

**KANSAS GEOLOGICAL SURVEY**  
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**Lateral Homogeneity in a "Middle Limestone Member" (Leavenworth)  
of a Kansas Pennsylvanian Megacyclothem**

by

**Donald F. Toomey**

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**KANSAS GEOLOGICAL SURVEY**  
1930 Constant Avenue  
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Lawrence, KS 66047

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RICE UNIVERSITY

LATERAL HOMOGENEITY IN A "MIDDLE LIMESTONE MEMBER" (LEAVENWORTH)  
OF A KANSAS PENNSYLVANIAN MEGACYCLOTHEM

by

Donald Francis Toomey

A THESIS SUBMITTED  
IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF  
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Thesis Director's signature:

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Houston, Texas  
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*you speak of only one grain in figure caption*

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ABSTRACT

The Leavenworth Limestone is the "middle-limestone member" of the Pennsylvanian (Virgilian) Oread Megacyclothem. It has long been known for its lateral persistence and uniformity. This study was initiated to test its lateral homogeneity by quantitative study of its recognizable parameters for the purpose of differentiating meaningful geological and paleontological associations, and facies. It was hoped, further, that the factors affecting the origin and distribution of the various facies constituents could be isolated and identified.

Samples from 33 outcrops localities from southwestern Iowa to northern Oklahoma were subjected to analyses. Point-count analysis was undertaken to determine quantitatively the volumetric abundance of the individual skeletal and nonskeletal grains present within the unit. Vector analysis of the point-count data using a high-speed digital computer delineated 3 geologically meaningful facies. These are: (1) skeletal mudstone facies--characterized by a relative abundance of diverse skeletal grains, (2) aggregate-grain facies--with an abundance of relatively large complex coated-grains, and (3) mudstone facies with a high percentage of lime mud and a reduction in organic constituents.

Skeletal mudstone occurs at 27 localities, and is the dominant Leavenworth Limestone facies. The fact that most of the outcrops localities represent one major facies suggests that the processes responsible for the distribution and abundance of grain types within this facies are interrelated, and probably represent strongly intercorrelated elements of a closely knit marine depositional environment. The aggregate-grain facies is present only at the northern and southern extremities of the

outcrop belt; it is apparently a modification of the skeletal mudstone facies in which aggregate-grains comprise up to 45 percent of the total rock. The distribution of this facies may possibly be related to increased algal growth in relatively shallower near-shore waters. The mudstone facies of southwestern Iowa (appears to be) a local occurrence which contains relatively little skeletal debris.

Total foram counts were statistically studied with the aid of the computer; three facies were defined. These are: (1) mobile foram biofacies--which contain the highest percentage of mobile smaller foraminifers, (2) fusulinid biofacies--dominated by an abundance of triticitid fusulinids, and (3) an encrusting foram biofacies--in which 3 encrusting foraminiferal genera represent the bulk facies characteristics.

The mobile foram biofacies comprises 20 outcrop localities, whereas the fusulinid biofacies is represented at 9 localities. Both foraminiferal biofacies are closely related. The encrusting foram biofacies is represented at 4 localities in southwestern Iowa. (The foraminiferal) results suggests that the biological mechanisms responsible for the Leavenworth foraminiferal (distribution) and abundance are relatively interrelated factors in a highly organized ecosystem.

The main advantage in using the statistical approach on the Leavenworth data was that all the data were given equal weight, and were treated in an impartial manner. Most importantly, the statistical approach facilitated the breakdown of many data bundles (variables) into as few as three theoretical variables that (contain) essentially all the information present in a much larger set of original observations.)

Study of (a number of) other parameters (insoluble residues, chemical analyses, microfauna and macrofauna, and clay mineralogy) all

materially aided in demonstrating the relative lateral uniformity of these elements in the Leavenworth Limestone.

Stratigraphic equivalency of the Salem School Limestone of northcentral Texas, to the Leavenworth Limestone of the Midcontinent Region, on the basis of stratigraphic position, lithologic similarity, and similar microfaunal content, is suggested.

## INTRODUCTION

The Leavenworth Limestone of Pennsylvanian<sup>#</sup>(Virgilian) age, which is exposed in the Midcontinent Region, has long been thought to represent a classic example of lateral homogeneity. Moore (1950, pp. 12-14) observed that the Leavenworth Limestone can be traced along outcrop for a distance of over 300 miles from southern Kansas to southwestern Iowa, and that this thin carbonate (nowhere thicker than 3 feet) can also be identified downdip into the western basinal area for a distance of at least 300 miles. The purpose of this study is to test the concept of lateral homogeneity, and to determine whether or not a very detailed study, that utilizes the "tried and tested" methods of the profession, coupled with the extensive usage of an electronic computer, can differentiate and delineate geologically significant (and meaningful) associations and facies,\* both in lithology and fauna across the outcrop belt. (2)

It is believed that once the Leavenworth's depositional and environmental setting has been established it will then be possible to compare the results with the data obtained from studies now in progress on other units of the Oread Megacyclothem, e.g., Toronto Limestone and Heebner Shale. (As a general (over-all) goal it is believed that when all these units have been environmentally and depositionally "finger-printed" it will be possible to gain a new insight into the role of the megacyclothem as a geological entity. (3) (4)

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\*The term facies is defined according to Moore (1949, p. 8) as: "...areally segregated parts of differing nature belonging to any genetically related body of sedimentary deposits."

### ACKNOWLEDGMENTS

This present study was supervised by Dr. Carey Croneis and Dr. Edward G. Purdy. Special thanks are given to Dr. Croneis, who in spite of many administrative demands, found time to offer helpful suggestions and encouragement. To Dr. Purdy, especial thanks are also due for his many helpful and stimulating suggestions brought about through numerous evocative discussions. All of the computer methods developed during this study are due almost entirely to his foresight and initiative. Dr. Thomas Pulley, of Rice University and the Houston Museum of Natural Science, read and discussed the manuscript with the writer and offered useful comments.

Field assistance by Arthur Troell and Keith Evans of Rice University, and Stanton Ball of the Kansas Geological Survey is gratefully acknowledged. Thanks are due Dr. Robert Downs and Dr. George A. Sanderson of Shell Oil Company for fusulinid information and identifications. Special thanks are due Dr. Downs who first discovered the unique fusulinid Waeringella in the Leavenworth Limestone, and who called the writer's attention to the occurrence of this same form in the <sup>presence</sup> Salem School Limestone of northcentral Texas. ~~Salem School Limestone.~~

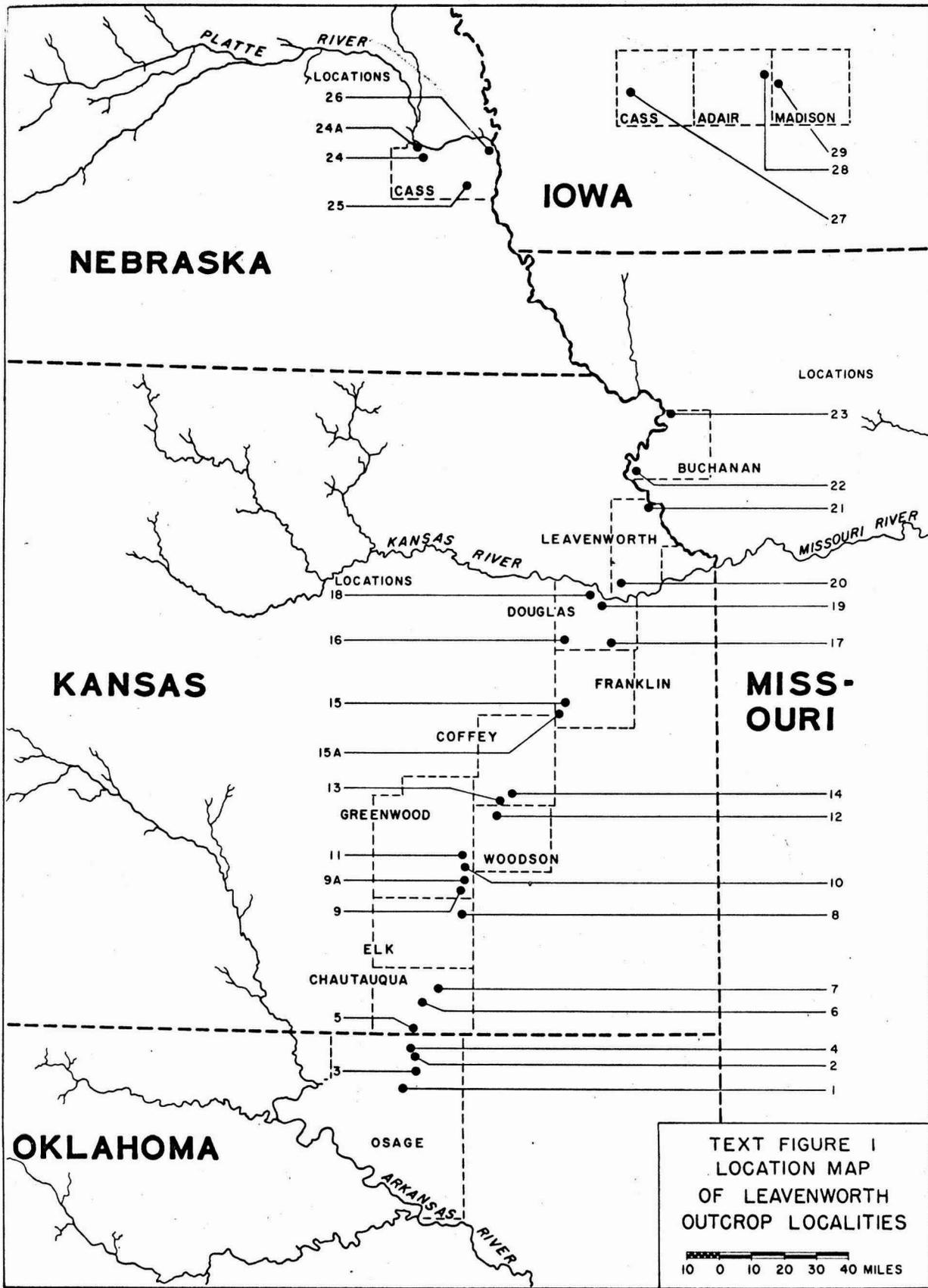
The following persons, all of Shell Development Company, aided the writer in the following ways: Dr. Robert Schwartz provided the writer with pertinent chemical data, especially the versenate analysis; Dan Shaw <sup>conducted?</sup> ran the clay mineralogy and trace element analyses; Otto Majewski offered many suggestions and much help on the general topic of skeletal petrography; photomicrographs were taken and prepared by Robert Girndt; and insoluble residues were prepared by David Pettus.

### FIELD AND LABORATORY METHODS

Preliminary reconnaissance field work was undertaken on the Leavenworth Limestone in Kansas during the summer of 1958. Brief visits were again made to the Kansas localities during 1962, <sup>and early</sup> Early in 1963 additional <sup>samples were</sup> collecting in Kansas and northern Oklahoma, was continued. During the month of July 1963, additional collections were made at outcrop localities from southwestern Nebraska and southwestern Iowa, thus <sup>more than</sup> completing an outcrop traverse of over 300 miles in length. In September 1963, one weekend was spent in examining and collecting the Leavenworth equivalent, the Salem School Limestone, in northcentral Texas. <sup>Southwest Iowa?</sup>

Thirty-four outcrop localities from southwestern Iowa to northcentral Texas were measured, and studied in detail for primary structures, fossil occurrences, and lithologic variability. A number of additional Leavenworth localities were visited and examined during the field work period. Large blocks representing the entire unit thickness at each locality were collected and returned to the laboratory. Before the sample was removed from the outcrop, the bedding plane direction was marked on the block. In all, over 100 <sup>more than</sup> large blocks were collected, each weighing on the order of 15 to 20 pounds.

<sup>(staked above)</sup>  
The rock samples were returned to the laboratory and sawed into manageable pieces, then slabbed parallel to the bedding plane. The slabs were coated with oil (Nujol) and examined under a low-power binocular microscope for additional sedimentary structures and fossils. Fossils that were found during this process were extracted from the rock, and filed <sup>(5)</sup> in the megafossil collections. A permanent sample collection consisting



*Legend does not show symbol for county boundaries.*

of approximately 4 pounds of rock from each outcrop locality was placed in labeled jars, and is now on open file in the Rice Geology Department. (1)

From the entire bulk of outcrop sample 175 large (2 x 3 inches) thin-sections were prepared and studied in detail. <sup>(2)</sup> ~~Out of this extensive~~ <sup>From</sup> thin-section collection 68 representative thin-sections were chosen for point-count analysis.

Two insoluble residues were prepared <sup>for</sup> from each outcrop locality by dissolving 100 gms of rock in 1:5 formic acid. The residues were weighed on an analytical balance, and examined and described under a binocular microscope. <sup>examined?</sup> Later the residues were (picked) for microfossils which were sorted and mounted on standard micropaleontological slides; approximately 25,000 specimens were picked, mounted, and identified.

Chemical analyses were run on one sample from each outcrop locality; these consisted of versenate analysis for calcite-dolomite percentages, and noncarbonate carbon analysis to determine the percentage of organic carbon.

X-ray diffraction patterns were run on all samples ~~in order to~~ determine the types and percentages of clay minerals present in the <sup>Leavenworth Limestone</sup> (Leavenworth Limestone). X-ray fluorescent spectrographic analyses were also run on all samples to determine the percentages of certain trace elements.

## STRATIGRAPHY

The Leavenworth Limestone is the "middle-limestone" member of the Oread Megacyclothem (Moore, 1936, pp. 30-34) of Pennsylvanian (Virgilian) age. The unit crops out in a linear belt that extends from northern Oklahoma, across eastern Kansas, northwestern Missouri, southeastern Nebraska, <sup>of near base</sup> and into southwestern Iowa; a distance well over 300 miles. Condra (1927, p. 38) originally described the unit and designated the type locality as Leavenworth, Kansas (roadcut on upland spur northwest of the Federal Penitentiary; Locality 21 of this report). The limestone is dark bluish-gray, fine-grained, dense, very hard, vertically jointed, moderately fossiliferous, and usually occurs as one prominent bed ranging in thickness from a little less than one foot to a little more than three feet. (1)

The Leavenworth Limestone is overlain (usually with a knife-sharp contact) by the distinctive hard, black shale and siltstone known as the Heebner. Across Kansas, the Heebner ranges in thickness from five to seven feet and consists of two units: (1) a lowermost black platy shale and siltstone usually containing small phosphatic concretions, conodonts, fish remains, occasional plant fragments, and thin-shelled pectinoid clams, and (2) an overlying gray to green, soft, clayey shale usually unfossiliferous at the base but which becomes progressively more fossiliferous toward the top. The Heebner remains fairly consistent\* in thickness and uniformity across most of the 14

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\*Two notable exceptions to this general rule, both in southwestern Iowa, may be cited: (1) at Locality 28, in Adair County, six inches of buff and olive clayey shale lies directly upon the Leavenworth. This atypical unit carries abundant brachiopods, Crurithyris and Wellerella (2)

outcrop belt from Elgin, <sup>Cherokee Co., Kansas,</sup> (southern Kansas) to Madison County, Iowa. South of Elgin, Kansas, in northern Osage County, Oklahoma, the Heebner undergoes facies change from the clearly divisible, relatively thin two-part unit, as noted above, to a fifty-two foot sequence of gray and blue shales with minor sandstone intercalations. The basal part of this shale sequence carries a marine fauna comprising crinoids, corals, pelecypods, and gastropods (Cooley, 1952, pp. 36-38).

Underlying the Leavenworth Limestone is the Snyderville Shale.

This sequence consists of approximately <sup>12</sup> twelve feet of gray to buff sandy shale (north of Locality 14; south of this locality the unit thickens to about 75 feet (Moore, 1936, p. 164) and contains several red shale units, red-stained sandstone units, and several discontinuous conglomeratic units. Generally speaking, the Snyderville is a structureless clay that weathers to irregularly-shaped blocky masses. Moore (1936, p. 164) noted that the Snyderville "has the character of an underclay." At most outcrop localities there is a thin (up to <sup>6</sup> six inches), extremely fossiliferous gray-green shale unit directly underlying the Leavenworth Limestone which contains very abundant chonetoid brachiopods. It has been observed that the megafauna from this interval becomes taxonomically more diversified and hence "more marine" in a northern direction.\* The contact of this unit with the overlying Leavenworth

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(Hershey, et. al., 1960, p. 41), (2) at Locality 29, in Madison County, seven inches of the same type of shale carrying abundant crinoid columnals also overlies the Leavenworth. In both cases this atypical shale unit is overlain by the typical two-part Heebner subdivision as found elsewhere.

\*This is discussed more fully in the section on the macrofauna.

Limestone appears to be gradational and conformable. Southward, in northern Osage County, Oklahoma, the Snyderville Shale thickens and merges gradually into the lower Virgilian Vamoosa Formation (a dominantly red-bed and clastic unit) and loses its individual identity; as do most all of the other Virgilian units (Branson, 1962, p. 449). *loses* *source instead of derivation?*

In discussing the stratigraphy of the Leavenworth Limestone, reference may be made to the generalized cross-section presented on text-figure 2. For sake of convenience and continuity the stratigraphic relationships of the Leavenworth Limestone will be delineated and discussed under six major geographic headings, which are as follows:

(1) southwestern Iowa, (2) southeastern Nebraska, (3) northwestern Missouri, (4) eastern Kansas, (5) northern Oklahoma, and (6) northcentral Texas.

(1) Southwestern Iowa: Condra and Upp (1933, pp. 13-14) made the first successful attempt to correlate the Virgilian sequence in southwestern Iowa with the better known Oread section of Nebraska. They described one section from Madison County, which is essentially identical to Locality 29 of this report. Their description of one foot <sup>2</sup> two inches of Leavenworth Limestone is:

"dark bluish-gray, very dense, with vertical joints, forms rectangular blocks, contains minute fusulinids, high-spined gastropods, bellerophontids, abundant algae growth and some bryozoa."

In Adair County they described (p. 18) the same thickness of Leavenworth Limestone at two localities along ~~the~~ Middle River, a little over a mile northwest of Locality 28 of this report. *west of*

In a second paper ~~later~~ that same year (Condra and Upp, 1933b, pp. 18-21), they described an outcrop of Leavenworth Limestone exposed

along the Nishnabotna River southwest of Lewis, Cass County, consisting of two beds of limestone approximately three feet thick. This outcrop is identical to that described by Hershey et. al. (1960, p. 53), and is Locality 27 of this report. However, it is difficult to explain how Condra and Upp failed to report the thin shale unit separating these two limestones.

Welp et. al. (1957, p. 419) measured and described Leavenworth Limestone from outcrops in the right bank of the Middle River, southeast of the village of Howe, Adair County, Iowa. At this locality one foot one inch of Leavenworth Limestone was described as a single, massive, blue-gray bed containing Ottonosia algal masses.

Payton and Thomas (1959, pp. 172-173) in a study of the Heebner <sup>shale</sup> reported an underlying dense, dark gray fusulinid-bearing limestone of the "Leavenworth type" (sic) in Madison County, Iowa. Their locality is one township south of Locality 29 of this report.

Hershey et. al. (1960) in an extensive restudy of all Pennsylvanian outcrops and core material from southwestern Iowa were able to (revise and correct <sup>2</sup> previous unreliable correlations and) relate the Iowa section to that of Nebraska. The rocks of the Oread Megacyclothem were recognized, and the Leavenworth Limestone delineated (p. 22) as:

"dark to medium bluish gray, weathering to light gray, dense to finely fragmental in texture, and breaks into rectangular fragments. The thickness is very constant, varying between 1.1 to 1.3 feet at exposures in Madison, Adair, and Cass Counties. The Leavenworth Limestone has been encountered in cores in Montgomery County... . The limestone contains embedded brachiopods and crinoidal fragments, but is chiefly characterized by abundant large Ottonosia."

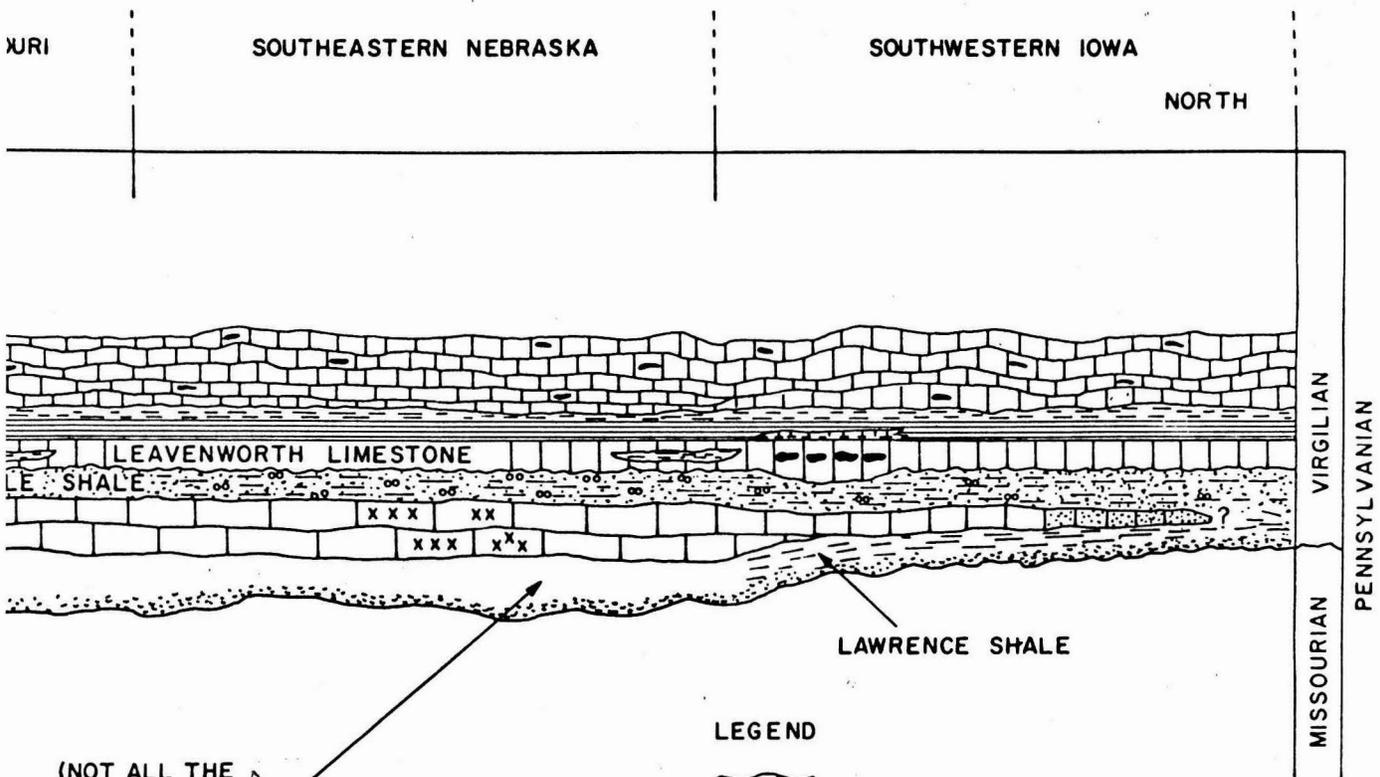
Of the reported Iowa localities two deserve added comment. In Cass County, along the Nishnabotna River, southwest of the town of Lewis,

the Leavenworth Limestone (Locality 27) is a thick (two feet seven inches) sequence of two limestones separated by a thin gray-green shale. The basal limestone unit (two feet thick) superficially appears to be "typical" Leavenworth, with the exception that it contains abundant nodules of black chert (seen nowhere else along the entire outcrop belt) and many well preserved brachiopods (Meekella and Composita). Overlying this limestone unit is a thin three inch gray-green calcareous shale carrying an abundant marine microfauna. This in turn, is overlain by a four inch, gray-brown, very argillaceous limestone. Hershey et al. (1960, p. 53) consider all three units as part of the Leavenworth Limestone, as does this writer. Overlying this Leavenworth sequence, with a knife-sharp contact, is typical black fissile Heebner Shale and Siltstone.

Hershey et al. (1960, p. 77) reported an anomalous so-called "Leavenworth Limestone" from a road ditch northwest of the village of Stennett, Montgomery County, Iowa, which was described as a six inch thick shale! This outcrop has not been seen by the writer but Hershey's description:

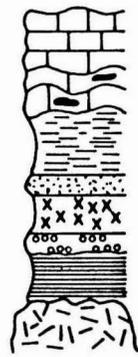
"shale, light gray, very limy with pellets of limestone, very fossiliferous with Chonetes, Stereostylus, ramose bryozoans, Composita and Marginifera"

would cause this writer to doubt the validity of the correlation. It is further noted that Hershey describes the overlying basal "Heebner" as a unit approaching a shaly lignite. The thinness, the exotic lithology, the highly fossiliferous nature of the unit, and the overlying shaly lignite all suggest some doubt that this is a part of the Oread sequence. (1) Apparently Hershey was not entirely convinced as he noted that "the Leavenworth Limestone as seen at this outcrop does not appear to be characteristic."



(NOT ALL THE STRATIGRAPHY PLOTTED)

LEGEND



- LIMESTONE  
(WAVY — BEDDED & CHERTY)
- GRAY AND/OR GREEN SHALE
- SANDSTONE OR SANDY
- RED SHALE OR RED STAIN
- CONGLOMERATE
- BLACK FISSILE SHALE
- POSITIVE AREA

FROM NORTHCENTRAL TEXAS TO SOUTHWESTERN IOWA

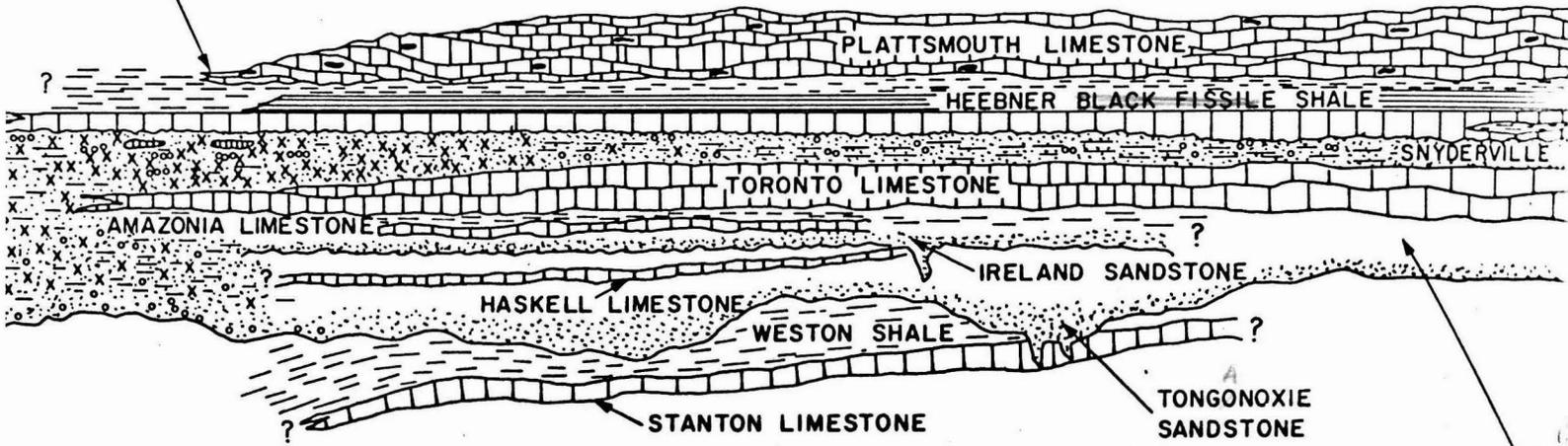
OKLAHOMA | KANSAS

KANSAS |

NORTHWESTERN MISSOURI

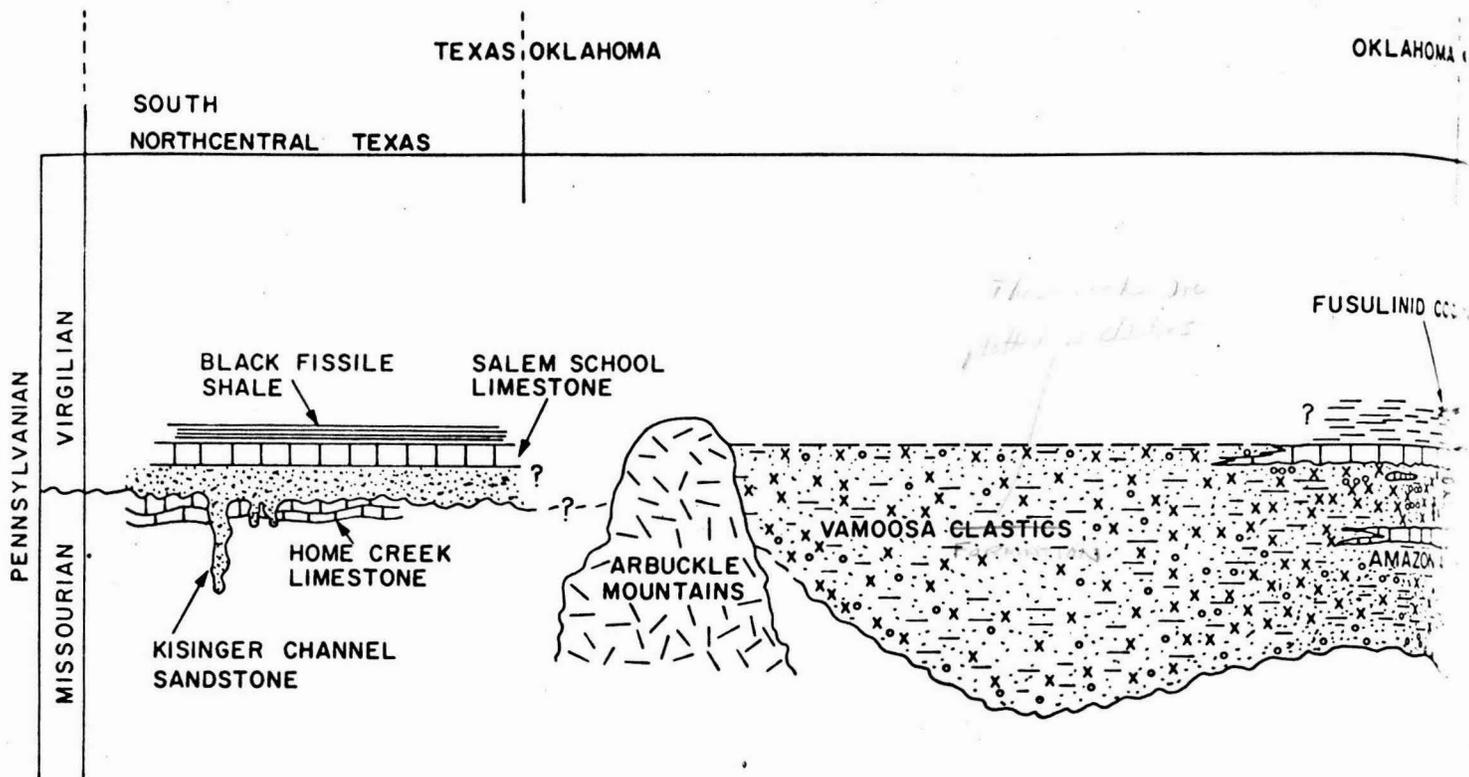
(POST PLATTSMOUTH  
STRATIGRAPHY  
NOT PLOTTED)

FUSULINID COQUINA



Rocks

N OF PERTINENT LOWER VIRGILIAN AND UPPER MISSOURIAN SEDIMENTS FA



TEXT FIGURE 2 GENERALIZED CROSS-SECTION OF PERI

Leavenworth Limestone has not been found in Iowa farther east than Locality 29 in Madison County, or north of Locality 28 in Adair County. Lack of outcrops, or poor outcrops primarily concealed by glacial drift, prevent detailed stratigraphic tracing of the unit in either of the above directions.

(2) Southeastern Nebraska: In Condra's (1927) classic volume on the stratigraphy of the Pennsylvanian System of Nebraska he defined the Leavenworth Limestone, and delineated its outcrop extent in southeastern Nebraska, and described a number of localities in Cass County. Two of the most pertinent localities are the exposure located in the city of Plattsmouth in the northeastern part of the county, and an exposure located in the Snyderville Quarries outside of the town of Nehawka in the southeastern part of the county.

The outcrop at Plattsmouth (Locality 26 of this report) is exposed in the bluffs along the southside of the Missouri River. This outcrop is now contained within the extensively worked Heebner Quarries. Condra (p. 136) reported the Leavenworth from this locality as two thin beds of dark bluish-gray, dense limestone one foot three inches thick. The outcrop at the Snyderville Quarries (Locality 25 of this report), north of Nehawka, consists of one foot four inches of Leavenworth described by Condra (p. 169) as "blue, brittle, massive, one or two beds, forms rectangular blocks."

*This material can be condensed.*

In 1930 Condra (pp. 37-38) described a section along Pawnee Creek in northwestern Cass County where he reported the thickness of Leavenworth Limestone as one foot ten inches; Locality 24 of this report was measured in approximately the same area. A more complete total Oread section was measured a little over a mile north of this locality. This exposure, adjacent to Pawnee Creek (Locality 24-A), is in Johansen's

*with Leavenworth Limestone*

Quarry. Here the Leavenworth is exposed as a single massive bed one foot seven inches thick. Of noteworthy occurrence at this locality is the abundance of large overturned blocks of the Leavenworth (due to quarrying operations) which expose the bottom of the unit displaying classic examples of burrowing structures (see plate 2).

(3) Northwestern Missouri: Outcrops of the Leavenworth Limestone in northwestern Missouri are isolated from exposures of the same strata in northeastern Nebraska due to the mantle of Pleistocene deposits in the uplands between, and also to the thick cover of Cretaceous sediments in parts of the intervening area.

Hinds (1915, p. 171) recognized Oread rocks in Buchanan County, northwestern Missouri, and noted that the sequence consisted of four beds of limestone separated by three beds of shale. The middle limestone (which is the Leavenworth of Condra, 1927) was delineated and described as:

"A dense, dark gray, even-bedded rock, in one or two layers, jointed perpendicularly, and about two feet thick."

A few measured sections (p. 177) ~~taken~~ just outside of the city of St. Joseph, <sup>Missouri</sup> in the bluffs along the east side of the Missouri River, ~~gave~~ <sup>less than</sup> thicknesses of slightly under two feet for (the middle limestone member of the Oread) <sup>See Hinds' description</sup>

Condra (1927, p. 99) described an Oread section at St. Joseph with two feet three inches of Leavenworth Limestone exposed along the bluffs on the east side of the Missouri River. Locality 23 of this report was measured and described in this same general area. Here the Leavenworth was found to consist of two beds of massive limestone

separated by a thin fossiliferous, gray-green marine shale; total thickness for the sequence is a little under two feet. The intervening shale unit is discontinuous and is only sporadically well developed along the line of outcrop exposed in the river bluffs. (1)

(4) Eastern Kansas: The Leavenworth Limestone is extensively exposed along the Oread outcrop belt in eastern Kansas from Leavenworth County in the north to Chautauqua County in the southern part of the state. For this report, nineteen Kansas sections were measured, described, and collected (see text-figure 1), although many more were visited and examined during the fieldwork. All of the numbered localities were either previously described in the literature, called to the writer's attention by various members of the Kansas Geological Survey, or found during the fieldwork session (when the entire Oread outcrop belt was literally "walked out.")

In eastern Kansas the Leavenworth consists of one massive bed of dense gray-blue limestone with prominent jointing features; the thickness varies only slightly from a little less than one foot to a maximum of exactly three feet, the average thickness is approximately one foot five inches. Reported occurrences and descriptions of Leavenworth Limestone exposures in southeastern Kansas are relatively numerous. A few of the more significant references are herewith noted: Condra (1927, p. 38) originally defined the Leavenworth Limestone and designated the type locality in Leavenworth County where the unit was recorded as two feet thick (Locality 21 of this report); Moore and Merriam (1959, p. 10) illustrated and described a detailed Oread section on the Kansas Turnpike, Douglas County, with a Leavenworth thickness of

one foot eight inches (Locality 18 of this report); Ball et al. (1963),<sup>①</sup> p. 34) reported and described a number of localities in Franklin County<sup>②</sup> where the thickness of the Leavenworth <sup>range</sup> ranged from one foot three inches to two feet three inches; O'Connor (1955, p. 18) noted that the Leavenworth in Osage County ranges in thickness from a little less than<sup>③</sup> one foot to two feet six inches; and Verville (1958, pp. 25-26) reported that the Leavenworth Limestone in Elk County averages about one foot three inches thick.

In southern Douglas County, northwestern Franklin County, and eastern Osage County, several local faults and structures have been observed which affect the underlying Douglas Group and the individual members of the overlying Oread.

Rich (1932b, p. 140) was the first to note that near Baldwin, Douglas County:

"South of a curved line, marked by sharp flexing and faulting which for several miles of its course closely follows the northern arc of a circle of about 4 miles radius, the lower of the three Oread limestones [Toronto] is missing; the middle limestone [Leavenworth] is thicker than the average and the shale interval between the middle and the upper limestone [Plattsmouth] is abnormally thick--16 feet instead of 6."

According to Rich these relations indicate:

"(a) uplift of the area south of the curved line so that the Toronto was either not deposited or was eroded after deposition; (b) a renewal of movement causing a relative sinking of the area south of the fault line while the Leavenworth Limestone and Heebner Shale were deposited; (c) deposition of Plattsmouth Limestone over all the area; and finally, (d) post-Plattsmouth faulting with downthrow to the south."

Patterson (1933), in his study of the Douglas Group, noted that the lower limestone of the Oread (Toronto) has been removed by post-Toronto, pre-Snyderville erosion in the area around Baldwin, and for at least 10 miles to the southwest of Baldwin.

Laughlin (1957), while mapping nearby areas of Franklin County, noted several areas in which the Toronto Limestone is absent, but showed adjacent areas ~~on each side~~ in which the Toronto is present.

O'Connor (1960, p. 65) stated:

"The principal fault affecting the surface rocks in southern Douglas County is of post-Toronto pre-Leavenworth age."

He further states (p. 69):

"The faulting and sharp flexures affecting the beds of the Douglas, Pedee, and Oread are judged, on the basis of data now available, to be chiefly nontectonic."

Laughlin, in a personal communication to O'Connor (1960, p. 64), noted an area (SW cor. sec. 29, T. 15 S., R. 18 E.) in which the Leavenworth Limestone is missing, but the overlying Plattsmouth Limestone and underlying Toronto Limestone are present (this is shown graphically by Jewett and Muilenburg, 1957, p. 57, and Ball, et al., 1963, pl. 2). Jewett and Muilenburg, (1957, p. 56) <sup>state</sup> thought that this situation may be due to low-angle faulting. In contrast, Ball, et al. (1963, p. 38) noted that:

"The Leavenworth Limestone and the Snyderville Shale are absent, but these rocks crop out in normal succession less than one-half mile in all directions from this exposure. Faulting may be <sup>part</sup> responsible for the anomalous stratigraphic conditions seen at this locality, but the authors cannot explain adequately this stratigraphic sequence."

(5) Northern Oklahoma: At Locality 5, <sup>just outside Elgin, southern</sup> in southern Chautauqua County, ~~just outside of the town of Elgin~~, the Leavenworth is typically exposed as a single massive bed one foot eight inches thick. Approximately four miles south of the Kansas State line, in Osage County, <sup>northern</sup> northern Oklahoma, the Leavenworth has thinned appreciably to a little <sup>less</sup> ~~little~~ less than one foot, and its character has also changed. Instead of

retaining the familiar, superficially uniform characteristics so apparent in Kansas and farther north, the Leavenworth at this locality is a single yellow~~colored~~ rubbly bed with much more obvious fossil material, especially fusulinids. This increase in fossil material is especially noticeable and dominant at the top of the bed. As the Leavenworth Limestone is traced further southward, the fusulinid-rich top dominates more and more of the unit, until at Locality 2 the Leavenworth is practically a fusulinid coquina with a thin (two inch) mud base. At Locality 3, four miles south of Locality 2, the fusulinid-rich top comprises a little less than half of the total unit. At Locality 1, the southernmost locality that this writer has been able to identify definite Leavenworth Limestone, the fusulinid-rich top is only about one to two inches thick, although the entire unit has thinned to only seven inches.

Of all the Oread units, the Leavenworth has the greatest lateral southward persistence. Locality 1 of this report marks the last time along the outcrop belt that the Leavenworth sensu stricto could be identified. Earlier reports (Winchester, 1922, p. 11; Heald, 1922, p. 27; and Clark, 1922, p. 93) of the "middle bed of the Oread" [Leavenworth] outcropping three to eleven miles farther south of Locality 1 have not been substantiated by this writer. Beckwith (1928, p. 22) stated that the middle limestone member of the Oread was present as far south as T. 24 N., R. 9 E. (vicinity of Wynona)--a distance of twenty miles south of Locality 1! Two days of intensive fieldwork in the area north and south of Pawhuska by this writer has failed to find any limestone that

could, with certainty, be called Leavenworth. <sup>cc</sup> The only beds that could possibly be confused with Leavenworth, (at those localities listed by Winchester, Heald, & Clark,) were discontinuous, thin limy sandstones.

Tanner (1956, pp. 52-53) also reported middle Oread [Leavenworth] in sec. 15, T. 26 N., R. 9 E. (just north of Pawhuska) and in his description noted that:

"The middle Oread is a thin limestone, decreasing from about four feet near the Kansas line to about four inches in sec. 15, T. 26 N., R. 9 E... . At many places the member possesses the wavy-bedding so common in limestones of the area."

Both the thickness reported for the Kansas equivalent and the wavy-bedding noted for the Oklahoma "middle Oread" leads this writer to believe that Tanner has probably confused the stratigraphy. In fact, his description more closely fits the upper Oread Limestone (Plattsmouth), which however, has not previously been reported this far south.

Cooley (1952), in his work on the facies changes in the Oread units in southern Kansas and northern Oklahoma, claimed that none of the Oread Limestone units were identifiable south of <sup>sec. 8,</sup> T. 28 N., R. 10 E., ~~sec. 8,~~ Osage County, Oklahoma. He reported that the Plattsmouth Limestone thins from seventeen feet thick in southern Kansas to thirteen inches at his locality 11 (<sup>sec. 19,</sup> T. 29 N., R. 10 E., ~~sec. 19~~) and <sup>Does this refer to the 17</sup> consists of <sup>on the 13th?</sup> a single massive, sandy fossiliferous limestone, that could be more aptly described as a fusulinid coquina. <sup>One fourth</sup> A quarter of a mile south of this locality the Plattsmouth Limestone is thin-covered or missing <sup>thin-covered?</sup> (Cooley, 1952, p. 35). Cooley was able to trace the Leavenworth Limestone only as far south as <sup>sec. 8,</sup> T. 28 N., R. 10 E., ~~sec. 8,~~ where he measured it as a <sup>inches</sup> twelve inch thick bed. This location is seven miles north of Locality 1

of this report which represents the farthest <sup>exposure</sup> southward occurrence of definite Leavenworth. The last <sup>exposure</sup> occurrence of the Toronto Limestone (basal Oread Limestone unit) was also noted at T. 28 N., R. 10 E., <sup>see 8</sup> sec. 8 where this unit had <sup>to</sup> thinned <sup>to</sup> eight inches of shaly-bedded limestone.

Of the two distinctive shale units of the Oread, the Heebner <sup>1</sup> undergoes the most radical facies changes in northern Oklahoma. Cooley (1952, p. 22) reports that at his Locality 4, in southern Chautauqua County, Kansas, the Heebner is typically exposed as a two-part unit with a thickness of a little more than eight feet. The two units (upper gray-green shale and lower black fissile shale) are separated by a zone of phosphatic nodules which occurs near the middle. Less than a mile south of the Kansas State line, in northern Osage County, Oklahoma, the Heebner <sup>is slightly more than 21 feet thick</sup> thickens to a little over twenty-one feet, and the distinctive two-part subdivision is <sup>How can a distinction be made?</sup> unrecognizable. In fact, black fissile shale <sup>possibly be unrecognizable</sup> is absent. Significantly, there is a sudden appearance of fossil benthonic organisms (corals, crinoids, brachiopods, and gastropods) which is not at all "typical" of the <sup>in Kansas</sup> Kansas Heebner. Farther south, at Cooley's Locality 11 <sup>see 11</sup> (T. 29 N., R. 10 E., <sup>see 19</sup> sec. 19), the Heebner reaches a maximum thickness of fifty-two feet eight inches.

The Snyderville Shale in southern Chautauqua County, Kansas, is a little less than <sup>40</sup> forty feet thick, and consists of gray to brown sandy shales and sandstones (Cooley, 1952, p. 25). At Cooley's Locality 13 in Osage County, Oklahoma, the Snyderville thickens to <sup>56</sup> fifty-six feet <sup>5</sup> five inches (Cooley, 1952, p. 40). Here <sup>is</sup> consists of buff-colored, massive, cross-bedded sandstones, sandy red and green shales, and brown siltstones.

The progressive southward disappearance of all of the Oread Limestone units in Osage County (the Plattsmouth and Toronto at T. 28 N., R. 10 E., ~~sec 8~~, and the Leavenworth at T. 27 N., R. 10 E., ~~sec. 18~~), and the increased thickness and facies changes of the Heebner, coupled with the increased thickness of the Snyderville, all materially add to the impossibility of differentiating these units as they gradually merge farther southward into the Vamoosa Formation, of which they are in part facies equivalents.

(6) Northcentral Texas: In southeastern Young County, north-central Texas, the Salem School Limestone (Lee, et. al., 1938, pp. 16-18) is exposed at Herron Bend, along the northside of the Brazos River. This limestone outcrops as one prominent bed ranging in thickness from ten inches to one foot three inches. The unit is massive, hard, dense, and breaks with a conchoidal fracture. It is sparingly fossiliferous, but commonly contains Ottonosia-like coated grains. The Salem School Limestone is believed by this writer to be the Texas stratigraphic and faunal equivalent of the Leavenworth Limestone. In support of this contention the following points are offered for consideration: (1) the lithology is identical to that of the Leavenworth Limestone, (2) its relative thinness, like that of the Leavenworth, is a distinctive attribute, (3) it is overlain by a black fissile shale (a lithologic entity not very common in the Pennsylvanian sediments of northcentral Texas), and (4) both the Salem School and the Leavenworth Limestones contain the markedly distinctive fusulinid Waeringella (Thompson, 1942, pp. 413-416), a fusulinid genus with a relatively short geologic range that is not present in other Virgilian units above or below the

Leavenworth Limestone in the Midcontinent\* or the Salem School Limestone in northcentral Texas.

*Text-figure 3 shows*  
A diagram showing this writer's interpretation of the stratigraphic correlation from Kansas to Texas, is given on text-figure 3.

Subsurface Data: Moore (1950, pp. 12-13, and text-figs. 4-6) noted and showed that the Leavenworth Limestone can be identified down-dip into basins for at least 300 miles west of the outcrop belt into northwestern Kansas.

Lukert (1949, pp. 140-141) stated that several members of the Oread Megacyclothem, including the Leavenworth Limestone, have been identified and traced from the Texas-Weinbrenner #1 Well, in Marion County, central Kansas, to the Olson-Smith #1 Well, in Noble County, northcentral Oklahoma, a distance of approximately 150 miles. Lukert's studies clearly show the marked similarity in sequence, in thickness, and in interval changes of the members of the Oread Megacyclothem. *see, TP, change of wells? what happens if water enters the field well log?*

Lukert (p. 141) stated that:

"the Heebner Shale...is less than 10 feet in thickness... Underlying the Heebner Shale is the Leavenworth Limestone, a very thin but persistent bed, which can generally be recognized on electrical logs. The...underlying...Snyderville

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\*Thompson (1942, p. 414) stated that the genus Waeringella:

... "is very widespread in the Midcontinent Region in strata equivalent in age to the Salem School Limestone. Also, undescribed representatives of this genus are known throughout most of the Virgil Series of the Upper Pennsylvanian."

This statement has not been borne out by later work in the Midcontinent and the Far West (Arizona, Utah, and Nevada). Indeed, all reported occurrences of Waeringella are restricted to a very thin geologic horizon consistently close to the base of the Virgilian (Downs, personal communication; Bissell, personal communication to Downs dated February 3, 1956; and Sabins and Ross (1963, p. 362)).

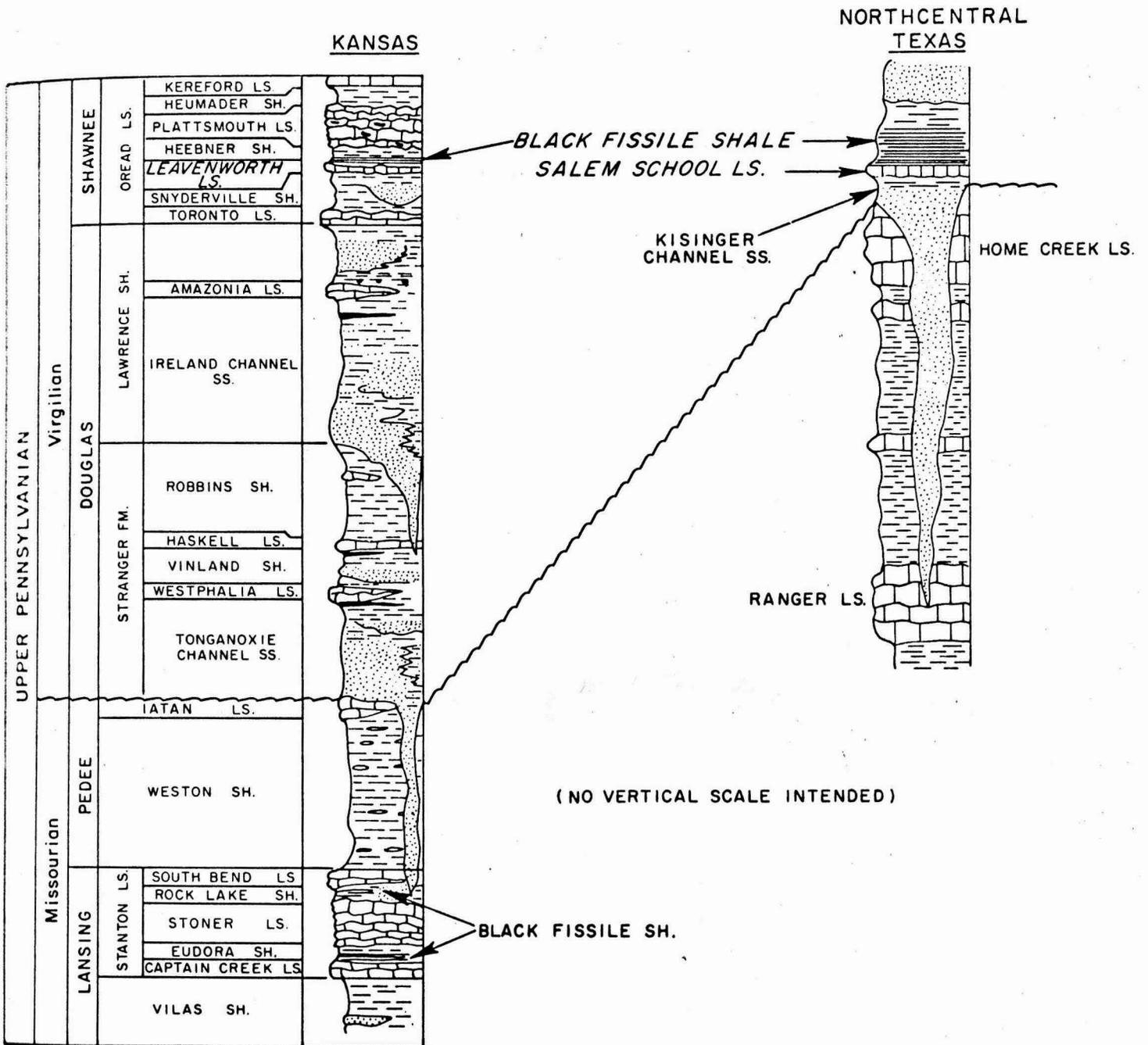
Shale...is very thin in two wells in Marion County, Kansas, but thickens gradually toward the south to nearly 200 feet in well No. 16." [Amerada-Newkirk #1 Well, Grant County, northcentral Oklahoma.] *No. 1 Newkirk,*

<sup>a</sup>Roscoe, Jr., (1962, p. 1365) in a study of the Pennsylvanian and Permian rocks of the Anadarko Basin (panhandle region of Oklahoma and Texas) *and western Kansas)* noted that the ~~Virgilian Oread~~ limestones thicken, merge, and become massive towards the basin. He further noted:

"The predominantly carbonate composition of the Shawnee Group [in part Oread] changes toward the Apishapa-Sierra Grande Uplift [positive element located in the area of what is now northeastern New Mexico and southeastern Colorado] to an interbedded limestone and shale facies; this sequence grades into the arkosic clastics that flank the uplift."

Stratigraphic Summary: <sup>In</sup> ~~As an over-all regional~~ summary, it can be said that the Leavenworth Limestone may be continuously traced and identified in outcrop from southwestern Iowa southward into northern Oklahoma. *In northern Oklahoma* Here the unit grades into the Virgilian clastics that were derived from the ancient Arbuckle Mountains during this time interval. All of the Virgilian carbonate units, including the Leavenworth Limestone, are unrecognizable as such within this clastic trough. *which trough? You haven't spoken of one previously.*

In northcentral Texas, southwest of the ~~above positive element~~, *Arbuckle Mountains,* the Salem School Limestone occupies the same approximate stratigraphic <sup>①</sup> position as the Leavenworth Limestone, and carries the same distinctive ~~Leavenworth~~ fusulinid Waeringella; hence, is believed to be the Texas stratigraphic equivalent. *# 20,* The Salem School Limestone outcrop area in Young County, Texas, marks the southernmost extent of the Leavenworth depositional area known to date.



TEXT FIGURE 3. STRATIGRAPHIC CORRELATION OF THE KANSAS AND TEXAS SECTIONS

*Note: Some changes in Douglas Group necessary, but can wait for a while.*

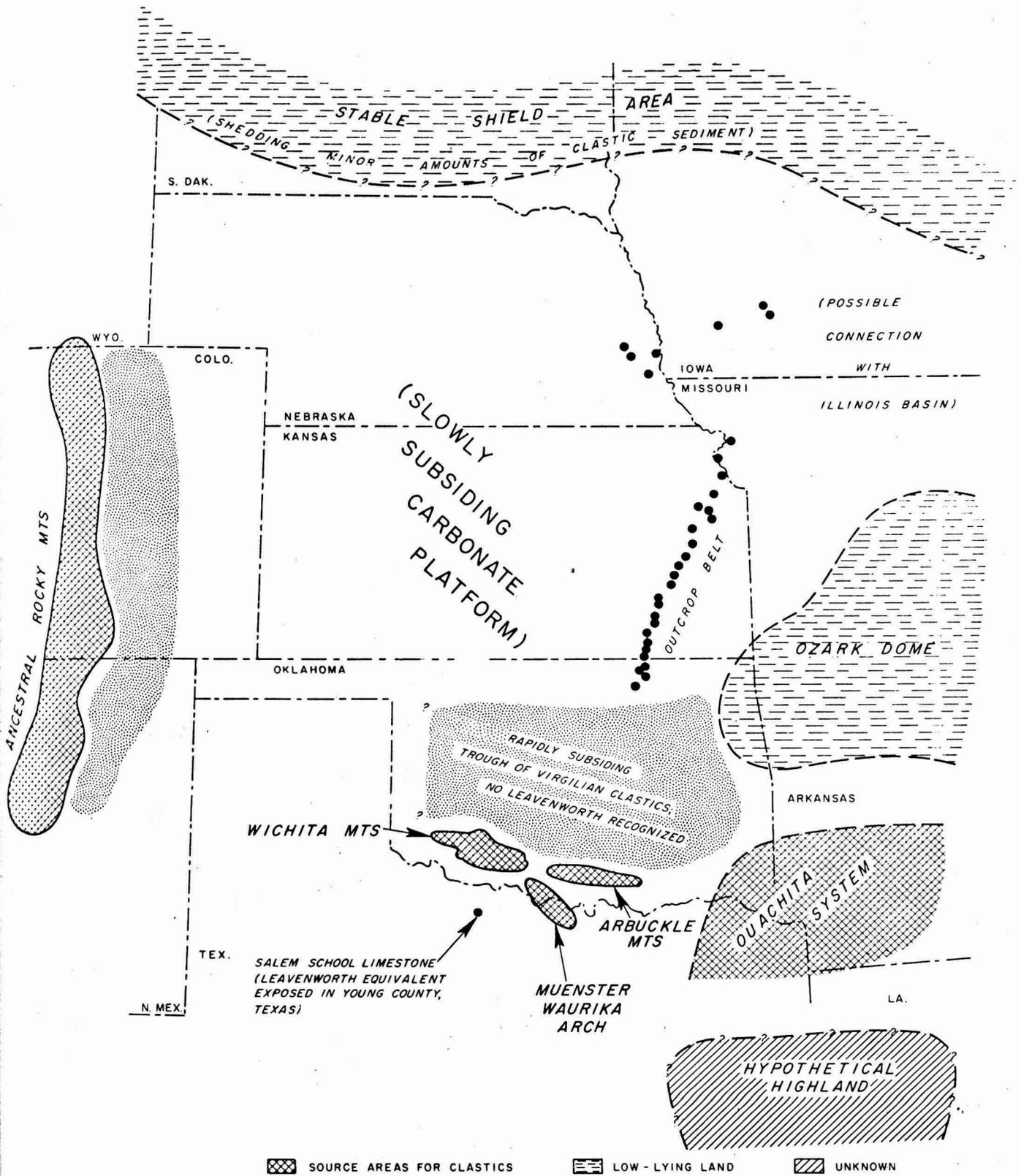
Subsurface data indicate that the Leavenworth Limestone is recognizable as a single, thin, persistent bed for approximately 300 miles west of the outcrop belt into northwestern Kansas. In a southern *Southward,* direction, the Leavenworth Limestone has been identified from central Kansas to northcentral Oklahoma. ~~Towards the Anadarko Basin,~~ in the panhandle region of Oklahoma and Texas, all of the Oread units thicken and merge and the Leavenworth Limestone as a singular distinctive unit cannot be recognized. ~~Farther westward,~~ *into* northeastern New Mexico and southeastern Colorado, the entire Virgilian sequence grades into the arkosic clastics ~~that were~~ *derived* from the ancestral Rockies ~~at this~~ time.

## PALEOGEOGRAPHY

The paleogeographic setting of the Midcontinent Region during time of deposition of the Leavenworth Limestone is postulated as shown in text-figure 4.

A broad, shallow, slowly subsiding, sedimentary platform existed in the area of Kansas, Oklahoma, Nebraska, and extended into adjacent states. The ancestral Rocky Mountains, lying to the west of the mid-continental platform, were probably actively supplying clastic debris along the western margin. On the eastern margin of the platform the Ozark Dome, primarily an Early Paleozoic positive element, was a relatively low-lying land remnant that was still covered with older Paleozoic carbonate rocks, that contributed little in the way of clastic debris into the depositional area. The land mass(es) to the north were a part(s) of an ancient stable shield area which was also covered with Early Paleozoic carbonate rock, and probably supplied little if any clastic material to this region during this time interval. The exact position of the northern shoreline is unknown. The occurrence of an eastern seaway connection with the Illinois Basin is problematical; a seaway connection probably existed during Early Pennsylvanian time, but may not have existed in Late Pennsylvanian time.

There is some controversy as to the conditions of the Ouachita System, at the southeast border of the area, during Virgilian time. According to some geologists (Miser, 1934, and Powers, 1928) the major



TEXT FIGURE 4 POSTULATED PALEOGEOGRAPHIC SETTING DURING LEAVENWORTH TIME

deformation of the Ouachita element took place during the Pennsylvanian. In contrast, Van Waterschoot van der Gracht (1931) differentiates two independent mountain systems: (1) the Wichita System which includes the Wichita and Arbuckle Mountains along with the Criner Hills, with several phases or orogeny during the Pennsylvanian Period, and (2) the Ouachita System with an Early Pennsylvanian orogenic phase followed by relative quiescence during most of the Pennsylvanian with final overthrusting in the Early Permian Period. Tanner (1956, p. 139) concluded from his studies that the Ouachita orogeny did not begin until Early Permian time. In a more recent work Branson (1962, p. 496) noted that the "Ouachita region seems to have continued as a source of sediments throughout Virgilian and Permian time." Further on (p. 499) Branson elaborated in more detail:

"Because of the abundance in the Virgilian sediments of southern Oklahoma of material derived from local mountain ranges, the part contemporaneously played by...the Ouachita region as a source of sediments is less clear than in earlier and later epochs. It is probable, however, that the vast sheets of Permian red beds deposited across the plains from Oklahoma to Wyoming after the Arbuckle, Wichita, and Amarillo ranges had in large part been buried, must have been derived chiefly from other sources, perhaps largely from the southeast...the Ouachitas were still a highland in Permian time."

Hence, it does seem probable that the Ouachita System did furnish some sediments to the region under discussion during Virgilian time. The mechanism that accomplished this was possibly an extensive river system in the Ouachitas which carried sediment down the north-western slope to the sea (Chenowith, 1959, pp. 232-235).

In southern Oklahoma an actively rising chain of mountains (Arbuckle-Wichita Mountains) was supplying large amounts of clastic

detritus to a rapidly subsiding adjacent clastic trough (Tanner, 1959, p. 335; Tomlinson and McBee, 1962, p. 497).

Tanner (1956, pp. 93-94) in his discussion of the Vamoosa Formation of central Oklahoma, concluded that the source of the outcropping Virgilian clastics in this region was the Arbuckle Mountains. He did this on the basis of (1) occurrence, thickness, and coarseness of clastics, (2) succession of north to south facies, and (3) the types of pebbles and cobbles in the Virgilian conglomerates. As to the pebbles and cobbles, Tanner was able to distinguish four principal types which he felt proved his case for an Arbuckle source. These are:

1. buff, subangular chert (most common)
2. banded buff and green subangular chert
3. brecciated (tectonic) chert
4. miscellaneous types including chalcedony, quartzite, quartz and clay plates.

Tanner (1956, p. 95) was convinced that such cherts are actually found in the Ordovician, Siluro-Devonian, and Pennsylvanian source sediments in the Arbuckle Mountains, and he found it unnecessary to postulate another source terrane. Later, Chenowith (1959, pp. 229-232) stated that quartzite is unknown in either the Arbuckle or Ouachita Mountains (the two most likely sources of the chert pebbles). He noted that to the south and southeast of the clastic area there were no known exposures of metamorphic rock, but that deep wells along the Muenster-Waurika Arch in Jefferson County, Oklahoma, have encountered gneiss beneath the Upper Pennsylvanian and hence a metamorphic terrane is regarded as existing in northcentral Texas and southcentral Oklahoma

(Chenowith, 1959, p. 231). This positive element can be traced southeastward to Denton County, Texas.

Chenowith also presented evidence that Tanner's chert and breccia pebbles are similar to the Arkansas Novaculite of the Ouachita Mountains. If we can assume that the breccia and much of the chert was derived from the Ouachita Mountains this still does not explain the source of the quartzite, since extensive deposits of this material are absent in the Ouachitas as well. If the source of the quartzite pebbles lay to the southeast it must have been south of the present Ouachita Mountains (Louisiana-East Texas Area), and might possibly be a southeastward extension of the Muenster-Waurika Arch (King, 1951, p. 140). Chenowith (1959, p. 232) believed that:

"The quartzite pebbles of the Vamoosa Formation of central Oklahoma most likely were eroded from a high area which, during Virgil time, lay south of the Red River in north-central Texas, east Texas, and Louisiana. Streams which rose in this positive area traversed the Ouachita Mountain region enroute to the sea. They were no doubt joined near the coast by shorter, more vigorous streams originating in the rising Arbuckle Mountains area."

The Vamoosa Formation is the oldest formation of the Virgilian Series in Oklahoma. The formation outcrops in a north-south trending band from northern Pontotoc County, through central Seminole County, in western Okfuskee and Creek Counties, and through central Osage County to the Kansas State line. In Kansas the Vamoosa Formation is correlated with the Douglas Group and a portion of the Shawnee Group (Oread). Lithologic variation within the Vamoosa Formation is extremely complex. Generally speaking, it changes facies from a southern section containing coarse conglomerates, sandstones, and shales, to a northern

section in Osage County containing sandstones, and increasing proportions of shales and limestones. It is within this general northern outcrop area that the Leavenworth Limestone per se is a recognizable unit and can be traced into the Kansas sections.

The Vamoosa Formation exhibits, throughout its entire outcrop extent, abundant current directional features of which cross-bedding laminations and ripple marks are dominant. Hicks (1962) studied paleocurrent directions in the Vamoosa Formation primarily determined from azimuths of cross-bedding laminations. The results of more than three hundred and fifty measurements along the outcrop belt show (Hicks, 1962, pp. 18-21) that the current directions south of Osage County indicate a regional slope north from the Arbuckle and Wichita Mountains and a northward spreading of clastic sediments. North of the Arkansas River (southernmost Osage County) the paleocurrent directions generally swing to the west and southwest, and near the Kansas State line the directional sedimentary structures are oriented to the southwest. The general pattern of paleocurrent directions, combined with an interpretation on the location of environments as given by Tanner (1959, pp. 331-335) implies that an early Virgilian depositional basin was located in central Osage County, Oklahoma. This basin received sediments from the south and possibly the southeast, and probably was a very shallow marine sea which expanded and contracted quite rapidly during early Virgilian time. It then appears that both Tanner and Chenowith are each in part correct as to the interpretation of the source terranes of the Virgilian clastics.

Most of Kansas and Nebraska comprised a slowly subsiding open-sea carbonate platform where limestones were prominent, but where shales

and sandstones were also deposited. This is in distinct contrast to the more rapidly subsiding clastic trough area in Oklahoma, as noted above, where limestones are indeed a rarity, and sandstones and conglomerates are prominent, with shales making up the bulk of the clastics. The Leavenworth Limestone displays relative uniformity across the outcrop belt from Kansas to Iowa. Very little in the way of clastic debris has been found in the limestone along the outcrop trend. It is apparent that both the Ozark Dome to the east and the relative stable shield area to the north were ineffectual sources of clastics to their immediate areas during Leavenworth time.

Southward, in Young County, Texas, the lithological and paleontological equivalent of the Leavenworth Limestone, known as the Salem School Limestone, is exposed southeast of Graham, Texas. The fact that this unit can be recognized so far south suggests that during Lower Virgilian time the Arbuckle-Wichita positive elements were isolated islands in the Virgilian Sea and did not form a continuous barrier separating northcentral Texas and the region to the north. Powers (1928, p. 1054) presented a paleogeographic reconstruction of the area which essentially shows similar relationships.

## CYCLES, CYCLOTHEMS, AND MEGACYCLOTHEMS

### Definition of Terms

Cycles may be defined as any series of events that is repeated with a constancy of pattern, whether this repetition is regular in time (rhythmic) or irregular. Constancy of arrangement of the constituent elements define the cyclic aspect. Wells (1960, p. 390) states:

"The deposits of such cycles have been described as being rhythmic by some authors and cyclic by others. Attempts have been made to attach distinct meanings to the two terms, but in fact there is often little difference in the sense in which they have been applied in the past. The essential concept of cyclic sedimentation, the deposits of which imply the repetition of a series of events rather than their mere recurrence, has remained the same."

Cyclic sequences from the Pennsylvanian rocks of Illinois were recognized and described by Udden as early as 1912. Phillips in 1836 (Hudson, 1926, p. 129 and Brough, 1929, p. 116) showed in his graphic sections of the Yoredale Series of northern England (Upper Viséan-Lower Namurian) a distinct cyclic sequence. He was perhaps the first geologist to recognize cyclic sedimentation as such, but he did not specifically call attention to it in the descriptive text.

In 1930, Weller noted that most of the different types of Pennsylvanian rocks of the eastern and central United States are associated in a rather distinctive stratigraphic sequence, or pattern, that is generally repeated numerous times. The strata that comprise a single sedimentary cycle of this type have been termed a cyclothem by Weller.

Moore (1936, p. 29) introduced the term megacyclothem for strata belonging to a group of successive sedimentary cycles which exhibits regularity of occurrence in sequence, and with each participant cyclothem being marked by some definitive character or characters. Megacyclothems, according to Moore, are exceptionally well developed in the Upper Pennsylvanian rocks of Kansas. Each distinguishable element in a cyclic succession is termed a phase.\* The term phantom phase (Reger, 1931) has been proposed to designate an element within a cyclic succession, which is theoretically expectable but which may be commonly absent.

#### Description of the Illinois Cyclothem and the Kansas Megacyclothem

Cyclothems are extremely variable. Lateral changes of members in both lithology and thickness and members missing or added, all contribute to the over-all variability and confusion. One would like to think that cyclothem variation is apparently directed towards simplicity, but in fact this does not appear to be the case. Reduction of a cyclothem to less than three members renders that particular cyclothem unrecognizable, whereas introduction of added members results in a more complex cyclothem. Weller (1957, p. 330) states:

"When they were first noted in outcrops the new members appeared to be erratic, but the checking of hundreds of field observations showed, that in Illinois, these members, although inconstant and discontinuous, are remarkably regular in their mutual stratigraphic relations."

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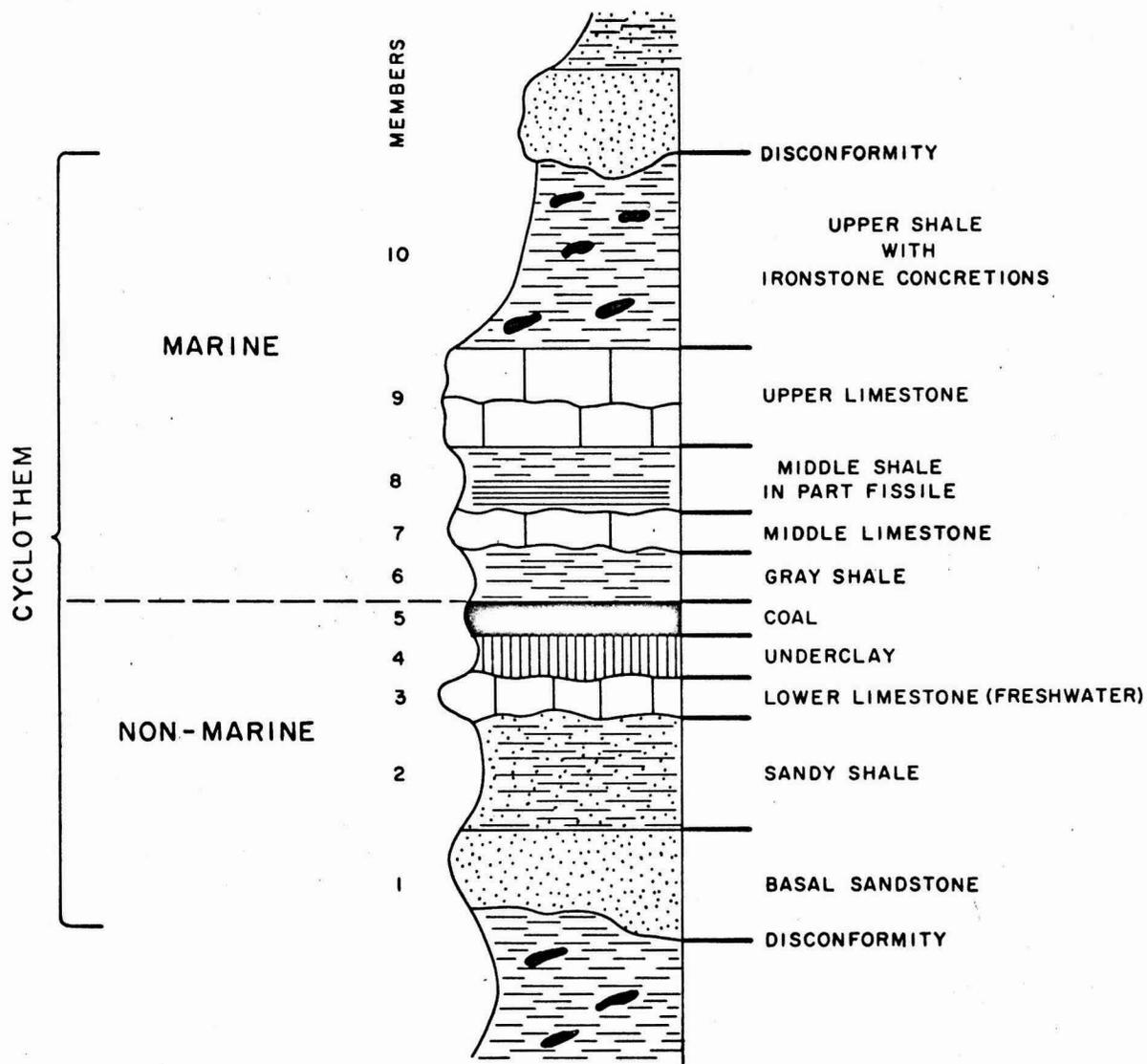
\*Wells (1947) term lithotope is essentially synonymous with the term phase as applied to cyclic sedimentation, since each phase of a cycle consists of a distinctive lithotope.

The "ideal cyclothem" as defined by Weller (1931, p. 163) for the Illinois Pennsylvanian, consists of 10 members which from bottom to top are: (1) basal quartzose sandstone which is commonly unconformable on the underlying cyclothem, (2) sandy to very silty shale, (3) a lower limestone which may in some cases be a fresh water limestone, (4) underclay, (5) coal, (6) lower erratic marine shale, (7) thin, impure middle limestone, (8) middle shale consisting of two intergrading parts; black fissile shale below becoming progressively calcareous above, (9) upper limestone (usually considered to represent the culmination of the most marine phase of the cyclothem), and (10) an upper marine shale with ironstone concretions (see text-figure 5). Members 1 through 5 are thought to have been deposited mostly under nonmarine conditions, whereas the upper five members are marine. The above succession is really theoretical since at least one member is invariably absent. Typically the cyclothem approximates 50 feet in thickness.

The Kansas cyclothem is envisaged by Moore (1936, pp. 24-25) as somewhat different than that of Illinois, in that they contain more marine members and less nonmarine members. The members of an "ideal" Kansas cyclothem, from bottom to top (following a sort of Dewey decimal series) is as follows: (.0) a basal quartzose sandstone which is usually unconformable on the underlying cyclothem, as shown by channeling, (.1a) shale which may contain land plant fossils, (.1b) underclay, (.1c) coal, (.2) shale typically with molluscan fauna, (.3) limestone, molluscan, or with mixed molluscan and molluscoid fauna, (.4) shale with bryozoans and brachiopods dominant, (.5) limestone containing fusulinids commonly

CYCLOTHEM

TEX



(THICKNESS APPROXIMATELY 50 FEET)

TEXT FIGURE 5 A COMPLETE "IDEALIZED" PENNSYLVANIAN CYCLOTHEM SUCCESSION AS RECOGNIZED IN ILLINOIS

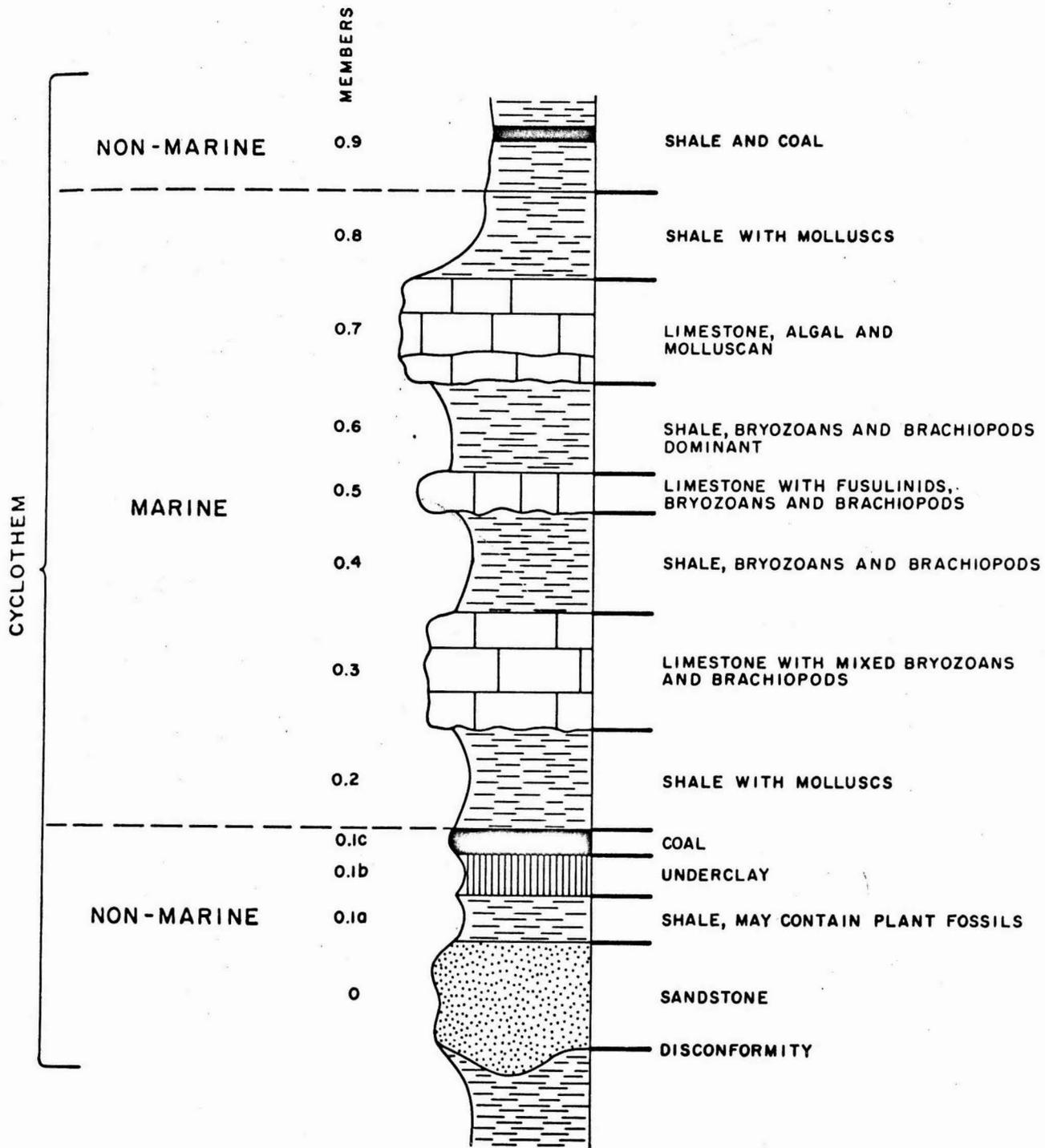
(MODIFIED FROM WELLER, 1957)

associated with bryozoans and brachiopods, (.6) shale with bryozoans and brachiopods dominant, (.7) limestone, algal-molluscan, or with mixed molluscan and bryozoan and brachiopod fauna, (.8) shale, typically with molluscan fauna, and (.9) shale (and coal). Members .0 and .1 in the initial part of the cyclothem and .9 at the end, are typically nonmarine; the remaining members are marine (see text-figure 6).

One outstanding feature of cyclic sedimentation of the Upper Pennsylvanian in Kansas, and in the northern midcontinent in general, is the repetition of complex, long, and varied sequences of sedimentary units and fossils--in reality, a cycle of "ideal" cyclothem, as described above, which Moore calls megacyclothem.

A most complete representation of this orderly arrangement of cyclic sets is observed in the Virgilian Shawnee Group, which comprises the Oread, Lecompton, and Deer Creek Megacyclothem (the Leavenworth Limestone is present as the middle limestone member of the Oread Megacyclothem). This orderly cyclic series of cyclothem, or megacyclothem, is shown on text-figure 7, and demonstrates the repetitive similarity of rock units within the Shawnee Group. With the Oread Megacyclothem specifically in mind, the following diagnostic features may be noted: (1) the only relatively "good" coal is very close to the base of the megacyclothem, (2) each of the major limestones are characterized by distinctive features--the brown ferruginous nature of the first (Toronto), the thin, blue, dense nature of the second limestone (Leavenworth), the light-gray, clean, wavy-bedded, and comparatively thick nature of the third (Plattsmouth), and by the thin, less distinctive characteristics of the fourth and fifth limestones (Kereford and Clay

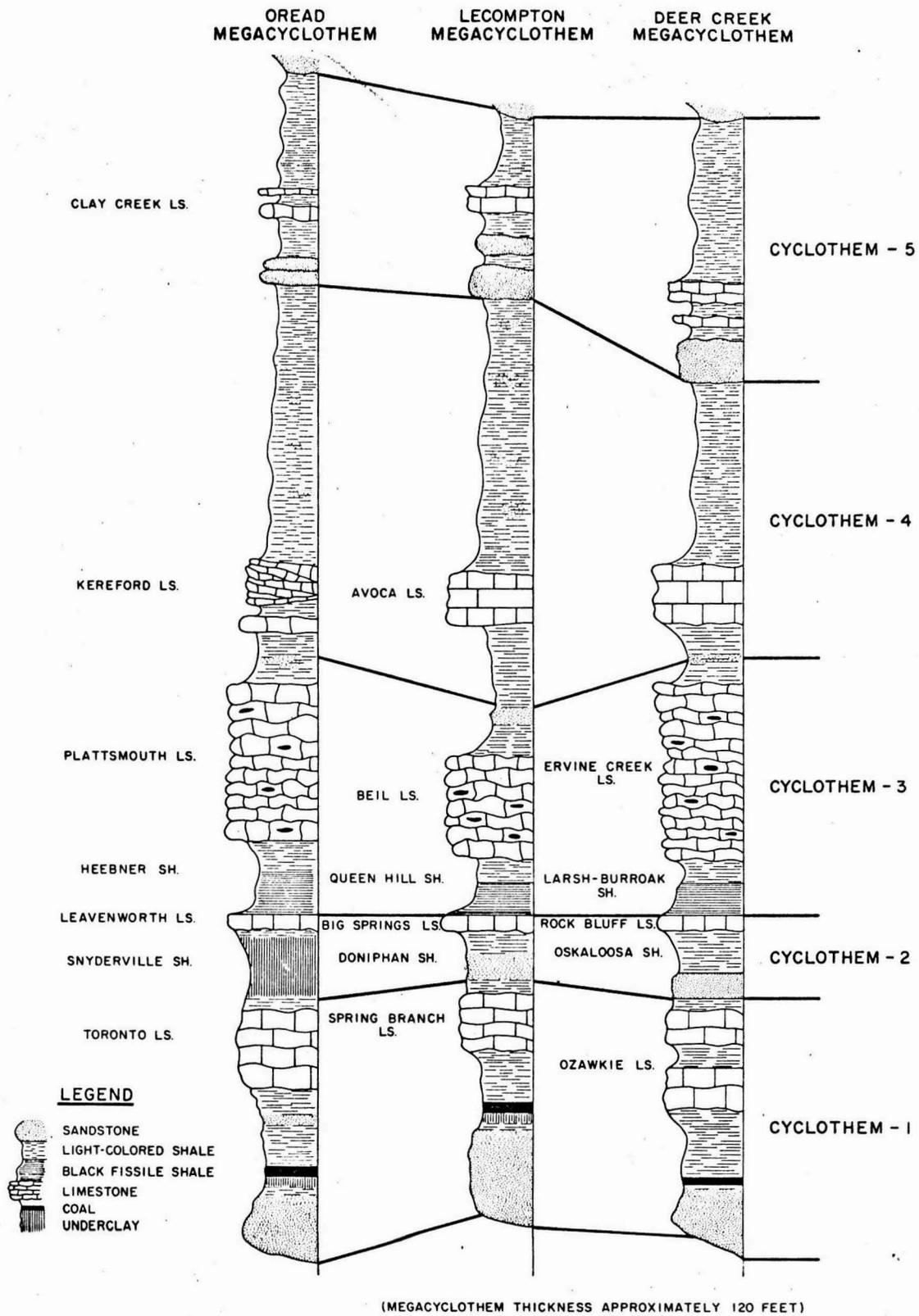
Creek), (3) each of the five limestones contains fusulinids, and other features which are diagnostic of the "ideal" cyclothem, and (4) found at the base of the third cyclothem is a unique black fissile shale, which is an important marker; since no other black shale occurs in any of the five cyclothem of the megacyclothem. Not only are the lithologies repeated with pronounced fidelity, and the general thicknesses of individual units much the same, but faunal occurrences and peculiarities are likewise duplicated. Hence, Moore's contention, that the entire unit sequence included within the megacyclothem demonstrates a number of complete or partially completed cyclothem, each differing from associated cycles in one or a number of characters, seems to be substantiated. Nevertheless, it could still be argued that the "ideal" cyclothem of the Illinois Pennsylvanian can be transformed into a rough equivalent of the so-called Kansas megacyclothem, i.e., the Shawnee (Oread) type, simply by expanding and adding members in the following manner: members 1 through 5 of the Illinois cyclothem may be equivalent to the sandstone through coal members of the Kansas megacyclothem; units 7, 8, and 9 of the Illinois cyclothem may be equivalent to the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone, respectively, of the Kansas megacyclothem. Accordingly, this would mean that both the Toronto Limestone and the other members above the Plattsmouth Limestone are added units. In reality the Kansas megacyclothem may be an enlarged and expanded single cyclothem, and not composed of several cyclothem as envisaged by Moore.



(THICKNESS APPROXIMATELY 50 FEET)

TEXT FIGURE 6 "IDEALIZED" PENNSYLVANIAN CYCLOTHEM SUCCESSION AS RECOGNIZED IN KANSAS

(MODIFIED FROM MOORE, 1936)



**TEXT FIGURE 7      TYPICAL MEGACYCLOTHEMS OF THE SHAWNEE GROUP (VIRGILIAN),  
 UPPER PENNSYLVANIAN, KANSAS**

(MODIFIED AFTER MOORE, 1950)

The Concept of Cyclothem Units Related to Depth Phases

In 1937, Elias suggested that it was possible to estimate the depth of deposition of marine limestones by relating the invertebrate fauna within a geologic stratum to its ecologic counterpart in present marine waters, and observing the depth of optimum life conditions for the modern forms. He assumed that the Permian assemblages he worked with, required a similar depth for their development. This led him to assign sea depths ranging from less than 20 feet for the Lingula-bearing dark shale phase of the cyclothem to about 200 feet for the fusulinid-rich phase of the cyclothem. In order to arrive at this fundamental hypothesis Elias had to indulge in one very basic assumption: namely that the "present is the key to the past," or more specifically that the classes of marine organisms of Late Paleozoic time lived largely in the same environments as the corresponding classes of organisms do today.

This is indeed classic Lyellian uniformitarianism! The basic question that should concern us as scientists, however, is whether or not we can blindly accept the inherent assumption of Elias, which really states that "nature is uniform." Perhaps, present organism distribution and environments cannot be used as a yardstick in attempting to reconstruct past geological environments. For, if we wish to ascertain how much can be assumed to explain logically past effects by present causes, we too must indulge in an extremely fundamental assumption--that of static nondevelopment of organisms and environments. Accordingly, if this point is to be determined in the light of modern casual agencies, paleoecologists are committed to the static concept that the ecological responses of a species do not change with time! Ergo, it becomes

difficult for a geologist or paleontologist to place unqualified confidence on paleoecological interpretations based on the ecology of modern species. The paleoecologist seems to be eternally damned in this "twilight zone" of his own making. On the one hand, he blindly accepts the dogma of uniformitarianism with all its inherent concepts of static nondevelopment, and on the other hand, perhaps, largely as a practicing paleontologist, he tries to react as an evolutionary taxonomist dealing with the dynamic aspects of organisms and environments. These two end members are irreconcilable in both fundamental principle and practice, and yet we constantly try to bridge the gap between the two extremes with Lyellian dogma contaminated with a priori reasoning. Elias' hypothesis is poor because it goes far beyond the available evidence, and most pointedly attaches an a priori postulate to their inferences. Scott (1963, p. 523) in a brilliant analysis of the justification of the Lyellian concept of uniformitarianism notes that:

"observational evidence cannot justify a statement that concern events beyond the range of experience."

From a strictly geological standpoint relatively little is known concerning the ecologic ranges of Pennsylvanian organisms. It can be said, that in a very broad sense certain faunal associations are known to exist in specific types of lithology, but the environments of deposition of these specific lithologic types are not well understood even in relative terms. Analogy with modern-day environments is made even more difficult because the Paleozoic seas appear to have been broad, shallow epicontinental seas for the most part, and there are few, if any, examples of this type of sea, on the same scale at least, at the present time.

One outstanding geological criticism that can be made of Elias' hypothesis is the fact that it was based on a detailed study of vertical stratigraphic sequences, with little attention to actual lateral facies changes in each bed as observed in the field. This writer regards lateral change as significant and fundamental to the over-all interpretation.

#### Theories of the Origin of Cyclothems

The cyclic, partially rhythmic fluctuations so common in Late Paleozoic sediments require explanation. Cyclic deposits are known from rocks of all ages, but only in the Late Paleozoic are they so definitive, widespread, and numerous. Various theories have been proposed to account for their origin; however, since the main purpose of this paper is not the investigation of causal relationships of cyclothems, only the most significant theories put forth to date will be briefly mentioned in order that we may ascertain the development of general thinking along this line. At least six very general theories have been proposed:

(1) climatic fluctuations from arid conditions to abundant rainfall in the source area with a uniformly subsiding depositional basin (Brough, 1922, and with some modification, Beerbower, 1961);

(2) differential uplift of source area with each erosional cycle proceeding to peneplanation and with a relatively constant subsidence of the depositional basin (Hudson, 1924);

(3) intermittent subsidence of the depositional basin with the depressed basin being filled with sediment before the renewal of subsidence (Stout, 1931);

(4) a series of diastrophic cycles affecting both the source area and the depositional basins (Weller, 1930, 1956, and 1957);

(5) uniform subsidence of the depositional basin with a succession of eustatic shifts in sea level up to many hundreds of feet, perhaps caused by continental glaciation in the Southern Hemisphere (Wanless and Sheperd, 1936, and with some modification Wheeler and Murray, 1957);

(6) various theories of differential accumulation and later differential compaction of sand, mud, and peat in a uniformly subsiding depositional basin (Robertson, 1948 and 1952, and van der Heide, 1950).

All have the same thing in common, that is, they are theories presented with only the barest outline of fact and corroborating data. The major difficulty seemingly has been in explaining the close vertical juxtaposition of stratigraphic units of supposedly shallow and deeper water origin, which are laterally continuous over distances measured in thousands of square miles. If we are to believe Elias (1937), we must assume that the widespread seas that covered the Midcontinent Region during Pennsylvanian and Permian time would have had to fluctuate in depth from 0 to 200 feet or more, well over 100 times. Fluctuations of this magnitude, number, constancy, and frequency are difficult to comprehend over a stable intracratonic platform or shelf area. It is more realistic and reasonable to assume that Elias' fusulinid limestones (with a depth relationship of 180 to 200 feet) were not formed in the deepest water environments of the cyclothem, but were deposited in relatively shallow water on the shelf areas, and that the primary cause of this type of cyclic sedimentation is not so strongly related to varying depth of water as was generally believed.

Known Facts Concerning Cyclothems

In order to avoid presumptuous theorizing as to the origin of cyclothems, it is perhaps much wiser to refrain from propounding modifications of existing hypotheses, but instead, to list and briefly discuss some generalized statements that are recognized by most workers as facts. Those facts are as follows:

(1) The actuality of the cyclic succession; the concept of cyclic sedimentation is almost universally acceptable, and is quite unnecessary to argue or to prove.

(2) Synchronicity of cyclothems; the widespread occurrence of very thin, but very distinctive beds, plus the uniformity of sequence is generally accepted as evidence for synchronous deposition of cyclothems.

(3) Widespread distribution of cyclothems, the extremely wide geographic distribution of Late Paleozoic cyclothems would tend to suggest that causal factors should be world-wide in extent.

(4) Local tectonic controls; resulting in cyclic deposition superimposed on local tectonic control. Accordingly, locally successive cyclothems resemble each other more specifically than their distant lateral variants.

(5) Development of channeling; most workers have interpreted channel development as diagnostic evidence of erosion on an emergent surface.

(6) Occurrence of cyclothems independent of lithologies; some workers have suggested that certain lithologic associations indicate a mechanism of origin, but most workers realize that none of the

associations are invariable, and that cyclic sedimentation is independent of the constituent members.

(7) Occurrence of cyclothems independent of environments; since the occurrence of either all-marine, all-terrestrial, or combinations thereof can be found it would tend to suggest that no particular type of environment is essential to cyclothem development.

(8) Uniqueness of the Late Paleozoic cyclothems; nowhere are cyclothems like those of the Late Paleozoic found in post-Permian or in pre-Mississippian rocks sections. This would suggest that a rather special set of world-wide conditions existed in which whole continents were essentially at world sea level. As Moore (1962, p. 94) noted, flat surfaces of whole continents were just awash.

(9) Existence of knife-sharp lithologic boundaries; abruptness of change from one type of sedimentary deposit to another giving rise to sharp boundaries as contrasted with gradational ones. Boundaries of this type are common within some cyclothems, and seem to emphatically deny slow change across the boundary of cyclic units. Although most workers recognize these knife-sharp contacts, no special consideration has been given to them.

#### Reasonable Conclusions to be Drawn from the Known Facts

Interpretation of the available evidence seems to point to the formation of cyclic sedimentation by constant eustatic changes of sea level affecting a slowly subsiding depositional basin. This is essentially the same hypothesis of Wanless and Sheperd (1936), but without invoking the glacial control theory to account for all sea level fluctuations.

Sea level changes that probably accompanied cyclothemic deposition have in the past been variously estimated. One main drawback is the fact that most estimates have much greater thicknesses than the cyclothem themselves. Wells (1960, p. 400) notes that eustatic changes in sea level can be caused by the modification of the total volume of water on the earth's surface through glaciation and by alteration in sea basin configuration by sedimentation and tectonic movements of the sea floor. Glacial effects can produce changes of ample magnitude, but lack of evidence of glaciation that is contemporaneous with the occurrence of Late Paleozoic cyclothem is an elusive factor. However, sedimentation and tectonic adjustment is sufficiently capable of affecting world-wide sea levels.

Wells (1960, p. 401) in a lucid summary of the reasons for cyclic sedimentation stated:

"It seems logical to imagine the two processes of displacement of water by sedimentation and accommodation of water by sea bottom movements as proceeding side by side and of the same order of magnitude, but by no means always counteracting one another. This would result in a continual oscillation of absolute sea level by perfectly normal geological processes. As it is the sum total of world-wide events that is involved and as over-all tectonic activity is surely as continuous a process as sedimentation, it is suggested that the effect of the combination of movements of the sea-bed throughout the oceans and displacement by sedimentation produced fluctuations of sea level, which may at times have become rather regular. In no case would it be necessary to invoke actual individual tectonic rhythms in any one place, and the only requirement for the development of cyclic sedimentation during such a period of regular sea levels changes would then be a gently subsiding basin of deposition."

In essence, the entire process for cyclic sedimentation suggests a fundamental, and recurring process which tends to demonstrate that major

transgressions and regressions of the sea are world-wide phenomena which may have a world-wide cause.

Qualitatively it is not difficult to understand cyclic sedimentation of the type clearly shown in the Late Paleozoic sediments of the Midcontinent. Shallow seas recurringly flooded the region and then withdrew. The record of these transgressions and regressions is indisputably imprinted upon the superposed stratified layers. Accordingly, the task of the geologist or paleoecologist is simply to interpret the rocks, but in fact, such an interpretation is largely impossible, or at best only speculative.

## PETROGRAPHY

The volumes by Cayeux (1916 and 1935) on the general topic of skeletal petrography, and that of Johnson (1951) represent all that has been written on this important but relatively neglected field of study. In particular, Paleozoic skeletal petrography has been almost totally neglected or when it is briefly treated, as in Johnson (1951), it is inadequate and not applicable to the general problem at hand--namely, just what are the diagnostic petrographic criteria needed to accurately identify randomly oriented skeletal particles commonly seen in thin-section? In an attempt towards solving this chronic problem many whole fossils and fragments, both from the Leavenworth Limestone and other Paleozoic limestones and shales, were embedded in plastic, thin-sectioned, and studied in detail under a petrographic microscope. It was believed that in this manner criteria could be determined which would allow the petrographer to accurately identify the randomly oriented skeletal fragments that are commonly present in most Paleozoic carbonate rocks. The results of this approach to the problem are outlined in the following brief résumé which lists those petrographic attributes which were found to be an aid in identifying the constituent particles found in the Leavenworth Limestone.

Algae: Fossil representatives of almost all of the major algal groups (red, green, and blue-green) occur as skeletal grains in the Leavenworth Limestone. On the basis of point count analysis they are quantitatively unimportant as rock builders; they attain a maximum of only 1.1 percent. Yet small algal fragments representing one or

more of the major groups can be found at each locality. Since this group in general does have great potential as paleoecologic indicators their recognition is of importance.

Rhodophycophyta (Red Algae)

1. Genus Archaeolithophyllum (red algae of uncertain affinity); rare fragments up to one inch in length occur only at Locality 29, Madison County, Iowa; in this instance the alga, along with other skeletal debris, serve as nuclei for the larger complex-type coated-grains referred to subsequently; they are platy, narrow (approximately 1/2 mm. wide), irregular-shaped, and characterized by curved rows of cells; along the plate margin the cells are rectangular, quite small, and poorly developed; towards the center of the plate the cells double in size and are distinctly polygonal; specimens are usually somewhat recrystallized but under crossed nicols enough of the cell outline can be delineated to accurately identify this form.

Chlorophycophyta (Green Algae)

Family Dasycladaceae\*

2. Genus Epimastopora; representatives of this alga are found in almost all of the Leavenworth localities as fragments varying in size from a maximum of a little over an inch in length to those fragments no larger than a millimeter; this alga probably had a

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\*At the Salem School Limestone (Leavenworth equivalent) locality in Young County, Texas, the dasyclad alga Anthracoporella makes up 8.8 percent of the rock. This form is distinguished by its branching and cylindrical central stem, and prominent, regularly-spaced circular pores; it is always recrystallized to blockly calcite mosaic.

cylindrical growth form (Johnson, 1963, p. 12); when cut in the tangential plane the larger fragments are characterized by regularly-spaced large round pores imparting to the specimen a perforated appearance; in longitudinal section these circular pores are seen to penetrate nearly all the way through the specimen impressing on the form an almost chambered-like appearance; the walls are invariably recrystallized to blocky mosaic calcite.

Family Codiaceae

3. Genus Eugonophyllum; small fragments of this alga are found in many of the Leavenworth localities across the outcrop belt; relatively larger fragments, an inch or so in length, are only found at the southern end of the outcrop belt in Osage County, Oklahoma; in this instance they serve as nuclei for the large complex-type coated-grain so common in the Leavenworth in northern Oklahoma; in some instances a few plate fragments have been trapped within the mass of organic debris forming the actual coated grain; the plates are straight to slightly curved with a diameter of approximately 0.5 mm.; with little recrystallization of the microstructure the utricles or "cells" are apt to be preserved; characteristically they appear in thin-section as small dark circles arranged in a straight line slightly out from the cortex; the medulla or central portion of the plate is usually recrystallized to blocky mosaic calcite; if the utricles are not preserved, small fragments can easily be confused for pelecypod remains.

Schizophyta (Blue-green Algae)

4. Genus Girvanella; this alga is relatively abundant along the entire Leavenworth outcrop belt; it commonly occurs as a mass of

flexuous tubes of uniform diameter (approximately 20 microns) twisted together in loosely aggregated masses resembling spaghetti; the walls are dark and well defined; no branching, tapering, or cross-partitions were seen in the tubes; Girvanella tubes are always found as an integral component of the organic debris trapped within the bean-shaped "Osagia-type" of coated-grain, although it is also present to a lesser degree within the larger complex-type of coated-grain.

#### Algae of Uncertain Systematic Position

5. Genus Tubiphytes; this problematical form, thought by some to be a hydrozoan (Rigby, 1958),\* is included under the algae as proposed by Maslov (1956). Johnson (1963, p. 139) also recognizes this form as algal, and refers to it under the algae of uncertain systematic position--a procedure followed by this writer. In this section this form is distinguished as a dark-gray to opaque calcareous encrusting organism up to 1 millimeter in diameter and composed of irregularly spaced lamellae showing varying degrees of density and development; a few irregular-shaped pores, randomly spaced within the fossil, probably represent the vanished encrusted organism; these tubes or pores are filled with clear secondary calcite and are highly irregular in size, and position within the enveloping mass; in reflected light the organism appears as a dull-white porcelaneous-textured tubiform mass closely resembling various Late Paleozoic encrusting Foraminifera. Tubiphytes is a rare constituent in the Leavenworth Limestone, but it is found

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\*A detailed summary of the history of this problematical form is given in Croneis and Toomey (1964).

most often in those localities in Douglas and Leavenworth Counties, Kansas, and Buchanan County, Missouri.

Coated-Grains: The term coated-grains is herein attributed to those concentrically laminated colonies whose main organic constituents appear to be algae, foraminifers, and bryozoans. They range in size from a little over 1 mm. to those that attain a maximum size diameter of at least three inches.\* The smaller colonies are regular and characteristically bean-shaped, whereas the larger colonies are much more irregular and loosely organized. Coated-grains are present at all Leavenworth localities except one, Locality 2 in northern Oklahoma. As constituent particles coated-grains are very abundant in the Leavenworth Limestone, especially at the northern and southern extremities of the outcrop belt where they compose up to 45 percent of the total rock. As a general over-all average across the entire outcrop belt coated-grains make up 10.2 percent of the rock.

The form genera Osagia and Ottonosia were erected by Twenhofel (1919) for two kinds of algaloid concretions that he found in the Lower Permian limestones of Kansas. In essence, Osagia Twenhofel represents the smaller coated-grains of this report, and Ottonosia Twenhofel represents the larger, more irregular, complex-type of coated-grains so common at both ends of the Leavenworth outcrop belt. Since both types

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\*It is fully realized that the word "grain" does imply a size connotation, i.e., a grain of wheat. However, previous usage of the word coated-grain for laminated colonies of a size range comparable to that attained by some Leavenworth forms seems justification enough for continued usage of the word coated-grain in this report.

of coated-grains commonly contain encrusting Foraminifera within their enveloping laminae the question arises as to whether or not the encrusting Foraminifera are casual or essential members of the colony. Henbest (1964, pp. 35-37) does not believe that the Foraminifera are essential to the colony. He recently emended Osagia and Ottonosia and restricted them to the Girvanella-like algal species that are the prime constituents of the colonies. The prime difference between the two form genera is one of size, with Osagia restricted to the small concretionary growths that completely surround the nuclei, and Ottonosia with its larger size and tendency to form encrustations on the top side of bottom supports. Henbest (1963, p. 35) noted that:

"Although most colonies of Ottonosia and Osagia do contain Foraminifera, some are composed of girvanellids alone. Unless girvanellids themselves are foraminifers instead of algae, which now seems unlikely, no specimens of Osagia and Ottonosia are composed entirely of foraminifers. These circumstances indicate that the foraminifers are not essential for the existence of Osagia and Ottonosia. Whether the association with the sedentary cornuspirids was beneficial, competitive, or predatory on the part of the animals is not evident. No evidence is seen for determining definitely whether the algae and foraminifers occupied the colony at the same time or alternately. The colonies vary in the dominance of one over the other, but the algae usually dominate. About the most that can be concluded is that Osagia and Ottonosia are colonies of algae (primarily) and Cornuspirinae (generally but not invariably)."

Under the emendation of Ottonosia, Henbest (1963, p. 37) noted that certain Pennsylvanian forms of algaloid growths from the Kessler Limestone of Arkansas started as colonies of Osagia and ended up as Ottonosia. Furthermore, he doubted that these two genera are distinguishable and suggested that Osagia is probably a junior synonym of Ottonosia. This writer takes exception to the above statement. All of

the coated-grains found in the Leavenworth Limestone were distinctive enough that they could easily be grouped under either Osagia or Ottonosia, no inter-gradation was seen. The reason for not using Twenhofel's generic designations was that it was felt that since these grains did contain a variety of identifiable organic elements it would perhaps be wiser to ignore the more specific terms of Osagia and Ottonosia and group them under the general heading of coated-grains. In this manner the individual organic elements, that occurred together within the grain, could retain some semblance of individuality instead of being "straight-jacketed" under one or another "catch-all" terms. In addition, the coated-grains of the Leavenworth were found to contain a much more complex organic assemblage than those described by Henbest.

1. The small, ellipsoidal or bean-shaped coated-grains range in size from approximately 1 mm. to a maximum of 30 mm. In most occurrences small pieces of shell debris (generally brachiopods) serve as nuclei; in some cases crinoid columnals also serve the same function. If the nucleus is a shell fragment it is usually recrystallized, whereas echinoderm nuclei seem to be unaffected by recrystallization. The organic make-up of the encrustations can be of two forms: (1) a sheer mass exclusively composed of girvanellid-like tubes, or (2) a mass of girvanellid-like tubes interspersed with many cornuspirid foraminifers, especially the form Hedraites. It is noteworthy that in colonies with dominant algaloid growths the encrusting foraminiferal wall is apt to be much more recrystallized than in those colonies which contain dominant foraminiferal material and only minor girvanellid-like tubes. This small, ellipsoidal coated-grain is present in most of the Leavenworth localities except Locality 2 in northern Oklahoma.

2. The larger, irregular-shaped, complex-type of coated-grain ranges in size from approximately 10 mm. to an observed maximum of 80 mm. The nuclei for this type of coated-grain can be extremely variable, although fragments of sponges are often encountered. Other observed nuclei consist of: fragments of algae (Archaeolithophyllum and Eugonophyllum), rugose corals of the lophophyllidid-type, encrusting bryozoan colonies, and various brachiopod and molluscan fragments. The laminae are concentric, subcircular and vary in diameter, but usually average six laminae per centimeter. These laminae are recrystallized to blocky calcite mosaic. No fine structure suggestive of the original algal sheaths can be seen. Within the colony girvanellid-like tubes form a conspicuously minor element. In many cases layers of mud are interspersed between the laminae. One characteristic faunal element found on some of the laminae of this type of coated-grain is the relatively large encrusting foraminifer Tetrataxis. Significantly, this form does not exhibit its usual distinctive conical shape, but instead seems to have molded or encrusted itself onto the algal laminae assuming a unique splayed growth-form. Apparently this change in growth-form is a morphological adaptation in response to the environment. Perhaps, Tetrataxis could have existed and continued its life processes trapped between the laminae while the coated-grain was still in a semi-solid state. In any case, the foraminifer Tetrataxis is an abundant and characteristic constituent of the complex-type of coated-grain.

Many of these large coated-grains show evidence for uneven and preferential growth of the "algal laminae." It is relatively common to

find large coated-grains in which the nucleus, usually a large flat shell fragment, has been encrusted with many laminae on one side only; further laminae were continually added on, but only in an upward direction. This would tend to suggest that the colony had not been moved about by wave and current action, but must have grown in relatively calm water without over turning to produce concentric laminae. A few of these large complex coated-grains show clear evidence of laminae truncation. In this instance the secondary laminae are added on to the grain with a different orientation than that possessed by the original laminae that surrounded the nucleus. When this takes place the original laminae are cut and truncated at varying angles with different degrees of intensity. This imparts to the coated-grain a very irregular shape. In some instances thick layers of mud occur between the different sets of laminae.

In reflected light the encrusting foraminiferal content of both coated-grain types can easily be determined, primarily due to the dull-gray porcelaneous texture and irregular growth habit of these foraminifers.

This type of coated-grain is mainly restricted to those localities in northern Oklahoma and southwestern Iowa; a few of the small bean-shaped coated-grains also occur in association with the more complex type at the above localities.

Foraminifera: Foraminiferal remains occur in all of the Leavenworth thin-sections. Two categories were delineated: (1) fusulinids which comprise up to 78 percent of the rock (only at Locality 2 in

northern Oklahoma), but which average 5.9 percent for the entire outcrop belt; of the fusulinids four genera were recognized; and (2) smaller Foraminifera (nonfusulinid) which occurred at all localities and ranged in abundance from .1 percent to a maximum of 3.6 percent with a total over-all average of 1 percent.

#### Fusulinids

1. Genus Millerella; minute forms usually less than 0.5 mm. in maximum diameter; discoidal in shape and with a short coiling axis; planispiral throughout growth; wall thin and hard to differentiate into its components (tectum and upper and lower tectoria); chomata asymmetrical and broad; tunnel high and narrow; septa convex anteriorly. This form is generally distinguished by its small size and characteristic shape. Millerella occurs in almost every Leavenworth outcrop locality.

2. Genus Staffella; test subspherical, planispiral with a rounded periphery; some specimens attain a maximum diameter of 2 mm.; proloculus small and circular; shell umbilicate; when seen the chomata are low, broad, and highly asymmetrical; the shell material on all of the Leavenworth forms is recrystallized to blocky calcite mosaic so that the original wall structure cannot be ascertained. The over-all shape and characteristic recrystallization phenomenon tend to differentiate this form. Staffella is present in most localities at the southern end of the outcrop belt (Localities 1 to 9A), and occurs in abundance in all of the Nebraska localities.

3. Genus Waeringella; shell fusiform, up to 3 mm. in length; poles sharply pointed; juvenarium endothyroid; tunnel singular, irregular,

and with a narrow angle; chomata narrow; axial filling well developed; septa numerous and straight in central portion of the shell; fluting mainly confined to polar regions; wall probably three layered. This form can be most readily identified by its "pinched-in" appearance in outline, the endothyroid juvenarium, and the well developed axial fillings. Waeringella is restricted to those localities along the southern end of the outcrop belt from Locality 1 in Osage County, Oklahoma, to Locality 12 in Woodson County, Kansas. This distinctive fusulinid also occurs in the Salem School Limestone (Leavenworth equivalent) in Young County, Texas.

4. Genera Triticites-Kansanella undifferentiated; these forms fail to exhibit radical differences in gross morphology or shell structure hence, generic identification in random thin-section is difficult and in many cases impossible. For this reason both forms have been "lumped together." In thin-section both are characterized by their relatively large size (up to 5 mm. in length); bluntly pointed poles; a central region that is usually inflated and has relatively steep lateral slopes; a wall structure that is usually well preserved and very distinctive--consists of a tectum and a keriotheca containing pronounced alveoli; tunnel is singular and straight; chomata distinct and asymmetrical; proloculus small; and fluting mainly in the central portion and extending to the polar regions. The Triticites-Kansanella group occurs in every Leavenworth Locality except Locality 27 in Cass County, southwestern Iowa.

### Smaller Foraminifera

1. Palaeotextulariidae; this family is probably only represented by forms presently referred under the genus Climacammina. The test is large (up to 2.5 mm. in length and up to 1 mm. in breadth); elongate, consisting of numerous distinct chambers after an initial spherical proloculus; early chambers in biserial arrangements--later ones uniserial; septa subdivide the chambers and extend at least half way across the test; septa show much variation in shape, curvature, and thickness; test wall thick and two layered; consists of a thin dark granular outer layer, and an incomplete thick inner clear fibrous layer in the form of a lining; no adventitious material was observed on the outer wall; aperture not observed in random section. Climacammina is mainly distinguished by its relatively large size, shape, chamber development, and characteristic wall structure. Climacammina occurs in all Leavenworth localities except Locality 2 in Osage County, Oklahoma.

2. Genus Bradyina; test involute, relatively large (up to 2 mm. in diameter); subspherical; chambers more or less inflated; number of chambers variable--usually 6-7; septal sutures depressed; sutures are double and composed of the turned-in walls of the adjoining chambers; apertures consist of a series of parallel slits which are irregular in distribution and outline; wall very finely granular and coarsely perforate; wall thick (up to 70 microns); wall thickness increases from approximately 20 microns in the initial chamber to approximately 70 microns in the last chamber. Bradyina is distinguished by its shape, septal sutures,

and coarsely perforate wall. Bradyina occurs in almost all Leavenworth localities except Locality 2 in Osage County, Oklahoma, Locality 18 in Douglas County, Kansas, and Locality 28 in Adair County, Iowa.

3. Genus Globivalvulina; test subglobular with a diameter of approximately 0.5 mm.; ventral side of test flattened, dorsal side strongly convex; chambers inflated and added on alternately on either side of an elongate axis with each chamber slightly overlapping the preceding one; chambers usually increase in size as they are added on; adult forms possess from 7-10 chambers; sutures distinct and depressed; some thin-sections show the wall structure to be like that of Bradyina but not as coarsely perforated, other sections show the wall as a dark finely granular layer (differences in appearance probably due to variation in thickness of the thin-section). Globivalvulina is distinguished by its shape, distinctive coiling, and wall structure. Globivalvulina occurs in relative abundance in all Leavenworth localities except Locality 2 in Osage County, northern Oklahoma.

4. Genus Tetrataxis; encrusting foraminifer; test subconical to depressed with an apical angle of approximately 140 degrees; flat to concave on bottom side, top of shell subrounded; length up to 2.5 mm., height up to 0.5 mm.; test contains up to six whorls with a maximum of six chambers per whorl; chambers taper inward and curve upward towards the dorsal surface; deep umbilical cavity on bottom side; wall relatively thick and consists of a thin dark outer fine-grained layer, and a thicker transversely fibrous or perforated inner layer. Tetrataxis is distinguished by its unique shape, umbilical

cavity, and characteristic wall structure. Tetrataxis has been found in all Leavenworth outcrop localities.

5. Genus Hemigordius; planispiral foraminifer; test circular and up to 1 mm. in diameter; consists of a non-septate tube that is glomospirally coiled about a relatively large circular proloculus. with additional growth the coils are planispiral and involute; wall imperforate. Hemigordius can be distinguished by its shape, glomospirally coiled juvenile stage, and imperforate wall structure. Hemigordius occurs sporadically across the outcrop; out of a total of 32 localities it is absent in eight widely spaced localities.

6. Genus Syzrania; foraminifer small, maximum length 0.6 mm., width 0.1 mm.; test is composed of an initial spheroidal chamber followed by a long non-septate tube-like secondary chamber; test wall is double layered; inner layer is thin, dark, and finely granular, outer layer is thick, light, glass-like and translucent; thickness of wall approximately 10 microns. Syzrania can be distinguished by its small size, and unique double layered wall. Syzrania occurs in all localities except Locality 2 in Osage County, northern Oklahoma, and Locality 28 in Adair County, southwestern Iowa.

7. Genus Endothyra; test small, up to 0.5 mm. in diameter; involute; planispirally coiled and asymmetrical; may possess up to three whorls with as many as eleven chambers in the final whorl; chambers inflated; septa thin and long, but this appears to be variable, as some observed septa are short and fairly blunt, may also be depressed (probably more than one species represented); test wall dark, granular, and approximately 25 microns thick. Endothyra is characterized by its

size, shape, coiling, and wall structure. Endothyra occurs in every Leavenworth outcrop locality except Locality 2 in Osage County, northern Oklahoma.

8. Genus Tuberitina; encrusting foraminifer; test assumes form of a single flask-like initial chamber with as many as three additional subspherical to ovate chambers added on, giving the appearance of a rectilinear series; last chamber usually possess a flattened basal disc which is somewhat thicker than the rest of the wall; the test wall is dark, thin (approximately 10 microns), and does contain minute pores when the section is thin enough to observe; maximum observed height for a three-chambered form is .75 mm.; the diameter of the chambers vary from .20 to .40 mm.; random sections cut obliquely through individual chambers give a circular section which may cause this form to be confused for calcispheres. Tuberitina can be distinguished by its encrusting growth-form, flask-like shape of the initial chamber, its distinctive method of adding on additional chambers in rectilinear series, and wall structure. Tuberitina occurs in all Leavenworth outcrop localities except Locality 2 in Osage County, northern Oklahoma, and Locality 10 in Greenwood County, Kansas.

9. Genus Hedraites; encrusting foraminifer; test consists of an initial chamber followed by a long tubular non-septate chamber; shell dimensions may be extremely variable because the tubiform shell usually doubles back and crisscrosses upon itself in a highly erratic manner; surface of the test is marked by small pits that give it a honeycombed appearance, however these pits are only rarely seen in

thin-section; the test wall is thick and imperforate; in reflected light the test wall has a dull-white porcelaneous appearance. Hedraites may be distinguished by its very erratic growth-form, pitted surface, and porcelaneous wall structure. This foraminifer occurs in every Leavenworth locality except Locality 9A in southern Greenwood County, Kansas.

Sponges: Cylindrical forms which attain a maximum diameter of 10 mm.; the central portion of the organism is commonly filled with mud and comprises at least one-third of the total diameter--this is the body cavity or spongocoel; the sponge wall is approximately 3 mm. thick and in transverse section commonly shows a trabecular network with apochetes entering the spongocoel; the sponge wall might be said to have a "vesicular-like" appearance due to the labyrinth of canals; in some sections oxeas (spicules) can be seen; canals are filled with clear sparry calcite. The Leavenworth forms seem to represent the demosponge Coelocladia. This form is easily distinguished as a sponge by its conspicuous spongocoel, labyrinth of canals, and spicules. In the point-counts Coelocladia was a conspicuous element only at Locality 3 in northern Oklahoma. However, a number of coelocladid sponge fragments were collected from Localities 28 and 29 in southwestern Iowa, and Locality 24-A in Cass County, Nebraska. In almost all cases the sponge fragments served as nuclei for the large complex-type coated-grains.

Corals: Only a few random sections of rugose corals cut at oblique angles were noted in the thin-sections; these have been compared

to the whole-specimens collected from the Leavenworth and they are all thought to represent the genus Lophophyllidium;\* in general they average about 6 mm. in diameter and are distinguished by the vertical partitions (septa) that project inward from the inner wall; the septa are of two sizes that alternate in position and are arranged symmetrically about a vertical axis; numerous small arched partitions (dissepiments) occur in an area marginal to the inner wall; at low magnification the fibrous skeletal micro-structure appears to have a "fuzzy" appearance; in the septa these fibers appear to be oriented normal to the vertical plane of the septum. In thin-section corals were extremely rare and were not encountered during the point-counts. However, they do occur in thin-sections from Locality 29 in Madison County, Iowa, and Locality 1, Osage County, Oklahoma. In both cases they served as the nuclei for the large complex-type coated-grains.

Crinoid Columnals: Circular, elliptical, quadrangular, or polygonal particles, usually with a slight orange color, and ranging in size from 2 mm. to a maximum of 15 mm.; the grains possess a conspicuous reticulate pattern and perforated structure; optically each particle acts as a single calcite crystal regardless of its size, and under cross nicols goes to unit extinction. Crinoid columnals can easily be distinguished by shape, structure, and optical properties. Crinoid columnals occur at every Leavenworth outcrop locality except Locality 2 in northern Oklahoma. They range in abundance from

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\*One Dibunophyllum was found at Locality 29, Madison County, Iowa.

.1 percent to a maximum of 3.1 percent of the total rock. The general over-all average for the entire outcrop belt is 1.2 percent.

Echinoid Spines: In transverse sections echinoid spines appear as highly ornamented discs composed of a meshwork of great variety and complexity; the spines range in diameter from 1 to 3 mm.; the common Leavenworth echinoid spine is a disc-shape form perforated by a centrally placed circular canal approximately 0.5 mm. wide; this canal is usually filled with mud; from this circular central portion narrow canals radiate outward to the edge and impart to the spine a "sun-burst" appearance; in longitudinal section the basal portion of the spine shows the characteristic posterior shank or shoulder, which in life fits over the tubercles; some fragments in longitudinal section reach a length of 7 mm.; the calcite that fills the spine meshwork is in optical continuity throughout the spine, with the c-axis parallel to the spine length. Echinoid spines can easily be distinguished by their shape, complex architecture, and optical properties under crossed nicols. Echinoid spines occur in only ten outcrop localities dispersed from Oklahoma to Nebraska; none were seen in the Iowa localities.

Bryozoa: Encrusting cyclostome bryozoa are the dominant forms found in the Leavenworth Limestone. They are colonial; the zooecial tubes are relatively long, and straight to gently curved in longitudinal section; in transverse section they are subcircular; the zooecia are surrounded by vesicular tissue; the zooecia appear to be unevenly spaced, but this is difficult to ascertain in unoriented section; sub-horizontal diaphragms are also present in the zooecial tubes; the walls are recrystallized to fine-grained calcite and are indistinctly bounded

from the void-filling calcite. In a good many instances the encrusting cyclostomes occur within the large complex coated-grains, serving either as nuclei for the coated-grains, or enmeshed between the "algal layers." Fragments of the cyclostome colonies are also found strewn through the thin-sections and associated with other organic debris. The diameter of one cyclostome colony from Locality 29, Madison County, Iowa, is 8 mm.

Sporadically scattered through a number of Leavenworth thin-sections are small fragments of cryptostome bryozoa (fenestrates). In sections cut normal to the bedding-plane the colony exhibits the form of "rows of small beads"; the beads are subcircular to elliptical and commonly show partitioning into a variable number of chambers; surrounding all but the bottom portion of the "beads" is a distinctive dark layer of foliated sclerenchyma tissue.

Bryozoans can be distinguished in thin-section by their growth-form, zooecial tubes, vesicular tissue, and the commonly present "row of beads" of the fenestrates. Bryozoans comprise from 0 percent to 1.3 percent of the total rock; with a general average across the entire outcrop belt of .2 percent. Bryozoans were point-counted in two-thirds of the outcrop localities dispersed along the entire length of the outcrop section.

Brachiopods: Of the two classes of brachiopods, Articulata and Inarticulata, only the Articulata were represented in the Leavenworth thin-sections. Within this class, three broad groups are recognized on the basis of the shell microstructure. Only two of the three groups could be recognized in the Leavenworth thin-sections; these are the pseudopunctate and the impunctate forms.

The pseudopunctate brachiopods have imperforate shells, but the shell contains stout granular rods or "spicules" which appear as depressions on the surface of weathered or exfoliated specimens. The impunctate brachiopods have dense, imperforate shells. The shells of both groups are composed of two carbonate layers; a thin outer layer and a thick inner layer. In well preserved specimens the thin outer layer (approximately 0.1 mm.) appears as a bright rind consisting of a sheet of calcite composed of elongate wedging crystals oriented with their long dimensions in the plane of the layer. The inner layer of the pseudopunctate brachiopods is fibrous-prismatic, or they may have a foliated microstructure composed of thin calcite lamellae. The inner layer of the impunctate forms consists of closely packed prisms inclined at an angle from the base of the outer layer to the inner shell surface; they appear as fine hair-like fibers.

The most abundant forms recognized in thin-section were the pseudopunctate Chonetacea and Productacea with their distinctive foliated shells. The chonetids are usually more densely pseudopunctate than the productids. The genus Chonetes has pseudopunctae arranged in rows. In the chonetid group the pseudopunctae are expressed on the inner surface of the valves as small nodes or pustules, whereas in the productids they are expressed as small internal spines. Some productids (Dictyoclostus) show, in transverse cuts of the pedicle valve, a sort of "dimpled" inner surface and an upward drag of the lamellae.

Numerous productid brachiopod spines were observed in thin-section. These can be identified as circular to subcircular forms,

approximately 1 mm. in diameter, containing a hollow center, whose microstructure consists of fine concentric lamellae similar to that of the inner carbonate layer. The distinguishing feature, which readily differentiates them from trilobite spines, is the light-colored outer rind or hyaline layer as observed under crossed nicols.

One genus of pseudopunctate Strophomenacea, Derbyia, was fairly common in some Leavenworth thin-sections. In transverse section Derbyia was characterized by the fine parallel lamellae of the inner carbonate layer and the closely spaced ribs on the exterior.

The genus Composita (Rostrospiracea) possesses a very distinctive shell microstructure. The ordinary fibrous-prismatic inner layer is split by a prismatic layer composed of small stout calcite crystals oriented perpendicular to the curvature of the shell. This prismatic layer wedges out anteriorly.

Brachiopods can easily be distinguished in thin-section by their size, shape, and microstructure. Some forms are even distinctive enough in thin-section to be recognizable at the generic level. Brachiopods point-counted in the Leavenworth thin-sections comprise from .2 percent to 5.5 percent of the total rock; the general over-all average across the entire outcrop belt is 1.6 percent. Brachiopods occur at all Leavenworth localities.

Molluscs: Three groups of molluscs are represented in the thin-sections of the Leavenworth Limestone; these are pelecypods, gastropods, and cephalopods. Of the above the gastropods are quantitatively the most important; pelecypod fragments are fairly common, but cephalopod remains

are extremely rare. All of the Leavenworth molluscs, whether originally composed of calcite, aragonite, or a combination thereof, are now totally recrystallized to a mosaic of sparry calcite.

Three morphologically different gastropods are common in the Leavenworth thin-sections: (1) small turbinoid forms up to 5 mm. in height, (2) narrow, high-spired forms up to 1.5 cm. in length, and (3) planispirally coiled forms up to 1 cm. in diameter. Since the original wall structure has been destroyed, gastropods can only be identified by their size and shape.

Only disarticulated fragments of pelecypods have been noted in the thin-sections. If the fragment is large enough to retain some of the organism's original shape, identification is a relatively easy matter however, small straight to slightly curved fragments less than .5 mm. in length can readily be mistaken for algal plate fragments (since all algal plates do not show diagnostic "cells" or utricles).

Two relatively large fragments of nautiloid cephalopods were identified by their size, shape, and chamber development.

Since all of the Leavenworth molluscs have had their original wall microstructure destroyed by recrystallization, size and shape are really the only diagnostic criteria usable in identification. Molluscs comprise from 0 percent to 3.5 percent of the total rock; the general over-all average across the outcrop belt is 1 percent. Molluscs occur as point-counted constituents in 75 percent of the localities across the entire length of the outcrop belt.

Ostracodes: Ostracodes are present in the Leavenworth thin-sections as articulated bivalves or single valves, ranging in size

from 0.5 mm. to 4 mm. in length; single valves resemble small pelecypods, whereas the articulated bivalves display the typical ostracodal feature of valve overlap along one margin. The shell possesses two distinctive features: (1) a relatively thick single-layered wall in which the calcite is prismatic in habit, and (2) a short, shelf-like projection (duplicature) fused to the interior margins of the main wall. Optically, under crossed-nicols, the ostracode wall shows progressive extinction. Ostracodes can be distinguished in thin-section by their over-all size and shape, duplicature, overlap of the valves, and prismatic microstructure of the wall.

Ostracodes are not a very abundant constituent particle in the Leavenworth Limestone. They comprise from 0 percent to 0.9 percent of the total rock. They average 0.2 percent for the entire outcrop belt and were point-counted in 75 percent of the outcrop localities.

Trilobites: These marine arthropods are a rare constituent particle of the Leavenworth Limestone. In thin-section the most common trilobite sections seen are oblique longitudinal sections of the axial thoracic segments, and sections cut through the glabella. The shape of the axial thoracic segments is distinctive and conveys the appearance of a single strand of cord wrapped around a stick and then cut longitudinally. The sections through the glabella have the appearance of the question-mark symbol (?). Trilobite fragments attain a length of 4-6 mm.

Trilobite microstructure is very distinctive, in that under crossed nicols it exhibits progressive undulose extinction.

Trilobite fragments can readily be identified in thin-section by their unique shape, and distinctive optical properties. In the Leavenworth Limestone trilobite fragments were point-counted in only seven localities, and these were distributed along the entire length of outcrop. The maximum percentage of trilobite fragments at any one locality was only 0.3 percent of the total rock.

Unknown Skeletal: Skeletal fragments which were too small (usually less than 1/8 mm.) to identify with any degree of certainty were tabulated as unknown skeletal. Much of the unknown skeletal constituents probably are very small mollusc or algal plate fragments in which it was impossible to accurately delineate one from the other. The remainder consisted of fragmented and corroded skeletal minutia. The unknown skeletal category averaged 4.2 percent of the total rock, and ranged from 0 percent at one locality to a maximum of 15.4 percent at Locality 20 in Leavenworth County, Kansas.

Pellets: This category was subdivided into two major groups: (1) definite fecal pellets up to 2 mm. in length, ovoid to elliptical in shape, and containing flecks of brown to rusty-colored organic matter; this type of pellet was usually found in straight to slightly curved sedimentary structures up to two inches in length, that were interpreted as burrows; characteristically, the pellets in the burrows were surrounded by sparry calcite; insoluble residues prepared from a number of the burrows yielded distinctive fecal pellets that possessed faint spiral surface markings, along with scolecodont remains; this would tend to suggest strongly that the structures are worm burrows;

x-ray examination of a few of the pellets indicated that the pellets were composed of a complex chitinophosphatic material; and (2) a second group of pellets which are dark gray to black, rounded to elliptical, and composed of microcrystalline calcite mud devoid of any internal structure; the maximum size range for this form was up to .5 mm. in length--most were somewhat smaller; type 2 pellet is quantitatively more abundant than type 1.

Pellets are a common particle constituent in the Leavenworth Limestone, and comprise from .3 percent to 6.7 percent of the total rock; they average 3.2 percent for the entire outcrop belt.

Mud: Following the usage of Dunham (1962, p. 113) the term mud is based upon particle size; grains being larger than 20 microns, and mud being smaller than 20 microns. Since the Leavenworth Limestone is a carbonate mud the most useful textural subdivision is on the basis of the abundance of grains. Dunham (op. cit.) notes that:

"Such subdivision allows mapping of gradients in rate of production of grains relative to rate of accumulation of mud."

In the Leavenworth Limestone grains comprise more than 10 percent of the total rock, but are not so abundant as to come in contact and support one another--in essence, the grains are floating in a mud matrix.

Dunham calls this subdivision mud-supported; rocks in which the grains furnish mutual support are called grain-supported; and those rocks that contain less than 10 percent grains are considered as mudstones.

Wackestones contain more than 10 percent skeletal grains. Adhering to the above subdivision, practically all of the Leavenworth Limestone can

be classified as wackestone. Point-count analysis indicates that the all average mud content for the Leavenworth Limestone is 66.9 percent, ranging from a low of 38 percent to a maximum of 86 percent. One outstanding exception to this general pattern was noted at Locality 2, Osage County, northern Oklahoma. Here the Leavenworth is dominantly a fusulinid coquina; there is no mud matrix; the skeletal grains are in contact and support one another; and all are embedded in a sparry calcite matrix. In this particular instance the Leavenworth Limestone can be classified as fusulinid grain-supported grainstone.

Spar: Spar is a type of calcite grain or crystal larger than 20 microns, and distinguished by its coarse crystal size and clarity. Folk (1962, p. 66) notes that the term spar alludes to its clarity both in hand specimens and in thin-section. Sparry calcite usually forms as a simple pore filling cement that is precipitated in place within the sediment, with crystal size dependent upon available size of the pore space and the speed of recrystallization. Sparry calcite crystals up to 1 mm. in size are not uncommon in the worm burrows present in the Leavenworth Limestone.

Probably many of the small patchy areas of sparry calcite noted in most Leavenworth thin-sections have formed by recrystallization of fine carbonate grains, or by recrystallization of portions of the mud matrix. Point-count analysis indicates that sparry calcite average 3.8 percent of the total rock. The spar content has an over-all range of from .4 percent to 18.6 percent (only at one locality; Locality 2 where the rock type is a fusulinid grain-supported grainstone).

Petrographic Synopsis: On the basis of point-count analysis of 64 large (2 x 3 inch) thin-sections the Leavenworth Limestone can be classified as a wackestone. Volumetrically the over-all composition of the Leavenworth consists of 26 percent skeletal grains (as noted and identified by the criteria listed in the above categories), and 73.9 percent non-skeletal material. Grouped under the non-skeletal category are pellets, mud, and spar.

### POINT-COUNT ANALYSIS

In order to determine the relative volumetric abundance of the individual skeletal and nonskeletal grain types present within a unit sample, point-count analysis was undertaken on 68 selected large (2 x 3 inches) thin-sections.

A Swift point-counter was affixed to a Leitz Ortholux binocular microscope so that equally spaced traverses could be made across selected thin-sections. At each click of the point-counter the slide was moved across the field of view 1/3 mm., and the skeletal grains or particles were counted and identified, if possible. A magnification range of from X 40 to X 100 was used. In this manner 500 points\* were counted for each thin-section, and a quantitative (volumetric) estimate of the skeletal and nonskeletal rock-forming constituents was obtained.

Only particle constituents larger than 1/8 mm. were identified, since particles smaller than 1/8 mm. are difficult to identify with certainty. These less than 1/8 mm. particles were tabulated as unknown skeletal debris. Both Ginsburg (1956) and Purdy (1960), in work on Recent carbonate sediments indicated that grains larger than 1/8 mm. accumulated in close proximity to where they are formed, in contrast to the minus 1/8 mm. fraction which contains a large percentage of grains formed in other environments. Significantly, Ginsburg (1956, p. 249)

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\*Purdy (1960, p. 68) notes that if 500 points are counted on a slide and if the true probability of occurrence of a constituent is 50 percent, there will only be 5 chances in 100 (95 percent confidence probability) that the point-count estimate of the probability of occurrence of that constituent will differ from 50 percent by more than  $\pm 4.5$  percent.

observed that variation in the physical environment of Recent carbonate depositional areas is reflected in the grain size and particle composition of their sediments. He concluded that ancient limestones could be analyzed in the same manner.

Every point-count on the slide was identified and assigned to one of the categories described in the preceding section on petrography.

In passing, it should be mentioned that in order to standardize the point-counting procedure certain subjective decisions were followed. For example, in traversing a slide with numerous fusulinids or whole brachiopod shells, the interseptal areas and hollow cavities or centers, which are most commonly recrystallized to sparry mosaic calcite, were tabulated under the group to which the parent fragment belonged. Likewise, skeletal grains coated by concentric "algal" laminae were counted as coated-grains. The various skeletal nuclei of the coated-grains were disregarded as a grain type per se, but instead, were counted simply as coated-grains. This was done primarily because it was felt that the last thing that happened to the grain in the depositional environment was perhaps the most significant from a geological standpoint. Nevertheless, a record was kept of the various types of nuclei present within the coated-grains.

## STATISTICAL METHODS

From point-count analysis of 68 large Leavenworth Limestone thin-sections a volumetric estimate of the percentage of constituent particles was obtained. An additional counting procedure was also undertaken on the same thin-sections in order to specifically determine the abundance and association of Foraminifera. In this instance, total Foraminifera were counted from the entire thin-section and grouped under 14 variables (genera or families).

One immediate and obvious shortcoming with the point-count data per se, is that they are merely an array of somewhat bewildering percentages that by themselves do not display any meaningful groupings. Nonetheless, the point-counts do furnish the necessary data to determine and develop some measure of similarity between the reacting variable constituents. For in a geological study of this type, in which the primary goal is to provide a path to better understanding of the complex interrelationships commonly encountered in multivariate data, the paramount objectives are threefold: (1) to attempt to determine the minimum number of causal relationships that can accurately account for the majority of the observed variations, (2) to attempt to identify these causal relationships with some degree of certainty, and (3) to delineate for each variable the relative importance of each cause (Imbrie, 1963, p. 7).

The mathematical computations needed to solve the above objectives confront the worker with an overwhelming, and an almost prohibitive time-consuming task. Necessary functions such as computing

correlation coefficients requires many hours of tedious computation, even with the use of a desk calculator. Fortunately, access to a modern high speed digital computer (IBM 7094) provided an extremely rapid means of dealing with multivariate data in which the desired information could be readily obtained in a matter of minutes instead of hours. For this study, which specifically entailed rotated orthogonal factor analyses, the program written by Manson and Imbrie (1964) was utilized.

To begin to make geologically meaningful sense out of the vast array of data gathered during the thin-section point-counts and total foraminiferal counts, it was first necessary to determine what samples most closely resemble what other samples.

This measure of sample similarity is determined between samples by utilizing all the available data; in this case by considering all 19 or 14 variables simultaneously. This can be accomplished by a vector representation assuming that the degree of difference between any two samples is represented in vector notation by the size of the angle between their respective vectors. However, as Imbrie and Purdy (1962, p. 257) have pointed out:

"the use of an angular measure of similarity strikes most geologists as bizarre, and it is convenient for some purposes to transform theta into a dimensionless parameter theta prime."

Theta prime ranges from plus 1.00 through .00 to minus 1.00, with these values corresponding respectively to theta values of 0, 45, and 90 degrees. Higher negative values reflect increasing dissimilarity; higher positive values increasing similarity.

Once the degree of similarity between given pairs of samples has been delineated the next step is to identify clusters of sample vectors in an n-coordinate system. In order to accomplish this the algebraic operation of factor analysis is performed. The mechanics of this procedure is given a lengthy treatment by Imbrie and Purdy (1962, pp. 257-261), and Imbrie (1963). Suffice it to say that two modes of analysis are possible: R-mode in which relationships among variables are fully explored and in which correlation coefficients are used, and the Q-mode in which relationships among cases are explored applying the function of  $\cos \theta$ .

It now becomes necessary to graphically display the group relationships between variables. By using a two-dimensional dendroid hierarchical representation, it is possible to extract the main features of the inter-cluster relationships and to display them as such. The construction of the dendrogram was achieved in the following way:

- (1) each variable was grouped with the factor on which it was loaded most highly;
- (2) the mean loading for each factor group of variables was computed by dividing the total intra-group loading by the number of variables in the group;
- (3) the similarity between factor groups was computed by summing all possible inter-group variable loadings and dividing by the number of total variables in both groups.

From the factor analysis of all Leavenworth Limestone samples, five distinct constituent particle factor reaction groups, and

four foraminiferal factor reaction groups have been identified (see text-figures 8 and 10). It now becomes desirable to relate the factor reaction groups to a geographic index, in this case, factor locality groups, which will in essence delineate facies.

The grouping procedure for this integral step is identical to that just described and consequently will not be repeated here.

## RESULTS OF THE CONSTITUENT PARTICLE ANALYSIS

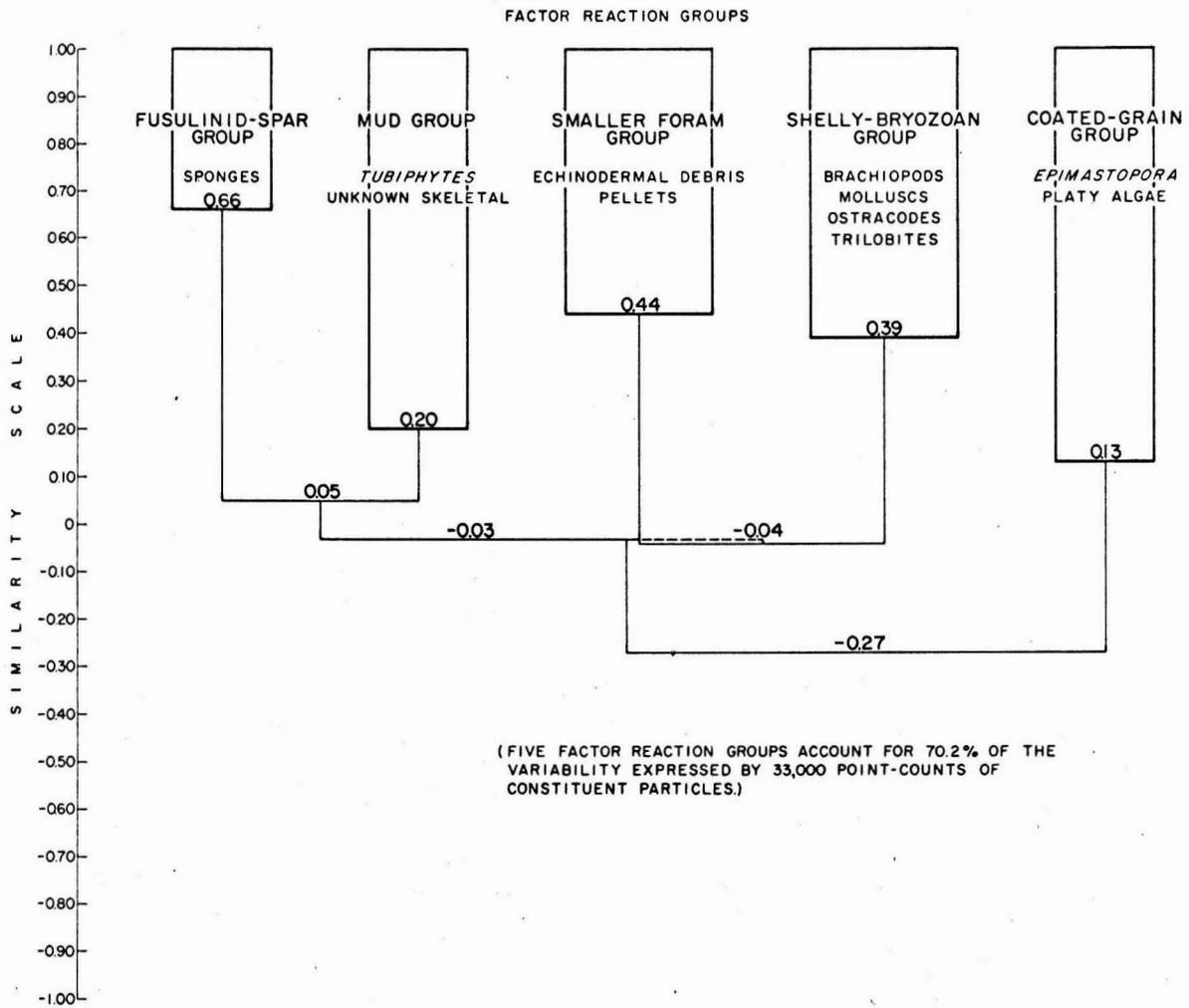
The principal results of applying the statistical methods, as outlined in the previous section, to the samples from 33 Leavenworth Limestone localities may be broadly outlined under the following headings.

### Factor Reaction Groups:

Upon the unbiased, equal and simultaneous consideration of 19 petrographic attributes, the Leavenworth variables grouped themselves into five discrete factor reaction groups. These five factor reaction groups account for 70.2 percent of the observed variability expressed by 33,000 point-counts of constituent particles. In other words, the data demonstrate what constituents tend to occur with what other constituents, and at what similarity level they are related.

Perusal of the Leavenworth constituent particle dendrogram (text-figure 8) shows that the members of the discrete fusulinid-spar-sponge group have the greatest similarity with one another at a mean similarity level of 0.66. Mud, Tubiphytes, and unknown skeletal debris constitute a second group, referred to as the mud group (since mud is the dominant constituent). The elements within this group are related at a mean similarity level of 0.20. The mud group is associated with the fusulinid-spar group at 0.05. The remainder of the dendrogram can be read and interpreted in a like manner.

The value of this type of hierarchial representation is that it documents the extent to which Leavenworth constituent particles tend to occur together in various unspecified environments. Accordingly,



TEXT FIGURE 8 LEAVENWORTH HIERARCHY DEPICTING SIMILARITY AMONG FIVE CONSTITUENT PARTICLE REACTION GROUPS

the hierarchy diagram shows four independently discrete factor reaction groups: (1) fusulinid-spar group, (2) mud group, (3) smaller foram group, and (4) a shelly-bryozoan group. These four factor reaction groups show descending inter-group similarity. The fifth factor reaction group (coated-grain) appears to be the most exclusive group, and is less closely related to any of the four preceding factor reaction groups. In fact, the level of similarity between the coated-grain group and the four other reaction groups is -0.27.

Factor Locality Groups:

Once it has been determined what constituents tend to occur together, it is then desirable to determine where they occur together along the outcrop belt--in reality, to delineate facies.

For the Leavenworth Limestone three factor locality groups, or facies, are recognizable. These are: (1) Skeletal mudstone facies, (2) Aggregate-grain facies, and (3) Mudstone facies. The three factor locality groups account for 82.1 percent of the variability expressed by the constituent particle data for the 33 Leavenworth localities.

Perusal of the hierarchial representation (text-figure 9) demonstrates that three independently discrete lithological families comprise the entire Leavenworth Limestone. Geographically, the skeletal mudstone facies is the most widespread since this facies contains 27 of the 33 localities, and stretches almost across the entire outcrop belt. Its meaning is bold and clear--the many processes contributing to the distribution and abundance of grain types within this facies are highly inter-related, and represent strongly inter-correlated elements

of a tightly knit marine environment. Without doubt, lateral homogeneity of the Leavenworth constituents is forcefully demonstrated.

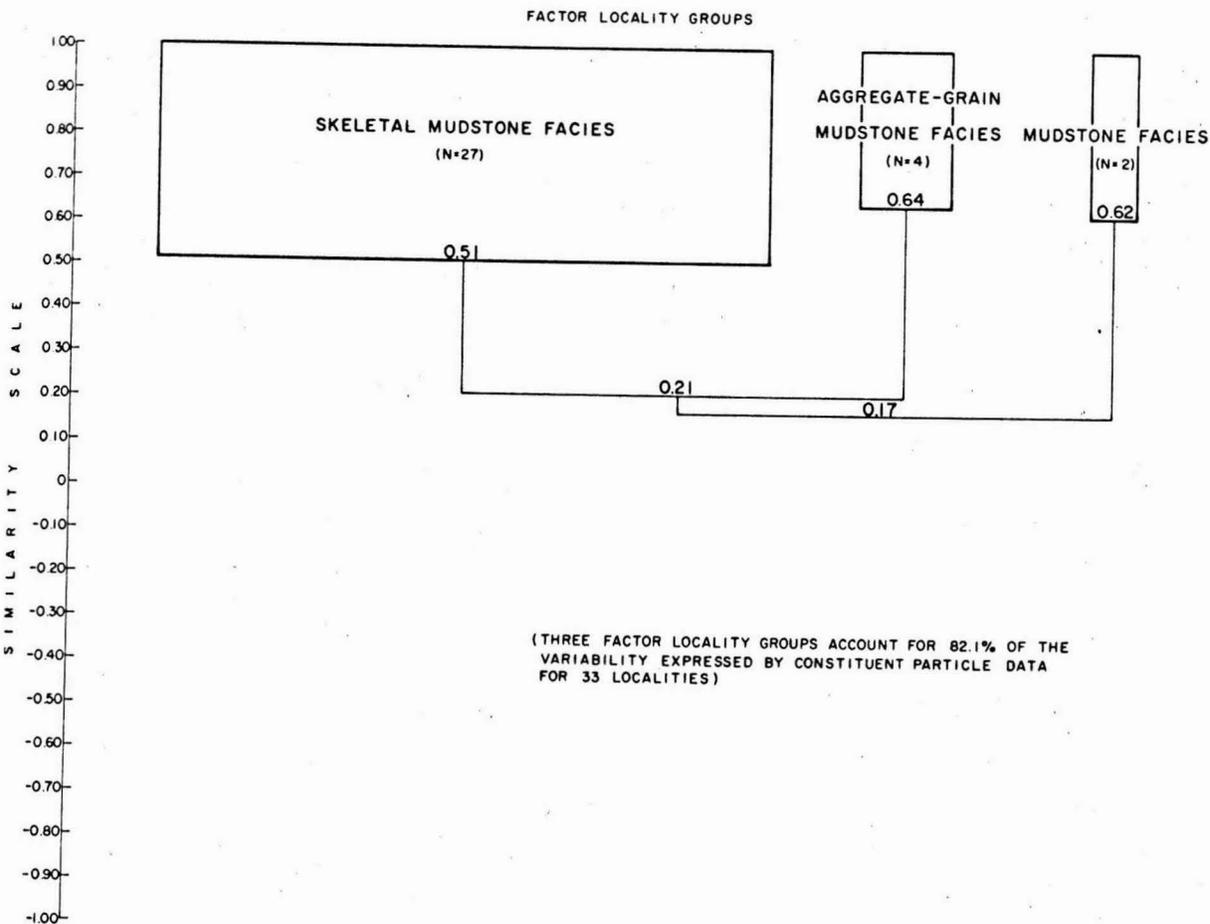
The aggregate-grain facies comprises four outcrop localities, and is geographically restricted to both the northern and southern extremities of the outcrop belt. The elements within this facies group are highly inter-related. The aggregate-grain facies is related to the skeletal mudstone facies at a mean similarity level of 0.21.

The mudstone facies is represented only by the two distinct limestone units present at Locality 27 in Cass County, Iowa. These two limestone units are superficially different from the rest of the Leavenworth in many respects (see discussion under stratigraphy). Correspondingly, the petrographic attributes of these two limestones demonstrates that they are also lithologically dissimilar from other Leavenworth localities, and can be distinguished as a separate facies. This mudstone facies is independently delineated as a discrete factor locality group, and is related to the skeletal mudstone facies and the aggregate grain facies at the relatively low level of 0.17.

Each of the recognized Leavenworth Limestone facies is characterized by distinctive properties whose salient features are presented below.

Skeletal Mudstone Facies:

As previously noted this facies comprises the majority of the Leavenworth Limestone localities. The principal distinguishing feature is the diversity of the particle constituent suite, for this is the only facies in which all 19 particle constituents were recorded. A



TEXT FIGURE 9 LEAVENWORTH HIERARCHY DEPICTING SIMILARITY AMONG THREE CONSTITUENT PARTICLE FACTOR LOCALITY GROUPS

statistical summary of the volumetric composition of the thin-sections from the 27 localities represented under this facies is given in Table 1.

Mud is the dominant component of this facies. Within this facies mud ranges from 38.0 to 85.9 percent, with a mean of 69.8 percent of the rock volume. Second in abundance is the small Osagia-type of coated-grain which is present in all thin-sections of this facies in amounts ranging from 0.5 to 33.0 percent, with a mean of 8.1 percent. Aside from spar, pellets, and unknown skeletal debris, fusulinids are the only other component present in amounts exceeding 4 percent. The total skeletal content has a mean of 22.8 percent. Spar accounts for 3.6 percent of the rock, and is present mainly as recrystallized mud. Of the three Leavenworth Limestone facies, pellets are the most abundant in the skeletal mudstone facies. Pellets have an observed range of from 0.5 to 6.7 percent, with a mean of 3.7 percent. Accordingly, this facies is apparently very homogeneous as no radical extreme or unique systematic variation was detected.

Table 1

VOLUMETRIC COMPOSITION OF THE SKELETAL MUDSTONE FACIES,  
 BASED ON 27 LEAVENWORTH LIMESTONE LOCALITIES

Constituent Particle	Mean	Standard Deviation	Observed Range
1. <u>Epimastopora</u>	0.03	0.3	0- 0.5
2. platy algae	0.05	0.04	0- 1.1
3. <u>Tubiphytes</u>	0.04	0.2	0- 0.7
4. coated-grains	8.1	7.1	0.5-33.0
5. forams (mobile)	0.7	0.4	0- 1.6
6. forams (encrusting)	0.4	0.5	0- 2.0
7. fusulinids	4.1	3.1	0.1-12.8
8. sponges	0.05	0.02	0- 1.5
9. echinoderms	1.4	0.2	0.1- 3.1
10. echinoid spines	0.1	0.3	0- 0.9
11. bryozoans	0.2	0.04	0- 0.6
12. brachiopods	1.7	1.1	0.3- 5.5
13. molluscs	1.2	0.8	0- 3.5
14. ostracodes	0.2	0.2	0- 0.9
15. trilobites	0.04	0.08	0- 0.3
16. unknown skeletal	4.5	2.8	1.4-15.4
17. pellets	3.7	1.8	0.5- 6.7
18. mud	69.8	8.7	38.0-85.9
19. spar	3.6	1.8	0.5- 7.9

Aggregate-Grain Facies:

This facies comprises 4 Leavenworth Limestone localities.

The facies localities are restricted to both the northern and southern extremities of the outcrop belt. The principal distinguishing features of this facies are the reduction of constituent particle diversity from 19 to 15 constituents, the over-all reduction in mud content, and the significant abundance of aggregate coated-grains (see Table 2).

The dominant component is mud with a mean of 38.7 percent by volume of the rock, and a range of from 0 to 66.9 percent. Second in abundance is the aggregate-grains present in 3 of the 4 facies localities, in amounts from 22.9 to 45.1 percent; the mean for this facies constituent is 27.9 percent. Fusulinids are the only other major organic constituent, and have an observed range of from 0.4 to 77.9 percent, and a mean of 21.2 percent. Fusulinids form the dominant rock constituent at Locality 2 in Osage County, Oklahoma, where the unit is practically a fusulinid coquina. The total skeletal content has a mean of 55.1 percent. Spar accounts for 5.3 percent of the rock, and is present mainly as void filling space between the fusulinid grains. Pellets comprise a very minor constituent of this facies, and only account for 0.9 percent of the total rock.

Table 2

VOLUMETRIC COMPOSITION OF THE AGGREGATE-GRAIN FACIES  
BASED ON 4 LEAVENWORTH LIMESTONE LOCALITIES

Constituent Particle	Mean	Standard Deviation	Observed Range
1. platy algae	0.1	0.9	0- 0.4
2. coated-grains (aggregate)	27.9	13.7	0-45.1
3. forams (mobile)	0.4	1.3	0- 0.9
4. forams (encrusting)	0.3	0.7	0.1- 0.6
5. fusulinids	21.2	37.9	0.4-77.9
6. echinoderms	0.8	0.6	0- 1.9
7. echinoid spines	0.02	0.2	0- 0.1
8. bryozoans	0.2	0.2	0- 0.5
9. brachiopods	1.0	1.7	0- 3.2
10. molluscs	0.3	0.9	0- 0.8
11. ostracodes	0.02	0.8	0- 0.1
12. unknown skeletal	2.9	1.3	0- 5.0
13. pellets	0.9	0.3	0- 1.4
14. mud	38.7	17.4	0-66.9
15. spar	5.3	8.8	0.4-18.6

Mudstone Facies:\*

This facies comprises the two limestone units from Locality 27 in Cass County, Iowa. The distinguishing features of this facies are the reduction in constituent particle diversity from a possible maximum of 19 constituents to 12, the very high percentage of mud, and the radical reduction in organic constituents (see Table 3).

Mud is the dominant component with a mean of 85 percent. Second in abundance is the small Osagia-type coated-grains, with a mean of 3.6 percent. Total skeletal content has a mean of only 10.7 percent. Spar accounts for 3.4 percent of the rock, and is mainly microspar probably recrystallized from the mud. Pellets are also a very minor constituent of this facies, and account for only 0.9 percent of the total rock.

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\*Strick adherence to the Dunham (1962) limestone classification scheme would consider all of the Leavenworth Limestone facies as wackestones with varying amounts of differing skeletal components. The facies designations used herein were used specifically to show a degree of differentiation within the broad wackestone grouping.

Table 3

VOLUMETRIC COMPOSITION OF THE MUDSTONE FACIES  
BASED ON 2 LEAVENWORTH LIMESTONE UNITS

Constituent Particle	Mean	Standard Deviation	Observed Range
1. coated-grains	3.6	0.4	3.5- 3.9
2. forams (encrusting)	0.1	0	0.1
3. echinoderms	0.8	0	0.8
4. bryozoans	0.8	0.8	0.2- 1.3
5. brachiopods	1.8	1.8	0.7- 2.9
6. molluscs	0.15	1.5	0- 0.3
7. ostracodes	0.1	0	0.1
8. trilobites	0.05	0.5	0- 0.1
9. unknown skeletal	3.3	0.1	3.2- 3.4
10. pellets	0.9	0.8	0.3- 1.5
11. mud	85.0	1.1	84.0-86.0
12. spar	3.4	2.9	1.3- 5.5

Facies Synopsis:

The results of the Leavenworth Limestone factor analysis confirms the fact, already determined through direct field observation, that this thin carbonate unit is extremely persistent, and laterally very homogeneous. The designation of the major part of the outcrop belt, from northern Oklahoma to southeastern Nebraska, as one major facies is indeed convincing. Significantly, however, two other facies were also delineated: (1) the aggregate-grain facies restricted to both northern and southern extremities of the outcrop belt, which probably demonstrates that a different set of environmental conditions was acting upon this portion of the ecosystem as shoreward direction was approached, and (2) the mudstone facies, which is apparently a local development in which the lack of skeletal debris is the most outstanding feature.

## RESULTS OF THE TOTAL FORAM COUNT ANALYSIS

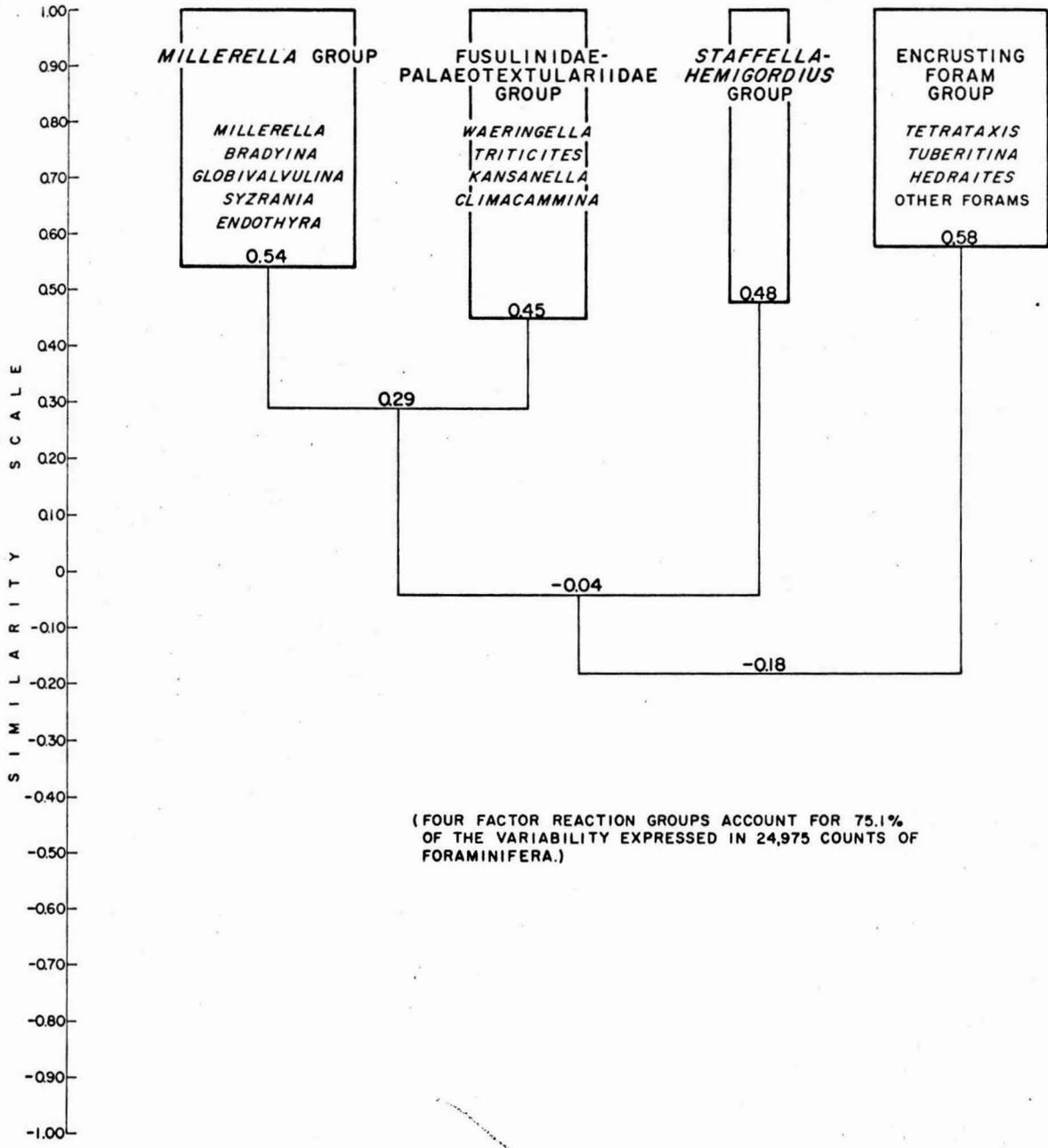
Results of the factor analysis of the total foram counts (24, 975) from thin-sections of 33 Leavenworth Limestone localities can be summarized under the following headings.

### Factor Reaction Groups

Based on equal and simultaneous consideration of 14 calcareous foraminiferal variables (genera or family groups), the foraminiferal constituents grouped themselves into four independently discrete factor reaction groups with definite disconformities among them. The boundaries are thought to reflect the discontinuities present within the system responsible for the observed facts. The four factor reaction groups account for 75.1 percent of the variability expressed in the total foraminiferal counts. The hierarchial representation (text-figure 10) not only demonstrates which Leavenworth Foraminifera tend to occur together, but also indicates the inter-relationships between the foraminiferal factor reaction groups.

The four foraminiferal factor reaction groups are: (1) Millerella group, (2) Fusulinidae-Palaeotextulariidae group, (3) Staffella-Hemigordius group, and (4) the encrusting foram group. The Millerella group comprises five genera, all of which are most closely related to each other at a mean similarity value of 0.54. The Millerella group is most closely related to the Fusulinidae-Palaeotextulariidae group, which comprises four genera and has a mean intergroup similarity value of 0.45. These two groups are the most similar foraminiferal factor reaction groups of the Leavenworth, and

FACTOR REACTION GROUPS



TEXT FIGURE 10 LEAVENWORTH HIERARCHY DEPICTING SIMILARITY AMONG FOUR FORAMINIFERAL FACTOR REACTION GROUPS

are related to one another at a similarity value of 0.29. The two remaining foraminiferal factor reaction groups are fairly exclusive entities. The Staffella-Hemigordius group, comprising only two genera, has a mean similarity value of 0.48, and is associated with the preceding two factor reaction groups at the low similarity level of -0.04. The remaining encrusting foram group, comprising at least four genera, possesses the highest mean intragroup similarity intensity (0.58) of all the foraminiferal factor reaction groups. However, this group possesses the least similarity to the preceding three factor reaction groups, and is associated with them at the low level of -0.18.

#### Factor Locality Groups

Three foraminiferal factor locality groups, or facies, are recognizable: (1) mobile foram facies comprising 20 localities, (2) fusulinid facies comprising nine localities, and (3) an encrusting foram facies comprising four localities. These factor locality groups account for 80.1 percent of the variability expressed by the foraminiferal counts for 33 Leavenworth localities (see text-figure 11). Each of the facies possesses a relatively high mean intragroup similarity. The mobile foram facies is most closely similar to the fusulinid facies, and is related to this facies at a level of 0.23. The encrusting foram facies, as also noted above in the factor reaction groups, shows high mean intragroups similarity but correspondingly low intergroup similarity (0.14) with the mobile foram facies and fusulinid facies.

#### Mobile Foram Facies:

The mobile foram facies has the greatest geographic spread (comprises 20 out of 33 localities), and highest mean intragroup

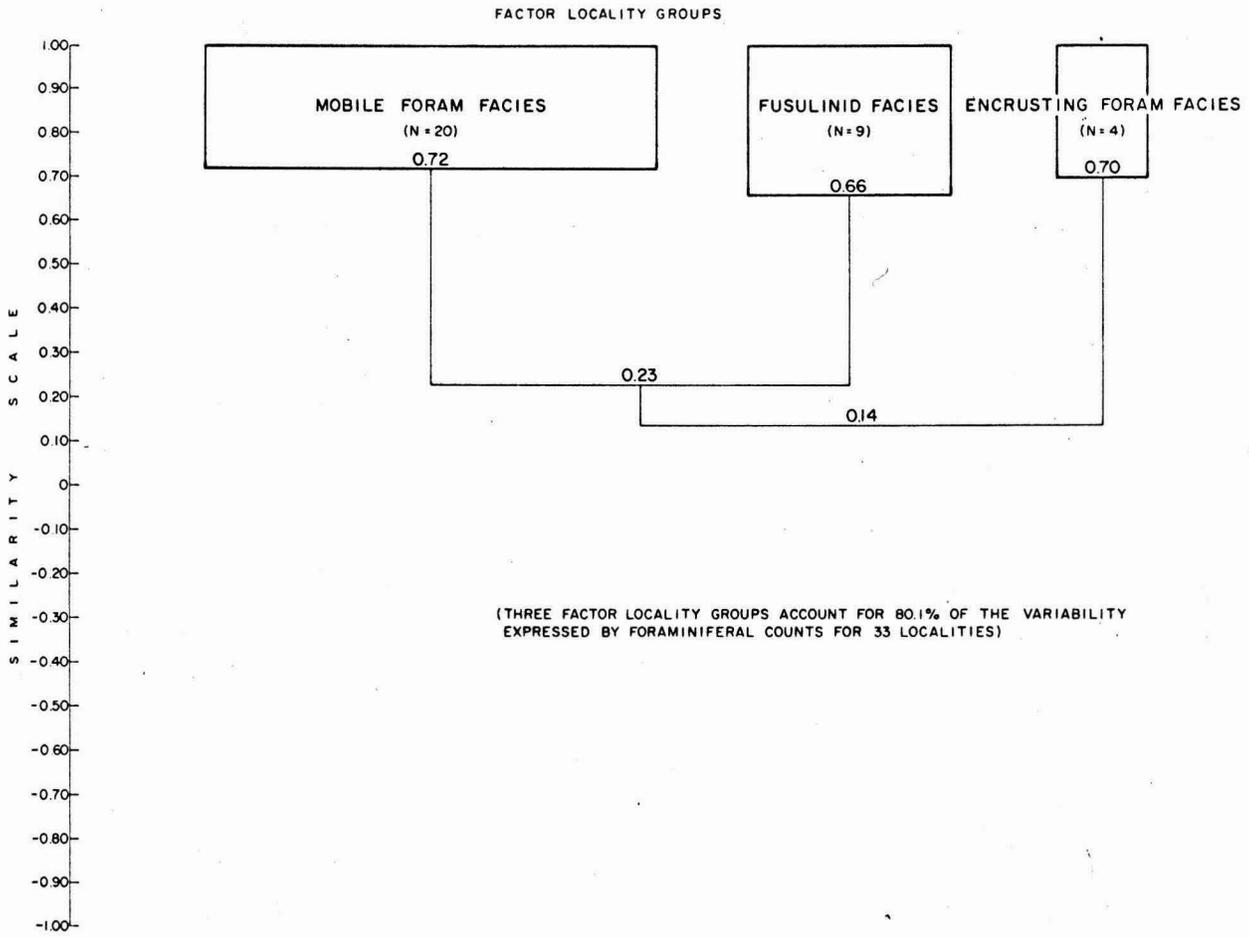
association (0.72) of all the Leavenworth foraminiferal facies. This facies also contains the highest percentage (33.7 percent) of mobile smaller foraminifers (Palaeotextulariidae, Bradyina, Globivalvulina, Syzrania, and Endothyra). The most dominant mobile foraminifer is Globivalvulina with a mean of 15.3 percent. Encrusting foraminifers comprise 24.3 percent and fusulinids 41.4 percent of the total foraminiferal assemblage. The percentage composition of this foraminiferal biofacies is given in Table 4.

The dominant characteristic of this biofacies is the relatively high percentage of mobile-type smaller foraminifers.

#### Fusulinid Facies

The fusulinid facies contains a dominant fusulinid assemblage comprising 58.6 percent of the total foram microfauna. This facies embraces nine localities spread from northern Oklahoma to southeastern Nebraska. Most abundant fusulinids occur at those northern Oklahoma localities where the fusulinid-rich top of the Leavenworth Limestone is well developed. The genus Triticites is the dominant fusulinid constituent. Mobile forams comprise 17.5 percent, and encrusting forams 24.1 percent of this facies. One mobile smaller foraminifer, Hemigordius, attains its highest mean (4.0 percent) within this facies. The fusulinid facies is most closely related to the mobile foram facies, and is associated with it at a similarity level of 0.23. Percentage composition of this foraminiferal biofacies is given in Table 5.

The dominant foraminiferal characteristic of this biofacies is the high percentage of fusulinids, especially the genus Triticites.



TEXT FIGURE II LEAVENWORTH HIERARCHY DEPICTING SIMILARITY AMONG THREE FORAMINIFERAL FACTOR LOCALITY GROUPS

Table 4

PERCENTAGE COMPOSITION OF THE MOBILE FORAM FACIES,  
BASED ON TOTAL FORAMINIFERAL COUNTS FOR  
20 LEAVENWORTH LIMESTONE LOCALITIES

Foraminifer	Mean	Standard Deviation	Observed Range
1. <u>Staffella</u>	1.1	1.9	0- 6.7
2. <u>Millerella</u>	2.7	1.7	.1- 6.1
3. <u>Waeringella</u>	.1	.61	0- .7
4. <u>Triticites-Kansanella</u>	37.5	18.8	4.3-67.1
5. <u>Palaeotextulariidae</u>	8.4	3.1	2.0-12.4
6. <u>Bradyina</u>	2.0	1.1	.2- 4.1
7. <u>Globivalvulina</u>	15.3	8.4	.4-27.4
8. <u>Endothyra</u>	6.2	4.6	.8-19.8
9. <u>Hemigordius</u>	.8	1.3	0- 5.9
10. <u>Syzrania</u>	1.0	.68	.1- 2.4
11. <u>Tetrataxis</u>	2.3	1.5	.1- 5.2
12. <u>Tuberitina</u>	12.5	10.1	1.1-46.6
13. <u>Hedraites</u>	9.5	12.3	0-57.2
14. Other forams	.005	.21	0- .9

Table 5

PERCENTAGE COMPOSITION OF THE FUSULINID FACIES,  
 BASED ON TOTAL FORAMINIFERAL COUNTS FOR  
 9 LEAVENWORTH LIMESTONE LOCALITIES

Foraminifer	Mean	Standard Deviation	Observed Range
1. <u>Staffella</u>	1.4	2.4	0- 7.9
2. <u>Millerella</u>	.9	.9	0- 2.9
3. <u>Waeringella</u>	.04	.1	0- .3
4. <u>Triticites-Kansanella</u>	56.4	17.2	39.0-99.3
5. <u>Palaeotextulariidae</u>	4.4	3.7	0-10.7
6. <u>Bradyina</u>	.8	1.2	0- 1.7
7. <u>Globivalvulina</u>	5.3	3.9	0-13.9
8. <u>Endothyra</u>	2.3	1.6	0- 5.5
9. <u>Hemigordius</u>	4.0	3.2	.3- 9.3
10. <u>Syzrania</u>	.7	1.6	0- 1.6
11. <u>Tetrataxis</u>	.6	1.2	.1- 1.3
12. <u>Tuberitina</u>	2.9	2.7	0- 9.4
13. <u>Hedraites</u>	20.6	12.9	.2-37.5
14. Other forams	.04	.08	0- .2

### Encrusting Foram Facies

This facies is dominated by three encrusting foraminiferal genera (Tetrataxis, Tuberitina, and Hedraites), which comprise 83.6 percent of the total foram assemblage. Four localities, restricted to southwestern Iowa, are included in this facies. Mobile forams constitute only 6.4 percent of the microfauna, and fusulinids only 9.6 percent. The foraminiferal constituents of this facies show high mean intragroup association (0.70), but possess relatively little similarity to the other two foraminiferal facies. Percentage composition of this foraminiferal biofacies is given in Table 6.

The principal foraminiferal characteristic of this biofacies is the dominance of encrusting-type foraminifers (Tetrataxis, Tuberitina, and Hedraites).

### Facies Synopsis:

Results of the foraminiferal factor analysis on 33 Leavenworth Limestone localities demonstrates that three factor locality groups, or facies, account for 80.0 percent of the observational data expressed by the total foraminiferal counts. Taking into consideration the inherent errors in the data, and the fact that only 14 parameters were identified, the simplicity of the results is outstanding.

Comparison of the foraminiferal biofacies with the constituent particle facies does show somewhat of a rough relationship. The data from both facies can be explained by three factor locality groups, with comparable levels of mean intragroup association. The main difference seems to be that when the Foraminifera are treated as a separate entity

Table 6

PERCENTAGE COMPOSITION OF THE ENCRUSTING FORAM FACIES,  
BASED ON TOTAL FORAMINIFERAL COUNTS FOR  
4 LEAVENWORTH LIMESTONE LOCALITIES

Foraminifer	Mean	Standard Deviation	Observed Range
1. <u>Millerella</u>	1.8	2.1	0- 5.1
2. <u>Triticites-Kansanella</u>	7.8	8.1	0-21.6
3. <u>Palaeotextulariidae</u>	.9	1.2	.6- 1.4
4. <u>Bradyina</u>	.4	.8	0- .8
5. <u>Globivalvulina</u>	.9	1.5	.3- 1.4
6. <u>Endothyra</u>	3.0	1.9	1.4- 5.6
7. <u>Hemigordius</u>	.4	1.2	0- .9
8. <u>Syzrania</u>	.3	1.6	0- 1.1
9. <u>Tetrataxis</u>	11.5	6.1	6.2-20.1
10. <u>Tuberitina</u>	44.0	5.5	27.1-61.1
11. <u>Hedraites</u>	28.1	15.9	11.4-49.3
12. Other forams	.6	1.7	0- 1.4

they do not appear to show quite the same type of environmental response. This is to be expected since in the foraminiferal analysis we are basically concerned with only one type of organism, and its response to the environment. This is in direct contrast to the constituent particle analysis where all 14 foraminiferal variables were lumped into three broad groups, and these in turn were compared with at least 12 other different organism groups.

Generally speaking, the mobile foram facies corresponds in part to the skeletal mud facies, with the notable exception that the mobile foram facies comprises seven less localities than the skeletal mudstone facies. These seven localities apparently combine with two other localities from the aggregate-grain facies, that also contained relatively abundant fusulinids, to create a separate fusulinid facies. The two remaining localities (28 and 29) under the aggregate-grain facies do contain abundant encrusting foraminifers (Tetrataxis), and hence split off to join two other localities high in encrusting foraminiferal content to form the distinctive encrusting foram facies.

RESULTS OF A SUBJECTIVE INTERPRETATIVE APPROACH  
UTILIZING COMPARABLE DATA

Prior to the present statistical analysis of the Leavenworth Limestone, a selected series of thin-sections from 22 localities extending from northern Oklahoma to southeastern Nebraska was subjected to routine binocular microscopic examination, and described in the normal manner. These petrographic data were integrated with the results obtained from studies of the insoluble residues, clay mineralogy, chemical analyses, and paleontology. The results were then subjectively and arbitrarily sorted and selected. The primary goal was an attempt to use subjectively all the data obtained thus far, and on this basis to determine meaningful geological and paleontological associations which would ultimately permit the establishment of sound facies. This method, although in some cases a very biased approach to data sorting and selection, is by no means unique to the profession, in that in most instances this is the type of approach followed by geologists in dealing with a study of this nature.

The basic results of this subjective approach to data interpretation indicated that the Leavenworth Limestone could be "broken up" into six "facies." These are:

<u>Facies</u>	<u>Geographic Extent</u>
1. coated-grain facies	Locality 1
2. fusulinid coquina facies	Locality 3
3.. kaolinitic biomicrite facies	Localities 2 through 9A

<u>Facies</u>	<u>Geographic Extent</u>
4. small foram biomicrite facies	Localities 10 through 14
5. low clay-high silt biomicrite facies	Localities 15A through 23
6. <u>Staffella</u> facies	Locality 24

Geological consideration and comparison of the above results with those obtained from the statistical analysis, in which an electronic digital computer was "fed" comparable data,\* indicated that the visual subjective approach tended to unrealistically overemphasize some aspects of the data. Accordingly, the typical human tendency to pick out and isolate the most obviously appearing parameters, without simultaneous consideration and comparison the other variables, and to decide subjectively whether a certain parameter is significant or not, and then to use it as a basis for stratigraphic subdivision, is fully evident. For example, facies 4 (small foram biomicrite facies) does contain a relatively greater percentage of certain distinctive smaller foraminifers, than other neighboring localities. However, the total over-all percentage of smaller foraminifers, on the basis of point-counts, shows that they comprise only 1 percent of the total rock for those localities within this "facies." In this instance, a few distinctive smaller foraminifers, although relatively unimportant volumetrically, but nonetheless eye-catching to the petrographer, formed the basis of a so-called "facies." Likewise, in facies 6 the

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\*The main difference in the data analyzed by the computer was that it consisted of quantitatively derived point-count percentages of the constituent particles, instead of visually estimated percentages.

distinctive fusulinid Staffella is a relatively outstanding constituent particle primarily because there is a low percentage of other types of skeletal debris. Point-counts on thin-sections from this locality show that Staffella makes up 3.5 percent of the total rock, yet there are other localities (i.e., Localities 6 and 9) represented under different "facies" which contain higher percentages of staffellids. In this case, relatively high percentage of other skeletal debris effectively masks and neutralizes the staffellid uniqueness. This process of attempting to read more into the available data than there is actual justification to do, can be a deadly process in which the end-result of trying to develop sound geological principles becomes subservient to the foible of pigeonholing.

Most importantly, the facies erected using the so-called tried and true methods of the profession were not geologically meaningful, because in utilizing the subjective approach the petrographer tends to extract the most obviously appearing constituents and use them as a basis upon which to build an unrealistic "facies." The main advantage in using the statistical approach was that all the data were given equal weight in delineating facies and associations, and were treated simultaneously and impartially. From the geological standpoint, the principal advantage lies in the fact that the statistical approach allowed and facilitated condensation of a large amount of data (variables) into as few as three to four groups of statistical variables, that essentially contained all the information that was present in a vastly larger original set of observations. Accordingly,

the 3 fundamental objectives in a geological study (1. the determination of the minimum number of casual relationships needed to explain the observed relationships, (2. the identification of these casual relationships, and (3. the relative importance of each cause) were more readily ascertained by using the statistical approach than by using the customary more subjective mode of analysis.

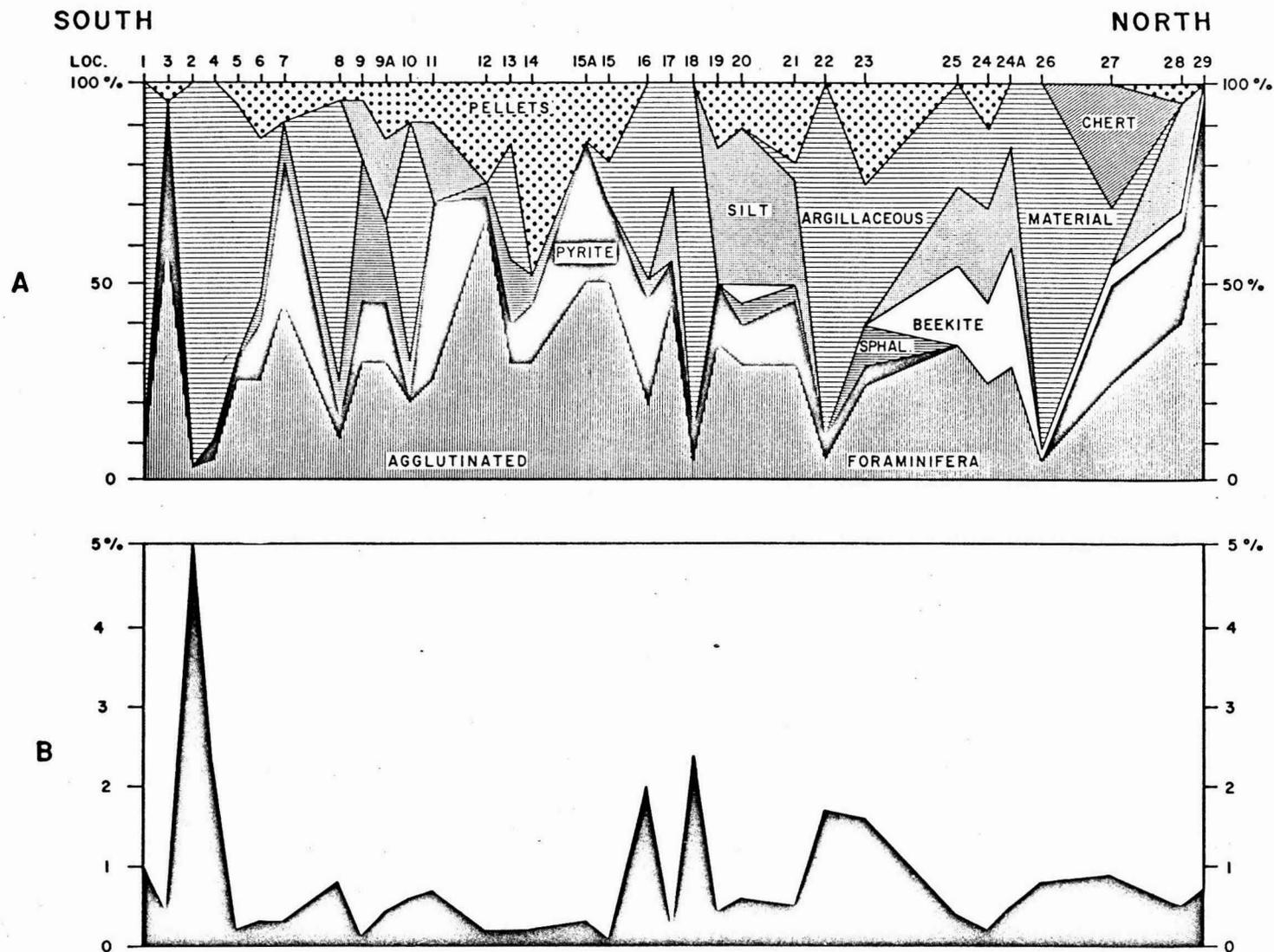
## INSOLUBLE RESIDUES

Two insoluble residues were made of Leavenworth Limestone samples from each outcrop locality. One hundred gram residues were prepared in the same general manner outlined by Ireland (1951, pp. 141, 143), with the exception that formic acid was used instead of commercial grade hydrochloric acid. Formic acid was utilized primarily because its reaction on the limestone was appreciably gentler, and as a result, the final residue product was "cleaner" and contained a more abundant and much better preserved microfauna.\* The fine fraction (minus two microns) was decanted and discarded. This size fraction is essentially identical to that used in the clay determinations. The insoluble residues described under this section are those commonly referred to as the coarse fraction (plus two microns in size). These are described in Appendix I, and their distribution is shown on text-figure 12.

Leavenworth insoluble residues consist of argillaceous material, microfauna (principally agglutinated Foraminifera), pyrite, fecal pellets, quartz silt, sphalerite, and beekite; arranged in a descending order of abundance. The most distinctive and persistent elements of the residue suite are the microfauna and the fecal pellets. Percentage of the coarse fraction residue ranges from a minimum of .1 percent to a maximum of 5 percent; total average percentage is .8 percent.

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\*Tests run with commercial grade hydrochloric acid failed to yield conodonts or whole fecal pellets.



TEXT FIGURE 12 A. PERCENTAGE COMPOSITION LEAVENWORTH INSOLUBLE RESIDUES (COARSE FRACTION)  
 B. TOTAL PERCENTAGE OF COARSE FRACTION (BY WEIGHT)

Argillaceous Material: This component consists of relatively large masses (up to 1 mm. in size) of flaky and sponge-like clay that the acid treatment has not been able to disaggregate. All of the argillaceous material present in the Leavenworth residues is heavily iron-stained. This type of residue is usually most common from the weathered top or bottom of the limestone unit. Argillaceous material occurs in 64 percent of the localities distributed along the entire length of outcrop. The total average percent of this residue component is 33 percent.

Microfauna: The microfauna consists principally of agglutinated Foraminifera, although conodonts, fish remains, and scolecodonts also occur in the residues. A residue microfauna is present at every locality and is the most persistent, and perhaps, the most diagnostic, of the residue components. The total average percentage of this component is 29 percent.

Pyrite (iron sulfide): The most common accessory mineral in the residues is pyrite; it occurs in 79 percent of the localities and averages 13.4 percent of the total residue. Pyrite usually occurs as small euhedra scattered through the carbonate matrix, and range in size from .05 to .12 mm. Pyrite can also occur as subhedral lath-like masses up to .5 mm. in diameter. In thin-section, the pyrite is seen to partially replace fusulinids, and to occur under arched surfaces of shell fragments. It is thought that decaying organic matter produced a local reducing environment in the sediment immediately after burial thus setting the scene for pyrite accumulation in situ. The relatively

dark color and hardness of the Leavenworth Limestone can probably be attributed to the high percentage of finely disseminated pyrite.

Fecal Pellets: This component occurs in 61 percent of the Leavenworth localities, and average 8.6 percent of the total residue. They are approximately 1 mm. in length, brown-colored, elliptical, and show faint surface spiral markings. Fecal pellets are most common at those localities that contain abundant worm burrows. X-ray analysis of a few of the fecal pellets indicates that they are composed of a poorly understood phosphate mineral complex. The pellets are well indurated but when crushed with a teasing needle they are seen to contain a good bit of carbonaceous matter, similar to spore cuticles. This writer is aware of no other instance where fecal pellets form such a relatively abundant and persistent insoluble residue component.

Quartz Silt: In 33 percent of the Leavenworth localities quartz silt averages 8.3 percent of the total insoluble residue. Silt size is fairly uniform at about .05 mm.; no secondary overgrowths were observed on any of the clastic grains.

Sphalerite (zinc sulfide): Sphalerite occurs in 39.3 percent of the Leavenworth localities, and averages only 4 percent of the total residue. This exotic secondary mineral is most abundant in residues derived from those localities in southern Kansas (Locality 7 to 13). The mineral was originally identified by X-ray diffraction, but can commonly be identified under the microscope by its characteristic "rosin-jack" color and resinous luster. The sphalerite appears to selectively replace Hemigordius-type foraminifers, productoid

brachiopod spines, bryozoans, and ostracodes.\* The zinc may have been carried in solution into the area from the mineralized southwest portion of the Ozark Dome, and the sphalerite replacement of fossils could have occurred in an immediately postdepositional reducing environment, in a manner similar to that, and contemporaneously with, the pyrite replacements.

Beekite: This component occurs in 27.2 percent of the Leavenworth localities, and averages only 2.7 percent of the total residue suite. With the exception of one occurrence in Kansas (Locality 20), beekite is mainly restricted to those localities in Iowa and Nebraska. It is most abundant in the Nebraska localities, where at Locality 24-A it comprises 30 percent of the insoluble residue. Beekite is a botryoidal, discoidal accretion of white opaque silica, and it is associated usually with fossil replacements. It forms a series of rough, concentric siliceous rings which may wholly or partially cover fossil surfaces.

Chert: The only occurrence of this component is at Locality 27 in Cass County, Iowa, where it comprises 30 percent of the residue. The chert is dark gray to black, and ranges in texture from chalcedonic to tripolitic. Relatively large chert nodules are common at this outcrop locality.

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\*Ver Steeg (1940, p. 259) reports sphalerite replacement of crinoid columnals and brachiopods in rocks of Mississippian age in Wooster, Ohio. He also notes that sphalerite is abundant and "appears to occur where fossils are numerous."

The Leavenworth insoluble residues can be subdivided into two main groups: (1) primary components--consisting of those elements which are indigenous to the unit and probably were formed in situ, or carried into the area during the time of deposition; these consist of clastic silt, microfauna, fecal pellets, and probably the pyrite and sphalerite; and (2) secondary components--consisting of those elements which formed after the limestone unit was hardened, and which may be referred to as postdepositional diagenetic effects; these consist of the argillaceous material, chert, and beekite. Of the two above groups, the primary components are the most useful since they represent a partial record of some of the processes that took place during the depositional interval.

The Leavenworth insoluble residue suite is characterized by its over-all relatively low residue percentage (less than 1 percent), the distinctive microfauna (in particular, Textularia, Bigenerina, and scolecodonts), and the unique occurrence of fecal pellets. These characteristics serve to distinguish and delineate the Leavenworth Limestone residues from those residues of the other principal limestones of the Oread Megacyclothem (Toronto and Plattsmouth).

## MICROFAUNA FROM INSOLUBLE RESIDUES

The microfauna derived from the insoluble residues of the Leavenworth Limestone consists primarily of agglutinated and silicified Foraminifera; although conodonts, fish remains, and scolecodonts also occur in the residues. The distribution and abundance of the Leavenworth microfaunal elements across the entire outcrop belt is shown in text-figure 13. This diagram is based on approximately 3,000 picked and mounted specimens.

Agglutinated And Silicified Foraminifera: Ireland (1956) reported 4 genera and 5 species of agglutinated Foraminifera from the Leavenworth Limestone insoluble residues of Douglas County, Kansas. Ireland's localities (A-1,2 and B-1,2) are essentially the same as Localities 16 and 19 of this report.

Consideration of the entire Leavenworth insoluble residue microfauna indicates that at least 9 agglutinated foraminiferal genera are represented in the residues, along with at least 2 genera of silicified calcareous foraminifers. The agglutinated genera are: Psammosphaera, Thuramina, Hyperamina, Reophax?, Minammodytes (formerly Tolypamina), Ammovertella, Ammobaculites, Textularia, and Bigenerina. Silicified calcareous genera are represented by Apterrinella? and Hemigordius. The most abundant and persistently occurring foraminifer is Minammodytes. Probably, the most diagnostic forms are the genera Textularia and Bigenerina.

Although Ireland (1956, p. 837) reported Textularia and Bigenerina from both the Toronto and Plattsmouth Limestones (a fact that

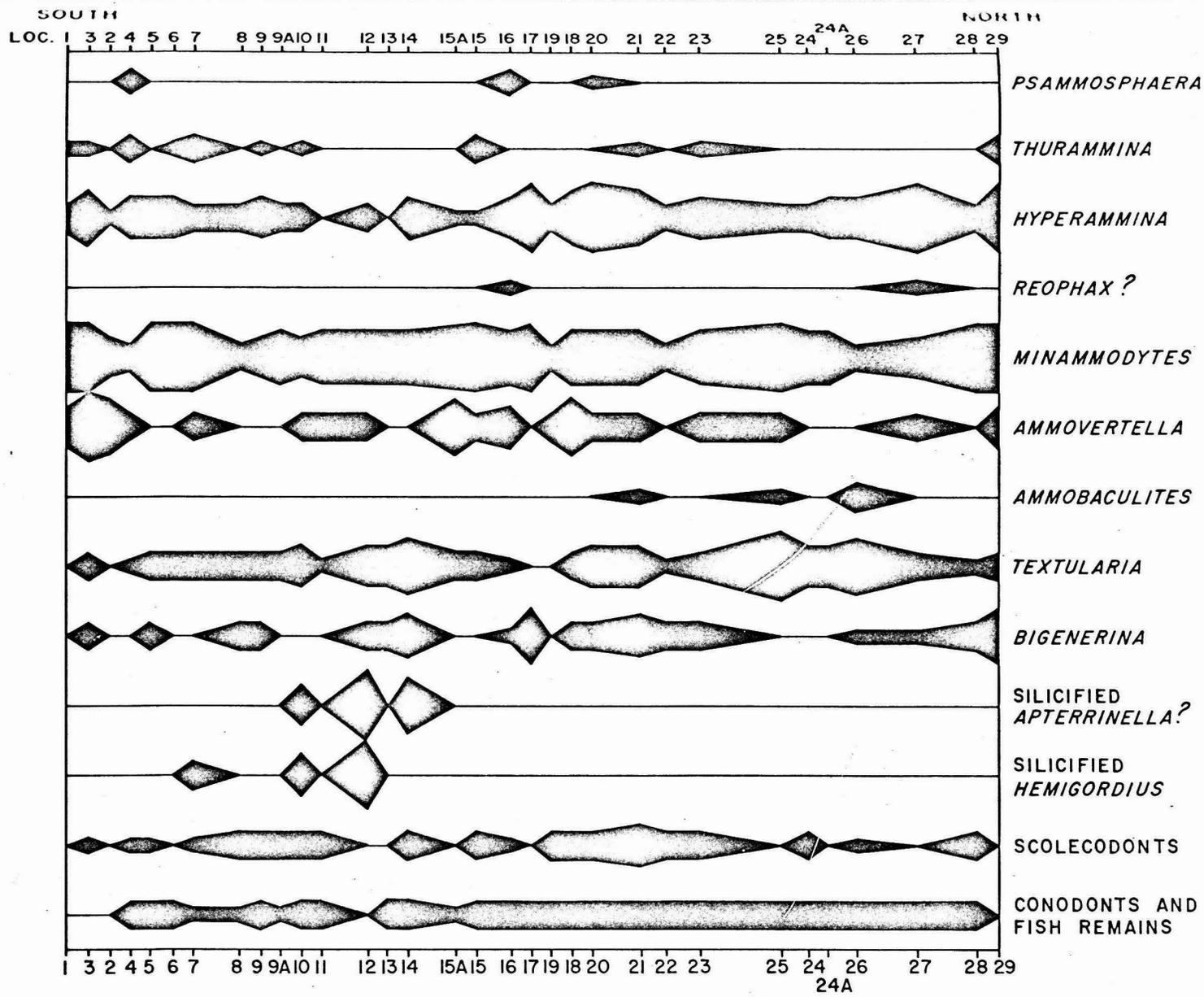
this writer has not been able to substantiate after examining at least 300 residues from the Toronto beds and approximately 50 residues from various Plattsmouth beds), he did not report them from the Leavenworth.

Accordingly, the results of this study would tend to indicate that both genera, since they are relatively abundant and laterally persistent, are good stratigraphic markers useful in delineating and differentiating the Leavenworth Limestone from the other Limestones within the Oread Megacyclothem.

In passing it may be noted that the agglutinated foraminiferal microfauna from the Salem School Limestone (Leavenworth equivalent) of northcentral Texas, also yields the distinctive genera Textularia and Bigenerina. In fact, both agglutinated foraminiferal suites are very similar with but one notable exception, that is, the occurrence and abundance of the genus Ammodiscus in the Salem School Limestone and its absence in the Leavenworth.

Examination of text-figure 13 shows that at least 5 agglutinated foraminiferal genera are relatively abundant across the entire outcrop belt. These are: Hyperammina, Minammodytes, Ammovertella, Textularia, and Bigenerina. Other exotic less abundant foraminifers appear to have a more limited distribution pattern. The distribution of the originally calcareous but now silicified genera, Apterrinella? and Hemigordius, generally coincides with the area of high sphalerite mineralization and replacement.

In an attempt to determine and compare the foraminiferal diversity of both the Leavenworth calcareous foraminifers, counted and



TEXT FIGURE 13 DISTRIBUTION OF LEAVENWORTH MICROFAUNA FROM INSOLUBLE RESIDUES (COARSE FRACTION)

identified from thin-sections, and those agglutinated foraminifers derived from the insoluble residues, a foraminiferal index was computed (see text-figure 14). This index was calculated by dividing the total number of forams per locality (total counted on a thin-section or total derived from a 100 gms. residue), by the number of genera represented by more than one specimen at that locality.

The results indicate that the calcareous foraminiferal assemblage does show somewhat of an increase in foraminiferal diversity in a southern landward direction. Whereas, the agglutinated foraminifers show an over-all relative uniformity with only minor differences, caused primarily by local changes in relative abundances. This difference can probably best be explained by assuming that most, if not all, of the calcareous Foraminifera were benthonic dwellers, and as bottom surface dwellers were exposed to the totality of edaphic environmental conditions. In effect, this would tend to place a delimiting factor on distribution and over-all diversity. Contrastingly, a goodly portion of the agglutinated foraminifers (e.g., Hyperammina, Textularia, and Bigenerina) may possibly have been members of the interstitial\* microfaunal community during a phase of their life cycle. In this capacity it is reasonable to assume that as an interstitial element the agglutinated foraminifers would probably be more insulated and isolated from adverse hydrographic ecologic pressures, such as temperature and salinity, and accordingly would show less over-all change or diversity across the outcrop belt because of this blanketing

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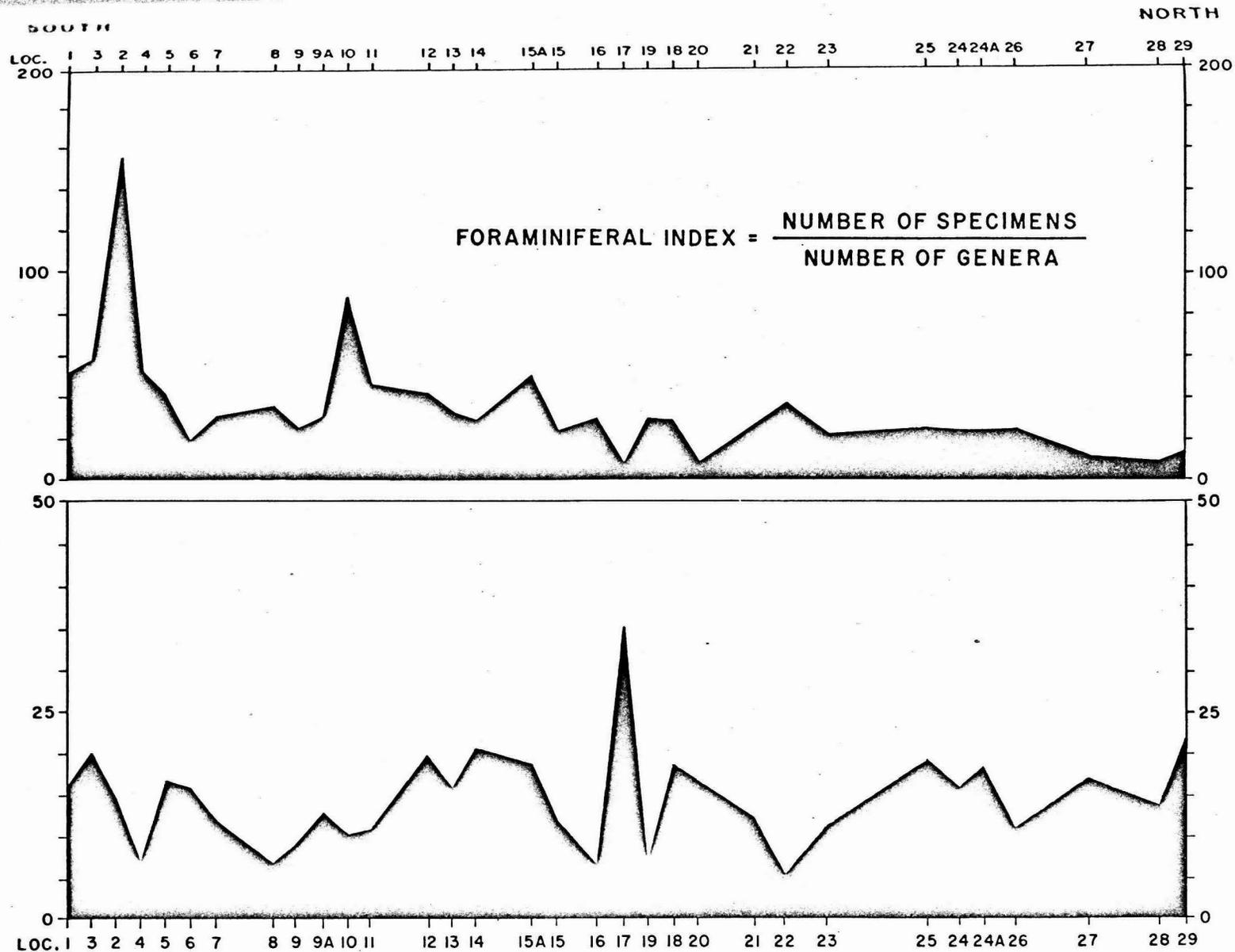
\*Microfauna that lives in the sediment interstices.

insulation. In effect this would only be true if the over-all bottom sediment texture remained constant. The fact that the Leavenworth Limestone has been shown to be such a laterally homogeneous unit would seem to offer a degree of supporting evidence.

Conodonts and Fish Remains: Both conodonts and fish remains are relatively rare faunal elements in the Leavenworth Limestone residues. Nonetheless, they are laterally persistent (see text-figure 13). At least 8 "genera" are represented, these are, according to abundance: Streptognathodus, Hindeodella, Spathognathodus, Cavusgnathus, Ozarkodina, Prioniodina, Synprioniodina?, and Idiognathodus. Little can be said concerning Leavenworth conodont distribution. Müller (1956, p. 1334), however, in an over-all appraisal of conodont studies to date, called particular attention to the conodonts' wide distribution in many different facies, the world-wide distribution of particular "species" and the bilateral symmetry (of the reconstructed animal), and deduced from these observations that they are the remains of free-swimming animals.

Fish remains consist of teeth and dermal denticles. The teeth show very little morphologic variability or size differentiation; all are approximately 1 mm. in length. Plate 13, Figure 13, shows a typical representative. Some workers have considered these teeth to be the remains of paleoniscoid fish.

Dermal denticles ("skin-teeth") are somewhat more abundant in the Leavenworth residues. The Leavenworth forms most closely resemble the described genus Moreyella, but comparison of an entire suite of



TEXT FIGURE 14

LEAVENWORTH FORAMINIFERAL INDICES

A. CALCAREOUS FORAMINIFERA (THIN-SECTIONS)

B. PRIMARILY AGGLUTINATED FORAMINIFERA (INSOLUBLE RESIDUES)

dermal denticles showed distinct gradation from this "genus" through the gamut of three other "genera" (Cooleyella, Cooperella, and Hammondella). It is believed that the dermal denticles are the remains of shark "skin-teeth." In an attempt to clarify this relationship a modern sand-shark (Squalus acanthias) was dissected, and the tough outer skin removed from various portions of the body and fins. The dissected areas were then boiled in sodium hydroxide and the denticles freed. Comparison of these freed dermal denticles with those described as various Paleozoic "genera" indicated that the modern forms from this one organism could be morphologically duplicated denticle for denticle with the various Paleozoic "genera." Most importantly, this forcefully demonstrated the intergrading morphologic variability of dermal denticles from a single modern-day shark; this variability presumably existed on Paleozoic shark hides too!

Scolecodonts: Black, shiny, silico-chitinous annelid worm-jaws, or scolecodonts, occur in many of the Leavenworth Limestone residues. They are at no place abundant, but do form a relatively persistent microfaunal element across the length of the outcrop. Typical representatives are shown in Plate 13, Figures 42 through 45. Therein illustrated are the principal morphological types. These could conceivably represent the complete maxillary apparatus of a Leavenworth annelid worm. It is noteworthy that in the present scolecodont classification scheme this jaw-apparatus, possibly from the mouth of one kind of individual, comprises at least 3 different "genera" of scolecodonts. Figures 42 and 45 would probably be referred to Arabellites; Figure 43 to Staurocephalites; and Figure 44 to Paleoenonites.

As a concluding process, in attempting to explore all methods of obtaining included organic remains from the Leavenworth Limestone, samples from all localities were dissolved in hydrofluoric acid. From the hydrofluoric acid residues strewn slides were prepared and examined under a biological microscope at a magnification of X 200. It was hoped that possibly spore material would be found, and that this material could be utilized in drawing information from another parameter. The results were negative as far as spores were concerned, since only a very few, very poorly preserved forms were found. However, while in the process of scanning the strewn slides a number of minute, uniquely distinctive organic remains were observed.

These minute microfossils have a saw-blade or hook-like appearance, and range in size from 60 to 140 microns in length and from 20 to 60 microns in height. A good many of them are fragmented. Most significantly, however, is the fact that they morphologically closely resemble the various types of larger scolecodonts as described above and probably they can be regarded as microscolecodonts.

A search of the literature indicates that these fossils have never been formally described. Formal description and illustration of these unique microfossils is anticipated at a later date.

## CHEMICAL ANALYSES

### Versenate Analysis:

In order to determine the presence, approximate percentages, and distribution of dolomite within the Leavenworth Limestone, versenate analyses were run on one sample per each locality. The method used was described by Schwartz (1956, pp. 115-122). A few of the samples that gave high percentages of dolomite by the versenate method were checked by X-ray diffraction, with generally good agreement.

The majority of samples contain negligible amounts of dolomite as determined by this method (3 percent of the samples contain more than 20 percent dolomite, and 52 percent contain less than 10 percent; the remaining 45 percent of the samples fall between 10 percent and 20 percent dolomite). The versenate method actually measures the percentages of magnesium, calcium, and sulfate ions in a solution prepared from the sample. These data are then calculated to percent dolomite, calcium sulfate (gypsum or anhydrite), and calcite, assuming that all of the magnesium goes to form dolomite. It is possible that some of the magnesium is present in the rock in other forms, such as solid solution in calcite or in/or on the clays, so that there may be actually somewhat less dolomite in most of the samples. Text-figure 15 illustrates the distribution and percentages of calcite and dolomite; no sulfate ion was found in any sample.\*

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\*The versenate method is not satisfactory for determining sulfate ion in quantities less than 3 percent.

The one sample with over 20 percent dolomite is Locality 22, Buchanan County, Missouri. This very localized occurrence of high dolomite percentage points out the fact that dolomite occurrence is not genetically associated with chertification (beekite and chert) in the Nebraska and Iowa localities.

Trace Element Analyses:

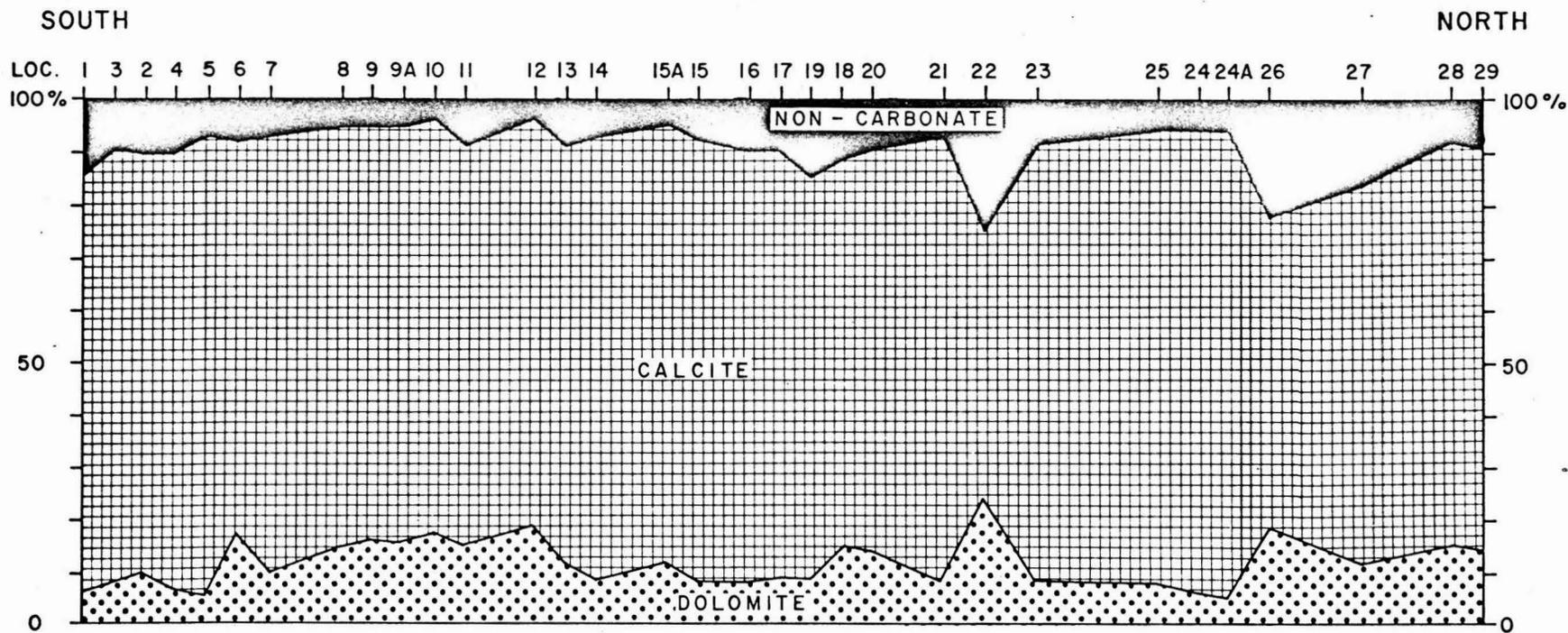
Thirty-four Leavenworth Limestone samples were analyzed by X-ray fluorescence spectrographic techniques in order to determine the percentage and distribution of six metallic trace elements (Fe, Zn, Sr, U, S, and P). Of these, only uranium was not present in detectable amounts.\* The distribution of the trace elements is highly variable (see Appendix II), and does not appear to show any meaningful distribution pattern.

Iron (Fe) is present in all samples and ranges from a maximum of 1.68 percent of a minimum of 0.26 percent; 55 percent of the samples contained more than 1 percent iron. High percent iron is not localized in any particular geographic area, but is erratically distributed across the entire outcrop belt. Most of the iron is probably present in the form of pyrite. Most clays can also absorb appreciable quantities of iron.

Zinc (Zn) is also present in 55 percent of the samples, and ranges from a maximum of 0.056 percent to a minimum of 0.001 percent. The highest zinc percentages occur in southern Kansas, in those areas where sphalerite (ZnS) makes up an appreciable percentage of the coarse fraction insoluble residue.

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\*Adams and Weaver (1958, p. 419) report that the Leavenworth Limestone has a normal Th/U ratio of 0.85.



TEXT FIGURE 15 PERCENTAGE LEAVENWORTH CARBONATE AND NON-CARBONATE  
(DETERMINED BY VERSENATE METHOD)

Strontium (Sr) is present in all localities and ranges from 0.150 percent to 0.020 percent. Relatively high strontium percents (plus 0.100 percent) occur in only 24.4 percent of the samples; these were not localized in any one particular area. The strontium is probably present as a trace impurity within the calcite crystal lattice, substituting for calcium.

Sulfur (S) is present in 55 percent of the samples, and ranges from a maximum of 2.5 percent to a minimum of 0.04 percent. No geographic preference for high sulfur content was noted. The percentage of sulfur is probably related to, and dependent upon, the occurrence of pyrite (FeS) and sphalerite (ZnS).

Phosphorous (P) is present in 82 percent of the samples, and ranges from 0.44 percent to 0.11 percent. No particular geographic preference for high percentage phosphorous was noted. Most of the phosphorous is probably present in the form of a complex organic phosphate mineral group. Its distribution in the Leavenworth is probably related to the occurrence and abundance of worm fecal pellets, since these do contain appreciable amounts of phosphate.

A cursory search of the literature reveals that very little has been accomplished in attempting to unravel some of the perplexing geochemical problems particular to, and inherent in Paleozoic sediments. Most of the literature seems to be concerned with analyses of trace elements with no attempt at synthesis, or trying to relate the geochemical data to geological processes. One notable exception to this general trend is that by Adams and Weaver (1958, pp. 417-419) in which the writers

attempted to demonstrate that the distribution of thorium/uranium ratios may reflect sedimentary processes and products. As a model they ran samples from most of the units of the Oread Megacyclothem (Leavenworth Limestone included). Their results showed that Th/U ratios varied according to rock type and probable environment of deposition, and might form a basis for characterizing and correlating cyclothem units.

Non-Carbonate Carbon Analysis:

The percentage noncarbonate carbon, that is, organic carbon other than that present in the carbonate, was determined on samples from all localities by the combustion-gravimetric method. This analysis was initiated because it was at first believed that the dark color of the limestone was perhaps due to relatively large amounts of finely disseminated organic carbon. Results of these analyses (see Appendix II) show that the Leavenworth Limestone contains organic carbon in amounts no greater than one-half of 1 percent, and could hardly account for the dark color of the limestone. More probably, this inherent dark color is primarily due to the presence of relatively high percentages of finely disseminated pyrite. In general, the content of organic carbon present in the Leavenworth Limestone is uniformly low throughout the length of the outcrop belt. Schwartz (personal communication) notes that organic-rich shales and limestones usually contain from 2 percent to 3 percent organic carbon.

## MACROFOSSILS

As a general statement, it can be said that the Leavenworth Limestone does not contain, or yield abundant macrofossils. This can be attributed to two basic causes: (1) due to the hard, dense nature of the rock, available specimens, even after considerable physical persuasion, are not easily yielded; hence, complete collections of potentially available specimens are never fully realized during the collecting process, and (2) the inherent nature of the Leavenworth sediment (mud with an almost complete absence of terrigenous detritus) does not offer itself to most benthonic organisms as a suitable or favorable environmental substrate on which organisms may develop and reproduce; thus, fossils should not be abundant.

A total of twenty localities, extending along the entire length of outcrop, was selected for detailed macrofossil collecting. An average of four hours collecting time was spent at each locality; during this time interval it was estimated that at least 100 pounds of rock was worked-over for fossil material. The results from this labor are indeed meager. From these twenty fossil collecting localities, stretching over a distance of more than 300 miles, only 579 specimens were obtained. Generally speaking, an average of 10 taxa were collected at each locality; usually less than 25 specimens were represented by the total number of taxa per locality. Most fossil specimens were incomplete or fragments.\*

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\*Macrofossil identifications are given in Appendix III. For this report productoid brachiopod identifications are based upon the work of Dunbar and Condra (1932); no attempt was made to apply the very detailed criteria

The Leavenworth macrofauna consists of the following faunal groups arranged in order of abundance and feeding type:\*

brachiopods	67.7%	suspension feeders
gastropods	15.5%	deposit feeders
pelecypods	4.4%	suspension feeders and/or deposit feeders
sponges	2.7%	suspension feeders
bryozoans	2.7%	suspension feeders
trilobites	2.7%	probably deposit feeders
corals	1.9%	suspension feeders
echinoids	1.7%	probably deposit feeders
cephalopods	.03%	carnivores
fish	.01%	carnivores

As a summary of feeding types the Leavenworth macrofauna comprises 79.4 percent suspension feeders, 19.9 percent deposit feeders, and less than 1 percent carnivores.

In studies of Recent benthonic faunas (Sanders, 1956, 1958; Purdy, 1964) it has been observed that in fine-grained mud bottoms the fauna is characterized generally by low population density and taxonomic

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given by Muir-Wood and Cooper (1960) in their revision of the family Productoidea, inasmuch as the identification of their "genera" requires the study of well preserved valve interiors. It may be noted in passing, that very few productoid brachiopod macrofaunas derived from Kansas Pennsylvanian limestones, would be able to meet the demanding "hair-splitting" standards imposed by Muir-Wood and Cooper in order to be "properly" identified.

\*Hunt (1925, pp. 567-568) recognized three basic feeding types: (1) suspension feeders are those organisms that feed on micro-organisms and/or organic detritus suspended in water, (2) deposit feeders feed on the same material on or in sediments, and (3) carnivores feed on other animals.

diversity. Purdy (1964) attributes this proven relationship to poor interstitial circulation resulting in the accumulation of toxic decomposition products and/or depletion in available oxygen; both processes producing a smothering effect on the fauna. In addition, substrates of this type are usually quite soft due to their high water content and impose upon the occupants the added hazard of experiencing difficulty in moving across them. In essence, this type of substrate represents a stress habitat, which most invertebrates have failed to exploit. It has been observed further that in substrates of fine texture, deposit feeders are more numerous than suspension feeders. This is the result of two basic relationships: (1) weaker bottom currents, associated with the accumulation of finer grained deposits, transport less suspended food material over a given bottom area per unit time and therefore tend to reduce the population density of suspension feeders, and (2) these same currents foster the deposition of increased amounts of organic detritus and fine-grained particles with sorbed organic matter and as a result increase the population density of deposit feeders.

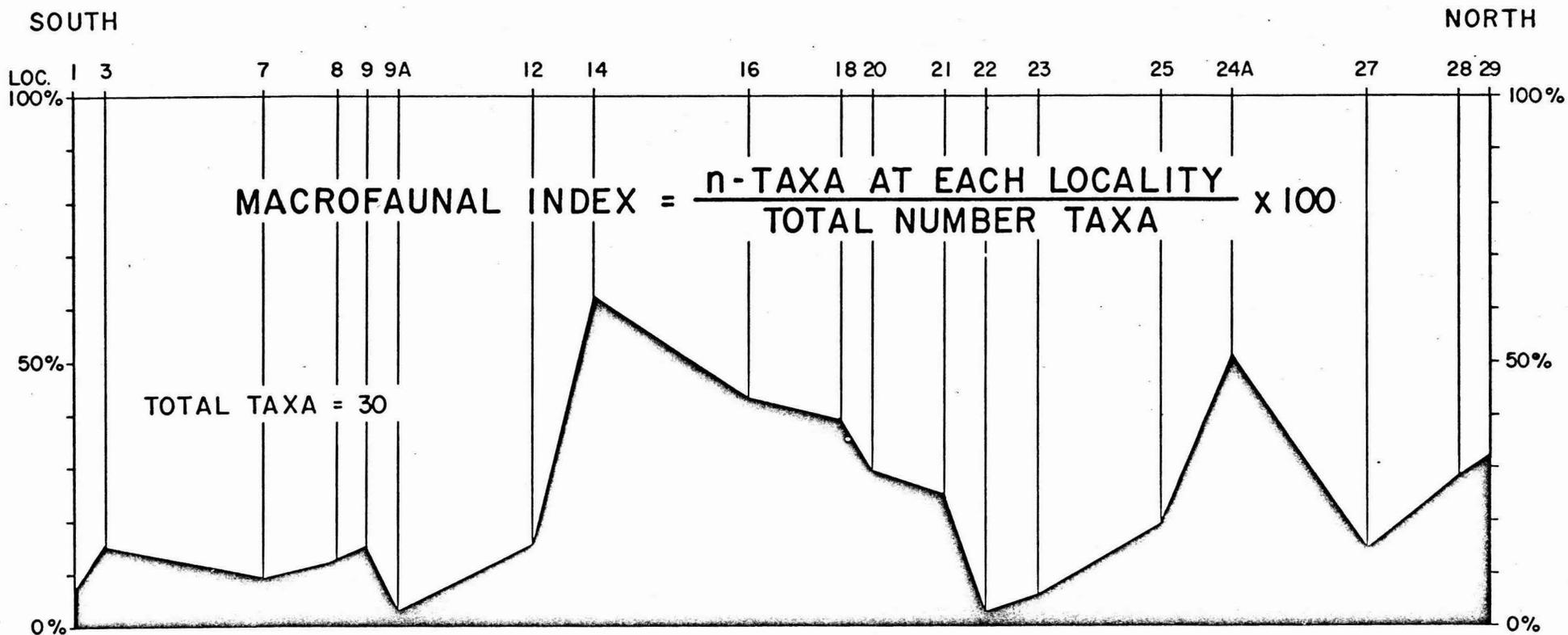
Thus, the results of studies on Recent faunas living on muddy substrates show a distinctly different relationship of suspension feeder versus deposit feeders than that observed in the Leavenworth Limestone. This can partly be explained as due to an evolutionary factor; that is, that the brachiopod habitat, which appears to have been fully exploited by suspension feeders during Leavenworth time, has been drastically altered since then through the successful encroachment and exploitation of this habitat by molluscs of several feeding types (of which deposit feeders comprise an appreciable portion). Hence, the over-all megafaunal

composition of Recent muddy substrates can be expected to be somewhat different in percentages of feeding types of the occupant organisms. However, this still does not account for the almost complete dominance of deposit feeders in Recent muddy-bottomed faunas and their minor role in the Leavenworth fauna. Perhaps, the vagaries of preservation have added their imprint on the ancient faunas in that the molluscs with their dominance of aragonitic shells are less likely to be preserved than the brachiopods. In this instance, the main difference may possibly be attributed to a preservation relict.

It also may be added that the Leavenworth Limestone unit does contain an appreciable amount of worm burrows (burrows contain pellets and worm-jaws). Perhaps, the deposit-feeding portion of the fauna was dominated by this soft-bodied group. If it were possible to compute the percentage of deposit feeding worms found in the Leavenworth, the over-all complexion of the macrofauna might closely parallel that of the Recent with respect to dominance of deposit feeders over suspension feeders.

In order that some idea of the taxonomic diversity of the Leavenworth macrofauna could be ascertained a macrofaunal index was computed (see text-figure 16). The macrofaunal index, or percent diversity, was plotted as a function of n-taxa at each locality over the maximum number of taxa possible at any one locality (in this case 30), multiplied by 100.

The diagram shows two areas with high taxonomic diversity separated by two intervening areas of very low diversity. The localities in Nebraska and Iowa represent the northernmost area of high diversity



TEXT FIGURE 16 LEAVENWORTH MACROFAUNAL INDEX

with a range from 17 percent to 53 percent. The Missouri localities are areas of lowest diversity (3 percent to 7 percent). The area of highest diversity (17 percent to 63 percent) is located in Kansas from northern Leavenworth County to northern Woodson County. The southernmost area, extending from southern Greenwood County, Kansas, to Osage County, northern Oklahoma is also an area of relatively low diversity (3 percent to 17 percent). This distribution pattern of Leavenworth macrofaunal diversity is anomalous, and is not readily explained. Most Late Paleozoic units that have been studied in this area (Mudge and Yochelson, 1962, p. 111) have shown an increase in the number of fossils and over-all macrofaunal diversity in a southern direction (southern Kansas and northern Oklahoma). It has been thought that this increase in microfaunal diversity is coupled with approach to shoreline in this direction. This is known to be the case with the Leavenworth, yet macrofaunal diversity appears to be relatively low in this area and does not seem to be influenced by proximity to shoreline. Perhaps, the two areas of low macrofaunal diversity represent areas of fluctuating bottom salinities or temperature, which may have been detrimental to macrofaunal expansion. However, other more subtle features such as turbidity, bottom-fouling, barriers, etc. could have equally as well been important in restricting organism distribution and expansion.

As previously mentioned (p. 6), the base of the Leavenworth Limestone is "plastered" by a very fossiliferous light-gray to green shale representing the uppermost interval of the Snyderville Shale. For the most part, the Snyderville Shale is principally a non-marine unit,

especially south of Locality 11, Greenwood County, Kansas. Nevertheless, abundant chonetoid brachiopods occur in the uppermost interval at all of the outcrops that were examined. The macrofauna from this upper interval is extremely interesting in that its composition assumes a "more marine" aspect as it is followed in a northern direction across the outcrop belt. At Locality 12 chonetoid brachiopods occur in profusion, with but few other brachiopods and pelecypods in association. An estimated ratio of chonetoids to other macrofossils would probably range on the order of 5000:1. From Locality 12 northward the macrofaunal assemblages undergo varied changes from a fauna almost completely dominated by chonetoid brachiopods to one in which other brachiopods (a good many productoids), pelecypods, echinoids, and finally bryozoa play an ever increasing role in the over-all macrofaunal composition. Nevertheless, chonetoid brachiopods still remain an important faunal participant throughout. This ever-increasing marine aspect can be readily demonstrated by the following series of faunal listings north of Locality 11:

Locality 12, Woodson County, Kansas:

brachiopods:

Neochonetes granulifer (Owen)  
(thousands of complete specimens)  
Derbyia crassa (Meek & Hayden)  
(2 single valves)

pelecypods:

Astartella vera Hall  
(2 fairly complete specimens)

Locality 14, Coffey County, Kansas:

brachiopods:

- Neochonetes granulifer (Owen)  
(thousands of complete specimens)  
Derbyia crassa (Meek & Hayden)  
(18 well preserved single valved specimens)  
Juresania sp.  
(6 incomplete specimens)

pelecypods:

- Nuculana bellistriata (Stevens)  
(1 complete specimen)  
Myalina (Orthomyalina) slocomi Sayre  
(6 fairly complete single-valved specimens)  
Astartella sp.  
(1 incomplete specimen)

Locality 23, Buchanan County, Missouri:

brachiopods:

- Neochonetes granulifer (Owen)  
(many hundreds of complete specimens)  
Derbyia crassa (Meek & Hayden)  
(22 fairly complete specimens)  
Juresania nebrascensis (Owen)  
(3 fairly complete specimens)  
Marginifera sp.  
(2 incomplete specimens)  
Dictyoclostus portlockianus var. crassico-  
costata Dunbar & Condra  
(6 complete specimens)  
Composita subtilita (Hall)  
(4 fairly complete specimens)

pelecypods:

- Edmondia sp.  
(3 fairly complete specimens)  
Myalina (Orthomyalina) slocomi Sayre  
(75 fairly complete single-valved specimens)

Locality 24, Cass County, Nebraska:

brachiopods:

- Neochonetes granulifer (Owen)  
(112 fairly complete specimens)  
Derbyia crassa (Meek & Hayden)  
(4 fairly complete specimens)  
Juresania nebrascensis (Owen)  
(2 complete specimens)  
Dictyoclostus portlockianus var. crassico-  
costatus Dunbar & Condra  
(5 fairly complete specimens)  
Neospirifer sp.  
(1 crushed specimen)  
Crurithyris expansa (Dunbar & Condra)  
(12 fairly complete specimens)  
Meekella striatocostata (Cox)  
(3 fairly complete specimens)

pelecypods:

- Wilkingia sp.  
(1 incomplete specimen)

echinoids:

numerous spines and plate fragments

bryozoans:

many rhomboporid-type fragments

The extreme dominance of one group of organisms, the chonetoid brachiopods, appears to be indicative of an environment of stress; one in which the ecologic pressures were particularly harsh for most organisms, with the resultant effect that competition was practically eliminated and only the hardy chonetoid brachiopods were able to survive, and, perhaps, most importantly, able to reproduce in abundance. The fact that there is an increased "normal marine" aspect to the fauna in a northern direction may possibly suggest that salinity fluctuations were particularly important for this interval, and that south of

Locality 14 the salinity was substantially lower, possibly brackish, with the above effect on organism distribution.

Gunter (1947), working with modern-day marine organisms along the shoreline, has noted that they possess various degrees of toleration to lowered salinities, and that species gradually drop out as the salinity gradient is traversed from higher to lower. In short, there is a direct relationship between an increase or decrease in salinity and the number of species of animals inhabiting a particular area.

Gunter (1947, p. 78) believes that it is:

"reasonable to assume that the same correlation between salinity and the number of species of animals living in the water held true in former geological eras. It follows that if a paleontologist working along a marine horizon finds that the number of species of animals increases, it is strong evidence that he is following a salinity gradient."

## CLAY MINERALOGY

The clay mineral suite present in the Leavenworth Limestone consists of illite ( $10 \text{ \AA}$ ), mixed layer illite-montmorillonite ( $11.5 \text{ \AA}$ ), chlorite ( $14 - 14.2 \text{ \AA}$ ), and kaolinite ( $7 \text{ \AA}$ ). The distribution pattern and relative percentages\* are shown in text-figure 17.

In general, the Leavenworth is characterized by a relative paucity of clay minerals.\*\* The southern end of the outcrop belt (Locality 1-4) has a higher clay mineral content than those localities to the north. Several localities at the northern end contain a meager clay suite, and the minus two size fraction consists primarily of clay-size quartz.

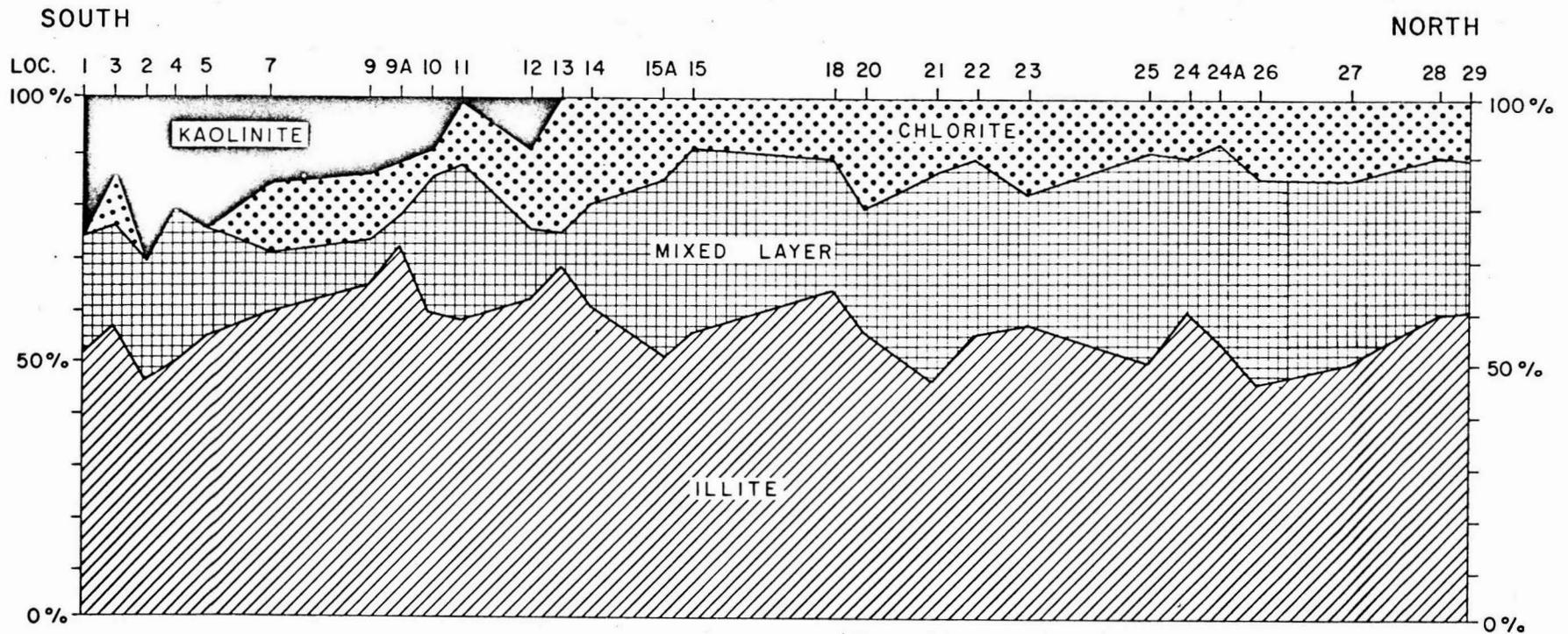
The clay plot shows a relatively uniform percentage distribution of illite, mixed layer, and chlorite from Locality 29 in southwestern Iowa to Locality 12 in Woodson County, Kansas. At Locality 12, kaolinite enters the clay suite and extends southward (with one exception; it is absent at Locality 11) as a generally expanding wedge. Apparently, kaolinite enters the clay suite at the expense of the chlorite and mixed layer components.

The over-all distribution pattern suggests two distinctive source areas. The southern source area where kaolinite is conspicuous,

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\*The clay minerals present have been calculated as a percentage of the total clay mineral suite at each locality, primarily based upon relative peak heights. Percentage figures can only be considered accurate to  $\pm 10$  percent. Percentages are given in Appendix IV.

\*\*Insufficient clay recoverable to make determinations from Localities 6, 8, 16, 17, and 19.



(INSUFFICIENT CLAY RECOVERABLE TO MAKE DETERMINATIONS FROM LOCALITIES 6,8,16,17 AND 19)

TEXT FIGURE 17 PERCENTAGE DISTRIBUTION OF LEAVENWORTH CLAY ASSEMBLAGES

and a northern area where the amount of clay minerals is small, though dominantly composed of illite, mixed layer, and chlorite.

The conspicuous kaolinite component at the southern end of the outcrop belt is, perhaps, the most outstanding feature of the Leavenworth clay pattern. This can be attributed to the fact that this general region is in closest proximity to a southerly active source area that was furnishing appreciable amounts of clastic debris into a rapidly subsiding trough located north of the Arbuckle-Wichita Mountains during Leavenworth time (see text-figure 4). Kaolinite is a decomposition product of feldspars (Calvert, 1964, p. 184 and Reiche, 1950, p. 49), and as such was probably carried from the source area by ancient streams and rivers flowing northward into the Leavenworth depositional region. Weaver (1958, p. 258) noted that clay minerals do not originate in their depositional environment, and that they are predominantly detrital in origin and reflect the character of their source area. Weaver also stated (p. 259) "that kaolinite is most common in continental and nearshore sediments." The Leavenworth distribution pattern would seem to fit this interpretation.

In a study of the Lower Permian Florena Shale, Imbrie et. al. (1959, p. 75) presented a clay distribution diagram showing a very similar kaolinite wedge extending from northern Oklahoma into southern Kansas. In this instance the southern source area is designated as the "Oklahoma Mountains."

It should be noted in passing that the Salem School Limestone (Leavenworth equivalent in northcentral Texas) carries a high kaolinite

component. The x-ray pattern indicates that kaolinite comprises 45 percent of the total, with mixed layer making up 30 percent, and illite 25 percent. It is interesting that no chlorite was found at this locality.

At the northern end of the Leavenworth outcrop belt most of the clay minerals drop out; although what clay minerals that are present do show a dominant illite-mixed layer-chlorite suite. This relationship suggests an independent northern source area, probably a metamorphic terrane, which was not actively undergoing erosion during Leavenworth time. The metamorphic terrane was probably the old northern stable shield area, which at this time was a very low-lying area contributing only minor amounts of clastic debris. This would tend to account for the conspicuous clay-size quartz fraction noted in the northern localities.

## CONCLUSIONS

### General Statement

The geological literature is replete with so-called geo-ecologic environmental interpretations of sedimentary units--more often grandiosely referred to as paleoecology. Nevertheless, in many instances it is difficult to comprehend what is actually meant by the word paleoecology. For, if it is meant by paleoecology the reconstructing of ancient environments in terms of known relations between living species and their environments, or in other words, saying that the past behavior and requirements of organisms is identical to their present behavior and requirements, we have again blindly pursued the path of Lyellian uniformitarianism. The outstanding difficulty with this interpretation and highly subjective approach is that it blatantly permits us to make statements about ancient environments that can never be directly verified. In addition, conflicts of evidence are usually frequent and demand ad hoc reasoning or argument to defend them. Accordingly, and most importantly, this approach specifically asserts that the relationships between the organisms and their environment is unalterably and profoundly static. How then can we escape from the trap of Lyellian uniformitarianism? Perhaps, as Scott (1963, p. 524) so lucidly stated, the best approach to this dilemma is to:

"...study the observable attributes of fossils (spatial distribution and abundance, disposition, size frequency distribution, etc.) in relation to the observable features of the associated sediments and the observable attributes of other fossils, with no necessary reference to present-day organisms or environments. Intensity of the relationships between attributes could be expressed statistically."

The principal advantage of this method is that it does not impose upon its adherents and practitioners a dual attribute regarding evolution, that is so implicit in the uniformitarianism creed. Hence, comparative paleoecological studies may, perhaps, be more rewarding than comparison and analogies with modern-day organisms. This approach can reveal changes in time and space and present to the worker a broad dynamic aspect, instead of a picture of perpetual static floundering.

#### Facts Dervied from the Leavenworth Data

This study has forcefully demonstrated to this writer that the concept of lateral homogeneity of the Leavenworth Limestone across the outcrop belt is indeed correct. The statistical method utilizing factor analysis for the constituent particle data and the total foraminiferal counts illustrates that most of the data can be explained by a relatively few factors. These factors essentially contain all the information derived from a much larger set of original observations.

In the case of the constituent particle analyses it was found that upon equal and simultaneous consideration of 19 petrographic variables the Leavenworth samples grouped themselves into five discrete factor reaction groups. These five reaction groups account for 70.2 percent of the observed variability expressed by the point-counts. In other words, the data demonstrated what constituents tend to occur with what other constituents, and at what quantitative level they are related. With the total foraminiferal counts four factor reaction groups accounted for 75.1 percent of the variability.

Once it had been determined what constituents tend to occur with one another, it was then desirable to compare one locality with another in order to determine the degree of related similarity. In other words, what localities more closely resemble what other localities. For the constituent particles of the Leavenworth Limestone three factor locality groups, or facies, were recognizable. These are: (1) skeletal mudstone facies, (2) aggregate-grain facies, and (3) mudstone facies. The three facies account for 82.1 percent of the total variability expressed by the constituent particle data for 33 Leavenworth localities. The designation of the major part of the outcrop localities (27) under one facies is indeed a convincing argument for lateral homogeneity. Significantly, two other facies were also delineated. Of these the aggregate-grain facies is restricted to those localities at both the northern and southern extremities of the outcrop belt, and comprises only four localities. The mudstone facies apparently represents a local condition in southwestern Iowa.

With respect to the Foraminifera, three foraminiferal factor locality groups, or foraminiferal biofacies, are recognizable: (1) mobile foram facies comprising 20 localities, (2) fusulinid facies containing nine localities, and (3) an encrusting foram facies representing four localities. These biofacies account for 80.1 percent of the variability expressed by the total foraminiferal counts for 33 Leavenworth localities.

As a control experiment, a subjective test using the "tried and true" methods of the profession with comparable raw data delineated

facies which are believed to be geologically unrealistic. The results of this experiment suggested that the data was consistently overplayed with the most emphasis being placed on the more obvious parameters. It was thought that the typically human tendency to neatly catalog and pigeonhole variables, even when it was not possible to decide whether they are significant or not, tended to mask the primary factors, and as a result, failed to establish meaningful lithological and paleontological associations.

Results from a study of the insoluble residues (coarse fraction) indicates that the Leavenworth Limestone is characterized by a relatively low residue percentage (less than 1 percent). The residues do carry a distinctive microfauna (in particular, certain diagnostic agglutinated Foraminifera and scolecodonts), and also contain unique fecal pellets. These characteristics tend to distinguish and delineate the Leavenworth Limestone from the other principal limestones of the Oread Megacyclothem.

Chemical analyses on the Leavenworth Limestone indicate the following: (1) versenate analysis to determine the presence, approximate percentage, and distribution of dolomite demonstrates that only one sample locality contained a maximum of 25 percent dolomite, and more than half the samples contained less than 10 percent; (2) trace element analyses of six elements (Fe, Zn, Sr, U, S, and P) shows a highly variable range without any apparent meaningful distribution pattern; (3) tests for organic carbon indicate that the Leavenworth Limestone contains amounts less than one-half of 1 percent, this minute quantity of organic carbon indicated could hardly account for the characteristic dark color of the Limestone; it is suggested that

the presence of relatively high percentages of finely disseminated pyrite impart to the rock its dark color and distinctive hardness.

The Leavenworth Limestone does not yield an abundant macrofauna. This is most probably due to the fact that the Leavenworth sediment, principally a mud with an absence of terrigenous detritus, does not offer a suitable substrate on which most benthonic organisms may develop and reproduce. For a substrate of this type is characterized by poor interstitial circulation resulting in the accumulation of toxic decomposition products and/or depletion in available oxygen. This would tend to produce a smothering effect on most organisms and thus restrict their development and exploitation of the habitat. The nature of the sediment appears to be more conducive to infaunal elements--in this case, probably marine annelid worms. This would tend to explain the abundantly re-worked and burrowed nature of the sediment, and the persistent presence of burrows containing fecal pellets and scolecodonts ("worm jaws").

The clay mineral suite present in the Leavenworth Limestone consists of illite, mixed layer illite-montmorillonite, chlorite, and kaolinite. The clay distribution pattern shows a relatively uniform percentage distribution of illite, mixed layer, and chlorite from Iowa to Woodson County, Kansas. In this general vicinity, kaolinite enters the clay suite and extends southward as a generally expanding wedge. Since kaolinite has been shown to be a decomposition product of feldspars, it has been suggested that land mass is approached in this general southward direction.

Generally speaking, it can be said that the Leavenworth Limestone is an unusual rock unit. It is unusual in the sense that it is so homogeneous; for lateral homogeneity in rock units is rather the exception than the rule. In itself, this homogeneity poses more problems than we might expect from such a thin, innocuous-appearing carbonate unit.

#### Outstanding Unanswered Questions

Outstanding among the many problems that remain unanswered in this study, three seem to require elucidation.

First of all, just what is the significance of the knife-sharp upper contact of the Leavenworth Limestone? What rational explanation can be offered for such a radical lithologic punctuation? Begrudgingly, it must be confessed that none can be offered! Nevertheless, some effort will be made to bring this problem more clearly into focus. It must be remembered that although the Leavenworth Limestone never attains a thickness greater than 3 feet its basal contact with the underlying Snyderville Shale is always gradational. The contact imprint at the base of the Leavenworth is always marked by a distinctive, irregular, undulated, burrowed surface. Contrastingly, the upper contact of the Leavenworth Limestone with the overlying Heebner Shale is everywhere knife-sharp. It is obvious that depositional conditions changed--but how? Does this surface represent a para-unconformity? If so, how can we visualize an unconformable surface in terms of areal extent of over 100 hundred thousand square miles that does not leave any other diagnostic imprint except the final product itself? The magnitude of the causal mechanism is incomprehensible! Yet if this depositional surface does represent an

unconformity, is it not reasonable to expect evidence of this, e.g., corrosion zones, concentrations of organic debris, or perhaps lithoclasts? However, two of these examples preclude subaerial exposure of the rock unit. Is it possible that the unit was never exposed above wave base? Instead, Heebner depositional conditions may have been imposed over this vast area completely and geologically instantaneously with no major change in water depth relationships. Moore (1929, p. 465) stated that:

"The association of these black shales (Heebner-type) with marine beds, their wide distribution, notwithstanding thinness, and the occurrence of marine fossils indicate origin in the sea. The black color is due to finely divided, disseminated iron sulphide and to much partly decomposed plant matter. An acid and toxic environment is indicated by the nature of the plant debris, the presence of sulphides, and the restriction of the scanty fauna to a few generally depauperate molluscs, linguloid and discinid brachiopods... conodonts, and planktonic organisms. The plants may represent sea weeds...The conditions suggest stagnation not unlike that of the coal swamps, and quiet undisturbed sedimentation of a humous muck. Extremely shallow water, with sunlight promoting abundant plant growth and aiding in partial decay, with too little depth for circulation and effective wave or tidal agitation, seem to offer the environment required."

It has been alternately suggested that the Heebner-type depositional conditions may have been caused by the peculiar interplay of enclosure and lack of circulation as that reported in the present-day Black Sea. Accordingly, this hypothesis necessitates considerable up and down movements of the sea floor, all through Late Paleozoic time, creating depositional environments which run the gamut from "normal" marine limestones to nonmarine sandstones, all of which must be repeated over and over again. Yet the depositional province for all of these Late Paleozoic sediments is that of a relatively stable

cratonic platform. The changes in conditions of both sedimentation and environment must surely have been accomplished without any great change of relative sea level.

A second unanswered problem that poises difficulty, but about which very little can be said, is how can we explain the production mechanism responsible for the predominance of fine mud in the Leavenworth Limestone? However, this problem is not unique to the Leavenworth, since no satisfactory explanation for the vast accumulation of lime mud present in all the Paleozoic Systems has even been put forward. Still the problem remains with us! Studies in the Recent (lucidly outlined by Purdy, 1963b, pp. 485-492) have indicated that both algal disintegration products (in the form of aragonite needles) and the disintegration of skeletal debris both aid appreciably in the formation of lime mud. But alas, the vast amount of lime mud that was present in the Paleozoic Seas, and in particular the Leavenworth Sea, cannot be explained by this mechanism alone. For, to decipher what this process was in the Paleozoic when we are totally unable to explain the formation of the majority of Recent lime muds, with all our available and readily measurable chemical and physical data on hand, is indeed presumptuous. Accordingly, the only logical conclusion that one can accept is that there must be some process, as yet unknown to us, that is playing the dominant role in lime mud production.

A third problem, which almost defies rational imagination, is the operating mechanism which causes a unit like the Leavenworth Limestone to be deposited so uniformly over such vast distances, and

to be preserved over equally extensive areas. Some discussion of this problem has been given in the section on cyclothems, but the basic contention as to the actual mechanism remains largely unanswered. In order to explain a depositional province of this sort, one might make analogy with a large bathtub in which the drain (wherever that may be) is periodically opened or closed, water added or clastics dumped in. In this model seemingly all processes are accomplished within an instant of geologic time, and all are continually repeated over and over with but few modifications of the original theme. Still a satisfactory and meaningful explanation eludes us.

Moore (1962, p. 99) in a concluding statement on Late Paleozoic cyclic problems noted that:

"...great advances surely have been made during the last two or three decades towards an understanding of the conditions of sedimentation and historical geology that are recorded by the Pennsylvanian and Permian cyclothems in the northern Midcontinent Region. At the same time, it is evident that as much or more remains to be learned before comprehension of geologists may be considered to be adequate."

#### Attempted Environmental Reconstruction

Detailed conclusions concerning the postulated depositional and environmental setting of the Leavenworth Limestone will not be attempted in this report. However, certain facts, which can be corroborated by the data presented throughout, allows us to make reasonable assumptions and educated speculations as to what the Leavenworth depositional environment may have been like in a general way.

The Leavenworth is a relatively homogeneous carbonate unit throughout its extent, and as such, the environmental regimen must

have been fairly uniform across most of the depositional basin. Point-count analysis has shown that the Leavenworth cannot be considered an abundantly fossiliferous unit. The lack of organism exploitation can be attributed to the fact that as a predominantly lime mud the unit did not offer a suitable substrate on which most benthonic organisms can either thrive or reproduce. It has been shown that a substrate of this type is characterized by poor sediment interstitial circulation resulting in the accumulation of toxic decomposition products and/or depletion in available oxygen. As an inevitable end-result this would produce a smothering effect on most benthonic organisms, and thus restrict their development and potential exploitation of the habitat. The nature of such a substrate would be more conducive to infaunal elements. The abundantly churned and burrowed nature of the Leavenworth and the presence of burrows containing fecal pellets and scolecodonts, suggests an abundant infaunal element consisting predominantly of worms.

The presence of algae, of one or more of the major groups, in samples from almost every outcrop locality suggests that the depositional environment occurred within the limits of the photic zone, since all algae are dependent on ample sunlight to accomplish photosynthesis. The precise bathymetry of the Leavenworth cannot be determined on this basis because the maximum depth of the photic zone can vary appreciably depending on water turbidity.

The abundance of the smaller, concentric, coated-grains of the osagid-type suggests that there was at least a modicum of bottom current agitation which produced the concentric growth-form of this

type of coated-grain. The abundance of the blue-green alga Girvanella and various encrusting foraminifers within the coated-grain would further tend to suggest relatively shallow water depths for this environment. The larger, irregular, more complex type of coated-grain, so common at both ends of the outcrop belt, shows thick concentric "algal" laminae, preferential laminae growth, and laminae truncation. These features suggest growth and development in somewhat shallower waters than the bulk of the Leavenworth--closer to shoreline where wave and bottom current action play an increasingly active role.

The occurrence and restriction of the mudstone facies to the area of southwestern Iowa suggests an interplay of a distinctive set of local environmental conditions. It is significant that in this region over-all organism distribution is greatly diminished and modified. For example, the bryozoan and foraminiferal components show a pronounced increase in encrusting types, yet no evidence of their host has been observed. It can perhaps be suggested, that this area supported a luxuriant growth of marine grasses of which encrusting organisms flourished and formed the dominant faunal element. Unfortunately, the grasses have not left their imprint in the geologic record.

The absence of any physical evidence, i.e., corrosion zones, lithoclasts, or distinctive petrological criteria, which would suggest subaerial exposure of the Leavenworth unit during or immediately following deposition is indeed noteworthy. It is altogether possible that the Leavenworth was never exposed above wave base, and that the

depositional conditions for the overlying Heebner Shale were imposed over a vast region completely and geologically instantaneously, with no major change in water depth relationships.

It is hoped that once studies now in progress on other units of the Oread Megacyclothem (Toronto Limestone, Heebner Shale) are completed it will be possible to gain new insight into the environmental and depositional role of these units, both as lateral and vertical sequences of events, which will ultimately aid in determining the role of the megacyclothem as a geological entity.

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APPENDIX I

INSOLUBLE RESIDUE DESCRIPTIONS (COARSE FRACTION)

Locality	Description	Percent
29	Agglutinated Foraminifera (65%): <u>Minammodytes</u> (very abundant), <u>Textularia</u> (rare), <u>Bigenerina</u> (abundant), <u>Hyperammina</u> (very abundant), <u>Ammovertella</u> (common), <u>Thurammina?</u> (rare); pyrite (33%) occurring as modules of subhedral crystals and as replaced sponge spicules; beekite fragments (2%); a few pelletal fragments and some silicified sponge spicules.	.7
28	Agglutinated Foraminifera (40%): <u>Minammodytes</u> (very abundant), <u>Textularia</u> (very rare), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (rare); pyrite (23%) occurring as nodules of subhedral crystals and as replaced sponge spicules; beekite fragments (2%); silt-size clastic quartz (30%); pellets and fragments (5%); some silicified sponge spicules; scolecodonts, (rare); conodonts: <u>Streptognathodus</u> (rare), <u>Hindeodella</u> (rare), <u>Spathognathodus</u> (very rare); and dermal denticles (rare).	.5

Locality	Description	Percent
27-2 (Upper)	Agglutinated Foraminifera (22%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (very abundant), <u>Ammovertella</u> (rare); pyrite (15%) mainly as replaced sponge spicules; silty argillaceous material (60%); beekite fragments (2%); few silicified sponge spicules; conodonts: <u>Streptognathodus</u> (very rare); <u>Hindeodella</u> (very rare).	.8
27-1 (Lower)	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (common), <u>Hyperammina</u> (very abundant), <u>Ammovertella</u> (rare), <u>Reophax</u> (very rare); pyrite (25%) mainly replacing sponge spicules; chert (30%) smooth to tripolitic textured; iron-stained argillaceous material (15%); beekite fragments (5%); few pelletal fragments; conodonts: <u>Streptognathodus</u> (rare); abundant silicified and pyritized sponge spicules.	1.1
26	Agglutinated Foraminifera (5%): <u>Minammodytes</u> (rare), <u>Textularia</u> (abundant), <u>Bigenerina</u> (very rare), <u>Hyperammina</u> (common), <u>Ammobaculites</u> (rare); gray-brown silty argillaceous material (93%); beekite fragments (2%); conodonts: <u>Hindeodella</u> (very rare), <u>Cavusgnathus</u> (very rare), <u>Prioniodina</u> (very rare); fish teeth and scolecodonts (very rare).	.8

Locality	Description	Percent
25	Agglutinated Foraminifera (35%): <u>Minammodytes</u> (very abundant), <u>Textularia</u> (very abundant), <u>Ammobaculites</u> (very rare), <u>Ammovertella</u> (rare), <u>Hyperammina</u> (rare); iron-stained argillaceous material (25%); silt-size clastic quartz (20%); beekite fragments (20%) conodonts: <u>Cavusgnathus</u> (very rare), <u>Hindeodella</u> (very rare); fish teeth (very rare).	.4
24 A	Agglutinated Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Hyperammina</u> (common); iron-stained argillaceous material (15%); silt-size clastic quartz (25%); beekite fragments (30%); conodonts: <u>Hindeodella</u> (very rare); fish teeth (very rare).	.5
24	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Hyperammina</u> (rare); few subhedral pyrite grains; silty argillaceous material (20%); silt-size clastic quartz (25%); pellets and fragments (10%); beekite fragments (20%); conodonts: <u>Streptognathodus</u> (very rare), <u>Hindeodella</u> (very rare); fish teeth (very rare); scolecodonts (rare).	.2

Locality	Description	Percent
23-2	Agglutinated Foraminifera (15%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (rare), <u>Bigenerina</u> (very rare), <u>Hyperammina</u> (rare), <u>Ammovertella</u> (rare); silty argillaceous material (70%); pellets and fragments (15%); scolecodonts (very rare).	2.5
23-1	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (rare), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (abundant), <u>Thurammina</u> (very rare), <u>Ammovertella</u> (rare); pyrite (5%) replacing fossil fragments; sphalerite (10%) replacing fossil fragments; gray silty argillaceous material (35%); pellets (25%); conodonts: <u>Spathognathodus</u> (rare); scolecodonts (rare); silicified sponge spicules (abundant).	.8
22	Agglutinated Foraminifera (5%): <u>Minammodytes</u> (rare), <u>Textularia</u> (very rare), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (rare); pyrite (5%) as subhedral crystals; gray silty argillaceous material (90%); conodonts: <u>Streptognathodus</u> (rare), <u>Spathognathodus</u> (rare); scolecodonts (rare).	1.7
21	Agglutinated Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Bigenerina</u> (common), <u>Hyperammina</u> (abundant), <u>Ammobaculites</u> (very rare),	

Locality	Description	Percent
	<p><u>Ammovertella</u> (rare), <u>Thuramina?</u> (very rare); pyrite (15%) mainly as lath-shaped subhedral crystals; iron-stained argillaceous material (5%); silt-size clastic quartz (25%); sphalerite fragments (5%); pellets and fragments (20%); few beekite fragments; conodonts: <u>Hindeodella</u> (rare), <u>Streptognathodus</u> (very rare); fish teeth (very rare); scolecodonts (common); silicified sponge spicules (common).</p>	.5
20	<p>Agglutinated Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Bigenerina</u> (rare), <u>Hyperamina</u> (very abundant), <u>Ammovertella</u> (rare), <u>Psammosphaera?</u> (very rare); pyrite (10%) mainly replacing fossils; silt-size clastic quartz (40%); sphalerite (5%); pellets and fragments (10%); beekite fragments (5%); conodonts: <u>Cavusgnathus</u> (very rare), <u>Hindeodella</u> (rare); fish teeth (very rare); scolecodonts (rare).</p>	.6
19	<p>Agglutinated Foraminifera (5%): <u>Minammodytes</u> (rare); <u>Ammovertella</u> (rare), <u>Hyperamina</u> (rare); pyrite (5%) mainly replacing fossils; silty argillaceous material (90%); few beekite fragments; conodonts: <u>Hindeodella</u> (very rare); fish teeth (rare), scolecodonts (rare).</p>	2.4

Locality	Description	Percent
18	Agglutinated Foraminifera (35%): <u>Minammodytes</u> (abundant), <u>Ammovertella</u> (abundant), <u>Hyperammina</u> (abundant), <u>Textularia</u> (rare), <u>Bigenerina</u> (rare); pyrite (15%) mainly replacing fossils; silt-size clastic quartz (35%); pellets and fragments (15%); conodonts; <u>Streptognathodus</u> (rare), <u>Spathognathodus</u> (rare), <u>Hindeodella</u> (rare); fish teeth (rare); scolecodonts (rare).	.4
17	Agglutinated Foraminifera (45%): <u>Minammodytes</u> (very abundant), <u>Hyperammina</u> (very abundant), <u>Bigenerina</u> (abundant); pyrite (10%) mainly replacing fossils; iron-stained argillaceous material (25%); silt-size clastic quartz (20%); conodonts: <u>Hindeodella</u> (rare); fish teeth (rare).	.2
16	Agglutinated Foraminifera (20%): <u>Minammodytes</u> (abundant), <u>Hyperammina</u> (common), <u>Ammovertella</u> (common), <u>Textularia</u> (very rare), <u>Bigenerina</u> (very rare), <u>Psammosphaera</u> (rare), <u>Reophax?</u> (very rare); pyrite (25%) as large nodules and fossil replacements; gray-brown argillaceous material (flakes) (50%); sphalerite (5%); conodonts: <u>Hindeodella</u> (rare), <u>Cavusgnathus</u> (very rare), <u>Streptognathodus</u> (rare), <u>Synprioniodina?</u> (very rare); sponge spicules (common); scolecodonts (very rare).	2.0

Locality	Description	Percent
15A	Agglutinated Foraminifera (50%): <u>Minammodytes</u> (very abundant), <u>Ammovertella</u> (abundant), <u>Textularia</u> (rare), <u>Hyperammina</u> (very rare); pyrite (35%) mainly as fossil replacements; pellets and fragments (15%); conodonts: <u>Streptognathodus</u> (very rare).	.3
15	Agglutinated Foraminifera (50%): <u>Minammodytes</u> (very abundant), <u>Textularia</u> (rare), <u>Ammovertella</u> (rare), <u>Hyperammina</u> (very rare), <u>Thurammina</u> (rare); pyrite (20%) as fossil replacements and nodules; iron-stained argillaceous material (10%); pellets and fragments (20%); conodonts: <u>Hindeodella</u> (rare), <u>Streptognathodus</u> (very rare), <u>Ozarkodina</u> (very rare), <u>Spathognathodus</u> (rare); fish teeth (very rare); scolecodonts (rare).	.1
14	Agglutinated and silicified Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Apterrinella</u> (abundant), <u>Textularia</u> (abundant), <u>Bigenerina</u> (common), <u>Hyperammina</u> (common); pyrite (15%) as fossil replacements and as euhedral cubes; sphalerite (5%); pellets and fragments (50%); conodonts: <u>Streptognathodus</u> (rare), <u>Hindeodella</u> (rare), <u>Cavusgnathus</u> (rare); fish teeth (very rare); scolecodonts (rare).	.2

Locality	Description	Percent
13	Agglutinated Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Textularia</u> (common), <u>Bigenerina</u> (rare); pyrite (10%); sphalerite (15%) mainly replacing fossils; pellets and fragments (15%); gray iron-stained argillaceous material (30%); conodonts: <u>Hindeodella</u> (rare), <u>Spathognathodus</u> (rare), <u>Ozarkodina</u> (very rare).	.2
12	Agglutinated and silicified Foraminifera (67%): <u>Minammodytes</u> (abundant), <u>Apterrinella</u> (very abundant), <u>Ammovertella</u> (rare), <u>Hemigordius</u> (very abundant), <u>Textularia</u> (common), <u>Bigenerina</u> (rare), <u>Hyperammia</u> (rare); pyrite (5%); sphalerite (3%); pellets and fragments (25%).	.2
11	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (abundant), <u>Ammovertella</u> (rare), <u>Textularia</u> (very rare); pyrite (45%) mainly as fossil replacements; silt-size clastic quartz (20%); pellets and fragments (10%); some beekite fragments; conodonts: <u>Hindeodella</u> (rare), <u>Prioniodina?</u> (very rare); fish teeth (very rare); scolecodonts (rare).	.7
10	Agglutinated and silicified Foraminifera (20%): <u>Minammodytes</u> (common), <u>Apterrinella</u> (common),	

Locality	Description	Percent
	<u>Textularia</u> (common), <u>Hemigordius</u> (common), <u>Ammovertella</u> (rare), <u>Hyperammina</u> (rare), <u>Thurammina</u> (very rare); sphalerite (10%) replacing fossils; silty iron-stained argillaceous material (60%); pellets and frag- ments (10%); conodonts: <u>Streptognathodus</u> (rare); scolecodonts (rare).	.6
9 A	Agglutinated and pyritized Foraminifera (30%): <u>Minammodytes</u> (abundant), <u>Hyperammina</u> (rare), <u>Textularia</u> (rare); pyrite (15%) replacing fossils; sphalerite (20%) replacing fossils; silt-size clastic quartz (20%); pellets and fragments (15%); fish teeth (very rare); scolecodonts (rare).	.4
9	Agglutinated Foraminifera (30%): <u>Minammodytes</u> (common), <u>Textularia</u> (rare), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (common), <u>Thurammina</u> (very rare); pyrite (15%); sphalerite (35%) replacing fossils; silt-size clastic quartz (15%); pellets and fragments (5%); conodonts: <u>Hindeodella</u> (very rare), unidentified one (very rare); fish teeth (very rare); scolecodonts (rare).	.1
8.	Agglutinated Foraminifera (10%): <u>Minammodytes</u> (rare), <u>Textularia</u> (rare), <u>Bigenerina</u> (rare),	

Locality	Description	Percent
	<u>Hyperammina</u> (rare); pyrite (5%); sphalerite (10%) replacing fossils; silty iron-stained argillaceous material (70%); pellets and fragments (5%); fish teeth (very rare); dermal denticles (very rare); scolecodonts (rare).	.8
7	Agglutinated and pyritized Foraminifera (45%): <u>Minammodytes</u> (very abundant), <u>Ammovertella</u> (rare), <u>Textularia</u> (rare), <u>Hyperammina</u> (rare), <u>Hemigordius</u> (rare), <u>Thurammina</u> (rare); pyrite (35%) mainly replacing fossils; sphalerite (10%) replacing fossils; pellets and fragments (10%); conodonts: <u>Hindeodella</u> (very rare); <u>Idiognathodus?</u> (very rare); scolecodonts (very rare).	.3
6	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (very abundant), <u>Hyperammina</u> (common), <u>Textularia</u> (rare), <u>Thurammina</u> (very rare); pyrite (15%); sphalerite (5%); pellets and fragments (15%); iron-stained argillaceous material (40%); conodonts; <u>Hindeodella</u> (rare), <u>Spathognathodus</u> (very rare).	.3
5	Agglutinated Foraminifera (25%): <u>Minammodytes</u> (very abundant), <u>Textularia</u> (rare), <u>Bigenerina</u> (rare), <u>Hyperammina</u> (common); pyrite (5%); pellets	

Locality	Description	Percent
	and fragments (5%); iron-stained argillaceous material (65%); conodonts; <u>Hindeodella</u> (very rare), <u>Streptognathodus</u> (rare); scolecodonts (very rare).	.2
4	Agglutinated Foraminifera (5%): <u>Minammodytes</u> (rare), <u>Textularia</u> (very rare), <u>Hyperammina</u> (common), <u>Ammovertella</u> (rare), <u>Thurammina</u> (rare), <u>Psammosphaera</u> (rare); pyrite (5%); silty iron-stained argillaceous material (90%); conodonts: <u>Cavusgnathus</u> (very rare); <u>Hindeodella</u> (very rare); scolecodonts (very rare).	2.3
3	Agglutinated Foraminifera (60%): <u>Minammodytes</u> (very abundant), <u>Hyperammina</u> (abundant), <u>Ammovertella</u> (very abundant), <u>Textularia</u> (rare), <u>Thurammina</u> (very rare); pyrite (35%) mainly replacing fossils; pellets and fragments (5%); scolecodonts (very rare).	.4
2	Agglutinated Foraminifera (2%): <u>Minammodytes</u> (common), <u>Hyperammina</u> (very rare), <u>Ammovertella</u> (abundant); silty iron-stained argillaceous material (98%).	5.0
1	Agglutinated Foraminifera (5%): <u>Minammodytes</u> (very abundant), <u>Thurammina</u> (very rare),	

Locality	Description	Percent
	<u>Hyperammina</u> (rare), <u>Ammovertella</u> (common); gray silty argillaceous material (95%); trace of pyrite.	1.0

Scale of microfossil abundance as follows:

Very rare	= 1	specimen
Rare	= 2-7	specimens
Common	= 8-15	specimens
Abundant	= 16-25	specimens
Very abundant	= +26	specimens

SHALE DESCRIPTIONS

Locality	Description
27	Light gray, slightly iron-stained calcareous shale, containing abundant fossil debris. Microfauna: foraminifers - <u>Tetrataxis</u> (very abundant), <u>Endothyra</u> (rare), <u>Endothyranella</u> (rare); crinoidal debris (very abundant); bryozoans (abundant); ephelic brachiopods (common) - <u>Rhipodomella?</u> , <u>Neospirifer?</u> , and <u>Crurithyris</u> ; brachiopod spines (abundant); echinoid spines (common); ostracods: <u>Amphissites</u> (rare); conodonts: <u>Streptognathodus</u> (very rare).
23	Light gray, slightly iron-stained fossiliferous calcareous shale, with minute black iron nodules. Megafauna: lophophyllid-type coral (very rare); Brachiopods: <u>Chonetina</u> sp. cf. <u>C. flemingi</u> (Norwood and Pratten) (very rare), and <u>Composita</u> sp. (very rare). Microfauna: foraminifers - fusulinids (very abundant); <u>Tetrataxis</u> (very abundant), <u>Hyperammina</u> (rare), <u>Cornuspira</u> (rare); crinoidal debris (abundant); ephelic brachiopods (rare) - <u>Cancrinella</u> , <u>Chonetina</u> , <u>Neospirifer</u> ; holothurian sclerites (common) - wheels ( <u>Protocaudina</u> ) and discs or plates ( <u>Eocaudina</u> ); bryozoans (abundant); echinoid spines (abundant); ostracods (common) - <u>Bairdia</u> and <u>Amphissites</u> .

SALEM SCHOOL LIMESTONE

Salem School Limestone, Young County, Texas; exposure at Herron Bend along the north side of the Brazos River, 1/2 mile south-east of Salem School, southeastern Young County. Limestone exposure occurs as one prominent bed ranging in thickness from 10 inches to 1 foot 3 inches. Unit jointed, hard, dense, and breaks with a conchoidal fracture. Surface of unit weathered to a rust-stained color; fresh surface brownish to bluish gray. Weathered surface of limestone contains numerous fossils: Ottonosia-like coated-grains, crinoid columnals, brachiopod fragments, small gastropods, and echinoid spines. Interior contains scattered Composita, and Derbyia with relatively abundant Marginifera. Burrows noted throughout; these were filled either with pyrite or fine-grained mud and pyrite. Base of limestone undulating and irregular; underlain by gray-green marine shale containing crinoid columnals and productoid brachiopods. Shale grades downward into underlying massive channel sandstone containing fragments of wood. Overlying the Salem School Limestone is approximately 15 feet of black, hard, fissile shale containing interbedded thin layers of gypsum. Actual contact between upper limestone and lowermost shale not seen due to poor exposure.

Insoluble Residue:

Locality	Description	Percent
SS	Agglutinated Foraminifera (40%): <u>Minammodytes</u> (very abundant), <u>Hyperammina</u> (very abundant), <u>Textularia</u> (common),	

Locality	Description	Percent
	<p><u>Bigenerina</u> (abundant); <u>Ammodiscus</u> (common); pyritized <u>Hemigordius</u> (rare); conodonts: <u>Streptognathodus</u> (very rare), <u>Ozarkodina</u> (very rare), <u>Hindeodella</u> (very rare); pyrite (25%); clastic silt-sized subrounded quartz grains (30%); iron-stained argillaceous material (5%).</p>	.23

APPENDIX II - CHEMICAL DATA

Versenate Analysis: Percent Weight (Titrimetric)

Locality	Calcium	Magnesium	Dolomite	Calcite
29	34.0	2.0	15.0	76.9
	34.0	1.9	14.0	77.1
28	34.4	2.2	16.0	76.9
	34.3	2.2	17.0	76.8
27 U	28.7	2.1	16.0	62.6
	28.5	2.1	16.0	62.5
27 L	35.1	0.8	6.3	84.3
	35.2	0.9	6.5	84.2
26	28.1	2.5	19.0	59.9
	28.0	2.5	19.0	59.8
25	36.4	1.1	8.3	86.3
	36.4	1.1	8.4	86.4
24 A	36.8	0.8	6.0	88.5
	36.7	0.8	5.9	88.5
24	36.6	1.0	7.8	87.2
	36.6	1.0	7.6	87.3
23	35.2	1.2	16.9	82.9
	35.2	1.3	16.8	82.8
22	26.0	3.2	24.0	51.8
	25.9	3.2	25.0	51.5
21	35.7	1.3	9.5	84.0
	35.7	1.2	9.1	84.2
20	34.3	1.8	14.0	77.8
	34.2	1.9	14.0	78.0
19	33.1	1.2	8.9	77.6
	32.9	1.2	9.4	77.3
18	33.3	2.0	15.0	74.8
	33.3	2.1	16.0	74.6

Locality	Calcium	Magnesium	Dolomite	Calcite
17	37.0	0.8	5.7	89.4
	37.1	0.8	6.0	89.2
16	35.2	1.1	8.6	83.3
	35.3	1.2	9.1	82.1
15 A	35.5	1.6	12.0	82.2
	35.5	1.6	12.0	82.0
15	35.5	1.1	8.3	84.2
	35.6	1.1	8.5	84.1
14	35.4	1.2	9.5	83.2
	35.4	1.2	9.3	83.4
13	34.7	1.5	11.0	80.7
	34.8	1.4	11.0	80.9
12	35.6	2.5	19.0	78.9
	35.7	2.4	18.0	79.1
11	34.1	2.1	16.0	76.6
	34.1	2.0	15.0	76.8
10	35.5	2.3	17.0	79.3
	35.6	2.4	18.0	79.1
9 A	34.5	2.2	17.0	77.3
	34.7	2.3	18.0	77.1
9	34.7	2.2	17.0	77.4
	34.7	2.3	18.0	77.1
8	35.0	2.1	16.0	78.6
	35.0	2.1	16.0	78.8
7	35.3	1.4	10.0	82.4
	35.3	1.2	9.1	83.2
6	33.2	2.4	18.0	73.2
	33.3	2.3	18.0	73.4
5	36.0	0.9	6.5	86.5
	36.1	0.9	6.7	86.4
4	34.9	1.0	7.7	82.9
	34.8	1.1	8.0	82.7

Locality	Calcium	Magnesium	Dolomite	Calcite
3	34.9	1.1	8.4	82.5
	34.8	1.1	8.0	82.7
2	34.0	1.3	10.0	79.5
	34.1	1.4	10.0	79.3
1	33.3	1.0	7.2	79.1
	33.2	1.1	7.6	78.9

Salem School Limestone:

SS	34.0	1.7	13.0	77.9
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% Iron	% Zinc	% Strontium	% Sulfur	% Phosphorous
L-1 (1.68)	L-6 (0.056)	L-11 (0.150)	L-16 (2.5)	L-1 (0.44)
L-26 (1.66)	L-13 (0.027)	L-22 (0.134)	L-14 (1.0)	L-27U (0.44)
L-4 (1.64)	L-12 (0.015)	L-19 (0.124)	L-19 (0.98)	L-19 (0.41)
L-3 (1.62)	L-11 (0.009)	L-17 (0.120)	L-17A (0.67)	L-3 (0.37)
L-2 (1.58)	L-25 (0.006)	L-9 (0.116)	L-15A (0.65)	L-15A (0.37)
L-15 (1.54)	L-7 (0.005)	L-9A (0.116)	L-28 (0.65)	L-2 (0.29)
L-22 (1.54)	L-23 (0.005)	L-2 (0.112)	L-17 (0.61)	L-4 (0.29)
L-16 (1.39)	L-17A (0.004)	L-10 (0.112)	L-9 (0.42)	L-9A (0.26)
L-9 (1.38)	L-24A (0.004)	L-15A (0.108)	L-27U (0.38)	L-12 (0.26)
L-27U (1.38)	L-8 (0.003)	L-3 (0.098)	L-22 (0.33)	L-14 (0.26)
L-14 (1.31)	L-27U (0.003)	L-15 (0.098)	L-29 (0.33)	L-22 (0.26)
L-9A (1.29)	L-4 (0.002)	L-8 (0.096)	L-1 (0.30)	L-24A (0.26)
L-20 (1.21)	L-9A (0.002)	L-6 (0.082)	L-4 (0.30)	L-6 (0.22)
L-15A (1.18)	L-15A (0.002)	L-12 (0.080)	L-5 (0.30)	L-10 (0.22)
L-8 (1.14)	L-1 (0.001)	L-5 (0.078)	L-11 (0.29)	L-21 (0.22)

Trace Element Analyses: (arranged in order of sample locality abundance)

% Iron	% Zinc	% Strontium	% Sulfur	% Phosphorous
L-17 (1.09)	L-15 (0.001)	L-13 (0.072)	L-15 (0.29)	L-23 (0.22)
L-5 (1.05)	L-21 (0.001)	L-7 (0.062)	L-26 (0.29)	L-24 (0.22)
L-6 (1.05)	L-24 (0.001)	L-17A (0.060)	L-7 (0.28)	L-28 (0.22)
L-19 (1.02)	L-26 (0.001)	L-23 (0.060)	L-24 (0.26)	L-11 (0.18)
L-7 (0.95)		L-11 (0.052)	L-12 (0.25)	L-13 (0.18)
L-10 (0.93)		L-14 (0.052)	L-20 (0.25)	L-17 (0.18)
L-12 (0.91)		L-29 (0.046)	L-21 (0.24)	L-20 (0.18)
L-28 (0.79)		L-4 (0.038)	L-9A (0.22)	L-26 (0.18)
L-11 (0.76)		L-24 (0.038)	L-6 (0.21)	L-17A (0.15)
L-21 (0.76)		L-28 (0.038)	L-13 (0.19)	L-7 (0.11)
L-17A (0.75)		L-20 (0.034)	L-23 (0.18)	L-8 (0.11)
L-29 (0.72)		L-25 (0.034)	L-10 (0.17)	L-25 (0.11)
L-23 (0.70)		L-26 (0.034)	L-3 (0.14)	L-29 (0.11)
L-18 (0.58)		L-18 (0.032)	L-24A (0.04)	
L-27L (0.58)		L-27L (0.032)		

Trace Element Analyses: (arranged in order of sample locality abundance)

% Iron	% Zinc	% Strontium	% Sulfur	% Phosphorous
L-13 (0.50)		L-16 (0.030)		
L-24 (0.36)		L-21 (0.026)		
L-24A (0.36)		L-24A (0.026)		
L-25 (0.26)		L-27U (0.020)		

Non-Carbonate Carbon Analysis:

Locality	% Non-Carbonate Carbon	Locality	% Non-Carbonate Carbon
29	0.18	15A	0.21
28	0.13	15	0.22
27U	0.22	14	0.45
27L	0.20	13	0.24
26	0.24	12	0.19
25	0.07	11	0.17
24A	0.06	10	0.39
24	0.18	9A	0.20
23	0.20	9	0.14
22	0.26	8	0.13
21	0.17	7	0.24
20	0.12	6	0.24
19	0.33	5	0.39
18	0.44	4	0.16
17A	0.17	3	0.19
17	0.19	2	0.34
16	0.26	1	0.57

APPENDIX III - MACROFAUNAL IDENTIFICATIONS

Locality 29

sponges:

Coelocladia? sp.  
(2 incomplete fragments)

corals:

lophophyllidid-type  
(3 fragments)  
Dibunophyllum sp.  
(1 fragment)

brachiopods:

Meekella sp. cf. M. striatocostata (Cox)  
(1 incomplete specimen)  
Chonetinella sp. cf. C. flemingi (Norwood & Pratten)  
(3 well preserved but incomplete specimens)  
Linoproductus sp.  
(1 incomplete specimen)  
Marginifera sp. cf. M. muricata Dunbar & Condra  
(1 fairly complete specimen)  
Neospirifer sp.  
(3 incomplete specimens)  
Condrathyris sp. cf. C. perplexa (McChesney)  
(3 specimens; 2 incomplete, 1 fairly complete)  
Composita? sp.  
(1 incomplete specimen)

gastropods:

Naticopsis sp.  
(2 specimens; 1 fairly complete, 1 crushed)

trilobites:

Ditomopyge sp. cf. D. olsoni (Williams)  
(3 specimens; 1 cephalon, 1 pygidium, 1 fragment)

Locality 28

sponges:

Coelocladia? sp.  
(2 incomplete fragments)

brachiopods:

Derbyia sp.  
(1 incomplete specimen)

Enteletes sp. cf. E. hemiplicatus (Hall)  
(1 fairly complete well preserved specimen)  
Linoproductus sp.  
(2 incomplete specimens)  
Neospirifer sp.  
(5 incomplete specimens)  
Composita sp.  
(4 incomplete specimens)

gastropods:  
bellerophontid-type  
(1 poorly preserved specimen)  
Naticopsis sp.  
(2 fragments)

trilobites:  
Ditomopyge sp. cf. D. olsoni (Williams)  
(1 incomplete cephalon)

Locality 27  
(Upper Limestone)

brachiopods:  
Neospirifer sp.  
(1 fairly complete specimen)  
Composita sp.  
(3 incomplete specimens)

(Lower Limestone)

corals:  
lophophyllidid-type  
(1 incomplete specimen)

brachiopods:  
Meekella sp. cf. M. striatocostata (Cox)  
(8 incomplete specimens)  
Linoproductus sp.  
(1 fragment)  
Cancrinella sp. cf. C. boonensis (Swallow)  
(1 incomplete specimen)  
Neospirifer sp.  
(3 incomplete specimens)  
Cond Rathyris sp. cf. C. perplexa (McChesney)  
(4 fairly complete specimens)  
Composita sp. cf. C. subtilita (Hall)  
(5 specimens; 1 fairly complete, 4 incomplete)

trilobites:  
Ditomopyge? sp.  
(1 fragment of a cephalon?)

Locality 25

corals:

lophophyllidid-type  
(1 incomplete specimen)

brachiopods:

Derbyia sp.  
(4 fragments)  
Neochonetes sp.  
(12 incomplete specimens)  
Linoproductus? sp.  
(3 fragments)  
Cancrinella? sp.  
(1 incomplete specimen)  
Composita? sp.  
(1 fragment)

echinoid remains:

1 plate and 1 spine

Locality 24-A

sponges:

Coelocladia? sp.  
(9 fragments)

corals:

lophophyllidid-type  
(1 incomplete specimen)

bryozoa:

rhomboporid-type  
(14 fragments)

brachiopods:

Derbyia sp. cf. D. crassa (Meek & Hayden)  
(10 specimens; 1 fairly complete, 9 fragments)  
Meekella sp. cf. M. striatocostata (Cox)  
(1 fairly complete but crushed specimen)  
Neochonetes sp. cf. N. granulifer (Owen)  
(75 fairly complete specimens)  
Chonetinella? sp.  
(2 incomplete specimens)  
Echinoconchus sp. cf. E. moorei (Dunbar & Condra)  
(3 incomplete specimens)  
Linoproductus sp. cf. L. prattenianus (Norwood & Pratten)  
(9 specimens; 7 fairly complete and 2 fragments)  
Dictyoclostus? sp.  
(2 fragments)

Marginifera? sp.

(1 incomplete specimen)

Neospirifer sp.

(20 incomplete specimens)

Crurithyris sp. cf. C. expansa (Dunbar & Condra)

(2 fairly complete specimens)

Composita sp. cf. C. subtilita (Hall)

(10 specimens; 2 fairly complete, 8 incomplete)

gastropods:

bellerophontid-type

(3 poorly preserved incomplete specimens)

unidentifiable

(2 poorly preserved incomplete specimens)

pelecypods:

unidentified mytilacid-type

(1 incomplete specimen)

unidentifiable

(1 incomplete poorly preserved specimen)

Wilkingia sp.

(1 incomplete specimen)

cephalopods:

nautiloid-type probably Pseudorthoceras sp.

(1 incomplete specimen)

echinoid remains:

2 plates and 1 spine

Locality 24

brachiopods:

Linoproductus sp. cf. L. prattenianus (Norwood & Pratten)

(1 incomplete specimen)

Locality 23

(Upper Limestone)

brachiopods:

Neochonetes? sp.

(1 poorly preserved fragment)

(Lower Limestone)

pelecypods:

Unidentifiable

(1 incomplete specimen)

Locality 22

brachiopods:

- inarticulate-type  
(1 incomplete specimen)
- Derbyia sp.  
(2 fragments)

Locality 21

brachiopods:

- Derbyia sp.  
(2 fragments)
- Neochonetes? sp.  
(2 incomplete specimens)
- Marginifera sp. cf. M. splendens (Norwood & Pratten)  
(5 fairly complete specimens)
- unidentified productid probably marginiferid-type  
(14 fairly complete specimens)
- Wellerella sp.  
(mold of 1 valve)
- Neospirifer? sp.  
(1 fragment)
- Composita sp. cf. C. subtilita (Hall)  
(5 specimens; 2 fairly complete, 3 fragments)

gastropods:

- Naticopsis? sp.  
(1 incomplete specimen)

pelecypods:

- Wilkingia sp.  
(1 incomplete specimen)

Locality 20

brachiopods:

- Neochonetes sp. cf. N. granulifer (Owen)  
(7 fairly complete specimens)
- Linoproductus sp.  
(3 specimens; 1 incomplete, 2 fragments)
- Marginifera sp. cf. M. splendens (Norwood & Pratten)  
(9 specimens; 6 fairly complete, 3 fragments)
- unidentified productoid probably marginiferid-type  
(10 incomplete specimens)
- Wellerella sp.  
(2 incomplete specimens)
- Condrathyris sp. cf. C. perplexa (McChesney)  
(4 specimens; 3 fairly complete, 1 fragment)
- Composita? sp.  
(1 poorly preserved incomplete specimen)

gastropods:

- Naticopsis? sp.  
(5 incomplete and crushed specimens)
- unidentifiable  
(1 incomplete specimen)

pelecypods:

- Wilkingia sp. cf. W. terminale (Hall)  
(2 specimens; 1 fairly complete, 1 poorly preserved)

trilobites:

- Ditomopyge sp. cf. D. olsoni (Williams)  
(10 fairly complete specimens; 2 cephalons,  
8 pygidia)

bone fragments:

- encrusted fish? bone  
(1 fragment)

Locality 18

brachiopods:

- Derbyia sp.  
(9 specimens; 4 incomplete, 5 fragments)
- Neochonetes sp.  
(4 incomplete specimens)
- Chonetinella sp. cf. C. flemingi (Norwood & Pratten)  
(6 specimens; 5 fairly complete, 1 fragment)
- Echinoconchus sp.  
(1 incomplete specimen)
- Cancrinella sp.  
(1 incomplete specimen)
- Dictyoclostus? sp.  
(2 incomplete specimens)
- Marginifera sp. cf. M. muricata (Dunbar & Condra)  
(1 fairly complete specimen, 2 fragments)
- Neospirifer sp.  
(1 fragment)
- Composita? sp.  
(1 incomplete specimen)

gastropods:

- Naticopsis sp. cf. N. scintilla (Girty)  
(18 incomplete specimens)
- Palaeostylus (Pseudozygopleura) sp.  
(2 incomplete specimens)

pelecypods:

- Wilkingia sp. cf. W. terminale (Hall)  
(3 incomplete specimens)
- unidentified  
(1 fairly complete specimen)

Locality 16

corals:

lophophyllidid-type  
(1 incomplete specimen)

brachiopods:

Derbyia sp.  
(1 incomplete specimen)  
Echinoconchus sp.  
(1 fragment)  
Linoproductus sp.  
(1 incomplete specimen)  
Marginifera sp. cf. M. muricata (Dunbar & Condra)  
(2 fairly complete specimens)  
Wellerella sp. cf. W. osagensis (Swallow)  
(1 complete specimen)  
W. sp. cf. W. osagensis var. immatura (Dunbar & Condra)  
(2 complete specimens)  
Condrathyris sp. cf. C. perplexa (McChesney)  
(2 incomplete specimens)  
Composita? sp.  
(1 crushed specimen)

gastropods:

Naticopsis sp. cf. N. scintilla (Girty)  
(17 incomplete specimens)  
bellerophonid-type  
(1 large incomplete specimen)  
Palaeostylus (Pseudozygopleura) sp.  
(3 incomplete and poorly preserved specimens)  
pleurotomarid-type  
(3 incomplete and poorly preserved specimens)

pelecypods:

Wilkingia sp. cf. W. terminale (Hall)  
(8 fairly complete specimens)

Locality 14

corals:

lophophyllidid-type  
(1 incomplete specimen)

bryozoa:

encrusting colonies  
(2 fairly complete specimens)

brachiopods:

- Derbyia sp. cf. D. crassa (Meek & Hayden)  
(10 fairly complete specimens)  
Meekella sp. cf. M. striatosostata (Cox)  
(2 fairly complete specimens)  
Neochonetes sp.  
(7 incomplete specimens)  
Chonetinella sp. cf. C. flemingi (Norwood & Pratten)  
(1 incomplete specimen)  
Cancrinella sp. cf. C. boonensis (Swallow)  
(1 fairly complete specimen)  
Dictyoclostus? sp.  
(1 fragment)  
Marginifera sp.  
(6 incomplete specimens)  
Cond Rathyris sp. cf. C. perplexa (McChesney)  
(1 fairly complete specimen)  
Crurithyris sp. cf. C. expansa (Dunbar & Condra)  
(2 fairly complete specimens)

gastropods:

- Naticopsis? sp.  
(3 incomplete specimens)  
Gosseletina? sp.  
(1 incomplete and poorly preserved specimen)  
Palaeostylus (Pseudozygopleura) sp.  
(7 incomplete and poorly preserved specimens)  
pleurotomarid-type  
(1 incomplete and poorly preserved specimen)  
Goniasma? sp.  
(11 incomplete and poorly preserved specimens)  
Worthenia? sp.  
(1 incomplete specimen)  
Euphemites? sp.  
(1 incomplete and poorly preserved specimen)  
Straparolus (Euomphalus) sp.  
(1 fairly complete specimen)

pelecypods:

- Aviculopecten? sp.  
(3 fragments)

cephalopods:

- unidentifiable ammonoid-type  
(1 poorly preserved specimen)

echinoid remains:

- 1 plate, 3 spines

Locality 12

corals:

lophophyllidid-type  
(1 incomplete specimen)

brachiopods:

Derbyia sp.  
(1 incomplete specimen)  
Meekella? sp.  
(1 fragment)  
Linoproductus sp.  
(2 incomplete specimens)

pelecypods:

unidentified  
(1 fairly complete specimen)

Locality 9-A

brachiopods:

Crurithyris sp.  
(3 incomplete specimens)

Locality 9

corals:

lophyphyllidid-type  
(1 incomplete specimen)

brachiopods:

Neochonetes? sp.  
(2 incomplete specimens)  
Linoproductus sp. cf. L. prattenianus (Norwood &  
Pratten)  
(9 incomplete specimens)  
Neospirifer sp.  
(1 incomplete specimen)

gastropods:

unidentified high-spined form  
(1 poorly preserved specimen)

Locality 8

brachiopods:

Derbyia? sp.  
(1 fragment)  
Neochonetes? sp.  
(6 incomplete specimens)

Composita? sp.  
(2 fragments)

trilobites:

Ditomopyge? sp.  
(1 incomplete pygidium)

Locality 7

brachiopods:

Derbyia sp. cf. D. crassa (Meek & Hayden)  
(6 incomplete specimens)

Neochonetes? sp.  
(1 incomplete specimen)

gastropods:

unidentified  
(1 poorly preserved specimen)

pelecypods:

Wilkingia sp.  
(1 incomplete specimen)

Locality 3

sponges:

Coelocladia? sp.  
(3 incomplete fragments)

brachiopods:

Meekella? sp.  
(1 incomplete specimen)

Chonetinella sp. cf. C. flemingi (Norwood & Pratten)  
(1 incomplete specimen)

Crurithyris? sp.  
(1 incomplete specimen)

gastropods:

Naticopsis? sp.  
(1 fragment)

Locality 1

corals:

lophyphyllidid-type  
(1 fragment)

brachiopods:

Derbyia sp. cf. D. crassa (Meek & Hayden)  
(4 specimens; 2 fairly complete, 2 fragments)

pelecypods:

Wilkingia? sp.

(2 incomplete and poorly preserved specimens)

echinoid remains:

1 spine

APPENDIX IV - PERCENT CLAY MINERALS

Locality	Illite	Mixed-Layer	Kaolinite	Chlorite
29	61	28	--	11
28	60	30	--	10
27 U	44	43	--	13
27 L	57	31	--	12
26	47	39	--	14
25	50	41	--	9
24 A	54	38	--	8
24	60	30	--	10
23	58	24	--	18
22	56	34	--	10
21	47	39	--	14
20	58	21	--	21
18	64	25	--	11
15 A	51	34	--	15
15	57	34	--	9
14	60	20	--	20
13	68	7	--	25
12	62	14	10	14
11	58	30	--	12
10	59	26	10	5
9 A	72	6	12	11
9	65	8	15	12

Locality	Illite	Mixed-Layer	Kaolinite	Chlorite
7	59	12	18	11
5	53	22	25	--
4	49	30	21	--
3	57	19	15	9
2	45	24	31	--
1	51	22	27	--

Insufficient clay recoverable to make determination from Localities 6, 8, 16, 17, and 19.

Salem School Limestone Locality:

SS	25	30	45	--
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APPENDIX V

REGISTER OF LOCALITIES (NORTH TO SOUTH) AND THICKNESSES

Locality	Thickness (feet)
29 SW 1/4 NW 1/4 sec. 7, T. 75 N., R. 29 W., Madison County, Iowa. Exposure on north side of stream bed approximately 150 yards east of north-south trending county road.	1.2
28 NE 1/4 NE 1/4 sec. 1, T. 75 N., R. 30 W., Adair County, Iowa. Exposure in a stream bed of a minor Middle River tributary.	1.1
27 SE 1/4 NE 1/4 sec. 16, T. 75 N., R. 37 W., Cass County, Iowa. Exposure at a rock cut in the Nishnabotna River just outside town of Lewis.	2.7
26 SE 1/4 NE 1/4 sec. 29, T. 12 N., R. 14 E., Cass County, Nebraska. Exposure in Heebner Quarries along Missouri River bluffs and at southernmost end of recent quarrying operations.*	1.5
25 NE 1/4 SE 1/4 sec. 10, T. 10 N., R. 12 E., Cass County, Nebraska. Exposure in old partially abandoned Snyderville Quarries.	1.9
24 SW 1/4 sec. 22, T. 12 N., R. 10 E., Cass County, Nebraska. Exposure along Pawnee Creek.	1.7
24A SW 1/4 NW 1/4 sec. 15, T. 12 N., R. 10 E., Cass County, Nebraska. Exposure in Johansen's Quarry outside town of South Bend.	1.7
23 SW 1/4 NE 1/4 sec. 30, T. 58 N., R. 35 W., Buchanan County, Missouri. Exposure in old abandoned quarry in bluffs above C. B. & O. Railroad tracks.	1.9
22 CSL sec. 22, T. 55 N., R. 37 W., Buchanan County, Missouri. Exposure is floor of old abandoned quarry. ---**	

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\*Exposure collected and described 11/59; by June, 1963 quarrying operations had destroyed exposures.

\*\*Exposed only on quarry floor; impossible to measure entire unit thickness.

Locality	Thickness (feet)
21 NW 1/4 NW 1/4 sec. 22, T. 8 S., T. 22 E., Leavenworth County, Kansas. Exposure in road- cut on State Highway 7; LEAVENWORTH TYPE LOCALITY.	1.9
20 CSL NW 1/4 sec. 8, T. 11 S., R. 21 E., Leavenworth County, Kansas. Exposure in roadcut along State Highway 16, west of town of Tongonoxie.	1.9
19 NW 1/4 sec. 36, T. 12 S., R. 19 E., Douglas County, Kansas. Exposure in town of Lawrence in a roadcut along U. S. Highway 40.	1.4
18 C NW 1/4 sec. 21, T. 12 S., R. 19 E., Douglas County, Kansas. Exposure in roadcut along Kansas Turnpike right outside city of Lawrence.	1.5
17 C sec. 27, T. 14 S., R. 20 E., Douglas County, Kansas. Exposure in roadcut along north-south trending county road outside town of Baldwin.	3.0
16 SW 1/4 SE 1/4 sec. 14, T. 14 S., R. 18 E., Douglas County, Kansas. Exposure in roadcut along east-west trending county road east of a prong of Lone Star Lake.	1.1
15 NW 1/4 NE 1/4 sec. 24, T. 18 S., R. 17 E., Franklin County, Kansas. Exposure in roadcut along U. S. Highway 50 southwest of town of Williamsburg.	.9
15A SW 1/4 NE 1/4 sec. 26, T. 18 S., R. 17 E., Franklin County, Kansas. Exposure in roadcut along north- south trending road along county line.	.9
14 C SE 1/4 sec. 2, T. 22 S., R. 15 E., Coffey County, Kansas. Exposure in quarry 1/4 miles east of the Neosho River.	.9
13 C N 1/2 SW 1/4 sec. 4, T. 23 S., R. 15 E., Coffey County, Kansas. Shallow depth core drilled 300 feet south of east-west trending county road.	.9
12 SW 1/4 SE 1/4 sec. 31, T. 23 S., R. 15 E., Woodson County, Kansas. Exposure consists of blocks of Leavenworth Limestone excavated for a stocktank, on north side of an east-west trending county road.	.9

Locality	Thickness (feet)
11 NE 1/4 SW 1/4 sec. 10, T. 26 S., R. 13 E., Greenwood County, Kansas. Exposure in bank along eastern edge of the flood area of the Toronto Dam and Reservoir.	1.3
10 CSL SW 1/4 sec. 33, T. 26 S., R. 13 E., Greenwood County, Kansas. Exposure along north side of east- west trending county road.	1.2
9A CWL sec. 21, T. 27 S., R. 13 E., Greenwood County, Kansas. Exposure in roadcut on north-south trending county road.	1.4
9 CSL sec. 29, T. 27 S., R. 13 E., Greenwood County, Kansas. Exposure in roadcut on east-west trending county road.	1.3
8 NE 1/4 NE 1/4 sec. 13, T. 29 S., R. 12 E., Elk County, Kansas. Exposure in roadcut on north- south trending county road.	1.5
7 CEL sec. 36, T. 32 S., R. 11 E., Chautauqua County, Kansas. Exposure in roadcut on north-south trending county road.	1.7
6 NE 1/4 NW 1/4 sec. 4, T. 34 S., R. 11 E., Chautauqua County, Kansas. Exposure located 1/4 mile northwest of junction of county road with U. S. Highway 166, west of town of Sedan.	1.6
5 NW 1/4 NE 1/4 sec. 12, T. 35 S., R. 10 E., Chautauqua County, Kansas. Exposure on hill in quarry 1-1/2 miles northeast of town of Elgin.	1.7
4 NE 1/4 NE 1/4 sec. 7, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure along curve on county road three miles due west of State Highway 99.	.9
3 CEL NE 1/4 sec. 29, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure along side of county road 1-1/2 miles northwest of junction with State Highway 99.	.9
2 NW 1/4 NW 1/4 sec. 8, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure along roadside on north- south trending county road just before curving to the west; approximately three miles due west of State Highway 99. This locality is very close to Locality 4.	.9

Locality

Thickness  
(feet)

1 C NW 1/4 sec. 18, T. 27 N., R. 10 E., Osage County,  
Oklahoma. Exposure about one mile west of State  
Highway 99; about 300 feet south of the county road  
and at least 30 feet below the road level in the  
north bank of a small stream gully.

.7

## Plate 1

5p  
Figure 1

Oread section exposed along the Kansas Turnpike at Locality 18, near city of Lawrence, Douglas County, Kansas. From the base to the top the following members are exposed: (1) Lawrence Shale at base, followed by (2) massive Toronto Limestone, overlain by (3) a grass-covered slope and slumped shale sequence of Snyderville, followed by (4) the thin, dark Leavenworth Limestone, above which is exposed (5) the lower black fissile shale member of the Heebner, which in turn is overlain by a covered section of the upper Heebner Shale; hill is capped by (6) the light-colored wavy-bedded Plattsmouth Limestone.

Figure 2

Close-up of a portion of the above section showing one and one-half feet of Leavenworth Limestone overlain by the lower member of the black fissile Heebner Shale. The contact of the Leavenworth Limestone with the overlying Heebner Shale is usually "knife-sharp."



1.



2.

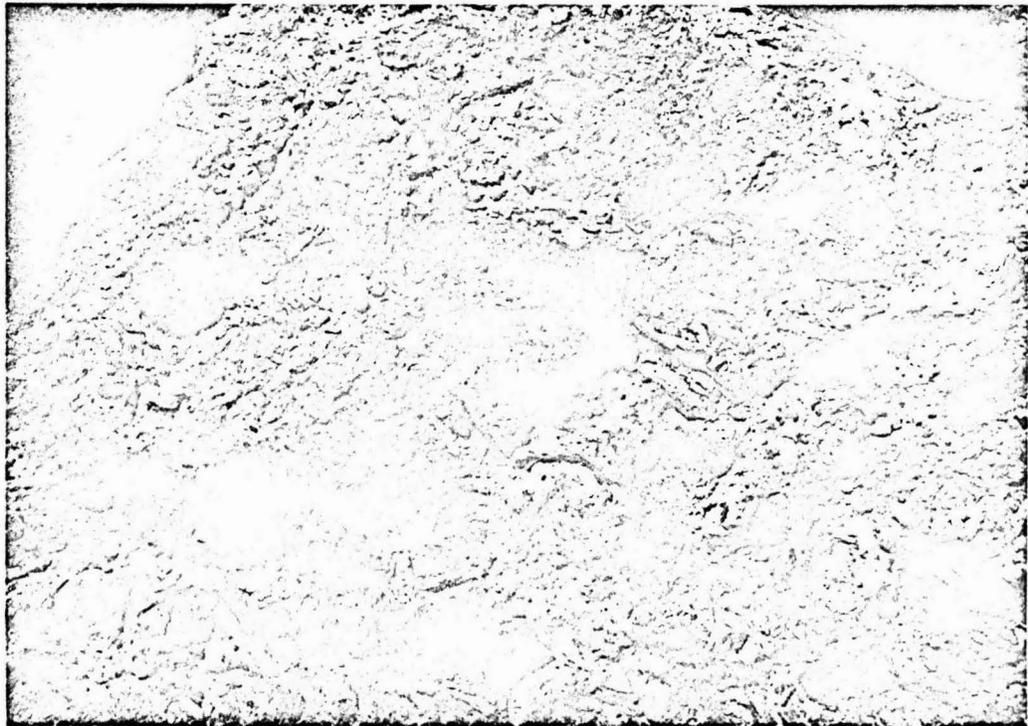
## Plate 2

Figure 1 Oread section exposed in Johansen's Quarry, Locality 24-A, near village of South Bend, Cass County, Nebraska. The Leavenworth Limestone is the thin, discontinuous unit exposed right below the tree line. The Toronto Limestone at this locality is very rubbly, and stained a distinctive red color by the overlying Snyderville Shale.

Figure 2 The underside of a block of Leavenworth Limestone, from the same locality, showing the typical burrowed base of the unit. Much fossil debris, especially chonetoid brachiopods, is "plastered" on the burrows. Length of pencil approximately 5 inches.



1.



2.

Plate 3

Figure 1 Close-up of Leavenworth Limestone, Locality 9-A, Greenwood County, Kansas. At this locality the Leavenworth Limestone is slightly over one foot thick. The broken-off block, in the center of the photograph, shows the Leavenworth's characteristic conchoidal fracture surface. Note the darker-colored, iron-stained weathered zones at the base and top of unit. Some brachiopods (Crurithyris) litter the top surface at this exposure.

Figure 2 The Leavenworth Limestone exposed in the bluffs east of the Missouri River at Locality 23, outside of St. Joseph, Buchanan County, Missouri. At this locality approximately 2 feet of Leavenworth Limestone is exposed as two units, separated by a thin gray-green marine shale carrying an abundant marine microfauna. This intervening shale unit is discontinuous, and only sporadically well developed along the line of outcrop exposed in the river bluffs.



1.



2.

Plate 4

Figures 1-2      Underside of Leavenworth Limestone block at Locality  
14, Coffey County, Kansas, showing a large prominent  
burrow. Figure 2 gives a close-up of the burrow  
showing abundant fossil debris "plastered" onto the  
burrow.



1.



2.

Plate 5

- Figure 1            Transverse thin-section photomicrograph of a worm-burrow at Locality 20, Leavenworth County, Kansas. Note fecal pellets within the burrow, and sparry calcite crystals filling the void space; photo X 16.
- Figure 2            Fecal pellet derived from an insoluble residue of a worm burrow in the Leavenworth Limestone at Locality 16, Douglas County, Kansas; photo X 44.
- Figure 3            Thin-section photomicrograph of a Leavenworth gastropod from Locality 15, Franklin County, Kansas, showing internal sediment and geopetal crystalline calcite filling. Void space within shell filled by blocky sparry calcite crystals; crystal size coarsens towards center of void space; photo X 8.
- Figure 4            Surface of Leavenworth Limestone exposed in a quarry floor at Locality 22, Buchanan County, Missouri. Note jointed and fractured surface of the Leavenworth. Length of sledge approximately 3 feet.



1.



2.



3.



4.

Plate 6

Figure 1

Transverse thin-section of a large complex-type coated-grain found at Locality 1, Osage County, Oklahoma. Note the very irregular shape of the grain and its relatively loose organization. Enclosed within the coated-grain are a number of entrapped algal Eugonophyllum plates (long, narrow, gray, slightly curved fragments, a few of which show the characteristic utricles or "cells"). At the top of the photo is an enmeshed lophophyllidid-type rugose coral. Grain shows preferential coating of the "algal laminae" on the upper surface. This particular coated-grain contains an unusually large amount of entrapped mud and diverse organic debris; photo X 3.



1.

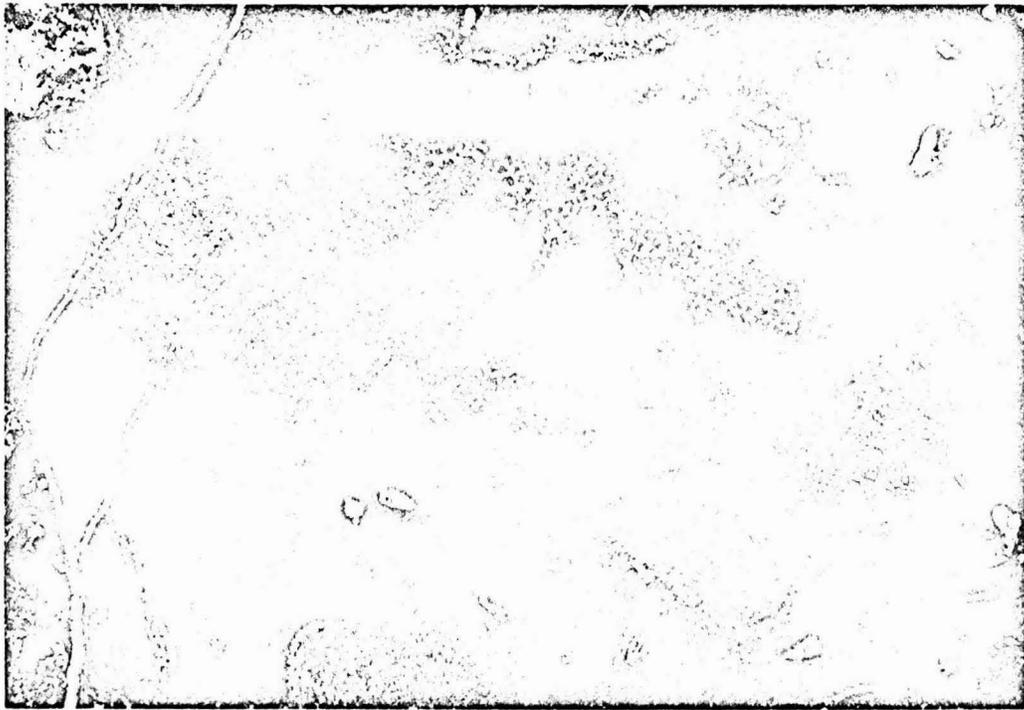
Plate 7

Figure 1      Small, bean-shaped, coated-grains found at Locality 4, Osage County, Oklahoma. These particular coated-grains contain a relatively high percentage of "algal" girvanellid-like tubes. Grain interiors are almost completely recrystallized; photo X 4.

Figure 2      Enlargement of a coated-grain from the same locality showing an included fragment of the dasyclad alga Epimastopora (porous fragment in top-center of grain). Some encrusting Foraminifera is present within this grain, but algaloid material is dominant. Note large areas of grain recrystallization; photo X 16.



1.



2.

Plate 8

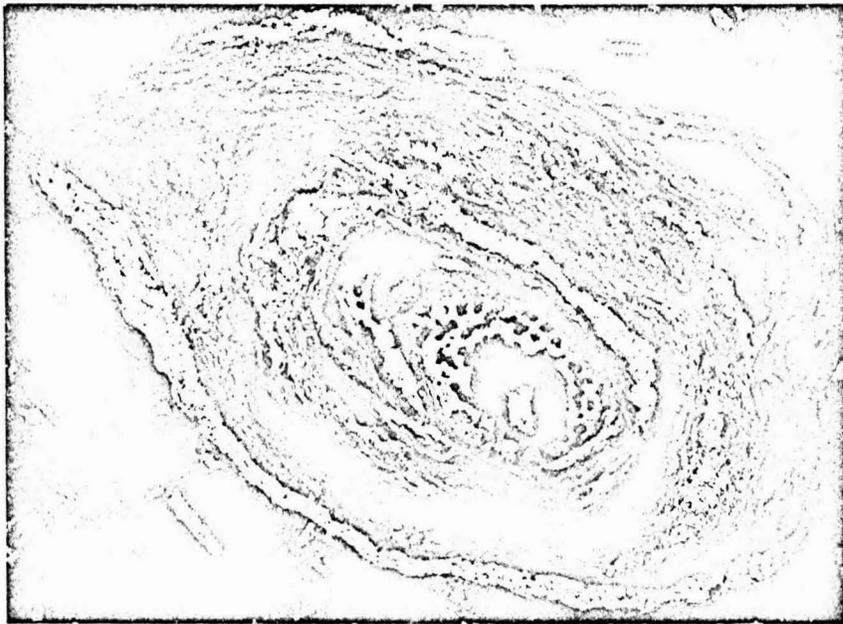
Figure 1 Longitudinal thin-section of a large, complex-type coated-grain found in the Leavenworth Limestone at Locality 28, Adair County, Iowa. Note preferential coating of the "algal laminae," with the outer laminae recrystallized to blocky calcite. The relatively large organism (which looks like a sieve-plate) near the bottom of the grain is a bryozoan; photo X 3-1/2.

Figure 2 Thin-section of a large, complex-type coated-grain from the same locality as above, showing well developed concentric laminae. A sponge serves as a nucleus for this coated-grain; photo X 7.

Figure 3 Longitudinal thin section of a large, complex-type coated-grain found at Locality 29, Madison County, Iowa. The nucleus for this coated-grain is a large, recrystallized, mollusc fragment. This grain is also preferentially coated with "algal laminae"; photo X 9.



1.



2.



3.

Plate 9

- Figure 1            Relatively large coated-grain found in the Leavenworth Limestone at Locality 29, Madison County, Iowa. In this coated-grain the concentric "algal-laminae" are extremely well-developed. The nucleus is a gastropod; photo X 3-1/2.
- Figure 2            Small osagid-type coated grain from Locality 15, Franklin County, Kansas. The nucleus (brachiopod fragment) and the surrounding algaloid growth are almost totally recrystallized. The only organic element that can be differentiated besides the brachiopod fragment, are occasional girvanellid-like tubes; photo X 10.
- Figure 3            Coated-grain found at Locality 11, Greenwood County, Kansas. The nucleus appears to be a bryozoan fragment. Note palaeotextulariid foraminifer at top left side, above coated-grain; photo X 8.
- Figure 4            Typical osagid-type coated-grains found at Locality 15, Franklin County, Kansas. Dark areas within coated-grains delineate concentrations of "algal" girvanellid-like tubes and encrusting foraminifers; photo X 10.



1.



2.



3.



4.

Plate 10

Figure 1

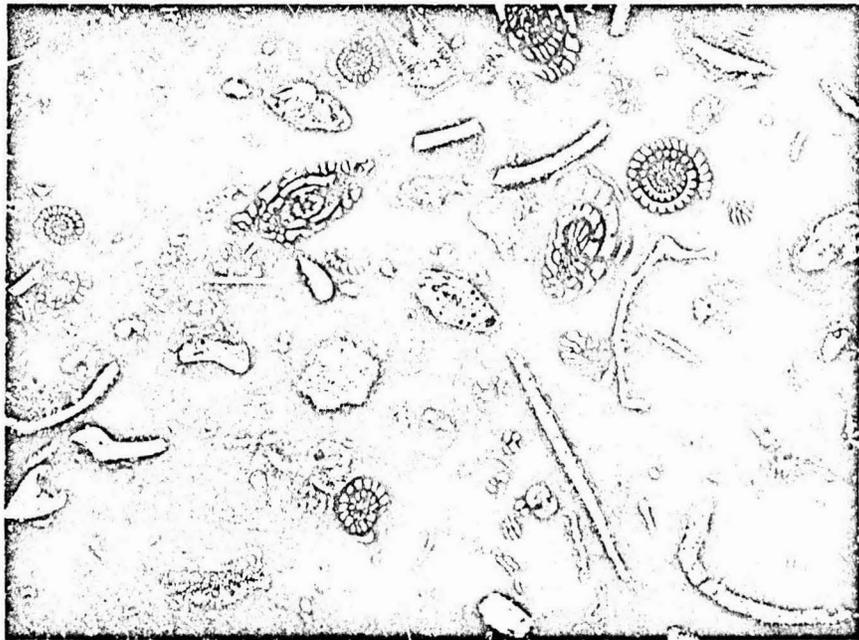
Thin-section photomicrograph (X5) of the Leavenworth Limestone at Locality 12, Woodson County, Kansas. The Leavenworth at this locality is composed of 26.4% skeletal grains, and 73.6% nonskeletal components (based upon point-count analysis). The dark elliptical forms scattered through the thin-section are typical osagid-type coated-grains. The large porous fossil fragment in the upper left corner of the thin-section is a tangential section of the dasyclad alga Epimastopora (the pores are molds of the primary branches).

Figure 2

Thin-section photomicrograph (X8) of the Leavenworth Limestone at Locality 3, Osage County, Oklahoma. The Leavenworth at this locality is composed of 51.3% skeletal grains, and 48.7% nonskeletal components (pellets, mud, and spar). The prominent recrystallized, somewhat triangular-shaped fossil fragment is a staffellid fusulinid.



1.

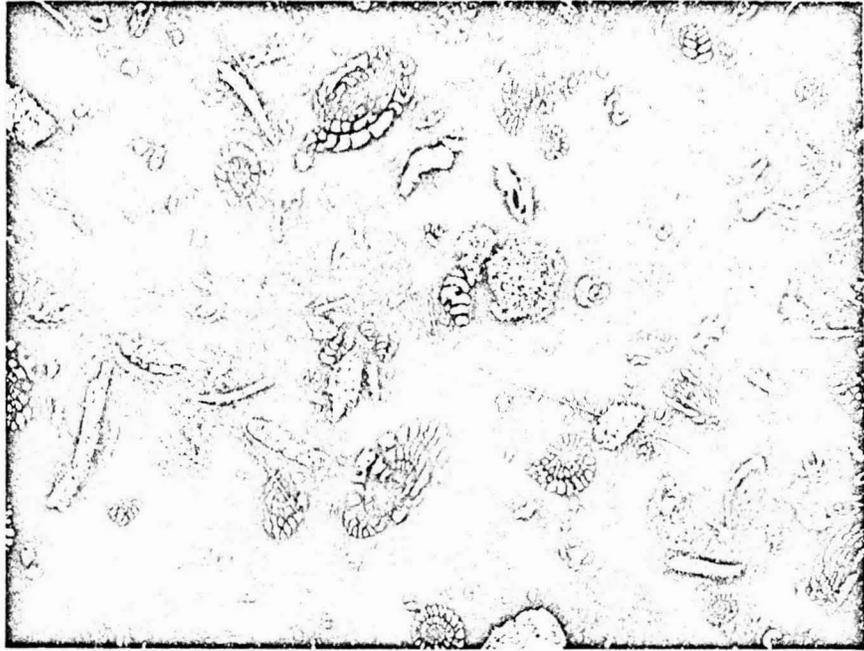


2.

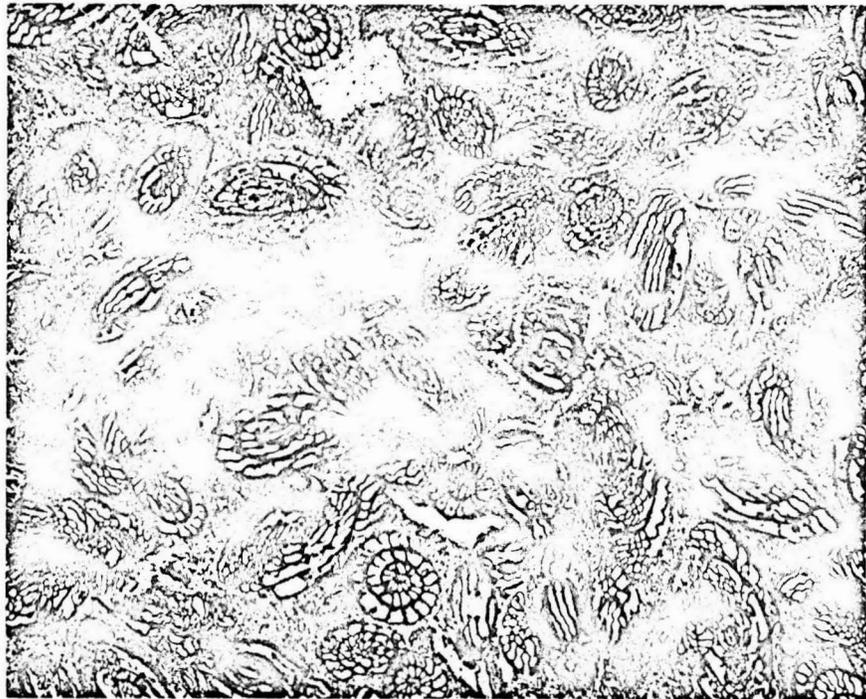
Plate 11

Figure 1 Thin-section photomicrograph (X8) of the Leavenworth Limestone at Locality 4, Osage County, Oklahoma. The Leavenworth at this locality is composed of 23.9% skeletal grains, and 76.1% nonskeletal grains. In the center of the thin-section there are a number of palaeotextulariid foraminifers. The left bottom quarter of the thin-section shows three fenestrate bryozoan stalks ("beads") cut obliquely through the fronds.

Figure 2 Thin-section photomicrograph (X8) of the Leavenworth Limestone at Locality 2, Osage County, Oklahoma. The Leavenworth at this locality is a fusulinid coquina (grainstone), and is composed of 81.4% skeletal grains and 18.6% spar. The skeletal grains are predominantly triticitid fusulinid foraminifers.



1.



2.

Plate 12

Figure 1 Thin-section photomicrograph (X4) of the Leavenworth Limestone from the Heebner Quarry at Plattsmouth; Locality 26, Cass County, Nebraska. The Leavenworth at this locality is composed of only 18.5% skeletal grains, and 81.5% nonskeletal components. Molluscs, especially small turbinate gastropods, are a conspicuous faunal element at this locality.

Figure 2 Thin-section photomicrograph (X8) of the Leavenworth Limestone at Locality 19, Douglas County, Kansas. The Leavenworth at this locality is composed of 19.8% skeletal grains, and 80.2% nonskeletal components. This thin-section shows a relatively large number of fusulinids and one almost totally recrystallized coated-grain, associated with diverse skeletal debris.



1.



2.

Plate 13

SOME REPRESENTATIVE LEAVENWORTH FOSSILS

- Figure 1      Meekella striatocostata (Cox), Locality 14, Coffey County,  
                 Kansas
- 2              Condrathyris perplexa (McChesney), Locality 14, Coffey,  
                 County, Kansas
- 3              Wellerella osagensis var. immatura Dunbar & Condra,  
                 Locality 16, Douglas County, Kansas
- 4              Palaeostylus (Pseudozygopleura) sp., Locality 14, Coffey  
                 County, Kansas
- 5              Goniasma? sp., Locality 14, Coffey County, Kansas
- 6-8           Wilkingia terminale (Hall), Locality 16, Douglas County,  
                 Kansas
- 9              Ammonoid cephalopod, Locality 14, Coffey County, Kansas
- 10             Straparolus (Euomphalus) umbilicatus (Meek & Worthen),  
                 Locality 14, Coffey County, Kansas
- 11-12        Naticopsis sp. cf. N. scintilla Girty, Locality 16,  
                 Douglas County, Kansas
- 13             Fish tooth, Locality 19, Douglas County, Kansas; X 22
- 14             Ozarkodina sp., Locality 22, Buchanan County, Missouri;  
                 X 45
- 15             Spathognathodus sp., Locality 22, Buchanan County,  
                 Missouri; X 45
- 16-17        Hindeodella sp., Locality 17, Douglas County, Kansas;  
                 X 35

- Figure 18      Streptognathodus sp., Locality 23, Buchanan County,  
                 Missouri; X 35
- 19-22      Hyperammina spp.  
19.      Locality 22, Buchanan County, Missouri; X 35  
20.      Locality 10, Greenwood County, Kansas; X 45  
21.      Locality 9, Greenwood County, Kansas; X 35  
22.      Locality 14, Coffey County, Kansas; X 35
- 23      Textularia sp., Locality 14, Coffey County, Kansas; X 45
- 24-25      Hemigordius sp. (silicified and pyritized), both X 45  
24.      Locality 4, Osage County, Oklahoma  
25.      Locality 7, Chautauqua County, Kansas
- 26      Ammovertella sp. Locality 18, Douglas County, Kansas;  
                 X 35
- 27      Fecal pellet, Locality 16, Douglas County, Kansas; X 22
- 28-33      Minammodytes sp., all X 35  
28-30.      Locality 15, Franklin County, Kansas  
31.      Locality 3, Osage County, Oklahoma  
32.      Locality 5, Chautauqua County, Kansas  
33.      Locality 16, Douglas County, Kansas
- 34-35      Apterrinella? sp. (silicified), both X 22  
34.      Locality 14, Coffey County, Kansas  
35.      Locality 10, Greenwood County, Kansas
- 36      Psammosphaera sp., Locality 4, Osage County, Oklahoma;  
                 X 45
- 37-41      Thurammina spp., all from Osage County, Oklahoma  
37.      Locality 4, X 35  
38.      Locality 3, X 45

40. Locality 4, X 35
41. Locality 3, X 45
- 42-45 Representative scolecodonts ("worm-jaws")
42. Locality 10, Greenwood County, Kansas; X 35
43. Locality 14, Coffey County, Kansas; X 35
44. Locality 14, Coffey County, Kansas; X 45
45. Locality 15, Franklin County, Kansas; X 45
- 46 Questionable carbonaceous fragment, Locality 14, Coffey  
County, Kansas; X 35

