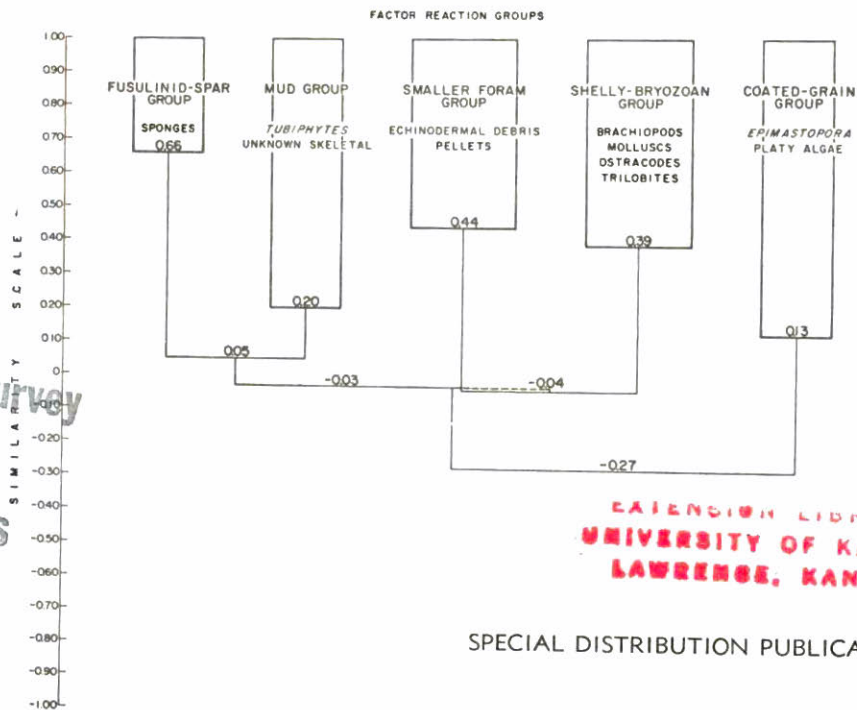


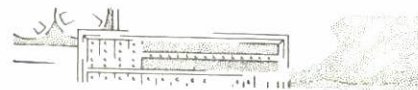
Application of Factor Analysis to a Facies Study of the Leavenworth Limestone (Pennsylvanian-Virgilian) of Kansas and Environs

By
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APPLICATION OF FACTOR ANALYSIS TO A FACIES
STUDY OF THE LEAVENWORTH LIMESTONE (PENNSYLVANIAN- VIRGILIAN)
OF KANSAS AND ENVIRONS

by

Donald F. Toomey

SUMMARY

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

Samples from 32 outcrop localities from southwestern Iowa to northern Oklahoma were subjected to analyses. Point-count analysis was undertaken to quantitatively determine the volumetric abundance of the individual skeletal and nonskeletal grains present within this thin limestone unit. Vector analysis of the point-count data using a highspeed digital computer delineated three geologically meaningful facies: (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 outcrop 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 also studied statistically with the aid of the computer; three biofacies were defined: (1) mobile foram biofacies -- which contains 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 three encrusting foraminiferal genera represent the bulk biofacies characteristics.

The mobile foram biofacies comprises 20 outcrop localities, whereas the fusulinid biofacies is represented at nine localities. Both foraminiferal biofacies are closely related. The encrusting foram biofacies is represented at three localities in southwestern Iowa. Results of the foraminiferal analysis suggest that the biological mechanism responsible for the Leavenworth foraminiferal distribution and abundance are relatively interrelated factors of a highly organized ecosystem.

One advantage in using the statistical approach on the Leavenworth variables was that all 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.

It is believed that the Leavenworth Limestone was deposited in relatively shallow water on a broad, slowly subsiding, carbonate platform. Consideration of all data indicates that the Leavenworth Limestone is a very persistent and laterally homogeneous carbonate unit. It is concluded that this lateral homogeneity results from a coincidence of the outcrop belt with depositional strike.

INTRODUCTION

The Leavenworth Limestone of Pennsylvanian (Virgilian) age, which is exposed along a linear outcrop belt in the Midcontinent Region, has long been thought to represent a classic example of lateral homogeneity. Moore (1950) 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 unit (everywhere less than 3 feet thick) 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 this assumed concept of lateral homogeneity, and to determine whether or not a very detailed study, coupled with extensive usage of an electronic computer, can differentiate and delineate geologically significant and meaningful associations and facies across the outcrop belt.

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. Early in 1963, additional collections were made in Kansas and northern Oklahoma, and during July, 1963, additional collections were made at outcrop localities from southeastern Nebraska and southwestern Iowa.

Thirty-two outcrop localities from southwestern Iowa to northern Oklahoma were measured and studied in detail for primary structures, fossil occurrence, and lithologic variability (Fig. 1). A number of additional Leavenworth localities were visited and examined during the field work (Toomey, 1964).

Acknowledgments. - Drs. Carey Croneis and Edward G. Purdy supervised the study; Dr. Thomas Pulley read the manuscript; field assistance was given by Drs. Arthur Troell, Keith Evans, and Stanton M. Ball; Drs. Robert Downs and George A. Sanderson helped with the fusulinid identifications; Dr. Robert Schwartz provided chemical data; Dan Shaw ran the clay mineralogy and trace-element analyses; and Otto Majewski offered suggestions on the petrography.

PALEOGEOGRAPHIC SETTING

A broad, shallow, slowly subsiding, sedimentary platform existed in the area of Kansas, Oklahoma, and Nebraska, and extended into adjacent states during deposition of the Leavenworth Limestone (Fig. 2). The ancestral Rocky Mountains, lying to the west of the midcontinental 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 remnant that was covered with older Paleozoic carbonate rocks that contributed little in the way of clastic debris into the depositional area. The land mass to the north was part of an ancient stable shield area which was also covered with early Paleozoic carbonate rock, and probably supplied little, if any, clastic material to the region during this time interval. The exact position of the northern shoreline is unknown. The occurrence of an eastern seaway connection with the

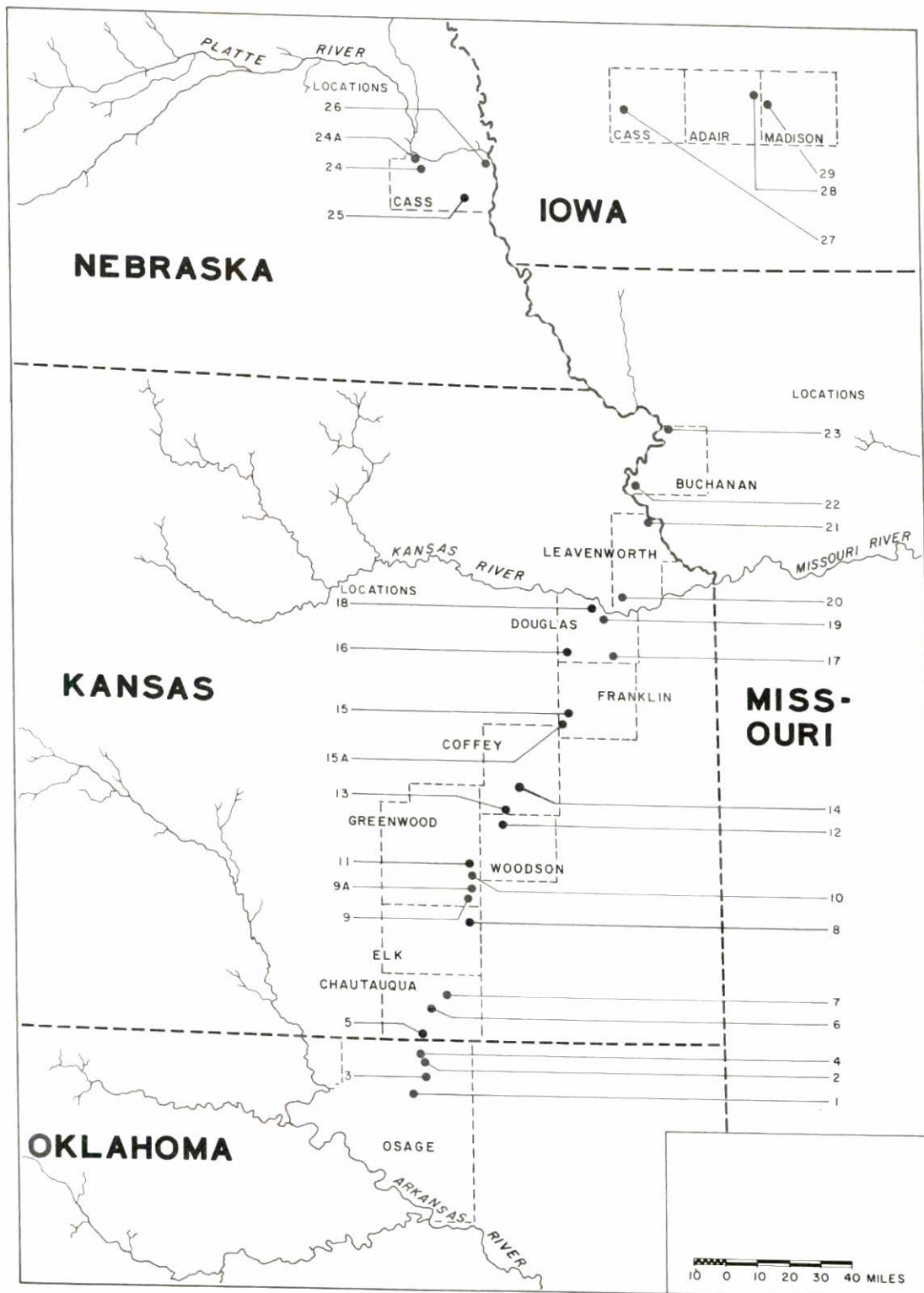


Figure 1.- Map showing location of Leavenworth outcrop localities.

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 conditions of the Ouachita System at the southeast border of the area, during Virgilian time. It does seem probable, however, that the Ouachita System furnished some sediment

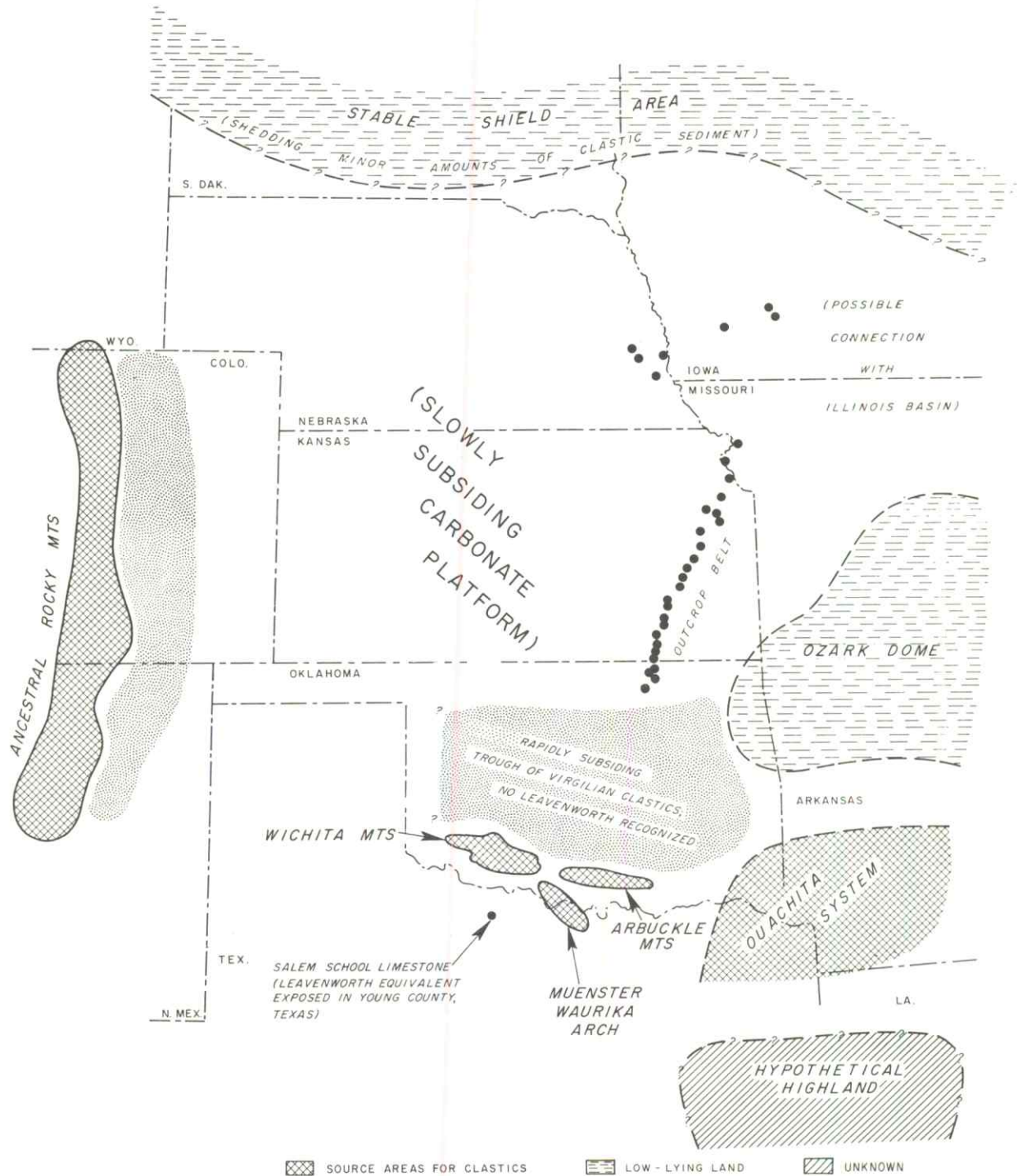


Figure 2.- Postulated paleogeographic setting during Leavenworth time.

to the region during Virgilian time. The mechanism involved was probably an extensive river drainage system in the Ouachitas which carried sediment down the northwestern slope to the sea (Chenoweth, 1959). 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, 1956, 1959; Tomlinson and McBee, 1962).

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, where limestone 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 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 relatively stable shield area to the north were ineffectual sources of clastics to their immediate areas during Leavenworth time.

STRATIGRAPHY

General Statement

The Leavenworth Limestone Member of the Oread Limestone ("middle-limestone member" of the Oread megacyclothem; Moore, 1936) is Upper Pennsylvanian (Virgilian) in age. The unit crops out in a linear belt that extends from northern Oklahoma across eastern Kansas, northwestern Missouri, southeastern Nebraska, and into southwestern Iowa (Fig. 3). Condra (1927) originally described the limestone and designated the type locality at Leavenworth, Kansas. The unit is a dark bluish-gray, fine-grained, dense, very hard, vertically jointed, moderately fossiliferous limestone, and usually occurs as one prominent bed ranging in thickness from about 1 to 3 feet.

The Leavenworth Limestone is overlain by the distinctive hard, black shale with phosphatic nodules known as the Heebner. Across Kansas, the Heebner Shale ranges in thickness from 5 to 7 feet and consists of two units: (1) a lowermost black, platy shale 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 progressively more fossiliferous toward the top. The Heebner remains fairly consistent in thickness and uniformity across most of the outcrop belt from Chautauqua County, Kansas, to Madison County, Iowa. In northern Osage County, Oklahoma, the Heebner undergoes facies change from the clearly divisible, relatively thin two-part unit, as noted above, to a 52-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).

Underlying the Leavenworth Limestone is the Snyderville Shale. This sequence consists of approximately 12 feet of gray to buff sandy shale north of Locality 14; south of this locality the unit thickens to about 75 feet (Moore, 1936) and contains several red shale units, red-stained sandstone units, and several very discontinuous conglomeratic units, including limestones. The Snyderville is a structureless clay that weathers to irregularly shaped blocky masses. Moore (1936) noted that the Snyderville "has the character of an underclay." At most outcrop localities there is a thin (up to 6 inches), extremely fossiliferous gray-green shale unit, containing very abundant chonetoid brachiopods, which directly underlies the Leavenworth Limestone. The contact of this unit with the overlying Leavenworth Limestone appears to be gradational and conformable. Southward, in northern Osage County, Oklahoma, the Snyderville Shale thickens and merges gradually into the lower part of the Vamoosa Formation (a dominantly redbed, clastic unit) losing its individual identity, as do most all of the other Virgilian units (Branson, 1962).

For a more complete discussion of the stratigraphy, the reader is referred to other publications (e.g., Merriam, 1963; Moore, 1936; Toomey, 1964).

Macrofossils

In general, the Leavenworth Limestone does not yield abundant macrofossils. This can be attributed to two basic causes: (1) due to the hard, dense nature of the rock, complete collections cannot be made, and (2) the inherent nature of the Leavenworth sediment (mud with an almost complete absence of terrigenous detritus) does not have favorable environmental substrate on which most benthonic organisms may develop and reproduce; hence, fossils are not abundant in this type of lithology.

Twenty localities, extending along the entire length of outcrop, were selected for detailed macrofossil collecting. An average of four hours collecting time was spent at each locality; at least 100 pounds of rock was diligently searched for fossil material. From these 20 fossil collecting localities, stretching over a distance of more than 300 miles, only 579 specimens were obtained and most were fragments.

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

brachiopods	68.3%	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	0.03%	carnivores
fish	0.01%	carnivores

*Hunt (1925) recognized three basic feeding types: (1) suspension feeders are those organisms that feed on microorganisms 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.

The Leavenworth macrofauna comprises 79.4 percent suspension feeders, 19.9 percent deposit feeders, and less than 1 percent carnivores.

In order that some idea of the taxonomic diversity of the Leavenworth macrofauna could be ascertained a macrofaunal index was computed (see Fig.4). 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.

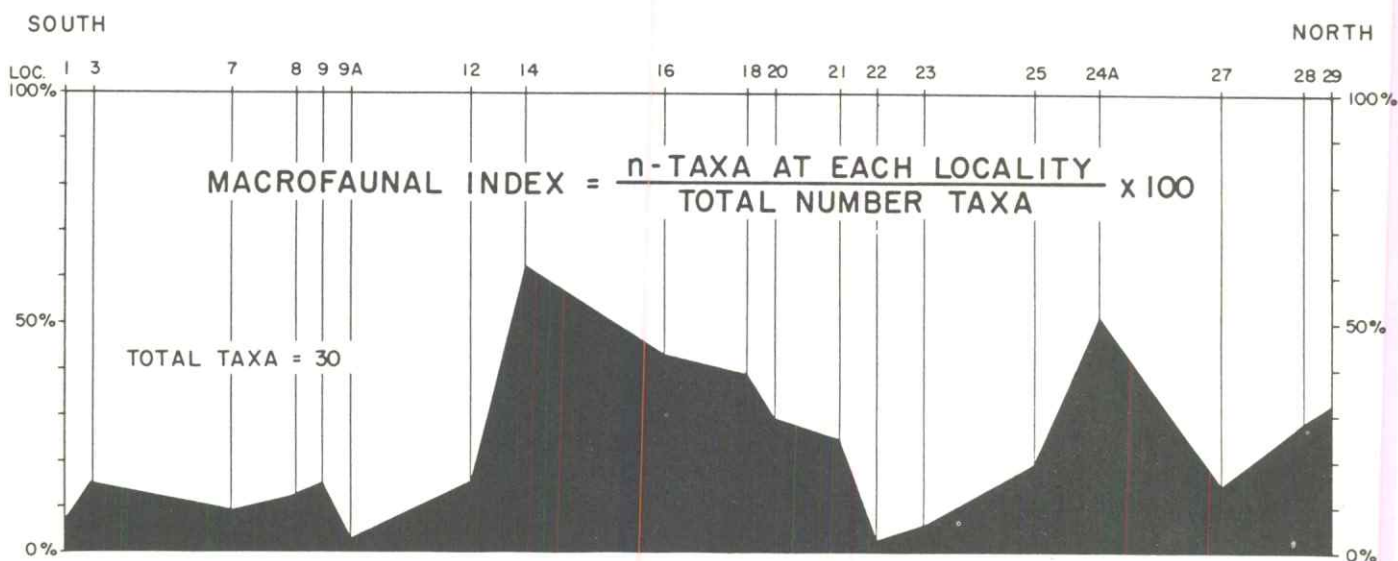


Figure 4.- Leavenworth macrofaunal index.

The diagram shows two areas with high taxonomic diversity, separated by two intervening areas of very low diversity. Localities in Nebraska and Iowa represent the northernmost area of high diversity with a range from 17 to 53 percent. The Missouri localities are areas of lowest diversity (3 to 7 percent). The area of highest diversity (17 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 to 17 percent). This distribution pattern of Leavenworth macrofaunal diversity is not readily explained. Most Late Paleozoic units that have been studied in this area (Mudge and Yochelson, 1962) have shown an increase in the number of fossils and overall macrofaunal diversity in a southern direction (southern Kansas and northern Oklahoma). It has been thought that this increase in macrofaunal 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, possibly due to shoaling, which may have been detrimental to

macrofaunal expansion. However, other more subtle features such as turbidity, bottom fouling, barriers, etc., could have been equally important in restricting organism distribution and expansion.

PETROGRAPHY

On the basis of point-count analyses of thin sections, the entire Leavenworth Limestone can be classified as a mud-supported skeletal wackestone. Volumetrically, the overall composition of the Leavenworth consists of 26 percent skeletal grains and 74 percent nonskeletal material. Grouped under the nonskeletal category are pellets, mud, and spar.

When large slabs of the entire Leavenworth were prepared, the limestone showed abundant evidence of organism burrowing and sediment churning. Organism (worm?) burrows are conspicuous, and are usually filled with relatively large fecal pellets. In addition, swirls of skeletal debris irregularly distributed in patches throughout the mud are commonplace. The effective organism burrowing and churning of sediment gives the rock an oatmeal-like appearance. Burrowed and churned sediment is a common enough occurrence in the Leavenworth that it is an easily recognizable gross feature on many of the large thin sections prepared for this study.

Insoluble Residues

Two insoluble residues were made of Leavenworth Limestone samples from each locality. One-hundred gram residues were prepared in the same general manner outlined by Ireland (1951), with the exception that formic acid was used instead of commercial grade hydrochloric acid.

The Leavenworth insoluble residue suite consists of argillaceous material, microfauna (principally agglutinated Foraminifera), pyrite, fecal pellets, quartz silt, sphalerite, and beekite; arranged in 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 0.1 percent to a maximum of 5 percent; total average percentage is 0.8 percent (Fig. 5).

Microfauna from Insoluble Residues

The microfauna derived from insoluble residues of the Leavenworth Limestone consists primarily of agglutinated and silicified Foraminifera, although scolecodonts, conodonts, and fish remains also occur. The distribution and abundance of Leavenworth microfaunal elements across the entire outcrop belt are shown in Figure 6. This diagram is based on approximately 3,000 picked and mounted specimens.

Chemical Analyses

Results of the chemical analyses of the Leavenworth Limestone are shown in Figure 7. (1) versenate analysis, which is used to determine the presence, approximate percentage, and distribution of dolomite,

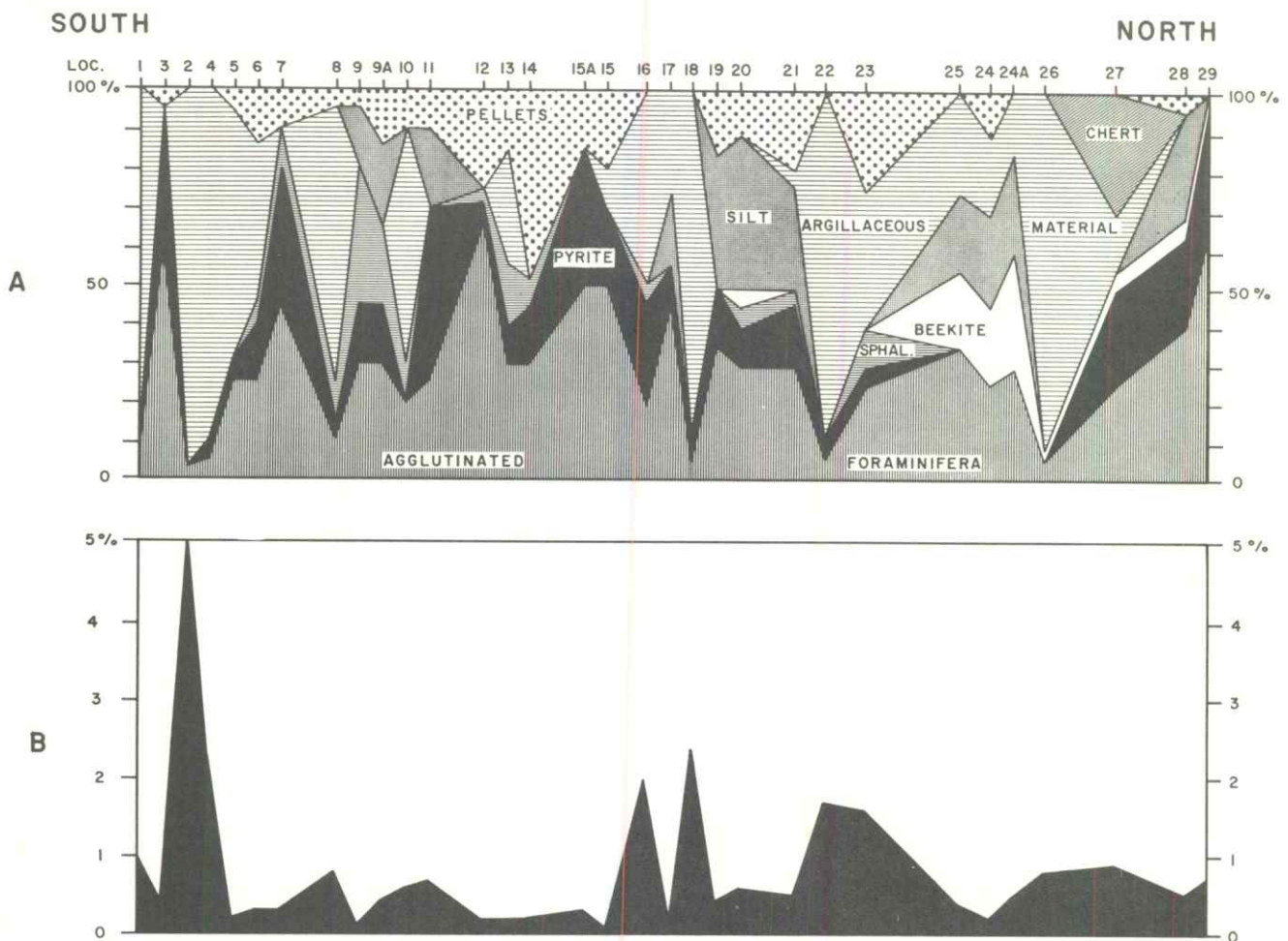


Figure 5.- A, Percentage composition Leavenworth insoluble residues (coarse fraction), B, total percentage of coarse fraction (by weight).

shows it attains a maximum of 25 percent, and more than half the samples contain less than 10 percent; (2) trace-element analyses of six elements (Fe, Zn, Sr, U, S, and P) show a highly variable range without any apparent meaningful distribution pattern; and (3) tests for organic carbon indicate that the Leavenworth Limestone contains amounts less than one-half of 1 percent indicating this minute quantity of organic carbon 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.

Clay Mineralogy

The clay mineral suite in the Leavenworth Limestone consists of illite ($10 \overset{\circ}{\text{A}}$), mixed-layer illite-montmorillonite ($11.5 \overset{\circ}{\text{A}}$), chlorite ($14 - 14.2 \overset{\circ}{\text{A}}$), and kaolinite ($7 \overset{\circ}{\text{A}}$). The distribution pattern and relative percentages* are shown in Figure 8.

*The clay minerals 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 ± 10 percent.

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.

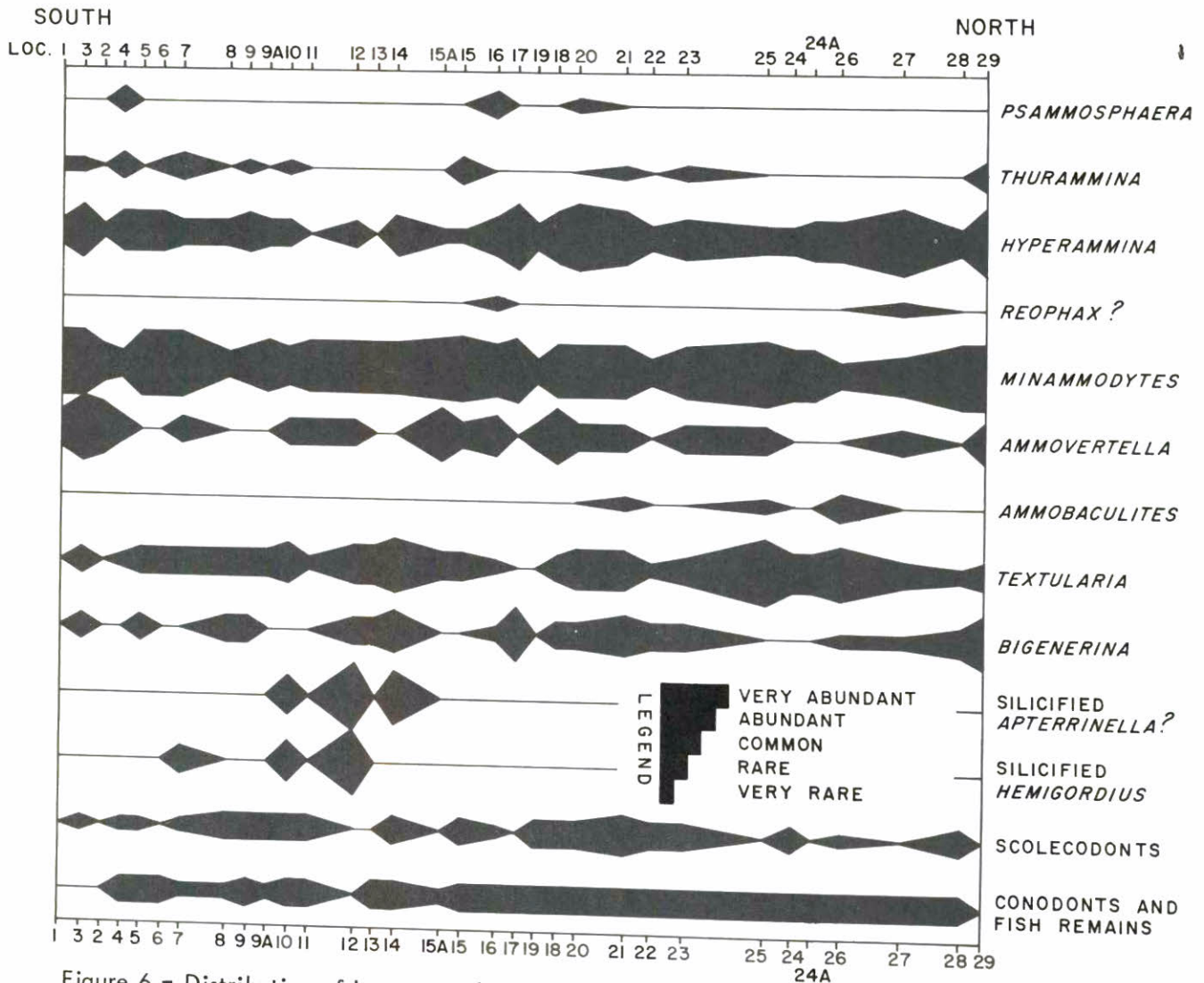


Figure 6.- Distribution of Leavenworth microfauna from insoluble residues (coarse fraction).

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 (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 overall distribution pattern suggests two distinctive source areas: (1) a southern source area where kaolinite is conspicuous, and (2) a northern area where the amount of clay minerals is small, though dominantly composed of illite, mixed layer, and chlorite.

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

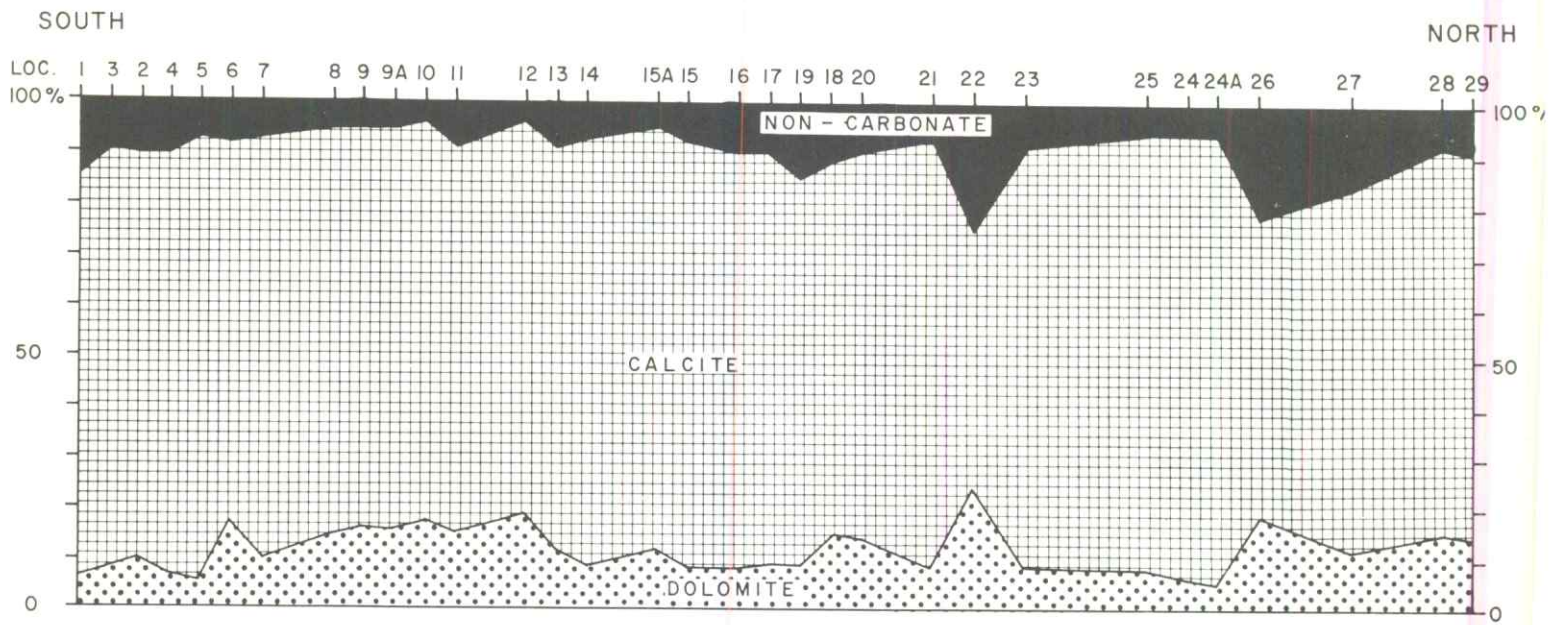


Figure 7.- Percentage Leavenworth carbonate and noncarbonate (determined by versenate method).

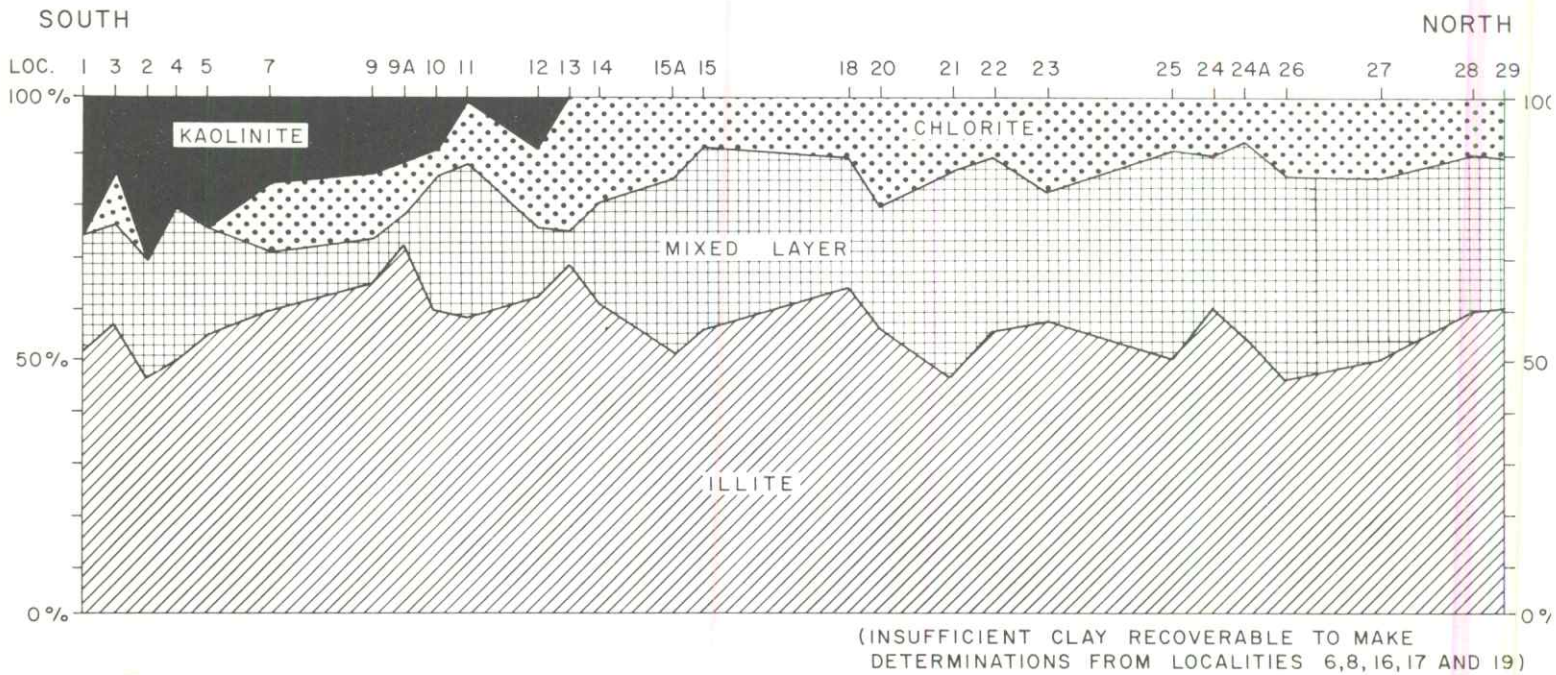


Figure 8.- Percentage distribution of Leavenworth clay assemblages.

STATISTICAL METHODS

The relative volumetric abundance of the individual skeletal and nonskeletal grain types present within a unit sample were determined by point-count analysis. Five-hundred points were counted for each of 68 selected, large (2 x 3 inches) Leavenworth thin sections. Only particle constituents larger than 1/8 mm were identified, because smaller particles were difficult to identify with certainty, and thus were tabulated as unknown skeletal debris. Both Ginsburg (1956) and Purdy (1960), noted in work on recent carbonate sediments that grains larger than 1/8 mm accumulated in close proximity to where they were formed, in contrast to the minus 1/8 mm fraction which contained a large percentage of grains formed in other environments. Significantly, Ginsburg (1956) 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.

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 sensu stricto, but instead, were counted simply as coated-grains. This was done because it was felt that the last thing that happened to the grain in the depositional environment was the most significant from a geological standpoint.

An additional counting procedure was undertaken on the thin sections 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 all the point-count data is that by themselves they do not display any meaningful groupings. Nonetheless, the point-counts do furnish necessary data to determine and develop some measure of similarity between the reacting variable constituents. In order to better understand the complex interrelationships commonly encountered in multivariate data, the paramount objectives are threefold: (1) to determine the minimum number of causal relationships that can accurately account for the majority of the observed variations, (2) 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). For this study, which specifically entailed rotated orthogonal factor analyses, a computer program written by Manson and Imbrie (1964) was utilized.

The measure of sample similarity is determined 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), 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 + 1.00 through 0.00 to - 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 are given a lengthy treatment by Imbrie and Purdy (1962), Imbrie (1963), and Harbaugh and Demirmen (1964). Two modes of analysis are possible: (1) R-mode in which relationships among variables are fully explored and in which correlation coefficients are used, and (2) the Q-mode in which relationships among cases are explored, applying the function of cosine 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 dendrogram was constructed 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 intragroup loading by the number of variables in the group;
- (3) the similarity between factor groups was computed by summing all possible intergroup 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 Fig. 9, 11). 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 or biofacies. The grouping procedure for this integral step is identical to that just described and consequently will not be repeated here.

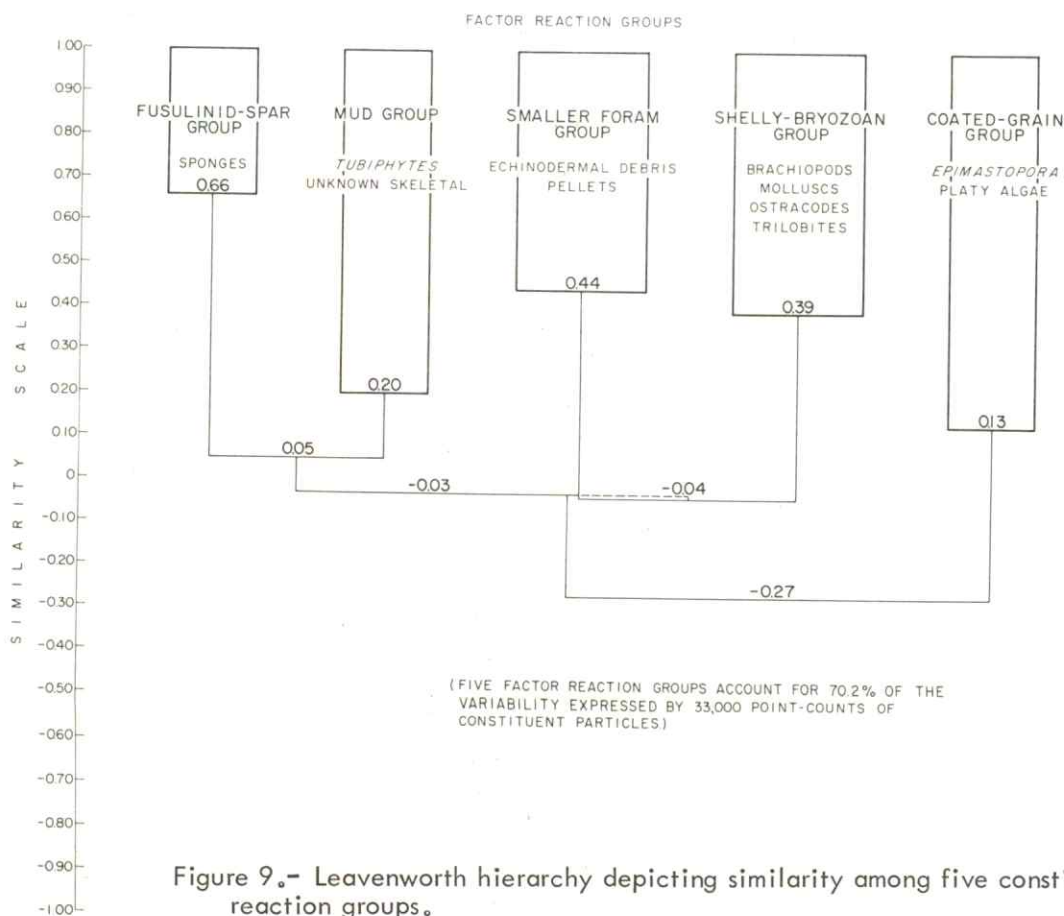
RESULTS OF CONSTITUENT PARTICLE ANALYSIS

The principal results of applying the statistical methods, as outlined in the previous section, to the samples from 32 Leavenworth Limestone localities may be broadly outlined under the following headings.

Factor Reaction Groups

From the unbiased, equal and simultaneous consideration of 19 petrographic attributes, the Leavenworth variables were grouped into five discrete factor reaction groups. These five 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 (Fig. 10) shows that 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.



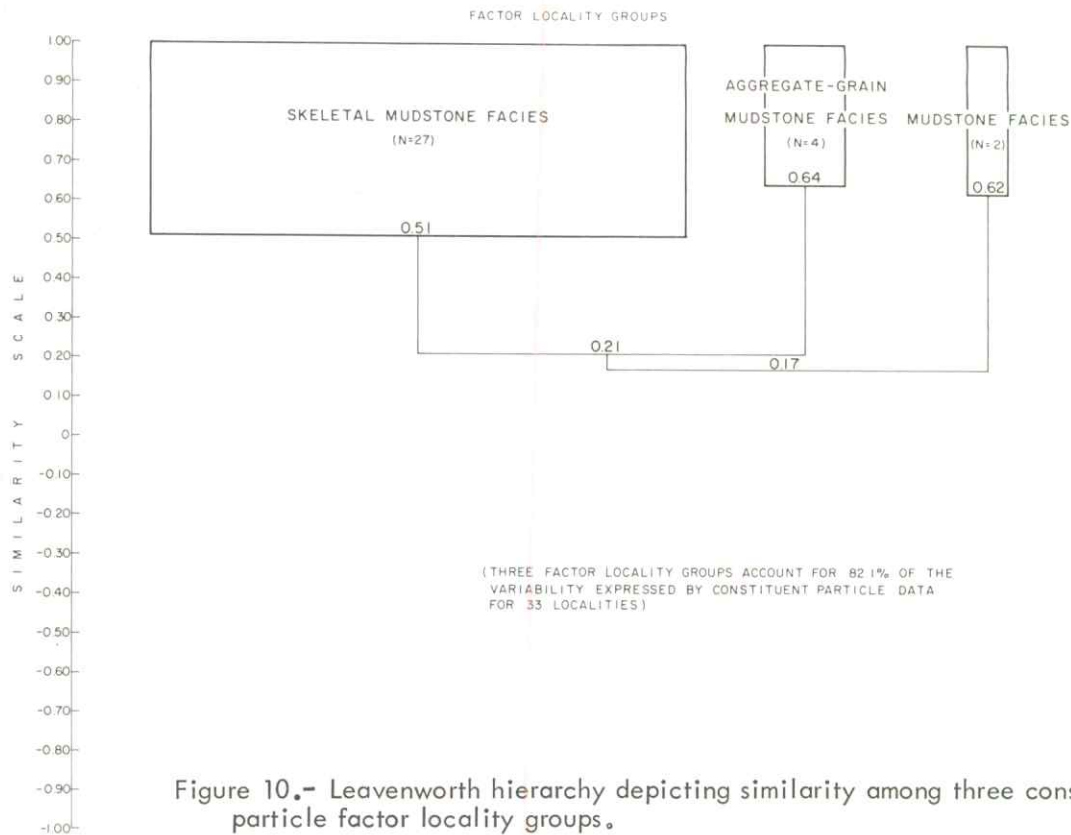


Figure 10.- Leavenworth hierarchy depicting similarity among three constituent particle factor locality groups.

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

It is desirable to determine what constituents tend to occur together along the outcrop belt--in reality, to delineate facies.

For the Leavenworth Limestone three factor locality groups, or facies are recognizable: (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 32 Leavenworth localities.

Perusal of the hierarchical representation (Fig. 10) demonstrates that three independently discrete lithological families comprise the entire Leavenworth Limestone. Geographically, the skeletal mudstone facies

is the most widespread since it contains 27 of the 32 localities, and extends almost across the entire outcrop belt. Its meaning is clear--the many processes contributing to the distribution and abundance of grain types within this facies are highly interrelated and represent strongly intercorrelated elements of a 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 are highly interrelated. 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 at Locality 27 in Cass County, Iowa. These two units are superficially different from the rest of the Leavenworth in many respects. Correspondingly, the petrographic attributes of these two limestones show 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.

Skeletal Mudstone Facies

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

Table 1. - Volumetric composition of the skeletal mudstone facies, based on 27 Leavenworth Limestone localities.

Constituent Particle	Mean	Standard Deviation	Observed Range, Percent
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

Mud is the dominant component of this facies. Percent of mud ranges from 38.0 to 85.9, with a mean of 69.8 percent of the rock volume. Second in abundance is the small Osgia-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 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.

Aggregate-Grain Facies

This facies comprises four Leavenworth Limestone localities restricted to 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 overall reduction in mud content, and the significant abundance of aggregate coated-grains (see Table 2).

Table 2. - Volumetric composition of the aggregate-grain facies based on 4 Leavenworth Limestone localities.

Constituent Particle	Mean	Standard Deviation	Observed Range, Percent
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

The dominant component is mud with a mean of 38.7 percent by volume of rock and a range of 0 to 66.9 percent. Second in abundance is the aggregate-grains present in three of the four 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 per-

cent. 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.

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).

Table 3. - Volumetric composition of the mudstone facies based on 2 Leavenworth Limestone units.

Constituent Particle	Mean	Standard Deviation	Observed Range, Percent
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

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.

Facies Synopsis

Results of the Leavenworth Limestone factor analysis substantiates what was determined through direct field observation, that this thin persistent carbonate unit is laterally 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 indicates that a

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

different set of environmental conditions was acting upon this portion of the ecosystem as the shore 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 TOTAL FORAM COUNT ANALYSIS

Results of the factor analysis of the total foram counts (24,975) from thin sections of 32 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 were grouped 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 hierarchical representation (Fig. 11) demonstrates which Leavenworth Foraminifera tend to occur together, and indicates the interrelationships 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 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 biofacies, are recognizable: (1) mobile foram biofacies comprising 20 localities, (2) fusulinid biofacies comprising nine localities, and (3) an encrusting foram biofacies comprising four localities. These factor locality groups account for 80.1 percent of the variability expressed by the foraminiferal counts for 32 Leavenworth localities (see Fig. 12). Each of the biofacies

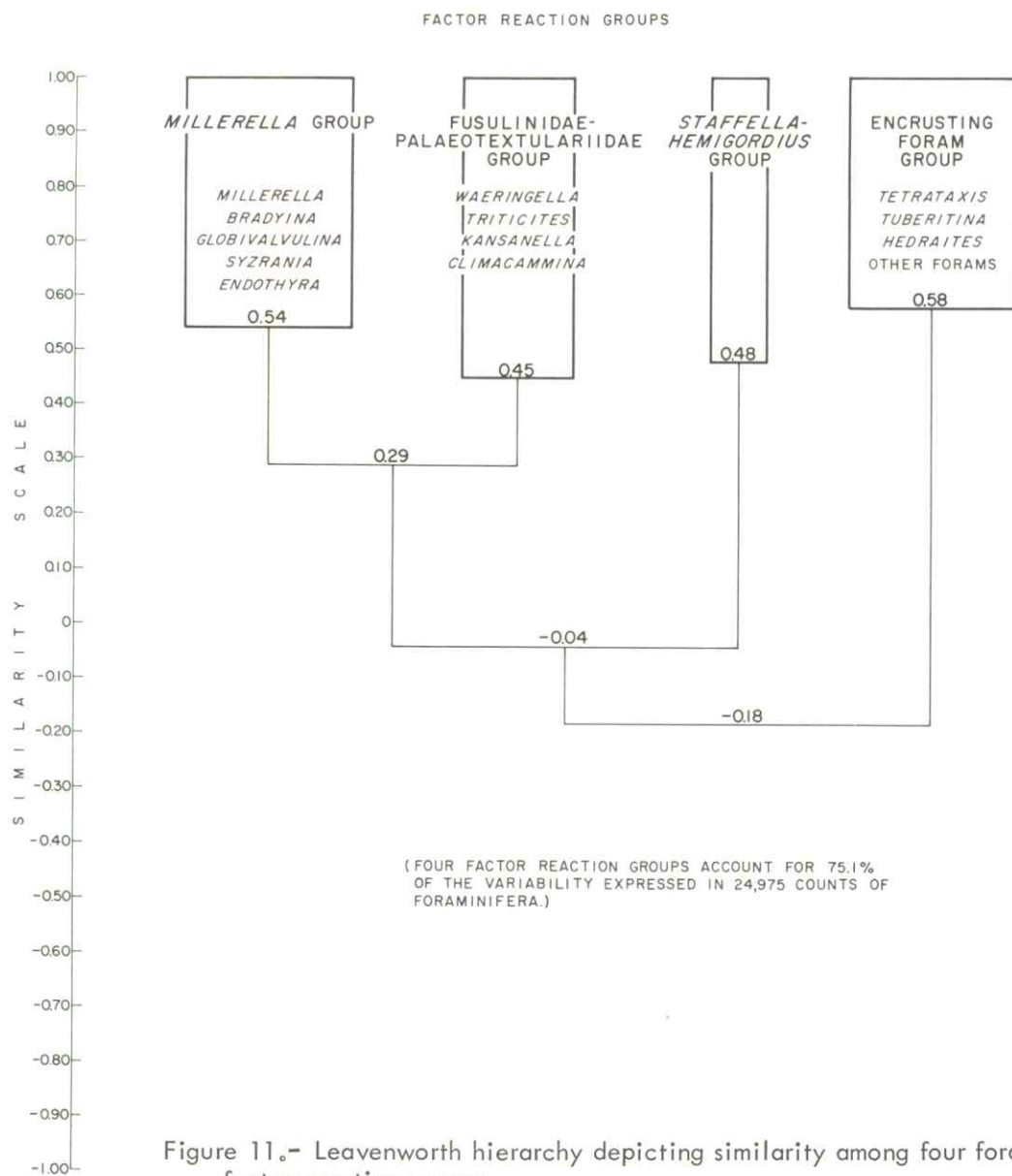


Figure 11.- Leavenworth hierarchy depicting similarity among four foraminiferal factor reaction groups.

possesses a relatively high mean intragroup similarity. The mobile foram biofacies is most similar to the fusulinid biofacies, and is related to this biofacies at a level of 0.23. The encrusting foram biofacies, as also noted above in the factor reaction groups, shows high mean intragroup similarity but correspondingly low intergroup similarity (0.14) with the mobile foram biofacies and fusulinid biofacies.

Mobile Foram Biofacies

The mobile foram biofacies has the greatest geographic spread (comprises 20 out of 32 localities), and highest mean intragroup association (0.72) of all the Leavenworth foraminiferal biofacies. This biofacies 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 foraminifera 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.

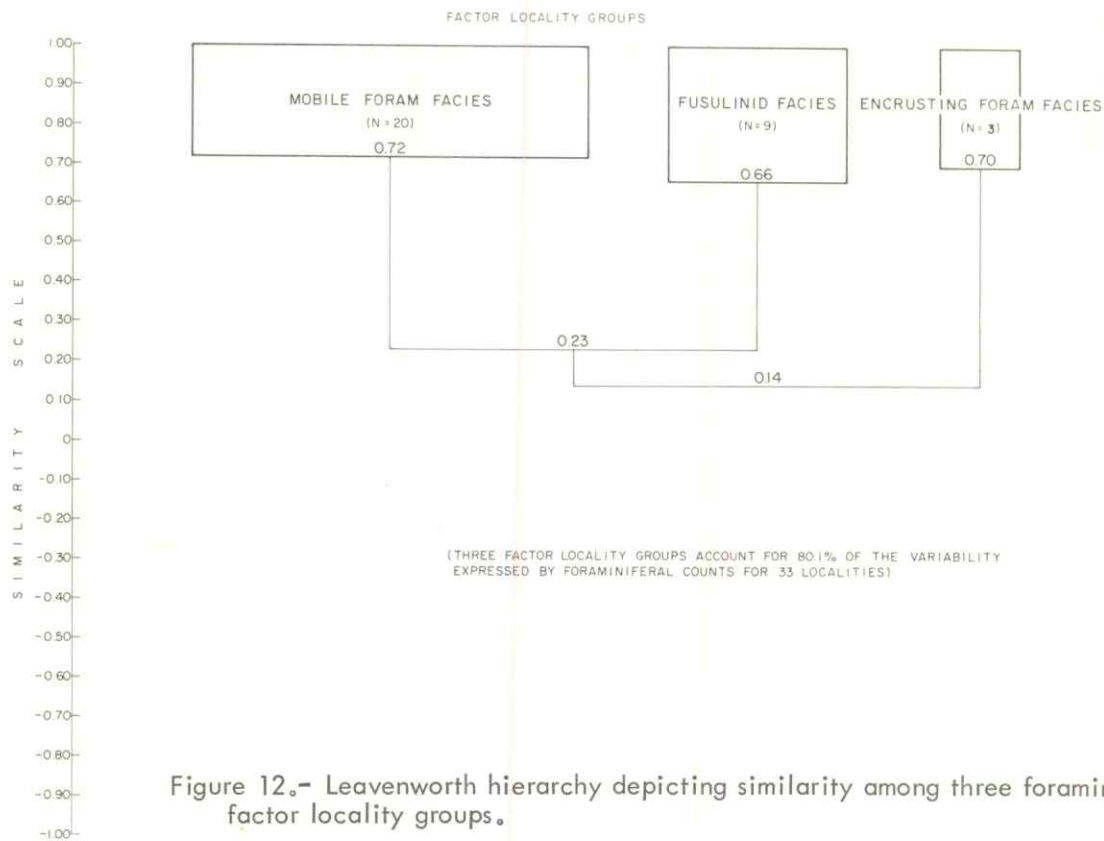


Figure 12.- Leavenworth hierarchy depicting similarity among three foraminiferal factor locality groups.

Table 4. - Percentage composition of the mobile foram biofacies based on total foraminiferal counts for 20 Leavenworth Limestone localities.

Foraminifer	Mean	Standard Deviation	Observed Range, Percent
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. <u>Other forams</u>	.005	.21	0- .9

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

Fusulinid Biofacies

The fusulinid biofacies contains a dominant fusulinid assemblage comprising 58.6 percent of the total foram microfauna. This biofacies includes 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 biofacies. One mobile smaller foraminifer, Hemigordius, attains its highest mean (4.0 percent) within this biofacies. The fusulinid biofacies is most closely related to the mobile foram biofacies, and is associated with it at a similarity level of 0.23. Percentage composition of the foraminiferal biofacies is given in Table 5.

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

Table 5. - Percentage composition of the fusulinid biofacies based on total foraminiferal counts for 9 Leavenworth Limestone localities.

Foraminifer	Mean	Standard Deviation	Observed Range, Percent
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. <u>Other forams</u>	.04	.08	0- .2

Encrusting Foram Biofacies

This biofacies 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 within this biofacies. 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 biofacies. 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).

Table 6. - Percentage composition of the encrusting foram biofacies based on total foraminiferal counts for three Leavenworth Limestone localities.

Foraminifer	Mean	Standard Deviation	Observed Range, Percent
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

Facies and Biofacies Synopsis

Results of the foraminiferal factor analysis demonstrate that three factor locality groups, or biofacies, 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 (Fig. 13).

Comparison of the foraminiferal biofacies with the constituent particle facies does show a slight relationship. The data from both facies and biofacies 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 they do not show the same type of environmental response. This is to be expected because in the foraminiferal analysis the basic concern was 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 compared with at least 12 other different organism groups.

The mobile foram biofacies corresponds in part to the skeletal mudstone facies, with the notable exception that the mobile foram biofacies comprises seven less localities than the skeletal mudstone facies. These seven

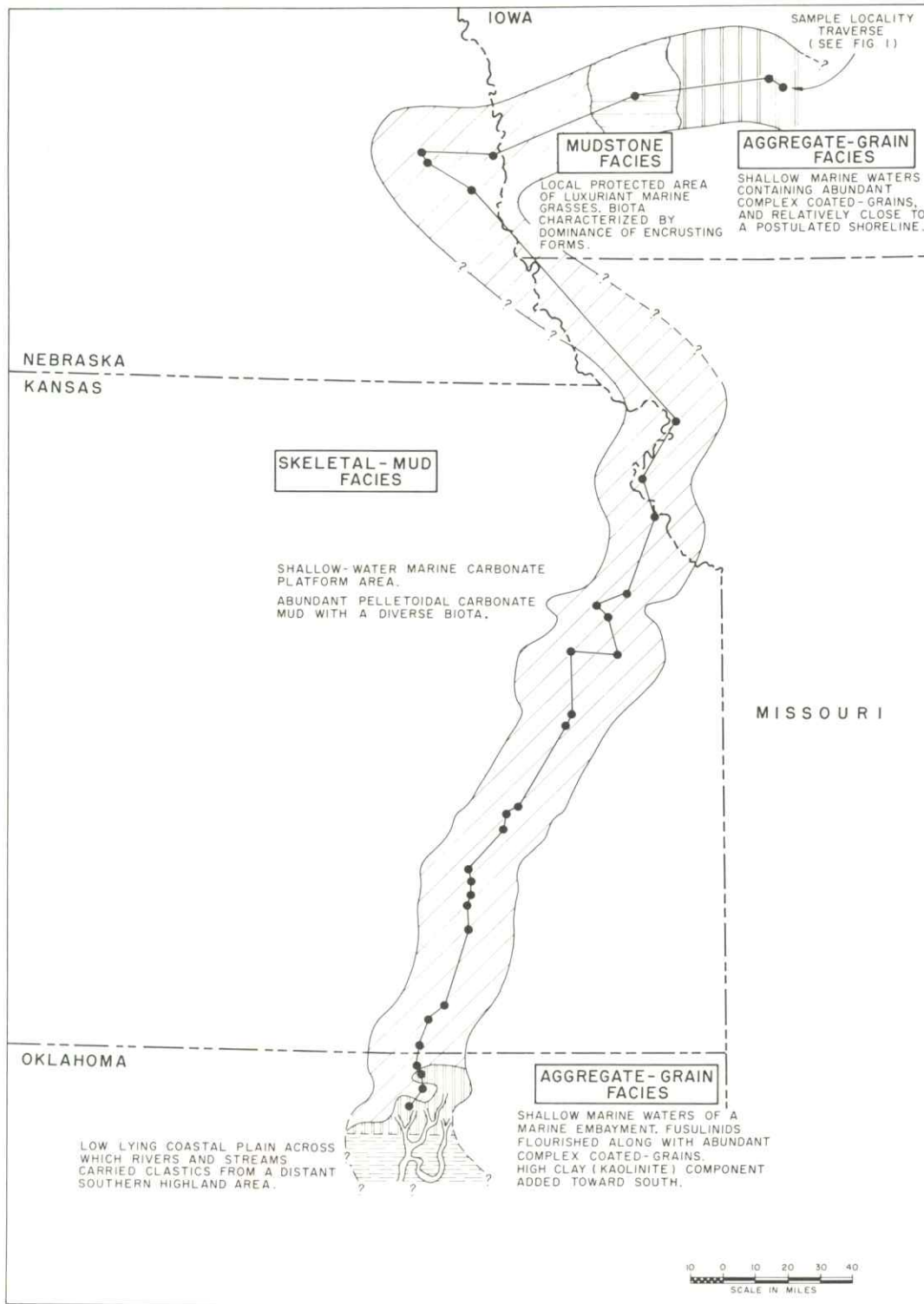


Figure 13.- Map showing environmental reconstruction of Leavenworth Limestone.

localities apparently combine with two other localities from the aggregate-grain biofacies, that also contained relatively abundant fusulinids, to create a separate fusulinid biofacies. The two remaining localities (28 and 29) under the aggregate-grain biofacies do contain abundant encrusting foraminifers (Tetrataxis), and hence split off to join two other localities high in encrusting foraminifer content to form the distinctive encrusting foram biofacies.

The primary advantage in applying statistical methods to the constituent particle point-counts and total foram count data, was that all the data were given equal weight in delineating facies and biofacies, and were treated simultaneously and impartially. From the geological standpoint, the principal advantage lies in the fact that the statistical approach facilitated condensation of a large amount of data (variables) into as few as three to four groups of statistical variables, which essentially contained all the information present in a vastly larger original set of observations. Accordingly, the three fundamental objectives in a geological study: (1) determination of the minimum number of causal relationships needed to explain the observed relationships, (2) identification of these causal relationships, and (3) relative importance of each cause, were more readily ascertained by using the statistical approach than by utilizing a more customary subjective mode of analysis.

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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 stream bed of 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 rock cut in 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. & Q Railroad tracks.	1.9
22	CSL sec. 22, T. 55 N., R. 37 W., Buchanan County, Missouri. Exposure is floor of old abandoned quarry.	**
21	NW 1/4 NW 1/4 sec. 22, T. 8 S., R. 22 E., Leavenworth County, Kansas. Exposure in roadcut 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 Tonganoxie.	1.9
19	NW 1/4 sec. 36, T. 12 S., R. 19 E., Douglas County, Kansas. Exposure in town of Lawrence in 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 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 mile east of 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 stocktank, on north side of an east-west trending county road.	.9
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 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
9	CSL sec. 29, T. 27 S., R. 13 E., Greenwood County, Kansas. Exposure in roadcut on east-west trending county road.	1.3
9A	CWL sec. 21, T. 27 S., R. 13 E., Greenwood County, Kansas. Exposure in roadcut on north-south trending county road.	1.4
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 3 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
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

*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.

COMPUTER CONTRIBUTIONS

Kansas Geological Survey
University of Kansas
Lawrence, Kansas

Special Distribution Publication

3.	BALGOL program for trend-surface mapping using an IBM 7090 computer, by J. W. Harbaugh, 1963	\$0.50
4.	FORTTRAN II program for coefficient of association (Match-Coeff) using an IBM 1620 computer, by R. L. Kaesler, F. W. Preston, and D. I. Good, 1963	\$0.25
9.	BALGOL programs for calculation of distance coefficients and correlation coefficients using an IBM 7090 computer, by J. W. Harbaugh, 1964	\$0.75
11.	Trend-surface analysis of regional and residual components of geologic structure in Kansas, by D. F. Merriam and J. W. Harbaugh, 1964	\$0.75
12.	FORTTRAN and FAP program for calculating and plotting time-trend curves using an IBM 7090 or 7094/1401 computer system, by W. T. Fox, 1964	\$0.75
13.	FORTTRAN program for factor and vector analysis of geologic data using an IBM 7090 or 7094/1401 computer system, by Vincent Manson and John Imbrie, 1964	\$1.00
14.	FORTTRAN II trend-surface program for the IBM 1620, by D. I. Good, 1964	\$1.00
15.	Application of factor analysis to petrologic variations of Americus Limestone (Lower Permian), Kansas and Oklahoma, by J. W. Harbaugh and Ferruh Demirmen, 1964	\$1.00
23.	ALGOL program for cross-association of nonnumeric sequences using a medium-size computer, by M. J. Sackin, P. H. A. Sneath, and D. F. Merriam, 1965	\$0.75
24.	BALGOL program and geologic application for single and double Fourier series using IBM 7090/7094 computers, by F. W. Preston and J. W. Harbaugh, 1965	\$1.00
26.	FORTTRAN II trend-surface program with unrestricted input for the IBM 1620 computer, by R. J. Sampson and J. C. Davis, 1966	\$0.50
27.	Application of factor analysis to a facies study of the Leavenworth Limestone (Pennsylvanian-Virgilian) of Kansas and Environs, by D. F. Toomey, 1966	\$0.75

Report of Studies

170-3	Mathematical conversion of section, township, and range notation to Cartesian Coordinates, by D. I. Good, 1964	\$0.50
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Bulletin

171	A computer method for four-variable trend analysis illustrated by a study of oil-gravity variations in southeastern Kansas, by J. W. Harbaugh, 1964	\$1.00
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Reprints (available for limited time)

Use of asymmetric frequency distribution curves of core analysis data in calculating oil reserves, by F. W. Preston and J. S. Van Scoyoc (reprinted from <u>Stanford University Publications</u> , Geological Sciences, v. 9, no. 2, 1964)	no charge
Pattern recognition studies of geologic structure using trend-surface analysis, by D. F. Merriam and R. H. Lippert (reprinted from <u>Colorado School Mines Quarterly</u> , v. 59, no. 4, 1964).	no charge
Trend-surface mapping of hydrodynamic oil traps with the IBM 7090/7094 computer by J. W. Harbaugh (reprinted from <u>Colorado School Mines Quarterly</u> , v. 59, no. 4, 1964)	no charge
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