in the northern Midcontinent region. A broad, regional study would undoubtedly lead to this conclusion. However, if the area studied in this report is a representative one, the details of local

stratigraphy are often complex and the postulated persistence of units does not exist.

Nevertheless, the cyclic character of the Zeandale strata is irrefutable. Absence of one or more phases of the typical cyclothem in a given area, or the appearance of "extra" beds, does not invalidate the concept.

The ultimate cause of cyclic sedimentation is unknown at the present time. A discussion of the various theories will not be attempted here. The interested reader is referred to Moore (1929, 1957), Weller (1931, 1956) Stout, (1931), van der Heide (1948) and Wanless and Shepard (1937).

SUMMARY AND CONCLUSIONS

1. The Zeandale Limestone (Virgilian Series, Wabaussee Group) contains three generally recognized members which can be distinguished on the basis of gross lithology. In descending order they are the Maple Hill Limestone, the Wamego Shale, and the Tarkio Limestone.

2. The Zeandale is bounded by the overlying Pillsbury Shale and the underlying Willard Shale.

3. The thickness of the Zeandale Limestone increases to the south.

4. The Zeandale forms a prominent escarpment in Shawnee County, and exposures are good in this area. However, the predominance of clastics in the Zeandale interval to the south results in little or no topographic elevation.

5. In the area of study the Maple Hill Limestone member is relatively constant in thickness and lithology, but it is not recognized south of Emporia in central Lyon County.

6. The Wamego Shale member is divided into two parts in Osage and Lyon Counties by an arenaceous limestone called the Stormont Limestone.

7. The Stormont Limestone is incorporated in an abnormal thickness of Tarkio Limestone at Locality 18, and is not definitely recognized north of this exposure.

8. Where the Stormont is present, the shale below is called Wamego₁, and the shale above is called Wamego₂. The Wamego₂ is characterized by two calcareous, fossiliferous zones.

9. The Tarkio Limestone member may be tentatively identified in the field by the presence of very large, robust, Triticites ventricosus.

10. The Tarkio Limestone member thins southward to a feather edge and is not recognized south of T. 17 S. in Osage County.

11. South of the point where the Tarkio pinches out the interval is called Willard-Wamego Shale. South of Emporia where the Maple Hill is not recognized, the interval is called the Willard-Pillsbury Shale.

12. Acetate peel and insoluble residue studies are superior to other types of sedimentary analysis for this type of study. Etched-blocks, and thin-sections did not

contribute significantly to the knowledge previously obtained.

13. The several distinctive microlithologies that were recognized from the study of acetate peel were often not coextensive with named stratigraphic units.

14. The Tarkio Limestone may be identified with reasonable accuracy on the basis of the very low percentage of coarse-fraction and high iron oxide content in the insoluble residues.

15. The Stormont Limestone is characterized by a very high percentage of subangular to subround, very fine sand grains of feldspar and quartz, in the coarse fraction of the insoluble residues.

16. A massive Osagia bearing bed which is separated by shale from the Tarkio Limestone in southern exposures (e.g. "Tarkio Osagite") can be traced northward into the Tarkio "type" locality, and therefore is described as a part of the Tarkio Limestone in this report.

17. On the basis of sedimentary analysis and field evidence, the arenaceous beds in Shawnee County (e.g. "Grove Arenite" and "South Shawnee Arenite") have been placed in the Wamego Shale and are probably not equivalent to either the Stormont Limestone or the "Tarkio Osagite".

18. The faunas of the Tarkio and Maple Hill Limestones are characterized by a dominance of fusulinids. This is interpreted as representing deposition in a far off-shore, marine environment.

19. The fauna of the Stormont indicates a near-shore, marine, depositional environment.

20. The fossiliferous, calcareous zones within the Wamego Shale may represent minor advances and retreats of a shallow sea.

21. The increase in clastic material to the south suggests an approach toward a shoreline. The source may have been in this direction, but other possible source directions cannot be eliminated from the results of this localized study.

22. The Zeandale strata comprise the regressive phase of the Tarkio Cyclothem, and the transgressive phase of the Maple Hill Cyclothem. The "ideal" Wabaunsee cyclic sequence is not completely developed in any single exposure.

23. Underclay and coal representing the .1ab and .1c phases of the Maple Hill Cyclothem persist throughout most of Lyon and Osage Counties. The underclay is seen to the north in some Shawnee County sections, but coal is not observed.

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APPENDIX A

MEASURED SECTIONS OF ZEANDALE LIMESTONE IN NORTHEASTERN KANSAS

Locality 1

Type section of Zeandale Limestone. SE NE NE Sec. 28, T. 19 S., R. 9 E., Riley County, along north-south farm access road south of Deep Creek to top of hill.

	Thickness feet
Zeandale Limestone (36.9 feet)	
Maple Hill Limestone member (1.9 feet)	
10. Limestone, light blue-gray, weathers light buff-brown, hard, very fine grained, thin-bedded; abundant slender fusulinids, <u>Ottonosia</u> algae, brachiopod fragments	1.9
Wamego Shale member (15.6 feet)	
9. Shale, brown, calcareous, fissile, grades into Maple Hill . . . . .	.4
8. Shale, blue-gray, clayey, in part underclay-like, alternating with carbonaceous material	3.6
7. Shale, green-brown, blocky, abundant <u>Lingula</u>	9.3
6. Shale, gray-brown, platy, no fossils observed	2.3
Tarkio Limestone member (10.4 feet)	
5. Limestone, dark gray-brown, weathers very dark brown, moderately hard, medium to fine grained, thin to medium wavy bedded; <u>Osagia</u> very abundant, large robust fusulinids and brachiopod fragments, abraided and algal coated, crinoid columnals	5.2

Locality 1 (Cont'd)

	Thickness feet
4. Limestone, light gray with red cast, weathers dark gray-brown, hard, very finely crystalline, massive, stylolites, vuggy; numerous large robust fusulinids, crinoid columnals, <u>Osgagia</u> at top, scattered shell fragments	2.5
3. Limestone, light red-gray, weathers light yellow-tan, very hard, very finely crystalline, thin, wavy bedded; large fusulinids in relief, <u>Lophophyllidium</u> brachiopods, crinoid columnals, <u>Ottonosia</u> algae	2.7
Willard Shale (29.7 feet)	
2. Shale, mostly covered, interval approximate	29.7
Emporia Limestone	
Elmont Limestone (2.1 feet)	
1. Limestone, blue-gray to light gray, weathers light tan-brown, hard, medium to coarse crystalline base, fine and conglomeratic at top; <u>Derbyia</u> , other brachiopods and pelecypods	2.1

Locality 2

Section measured in the NE Sec. 2, T. 10 S., R. 14 E., Shawnee County, in gullies above stock pond and in stream to south.

Zeandale Limestone (24.9 feet)

Maple Hill Limestone member (1.4 feet)

- | | |
|--|-----|
| 14. Limestone, red-gray, weathers gray-tan, hard, slabby; crinoid columnals, slender fusulinids, pelecypods, small <u>Neospirifer</u> and other brachiopods, bryozoans, very abundant <u>Ottonosia</u> in upper half | 1.4 |
|--|-----|

Locality 2 (Cont'd)

	Thickness feet
Wamego Shale (21.2 feet)	
13. Shale, dark gray, clayey, siltstone partings	5.0
12. Shale, black, platy . . . . .	.2
11. Shale, medium gray, clayey, plant remains in upper part	5.3
10. Shale, dark gray, blocky	2.0
9. Limy, shale nodules, yellow-brown, non resistant; pectenids, brachiopods, crinoid columnals . . . . .	.4
8. Shale, green to yellow-brown, clayey, mostly covered	4.8 =
7. Limestone, yellow-buff, irregular, non resistant, gastropods, brachiopods, crinoid columnals, pelecynods, spines, all very abundant	1.3 =
6. Covered interval	2.2
Tarkio Limestone member (2.3 feet)	
5. Limestone, dark brown to gray-brown, weathers light yellow-brown, massive; <u>Echinoconchous</u> , <u>Meekella</u> , and other brachiopods, small horn corals, <u>Osagia</u> , <u>Ottonosia</u> , ramose bryozoans, crinoid columnals at top, sparse fusulinids in lower one foot, abundant elsewhere . . .	2.3
Willard Shale (7.1 feet exposed)	
4. Shale, green-gray, silty, calcareous, nodular at top, grades into Tarkio . . .	.6
3. Shale, yellow-brown to gray, clayey, no fossils observed	1.5

Locality 2 (Cont'd)

	Thickness feet
2. Shale, dark gray, silty, micaceous, upper half more clayey with numerous plant fossils and carbonaceous material . . .	2.0
1. Shale, dark gray, silty, very hard . . .	3.0

Locality 3

Section measured CSL SW of Sec. 9, T. 10 S.,
R. 15, E., Shawnee County, in east-west road NE
of large stock pond and in gullies above pond to
east.

Zeandale Limestone (14 feet)

Maple Hill Limestone member (over 1 foot)

13. Limestone, dark blue-gray, weathers brown-gray, very finely crystalline; brachiopod spines and shell fragments abundant, crinoid columnals, <u>Ottonosia</u> at top, small horn corals	1.0
--	-----

Wamego Shale member (11 feet)

12. Covered interval	5.3 ±
11. Limestone, yellow-brown, argillaceous, poorly exposed, irregular, thin-bedded; no fossils observed	2.7
10. Limestone, buff-brown, weathers dark red-brown, arenaceous; large crinoid columnals, productid brachiopods, <u>Ottonosia</u> at top	1.0 ±
9. Covered interval	2.0 ±

Locality 3 (Cont'd)

	Thickness feet
Tarkio Limestone (2 feet)	
8. Limestone, gray-brown, weathers light gray to yellow-brown, dense, medium-bedded; very abundant large robust fusulinids, large crinoid columnals, echinoid plates, <u>Ottonosia</u> . . . . .	.8
7. Limestone, medium gray, weathers light yellow-brown to gray-brown; fusulinids in relief, crinoid columnals, brachiopod fragments	1.2
Willard Shale (30 feet exposed)	
6. Shale, brown to yellow-brown, earthy, calcareous; no fossils observed . . . . .	.6
5. Shale, gray and yellow, silty to clayey, micaceous	1.0
4. Shale, gray-purple, limonite stained, silty to sandy, micaceous, with small ironstone concretions	6.6
3. Sandstone, very fine grained, poorly consolidated, micaceous, non-calcareous; contacts gradational top and bottom; no fossils	1.8
2. Shale, gray and yellow, sandy, micaceous; no fossils observed	5.0
1. Shale, green-yellow, clayey	15.0

Locality 4

Section measured at CWL Sec. 18, T. 10 S., R. 15 E., Shawnee County, along east-west road in an easterly direction from the intersection to the top of the hill.

Locality 4 (Cont'd)

Thickness
feet

Zeandale Limestone (12.6 feet exposed)

Wamego Shale member (9.6 feet exposed)

- | | |
|--|-----|
| 8. Limestone, arenaceous, medium brown to light yellow-brown, weathers dark yellow-brown, moderately hard, finely granular, thin, wavy bedded, micaceous; brachiopods abundant in upper 1.5 feet, <u>Dictyocelestus</u> , <u>Juresania</u> , <u>Linoproductus</u> , <u>Derbyia</u> | 3.0 |
| 7. Shale, sandy to silty with very thin calcareous silstone partings, light tan-brown to yellow-brown | 1.3 |
| 6. Sandstone, brown, poorly cemented, micaceous | .2 |
| 5. Shale, light gray, sandy to silty, micaceous | 1.0 |
| 4. Covered interval, probably shale | 4.1 |

Tarkio Limestone member (3 feet)

- | | |
|---|-----|
| 3. Limestone, brown to light gray-brown, weathers dark yellow-brown, very fine granular, hard, thin-bedded; very abundant large robust fusulinids, scattered brachiopod fragments | .6 |
| 2. Limestone, gray to yellow-brown, weathers yellow-brown with abundant large, robust fusulinids in relief, fine grained, hard, massive, widely spaced vertical joints; scattered small crinoid columnals, brachiopod fragments, <u>Dictyocelestus</u> , linear algae (?) | 2.4 |

Willard Shale (33 feet)

- | | |
|---|--------|
| 1. Covered interval to top of Emporia Limestone | 33.0 ± |
|---|--------|

Locality 5

Section measured SE NE Sec. 22, T. 10 S., R. 14 E.,
Shawnee County, at intersection of north-south access road
and main east-west road.

Thickness
feet

Zeandale Limestone (13.5 feet exposed)

Wamego Shale member (10.2 feet exposed)

- | | |
|--|-----|
| 10. Limestone, arenaceous, light gray-brown to medium brown, weathers light yellow-gray, moderately hard, very fine grained, thin, irregular-bedded, micaceous; <u>Dietyoclostus</u> , <u>Derbyia</u> , <u>Linoproductus</u> , and abundant brachiopod fragments, large crinoid columnals; magnetite | 1.4 |
| 9. Alternating shale and sandy limestone, gray and brown; limestone units irregular except .4 foot unit in center. Abundant productid brachiopods | 2.8 |
| 8. Shale, gray and brown, calcareous, thin, non-persistent, limy partings, all micaceous | 1.9 |
| 7. Shale, light gray to green-gray, silty to sandy, micaceous, calcareous | 4.1 |

Tarkio Limestone member (3.3 feet)

- | | |
|---|-----|
| 6. Limestone, medium gray to gray-brown, weathers dark red-brown, hard, very fine grained, massive, prominent widely spaced, vertical joints, weathers shelly on top, sharp upper and lower contacts; very abundant large fusulinids throughout, sparse echinoid spines, brachiopods, small crinoid columnals, <u>Osagia</u> encrusting brachiopod fragments lower 1 foot, small gastropods at top, <u>Lophophyllidium</u> center | 3.3 |
|---|-----|

Locality 5 (Cont'd)

	Thickness feet
Willard Shale (17.2 feet exposed)	
5. Shale, yellow-brown, clayey, with gray clay streaks . . . . .	.8
4. Shale, gray-blue and brown, clayey, red clay parting at top . . . . .	.9
3. Shale, blue-gray, underclay-like, alternates with carbonaceous material. Non-persistent thin sandstone at base .	.6
2. Underclay, blue-gray, carbonaceous streaks and plant remains . . . . .	.3
1. Shale, blue-gray, clayey to sandy, micaceous in part	15.0 +

Locality 6

Section measured in SW SW SW Sec. 25, T. 10
S., R. 13 E., Shawnee County, along east-west road
and in field to north about 30 yards west of bridge
and opposite abandon house.

Zeandale Limestone (18.7 feet)

Maple Hill Limestone member (1-foot)

- | | |
|--|-----|
| 7. Limestone, red-gray, weathers light
yellow-tan, hard, finely crystalline;
slender fusulinids, small crinoid
columnals, brachiopod fragments, abundant
spines. Exposed as float in the field . | 1.0 |
|--|-----|

Wamego Shale member (15.4 feet)

- | | |
|--|-----|
| 6. Shale, blue-gray, clayey, poorly
exposed | 4.3 |
|--|-----|

Locality 6 (Cont'd)

	Thickness feet
5. Limestone, medium chocolate brown, weathers light tan-brown, coarsely crystalline; ramose and fenestrate bryozoans, large crinoid columnals, small brachiopods and spines . . . . .	.6 ±
4. Shale, covered interval	7.3 ±
3. Limestone, dark brown to yellow-brown, weathers yellow, soft, argillaceous, numerous calcite veinlets; productid brachiopods more or less abundant in zones. Mostly covered	2.0
2. Shale, yellow, calcareous, earthy, mostly covered	1.2 ±

Tarkio Limestone member (2.3 feet)

1. Limestone, light to medium gray, weathers light yellow-brown at base to dark red-brown at top, massive; very abundant fusulinids, sparse crinoid columnals, <u>Ottonosia</u> on top	2.3
--	-----

Locality 7

Section measured in SE SE Sec. 22, T. 11 S., R. 13 E., 1.5 miles due south of Willard on hill south of Post Creek Bridge.

Zeandale Limestone (18 feet)

Maple Hill Limestone member (2 feet)

17. Limestone, light blue-gray, weathers light gray to light buff-tan, very hard, finely crystalline, thin to medium bedded, small calcite veinlets, pyrite; fusulinids, small crinoid columnals, <u>Aviculopectens</u>	2.0
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Locality 7 (Cont'd)

	Thickness feet
Wamego Shale member (11.6 feet)	
16. Shale, green to yellow, calcareous, limy nodules, transition into Maple Hill3
15. Lignite band . . . . .	.1
14. Shale, yellow-brown, silty; carbonaceous material . . . . .	.5
13. Shale, green-gray, weathers very light gray, clayey, numerous thin limonite stained color bands; no fossils observed	4.7
12. Shale, green-gray, blocky, clay; no fossils observed	1.9
11. Shale, green, silty, calcareous; small shell fragments . . . . .	.4
10. Limestone, red-brown, nodular; very abundant <u>Osagia</u> , crinoid columnals, shell fragments . . . . .	.2
9. Shale, green-gray, calcareous; very abundant mixed fauna, brachiopods and spines, pelecypods, shell fragments . .	.5
8. Shale, green, blocky, clayey, silty in part, mostly covered	2.5
Tarkio Limestone member (4.4 feet)	
7. Limestone, light gray to light gray-brown, weathers dark brown to dark yellow-brown, hard, very finely crystalline, massive-bedded, breaks down into irregular wedges; numerous large crinoid columnals, large productid brachiopods and fragments, very abundant fusulinids, especially in center, <u>Osagia</u> in center, <u>Ottonosis</u> at top. Large vugs filled with red-orange celestite crystals in upper 1 foot	4.4

Locality 7 (Cont'd)

Thickness
feet

Willard Shale (43 feet exposed)

- | | |
|---|--------|
| 6. Shale, brown and blue-gray, micaceous, clayey, thin layers of yellow-brown calcareous siltstone; no fossils observed | 15.0 |
| 5. Shale, blue, silty, blocky; no fossils observed | 5.0 |
| 4. Shale, brown to gray, blocky, silty; no fossils observed | 5.0 |
| 3. Shale, gray-green clayey, thin brown sandstone at base | 5.0 † |
| 2. Shale, silver-gray clay, in part under-clay-like, abundant thin siltstone lenses | 3.0 |
| 1. Covered interval | 10.0 † |

Locality 8

Section measured in SW SW Sec. 29, T. 11 S., R. 14 E., Shawnee County, along north side of US 40, .5 mile west of Valencia Cemetery, south of landing field and hanger.

Zeandale Limestone (19.5 feet)

Maple Hill Limestone member (1.6 feet)

- | | |
|--|-----|
| 11. Limestone, light gray, weathers gray-brown with reddish cast at top, slabby at top, hard, very finely crystalline, gradational contacts above and below; crinoid columnals, scattered fusulinids more abundant at top, gastropods, brachiopod fragments and spines, <u>Osgia</u> . . | 1.6 |
|--|-----|

Locality 8 (Cont'd)

	Thickness feet
Wamego Shale member (10.5 feet)	
10. Shale, yellow-brown, calcareous, limy nodules . . . . .	.8
9. Shale, brown-green, clayey	1.0
8. Shale, gray and yellow, clayey, fissile	2.2
7. Shale, dark gray-green, clayey, abundant <u>Promytilus</u> . Top 0.3 foot brown-yellow calcareous, no fossils observed	3.0
6. Shale, green-gray, blocky, slightly calcareous, persistent limy zones with very abundant mixed fauna at 1 foot, 2.3 feet and 3.2 feet. The zone at 2.3 feet is best developed reaching a thickness of 0.6 foot. <u>Juresania</u> and other brachiopods, fenestrate and ramose bryozoans, <u>Myalina</u> , <u>Promytilus</u> , echinoid spines, crinoid columnals, ostracods . .	3.5
Tarkio Limestone member (7.4 feet)	
5. Limestone, light gray-brown, weathers light buff-tan, moderately soft, sub-collitic, osagite	1.0
4. Limestone, light gray, weathers brown to gray, moderately hard, medium-grained, thin-bedded, fossiliferous; <u>Osagia</u> , scattered fusulinids, small crinoid columnals, ramose bryozoans, sparse brachiopods and shell fragments. Top contact irregular and thickness of bed ranges from 0.7 foot to	1.1
3. Limestone, light brown, weathers dark brown-yellow, hard, massive-bedded, widely spaced vertical joints, wavy, transitional contacts above and below. Very abundant large, robust, <u>Triticites</u> , sparse brachiopods, <u>Dictyoclostus</u> , very large crinoid columnals, vugs lined with celestite crystals common in center	5.3

Locality 8 (Cont'd)

Thickness
feet

Willard Shale (3.6 feet exposed)

- | | |
|--|-----|
| 2. Shale, gray, micaceous, silty, very abundant fossils in upper .3 foot. Small brachiopods, <u>Hustedia</u> , large and small crinoid columnals, wavy contact with Tarkio above | 2.6 |
| 1. Shale, brown, silty, micaceous | 1.0 |

Locality 9

Section measured CSL SE Sec. 12, T. 12 S.,
R. 13 E., Shawnee County, on east-west road one-
fourth mile east of half-section intersection.

Zeandale Limestone (17.7 feet)

Maple Hill member (1.4 feet)

- | | |
|---|-----|
| 5. Limestone, gray, weathers light gray-tan, shelly, red stained on top, fine crystalline, medium-bedded; slender fusulinids at top, crinoid columnals, brachiopods; poorly exposed | 1.4 |
|---|-----|

Wamego Shale member (9.6 feet)

- | | |
|-------------------------------|-----|
| 4. Covered interval | 9.6 |
|-------------------------------|-----|

Tarkio Limestone member (6.7 feet)

- | | |
|---|-----|
| 3. Limestone, light gray-tan, weathers light yellow-brown, moderately soft, coarse clastic, massive-bedded, suboolitic oolite, porous, vuggy at base, less porous top; very abundant brachiopod fragments, robust fusulinids, crinoid columnals, fenestrate bryozoans, <u>Osgia</u> coating all fragments | 2.4 |
|---|-----|

Locality 9 (Cont'd)

	Thickness feet
2. Limestone, light gray-yellow, weathers, deep yellow-brown, fine-grained, hard, medium to thick-bedded; <u>Triticites</u> abundant, crinoid columnals, scattered brachiopods	4.3
 Willard Shale	
1. Shale, gray and yellow, silty to sandy, poorly exposed . . . . .	.3

Locality 10

Section measured C Sec. 18, T. 12 S., R. 13 E., Shawnee County, along top of steep bluff north of Kansas highway 4.

Zeandale Limestone (11.8 feet exposed)

Tarkio Limestone member (11.8 feet)

8. Limestone, brown to red-brown, weathered yellow-buff, thin, irregularly bedded, clastic osagite . . . . .	.2
7. Limestone, light tan-gray, weathers medium gray, massive, vuggy, "pit and cusp" weathering; abundant shell fragments, <u>Osagia</u> encrusting all	4.3
6. Limestone, light gray, weathers medium to dark gray, poorly consolidated, porous, osagite; very abundant <u>Myalina</u> , <u>Aviculopecten</u> , gastropods, fenestrate bryozoans, productid brachiopods, crinoid columnals	1.0
5. Shale, calcareous, occasional limy nodules; <u>Myalina</u> , other near-shore invertebrates . . . . .	.3

Locality 10 (Cont'd)

	Thickness feet
4. Limestone, red-brown, weathers dark gray-brown, massive, sub-collitic, porous, Osagite; very abundant shell fragments, coated with <u>Osagia</u>	2.3
3. Limestone, brown-gray, weathers dark brown-gray, porous, sub-collitic Osagite, wavy contacts above and below; very abundant shell fragments heavily coated with <u>Osagia</u> , robust fusulinids, uncoated or lightly covered . . . . .	.8
2. Limestone, gray-brown, weathers yellow-brown, dark brown at base, argillaceous, thick-bedded at top to thin-bedded at base, grades into above limestone with wavy irregular contact; very abundant <u>Triticites</u> , occasional brachiopods . . .	2.9

Willard Shale

1. Shale, yellow-brown, calcareous, earthy, poorly exposed8
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Locality 11

Composite section. Tarkio and Wamego from SE Sec. 23, T. 12 S., R. 13 E., Shawnee County, along Kansas highway 4 on south bank of Mission Creek. Maple Hill and Wamego interval along Shawnee-Wabaunsee County line in SW Sec. 23 on north bank of Mission Creek.

Zeandale Limestone (24.1 feet)

Maple Hill Limestone member (1.7 feet)

Locality 11 (Cont'd)

	Thickness feet
10. Limestone, medium gray, weathers gray, slabby and red stained on top, widely spaced vertical joints, hard, finely crystalline; small crinoid columnals, small fusulinids, brachiopods	1.7
Wamego Shale member (10.1 feet)	
9. Covered interval	8.4
8. Limestone, dark red-brown, medium-crystalline, hard, thin-bedded osagite; <u>Myalina</u> and other pelecypods, ramose bryozoans, <u>Chonetes</u> , and numerous brachiopod shell fragments and spines .	.2
7. Covered interval	1.5
Tarkio Limestone member (12.3 feet)	
6. Limestone, light to medium gray, weathers gray-brown, porous, vuggy, sub-collitic, osagite; abundant fragments of shells, ramose bryozoans, spines, <u>Enteletes</u> , fusulinids, all fragments coated with <u>Osagia</u> in lower 0.8 foot, above, recognizable fossil fragments absent	2.2
5. Limestone, red-brown, weathers dark gray, wavy-bedded; very abundant shell fragments, <u>Chonetes</u> , <u>Neospirifer</u> , brachiopod spines, large and small crinoid columnals, scattered robust fusulinids, encrusting <u>Osagia</u> , crinoid plates, ramose bryozoans . . . . .	.5
4. Limestone, light gray-brown, weathers yellow-gray, silty to sandy, impure, wavy-bedded, moderately soft at base; upper 0.5 foot, hard, osagite with abundant <u>Marginiferia</u> , <u>Dictyoclostus</u> , brachiopod spines, pelecypods, large crinoid columnals, echinoid plates, scattered large robust fusulinids, <u>Osagia</u>	1.2

Locality 11 (Cont'd)

	Thickness feet
3. Shale, green-gray, silty, calcareous, grades into blue-green silty, with calcareous nodules at top, no fossils observed. Largely covered	3.7
Tarkio Limestone member	
2. Limestone, brown-gray, weathers yellow-brown, hard, dense, thick-bedded; very abundant fusulinids, ramose bryozoans, <u>Lophophyllidium</u> , <u>Dictyocelestus</u> , <u>Enteletes</u>	1.2
1. Limestone, gray-brown, weathers yellow-brown, hard, massive, very abundant <u>Triticites</u> , fusulinids, fenestrate bryozoans, <u>Lophophyllidium</u> , <u>Meekella</u> , <u>Composita</u> , <u>Neospirifer</u> , brachiopod fragments and very abundant crinoid columnals upper .5 foot	3.5

Locality 12

Section measured near CSL Sec. 25, T. 12 S., R. 13 E., Shawnee County, on small tributary of Haskell Creek, about 100 yards north of bridge.

Zeandale Limestone (23 feet)

Maple Hill Limestone member (1.2 feet)

10. Limestone, blue-gray, weathers gray-tan with red cast on shelly top, dense, medium-bedded; crinoid columnals, small fusulinids, many shell fragments, ramose bryozoans, scattered "Marksia"	1.2
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Wamego Shale (9.9 feet)

9. Shale, green-brown, calcareous, mostly covered	7.9
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Locality 12 (Cont'd)

	Thickness feet
8. Limestone, red-brown, weathers medium brown, hard, thin-bedded, ossagite4
7. Shale, blue-green, calcareous	1.6
Tarkio Limestone member (11.9 feet)	
6. Limestone, gray-brown, red-gray in part, weathers light yellow-brown, moderately hard, arenaceous at base, more dense upward, thin to medium-bedded; abundant <u>Neospirifer</u> , <u>Chonetes</u> , <u>Juresania</u> , spines " <u>Marksia</u> ", <u>Myalina</u> , very large crinoid columnals	2.7
5. Limestone, light gray-green, weathers yellow-brown, soft, thin-bedded, arenaceous, micaceous; no fossils observed	1.0
4. Shale, green-gray, clayey, becomes more silty and micaceous upward, grades into above; very abundant ostracods near top	2.9
3. Limestone, light tan-gray, weathers light yellow-brown, very hard, very finely crystalline, medium-bedded, vuggy in part; large robust <u>Triticites</u> , brachiopod fragments, ramose bryozoans, numerous shell fragments, " <u>Marksia</u> "; magnetite, celestite	1.4
2. Limestone, brown-gray, weathers yellow-brown, hard, medium to fine-grained, medium to thin-bedded, <u>Triticites</u> , <u>Lophophyllidium</u> , small brachiopods, numerous shell fragments	1.9
1. Limestone, blue-gray, weathers light gray to yellow-brown, hard, very fine grained, argillaceous at top, massive; robust fusulinids, crinoid columnals, small brachiopods, <u>Ottonosia</u> , " <u>Marksia</u> " .	2.0

Locality 13

Section measured in SE SE Sec. 25, T. 12 S., R. 13 E., Shawnee County, on the west bank of Haskell Creek, about 40 yards NW of section corner.

	Thickness feet
Zeandale Limestone (13.2 feet exposed)	
Terkio Limestone (13.2 feet)	
7. Limestone, red-gray to light gray, weathers gray-brown, hard, massive-bedded, uneven pitted surface; abundant <u>Neospirifer</u> , and other brachiopod fragments, echinoid spines and plates, <u>Osagia</u>	1.6
6. Covered interval, probably shale	2.1
5. Limestone, gray poorly consolidated, weathers to rubble, highly stained by limonite, irregular-bedded, micaceous; no fossils observed. .2 foot sandy shale separation at 1.5 feet	2.0
4. Shale, blue-gray, clayey, micaceous with limonite stained calcareous nodules	1.2
3. Limestone, light tan-gray, weathers light yellow-gray to very light gray, very hard, finely crystalline, medium to thin-bedded; robust fusulinids, algal (?) sparse shell fragments	1.3
2. Limestone, brown-gray, weathers light yellow-brown, medium to fine-grained, thin-bedded; <u>Composita</u> and other brachiopod fragments, <u>Lophophyllidium</u> , fusulinids common, but do not weather in relief	2.0
1. Limestone, blue-gray to medium gray, weathers gray-brown, hard, very fine grained, thick-bedded; very abundant fusulinids in relief, crinoid columnals, <u>Hustedia</u> and other brachiopods; rather abundant disseminated pyrite	2.0

Locality 14

Composite section. Maple Hill from CSL SW Sec. 32, T. 12 S., R. 14 E., Shawnee County, in roadside, ditch east of stream. Tarkio and Wamego from NE SW Sec. 32, along south side of stream.

	Thickness feet
Zeandale Limestone (24.9 feet)	
Maple Hill Limestone (1.6 feet)	
9. Limestone, gray-red, weathers light tan-brown, hard, very finely crystalline, thick-bedded, slabby weathered; numerous fusulinids at top, crinoid remains, ramose bryozoans, gastropods, <u>Bellerophon</u> , <u>Ottonosia</u> at top	1.6
Wamego Shale member (14 feet [±])	
8. Shale, gray, underclay-like	1.0
7. Shale, gray-brown, blocky, most covered	13.0
Tarkio Limestone member (9.3 feet)	
6. Limestone, medium red-brown, weathers brown-gray with porous surface, dense, very thin-bedded; brachiopod fragments, very abundant <u>Osgia</u> . . . . .	.8
5. Covered interval, thickness approximate . . . . .	.5
4. Limestone, gray, weathers orange-yellow, very soft, fine to medium-grained, arenaceous, very thin-bedded, irregular; crinoid columnals, <u>Necospirifer</u> , small brachiopods, spines and shell fragments, all concentrated in upper part	1.8
3. Shale, blue-gray, micaceous, calcareous nodules	1.1
2. Limestone, light gray, weathers gray-yellow, hard, fine to medium-crystalline, thick-bedded, vuggy; robust fusulinids, brachiopods, shell fragments, "Marsia"	1.2

Locality 14 (Cont'd)

Thickness
feet

- | | |
|---|-----|
| 1. Limestone, medium gray, weathers gray-brown, hard very finely crystalline, medium to thin-bedded; fusulinids, brachiopods, partially pyritized shell fragments | 3.9 |
|---|-----|

Locality 15

Section measured in SE Sec. 17, T. 13 S., R. 14 E., Shawnee County on NW face of quarry west of road.

Leandale Limestone (16.5 feet exposed)

Wamego Shale member (11.5 feet exposed)

- | | |
|--|-----|
| 7. Limestone, medium brown to yellow-brown, silty to sandy, medium to thin-bedded; fenestrate bryozoans, productid brachiopod fragments, most abundant in center, <u>Neospirifer</u> , <u>Echinoconchus</u> , crinoid columnals. May be Stormont | 1.5 |
| 6. Shale, light gray to yellow-gray, hard, blocky, no fossils observed | 5.5 |
| 5. Shale, green-gray, with abundant thin, yellow siltstone partings | 3.5 |
| 4. Shale, dark gray-black, blocky, clayey | 1.0 |

Tarkio Limestone member (5 feet)

- | | |
|---|-----|
| 3. Limestone, gray, weathers yellow-brown, massive, poorly exposed; abundant robust fusulinids, small brachiopods, shell fragments, crinoid columnals, <u>Ottonosia</u> abundant near top | 5.0 |
|---|-----|

Willard Shale (12.5 feet exposed)

- | | |
|--|-----|
| 2. Shale, brown-gray, earthy, fragmental fossils | 2.5 |
|--|-----|

Locality 15 (Cont'd)

	Thickness feet
1. Shale, dark gray, blocky at top, fissile toward bottom. Very large ironstone concretions about 7.5 feet from top . .	10.0

Locality 16

Section measured in NE SW Sec. 21, T. 13 S., R. 14 E., Shawnee County, along both sides of east-west county road and up farm access road to south. Upper 14 feet from south-facing roadcut one-half mile west.

Zeandale Limestone (28.9 feet exposed)

15. Limestone float, light blue-gray, weathers light tan-brown, with reddish cast; echinoid plates, brachiopod spines, abundant brachiopod shell fragments, small fusulinids. Possibly Maple Hill Limestone.

Wamego Shale member (23.8 feet)

- | | |
|---|-----|
| 14. Covered interval | 2.6 |
| 13. Calcareous zone, gray-tan to light brown, nodular, impure; no fossils observed . . | 1.4 |
| 12. Covered shale interval | 5.8 |
| 11. Limestone, light gray and mottled yellow, weathers yellow-brown, nodular, impure, silty to sandy; abundant <u>Neospirifer</u> and other brachiopod fragments, crinoid columnals. Beds 9, 10 and 11 may be Stormont | .7 |
| 10. Shale, green-gray, silty, micaceous, calcareous zone at 2.0 feet with very abundant fossils including brachiopod shell fragments, <u>Neospirifer</u> , <u>Dictyocelestus</u> , <u>Linoproductus</u> , crinoid columnals | 2.8 |

Locality 16 (Cont'd)

	Thickness feet
9. Limestone, brown, moderately soft, medium-crystalline, nodular, impure at top; abundant fossils throughout, <u>Myalina</u> , pectenids and other pelecypods, crinoid columnals, shell fragments, plant stems at base . . . . .	.8
8. Shale, blue-gray, blocky, clayey, abundant platy calcareous siltstone layers at top	5.5
7. Shale, medium green-gray, blocky, clayey, becomes silty, micaceous, near top	4.2

Tarkio Limestone member (5.1 feet)

6. Limestone, light gray to gray-brown, hard, very fine-grained, massive; very abundant large robust fusulinids, crinoid columnals, ramose bryozoans, brachiopod shell fragments, <u>Dietyoclostus</u> , <u>Ottonosia</u> near top	5.1
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Willard Shale (17.6 feet)

5. Shale, green-gray, blocky, abundant marine fossils in upper 5 feet; <u>Muculana</u> , small <u>Neospirifer</u> , <u>Derbyia</u> , <u>Chonetes</u> , very small planispiral gastropods	8.0
4. Shale, yellow-brown to gray, blocky, fissile at base; no fossils observed. Very large ironstone concretions 6.3 feet above bed 3	9.6

Emporia Limestone

Elmont Limestone (3.1 feet)

3. Limestone, dark brown-gray, hard, dense, vertical jointed; algal . . . . .	.9
2. Shale, brown-gray, calcareous; zones of abundant brachiopods and bryozoans . . . .	.8
1. Limestone, light gray, dark, dense, vertical jointed	1.4

Locality 17

Section measured CWL NE Sec. 29, T. 13 S., R. 14.,
Shawnee County, along east side of north-south county road
150 yards south of Wakarusa River.

Thickness
feet

Zeandale Limestone (14 feet exposed)

Wamego Shale member (10.3 feet)

- 6. Limestone, light brown, weathers deep yellow-brown, rounded and smooth surface, soft, very fine-grained, arenaceous, micaceous; no fossils observed. Beds 5 and 6 may be Stormont 0.7
- 5. Limestone, light gray to gray-brown, weathers rich yellow-brown, moderately soft, very fine-grained, arenaceous, micaceous, massive, vertical joints; no fossils observed 2.4
- 4. Shale, yellow-green to green-gray, silty to sandy micaceous; no fossils observed. Partly covered 3.2
- 3. Shale, blue-gray to yellow-green, clayey to silty, sparse fossil fragments, partly covered 4.0

Called "Staircase" as a unit

Tarkio Limestone member (3.7 feet)

- 2. Limestone, medium gray to brown-gray, weathers yellow-brown, massive, widely spaced vertical joints, hard, very fine-grained in lower 1.3 feet and upper .6 foot with fusulinids weathering to relief. Center 1.8 foot is finely crystalline, fossils not in relief. Gastropods, brachiopods, Meekella, Dielasma, Dictyoelostes, Hustedia, abundant shell fragments and spines, crinoid columnals, Ottonosia at 1.5 feet 3.7

Locality 17 (Cont'd)

Thickness
feet

Willard Shale

1. Shale, gray to light yellow-green,
blocky, mostly covered 2.0

Locality 18

Section measured near the center of Sec. 3, T.
14 S., R. 14 E., Osage County, on the southeast side
of the Kansas Turnpike, one-half mile north of
bridge number 213.

Zeandale Limestone (20 feet)

Maple Hill Limestone member (1.6 feet)

14. Limestone, medium to dark gray, weathers
light buff-brown, reddish cast on top,
very hard, finely crystalline, thick-
bedded; small fusulinids in upper 1.0
foot, small crinoid columnals, brachiopods
and shell fragments, gastropods, ramose
bryozoans, large and small Ottonosia at
and near top. "Markisia" especially
abundant at base 1.6

Wamego₂ Shale member (10 feet)

13. Shale, gray, mottled yellow, carbonaceous
material and underclay. Top .2 foot
calcareous, fossiliferous, grades into
Maple Hill8
12. Shale, gray-blue, clayey, pelecypods and
brachiopods in upper part 2.5
11. Limestone, blue-gray, weathered reddish
tan, hard, medium-grained, oolitic, very
thin-bedded, shell fragments, spines,
crinoid columnals, "Markisia", pyrite 2

Locality 18 (Cont'd)

	Thickness feet
10. Shale, green to yellow-brown, blocky .	2.5
9. Limestone, dark gray to gray-brown, weathers light yellow-brown, moderately hard, wavy, thin-bedded, lower .8 foot argillaceous conglomeratic; numerous brachiopods, <u>Composita</u> . Upper .7 foot medium-grained, oolitic, numerous near-shore invertebrates, moderately high-spired and small planispired gastropods, <u>Septimyalina</u> , <u>Myalina</u> , very abundant, well worked shell fragments, <u>Dictyoclostus</u> , <u>Polypora</u> and other fenestrate bryozoans .	1.5
8. Shale, green-brown to gray-yellow, blocky, very abundant pyrite clusters; no fossils observed	2.5
Tarkio Limestone member (8.4 feet)	
7. Limestone, very light gray, weathers light buff, very hard, wavy-bedded, vuggy; <u>Osagia</u> , brachiopods common in lower .8 feet	1.6
6. Limestone, very light gray, weathers light buff, hard, microcrystalline, medium-bedded; large robust fusulinids, crinoid columnals, <u>Composita</u> , shell fragments, scattered ooliths, small <u>Ottonosia</u> algae	1.0
5. Limestone, light gray to yellow-gray, weathers deep yellow-brown, hard, dense, very fine grained, massive; abundant <u>Friticites</u> , lower 5 feet, small horn corals, no brachiopods observed in lower 4 feet, but numerous above, crinoid columnals. Top is vuggy, lined with well developed celestite crystals	5.5
4. Limestone, light gray, weathers light brown, soft, arenaceous, fusulinids, crinoid columnals, ramose bryozoans, sparse brachiopod fragments, "Marksia"; pyrite . . . . .	.3

Locality 18 (Cont'd)

	Thickness feet
Willard Shale (39.4 feet)	
3. Shale, silver to blue-gray, micaceous, silty, transitional contact with Tarkio	14.4
2. Shale, dark gray-brown, silty, plant fossils above 13 feet	19.0
1. Shale, dark gray, clayey	6.0
Eaporia Limestone, top of Elmont Limestone member.	

Locality 19

Section measured in NE Sec. 9, T. 14 S., R. 14 E., Osage County, on northwest side of the Kansas Turnpike, 100 yards north of milepost 73.

Zeandale Limestone (25.7 feet)

Maple Hill Limestone member (1.3 feet)

17. Limestone, medium gray to light gray-brown, weathers light yellow-brown, deep red-brown on top, very hard, very fine grained; in upper .9 foot, abundant shell fragments, gastropods, small fusulinids, crinoid columnals, "Merksia". Argillaceous base, very abundant "Merksia", no fusulinids, sparse shell fragments. Ottonosia at top 1.3

Wamego2 Shale member (10.9 feet)

16. Shale, buff-gray, fissile, calcareous 4
15. Shale, light gray, mottled yellow and yellow-brown, in part, underclay-like; very abundant plant remains, ostracods 7
14. Shale, green-brown, blocky 2.4

Locality 19 (Cont'd)

	Thickness feet
13. Limestone, very argillaceous, irregular, wavy-bedded, abundant fossil fragments at random orientation; productid shells and spines, crinoid columnals, pelecypods; angular limestone fragments . . . . .	.5
12. Shale, gray-green, fissile, thin, persistent limestone with very abundant mixed fauna at 1.1 feet. <u>Dictyoclostus</u> , <u>Juresania</u> , gastropods, <u>Aviculopecten</u> , shell fragments and spines, all at random orientation	2.9
11. Limestone, dark gray-brown and mottled yellow, conglomeratic, oolitic, in basal 0.4 foot; shale parting 0.1 foot; coarse-grained, thin-bedded lime, with abundant molluscan fauna, <u>Dielasma</u> , <u>Composita</u> , <u>Dictyoclostus</u> , <u>Myalina</u> , <u>Aviculopecten</u> . Total thickness . . . . .	.6
10. Shale, dark green-gray to yellow-gray, blocky, breaks in conchoidal fracture, disseminated calcareous nodules, sparse pelecypods including <u>Promytilus</u> in top 1 foot	3.4
Stormont Limestone member (1.2 feet)	
9. Limestone, light gray-brown, dark brown wavy bands, weathers brown-gray, moderately soft, medium-grained, sub-oolitic; large and small crinoid columnals, ramose bryozoans, <u>Composita</u> , and other brachiopods, shell fragments, "Marksia". Fossils more abundant in lower 1 foot . .	1.2
Wamego ₁ Shale member (5.5 feet)	
8. Shale, light green to blue-gray, calcareous, abundant calcareous nodules at top; sparse spines and shell fragments .	2.0
7. Shale, yellow-brown, calcareous, poorly consolidated, nodular . . . . .	.6

Locality 19 (Cont'd)

	Thickness feet
6. Shale, gray-green, blocky, calcareous nodules in lower .5 foot	2.9
Tarkio Limestone member (4.8 feet)	
5. Limestone, medium brown-gray, weathers light gray-tan, hard, thick-bedded, very fine grained; sparse, very large, robust fusulinids in lower part, abundant small fusulinids in upper part, brachiopods, crinoid columnals, <u>Ottonosia</u> at top . .	2.2
4. Limestone, light gray, weathers light brown-yellow, hard, massive, very fine grained, widely spaced vertical joints, wavy gradational contact below; large robust fusulinids, especially at base, brachiopods, <u>Composita</u> , <u>Ottonosia</u> at top surface	2.6
Willard Shale (3.8 feet exposed)	
3. Shale, yellow-brown, calcareous, lime nodules; abundant fusulinids, irregular thickness, grades into Tarkio . . . . .	.2
2. Shale, dark buff-brown, silty, micaceous, slightly calcareous . . . . .	.6
1. Shale, dark gray, silty to sandy, micaceous, pelecypods	3.0

Locality 20

Section measured at CWL Sec. 9, T. 14 S., R. 14 E., Osage County, along road up south bank of Wakarusa Creek. Type locality of Stormont Limestone.

Zeandale Limestone (30.5 feet)

Locality 20 (Cont'd)

	Thickness feet
Maple Hill Limestone member (1.2 feet)	
10. Limestone, dark gray, slabby weathering with reddish cast, moderately hard, very fine grained, thick-bedded; small, slender fusulinids, brachiopods, shell fragments, abundant crinoid columnals; pyrite . . .	1.2
Wamego ₂ Shale member (11.4 feet)	
9. Shale, medium gray, clayey, mostly covered. Thin coal at .7 feet	3.6
8. Limestone, poorly consolidated, yellow-brown, earthy . . . . .	.7
7. Covered interval, probably shale	3.8
6. Limestone, brown to yellow-brown, argillaceous, conglomeratic appearance, calcite veinlets; abundant shell fragments	.3
5. Covered interval, probably shale	3.0
Stormont Limestone member (2.2 feet)	
4. Limestone, very light gray to buff, hard, fine-grained, thick-bedded; very abundant small shell fragments, crinoid columnals, fusulinids, linear algal (?); pyrite	2.2
Wamego ₁ Shale member (11.4 feet)	
3. Covered interval, probably shale	11.4
Tarkio Limestone member (4.3 feet)	
2. Limestone, light gray-brown, weathers gray, hard, very fine to finely crystalline, thick-bedded, wavy gradational contact with bed 1; large robust fusulinids, sparse crinoid columnals, small brachiopods, "Marksia", <u>Ottonosia</u> ; scattered pyrite	1.4

Locality 20 (Cont'd)

Thickness
feet

1. Limestone, light gray-brown to buff-brown, weathers dark yellow-brown, moderately hard to hard, very finely crystalline, massive; abundant large, robust fusulinids throughout, but less abundant in center 1 foot. Enteleles, Dictyoclostus, Echinoconchus, and shell fragments, Lophophyllidium 2.9

Locality 21

Section measured in NE Sec. 30, T. 14 S., R. 14 E., Osage County, in quarry south of east-west county road and east of Kansas Turnpike, continuing up ditch along east side of turnpike.

Pillsbury Shale

11. Shale, yellow-brown, blocky, abundant large ironstone concretions 10.0

Zeandale Limestone (38.4 feet)

Maple Hill Limestone member (1.6 feet)

10. Limestone, gray to gray-brown, weathers light tan-brown, hard, very fine grained in part, medium-grained at top, prominent vertical joints; crinoid columnals, fusulinids in top .4 feet, brachiopods, Dictyoclostus, Composita, "Markisia" 1.3
9. Limestone, light green-brown, weathers buff-tan, very fine-grained with coarse detrital fragments; Dictyoclostus, Derbyia, brachiopod spines, Aviculopecten and other shell fragments, "Markisia", sparse fusulinids3

Locality 21 (Cont'd)

	Thickness feet
Wamego Shale member (32.4 feet)	
8. Shale, abundant plant and carbonaceous material alternating with underclay-like material. Upper .3 foot with calcareous nodules, grades into Maple Hill	1.2
7. Brown blocky shale, mostly covered	21.0 †
6. Shale, green-gray to brown, calcareous in lower part with brachiopods. Grades into clay with no fossils	10.2 †
Tarkio Limestone member (4.4 feet)	
5. Limestone, tan-brown, shattery, small fusulinids, brachiopod fragments, <u>Ottonosia</u> ; grades into upper shale . . . . .	.2
4. Limestone, dark gray, weathers yellow-brown, hard; abundant large robust fusulinids weathering in relief, <u>Hustedia</u> , <u>Dictyoelostus</u> , large horn corals, crinoid columnals, large <u>Ottonosia</u> in upper 1.2 feet	2.6
3. Limestone, dark gray-brown; fusulinids in relief, small horn corals, large crinoid columnals, fenestrate bryozoans, brachiopods, <u>Hustedia</u> , <u>Dictyoelostus</u>	1.4
Willard Shale (4.2 feet exposed)	
2. Shale, brown to yellow-brown, clayey, calcareous at top with numerous fossils; brachiopods, <u>Hustedia</u> , <u>Dictyoelostus</u> , <u>Chonetes</u> , fenestrate bryozoans, crinoid columnals	1.2
1. Shale, dark gray-blue, silty to clayey, very abundant crinoid columnals, brachiopods at top only	3.0

Locality 22

Section measured in NE Sec. 11, T. 15 S., R. 13 E.,
Osage County, along west side of Kansas Turnpike starting
100 yards southwest of bridge number 205.

Thickness
feet

Zeandale Limestone (31.7 feet exposed)

Wamego₂ Shale member (9.2 feet exposed)

- | | |
|--|-----|
| 12. Limestone, gray-brown, weathers reddish, argillaceous, moderately hard, very thin-bedded; <u>Composita</u> and other brachiopod fragments, <u>Myalina</u> , <u>Promytilus</u> , abraded crinoid columnals and fusulinids | 0.3 |
| 11. Shale, yellow-gray to green-gray, clayey, fissile, calcareous, sparse, possible shell fragments | 4.0 |
| 10. Limestone, gray-brown, weathers yellow-tan, oolitic, moderately hard, thick-bedded; brachiopods, gastropods, pelecypods | 1.1 |
| 9. Shale, brown, clayey | 3.8 |

Stormont Limestone member (3.7 feet)

- | | |
|---|-----|
| 8. Limestone, gray-brown, arenaceous, weathers light yellow-brown, moderately hard at top, soft base; <u>Neospirifer</u> , <u>Dietyoclostus</u> , brachiopod fragments, gastropods, fenestrate bryozoans, <u>Osagia</u> , "Marksia" | 3.7 |
|---|-----|

Wamego₁ Shale member (17.5 feet)

- | | |
|---|-----|
| 7. Shale, green-gray to yellow-green, blocky, silty and micaceous in upper part as grades into Stormont | 6.5 |
| 6. Shale, light brown to dark brown | 7.0 |
| 5. Shale, green-yellow, clayey | 2.0 |

Locality 22 (Cont'd)

Thickness
feet

Tarkio Limestone member (1.3 feet)

4. Limestone, dark gray-brown, weathers deep yellow-brown, hard, very fine grained; abundant fusulinids in relief, small crinoid columnals, ramose bryozoans, brachiopods more numerous in top .5 feet. Dietycclostus, Ottonesia, especially at top 1.3

Willard Shale (5 feet exposed)

3. Shale, yellow-brown, calcareous, fissile, grades into Tarkio; abundant fusulinids, brachiopods, Chonetes, calcareous nodules near top5
2. Shale, green, blocky, slightly calcareous; brachiopods5
1. Shale, gray, blocky, yellow stained, joint fillings 3.0 †

Locality 23

Composite section. Tarkio through Stormont measured in SW Sec. 11, T. 15 S., R. 13 E., Osage County, on Kansas highway 4 50 yards east of Wabaunsee County line, Wamego and Maple Hill from CNL Sec. 15, Wabaunsee County.

Pillsbury Shale

20. Shale, green, clayey, abundant siltstone concretions. 8.0

Zeandale Limestone (50.4 feet)

Maple Hill Limestone member (1.2 feet)

Locality 23 (Cont'd)

	Thickness feet
19. Limestone, dark gray, weathers gray-brown, slabby, red on top, hard, very fine crystalline; small fusulinids abundant, crinoid remains, ramose bryozoans, productid brachiopods, spines, shell fragments, <u>Ottonosia</u> at top	1.2
Wamego ₂ Shale member (22.7 feet)	
18. Shale, silver-gray, underclay-like in part	1.2
17. Shale, gray and yellow, clayey	3.0
16. Covered interval	5.1
15. Shale, blue-gray, clayey	1.5
14. Limestone nodules, or limy shale, crinoid columnals, gastropods, pelecypods, bryozoans . . . . .	.1
13. Underclay, silver-gray . . . . .	.3 †
12. Shale, green-brown, gray-brown toward base, blocky, no fossils observed . . .	4.5
11. Limestone, gray, argillaceous, impure, gastropods, pelecypods, crinoid columnals	1.0
10. Covered interval, shale . . . . .	.6 †
Stormont Limestone member (2.5 feet)	
9. Limestone, gray-brown, "I-beam" weathering, arenaceous, sub-collitic; brachiopod fragments, <u>Neospirifer</u> , pelecypods, <u>Nyalina</u> , <u>Gellerophon</u>	1.6
8. Limestone, gray-brown, weathers medium brown, moderately resistant, arenaceous, irregular-bedded, abundant <u>Neospirifer</u> .	.9
Wamego ₁ Shale member (21.5 feet)	
7. Shale, gray-brown, sandy, calcareous, numerous hard sandy, calcareous nodules .	2.0

Locality 23 (Cont'd)

	Thickness feet
6. Covered interval	19.5
Tarkio Limestone member (2.5 feet)	
5. Limestone, dark gray-brown, weathers dark yellow-brown, hard, very fine grained, weathers in irregular slabs; fusulinids, <u>Dictyoelostus</u> , brachiopod spines, large <u>Ottonosia</u> . . . . .	.9
4. Limestone, dark gray to gray-brown, weathers yellow-brown, very fine grained, massive, widely spaced vertical joints; abundant <u>Triticites</u> , brachiopods, crinoid columnals	1.6
Willard Shale (4.2 feet exposed)	
3. Shale, brown, calcareous, nodular, abundant large robust fusulinids . . .	.2
2. Shale, gray, yellow-brown stained, clayey	2.0
1. Shale, gray-blue to brown, fissile . .	2.0

Locality 24

Section measured in NW Sec. 15, T. 16 S., R. 13 E., Lyon County, in ditch along east side of road 50 yards south of section corner.

Zeandale Limestone (6 feet exposed)

Maple Hill Limestone (1 foot)

- | | |
|--|-------|
| 6. Limestone, medium to dark gray, weathers gray to light yellow-tan with reddish cast; small fusulinids, brachiopod fragments, crinoid columnals, echinoid spines and plates, "Marksia" and large <u>Ottonosia</u> , gastropods, small horn corals, <u>Aulopora</u> . | 1.0 + |
|--|-------|

Locality 24 (Cont'd)

	Thickness feet
Wamego ₂ Shale member (5 feet exposed)	
5. Shale, yellow-brown, clayey, very thin sandy partings . . . . .	.8
4. Underclay, silver-gray . . . . .	.2
3. Shale, yellow-brown stained gray clay, in part underclay-like . . . . .	.8
2. Coal, poor quality . . . . .	.2
1. Shale, silver-gray underclay-like, with very thin yellow-brown shale partings . .	3.0

Locality 25

Composite section. Stormont in NW Sec. 27, T. 16 S., R. 13 E., Lyon County, on north side of Missouri-Pacific railroad tracks, one-quarter mile east of section line. Tarkio in NE SW Sec. 23 on railroad one-half mile SE of county line railroad crossing.

Zeandale Limestone (27.6 feet exposed)

Stormont Limestone member (2.5 feet)

- | | |
|--|-----|
| 6. Limestone, light gray, weathers green-gray to buff-tan, moderately hard, very fine grained to fine-grained at base, thick-bedded; very abundant crinoid columnals, <u>Derbyia</u> , <u>Neospirifer</u> and other brachiopods and shell fragments, ramose bryozoans, gastropods, pelecypods, <u>Myalina</u> , fossils not observed in lower 1.5 feet | 2.5 |
|--|-----|

Wamego₁ Shale member (23.3 feet)

Locality 25 (Cont'd)

	Thickness feet
7. Shale, green-gray, silty to sandy, calcareous nodules; no fossils observed	.6
6. Sandstone, gray-brown, calcareous, poorly consolidated . . . . .	.3
5. Shale, green-brown, contains sandy calcareous nodules in part . . . . .	.6
4. Sandstone, gray-green, calcareous; no fossils . . . . .	.6
3. Shale, green-brown, very sandy, poorly exposed	2.0
2. Covered interval, approximate thickness	19.2

Tarkio Limestone member (2 feet)

- | | |
|---|-----|
| 1. Limestone, light gray, weathers light yellow-brown, hard, medium to thin-bedded, abundant robust fusulinids throughout, brachiopods in center, horn coral near top, <u>Ottonosia</u> in upper 2 beds | 2.0 |
|---|-----|

Locality 26

Section measured SW Sec. 6, T. 17 S., R. 14

E., Osage County, in creek on east side of road

.1 mile north of section corner.

Zeandale Limestone

Tarkio Limestone member (1 foot)

- | | |
|--|-------|
| 1. Limestone, light gray-tan, weathers light yellow-tan, very fine grained, moderately hard, thin-bedded; very abundant fusulinids in relief, crinoid columnals, brachiopod fragments, ramose bryozoans; poorly exposed. Last recognized exposure of Tarkio Limestone. | 1.0 ± |
|--|-------|

Locality 27

Section measured NE Sec. 11 T. 17 S., R. 12 E., Lyon County, along north-south road from section corner intersection up hill to barn.

	Thickness feet
Zeandale Limestone (32.2 feet exposed)	
Maple Hill Limestone member (1.3 feet)	
7. Limestone, medium to dark gray-brown, weathers gray to light yellow-tan, slabby, hard, very finely crystalline; abundant fossil fragments, slender fusulinids, ramose bryozoans, small crinoid columnals, small gastropods, brachiopod spines, algae (?), "Marksia"	1.3
Wamego ₂ Shale member (27.1 feet)	
6. Shale, gray to light yellow, in part underclay-like, smutty carbonaceous layers above	2.8
5. Sandstone, light brown, thin-bedded, fine-grained . . . . .	.3
4. Shale, gray-green, thin-bedded, clayey, abundant thin, silty, micaceous partings, poorly exposed	13.0
3. Covered interval, shale	11.0 *
Stormont Limestone member (2.6 feet)	
2. Limestone, light gray-brown, weathers medium buff-brown or yellow-tan, arenaceous, massive; very abundant <u>Osagia</u> throughout; top 1 foot only brachiopods, crinoid columnals, shell fragments	2.6
Willard - Wamego ₁ Shale (1.2 feet exposed)	

Locality 27 (Cont'd)

Thickness
feet

- | | |
|---|-----|
| 1. Shale, green, yellow stained, micaceous, slightly calcareous, sandy to silty, abundant silty calcareous nodules; no fossils observed | 1.2 |
|---|-----|

Locality 28

Section measured CWL Sec. 14, T. 17, S., R. 12 E., Lyon County, along east-west road, 20 yards east of intersection.

Zeandale Limestone (7.2 feet exposed)

Maple Hill Limestone (0.8 foot)

- | | |
|---|----|
| 5. Limestone, dark gray, weathers light yellow-tan with reddish cast, thin, wavy-bedded; many fossils, including small fusulinids, crinoid columnals, shell fragments, brachiopod spines, ramose bryozoans; <u>Ottonosia</u> at top | .8 |
|---|----|

Wamego₂ Shale member (6.4 feet exposed)

- | | |
|---|-----|
| 4. Shale, brown, micaceous, silty, calcareous, small calcareous nodules | .7 |
| 3. Shale, gray to silver, sandy, micaceous | .6 |
| 2. Sandstone, light buff-brown, calcareous, thin-bedded | 1.1 |
| 1. Shale, brown-green, sandy, micaceous, no fossils observed | 4.0 |

Locality 29

Composite section. Stormont from NE Sec. 22, T. 18 S., R. 12 E., Lyon County, on AT&SF railroad

Locality 30 (Cont'd)

	Thickness feet
Dry Shale member covered	9.0
Dover Limestone member (1.7 feet)	
6. Limestone, light gray-tan weathers gray, thick-bedded; large robust fusulinids, crinoid columnals, <u>Ottonosia</u>	1.7
Pillsbury Shale (6.6 feet)	
5. Shale, green-gray, yellow stained, clayey, partly covered	6.6
Zeandale Limestone (4.9 feet exposed)	
Maple Hill Limestone member (1.4 feet)	
4. Limestone, pink to gray, weathers reddish-brown, hard, very fine crystalline, medium-bedded; very abundant crinoid remains, small <u>Neospirifer</u> and productid brachiopods, many brachiopod spines, echinoid spines and plates, small fusulinids on uneven top surface	1.4
Wamego ₂ Shale member (3.5 feet exposed)	
3. Shale, green-gray fissile almost black at top. Grades into Maple Hill . . . . .	.4
2. Shale, gray, hard, silty, thin-bedded, numerous red siltstone concretions at base	1.3
1. Shale, yellow-brown, sandy, very thin bedded. Base is well consolidated - almost a sandstone	1.8 +

Locality 31

Section measured CSL Sec. 3, T. 19 S., R. 11
E., Lyon County, on west side of Kansas highway 99

Locality 31 (Cont'd)

Thickness
feet

about 200 yards south of abandon railroad bed.

Stetler Limestone

Dover Limestone member (1.4 feet)

5. Limestone, medium gray, weathers gray-yellow-tan, hard, massive-bedded, contact sharp at base, irregular at top; very abundant crinoid columnals, fusulinids, horn corals, brachiopod fragments, and large Ottonesia 1.4

Pillsbury Shale (3.6 feet)

4. Shale, green-yellow, clayey, mostly covered 3.6

Zeandale Limestone (16.1 feet exposed)

Maple Hill Limestone member (1.1 feet)

3. Limestone, gray-brown to red-gray at top, weathers light yellow-brown, moderately hard, very fine grained, argillaceous, thick-bedded; numerous crinoid columnals, small fusulinids, shell fragments, ramose bryozoans, small encrusting algae, gastropods 1.1

Wamego₂ Shale member (15 feet exposed)

2. Shale, gray-brown, clayey, mostly covered, blocky 2.0
1. Shale, covered 13.0 +

APPENDIX B

LOCATIONS OF PARTIAL ZEANDALE OUTCROP IN NORTHEASTERN
KANSAS NOT INCLUDED IN MEASURED SECTIONS

Locality A

CNL NE Sec. 9, T. 10 S., R. 15 E., Shawnee County, along east-west road in ditches 100 yards west of intersection.

Wamego Shale - 3 feet
Tarkio Limestone - 2 feet

Locality B

NW SW Sec. 21, T. 10 S., R. 14 E., Shawnee County, three-quarter mile south of Grove near hill top on west side of road.

Wamego Shale - 6 feet
Tarkio Limestone - 2.6 feet

Locality C

CWL SE Sec. 25, T. 11 S., R. 13 E., Shawnee County, on east side of north-south road just north of West Union School.

Tarkio Limestone - over 4 feet

Locality D

NW NW Sec. 1, T. 11 S., R. 13., Shawnee County, on south side of east-west road.

Tarkio Limestone - 6.8 feet

Locality E

SE SW Sec. 31, T. 11 S., R. 14 E., Shawnee County, approximately one-quarter mile east of section corner.

Maple Hill Limestone - 1.5 feet
Wamego Shale - 9 feet
Tarkio Limestone - 6.6 feet

Locality F

SW Sec. 1, T. 12 S., R. 13 E., Shawnee County, in creek and up road to east.

Maple Hill Limestone - 1.4 feet
Wamego Shale - 9.7 feet
Tarkio Limestone - 6.4 feet

Locality G

NE Sec. 19, T. 12 S., R. 14 E., Shawnee County, at bend in road 300 yards south of section corner.

Tarkio Limestone - 3.8 feet
Willard Shale - 37.2 feet

Locality H

CWL SE Sec. 19, T. 12 S., R. 14 E., Shawnee County in creek bank and north from bridge.

Maple Hill Limestone - over 1 foot
Wamego Shale - 13.7 feet
Tarkio Limestone - 4 feet

Locality I

SE Sec. 15, T. 12 S., R. 14 E., Shawnee County, in road out west from creek to top of hill.

Tarkio Limestone - 8.4 feet
Willard Shale - 42 feet

Locality J

CSL SE Sec. 22, T. 12 S., R. 14 E., Shawnee County, on north side of east-west road just east of Blacksmith Creek Bridge.

Maple Hill Limestone - 1.4 feet
Wamego Shale - 14.2 feet
Tarkio Limestone - over 3 feet

Locality K

SW NW Sec. 29, T. 12 S., R. 15 E., Shawnee County, along north-south road, .6 mile north of intersection.

Tarkio Limestone - 2 feet

Locality L

SE Sec. 3, T. 13 S., R. 14 E., Shawnee County, along east-west road, 100 yards east of small tributary of Wakarusa River.

Tarkio Limestone - 3.5 feet

Locality M

SW Sec. 28, T. 13 S., R. 14 E., Shawnee County in farm access road 30 yards east of bridge.

Tarkio Limestone - 3 feet

Locality N

CNL Sec. 1, T. 14 S., R. 13 E., Osage County, 150 yards south of section line on west side of Kansas Turnpike.

Tarkio Limestone - 3.7 feet
Willard Shale - 15.4 feet

Locality O

CSL Sec. 2, T. 15 S., R. 13 E., Osage County, exposed on north side of east-west county road at half-section-line fence.

Stormont Limestone - 2.1 feet
Wamego₁ Shale - 16.7 feet
Tarkio Limestone - top exposed

Locality P

NE NE Sec. 11, T. 15 S., R. 13 E., Osage County, in county road cut just northwest of Kansas Turnpike bridge number 205.

Tarkio Limestone - 3.2 feet

Locality Q

NW Sec. 14, T. 15 S., R. 13 E., in cut on Kansas Turnpike, 200 yards north of bridge number 202.

Wamego₂ Shale
Stormont Limestone
Wamego₁ Shale

Locality R

SE Sec. 22, T. 15 S., R. 13 E., Lyon County, approximately one-quarter mile north and 40 yards west of section line in deep northwest trending ravine.

Pillsbury Shale - 3 feet
 Maple Hill Limestone - 1.2 feet
 Wamego₂ Shale - 4.2 feet

Locality S

SW Sec. 24, T. 15 S., R. 13 E., Osage County, in ditch on east side of north-south road 150 yards north of school.

Tarkio Limestone - 1.3 feet

Locality T

CWL Sec. 6, T. 16 S., R. 14 E., Osage County, east of road just south of creek and stock ponds.

Tarkio Limestone - .8 foot

Locality U

NW SW Sec. 14, T. 16 S., R. 13 E., Osage County, in roadcut 200 yards south of Salt Creek.

Tarkio Limestone - 2.9 feet
 Willard Shale - 9 feet

Locality V

SE Sec. 22, NE Sec. 27, T. 16 S., R. 13 E., Lyon County, in Missouri Pacific Railroad cut southeast of northeast-southwest jog in county road.

Stormont Limestone - 2.2 feet

Locality W

CWL Sec. 23, T. 17 S., R. 12 E., Lyon County, southwest corner of intersection in ditch.

Maple Hill Limestone

Locality X

SW NE Sec. 23, T. 17 S., R. 12 E., Lyon County, below south end of Lake Wilhite Dam.

Maple Hill Limestone

Locality Y

SE Sec. 26, T. 17 S., R. 12 E., Lyon County, in deep drainage ditch on north side of east-west road about 85 yards west of section corner.

Maple Hill Limestone - 1.1 feet
Wamego₂ Shale - 7.6 feet

Locality Z

CNL Sec. 33, T. 18 S., R. 12 E., Lyon County, in ditches along south side of east-west road.

Dover Limestone - 1.5 feet
Pillsbury Shale - 6.1 feet
Maple Hill Limestone - 1.2 feet
Wamego₂ Shale - approximately 29.5 feet

APPENDIX C

CONSTITUENT PERCENTAGES OF THE COARSE FRACTION
OF THE INSOLUBLE RESIDUES OF THE ZENDALE LIMESTONE.

Number	Percent	
1-T-3a	90	Limonite aggregates, spongelike
	6	Arenaceous foraminifer
	3	Pyrite
1-T-3b	45	Feldspar, loose, silt size
	25	Arenaceous foraminifer
	25	Quartz, loose, very fine, subround, frosted
	3	Muscovite flakes
	1	Selenite
	1	Pyrite
1-T-4a	85	Limonite aggregates
	10	Arenaceous foraminifer
	5	Fibrous gypsum
	T	Pyrite
1-T-4b	65	Limonite aggregates
	33	Arenaceous foraminifer
	2	Quartz, loose, fine, euhedral
1-T-5a	70	Arenaceous foraminifer
	30	Quartz, loose, very fine, subround
	T	Muscovite flakes
	T	Glauconite
	T	Limonite aggregates
1-T-5b	35	Arenaceous foraminifer
	35	Quartz, loose, silt size, subround
	25	Feldspar, loose, silt size, subangular
	3	Muscovite flakes
	1	Selenite
	1	Glauconite
1-N-10	79	Arenaceous foraminifer and probables
	15	Silt aggregates, brown
	5	Pyrite
	1	Selenite
	T	Carbonaceous material
	T	Muscovite flakes

Number	Percent	Description
A-T-a	60	Quartz, loose, very fine, subround, frosted
	29	Arenaceous foraminifer
	8	Limonite aggregates, spongelike
	2	Muscovite flakes
	1	Drusy quartz
	T	Celestite
A-T-b	80	Limonite aggregates, spongelike
	12	Arenaceous foraminifer
	5	Quartz, loose, subround, frosted
	3	Selenite
	T	Celestite
A-T-c	85	Limonite aggregates, spongelike
	11	Arenaceous foraminifer and probables
	3	Quartz, loose, very fine, subround, frosted
	T	Muscovite flakes
A-W ₁	50	Quartz, loose, very fine, subround frosted
	29	Feldspar, loose, very fine, subangular
	10	Clay aggregates
	5	Chert, granular
	5	Arenaceous foraminifer
	T	Pyrite
3-T-8	80	Quartz, loose, very fine, subround
	10	Arenaceous foraminifer
	8	Limonite aggregates, spongelike
	2	Gypsum, fibrous
	T	Muscovite
3-M-13	48	Silt aggregates, light brown
	20	Feldspar, loose, very fine, subangular
	15	Quartz, loose, very fine, subangular to subround
	10	Arenaceous foraminifer
	6	Carbonaceous material
	1	Muscovite
4-T-2	65	Limonite, in part replacing foraminifer
	30	Silt aggregates, brown
	3	Quartz, loose, silt size, subangular
	2	Arenaceous foraminifer
	T	Pyrite

Number	Percent	Description
4-T-3	85	Quartz, loose, very fine, subangular to subround
	7	Feldspar, loose, very fine, subangular
	3	Beekite
	3	Muscovite
	2	Arenaceous foraminifer - probables
	T	Glauconite
4-W-8	70	Feldspar, loose, very fine, subangular
	25	Quartz, loose, very fine, subangular to subround
	5	Muscovite
5-T-6a	50	Feldspar, loose, very fine, subangular
	43	Quartz, loose, very fine, subangular, frosted
	3	Arenaceous foraminifer
	2	Selenite
	2	Beekite
	T	Muscovite flakes
5-T-6b	50	Arenaceous foraminifer
	43	Quartz, loose, very fine, subangular - subround, frosted
	5	Magnetite
	2	Pyrite
	T	Selenite
5-T-6c	40	Arenaceous foraminifer and probables
	30	Quartz, loose, very fine, subangular, frosted
	30	Feldspar, loose, very fine, angular
	T	Pyrite
	T	Muscovite flakes
6-T-1	60	Quartz, loose, silt size, subround - subangular
	33	Feldspar, loose, silt size, subround
	4	Muscovite flakes
	3	Arenaceous foraminifer
	T	Fibrous gypsum
6-W-3	65	Feldspar, loose, very fine, subround
	28	Quartz, loose, very fine, subround
	4	Muscovite flakes
	2	Arenaceous foraminifer
	1	Biotite flakes

Number	Percent	Description
6-W-5	100	Arenaceous foraminifer
6-M(?) -7	99	Selenite, loose, elongate crystals
	1	Arenaceous foraminifer
7-T-7a	45	Quartz, loose, very fine, subround, frosted
	40	Limonite aggregates, well consolidated
	3	Feldspar, loose, very fine, subangular
	2	Muscovite flakes
	T	Fibrous gypsum
	T	Silt aggregates, black
7-T-7b	50	Arenaceous foraminifer and probables
	34	Silt aggregates, black
	5	Beekite
	5	Limonite aggregates, spongelike
	4	Quartz, loose, subround, frosted
	2	Fibrous gypsum
7-T-7c	88	Limonite, aggregates, spongelike
	10	Celestite
	1	Arenaceous foraminifer
	1	Beekite
	T	Quartz, loose, subround, polished - frosted
	T	Silt aggregates, black
	T	Pyrite
7-T-7d	92	Silt aggregates, black
	4	Fibrous gypsum
	2	Beekite
	1	Arenaceous foraminifer
	1	Quartz, loose, subround, frosted
	T	Selenite
7-T-7e	94	Celestite
	4	Limonite aggregates, spongelike
	1	Fibrous gypsum
	1	Quartz, loose, very fine, subangular
	T	Muscovite flakes
	T	Arenaceous foraminifer, probables
8-T-3a	50	Limonite aggregates
	46	Quartz, loose, very fine, subround, frosted
	3	Muscovite flakes
	1	Selenite
	T	Tourmaline

Number	Percent	Description
8-T-3b	95	Quartz, loose, very fine, subround, frosted
	4	Arenaceous foraminifer and probables
	1	Fibrous gypsum
	T	Pyrite
8-T-4	90	Quartz, loose, silt size, subround, frosted
	4	Limonite aggregates
	3	Arenaceous foraminifer
	3	Muscovite flakes
	T	Tourmaline
8-T-5	50	Arenaceous foraminifer and probables
	18	Quartz, loose, very fine, subangular
	15	Feldspar, loose, very fine, subangular
	15	Limonite aggregates
	2	Muscovite flakes
	T	Glauconite
	T	Pyrite
8-M-11a	78	Pyrite
	20	Celestite
	2	Arenaceous foraminifer
	T	Beekite
8-M-11b	89	Arenaceous foraminifer and probables
	10	Beekite
	T	Fibrous gypsum
9-T-3	70	Arenaceous foraminifer
	20	Quartz, loose, very fine, subangular, frosted
	10	Feldspar, loose, very fine, subangular
	T	Glauconite
	T	Muscovite flakes
9-M-5	75	Selenite crystals
	15	Pyrite
	10	Celestite
	T	Arenaceous foraminifer
12-T-1a	50	Limonite aggregates, spongelike
	35	Arenaceous foraminifer
	10	Silt aggregates, brown
	5	Quartz, loose, very fine, subround, frosted
	T	Muscovite flakes
	T	Beekite

Number	Percent	Description
12-T-1b	50	Arenaceous foraminifer and probables
	25	Limonite aggregates
	25	Silt aggregates, brown, spongelike
	T	Muscovite flakes
	T	Tourmaline
12-T-2a	40	Arenaceous foraminifer and probables
	30	Limonite aggregates
	20	Pyrite
	10	Quartz, loose, very fine
	T	Spines and/or spicules
	T	Fibrous gypsum
12-T-2b	60	Celestite
	40	Pyrite
	T	Quartz, loose, fine, subhedral
	T	Fibrous gypsum
12-T-3	55	Pyrite
	42	Arenaceous foraminifer
	3	Fibrous gypsum
	T	Feldspar, loose, very fine, subangular
12-T-5	66	Feldspar, loose, very fine, subround
	30	Quartz, loose, very fine, subround, frosted
	4	Muscovite flakes
	T	Chlorite
12-T-6	40	Quartz, loose, very fine, subangular
	35	Feldspar, loose, very fine, subangular
	20	Arenaceous foraminifer
	4	Muscovite flakes
	1	Tourmaline
	T	Fibrous gypsum
12-M-10	85	Quartz, loose, very fine, subangular - subround, frosted
	7	Arenaceous foraminifer
	7	Feldspar, loose, very fine, subangular
	1	Muscovite flakes
	T	Clay aggregates
	14-T-1a	80	Quartz, loose, very fine, subround
8		Arenaceous foraminifer
8		Clay aggregates, brown, spongelike
2		Beekite
2		Fibrous gypsum
T		Pyrite

Number	Percent	Description
14-T-1b	50	Limonite, in part replacing fusulinid structure
	45	Silicified fusulinid fragments
	5	Arenaceous foraminifer
	T	Magnetite
14-T-1c	70	Arenaceous foraminifer
	25	Clay aggregates, brown
	3	Quartz, loose, coarse silt size, subround
	2	Pyrite
14-M-9	60	Feldspar, loose, coarse silt, subround
	30	Quartz, loose, very fine, subround
	10	Silt aggregates, brown
	5	Arenaceous foraminifer and probables
	4	Muscovite flakes
	1	Carbonaceous material
16-T-6a	35	Quartz, loose, very fine, subround
	30	Arenaceous foraminifer
	20	Feldspar, loose, coarse silt size, subangular
	15	Limonite aggregates, spongelike
	T	Muscovite flakes
16-T-6b	60	Limonite aggregates, spongelike
	37	Arenaceous foraminifer
	2	Feldspar, loose, very fine, subangular
	1	Fibrous gypsum
	T	Pyrite
16-T-6c	99	Arenaceous foraminifer and probables
	T	Fibrous gypsum
	T	Muscovite flakes
17-T-2a	60	Arenaceous foraminifer
	15	Clay aggregates, spongelike
	15	Quartz, loose, very fine, subangular
	3	Feldspar, loose, very fine, subangular
	3	Pyrite
	2	Fibrous gypsum
17-T-2b	85	Limonite aggregates, spongelike
	10	Arenaceous foraminifer
	5	Siliceous fusulinid fragments
	T	Fibrous gypsum

Number	Percent	Description
17-T-2e	67	Clay aggregates, spongelike, medium brown
	30	Limonite aggregates, spongelike
	3	Arenaceous foraminifer
	T	Fibrous gypsum
17-W-5a	60	Feldspar, loose, very fine, subangular
	38	Quartz, loose, very fine, subangular
	2	Pyrite
	T	Muscovite flakes
17-W-5b	57	Feldspar, loose, very fine, subangular
	30	Quartz, loose, very fine, subangular
	10	Muscovite flakes
	2	Pyrite aggregates
	T	Celestite
17-W-5c	55	Feldspar, loose, very fine, subangular
	20	Quartz, loose, very fine, subangular
	20	Limonite aggregates, spongelike
	5	Muscovite flakes
17-W-6	66	Feldspar, loose, very fine, subangular
	20	Quartz, loose, very fine, subangular
	14	Muscovite flakes
	T	Tourmaline
18-T-4	73	Quartz, loose, very fine, subangular
	10	Pyrite
	7	Feldspar, loose, very fine, subangular
	5	Arenaceous foraminifer
	5	Muscovite flakes
T	Tourmaline	
18-T-5a	40	Pyrite euhedral
	40	Quartz, loose, very fine, subround
	11	Feldspar, loose, very fine, subangular
	7	Arenaceous foraminifer
	2	Muscovite flakes
18-T-5b	45	Quartz, loose, very fine, subhedral
	35	Limonite aggregates, spongelike
	7	Arenaceous foraminifer
	7	Feldspar, loose, very fine, subangular
	6	Pyrite

Number	Percent	Description
18-T-5c	57	Limonite aggregates, spongelike
	40	Chert, fine, granular
	3	Arenaceous foraminifer
18-T-6	45	Arenaceous foraminifer
	20	Limonite aggregates, spongelike
	20	Pyrite
	14	Silt aggregates, silver-gray
	1	Fibrous gypsum
18-T-7	55	Feldspar, loose, very fine, subangular
	20	Limonite aggregates, spongelike
	15	Quartz, loose, coarse silt, subangular
	7	Arenaceous foraminifer
	3	Muscovite flakes
18-W-9a	70	Feldspar, loose, very fine, subangular
	16	Quartz, loose, very fine - fine, subround, polished
	10	Silt aggregates, gray
	2	Arenaceous foraminifer
	2	Carbonaceous material
	T	Muscovite
18-W-9b	60	Pyrite
	20	Feldspar, loose, coarse silt, subangular
	15	Quartz, loose, coarse silt, subangular - Subround
	5	Arenaceous foraminifer
18-W-11	70	Pyrite
	20	Silt aggregates, brown
	10	Arenaceous foraminifer and probables
18-M-14	90	Pyrite, euhedral and aggregates
	10	Arenaceous foraminifer
	T	Carbonaceous material
19-T-4a	90	Limonite aggregates, spongelike
	10	Siliceous fusulinid fragments
	T	Fibrous gypsum
19-T-4b	93	Arenaceous foraminifer and probables
	4	Limonite aggregates, spongelike
	3	Quartz, loose, coarse silt, subangular

Number	Percent	Description
19-T-5a	94	Arenaceous foraminifer
	3	Selenite
	3	Siliceous fusulinid fragments
19-T-5b	95	Arenaceous foraminifer
	3	Siliceous fusulinid fragments
	2	Limonite aggregates, spongelike
	T	Fibrous gypsum
19-S-9	40	Feldspar, loose, coarse silt, subround
	30	Limonite aggregates
	17	Quartz, loose, very fine, subangular
	10	Arenaceous foraminifer
	3	Quartz, loose, fine, euhedral
	T	Muscovite flakes
19-W-11	50	Feldspar, loose, coarse silt, subangular
	30	Quartz, loose, very fine, subangular
	15	Limonite aggregates, spongelike
	3	Arenaceous foraminifer
	2	Chert, fine, granular
19-W-12	60	Quartz, loose, very fine, subangular
	38	Feldspar, loose, very fine sand - coarse silt, subangular
	1	Arenaceous foraminifer
	1	Carbonaceous material
	T	Tourmaline
19-M-17a	55	Quartz, loose, subangular
	18	Arenaceous foraminifer
	15	Siliceous fusulinid fragments
	5	Clay aggregates, gray
	5	Carbonaceous material
	2	Muscovite flakes
19-M-17b	70	Limonite aggregates spongelike
	20	Siliceous fusulinid fragments
	5	Arenaceous foraminifer
	5	Clay aggregates, gray
20-T-1a	40	Arenaceous foraminifer and probables
	25	Siliceous fusulinid fragments
	25	Magnetite
	10	Quartz, loose, coarse silt, subangular
	T	Beekite
	T	Fibrous gypsum

Number	Percent	Description
20-T-1b	50	Feldspar, loose, fine silt, subangular
	30	Arenaceous foraminifer and probables
	10	Quartz, loose, very fine, subround
	7	Celestite
	3	Magnetite
20-T-1c	60	Siliceous fusulinid fragments
	30	Arenaceous foraminifer and probables
	8	Feldspar, loose, very fine, subangular
	2	Magnetite
20-T-2	60	Limonite aggregates, spongelike
	15	Arenaceous foraminifer
	2	Celestite
	2	Magnetite
	1	Beekite
20-S-4	60	Feldspar, loose, very fine, subangular
	15	Quartz, loose, very fine, subangular
	15	Arenaceous foraminifer
	5	Euhedral pyrite
	5	Muscovite flakes
20-M-10	35	Quartz, loose, very fine, subangular
	30	Feldspar, loose, very fine, subangular
	30	Clay aggregates, brown
	8	Arenaceous foraminifer
	5	Pyrite
	2	Carbonaceous material
	7	Siliceous fusulinid fragments
21-M-10a	75	Arenaceous foraminifer and probables
	20	Limonite aggregates, spongelike
	5	Quartz, loose, very fine, subangular
	7	Spines and/or sponge spicules
21-M-10b	45	Arenaceous foraminifer
	25	Siliceous fusulinid fragments
	25	Clay aggregates, gray and yellow
	5	Pyrite aggregates
	7	Selenite
N-T-a	55	Arenaceous foraminifer
	40	Clay aggregates, spongelike, brown
	3	Feldspar, loose, coarse silt, subangular
	1	Pyrite
	1	Fibrous gypsum

Number	Percent	Description
N-T-b	98	Arenaceous foraminifer
	1	Carbonaceous material
N-T-c	99	Arenaceous foraminifer
	1	Limonite aggregates
	T	Muscovite flakes
22-T-4a	86	Clay aggregates, spongelike, brown
	8	Quartz, loose, silt size, subangular
	5	Arenaceous foraminifer
	1	Pyritized ramose bryozoans
22-T-4b	40	Arenaceous foraminifer
	25	Feldspar, loose, coarse silt, subangular
	15	Quartz, loose, very fine, subangular
	13	Clay aggregates, brown
	5	Beekite
	2	Pyrite
22-S-8	65	Feldspar, loose, very fine, subangular
	23	Quartz, loose, very fine, subround
	5	Limonite aggregates, spongelike
	4	Muscovite flakes
	3	Arenaceous foraminifer
	T	Tourmaline
22-W-10	77	Quartz, loose, very fine, subround
	10	Feldspar, loose, very fine, subangular
	10	Limonite aggregates, spongelike
	3	Arenaceous foraminifer
	T	Tourmaline
23-T-4a	85	Clay aggregates, spongelike, brown
	10	Arenaceous foraminifer
	5	Pyrite aggregates
23-T-4b	95	Clay aggregates, spongelike, brown
	3	Arenaceous foraminifer
	1	Siliceous fusulinid fragments
	T	Feldspar, loose, medium silt, subangular
23-T-5a	45	Clay aggregates, spongelike, brown
	35	Pyrite
	10	Arenaceous foraminifer
	7	Beekite
	3	Siliceous fusulinid fragments
	T	Quartz, medium sand, subhedral

Number	Percent	Description
23-T-5b	55	Clay aggregates, spongelike, brown
	32	Beekite
	6	Quartz, loose, fine, subhedral
	5	Arenaceous foraminifer
	2	Pyrite
	T	Muscovite flakes
23-S-8a	74	Feldspar, loose, very fine, subangular
	13	Quartz, loose, very fine, subangular
	10	Clay aggregates
	3	Muscovite flakes
23-S-8b	94	Feldspar, loose, very fine, subangular
	5	Mica flakes
	1	Arenaceous foraminifer
	T	Quartz, loose, medium sand, subround
23-S-9a	65	Feldspar, loose, very fine, subangular
	15	Quartz, loose, very fine, subangular
	8	Limonite aggregates, spongelike
	7	Mica flakes
	5	Arenaceous foraminifer
23-S-9b	75	Feldspar, loose, very fine, subangular
	15	Arenaceous foraminifer
	5	Quartz, loose, very fine, subangular
	5	Mica flakes
	T	Fibrous gypsum
23-M-19a	63	Clay aggregates, brown
	20	Arenaceous foraminifer
	15	Quartz, loose, very fine, subangular
	2	Pyrite
23-M-19b	50	Limonite aggregates, spongelike
	35	Arenaceous foraminifer
	10	Pyrite
	5	Quartz, loose, very fine, subangular
	T	Carbonaceous material
24-M-6	85	Limonite aggregates, spongelike
	10	Arenaceous foraminifer
	5	Quartz, loose, very fine, subangular
	T	Muscovite flakes
	T	Siliceous fusulinid fragments

Number	Percent	Description
U-T-a	60	Feldspar, loose, very fine, subangular
	32	Quartz, loose, very fine, subangular
	3	Beekite
	3	Muscovite flakes
	2	Arenaceous foraminifer
U-T-b	98	Arenaceous foraminifer and probables
	1	Muscovite flakes
	1	Fibrous gypsum
25-S-8b	70	Feldspar, loose, very fine, subangular
	17	Limonite aggregates
	6	Arenaceous foraminifer
	5	Quartz, loose, very fine, subround
	2	Muscovite flakes
26-T-1	40	Limonite aggregates, spongelike
	35	Clay aggregates, hard, brown to black
	20	Arenaceous foraminifer and probables
	5	Muscovite flakes
27-S-2a	50	Feldspar, loose, very fine, subangular
	30	Quartz, loose, very fine, subangular
	15	Arenaceous foraminifer
	4	Muscovite flakes
	7	Tourmaline
27-S-2b	45	Feldspar, loose, very fine, subangular
	20	Quartz, loose, very fine, subangular
	17	Arenaceous foraminifer
	15	Limonite aggregates
	3	Mica flakes
27-M-7	50	Limonite
	20	Arenaceous foraminifer
	15	Quartz, loose, fine, subangular
	8	Selenite
	7	Carbonaceous material
28-M-5	98	Silt Aggregates
	1	Arenaceous foraminifer
	1	Quartz, loose, fine, subround
	T	Muscovite flakes
	T	Carbonaceous material

Number	Percent	Description
Y-M	97	Clay aggregates, brown, spongelike
	2	Quartz, loose, fine, subround
	1	Arenaceous foraminifer
	T	Carbonaceous material
29-S-1a	79	Feldspar, loose, very fine, subangular
	15	Quartz, loose, very fine, subangular
	4	Muscovite flakes
	2	Biotite flakes
	T	Tourmaline
29-S-1b	70	Feldspar, loose, coarse silt, subangular
	17	Quartz, loose, very fine, subangular
	8	Muscovite flakes
	4	Biotite flakes
	1	Arenaceous foraminifer
29-M-4	85	Limonite
	13	Arenaceous foraminifer and probables
	2	Quartz, loose, fine, subround
30-M-4	65	Arenaceous foraminifer
	32	Quartz, fine, loose, subround
	2	Fibrous gypsum
	1	Limonite aggregates, spongelike
31-M-3	55	Arenaceous foraminifer
	45	Quartz, loose, fine, subangular - subround
	T	Pyrite
	T	Carbonaceous material

APPENDIX D

PERCENTAGE CHART OF INSOLUBLE RESIDUE ANALYSIS OF THE
ZEANDALE LIMESTONE

Sample Number*	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
1-T-3a	3.8	8.0	92.0
1-T-3b	5.1	1.0	99.0
1-T-4a	2.7	6.1	93.9
1-T-4b	3.0	10.0	90.0
1-T-5a	5.9	41.5	58.5
1-T-5b	5.2	7.7	92.3
1-M-10	5.0	4.0	96.0
A-T-a	12.4	1.2	98.8
A-T-b	5.8	6.1	93.9
A-T-c	13.1	7.2	92.8
A-W-	32.4	1.1	98.9
3-T-8	7.4	1.4	98.6
3-M-13	13.2	23.7	76.3
4-T-2	11.3	1.3	98.7
4-T-3	15.7	53.8	46.2

*Numerals and capital letters between dashes refer respectively to outcrop locality, Zeandale member, and bed number in measured sections. Lower case letter to extreme right denotes position within a single bed. e.g., sample 1-T-3a was obtained from Locality 1, Tarkio Limestone member, lower part of bed 3 in described sections. Sample 1-T-3b is stratigraphically higher.

Appendix D (Cont'd)

Sample Number	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
4-W-8	50.8	71.7	28.3
5-T-6a	9.5	.6	99.4
5-T-6b	8.2	.6	99.4
5-T-6c	12.9	.8	99.2
5-W-10	54.9	76.6	23.4
6-T-1	5.0	2.0	98.0
6-W-3	32.1	16.1	83.9
6-W-5	10.3	8.3	91.7
6-M-7	17.1	2.6	97.4
7-T-7a	11.4	3.8	96.2
7-T-7b	12.9	.3	99.7
7-T-7c	15.6	2.4	97.6
7-T-7d	10.8	.1	99.9
7-T-7e	8.8	4.2	95.8
7-M-17	5.5	17.4	82.6
8-T-3a	17.8	7.6	92.4
8-T-3b	7.6	.7	99.3
8-T-4	10.3	5.8	94.2
8-T-5	6.1	28.7	71.3
8-M-11a	2.9	22.8	77.2
8-M-11b	14.7	2.4	97.6
9-T-3	5.7	16.8	83.2

Appendix D (Cont'd)

Sample Number	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
9-M-5	6.9	43.9	56.1
12-T-1a	8.6	.8	99.2
12-T-1b	15.9	.8	99.2
12-T-2a	6.7	1.5	98.5
12-T-2b	4.8	30.1	69.9
12-T-3	4.4	9.1	90.9
12-T-5	48.0	27.8	72.2
12-T-6	17.1	16.7	83.3
12-M-10	18.4	2.7	97.3
14-T-1a	15.1	2.6	97.4
14-T-1b	8.1	8.6	91.4
14-T-1c	8.1	4.3	95.7
14-M-9	11.8	9.3	90.7
16-T-6a	10.6	2.4	97.6
16-T-6b	7.2	.7	99.3
16-T-6c	10.9	.5	99.5
17-T-2a	13.3	3.8	96.2
17-T-2b	6.8	9.6	90.4
17-T-2c	4.7	5.4	94.6
17-T-2d	5.8	25.0	75.0
17-T-2e	8.6	1.8	98.2
17-W-5a	35.0	45.6	54.4
17-W-5b	36.5	61.3	38.7

Appendix D (Cont'd)

Sample Number	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
17-W-5c	28.7	44.7	55.3
17-W-6	38.9	41.6	58.4
18-T-4	39.7	28.1	71.9
18-T-5a	8.0	5.4	94.6
18-T-5b	7.8	3.4	96.6
18-T-5c	4.0	21.5	78.5
18-T-6	3.1	1.1	98.9
18-T(S)-7	11.4	22.3	77.7
18-W-9a	15.1	10.0	90.0
18-W-9b	5.5	20.0	80.0
18-W-11	23.4	43.3	56.7
18-M-14	15.3	5.9	94.1
19-T-4a	15.1	5.6	94.4
19-T-4b	11.2	.4	99.6
19-T-5a	17.9	1.1	98.9
19-T-5b	10.6	1.4	98.6
19-S-9	16.6	11.2	88.8
19-W ₂ -11	20.3	18.2	81.8
19-W ₂ -12	22.5	15.8	84.2
19-M-17a	25.1	3.5	96.5
19-M-17b	16.0	10.3	89.7
20-T-1a	10.0	2.8	97.2

Appendix D (Cont'd)

Sample Number	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
20-T-1b	17.5	1.1	98.9
20-T-1c	13.9	3.2	96.8
20-T-2	6.4	1.6	98.4
20-S-4	17.4	33.6	66.4
20-M-10	15.6	2.9	97.1
21-M-10a	20.8	2.6	97.4
21-M-10b	6.7	7.5	92.5
N-T-a	15.0	4.0	96.0
N-T-b	13.6	2.9	97.1
N-T-c	18.2	.6	99.4
22-T-4a	17.9	1.3	98.7
22-T-4b	15.3	.4	99.6
22-S-8	23.7	27.2	72.8
22-W ₂ -10	15.6	7.1	92.9
23-T-4a	16.8	1.6	98.4
23-T-4b	11.1	6.6	93.4
23-T-5a	10.9	2.1	97.9
23-T-5b	12.0	.6	99.4
23-S-8a	21.2	23.6	76.4
23-S-8b	17.4	13.2	86.8
23-S-9a	26.7	76.0	24.0
23-S-9b	20.4	61.3	38.7

Appendix D (Cont'd)

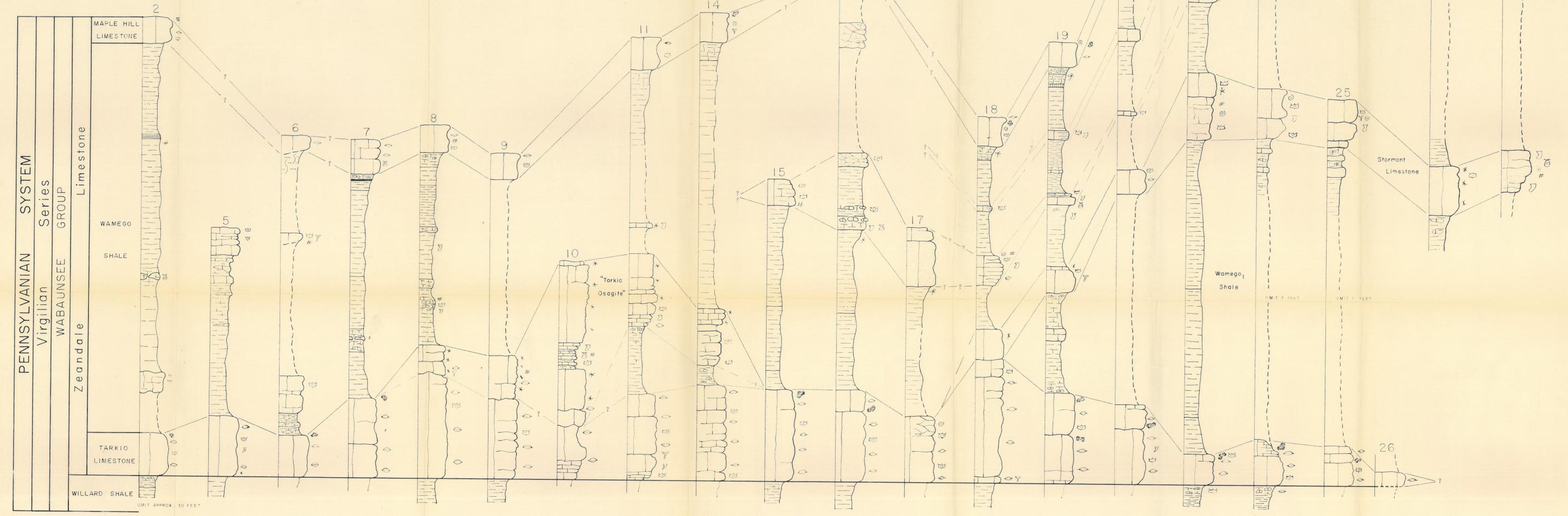
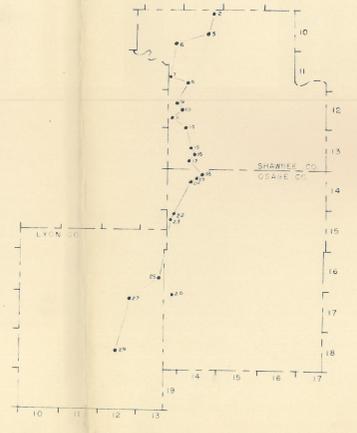
Sample Number	<u>Total Residue</u> percent of original sample	<u>Coarse Fraction</u> percent of residue	<u>Fine Fraction</u> percent of residue
23-M-19a	6.9	5.8	94.2
23-M-19b	7.2	9.0	91.0
24-M-6	6.1	9.1	90.9
U-T-a	11.8	1.4	98.6
U-T-b	19.2	.7	99.3
25-W ₁ -4	64.2	50.7	49.3
25-S-8a	66.2	69.4	30.6
25-S-8b	21.4	60.7	39.3
26-T-1	18.6	4.6	95.4
27-S-2a	9.5	23.3	76.7
27-S-2b	7.6	17.2	82.8
27-M-7	9.5	8.5	91.5
28-M-5	15.5	13.5	86.5
Y-M-	9.8	9.0	91.0
29-S-1a	45.7	93.8	6.2
29-S-1b	27.5	86.4	13.6
29-M-4	8.6	8.1	91.9
30-M-4	15.2	2.6	97.4
31-M-3	16.2	9.0	91.0

EXPLANATION

LITHOLOGY	PALEONTOLOGY
Arenaceous limestone	Fusulinids
Silty or sandy shale	Brachiopods
Argillaceous limestone	Pectenacea
Calcareous shale	Mytilacea
Nodular limestone	Solitary corals
Fissile shale	Gastropods
Massive limestone	Fenestrate bryozoans
Blocky, clay shale	Ramosse bryozoans
Coal	Ottanosia
Underclay	Osagia
	Plant fragments



DATUM - BASE OF TARKIO



CORRELATION CHART OF THE ZEANDALE LIMESTONE