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PALEOECOLOGIC STUDY OF THE OKETO SHALE (LOWER PERMIAN) IN NORTH CENTRAL KANSAS

by

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INTRODUCTION

Purpose of Investigation

This investigation is a paleoecologic study of the Oketo Shale Member of the Barneston Limestone (Lower Permian) based on (1) preferred compass orientations of megafossils, (2) animal-substrate relationships, (3) general depositional environment, (4) temporal and spatial changes within the unit, and (5) comparison with animal-substrate relations of similar organisms from the Pennsylvanian (Pearce, 1973).

Location

This study was confined to Riley and Geary Counties, Kansas. Thirteen measured and sampled sections were used, five in Riley County and eight in Geary County (fig. 1).

Previous Investigations

Jewett (1941) first described the Oketo Shale although the term was previously well known having appeared on "several published stratigraphic sections (Moore, 1936, figs. 4 and 45; 1940, fig. 15) and Moore is the author of the term" (Jewett, 1941).

McMillen and West (1971) and McMillen (1972) investigated several benthic communities in the Oketo Shale and Kues (1973) is presently studying the member regionally.

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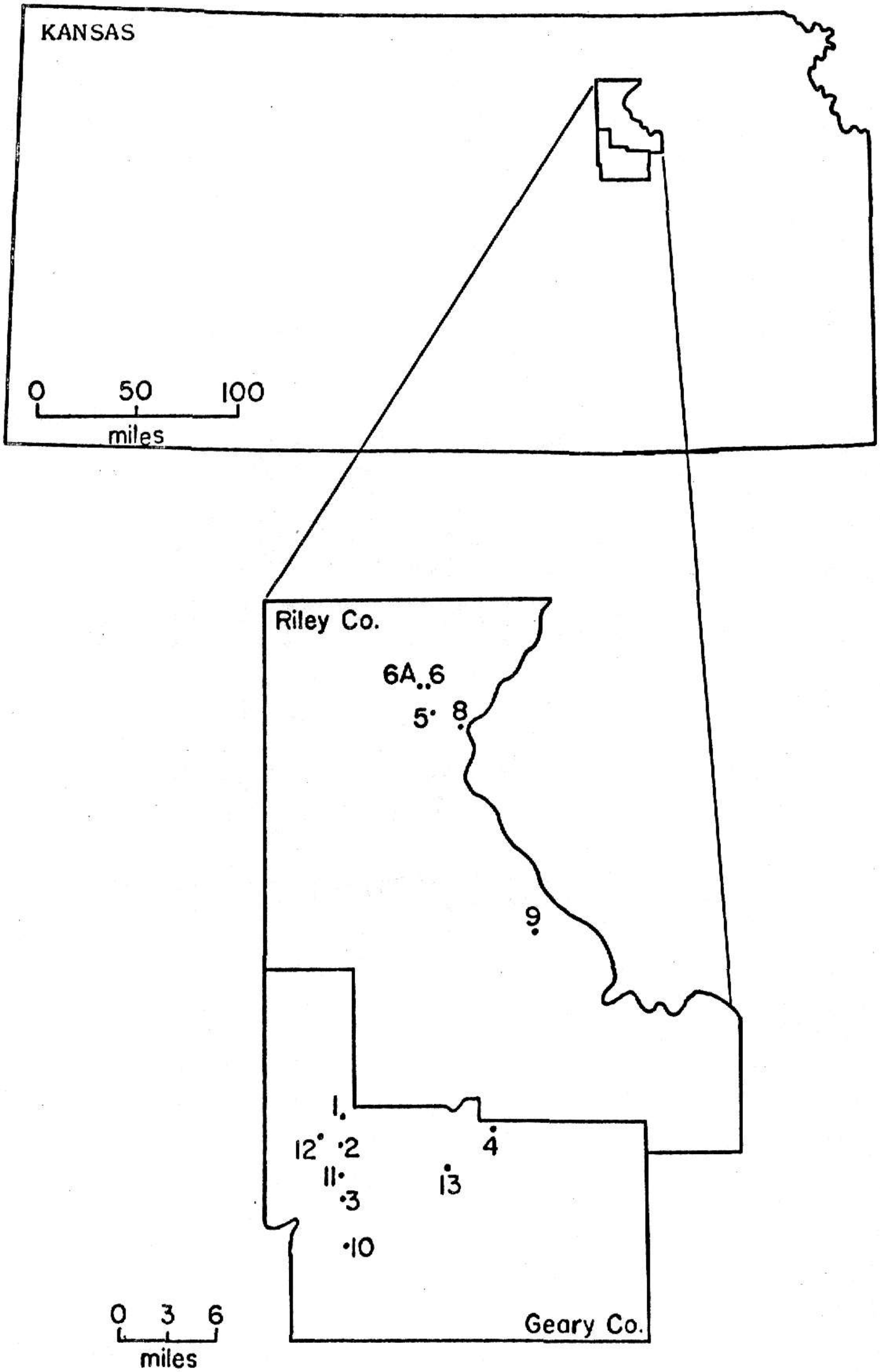

Figure 1. Location of Measured Sections.

METHODS OF INVESTIGATION

Field Procedure

Each outcrop of Oketo Shale was measured and described in detail (Appendix I). Because the upper and lower boundaries of the Oketo are not easily recognized, portions of the overlying Fort Riley Limestone (up to the first massive limestone bed or "rimrock") and the underlying Florence Limestone (down to the first occurrence of chert) were included.

After measurement and description the entire outcrop was examined for in situ pholadomyids and Reticulatia cf. huecoensis King. Size, orientation and location were recorded for each individual (figs. 2 and 3) and specimens collected for laboratory study. This procedure was followed for 11 of the 13 localities. Localities 3 and 9 were studied in the following manner.

A grid was constructed for an area five meters long and the width-of-the-Oketo Shale at Localities 3 and 9 (Photo 1). Two factors decided the placement of the grid, (1) accessibility to the face of the outcrop and (2) verticality of the face. A vertical face was necessary to bring the grid close to the outcrop for accurate plotting of fossil positions. Because these two factors rarely coincided, a compromise locality was chosen for both grid studies. Stakes five meters apart were driven into the contact of the Fort Riley Limestone and Oketo Shale and two more driven into the contact of the Oketo Shale and the Florence Limestone directly below the first two

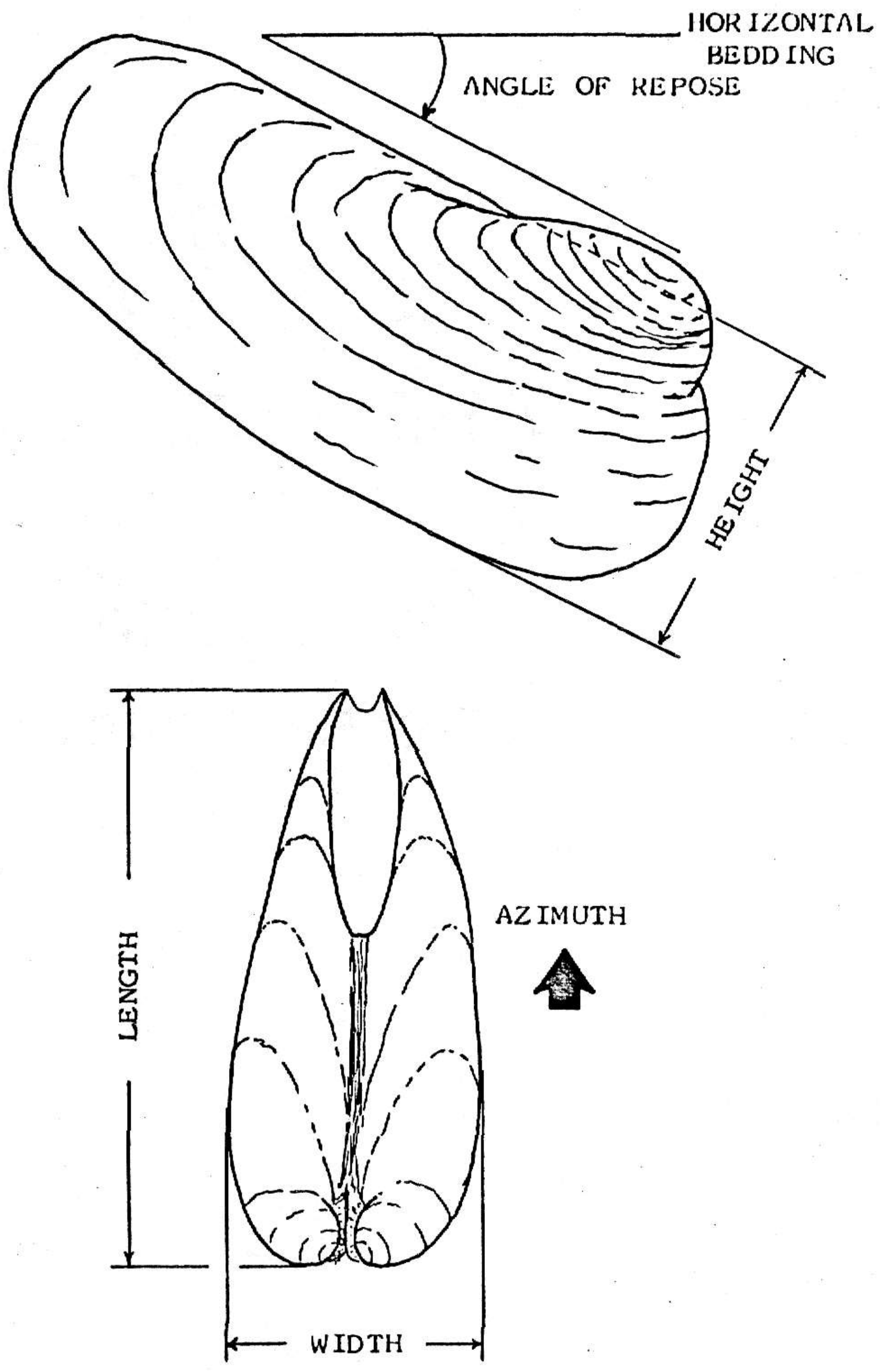

Figure 2. Pholadomyid Orientation Angles and Size Measurements.

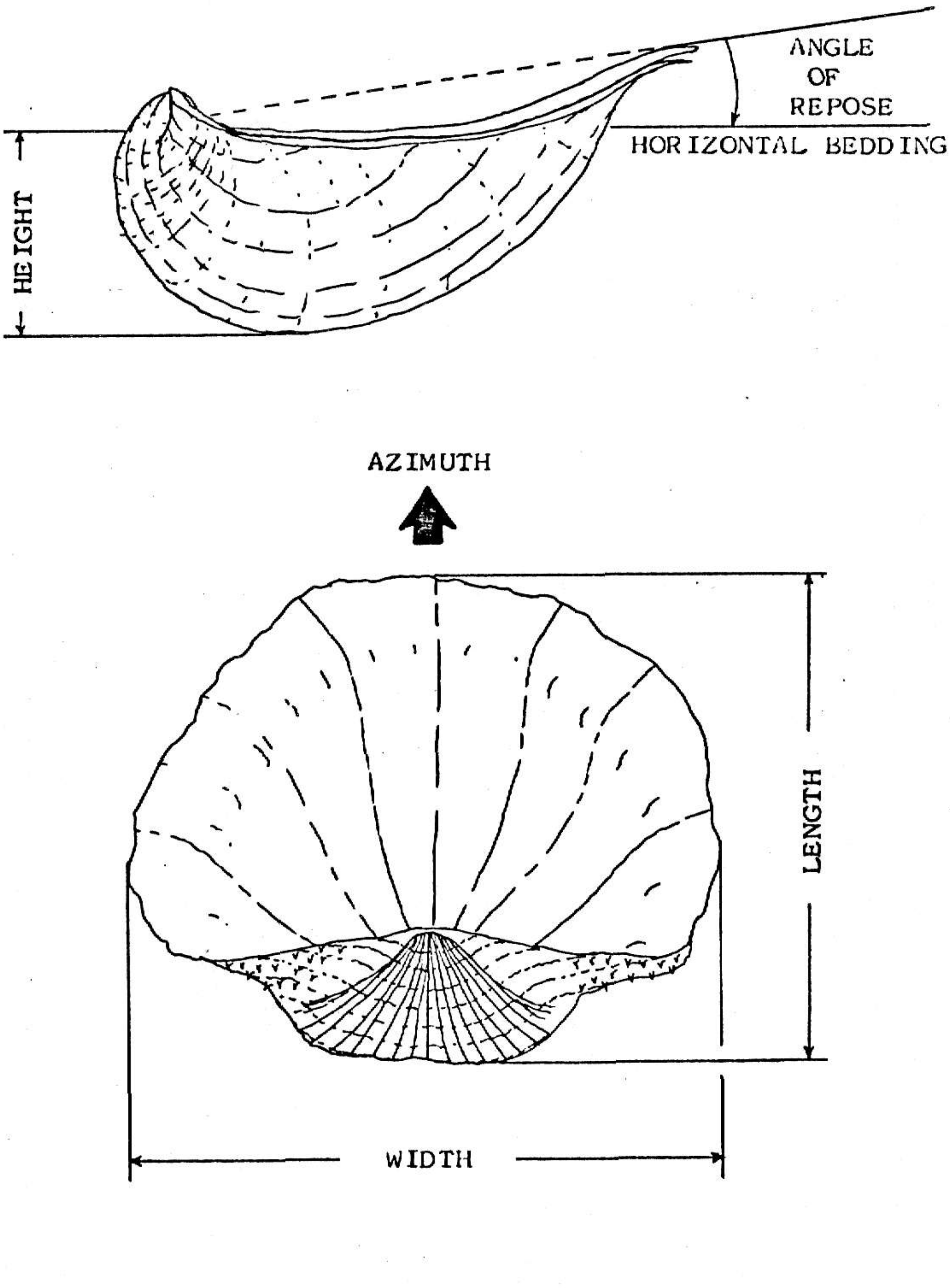

Figure 3. <u>Reticulatia</u> cf. <u>huecoensis</u> Orientation Angles and

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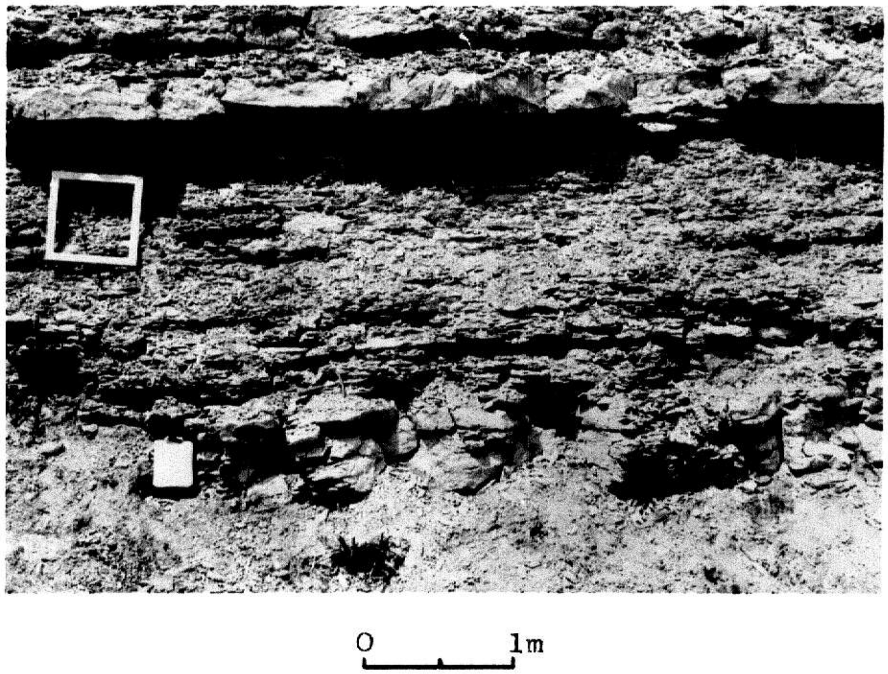


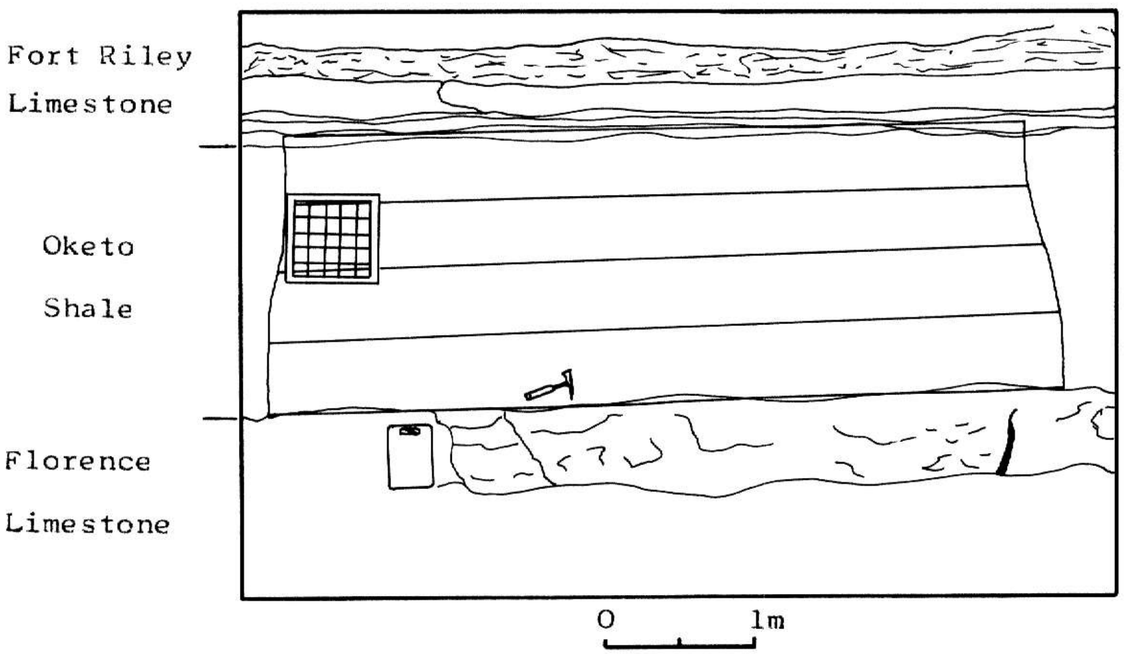


Photo 1. Grid Square Placement at Locality 9.

stakes. A large rectangle was formed by connecting the stakes with heavy cord. The sides of the rectangle were marked every half a meter. Horizontal guide strings were attached at the half-meter marks on the short sides of the rectangle and marked at half-meter intervals.

A half a meter square wooden frame (a quarter of a square meter) with a wire grid of 25 square decimeters was constructed for use in conjunction with the larger grid. This small grid was passed along the guide cords of the large grid and every visible macrofossil was plotted and described on a data sheet (Appendix IX).

Laboratory Procedure

General Statement.--To determine lateral changes within the unit, four localities (6A, 9, 10, 12) at the extremities of the study area were selected for detailed laboratory analysis.

Insoluble Residue Analysis.--The procedure for obtaining insoluble residues in this study is a modification of that used by Scott (1973). A three ounce jar was filled with crushed sample and oven-dried for about 12 hours. Approximately 20 g of sample (at room temperature) were placed in an 800 ml beaker. The samples were covered with water to reduce initial effervescence. Two hundred ml of 2N HCl were added slowly. After 20 minutes an additional 300 ml of acid were added and the samples allowed to sit overnight.

The clear acid solution was decanted carefully to avoid loss of suspended particles. Residue and acid were washed and centrifuged repeatedly until a pH of about 7 was obtained from the supernatant. To separate the sand from the finer fractions, the residue was wet sieved through a 230 mesh (4 Ø) sieve. Silt and clay fractions were collected in an 800 ml beaker and the sand transferred to weighed (nearest .0001 g) 50 ml beakers. A few drops of acid were added to the sand fraction to confirm total solution of carbonate and rinsed with distilled water to remove the acid.

To separate the silt fraction from the clay fraction (less than 2 mu) the silt-clay fraction was transferred to 100 ml tubes and centrifuged in an IEC International Centrifuge, Size 2, Model K with a 240 head. Each tube was filled to a depth of 10 cm, room temperature checked, temperature correction applied to centrifuging time and solution centrifuged at 750 rpm (Jackson, 1956). The supernatant containing the clay was decanted into an 800 ml beaker. Distilled water was added to the silt residue to bring the fluid level to 10 cm and the mixture recentrifuged. This washing was repeated until a clear supernatant was obtained. The silt residue was transferred to weighed 50 ml beakers. The remaining clay solution was transferred to several tubes and centrifuged at 2100 rpm for 30 minutes. This procedure was repeated until the clay solution could be contained in a single 100 ml weighed beaker.

The three size fractions were oven-dried overnight, allowed to cool to room temperature and weighed to the nearest .0001 g, and retained for further study.

The sand fraction of each insoluble residue was examined with a binocular microscope using reflected light and visual estimates of each component were made using charts (Terry and Chilingar, 1955).

Because silt and clay mineralogy is usually not discussed in environmental literature, determination of different components was not performed on a large scale. Residual clays were used in paleosalinity determinations.

Thin Section Analysis.--Thin sections of all beds in the four localities were prepared but four of the beds above the lowest Fort Riley Limestone "rimrock" at Locality 10 were not studied in detail because comparable beds were not measured at other localities. Field work was initiated at Locality 10 where a measurement of the entire exposed outcrop was made. At other localities the absence of the upper Fort Riley beds necessitated using the lower "rimrock" bed as a datum.

Blocks approximately 30 by 20 mm by 1 cm were cut from oriented field samples and thin sections prepared on a Hillquist Thin Section Machine. No cover glasses were affixed because the slides were later used for x-ray diffraction analysis of carbonates.

An area 30 by 20 mm was examined on each slide in increments of 1 mm on the long side and 2 mm on the short side (300 points total), using a petrographic microscope equipped with a mechanical stage. Because of the irregular outline and size variation of many of the blocks, the total number of points seldom equalled exactly 300. Each point represents the intersection of the crosshairs on a lithologic and/or biologic component and data are in Appendix II.

X-ray Diffraction Analysis.--X-ray analysis was used to identify carbonate minerals in each bed of the four localities. Samples consisted of uncovered thin sections oriented in the goniometer perpendicular to bedding. Only areas of the slide considered characteristic of the general lithology of the bed were exposed to the x-ray beam.

Diffractometer settings were:

(1) Chart speed - 30 inches per hour
(2) Scanning speed - 1° per minute and ¼° per minute
(3) Target - Ni, filtered Cu K alpha radiation
(4) Diverging slit - 1°
(5) Receiving slit - 0.003 inches
(6) Antiscatter slit - 1°
(7) Kilovoltage - 35 kilovolts
(8) Milliamperage - 18 milliamperes
(9) Time constant - 2 seconds
(10) Detector voltage - 1.62 kilovolts
(11) Pulse height analyzer level - 5.04 volts
(12) Pulse height analyzer window - 2.20 volts
(13) Scale factor - 1 K and 5 K.

Slides were scanned from 32° to 20° at a scale factor of 1000 cps to obtain sharp peaks for quartz, which was used as an internal standard, and also to detect any dolomite. A second run from 32° to 26° at 5 K was made to determine percent $MgCO_3$ in the calcite.

If the major peak of quartz (3.343 Å) was displaced more than 0.002 Å, the peak was adjusted to the standard (3.343 Å) by adding or subtracting fractions of degrees from the diffractogram peaks. This correction was applied to the major peak for calcite on the diffractogram. The d-spacing was determined and the resultant value plotted on a curve (fig. 4) constructed by Goldsmith, Graf and Joensuu (in Mueller, 1967, p. 190) to ascertain molecular percent of $MgCO_3$ in the calcite

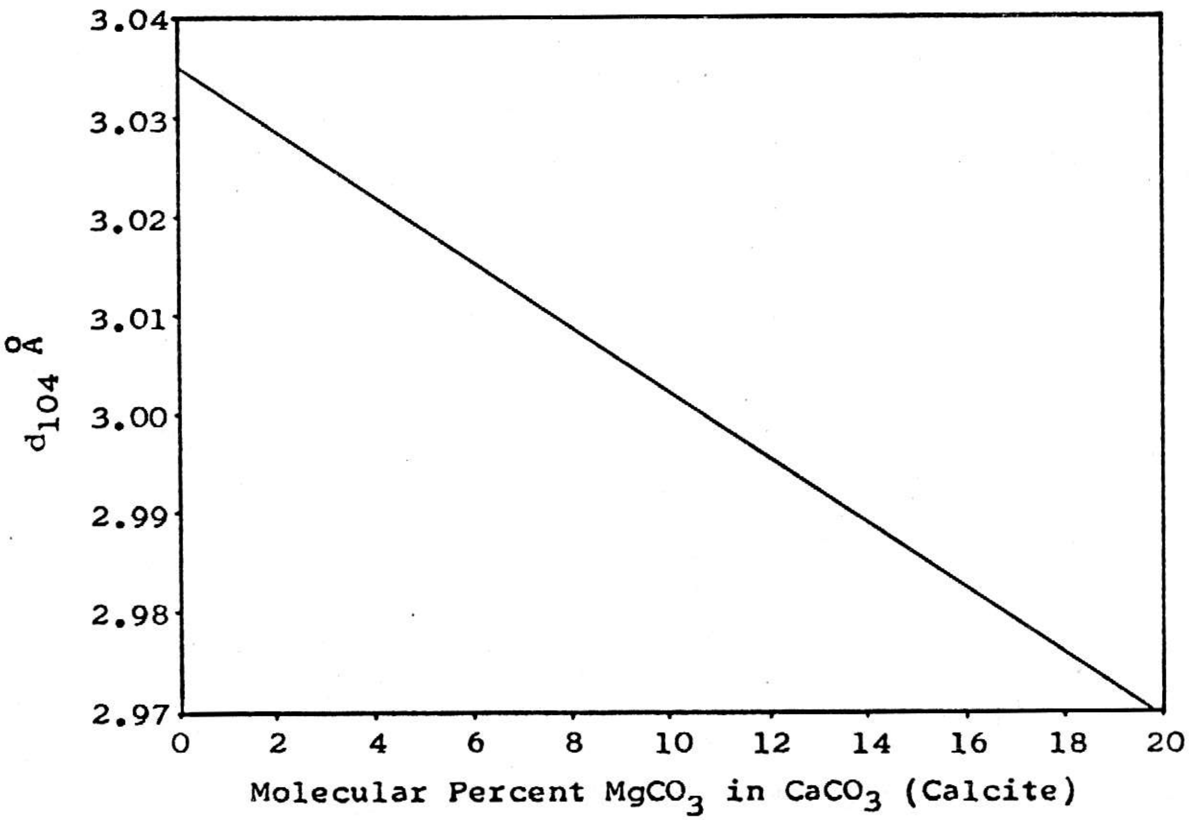


Figure 4. Relation Between Amount of $MgCO_3$ in High-magnesium Calcite and Position of the (104) Reflection (after Goldsmith, Graf and Joensuu, in Mueller, 1967, p. 190).

structure. The presence of dolomite (ankerite) was also determined from the diffractograms.

Paleosalinity Analysis.--The method of determining paleosalinities follows closely that of Nelson (1967). Jeppesen (1972) gives a good review of the method and explains the chemistry involved.

Fractionation of Phosphorus Species.--Each sample was treated according to the four fractionation procedures outlined below.

Sample Preparation. Twiss (1974) suggested using the clay fraction ($<$ 2 mu) of a ground sample to help eliminate organic phosphates that may interfere with accurate determination of inorganic phosphates upon which Nelson based his conclusions. Samples were selected from insoluble residue clay fractions from the four outcrops and matrices surrounding four pholadomyid and four *Reticulatia* cf. *huecoensis* King specimens. To test the validity of results, four whole rock samples were analyzed, three of which were duplicates of three of the above fractions. These four samples were ground in a mortar and sieved through a 230 mesh standard sieve. Half a gram of all samples was placed in 100 ml centrifuge tubes for extraction of phosphates.

Extraction of Al-phosphate. To the 0.50 g sample 25 ml of 1 N NH_4Cl was added and shaken at approximately 250 cyc/min for 30 minutes, removing water soluble and loosely bound phosphorus and exchangeable calcium. The suspension was centrifuged at 2100 rpm for 10 minutes and the supernatant solution discarded. Twenty five milliliters of neutral 0.5 N NH_4F were added to the residue remaining and the suspension shaken for one hour. The suspension was centrifuged and the supernatant solution discarded.

Extraction of Fe-phosphate. The residue remaining after Al-phosphate extraction was washed twice with 25 ml of saturated NaCl solution. Then 25 ml of 9.1 N NaOH were added, the suspension shaken for 17 hours, and centrifuged at 2100 rpm for 10 minutes. The clear soltuion was used in spectrophotometric analysis for phosphorus.

Extraction of Ca-phosphate. The residue retained from the Fe-phosphate extraction was washed twice with 25 ml of saturated NaCl solution. Then 25 ml of 0.5 N H_2SO_4 were added and the suspension shaken for 1 hour. The suspension was centrifuged at 2100 rpm for 10 minutes and the supernatant decanted and saved for spectrophotometric analysis of phosphorus.

Phosphorus Determinations.-- A Coleman Model 14 Spectrophotometer set at 660 mu was used for phosphorus determinations. A calibration curve (fig. 5) was constructed using six known concentrations ranging from 0.5 to 12.5 ppm phosphorus.

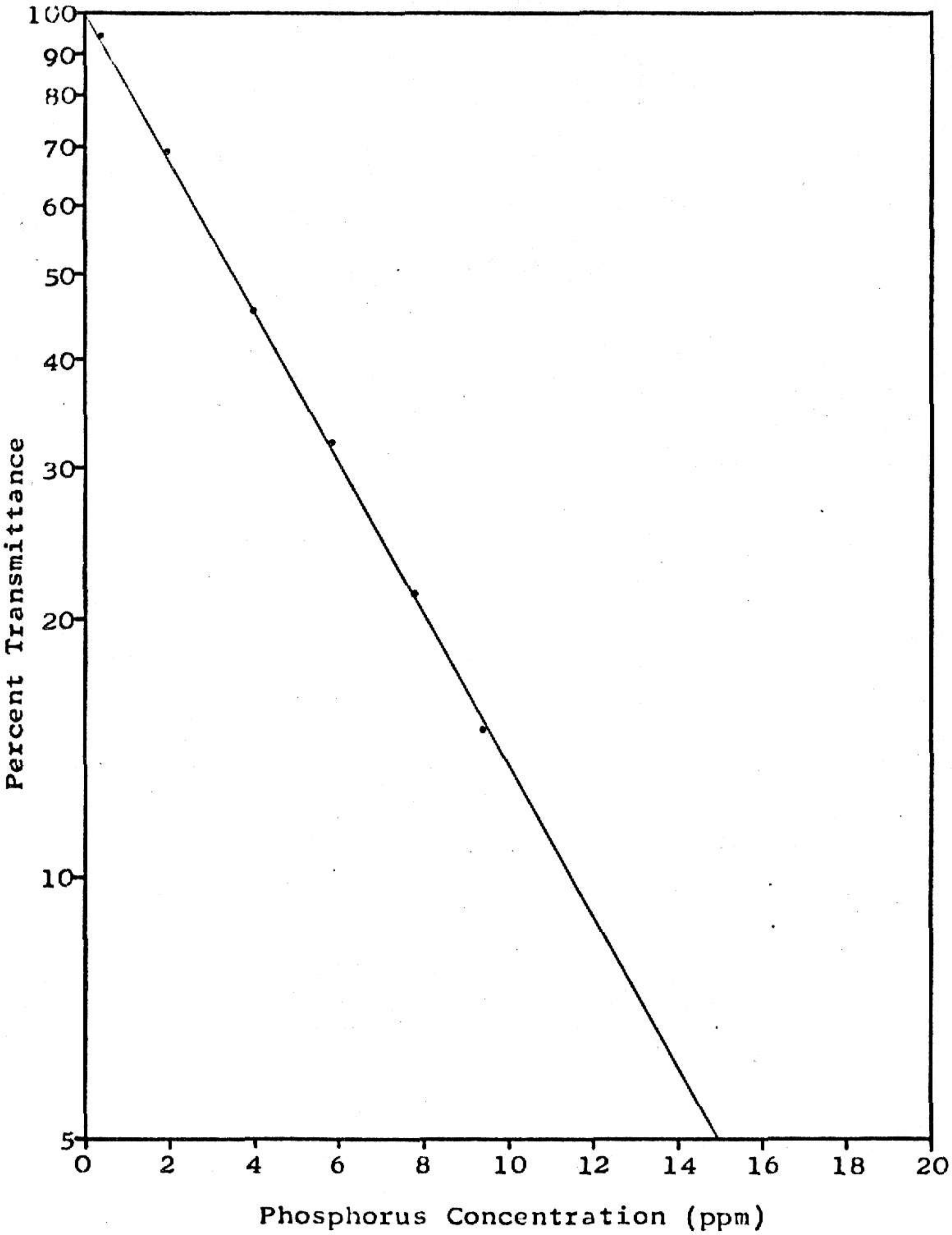


Figure 5. Concentration-transmittance Calibration Curve.

From this curve phosphorus concentrations of sample solutions were determined from percent transmittance observed on the spectrophotometer. The blank solution used in the spectrophotometer was prepared using the procedure outlined below, except that distilled water was used in place of the 3 ml sample.

Phosphorus determinations were made using the procedure of Jackson (1958), modified by Nelson (1967) and outlined by Jeppesen (1972, p. 28),

> A 3 ml aliquot of phosphorus solution was transferred by pipette to a 50 ml volumetric flask and diluted with distilled water to about 20 ml. (Two drops of 2,6-dinitrophenol indicator was added.) The pH of the solution was adjusted to about 3 by addition of 2N NaOH until 2,6-dinitrophenol indicator turned yellow. Dropwise, 2N H_2SO_4 was added until the solution became colorless, followed by the addition of 2 ml of sulfomolybdic acid solution by pipette. Distilled water was added to a volume of about 48 ml and the solution mixed. Three drops of chlorostannous reductant were added to develop the color. Distilled water was added to make up the 50 ml volume and the solution mixed.

Because the resulting blue color is unstable, the time required to read the spectrophotometer is critical. To keep results as comparable as possible each sample was immediately inserted into the instrument after the reductant was added and allowed to sit 60 seconds before measurement.

Procedures followed for preparation of reagents, known phosphorus solutions, and apparatus needed for extraction and determination are in Appendix III.

Salinity Determinations.--Salinity values were derived by plotting the calcium phosphate ratio $\frac{CaPO_4}{CaPO_4 + FePO_4}$ on

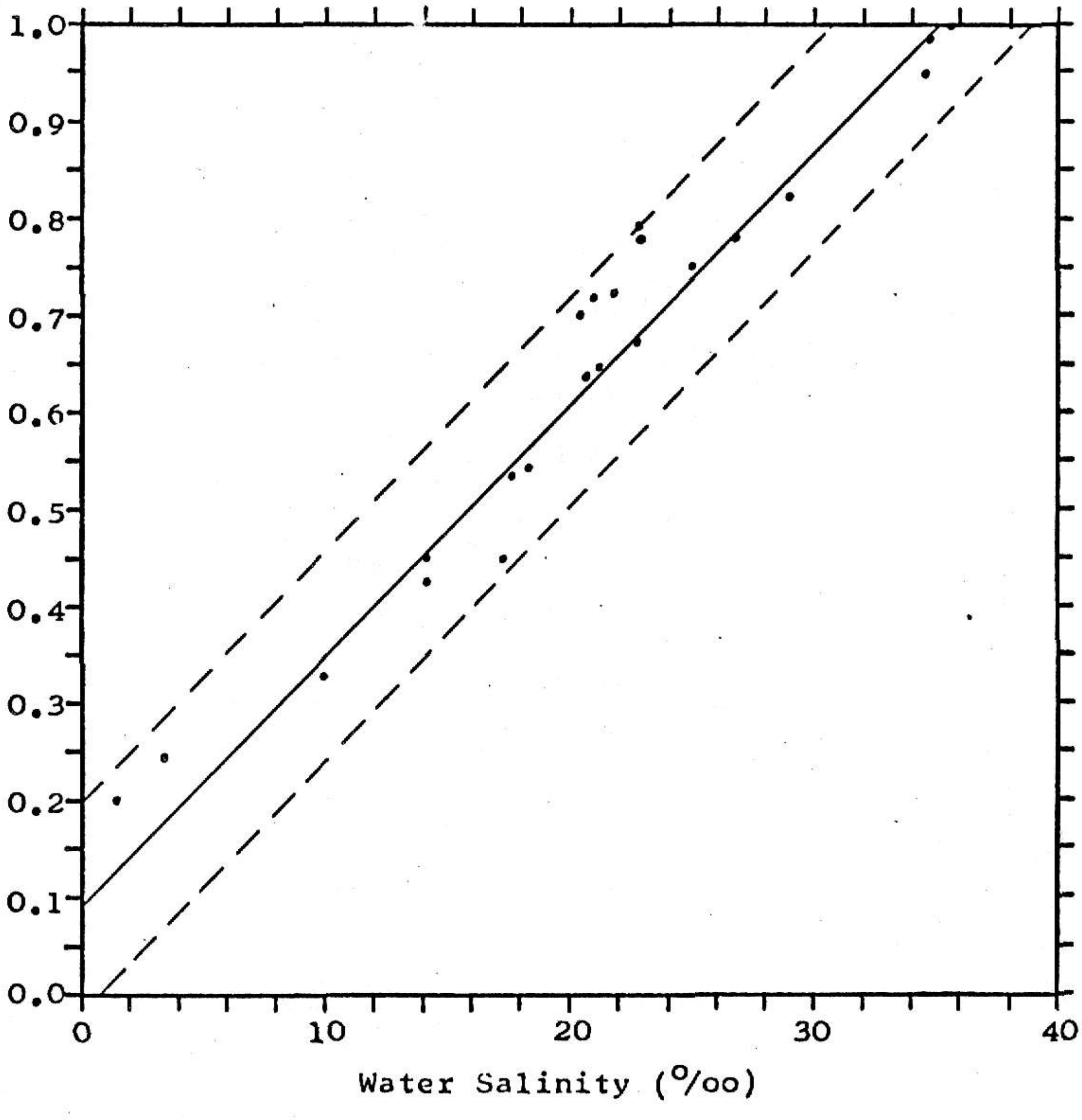


Figure 6. Relation Between Calcium-phosphate Fraction and Bottom Water Salinity (after Nelson, 1967, p. 919).

Figure 6. Nelson reports that these salinity values are accurate to within ± 4 parts per thousand (dashed lines).

GEOLOGIC SETTING

Stratigraphy

The Oketo Shale is the middle member of the Barneston Limestone, Chase Group, Gearyan Stage, Lower Permian Series, Permian System of Kansas. Moore (1936) named the unit after the town of Oketo, Marshall County, Kansas but never described it in detail. Oddly enough no good exposures now exist near Oketo (Kues, 1973). Jewett (1941, p. 76) defined the member:

> as the middle member of the Barneston Limestone, a bed of shale separating the flinty Florence limestone below from the Fort Riley limestone. Its thickness ranges from a feather edge to several feet. It is calcareous and locally contains one or more beds of limestone. The top of the Florence limestone is placed at the top of the uppermost flint bearing beds in the Barneston limestone, and the base of the Fort Riley limestone is placed at the base of the lowermost limestone layers directly below the strata to which the name Fort Riley was originally applied. Wherever shale occurs between the Florence and Fort Riley limestone, as their boundaries are thus defined, the shale is properly called the Oketo.

Photo 2 is a typical outcrop of the Oketo Shale in the study area.

The original Fort Riley Limestone Member of the Barneston Limestone included only the massive "rimrock" as conspicuous in the Fort Riley Military Reservation area. "Prosser and Beede (1904, p. 4) extended the contacts 'to include the thinner bedded limestones both above and below the massive Fort Riley main ledge'" (Jewett, 1941, p. 77).

Photo 2. Typical Oketo Shale Outcrop in Riley and Geary Counties, Kansas (Locality 9).

The Oketo Shale ranges in thickness from a feather edge in southern Kansas to 17 feet in northern Riley County. The unit extends into Nebraska to the north but thins to the south until it pinches out in southern Cowley County, where the Fort Riley Limestone lies directly above the Florence Limestone. However, the lower Fort Riley Limestone contains discontinuous "muddy" yellowish gray to gray lenses several feet thick that may be equivalent to the Oketo Shale. The lenses are bioturbated and contain *Reticulatia* cf. *huecoensis* and *Derbyia* spp., but no pholadomyids were observed.

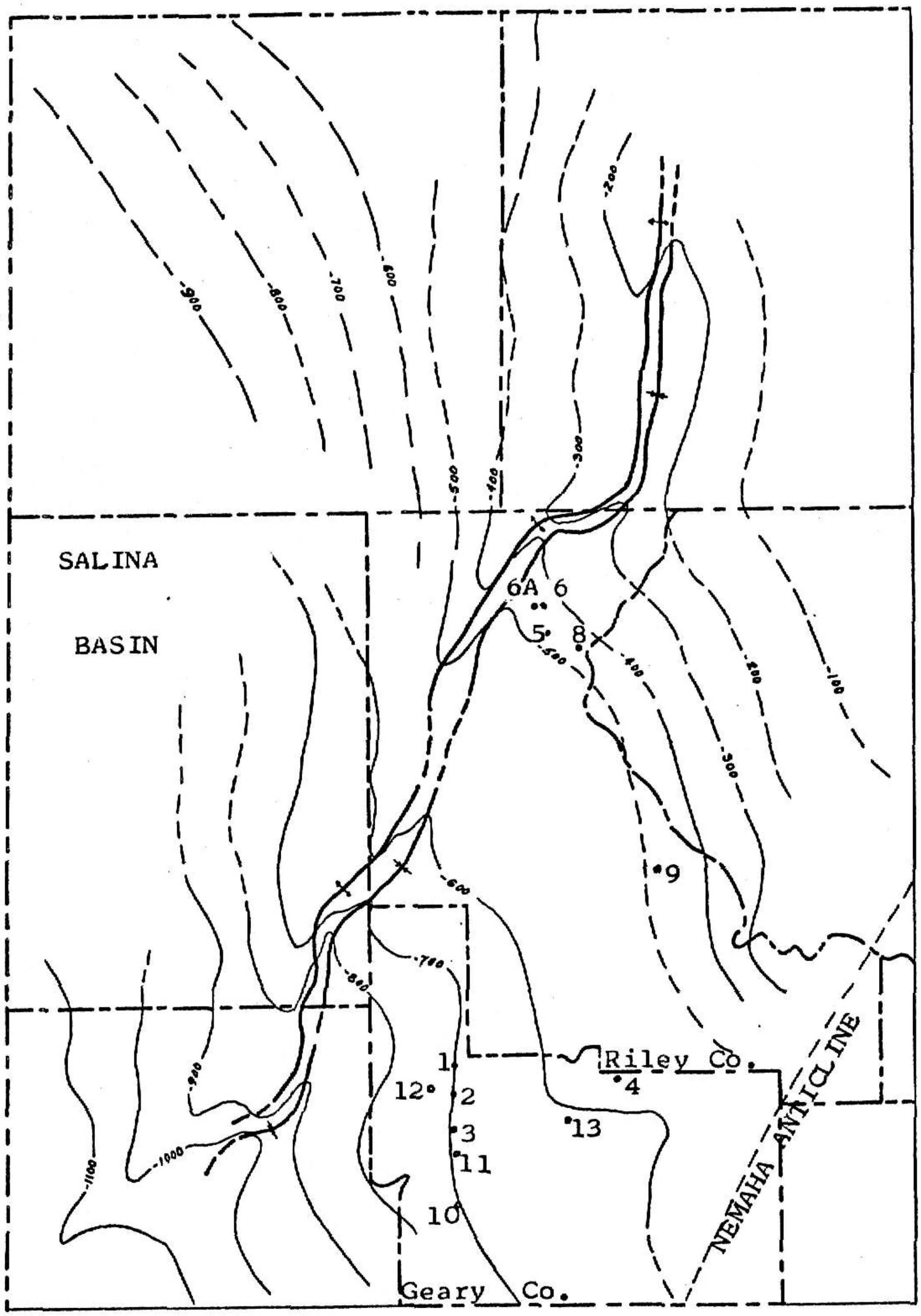
Structure

The area of study is within the Irving Syncline on the eastern extremity of the Salina Basin where it laps onto the western flank of the Nemaha Anticline. Regional dip is less than 1° to the west. The Abilene Anticline, a minor structural extension of the Nemaha Anticline, trends northeast-southwest through west central Riley County (fig. 7).

CORRELATION OF STRATIGRAPHIC COLUMNS

Geometry of the Oketo Shale is illustrated by a fence block diagram (fig. 8). Information from 12 of the 13 measured sections was used to plot lithologies. Locality 11 was not used because its incorporation would have masked the eastward extension to Locality 9.

The 12 localities were plotted on the surface of the projected block diagram. A vertical line was drawn from each locality to a depth equivalent to the thickest section (6A-2.57 m).



EXPLANATION

Surface Axis of Abilene Anticline

Surface Axis of Irving Syncline

-100 Subsurface Contours on Mississippian-Pennsylvanian Contact

•10 Measured Sections

Contour Interval 100 feet

Datum: Sea Level

Figure 7. Structure Contour Map Showing Abilene Anticline, Irving Syncline and Adjacent Structural Features (modified from Shenkel, 1959, p. 118).

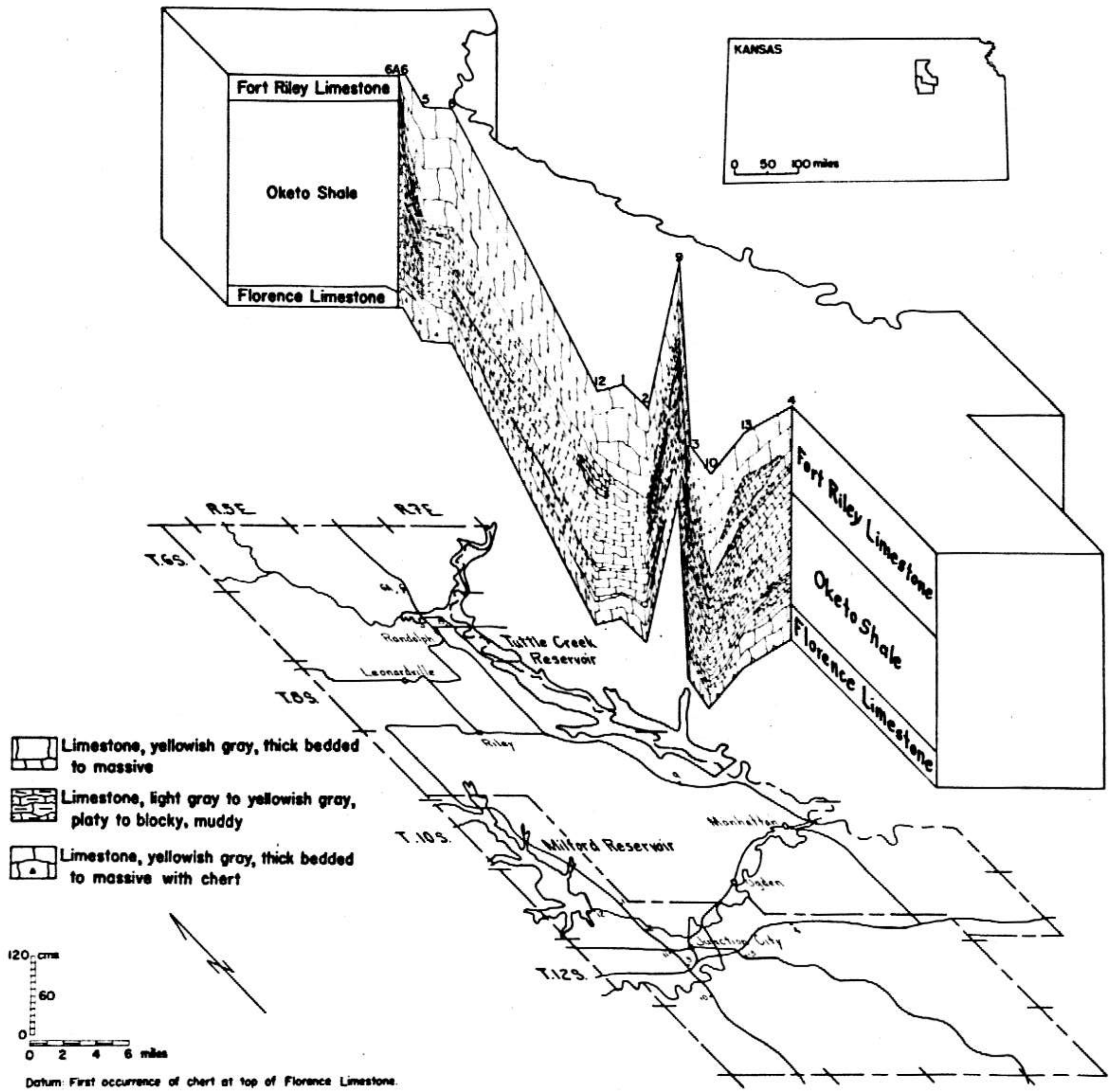


Figure 8. Panel Diagram of the Oketo Shale in Riley and Geary Counties, Kansas.

Lithology was plotted on the vertical line under each location and correlated from right (Locality 4) to left (Locality 6A) using lithologic similarities.

PETROLOGY

Insoluble Residues

General Statement.--Yarrow (1974) believed the Nemaha Anticline to be a minor influence during deposition of the Hughes Creek Shale. West, et al., (1972) asserted the Nemaha's influence on the Crouse Limestone, which is approximately 190 feet below the Oketo Shale. The asymmetrical, southwesterly plunging Irving Syncline underlies most of the study area, opening up into the Salina Basin to the southwest.

The area studied is bounded on the northwest by the Abilene Anticline and the southeast by a minor arching extension of the Nemaha Anticline. During Oketo deposition the Irving Syncline was probably nearly filled and erratic thickening and thinning of the unit (fig. 8) suggests deposition on a relatively horizontal plane with a gently rolling or hummocky surface.

A plot of average insoluble residue percentages of only the Oketo Shale (Table 1) on a map of the area (fig. 9), shows the effect of the two anticlines. Locality 6A (north) and Locality 10 (south) have higher insoluble contents than the other two localities and may reflect some influx of terrigenous sediment from topographic highs. Perhaps during a regressive phase of sea level change wave base was lowered

Table 1

Insoluble Residues in Percent of Whole Rock Sample

Sample No.*	Sand	Silt	Clay	Total
6A-1	1.1828	2.5545	1.6537	5.3910
6A-2	0.5633	7.6623	3.0192	11.2448
6A-3	0.5678	24.8052	5.3702	30.7432
6A-3B	4.6494	7.2658	8.2106	20.1258
6A-4-1	0.3361	26.1396	12.9612	39.4369
6A-4-2	0.2426	36.5318	16.4885	53.2629
6A-4-3	0.1767	12.3883	6.7650	19.3300
6A-5	0.3552	13.6742	7.0015	21.0309
6A-6	0.7692	8.1573	4.3773	13.3038
9-1	0.0759	8.4791	2.7362	11.2912
9-2	4.3874	25.7460	18.8960	49.0294
9-3	0.3426	18.1791	6.0641	24.5858
9-4	0.3377	8.4257	11.8685	20.6319
9-5	0.5411	16.9236	3.6696	21.1343
9-6	2.2344	12.1369	5.5752	19.9465
9-7	2.4834	10.9024	4.0724	17.4582
9-8	3.2207	10.3211	3.7689	17.3107
9-9	1.9077	9.0635	3.5974	14.5686
9-10	1.0064	4.1985	5.3885	10.5934
10-1	0.0442	3.0438	1.6148	4.7028
10-2	0.3142	4.5581	2.9006	7.7729
10-3	0.0332	1.5528	0.7554	2.3414
10-4	0.5040	16.1344	6.0822	22.7206
10-5	0.6511	15.1440	4.3014	20.0965
10-6G	0.6171	6.2182	1.9220	8.7573
10-6Y	0.4955	8.2589	4.1118	12.8662
10-7	0.1469	25.8835	13.3487	39.3791
10-8	0.1599	22.9919	12.8241	35.9759
10-9	0.0850	29.6750	14.3850	44.1450
10-10	0.4453	25.0329	14.3901	39.8673
10-11	0.8655	9.2556	3.7415	13.8626
10-12	0.2504	3.8670	1.9298	6.0472
12-1	0.1410	4.1951	1.2568	5.5929
12-2	0.2315	11.7879	0.1393	12.1587
12-3	0.4818	17.0540	3.8753	21.4111
12-4	0.3095	14.7205	4.9618	19.9918
12-5	1.1406	17.1855	3.3341	21.6602
12-6	0.6349	5.6730	2.7417	9.0496

*For explanation of sample numbering system see Introduction to Appendices, p. 87.

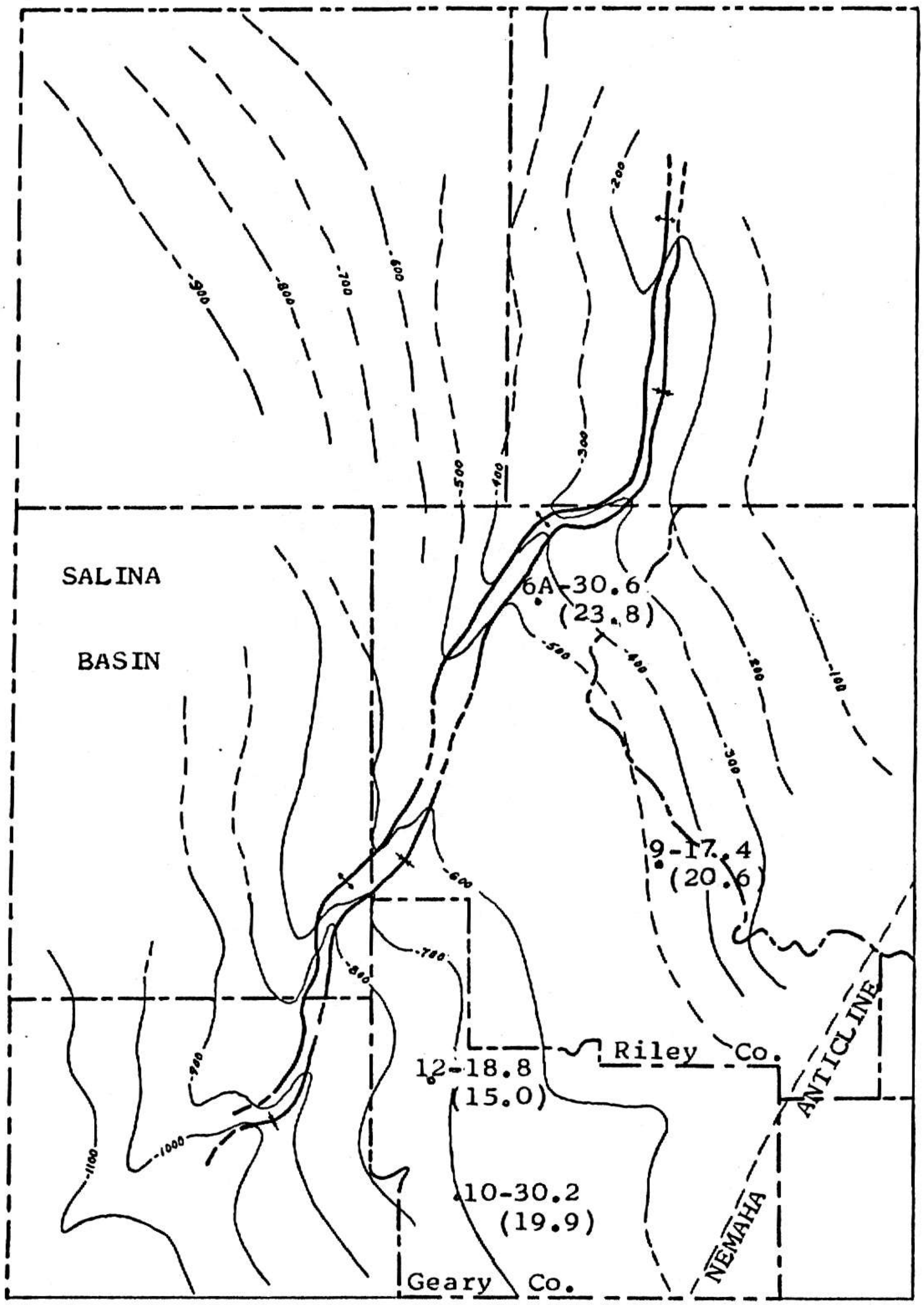


Figure 9. Relationship Between Percent Insoluble Residue and Structural Features (see fig. 7 and text for explanation).

and the submarine topographic highs eroded and the resultant sediments were carried into the basin of deposition. Values in parentheses (fig. 9) represent an average of percent insolubles (Table 1) for all beds below the Fort Riley "rimrock" through the first bed of the top of the Florence Limestone. In three of four localities the insoluble content decreases, indicating a decline of terrigenous influx into the basin. At Locality 9 insoluble content increases, probably because it is nearest the crest of the major Nemaha folding and continued to receive terrigenous sediment for a longer period during marine transgression. Grossnickle (1961) inferred from algal data that the Fort Riley "rimrock" at Locality 9 (my locality number) was deposited in a hypersaline environment during a marine regression. Based on insoluble residue results, my study indicates that the sea was transgressing, at least through basal "rimrock" time.

Kues (1973) suggested moving the boundary of the Oketo up to include the thin limestones now included in the Fort Riley Limestone. Based on insoluble residue percentages (Table 1) this is reasonable. At Localities 9 and 10 there is a sharp decrease (49 to 11 percent and 22 to 2 percent, respectively) in insoluble content at the base of the "rimrock" while at Localities 6A and 12 the contact with the Fort Riley is more gradational (11 to 5 percent and 12 to 5 percent, respectively). Other parameters should be considered before a decision is made.

Binocular Examination of Sand Fractions.--Listed in Appendix IV are the relative percentages of each component of the insoluble sand fractions from the four localities and from casts and matrices of selected macrofossils.

Glass occurs as volcanic shards averaging less than one percent in 7 out of 12 beds at both Locality 10 and in the samples of Florence Limestone at Locality 6. Shards are characterized by their clarity, angularity and conchoidally fractured surfaces. Hartig (1954, p. 7), concerning volcanic glass, stated that due to the mode of transport (wind) "it is doubtful that traces of volcanic glass are absent from any sub-aqueous or sub-aerial sediment,...". Consequently, environmental significance of this component is dubious, except that it indicates volcanic activity and/or wind blown volcanic glass shards during deposition.

Micaceous claystone grains may actually be coagulations of silt and clay that failed to disperse during washing and sieving. Their texture is grainy to flakey and somewhat "glittery," thus the adjective micaceous was added. They are quite soft and when broken are homogeneous.

Single clear flakes and a few books, several flakes thick, of muscovite occur which may be of igneous, metamorphic, or sedimentary origin.

Organo-phosphatic fragments occur as thin flakes that are light brown to jet black and have a silky to resinous luster. They are called organo-phosphatic because they resemble scolecodonts, which are also included in this category. Of the 56 samples examined only eight whole scolecodonts were found. The residues were not treated to remove organic matter and some flakes could be Recent plant rootlets, insect debris, etc.

Pyrite occurs primarily as complete or partial replacement of foraminiferid tests but it has also replaced some fecal pellets and/or castings. Tests of species of *Ammodiscus* and *Glomospira* are more commonly replaced by pyrite than are tests of *Ammovertella* or *Tolypammina*. Botryoidal spheres and irregular cylindrical fragments are assumed to be fecal pellets of small invertebrates. Organic matter is often pyritized in a reducing environment (Berner, 1971, p. 106). This pyritization probably took place after burial because reducing conditions are not generally amenable to life functions of animals.

Limonitic clays occurred as orangish brown (10R5/6) "balls" and probably are produced by oxidation of pyrite grains. The highest percentage of limonite occurred immediately above the highest percentage of pyrite (Appendix IV). Perhaps alternating or intermittent periods of reducing and oxidizing conditions existed.

Quartz, as used here, refers to distinct mineral grains of allogenic quartz. It is probably the most common terrigenous component in sand and silt fractions of carbonate rocks. Ninety five percent (estimated) of the grains were fine to very fine sand size. The few medium sand grains were well rounded, but some subangular to subround grains of finer sizes were present. Evidently the source area was far removed or only fine grained sands were available for transportation and deposition.

Insoluble sand fractions from the four localities averaged 82.4 percent silicified fossil fragments. Included in this category are arenaceous foraminiferids with silica cement or tests of calcareous foraminiferids replaced by silica.

Ideally the percentage of replaced constituents should be subtracted from the sand fraction percentage to yield the terrigenous sand fraction in the total insolubles. Because the sand fraction averages less than 0.8 percent of the insoluble residues, removal of authigenic minerals would reduce the sand content to an insignificant figure.

Appendix IV lists the major silicified taxa in order of estimated abundance in each sample. Brachiopod fragments were predominant in 28 of 56 samples examined. Foraminiferids were predominant in 27 and no fossils were found in the remaining sample (9-2). Four genera of foraminiferids, *Ammodiscus* sp., *Ammovertella* sp., *Glomospira* sp., and *Tolypammina* sp., were tentatively identified using Ireland (1956). Ireland (p. 840) said that "arenaceous Foraminiferida seem to prefer the environment of shallower water of the regressive phase" but "are tolerant of the deeper water phase of the maximum transgression." Therefore no conclusive inference can be made on direction of sea level change based on foraminiferids. All genera named above are siliceous but a few endothyrids, which are normally calcareous, were also identified.

Minor constituents included crinoid columnals, echinoid spines, fenestrate bryozoans, and monactinellid sponge spicules. Of these four groups only the sponge spicules may have been originally siliceous.

Thin Sections

Folk (1959) divided sedimentary rock constituents into three major categories: orthochemical, allochemical, and terrigenous. Orthochems are chemically precipitated within the basin of deposition and usually compose the matrix of a rock and/or cavity fillings or replacement products. Allochems are precipitated within the basin of deposition but have a "higher degree of organization" than orthochems and may have been transported to the depositional site from somewhere else within the basin. Allochems include fossils, oolites, pellets (fecal?) and/or intraclasts. Terrigenous components are derived from erosion of a land area outside the basin of deposition and include quartz, muscovite, clay minerals, rock fragments, etc.

Orthochemical Components.--Orthochemical components are subdivided into three classes, (1) micrite, (2) microspar and (3) spar.

Micrite is microcrystalline calcite composed of grains 1-4 microns in diameter and is usually subtranslucent.

Microspar is a coarse variety of micrite 4-10 microns in diameter, and translucent. It is probably an aggrading recrystallization product of micrite and is commonly interspersed throughout a micrite matrix.

Spar is composed of calcite forming crystals or grains larger than 10 microns in diameter. Its coarse grain size and clarity distinguish it from the two aforementioned calcite types. Spar usually occurs as a pore filling cement but can be the result of aggrading recrystallization of microspar (Folk, 1959). The most common occurrence of spar in the Oketo thin sections is as a replacement of fossil fragments and as infillings of fossil shells.

Allochemical Components.--Folk (1959, p. 4) stated that "...only four types of allochems are of importance: intraclasts, oolites, fossils, and pellets." Of these four types oolites were never observed and only one occurrence of an intraclast occurred in a burrow filling which I believe was probably dislodged during burrow construction and became incorporated in the filling. Although the intraclast does not indicate current surges as Folk hypothesizes, it does imply that some sediment was consolidated during deposition.

Pellets are also a minor constituent, averaging less than one percent (Appendix II), but are more prevalent than intraclasts. Pellets took the form of spheroidal to ovate, reddish brown, structureless grains and are associated with bioturbated beds and burrow fillings. Most occur as isolated grains, ranging in size from 0.06 to 0.30 mm, and in clusters or chains. Because of their associations these pellets are probably invertebrate feces, but to assign them to a particular phylum would be presumptuous.

Fossils compose 96.2 percent of the allochems in each sampled bed (Appendix II). Characteristics helpful in identifying fossil fragments are listed below:

Brachiopods	Preservation of shell microstructure, cross-sectional views of costae or plications, and general crescentic forms of fragments.

Bivalves	Crescentic cross section and lack of shell microstructure as a result of recrystallization were the two main features of bivalve fragments.
Bryozoans	Fenestrate cross section and fibrous appearance identified fenestrate bryozoans. Honeycombed cross section was typical in ramose and fistuliporid Bryozoa.
Crinoids	Inflated shape, micro-vesicular texture and straight extinction are typical of crinoid plates and columnals. Water filled vacuoles extinguish as a single crystal unit.
Echinoids	Echinoids were not common but dark and light reticulate patterns are distinctive and they extinguish as a crystal unit.
Foraminiferids	Two groups of foraminiferids were identified, endothyrids and opthalmids. A spirally segmented shape and resinous brown color, respectively identified these two elements. Both groups were tabulated collectively as Foraminiferida.
Gastropods	All gastropods identified in thin section were high-spired and usually preserved as sparry shells with micritic chamber fillings.
Ostracodes	Only smooth shelled ostracodes were present. Microprismatic to fibrous microstructure was visible in some specimens but most were recrystallized to sparry calcite. Their bivalved and/or crescentic cross section and small size (0.4 - 0.9 mm) are diagnostic.
Algae	Osagia, described by Henbest (1963) as a symbiotic association of Girvanella (an alga) and Hedraites (a foraminiferid), is the dominant algal representative. It occurs almost exclusively as encrustations around fossil fragments but also as solid ovate masses. The color ranges from a deep brown to a blurry gray in polarized light.

> Henbest (1963, p. 36) stated that *Osagia* is an "abundant constituent of shallow water (photic zone) marine communities of Mississippian to Permian time." Some degree of turbulence is required to roll grains over to allow algae to grow in concentric layers around a nucleus. Turbulence is more common in shallow water, and light sufficient for photosynthesis is usually limited to the upper 100 meters of ocean waters. This depth, of course, depends on the degree of turbidity.
>
> In two beds (10-5 and 10-6) an unusual fossil was observed that could not be positively identified (Plate I, fig. 5). The pseudocoiled appearance was initially believed to be a fusulinid but the irregularity of the perimeters eliminated that possibility. These *Osagia* encrusted grains were tentatively identified as a variety of dasycladacean algae similar to *Diplopora* sp. Their occurrence only in burrow fillings is puzzling. Perhaps some burrowing organism selectively gathered these algal "balls" and stored them for later ingestion or they rolled into the empty burrows.

Terrigenous Components.--Muscovite and quartz are the only terrigenous components identified in thin section and compose 6 percent or less of each of the samples (Appendix II). Insoluble residue analysis indicated clay minerals but these were not identified in thin section because of the high percentage of calcite and iron oxide staining.

Fine to very fine sand-sized flakes of muscovite are oriented parallel to bedding and quartz occurs only as coarse to fine silt size grains.

Diagenetic Minerals.--Iron compounds and microquartz are considered probable diagenetic products. Included in the iron compound category are limonite-stained clays and/or carbonates, limonite, and pyrite. Pyrite, which has already been discussed as an insoluble residue, is probably the parent mineral from which the limonite was derived.

Fibrous, or chalcedonic, microquartz occurs as a replacement product in fossil fragments except in the top bed of the Florence Limestone where it forms the matrix of chert nodules. Areas of silicification in fossil fragments are always in the central portions of fragments, never intersecting the periphery, and are stained to some degree by iron. Only crinoid and brachiopod fragments are commonly affected, but a few bryozoan and echinoid fragments are also partly silicified.

X-ray Diffractograms

Calcite and quartz are the two dominant minerals in all four studied localities of the Oketo Shale. Minor quantities of ankerite, an iron-rich dolomite, are present at all localities. At Localities 10 and 6A, ankerite is much higher stratigraphically than at Localities 9 and 12. The anomalous relationships between ankerite distribution and position within the Irving synclinal basin leads me to believe that the origin of the ankerite was not penecontemporaneous but rather occurred later in the diagenetic history of the unit. No correlation exists between molecular percent $MgCO_3$ in calcite and occurrence of ankerite (Table 2), which may indicate that ankerite originates as a primary mineral and not as an alteration product of calcite.

One sample (12-3) of an insoluble silt fraction was analyzed by x-ray diffraction. The dominant mineral is quartz

Table 2

X-Ray Diffraction Data: Molecular Percent $MgCO_3$ and Ankerite

Locality - Bed*	Molecular Percent $MgCO_3$	Ankerite**
6A-1	1.65	
6A-2	1.35	X
6A-3	1.35	X
6A-4	1.65	X
6A-5	1.35	X
6A-6	1.65	X
9-1	.75	
9-2	1.65	
9-3	.75	
9-4	1.35	
9-5	1.65	
9-6	1.35	
9-7	2.55	
9-8	1.65	X
9-9	1.35	X
9-10***	.75	
10-5	1.35	
10-6G	.75	
10-6Y	.75	
10-7	1.95	X
10-8	1.65	X
10-9	1.65	X
10-10	1.35	X
10-11	.75	
10-12	.75	X
12-1	1.05	
12-2	1.35	
12-3	1.35	
12-4	0.00	
12-5	2.30	X
12-6	1.35	X

*For explanation of numbering system see Introduction to Appendices, p. 87.

**X = Presence of ankerite

***Chert bed

and minor quantities of muscovite and several other unidentified minerals.

One sample (6A-3B) of silicified fossil fragments was ground by mortar and pestle and analyzed by x-ray diffraction. Quartz proved to be the dominant mineral and a small amount of calcite was protected from acid dissolution probably by overgrowths of microquartz.

Paleosalinities

Values in Table 3 indicate that the Oketo depositional area spanned both fresh and marine water environments. Closer examination reveals a definite anomaly. Samples consisting only of clay fractions have consistently low salinity values, but whole rock samples approach average marine salinity (35 $^{o}/oo$). Obviously there is something wrong with the sample preparation technique.

Golterman (1973, p. 528) quoting Harter about lake muds stated:

> ... that between half and all of the phosphate adsorbed by mud was recovered in the NH_4F ($AlPO_4$) and NaOH ($FePO_4$) extracts.... Since none of the adsorbed phosphate was found in a form extractable with H_2SO_4 (calcium phosphate) the remainder was assumed to have been incorporated into organisms.

Although calcium phosphate is more abundant in marine sediments than the other two compounds, it is also selectively incorporated into marine skeletons. Removal of calcium phosphate would lower the ratio used for salinity determinations. Perhaps using a whole rock sample replaces the $CaPO_4$ in the form of organically produced skeletal matter.

Table 3

Paleosalinity Estimates Based on Sedimentary Phosphates

Sample No.*	$Ca-PO_4$ Conc. (ppm)	$Fe-PO_4$ Conc. (ppm)	$\frac{Ca}{Ca + Fe}$	Salinity** 0/00
6A-4-2	0.7	1.2	.346	10
9-7	0.6	2.2	.217	5
10-8	0.7	1.4	.322	9
12-4	0.4	0.5	.432	13
12-4***	2.5	0.4	.862	30
P.4-16m	0.1	10.5	.010	0
P.8-9m***	3.5	0.4	.897	31
P.9-D-7m	0.8	0.5	.615	20
P.10-16c	0.5	0.6	.458	14
P.13-0m	0.7	1.8	.280	7
P.13-0m***	2.1	0.5	.808	28
R.1-6&7m	1.4	5.8	.191	4
$\bar{R}$.10-4m	0.3	0.5	.420	13
$\bar{R}$.10-4m***	3.5	0.5	.875	30
$\bar{R}$.11-5m	0.9	2.3	.283	7
$\bar{R}$.13-0m	1.1	4.5	.196	4

*For explanation of sample numbering system see Introduction to Appendices, p. 87.

**Paleosalinities estimated from Figure 6.

***Values obtained from whole rock sample (for explanation, see text, p. 12).

Golterman (1973) stated that Olsen, using radioactive phosphorus, found adsorption of phosphorus to be affected by Eh conditions in the sediments. In an oxidizing environment sediments exchange and adsorb more phosphorus than they would in a reducing environment. Therefore, phosphorus ratios in rock samples could be variable at time of deposition depending on Eh at the sediment-water interface and undergo many subsequent changes during burial (often accompanied by reducing conditions), later diagenesis, and finally, oxidizing conditions during weathering. The pyrite and limonite in nearly all (45 of 56) samples indicate that both reducing and oxidizing conditions have existed in Oketo sediments either before, during, or after its lithification.

Inconsistency of salinity values may be due to any or all of the factors mentioned above, but I favor selective removal of $CaPO_4$. In every case the amount of calcium phosphate increases when a whole sample is used, while iron phosphate remains nearly constant. Addition of calcium phosphate is the best explanation of this increase; the origin of this calcium phosphate is uncertain, but is believed to be organic.

More research needs to be done on this method of paleosalinity determination before accurate results can be obtained from a wide variety of rock types.

PALEOBIOLOGY

Descriptions of Studied Macrofossils

During the field work I was under the impression that all large *in situ* bivalves in the area surveyed belonged to the genus *Wilkingia*. This impression was generated by the common usage of the name by the faculty and graduate students that helped me decide to work on the Oketo Shale. However, upon close examination of collected specimens, which were internal casts, I discovered that at least three genera were represented, *Exochorhynchus*, *Wilkingia* and *Chaenomya*.

One major problem developed with this discovery. Orientation and size data had been collected under the name *Wilkingia* and all measured specimens were not collected for laboratory study. Therefore an undetermined number of each of the three genera was sampled. The result was that the amount of workable data was reduced by nearly two thirds. Only data from the 27 positively identified specimens, 4 *Wilkingia* cf. *terminale* Hall, 3 *Chaenomya* cf. *cooperi* Meek and Hayden, and 20 *Exochorhynchus* cf. *altirostratus* Meek and Hayden, were used in reconstructing the autecology of each genus (Appendices V and VI). Conceivably all three genera could have demonstrated different azimuth orientations. Because of classificatory problems and small sample sizes all phyladomyids were combined into one group to test randomness of azimuth orientation. Combining these different genera infers that organisms of similar morphology and life habits assume similar orientations in the substrate. To the best of my knowledge this premise has not been confirmed by modern studies. No such problems were encountered for the large brachiopod, Reticulatia cf. huecoensis.

Phylum Mollusca Linne, 1758
Class Bivalvia Linne, 1758
Subclass Anomalodesmata Dall, 1889
Order Pholadomyoida Newell, 1965
Superfamily, Pholadomyacea Gray, 1847
Family Pholadomyidae Gray, 1847
Genus Wilkingia Wilson, 1958
Wilkingia cf. terminale Hall, 1852

Morphology.--Wilkingia is elongate ovate, inflated at the anterior and umbonal regions and narrows posteriorly. The beaks are incurved and depressed and located about 0.25 percent of the overall length posterior of the anterior margin. There is a variable anterior and pronounced posterior gape. A deep pallial sinus is described by Wilson (1959) and Runnegar (1972) but is not preserved on any of the specimens studied. The species W. cf. terminale is used because of the similarity between my species and those described in Mudge and Yochelson (1962, p. 90). This genus differs from Exochorhynchus in having a distinct anterior bulge and from Chaenomya in having a narrower posterior gape and being larger.

Life Position and Habits.--Inferred life position for Wilkingia cf. terminale is with its plane of commissure vertical and its dorsal margin at an acute angle to bedding, anterior end down (Photo 3 and fig. 10).

Pearce (1973) compared Wilkingia to Grammysia obliqua (Silurian). Comparison of length to height ratios (2.3 to 1.9, respectively) shows a noticeable difference in the two genera. Also, the average angle of repose for Grammysia is

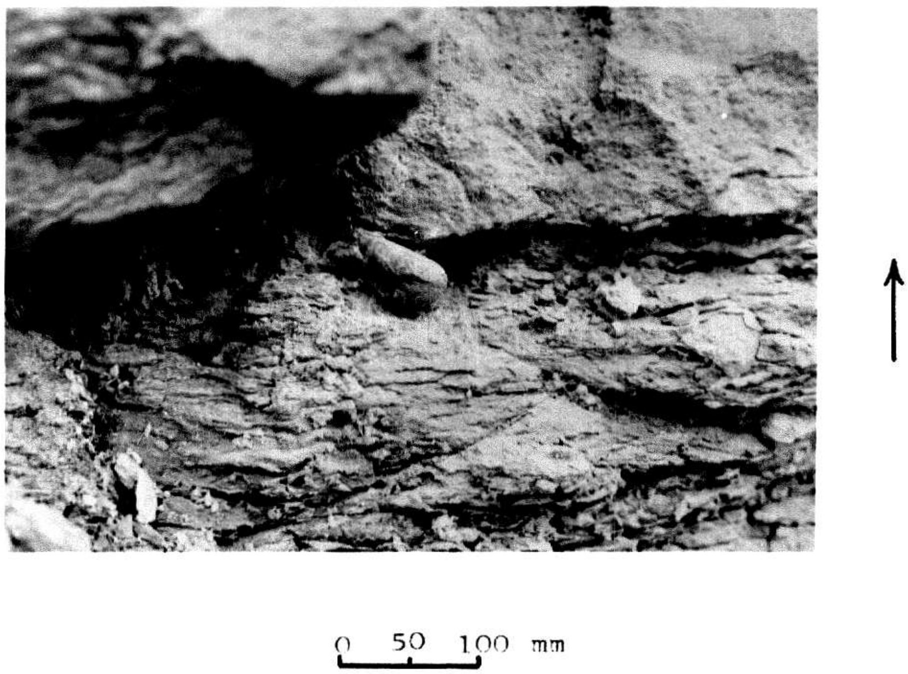


Photo 3. Wilkingia cf. terminale in life position (center). (Oblique right anterior view, beaks are to right, posterior embedded in matrix.)

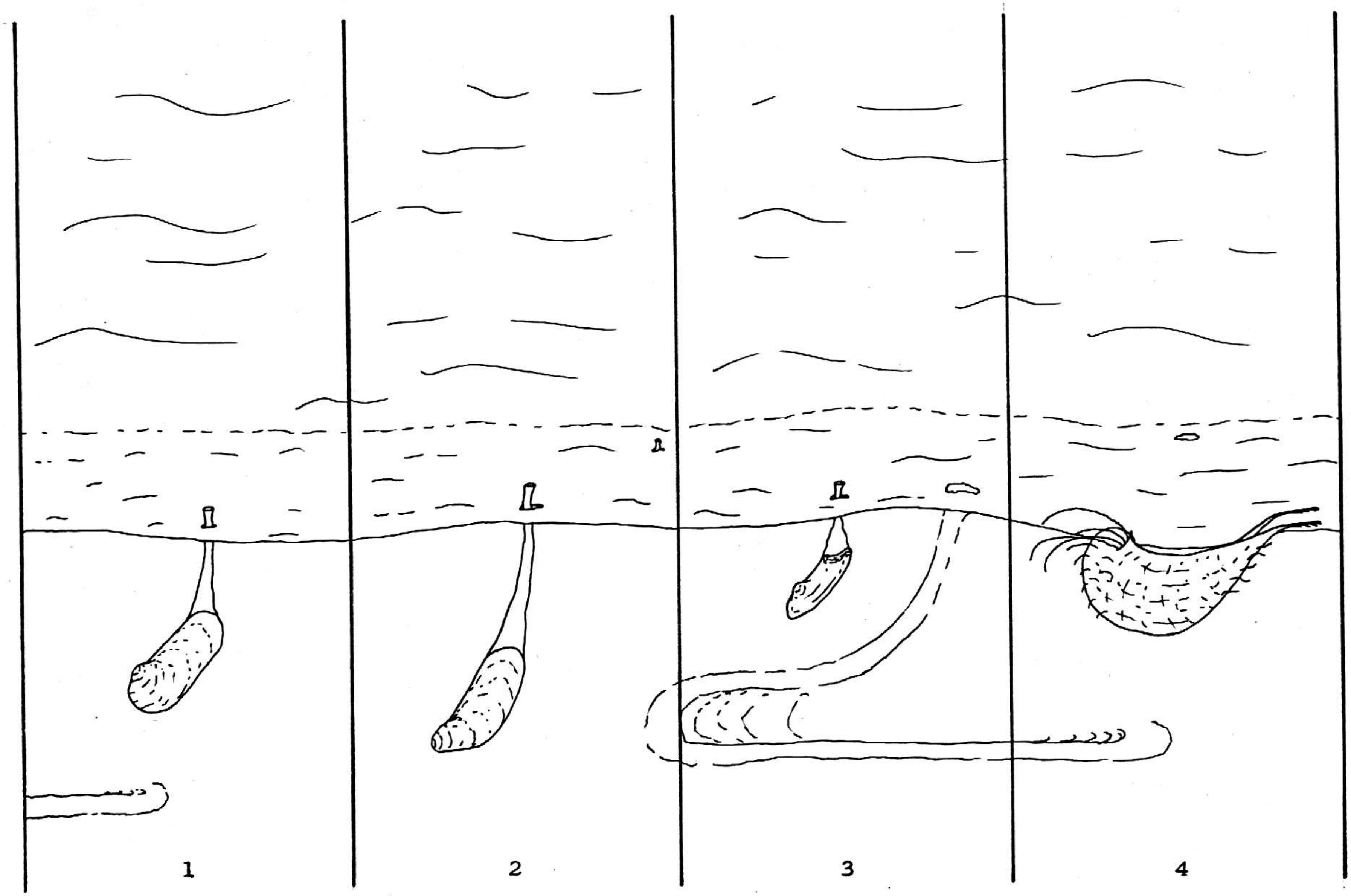


Figure 10. Inferred Life Positions of Studied Macrofossils in the Oketo Shale.
1- Horizontal burrow, _Wilkingia_ cf. _terminale_ , 2- _Exochorhynchus_ cf. _altirostratus_,
3- _Chaenomya_ cf. _cooperi_, oblique and horizontal burrow, 4- _Reticulatia_ cf. _huecoensis_.

30° to 45° (Bambach, 1971) while that of Wilkingia is 26° (Pearce, 1973).

My data on Wilkingia reveal an average length to height ratio of 3.0 (Appendix VI) and an average angle of repose of 18.5° (Appendix V). The increased length to height ratios in Wilkingia may indicate a long and large siphonal tube.

Cox (in Moore, 1969, p. N838) described the genus as having the "beaks placed 0.2 to 0.25 behind front margin." This beak placement parameter corresponds to anterior length (AL) as used by Bambach (1969, p. 170) to infer a large siphon. A value of 0.2 to 0.25 (AL) would give a ratio of 0.25 to 0.33 (AL/L) and infer an elongate posterior. Bambach (1969, p. 170) stated "...large siphons or reduced anteriors, as seen in many sessile forms such as the grammysioids or mytilids, may be reflected in an expanded or elongate posterior end."

The reduced angle of repose may be an adaptation to stabilize the shell or it may be the result of compaction during early diagenesis.

Runnegar (1972) compared Wilkingia to the rare "living" species Pholadomya candida Sowerby. External morphology of the two are similar (Plate II). By comparing adductor muscle scars of P. candida with those of several species of Wilkingia, Runnegar inferred that the extinct genus probably lived in a similar environment and possessed similar life habits.

Cox (in Moore, 1969, p. N827) stated that most pholadomyids are deep water inhabitants. Runnegar, however, reported finding P. candida in muddy sediments of a harbor channel as well as in sand at depths of 10 to 20 feet less than 60 feet off shore and stated (p. 46):

> *P. candida* inhabited a sandy to muddy sublittoral environment. Like *Mya* it probably burrowed deeply and would be washed ashore only after being exhumed by storm waves. The (atrophied) foot and pedal orifice are so small that it would be impossible for the animal to reburrow after being disinterred.

Thus *P. candida* is a "passive burrower."

The fact that *Wilkingia* is always found articulated supports an infaunal habit. Pholadomyids are present at the end of burrows up to half a meter deep in a clam burrowed unit of the Three Mile Limestone in Cowley County, Kansas (Plate II, fig. 5) and thus may have been deep infaunal organisms.

Because most deep burrowers tend to orient their long dimension perpendicular to bedding, the low angle of repose of *Wilkingia* is puzzling. Perhaps the soft character of the substrate forced rotation of the shell to afford a broader surface (ventral margin) for support. This rotation would tend to "kink" the siphons, but shift of the posterior gape toward the dorsal anterior probably effectively countered the "kinking." Compaction during early diagenesis undoubtedly had some disorienting effect on the angle of repose and in life the angle was probably higher than at present.

Genus *Exochorhynchus* Meek and Hayden, 1864
Exochorhynchus cf. *altirostratus* Meek and Hayden, 1864

Classification.--Meek and Hayden originally described the species as *Allorisma*? *altirostrata* in 1858 but subsequently changed the name to *Sedgwickia*? *altirostrata* in 1864 (Meek and Hayden, 1864, p. 41). In their comments on the generic name they suggested that if certain internal characters, unknown at that time, were sufficient to establish a new genus then the name Exochorhynchus should be used. Evidently such characters were found because the Treatise on Invertebrate Paleontology (Moore, 1969, p. N831) has adopted the suggested name. However, the species pictured is referred to as E. altirostratus. The ending -us has replaced -a because in changing the generic name the gender was also changed from feminine to masculine. A rule of zoological nomenclature is that a species name must agree in gender with the generic name, thus the species name altirostratus, is correct.

Morphology.--The internal cast is longitudinally oblong to oval and highly inflated in the umbonal region. The beaks are terminal, incurved, and elevated slightly above the dorsal margin. The anterior edge is perpendicular to, or depressed forming an acute angle with, the dorsal margin. A slight gape is present in the anteroventral region but closes posteriorly. The ventral margin is straight to slightly convex while the posterior margin is broadly rounded with gapes, nearly half as wide as the shell width. Internal, reflecting external, ornamentation consists of concentric ribs radiating from the beaks. These ribs are well defined across the umbones but flatten out and disperse toward the margins (Plate II, fig. 4a). An umbonal sulcus is described for the genus but was not observed in my specimens and may be a result of poor preservation. To my knowledge there is only one species, altirostratus, in this genus and my specimens possess the basic specific characteristics stated by Meek and Hayden (1864, p. 41). The main morphological difference between *Exochorhynchus* and *Wilkingia* is the lack of an anterior bulge in *Exochorhynchus*; its larger size (Table 4), terminal beaks, and narrower posterior gape distinguish it from *Chaenomya*.

Life Position and Habits.--Because *E*. cf. *altirostratus* is morphologically similar to *Wilkingia* cf. *terminale* its life position (fig. 10 and Photo 4) and habits are presumably similar. The elevation of the beaks is probably a consequence of depression of the anterior margin. This depression presumably was an adaptation to help the animal obtain a stable position as it burrowed in relatively soft, but adhesive mud. The flattened anterior would offer a broader surface for support than a tapered one and enable a higher angle of repose (27°, Appendix V) than that demonstrated by *Wilkingia*. A higher angle may have permitted *E*. cf. *altirostratus* to burrow deeper and thus escape predation and/or disinterment. Using Bambach's technique, the AL/L ratio of *Exochorhynchus* would be 0.00 and indicate total atrophy of an anterior bulge. The extreme anterior position of the beaks further supports the presence of a large siphon, possibly larger and/or longer than in *Wilkingia*, enabling it to burrow deeper. Stratification within the substrate would not enable the two species to outcompete one another for nutrients at the surface unless stratification was also effected above the sediment-water interface by extension or retraction of the siphon. Stratification above the sediment-water interface would enable some individuals to

Table 4

Pholadomyid Basic Statistics

	Minimum	Maximum	Mean	Variance	Std. Deviation	Std. Error of Mean
			Wilkingia cf. *terminale*			
Length (mm)	59	100	84	308.7	17.6	8.8
Width (mm)	23	38	34	56.2	7.5	3.8
Height (mm)	22	41	29	66.9	8.2	4.1
			Chaenomya cf. *cooperi*			
Length (mm)	44	54	48	28.0	5.3	3.0
Width (mm)	19	20	19	0.3	0.6	0.3
Height (mm)	17	20	19	2.3	1.5	0.9
			Exochorhynchus cf. *altirostratus*			
Length (mm)	46	105	71	216.7	14.7	3.3
Width (mm)	22	44	34	49.6	7.0	1.6
Height (mm)	18	38	28	55.6	7.4	1.7
			Taxonomically Undifferentiated Pholadomyids			
Length (mm)	12	106	64	663.3	25.8	4.0
Width (mm)	5	46	29	134.4	11.6	1.8
Height (mm)	5	41	24	69.6	8.3	1.3

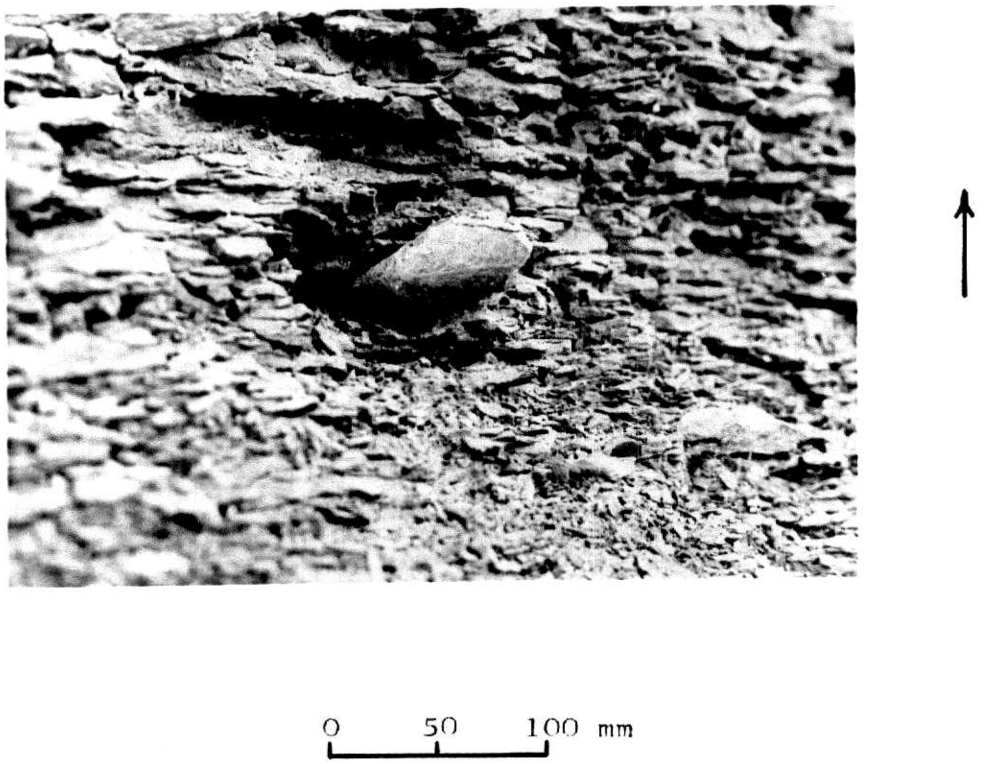


Photo 4. Exochorhynchus cf. altirostratus in life position (center). (Oblique, left lateral posterior view, beak is to left rear and partially hidden by matrix.)

draw nutrients from different levels and thus lessen competition. However, exposure of a large area of the siphon above the substrate would make it vulnerable to predators. For example, Trevallion (1970) found that young fish fed on the exposed inhalent siphons of Tellina tennuis, an infaunal bivalve. No evidence of vertebrates (fish) were found in any of the laboratory analyses, although they may have been present, and perhaps "siphonal stratification" was beneficial despite its disadvantages.

Genus Chaenomya Meek, 1894
Chaenomya cf. cooperi Meek and Hayden, 1864

Morphology.--The shell is oblong, subcylindrical and the posterior is abruptly truncated obliquely with a gape equalling shell width. The anterior is narrowly rounded with a narrow gape on the ventral side. Beaks are incurved, depressed and located half way between the anterior margin and the middle of the shell. Irregularly spaced concentric ribs radiate from the beaks toward the margins and bend abruptly anteriorly when they approach the posterior gape, resulting in a wrinkled texture around the opening (Plate II, figs. 2a and b). Chaenomya cf. C. cooperi can be distinguished from other species of Chaenomya by its proportionally shorter form, more distinctly truncated and shorter posterior end and less prominent beaks. It is easily differentiated from the other two bivalves (Wilkingia and Exochorhynchus) by its smaller size, less distinct concentric ornamentation and extremely wide posterior gape. Because it could be easily distinguished from

Wilkingia and Exochorhynchus in the field, no specimens of Chaenomya cf. cooperi are included in the Taxonomically Undifferentiated Pholadomyids in the tables and appendices.

Life Position and Habits.--Because of its smaller size (Table 4) Chaenomya undoubtedly lived at a shallower depth than the larger pholadomyids (fig. 10), but its orientation is presumably the same based on similar morphology and angle of repose (Appendix V). The extreme gape possibly prevented full retraction of the siphon into the shell and for reasons of protecting its exposed siphon, the clam necessarily burrowed completely below the sediment surface. Only three specimens of Chaenomya were found in the Oketo Shale. Rarity of this species could be explained by its vulnerability to predation or disturbance, or more likely by competitive exclusion by the larger bivalves. Its smaller form could also be overlooked in sampling.

Phylum Brachiopoda Dumeril, 1806
Class Articulata Huxley, 1869
Order Strophomenida Opik, 1934
Suborder Productidina Waagen, 1883
Superfamily Productacea Gray, 1840
Family Dictyoclotidae Stehli, 1954
Genus Reticulatia Muir-Wood and Cooper, 1960
Reticulatia cf. huecoensis King, 1931

Morphology.--The shell is large (Appendix VII), subquadrate, elongate longitudinally, and strongly concavo-convex. The pedicle valve has a strongly curved, sulcate trail consisting of overlapping shell lamellae and is ornamented by a reticulate pattern of tubercles over most of the posterior surface. Small spines are present along the hinge line extensions, or "ears."

The brachial valve overlaps the pedicle valve ears and trail, and has tubercles forming a reticulate pattern on the exterior. The brachial interior is marked with two large lobate, brachial ridges on either side of a median septum. A trilobate cardinal process extends past the hinge line on the midposterior margin. Two pair of elongate adductor scars are located midway between the cardinal process and brachial ridges on either side of the median septum. Muir-Wood and Cooper (1960, p. 284) only describe one species of *Reticulatia*, i.e., *R. huecoensis* from the Permian.

Life Position and Habits.--Lack of cementation scars and pedicle opening suggests a free-lying mode of life for *Reticulatia* (fig. 10 and Photo 5). Living on a soft substrate, as the Oketo Shale probably represents, the strongly convex pedicle valve undoubtedly settled into the sediment to some degree. Spines along the hinge line, together with the ears, probably served to prevent sinking of the posterior edge where most of the visceral and muscular weight was concentrated. As growth proceded, however, added weight caused the unsupported anterior to settle. Had the valves settled below the sediment surface, the lophophore would have certainly become clogged and proved fatal to the animal. A geniculated trail was secreted to add a large supportive area to the anterior margin (Plate III, fig. 1) and prevented its sinking into the mud.

The angle of repose averages 9.4° and tends to decrease during ontogeny (fig. 11). This decrease indicates a rotation (although slight) to the horizontal as the animal ages and further supports the function of the trail suggested above.

0 45 mm

Photo 5. Reticulatia cf. huecoensis in life position (center). (Left lateral view, matrix removed to expose specimen, beak is to right.)

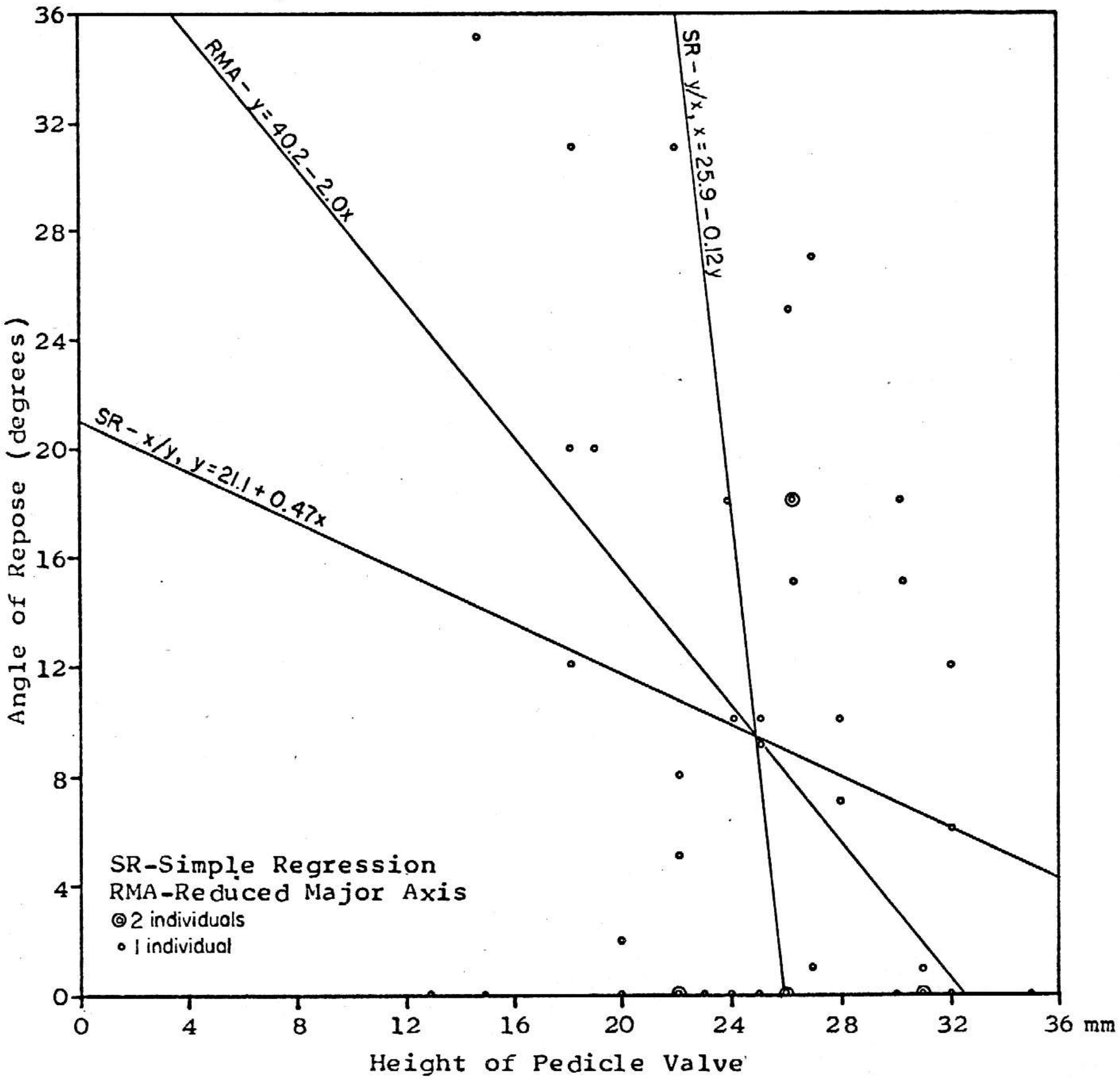


Figure 11. Correlation of Angle of Repose and Pedicle Valve Height in <u>Reticulatia</u> cf. <u>huecoensis</u>.

Burrow Casts

Morphology.--One of the first things one notices when examining the Oketo Shale is the presence of large burrows (up to 4 cm in diameter, Photos 6 and 7). These burrows are all casts and occur horizontally, vertically and obliquely to bedding. They may be straight or sinuous and some horizontal burrows are u-shaped. All but vertical burrows are somewhat flattened parallel to bedding probably as a result of compaction. A keel is present on the top of some of the oblique and vertical burrows. Diameters remain constant except in the u-shaped bends where they usually broaden slightly. Spreite structure occurs in many burrows between subparallel limbs of horizontal burrows. Insoluble and thin section data (Table 5 and Appendix II, p. 146) reveal no noticeable lithologic differences between burrow fillings and the surrounding rock matrix, with the possible exception of a higher percentage of *Osagia*-coated grains in the burrow. There is no apparent lining of the burrows and the nearly horizontal stratification (Plate III, figs. 2a and b) is probably due to gradual backfilling.

Based on the descriptions above and comparison with illustrations (Lessertisseur, 1955, p. 70 and Planche IX; Häntzschel, 1962, fig. 129, 2a, b, and p. W210; and Sellwood, *in* Crimes and Harper, 1970, pl. 1, p. 493) the burrow casts that did not have keels are classified in the ichnogenus *Rhizocorallium*.

Origin and Environmental Significance.--Sellwood (*in* Crimes and Harper, 1970, p. 495) said:

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

THIS IS AS RECEIVED FROM CUSTOMER.

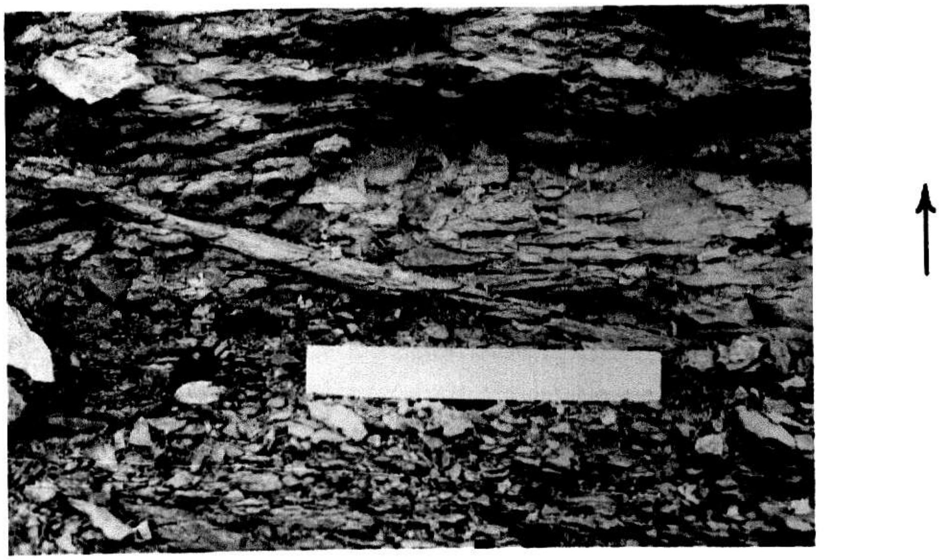


Photo 6. Oblique burrow with dorsal "keel". (Ruler is 155 mm long.)

Photo 7. Horizontal u-shaped burrows (30 m east of Locality 11 on top of Bed 2, ruler is 155 mm long).

Table 5

Insoluble Residues in Percent of Whole Rock Sample for Selected Fossil Casts and Matrices

Sample No.	Sand	Silt	Clay	Total
P.4-16c	0.1679	6.6183	14.3386	21.1248
P.4-16m	0.9437	12.9308	7.4159	21.2904
P.6A-6c	0.6332	9.1421	3.3111	13.0864
P.6A-6m	0.9187	14.1406	2.8386	17.8979
P.8-9c	0.5020	19.7274	5.5779	25.8073
P.8-9m	0.7104	17.1360	4.4978	22.3442
P.8-10c	0.1797	2.4307	9.8825	12.4929
P.8-10m	0.3045	13.8076	4.4859	18.5980
P.9-D-7c	0.3118	17.7378	7.0576	25.1072
P.9-D-7m	0.0988	11.4325	13.1256	24.6569
P.10-16c	1.7785	15.4321	6.2292	23.4398
P.10-16m	0.4908	3.8723	21.4688	25.8320
P.13-0c	0.0799	2.7647	20.6500	23.4946
P.13-0m	1.1809	4.7442	13.1131	19.0382
R.1-6&7m	1.8694	14.1337	3.8850	19.8881
R.1-16m	0.7582	14.6344	5.2820	20.6746
R.6A-3m	3.3764	7.3866	1.4908	12.2538
R.10-4m	0.9437	18.3930	5.7684	25.1051
R.11-5m	0.2912	19.8308	4.2885	24.4105
R.13-0m	1.0738	17.3961	3.5021	21.9720
B.13-4	1.0394	9.9909	2.5984	13.6287

> the *Rhizocorallium* animal was similar in its mode of life to some recent callianassid crustaceans which exhibit deposit- and suspension-feeding at different stages in their life history to suit the particular requirements of the time. These callianassids deposit-feed whilst they excavate the systems and then suspension-feed once the systems have been completed (McGinitie, 1934). It is probable that the crustaceans that constructed *Rhizocorallium* burrows also adopted this form of dual existence.

Ager and Wallace (*in* Crimes and Harper, 1970, p. 15) infer energy levels and shore proximity for *Rhizocorallium*. Horizontal *Rhizocorallium* burrows suggest low energy, infralittoral to fairly deep infralittoral environments, and oblique burrows imply high energy and "just (sic) subtidal" environments.

If one believes Sellwood, oblique and horizontal burrows could occur in the same environment. Field examination indicated that oblique burrows nearly always led to horizontal burrows. Petrologic data favors the relatively low energy, infralittoral to deep infralittoral environments of Ager and Wallace with little evidence of high energy, subtidal environments.

Nowhere were body fossils found immediately associated with burrows. *Pteronites* sp. (Bivalvia), which is common in the Oketo Shale, does possess a "keel" of sorts formed by the protrusion of the hingement on the dorsal side. Pearce (1973) inferred that *Pteronites* cf. *peracuta* lived semi-infaunally and was inclined at about 63° to bedding; however in this study, *Pteronites* was either vertical or lying parallel to bedding. This bivalve is the only preserved organism that could have possibly made a "keeled" burrow, but studies of Recent relatives of Pteronites indicate a burrowing habit unlikely (Pearce, 1973, p. 37).

Pholadomyids may have produced some vertical burrows (Plate II, fig. 5) and scolecodonts indicate polychaete worms, some of which deposit-feed or suspension-feed in burrows. Schafer (1972, p. 178) stated that polychaete worms that die in their burrows usually leave no trace. Further research on Oketo burrow casts may help explain their origin.

Organism-Substrate Relationships

General Statement.--Pholadomyids and Reticulatia occur together in the field, thus similar results were expected and obtained from laboratory analysis of matrices. Data discussed below, unless otherwise referenced, are in Appendices I and II and rock names are those defined by Folk (1959).

Pholadomyid Substrate Types.--The three pholadomyid genera described earlier occur predominantly in silty biomicrite but are also in algal biomicrite (10-6G). The original character of the substrate was probably a relatively soft silty bioclastic carbonate mud. Allochemical grain sizes ranging from .031 to 1.000 mm make the rocks coarse calcilutites to coarse calcarenites. Osagia-coated grains and crinoid debris are the most common biotic components. Insoluble residues range from 12.5 to 25.8 percent and average 21 percent (Table 5). This amount was probably sufficient to add enough "body" to the carbonate "soup" to support the organisms in their life positions. Insoluble content of all samples is below 26 percent and possibly represents the maximum level of terrigenous influx tolerated by the feeding and respiratory mechanisms of these bivalves.

One argument against this hypothesis is that if one compares pholadomyid (and Reticulatia) occurrences in different beds of the Oketo Shale (Appendix I) with the insoluble contents of those beds (Table 1), then these fossils occur in beds containing over 35 percent insolubles. If turbidity were low, populations of quiet water organisms could theoretically inhabit highly terrigenous sediments because the high concentration of suspended sediment, not the character or composition of the bottom, fouls feeding organs. Turbidity is a function of grain size and amount of available energy to suspend grains.

Comparing insolubles in the casts with those of the surrounding matrices revealed four of seven individuals to have percentages of sand and silt higher in the matrix than in the cast, but for the three others the opposite was true.

One thin section of a Wilkingia cf. terminale cast was examined. The rock is a medium calcarenite, biomicrite; Osagia and foraminiferids are the two most common allochems. Comparing this rock type with the matrices mentioned above revealed no selective size sorting within the cast.

Pearce (1973), using thin section data, observed that casts of Wilkingia cf. elliptica (Phillips) did not vary greatly from the surrounding matrix in either composition or grain size. He attributed this homogeneity to the posterior gape that allowed grains of different sizes to enter the dead shell. His specimens were found in fine to coarse calcarenites with 19 to 25 percent insoluble residue.

Comparison of my data with those of Pearce revealed that substrate preference of Wilkingia and some related genera did not change significantly between Upper Pennsylvanian and Lower Permian time.

Reticulatia cf. huecoensis Substrate Types.-- Reticulatia occurred in a broader range of rock types than the pholadomyids, indicating more adaptability to substrate. Silty to silty brachiopod biomicrite to algal biomicrite are the most common matrices for Reticulatia. Grain sizes range from very fine calcarenites to medium calcarenites. Insoluble residues range from 12 to 25 percent and average 21 percent. The broader surface area that this brachiopod presents to the substrate may have enabled it to inhabit softer substrates than those necessary for pholadomyids. The most commonly associated allochems are the same as for the bivalves (Osagia-coated grains and crinoid debris) with the addition of brachiopod debris. The original substrate was probably a relatively soft silty bioclastic carbonate mud. The sediment in which Reticulatia lived may have been softer than that of the pholadomyids because it lived at the sediment-water interface where bottom sediments are usually looser, caused by less compaction and supersaturation.

One thin section of an articulated Reticulatia cf. huecoensis was prepared but a point count was not performed.

It is evident in Plate III, Figure 1c that the matrix contained in the brachial valve depression is coarser than that between the two valves. A few isolated foraminiferids and a piece of Derbyia sp. are the only allochems in the micritic filling. The external matrix, however, contains ostracodes, crinoid columnals, and brachiopod debris. Clearly this particular individual died in life position and the dead shell was infilled by shifting sediment with the partially closed valves acting as a particle sorter. Two large pieces of Derbyia sp., one within the body cavity, and one wedged between the valves, are evidence that some bottom turbulence was involved and that the shell did not become filled simply by burial.

Interpretation of Azimuth Orientation Data

Tables 6 and 7 show the distributions of azimuths for all pholadomyids and Reticulatia, respectively. The method of tabulation is from Royse (1970). To test randomness of orientation, a Rayleigh z statistic (Reyment, 1971, pp. 41-45) was calculated for these two taxa at each measured section (Tables 6 and 7 and Appendix VIII). Only one locality, Locality 11, proved to be significant at the .05 alpha level (Reyment, 1971, p. 192) for pholadomyid orientations. Significance is not great, however, because the statistic is not significant at the .01 alpha level. Interestingly, Reticulatia is close to being significant at Locality 11 also. Because Locality 11 was not studied in detail, no explanation can be given for this preferred orientation, other than to suggest that it may only be coincidental.

Table 6

Summary of Azimuth Orientation of Pholadomyids in the Oketo Shale Member, Riley and Geary Counties, Kansas

Measured Section	Midpoints of 30-degree Classes												Rayleigh z Statistic
	0	30	60	90	120	150	180	210	240	270	300	330	
1				1		1					1		0.179
3			2		1		1	3		1		2	0.268
4	1	1	2			5	4	1		1		3	0.940
6A		1		1	1	2	2			1		2	0.122
8		1	1			2	1			1			0.622
9	1					1		1			1		0.201
10						1	1			2	1	3	2.058
11						1		2		2	2	2	3.125*
13	1	1		1		1	2			1	1	4	1.022

*Significant at .05 alpha level.

Table 7

Summary of Azimuth Orientation of _Reticulatia_ cf. _huecoensis_ in the Oketo Shale Member, Riley and Geary Counties, Kansas

Measured Section	Midpoints of 30-degree Classes 0	30	60	90	120	150	180	210	240	270	300	330	Rayleigh z Statistic*
1		1		2					1		1	1	0.454
3		1	2			1		1		1		1	0.219
4			1			1					1		0.089
6A								2					2.000
8			2			1	1						1.433
9					1			1					1.000
10	3				1	1		1				2	0.783
11	3		1							1	1		2.833
13		1	1			1		1			2		0.089

*All values are insignificant at .05 alpha level for each measured section.

It would have been desirable to test the azimuth orientation of each of the three pholadomyid genera but this was not possible because of (1) classificatory problems mentioned previously and (2) the small number of specimens of positively identified Wilkingia (total of 4 from all localities) and Chaenomya (total of 3 from all localities). However, by combining all specimens of Exochorhynchus (total of 20 from all localities) it was possible to test whether there was any difference in azimuth orientation between small (young) individuals (45-65mm length) and large (adult?) individuals (75-105 mm length). A frequency distribution was constructed (Table 8A) and those classes smaller than the mode were lumped together and their azimuth orientations compared to those of classes larger than the mode (Table 8B). The larger individuals show a greater degree of preferred orientation (1.000) than the smaller ones (0.505), but neither is significant.

Three alternatives can be given for random orientation of these organisms, (1) there was no water movement, (2) water movement was so variable that organisms were constantly changing their positions to coincide with it, or (3) water movement did exist but did not influence orientation. Total absence of currents in a body of water the size of the Permian sea would be highly unlikely, thus alternative one can be eliminated. Because the organisms studied were large and primarily infaunal, a change in azimuth would have been difficult, if not impossible, after interment in a soft, but firm substrate. However, variable currents may have influenced them during

Table 8

Comparison of Azimuth Orientations Between Small and Large Specimens of <u>Exochorhynchus</u> cf. <u>altirostratus</u>

A. Size Frequency Distribution

Class Interval (mm)	Class Mark (mm)	Frequency	Cumulative Frequency
45-55	50	3	3
55-65	60	4	7
65-75	70	6	13
75-85	80	4	17
85-95	90	2	19
95-105	100	1	20

B. Test for Randomness of Orientation (Rayleigh z Statistic)*

Sample No.	Length (mm)	Azimuth	Midpoint of Class (x_i)	Sine x_i	Cosine x_i
3-E-10	47	S80W	270	-1.000	0.000
4-6	55	N21W	330	-0.500	0.866
6A-3	46	S25E	150	0.500	-0.866
9-D-2	63	N50W	300	-0.866	0.500
9-D-7	62	S20E	150	0.500	-0.866
10-7	59	N63W	300	-0.866	0.500
10-7	64	S23E	150	0.500	-0.866
				V = -1.732	W = -0.732

$$z = \frac{V^2 + W^2}{N} = \frac{3.00 + 0.536}{7} = 0.505^{**}$$

Sample No.	Length (mm)	Azimuth	Midpoint of Class (x_i)	Sine x_i	Cosine x_i
1-4	82	S30E	150	0.500	-0.866
4-5	88	S20E	150	0.500	-0.866
4-6	90	S13E	180	0.000	-1.000
4-6	82	S45E	120	0.866	-0.500
8-11	84	S10E	180	0.000	-1.000
10-8	105	N35W	330	-0.500	0.866
13-6	79	N28W	330	-0.500	0.866
				V = 0.866	W = -2.500

$$z = \frac{V^2 + W^2}{N} = \frac{0.750 + 6.25}{7} = 1.000^{**}$$

*See Appendix VIII, p. 161.

**Not significant at .05 alpha level.

their initial orientation on the "soupy" surface layer of the substrate, randomly distributing their directions over a period of time. The simplicity of number 3 and other supportive evidence for a quiet water environment make this last alternative the most plausible.

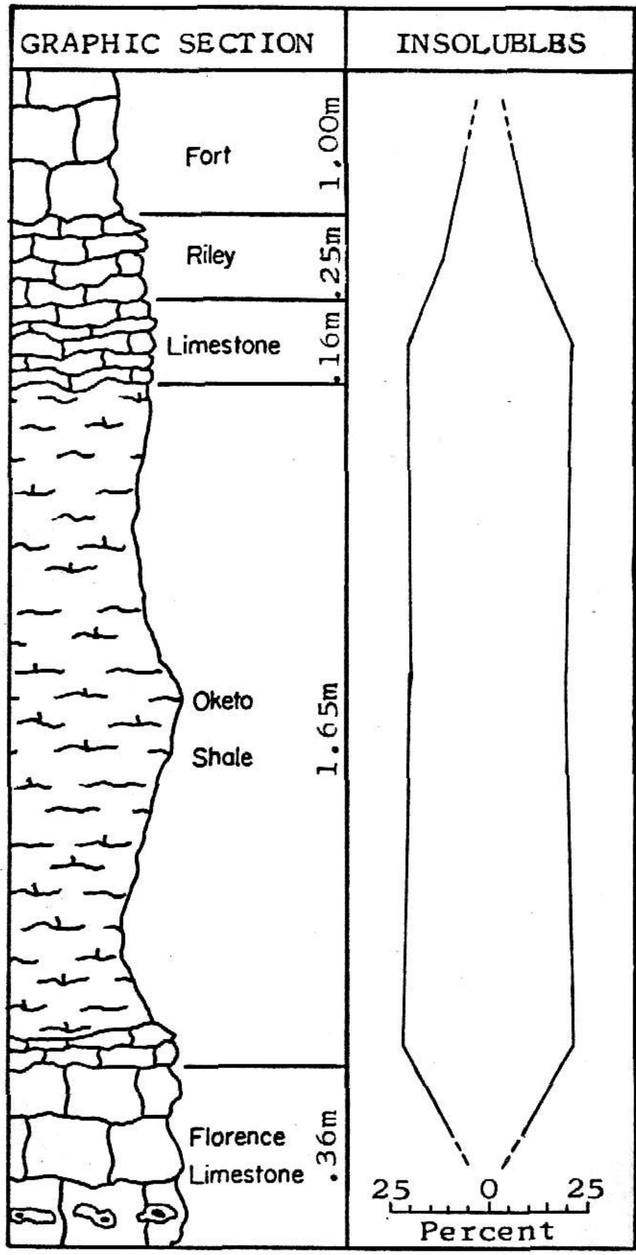
ENVIRONMENT OF DEPOSITION

General Statement

Figure 12 is a generalized picture of the depositional history of the Oketo Shale. Most data is taken from Locality 12 because the thickness of the Oketo Shale here (1.65 m) approximates the average thickness of the unit (1.60 m), and the general appearance of the outcrop is typical of the Oketo.

The low insoluble content, fine grained micritic lithology, and presence of only crinoid debris in the upper Florence Limestone Member is indicative of a moderately shallow, relatively quiet water environment. The character of the substrate was probably a very soft carbonate mud. Structural evidence (p. 19) suggests that the depositional basin may have been an embayed shelf.

During the deposition of the basal Oketo Shale a rapid rise in insoluble residue and increased allochem grain size implies closer proximity to a high energy environment, i.e., littoral zone. These increases also probably added firmness to more "soupy" carbonate muds of upper Florence time. The environment apparently stabilized enough at this time to allow bivalves and brachiopods to begin establishing themselves.



GRAPHIC SECTION	INSOLUBLBS	LITHOLOGY	MACROFOSSILS	DEPOSITIONAL ENVIRONMENT
Fort 1.00m		Biomicrite, medium calcarenite	Crinoid debris	Moderately shallow shelf non-bioturbated, soft carbonate mud substrate; transgression
Riley .25m		*Osagia* biomicrudite, fine calcirudite	Crinoid debris, *Crurithyris*	Shallow shelf; non-bioturbated, soft carbonate mud substrate; transgression-regression transition
Limestone .16m		Silty biomicrudite, fine calcirudite	Crinoid debris	
Oketo Shale 1.65m		Biomicrudite, fine calcirudite	Brachiopods, (*Reticulatia*), pholadomyids, horizontal and oblique burrows	Shallow shelf, infralittoral; bioturbated, soft to moderately firm carbonate mud substrate; regression
		Biomicrudite, fine calcirudite	Crinoid debris, bryozoan debris	Shallow shelf; non-bioturbated, soft carbonate mud substrate; transgression-regression transition
Florence Limestone .36m		Biomicrite, medium calcarenite	Crinoid debris	Moderately shallow shelf non-bioturbated, soft carbonate mud substrate; transgression

Figure 12. Generalized Biologic and Sedimentologic Characteristics of the Oketo Shale.

By middle Oketo time brachiopods and bivalves were well established. Burrowing patterns suggest an infralittoral environment and during this period water depth was probably at a minimum.

The thin bedded limestones overlying the "shaley" beds of the Oketo Shale represent a gradual landward migration of the littoral zone. Decrease in insolubles best reflects this trend in that it indicates an increasing distance to a terrigenous source area. The disappearance of large bivalves and brachiopods occurs in this interval and by lower Fort Riley "rimrock" time conditions seem to resemble those of the upper Florence, completing a transgressive-regressive-transgressive sequence.

Vertical Grid Square Study

Interpretation.--Graphic representations of Localities 3 and 9 are contained in Appendix IX which also includes location and identity of fossils and rock color and bedding characteristics. Each outcrop was treated as a unit and assumed to be a representative sample of the Oketo fossil assemblage and lithology at each locality.

These vertical sections represent a summation of all preservable changes that occurred throughout the depositional history of the unit. Vertical changes in fossil content during deposition are shown by flame diagrams (figs. 13 and 14). These diagrams were constructed by laterally traversing the outcrop maps (Appendix IX) at one decimeter increments and counting the number of each taxonomic group in that interval.

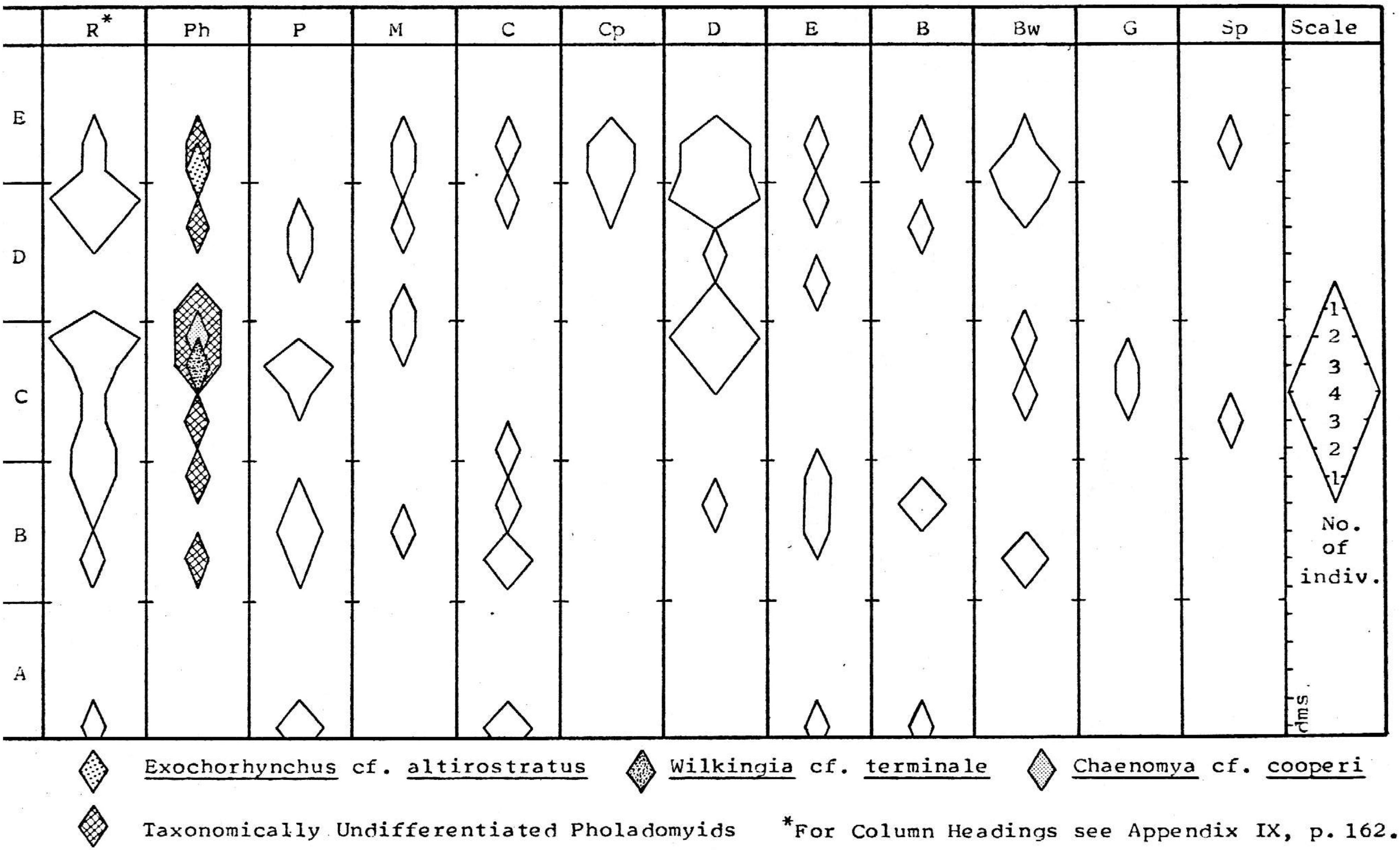
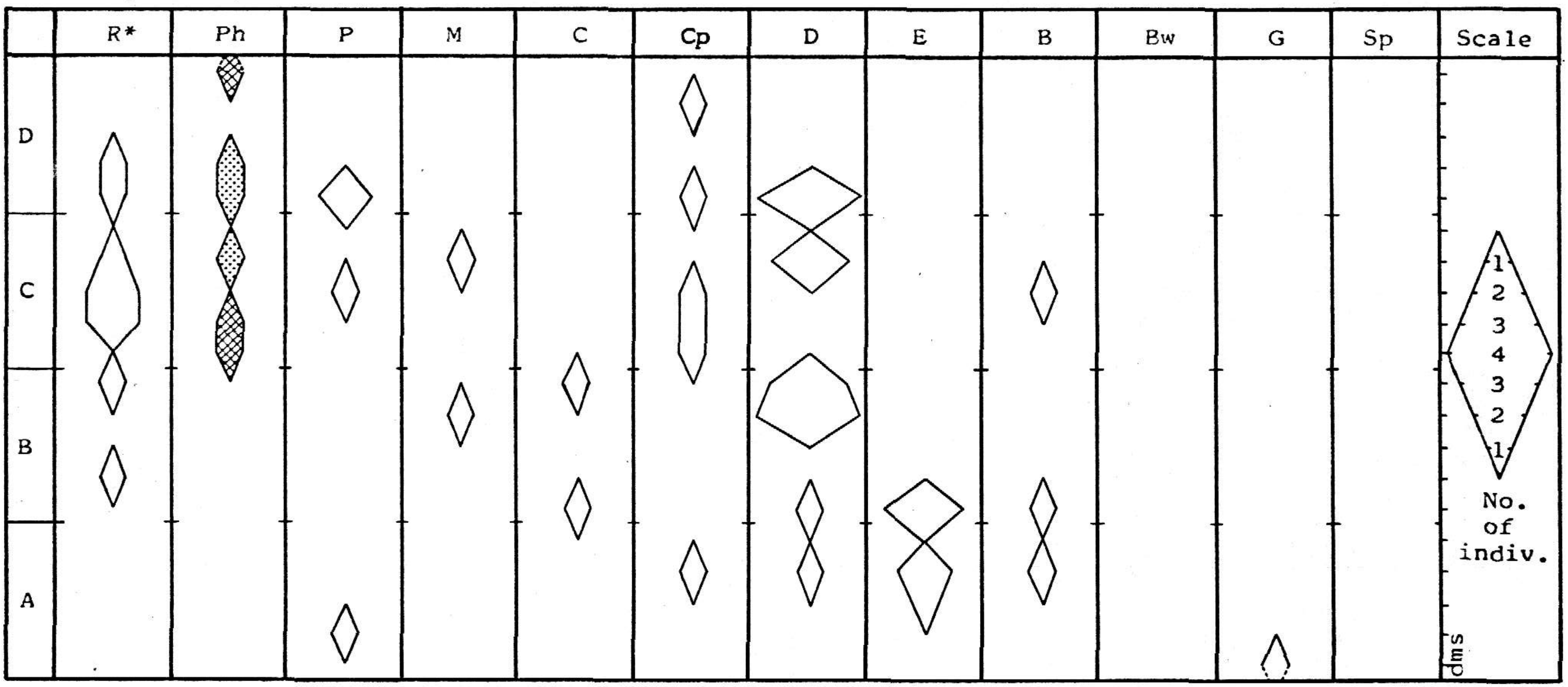


Figure 13. Flame Diagram of Vertical Fossil Distribution at Locality 3.



Exochorhynchus cf. altirostratus   Taxonomically Undifferentiated Pholadomyids

* For Column Headings see Appendix IX, p. 162.

Figure 14. Flame Diagram of Vertical Fossil Distribution at Locality 9.

The number was then plotted under the correct group on a line bisecting the interval. Points were connected vertically across intervals to produce the flame pattern.

One problem that arose when the comparison of localities was attempted was that of which horizon to use as a datum. When the Oketo-Florence contact was aligned, eight of the eleven taxonomic groups were found lower at Locality 9 than at Locality 3. The two groups that were higher at Locality 9 were pholadomyids and *Pteronites*, both infaunal. The other group, burrows, was absent at Locality 9. Perhaps a layer of dense mud or clay prohibited deeper burrowing at Locality 9. This hypothesis does not hold, however, when the datum is shifted to the upper contact with the Fort Riley Limestone. In this case four groups ascend, four descend, and two remain at about the same level. Displacement of the different groups is not as great using this latter datum and therefore it probably provides a simpler explanation of the biological history of the unit.

The positions of *Chaenomya* and *Wilkingia* support the relative depth of burial as postulated earlier, *i.e.*, *Chaenomya* resided at a shallower depth than *Wilkingia*. The position of *Exochorhynchus*, however, lends no support to its hypothesized depth of burial (below the other two bivalves) and, in fact, suggests that the genus may not have been contemporaneous with *Wilkingia* and *Chaenomya*. Unfortunately data are not available to explain the replacement of *Wilkingia* and *Chaenomya* by *Exochorhynchus*, which is best demonstrated at Locality 3, because this locality was not studied in detail. Exochorhynchus occurs at about the same stratigraphic level (Bed 7) at Locality 9 and laboratory results for this level do not indicate significant lithologic change. If Exochorhynchus did replace the other pholadomyids, reasons are not evident in the lithologic record. There is an apparent hiatus below the Exochorhynchus horizon at Locality 9 reflected in all other groups except Pteronites and may represent unfavorable environmental conditions. Reticulatia and Derbyia sp. made fairly rapid recoveries but Wilkingia and Chaenomya were evidently incapable of reestablishing themselves and Exochorhynchus became the dominant pholadomyid. No such pattern is apparent at Locality 3.

A noticeable lack of fossils near the base of the Oketo Shale at Locality 3 may represent transition into a suitable environment needed by the studied organisms. This "barren" unit is not present at Locality 9 and accounts for the large shift in taxonomic groups when the sections are compared using the Florence contact.

Reticulatia cf. huecoensis and Derbyia sp. at both localities are the dominant organisms, and pholadomyids are a distant third. Pteronites, which has been suggested as a possible burrower, is better represented at Locality 3 than at Locality 9 and there is a corresponding abundance of burrows in the former locality and a noticeable absence in the latter. Pholadomyids, also burrowers, are more abundant in the burrowed locality.
A general trend toward more specimens in the upper half of both localities suggests a more favorable environment upward

(later Oketo deposition). Because the contact between the Fort Riley Limestone and the Oketo Shale is more gradational than the lower contact with the Florence Limestone, conditions were probably more constant and suitable for habitation and growth of invertebrates during upper Oketo time.

Simultaneous abundance of Reticulatia and Derbyia sp. raises the question of whether competition existed between the two. As mentioned before, Reticulatia was quasi-infaunal, feeding just above the sediment-water interface. Derbyia sp., however, is believed to have cemented its pedicle valve to hard elements on the substrate and therefore inhabited a higher feeding level (Table 9) than Reticulatia. One specimen, a juvenile Derbyia sp., attached to an overturned Reticulatia pedicle valve was found at Locality 6. This stratification probably relieved competition for nutrients as well as for space. Evidently nutrients were plentiful enough to support many suspension feeders. All taxonomic groups, except gastropods and perhaps some burrowers, are also suspension feeders (Table 9). Influence of infaunal groups on competition is indeterminable because the level at which they resided and therefore with which surface community they competed is unknown.

Thirteen parameters were measured for each fossil or fossil fragment encountered within the grid squares (Appendix IX). As mentioned earlier the entire vertical interval is considered a single time plane and I can compare the total Oketo fossil assemblage in terms of these parameters (Table 10) at the two localities.

Table 9

Autecology of Fossils*

Modes of Life	Feeding Behavior
I - Infaunal	LS - Low level suspension
E - Epifaunal	HS - High level suspension
Q - Quasi-infaunal	C - Collector
S - Semi-infaunal	Carn - Carnivore
N - Nektonic	

Taxonomic Group	Mode of Life	Feeding Behavior
Ectoprocts (Bryozoans)	E	HS
Brachiopods		
Reticulatia cf. *huecoensis*	Q	LS
Crurithyris sp.	E	HS
Composita sp.	E	HS
Derbyia sp.	E	HS
Meekella sp.	E	HS
Bivalves		
Wilkingia cf. *terminale*	I	LS
Exochorhynchus cf. *altirostratus*	I	LS
Chaenomya cf. *cooperi*	I	LS
Pteronites sp.	S?	LS
Septimyalina? sp.	E	HS
Gastropods		
Straporollus (A.) sp.	E-S	C
Echinoderms		
Crinoids	E	HS
Burrowing organisms		
(arthropods and/or annelids)	I	C-LS-HS

*Modified from Yarrow (1974, p. 26).

Table 10

Comparison of Fossil Condition, Size, Orientation and Substrate Associations at Localities 3 and 9

	Locality 3	Locality 9
Unbroken	11*	31
Articulated	41	29
Pedicle valves	64	50
Brachial valves	36	50
Right valves	50	0
Left valves	50	0
In inferred life position	29	20
Convex up	76	74
Convex down	24	26
Substrate**		
Ys	26	67
Yb	0	18
Gs	50	5
Gb	18	7
Yls	5	2
Mean length	33.6 mm	30.9 mm
Mean width	23.9 mm	23.4 mm
Mean height	13.8 mm	11.7 mm

*Values are percentages unless otherwise indicated.

**For explanation of abbreviations, see Appendix IX, p. 163.

Percentage of unbroken specimens is greater at Locality 9 than at Locality 3 which was not expected because Locality 9 was believed to have been in a higher energy environment, *i. e.*, shallower water, thus making it more conducive to shell breakage. However when one examines the unbroken species, nearly 41 percent of the unbroken specimens at Locality 9 are infaunal whereas only 23 percent are infaunal at Locality 3. Infaunal specimens would be less prone to breakage than epifaunal ones. I also attribute a high percentage of breakage at both outcrops to weathering.

Articulation percentages support calmer conditions at Locality 3 but still only 41 percent of the fossils are articulated which indicates some bottom turbulence or predation. *In situ* organisms studied do not indicate any preferred orientation which could have possibly suggested wave or current direction.

The ratio of brachial valves to pedicle valves at Locality 9 is 1:1 but at Locality 3 it is 1:1.8. Fagerstrom (1964, p. 1203) suggested that a fossil community, or life assemblage, should possess a ratio of opposite valves of about 1. He also stated that a transported assemblage, especially one of brachiopods, should have a ratio greatly removed from 1 as a result of selective sorting of the hydrodynamically different valves. A mixture of the two types of assemblages should have intermediate values. I can only conclude from the ratios that more selective removal of shells occurred at Locality 3 than at Locality 9 during the period of deposition. Right valve:

left valve ratio comparisons are omitted because of the small sample size (2).

A t-test of means (Table 11) on the three size parameters indicated that the average size of fossils at the two localities is nearly equal, inferring that perhaps energy conditions were about the same. This supposition, of course, rests on the fact that most of the fossils are fragments. Degree of fragmentation is a function of available energy and/or predation, discounting diagenesis and weathering.

Table 11

Statistical Comparison of Sizes of Fossils from Localities 3 and 9

	Locality 3			Locality 9			t-test
	σ	$\bar{X}$	n	σ	$\bar{X}$	n	
Length (mm)	26.8	32.0	84	20.5	30.9	43	0.257*
Width (mm)	18.3	26.4	93	16.0	23.4	48	1.003*
Height (mm)	11.5	13.6	101	8.6	11.5	54	1.280*

*Not significant at .05 alpha level.

More individuals are in presumed life position at Locality 3 (29 percent) than at Locality 9 (20 percent) although both values are low. I do not believe the differences are great enough to infer greater predation or bottom turbulence at Locality 9 although it would tend to support shore proximity (*i.e.*, more energy).

Reviewing insoluble residue, thin section, x-ray diffraction, and visual field data, I conclude that the variation from yellowish gray to light gray is due to chemical differences within the rock possibly catalized by diagenetic or weathering phenomena. Differences in clay mineralogy may be responsible, but the amorphous distribution of color within a single outcrop does not seem obtainable by normal slow settling of clay particles. Miesse (1974) found no differences in clay mineralogy in a study of red and green shales of the Eskridge Shale in Kansas. There seems to be no correlation of color with any of the studied parameters including fossil distribution.

Data from the grid analysis (Table 10) reflects this lack of correlation. At Locality 9, 67 percent of the fossils are in yellowish gray, platy, silty limestone but 58 percent of the fossils at Locality 3 are in light gray, platy, silty limestone. Blocky lithologies of both outcrops contained fewer fossils than platy lithologies. This could be an accurate representation of actual conditions or it may reflect sampling error; fossils are more difficult to distinguish where encased in massive limestone. Fine-grained texture of the matrix is probably one of the best indicators of relatively calm bottom conditions.

Convex up-convex down data are nearly identical for both localities (Table 10). Convex up is hydrodynamically stable for an arched shell. At both localities approximately 75 percent of all arched valves were oriented in the convex up position. Bottom currents or oscillations were evidently strong enough to overturn dead shells. Many *Reticulatia* valves were observed inverted (pedicle valve up), and living nearly completely buried in the sediment, a relatively strong current or wave (i.e., storms) would have been needed to overturn them or perhaps some unknown predator rooted the living animals out of the bottom exposing them to hydrodynamically stabilizing forces.

All too often data are manipulated to fit a preconceived situation. Perhaps these two localities did not experience noticeably different environmental conditions and choice of sampling areas is responsible for most of the disparities. Of the six parameters that could be used to infer energy levels, three implied higher energy at Locality 9 and three implied higher energy at Locality 3. Even these contradictory results can be meaningful. An unknown period of time passed during the deposition of the Oketo Shale and it is reasonable to assume that energy levels could have fluctuated from high to low many times.

Considering all parameters, both lithologic and biologic, a relatively low energy hydrological environment must have existed during Oketo deposition. Periodic turbulence, predation and/or burrowing disturbed an otherwise stable bottom and its biotic inhabitants. Water depth was probably uniform over most of the depositional area with possibly slight submarine topographic highs to the east.

Criticism.--The grid square method of study is actually a modification of the stretched-line method (Johnson, 1960).

Johnson used only a line, or several lines (strings), stretched along a predetermined distance at one or more specific horizons, and all fossils touching the string were measured and collected for detailed study. Some short-comings of the method are mentioned by Johnson (1960, p. 1083) but Ager's (1963, p. 230) comment, "below a certain density the method ceases to be practical" seemed most applicable when the vertical study idea was initiated. The density of fossils appeared low during field reconnaissance and for this reason the grid method was adopted to multiply the surface area covered and give a better representation of the fossil distribution. The calculated density for Localities 3 and 9 was 9.2 and 5.5 fossils per square meter, respectively (Appendix IX), which are low densities when one considers the average size of the fossils or fossil fragments (Table 10).

Another problem encountered in data collection was the difficulty in removing some specimens from the outcrop for measurement because of tenacity and/or massiveness of the matrix. The verticality of the face under study can also be hampering. If the unit is not at ground level or does not have a natural bench below it, access to the face is difficult.

SUMMARY AND CONCLUSIONS

Fossil azimuths proved to be random in all but one sampled locality of the Oketo Shale, indicating that currents or waves had no effect on orientation of large <u>in situ</u> invertebrates.

Large pholadomyid bivalves and Reticulatia, a large brachiopod, preferred similar substrates, both living in silty bioclastic carbonate muds. The infaunal mode of life permitted preservation of the bivalves in approximate life position but the quasi-infaunal habitat of Reticulatia was not as conducive to *in situ* burial.

The original substrate was probably a relatively soft silty carbonate mud deposited on a shallow embayed shelf. Slight petrologic changes occurred both vertically and horizontally throughout deposition of the Oketo Shale. Vertical changes were caused by fluctuations in sea level and/or wave base and subsequent influxes of terrigenous components or increased carbonate depositon. Horizontal changes were primarily caused by proximity of the Abilene and Nemaha Anticlines. Although these structures were probably minor topographic (and submarine) highs, they almost certainly contributed terrigenous components to the northern and southern extents of the shale. The term "shale" is used by convention even though insoluble data revealed that the Oketo is actually a muddy limestone.

Upper Oketo conditions appear to have been more conducive to biotic habitation than those during lower Oketo time. A detailed vertical study along a dip section produced conflicting results. Evidently bottom conditions were fairly uniform over the entire depositional area.

Paleosalinity determinations were inconclusive; salinities were not consistent with fossil data. Sample preparation is believed to be the reason for the anomalous results.

More work needs to be done using the phosphate method, which may explain why it has not been widely adopted by geologists to determine paleosalinity.

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INTRODUCTION TO APPENDICES

Beds are numbered from top to bottom and appear in stratigraphic order, youngest on top. For example, Sample 6A-1 is a sample from Bed 1 at Locality 6A and is the uppermost bed measured. Color designations are from Goddard, *et al.*, 1963. All measurements are in the metric system.

Listed below are examples of sample numbers and their meanings:

6A-3B	=	Locality 6A, Bed 3 near base.
6A-4-1	=	Locality 6A, Bed 4, Subsample 1 (occurs in a sequence of 3 numbers, -4-1, -4-2, -4-3, indicating samples taken at 30, 60, and 90 cms below top contact of Bed 4.
10-6G or Y	=	Locality 10, Bed 6, sample taken from a gray (N7) area; Y indicates sample taken from yellow (5Y7/2) area.
P.6A-6c or m	=	Pholadomyid from Locality 6A, Bed 6, c = cast, m = matrix.
R.1-5m	=	*Reticulatia* from Locality 1, Bed 5, m = matrix.
P.13-Om	-	Pholadomyid from Locality 13, O = float sample, m = matrix.

APPENDIX I

Measured Section 1

Date measured: 18 July 1973 Measured by: J. R. Griffin, Jr.

Locality: NW¼, SE¼, SE¼, Sec. 22, T.11S., R.5E., Geary County, Kansas; roadcut on east side of U.S. 77, 1 mile north of Republican River Bridge.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive; sol'n cavities (1-2 cm); crinoid debris.	1.00 m
2	Limestone, yellowish gray (5Y7/2) to light gray (N7), color changes via amorphous patches from several inches to several meters in greatest dimension, often crosses bedding planes continuously, thinly bedded (2-8 cm).	.25 m
3	Limestone, yellowish gray (5Y7/2), massive; crinoid debris.	.39 m
4	Mudstone, calcareous, yellowish gray (5Y7/2); platy to crumbly; *Reticulatia*, *Wilkingia*, *Composita*, burrows.	.19 m

5	Mudstone, light gray (N7), calcareous, platy to blocky, yellowish gray (5Y7/2) mottled in places, erosion resistant zone (discontinuous) 45 cm from top, spheroidal weathering not pronounced but present; *Reticulatia*, *Wilkingia*, *Composita*, *Pteronites*, burrows.	1.20 m
6	Mudstone, calcareous, yellowish gray (5Y7/2), sharp contact at top; *Reticulatia*.	.30 m
7	Limestone, yellowish gray (5Y7/2), platy, iron-stained throughout; crinoid debris.	.03 m
8	Limestone, yellowish gray (5Y7/2), massive, black and white chert nodule layer 37 cm below top; base covered.	.37 m
		Total = 3.73 m

Measured Section 2

Date measured: 18 July 1973 Measured by: J. R. Griffin, Jr.

Locality: SE¼, SW¼, NW¼, Sec. 34, T.11S., R.5E., Geary County, Kansas; roadcut on east side of U.S. 77, 6 miles south of U.S. 77 and U.S. 77 Alt. intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive, undulatory contacts, sol'n cavities; Wilkingia, Reticulatia, burrows.	.30 m
2	Mudstone, yellowish gray (5Y7/2), some burrows (2-4 cm in diameter), calcareous.	.21 m
3	Mudstone, light gray (N7), platy to blocky, blocky areas weather spheroidally, erosion resistant zone 55 cm from top (massive to blocky); Derbyia, Reticulatia, Pteronites, Straporollus; calcareous.	1.20 m
4	Mudstone, yellowish gray (5Y7/2), platy to blocky; non-fossiliferous? ; calcareous.	.20 m
5	Limestone, yellowish gray (5Y7/2), thin-bedded (1-2 cm); Derbyia, Crurithyris, crinoid debris.	.08 m
6	Limestone, yellowish gray (5Y7/2), massive; crinoid and echinoid debris, Reticulatia.	.43 m

7	Limestone, yellowish gray (5Y7/2), massive; crinoid and echinoid debris; black and white chert nodules at base, limestone continues, base covered.	.10 m
	Total	= 2.52 m

Measured Section 3

Date measured: 12 July 1973   Measured by: J. R. Griffin, Jr.

Locality: Near center of NW¼, SE¼, Sec. 15, T.12S., R.5E., Geary County, Kansas; roadcut on east side of U.S. 77, .25 miles north of U.S. 77 and I-70 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), blocky to thin-bedded (1-5 cm), fossiliferous, crinoid, bryozoan, bivalve, brachiopod fragments.	.05 m
2	Limestone, yellowish gray (5Y7/2), massive; burrows (1-3 cm in diameter).	.27 m
3	Limestone, yellowish gray (5Y7/2), platy, upper surface iron-stained where exposed, stylolites in lower 2 cm; crinoid, brachiopod fragments.	.09 m
4	Limestone, yellowish gray (5Y7/2), massive, crinoid fragments, sol'n cavities numerous in upper 45 cm.	1.42 m
5	Limestone, yellowish gray (5Y7/2), blocky to thin-bedded, iron-stained; <u>Derbyia</u>, <u>Composita</u>, crinoid, echinoid, bryozoan debris.	.16 m

6	Mudstone, calcareous, yellowish gray (5Y7/2), platy; Reticulatia, Derbyia, Composita, small burrows (less than 1 cm in diameter).	.24 m
7	Limestone, yellowish gray (5Y7/2) to light gray (N7), crinoid, brachiopod debris.	.05 m
8	Mudstone, calcareous, light gray to yellowish gray, blocky to platy; large (2-4 cm) horizontal and oblique burrows.	.29 m
9	Limestone, yellowish gray (5Y7/2), discontinuous.	.04 m
10	Mudstone, calcareous, yellowish gray (5Y7/2), platy to blocky; Wilkingia, Pteronites, crinoid debris.	.32 m
11	Mudstone, calcareous, light gray (N7), blocky to platy; erosion resistant zone(approximately 10 cm thick) 27 cm from top; Wilkingia, Reticulatia.	.87 m
12	Limestone, yellowish gray (5Y7/2) to light gray (N7), blocky, thin-bedded (0.5-5 cm).	.14 m
13	Limestone, yellowish gray, massive; zone of chert nodules 36 cm from top; below unmeasured; Reticulatia, crinoid, brachiopod, bryozoan debris.	.36 m
	Total=	4.30 m

Measured Section 4

Date measured: 23 July 1973 Measured by: J. R. Griffin, Jr.

Locality: NE¼, NE¼, SE¼, Sec. 30, T.11S., R.7E., Geary County, Kansas; roadcut on south side of I-70, 1.7 miles east of exit 304 (Humbolt Creek Road).

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive; sol'n cavities 1-3 cm in diameter), stylolites locally near base; lower 30-40 cm show gradation into Bed 2; crinoid, echinoid debris.	1.50 m
2	Limestone, yellowish gray (5Y7/2), thin-bedded to massive (2-5 cm); _Reticulatia_, _Wilkingia_, _Derbyia_, _Pteronites_, crinoid debris, burrows (1-3 cm in diameter).	.77 m
3	Mudstone, yellowish gray (5Y7/2) to light gray (N7); burrows; calcareous.	.10 m
4	Limestone, yellowish gray (5Y7/2), massive; _Reticulatia_, crinoid debris, burrows; mostly covered by talus and grass.	.33 m
5	Mudstone, yellowish gray (5Y7/2), platy, non-fossiliferous?; calcareous.	.34 m

6	Mudstone, light gray (N7) to yellowish gray (5Y7/2), platy to blocky; erosion resistant zone 45 cm from top; _Wilkingia_, _Reticulatia_, _Composita_, _Derbyia_, _Crurithyris_, _Pteronites_; calcareous.	.90 m
7	Limestone, yellowish gray (5Y7/2), very thinly bedded (2-5 mm); non-fossiliferous?.	.08 m
8	Limestone, yellowish gray (5Y7/2), massive; crinoid, echinoid, bryozoan debris.	.15 m
9	Mudstone, light gray (N7) to yellowish gray (5Y7/2), platy to blocky; non-fossiliferous?; calcareous.	.25 m
10	Limestone, yellowish gray (5Y7/2), massive to blocky, white and black chert nodule layer 25 cm from top; below unmeasured.	.25 m
	Total	= 4.97 m

Measured Section 5

Date measured: 30 July 1973 Measured by: J. R. Griffin, Jr.

Locality: NE¼, SW¼, NE¼, Sec. 9, T.7S., R.6E., Riley County, Kansas; roadcut on west side of U. S. 77, 2.5 miles north of Randolph, Kansas.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive to platy, thinly bedded near base, Reticulatia.	.35 m
2	Mudstone, calcareous, yellowish gray (5Y7/2), platy to crumbly; non-fossiliferous?.	.12 m
3	Limestone, muddy?, yellowish gray (5Y7/2); platy to blocky, "fossil hash" of Composita, Derbyia, Reticulatia, bryozoan debris, burrows (1-2 cm in diameter).	.06 m
4	Mudstone, calcareous, yellowish gray (5Y7/2), platy to crumbly; Reticulatia.	.09 m
5	Limestone, muddy?, yellowish gray to light gray (N7), massive to blocky, undulatory contacts; Reticulatia.	.03 m
6	Mudstone, calcareous, yellowish gray to light gray (N7), platy to blocky; non-fossiliferous?.	.13 m

7	Mudstone?, calcareous, yellowish gray to brownish gray, undulatory contacts, discontinuous, massive to blocky.	.03 m
8	Mudstone, calcareous, yellowish gray (5Y7/2) platy; non-fossiliferous?.	.14 m
9	Mudstone, calcareous, yellowish gray, massive to blocky; crinoid debris.	.14 m
10	Mudstone, calcareous, yellowish gray (5Y7/2), blocky to platy; <u>Reticulatia</u>.	.15 m
11	Mudstone, calcareous, yellowish gray (5Y7/2), blocky; brachiopod, crinoid debris.	.09 m
12	Mudstone, calcareous, yellowish gray (5Y7/2), platy, non-fossiliferous?.	.15 m
13	Mudstone, calcareous, yellowish gray (5Y7/2), massive to blocky, discontinuous; non-fossiliferous?.	.05 m
14	Mudstone, calcareous, yellowish gray (5Y7/2), platy to crumbly; non-fossiliferous?.	.04 m
15	Limestone, yellowish gray (5Y7/2), massive, crinoid debris; black and white chert nodule layer 65 cm from top.	.65 m
	Total	= 2.22 m

Measured Section 6

Date measured: 30 July 1973 Measured by: J. R. Griffin, Jr.

Locality: Near center of N½, NW¼, SE¼, Sec. 33, T.6S., R.6E., Riley County, Kansas; roadcut on south side of Riley County Highway 376, 0.2 miles west of 376 and U.S. 77 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive to blocky, top 45 cm contain sol'n cavities up to several cm; stylolites occur approximately 15 cm above base; crinoid debris.	1.65 m
2	Limestone, yellowish gray (5Y7/2), blocky to massive, undulatory bedding planes; crinoid debris.	.25 m
3	Limestone, yellowish gray (5Y7/2), blocky to platy, undulatory bedding planes, mudstone lenses appear periodically near center.	.15 m
4	Mudstone, calcareous, yellowish gray, platy to crumbly, burrows (0.5-0.3 cm in diameter).	.09 m
5	Limestone, yellowish gray (5Y7/2), massive; crinoid, echinoid debris.	.13 m
6	Mudstone, calcareous, yellowish gray (5Y7/2), crumbly to blocky, intermittent limestone?	

stringers or lenses; approximately 30 cm from top is erosion resistant zone with concentration of myalinids, Reticulatia, Derbyia, Composita, Meekella, Crurithyris, bryozoan and crinoid debris, one Wilkingia found in float. 1.50 m

7 Limestone?, "muddy", yellowish gray, blocky; no fossils?. .15 m

8 Mudstone, calcareous, yellowish gray (5Y7/2), blocky to platy, no fossils?. .13 m

9 Limestone, yellowish gray (5Y7/2), massive; echinoid debris; chert (black and white nodules) at base. .30 m

Total = 4.35 m

Measured Section 6A

Date measured: 31 July 1973 Measured by: J. R. Griffin, Jr.

Locality: NE¼, NW¼, SE¼, Sec. 31, T.6S., R.6E., Riley County, Kansas; roadcut on south side of Riley County Highway 376, 2.4 miles west of 376 and U.S. 77 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive to blocky; crinoid, echinoid debris.	2.03 m
2	Limestone, yellowish gray (5Y7/2), blocky to platy, undulatory bedding planes; *Reticulatia*, *Derbyia*.	.33 m
3	Mudstone?, calcareous, light gray (N7) wedges out west into yellowish gray (5Y7/2) mudstone (calcareous), blocky; *Reticulatia*, *Composita*, *Wilkingia*.	.45 m
4	Mudstone, calcareous, yellowish gray (5Y7/2) to light gray (N7), blocky to platy, 6 cm erosion resistant zone of limestone (muddy?) 1.60 m from top; occasional appearance of chert at base but float masks the feature; *Wilkingia*, *Reticulatia*.	2.05 m
5	Mudstone, yellowish gray (5Y7/2), calcareous, platy; no fossils.	.07 m

6	Limestone, yellowish gray (5Y7/2), massive; chert nodule layer (white, yellow and gray) 20 cm from top.	.20 m
		Total = 5.13 m

Measured Section 8

Date measured: 29 July 1973 Measured by: J. R. Griffin, Jr.

Locality: SW¼, SE¼, SE¼, Sec. 15, T.7S., R6E., Riley County, Kansas; roadcut on north side of K-16, 1.75 miles east of U.S. 77 and K-16 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2) to light gray (N7), reddish brown at top, massive, with yellowish gray to light gray mudstone lenses to discontinuous beds in lower one-third, massive grades to thin-bedded undulatory zone in lower 1 m; basal 306 cm "fossil hash" of *Composita*, *Derbyia*, *Reticulatia*; crinoid debris, echinoid, brachiopod fragments, burrows.	3.00 m
2	Mudstone, light gray (N7) to yellowish gray (5Y7/2); platy to crumbly; *Reticulatia*; calcareous.	.04 m
3	Mudstone?, calcareous, light gray (N7) to yellowish gray (5Y7/2), blocky; *Composita*, *Derbyia*, bryozoans.	.03 m
4	Mudstone, light gray (N7) to yellowish gray (5Y7/2), crumbly to blocky, dense mudstone? stringers and lenses; calcareous; *Composita*, *Reticulatia*, bryozoans.	.09 m

5	Mudstone?, calcareous, light gray (N7) to yellowish gray (5Y7/2), blocky; <u>Reticulatia</u>, <u>Derbyia</u>, bryozoan and crinoid debris.	.05 m
6	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), crumbly to blocky; <u>Reticulatia</u>, <u>Derbyia</u>.	.12 m
7	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), platy to blocky; non-fossiliferous?.	.04 m
8	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), blocky, "lenses" of "fossil hash", <u>Reticulatia</u>, <u>Derbyia</u>, bryozoan and crinoid debris.	.08 m
9	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), platy to blocky; non-fossiliferous?.	.05 m
10	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), shaly to blocky; non-fossiliferous?.	.35 m
11	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), blocky to platy; non-fossiliferous?.	.42 m

12	Limestone, yellowish gray (5Y7/2) with light gray (N7) patches, massive to blocky; crinoid, brachiopod debris; white and black chert nodule layer 45 cm from top.	.46 m
	Total	= 4.73 m

Measured Section 9

Date measured: 27 July 1973   Measured by: J. R. Griffin, Jr.

Locality: Western edge of NW¼, NE¼, SE¼, Sec. 21, T.9S., R.7E., Riley County, Kansas; roadcut on north side of U.S. 24, 1.4 miles west of U.S. 24 and K-113 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive, sol'n cavities; crinoid, echinoid debris.	.79 m
2	Mudstone?, calcareous, yellowish gray (5Y7/2) to light gray (N7); *Derbyia*, *Crurithyris*.	.08 m
3	Limestone, yellowish gray (5Y7/2), platy to massive; bryozoans, crinoids, brachiopods.	.36 m
4	Limestone, yellowish gray (5Y7/2), thin-bedded, blocky, burrows.	.23 m
5	Limestone, yellowish gray (5Y7/2), massive, gradational contact with Bed 4.	.28 m
6	Limestone, yellowish gray (5Y7/2) to dark reddish brown to reddish gray (iron-staining); high concentration of fossil brachiopods, beds 3-5 cm thick; lower 2 cm is "fossil hash" of brachiopods, crinoid debris and gastropods, *Composita*, *Derbyia*, *Crurithyris*, *Reticulatia*.	1.13 m

7	Mudstone, yellowish gray (5Y7/2), blocky, erosion resistant zone 55 cm down, calcareous; <u>Reticulatia</u>, <u>Pteronites</u>, <u>Wilkingia</u>, crinoid and bryozoan debris.	1.13 m
8	Mudstone, yellowish gray (5Y7/2) to light gray (N7), (gray areas are amorphous to lensoidal and discontinuous), platy to blocky; muddy limestone? forms resistant ledges discontinuously.	.68 m
9	Limestone, yellowish gray (5Y7/2) to light gray (N7), blocky to massive; lower 10 cm contain white and dark gray chert nodules.	.50 m
	Total =	5.18 m

Measured Section 10

Date measured: 1 August 1973 Measured by: J. R. Griffin, Jr.

Locality: SE¼, SW¼, NE¼, Sec. 34, T.12S., R.5E., Geary County, Kansas; roadcut on west side of U.S. 77, 2 miles south of U.S. 77 and I-70 intersection; noticeable bench marks Oketo-Fort Riley contact.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), dense, massive to blocky, burrows (2-4 cm in diameter).	.24 m
2	Limestone, yellowish gray (5Y7/2) to light gray (N7), blocky, undulatory bedding planes; Reticulatia, brachiopod and bivalve fragments (2-3 cm across).	.16 m
3	Limestone, yellowish gray (5Y7/2), massive, dense with sol'n cavities up to 2 cm in diameter; burrows up to 8 cm in diameter; crinoidal zone 50 cm wide extends upward from approximately 30 cm above bed base.	1.70 m
4	Limestone, yellowish gray (5Y7/2) to light gray (N7), platy, crinoidal content noticeably higher than base of Bed 3.	.24 m
5	Limestone, yellowish gray (5Y7/2) to light gray (N7), blocky, crinoid fragments.	.30 m

6	Limestone, muddy?, light gray (N7) to yellowish gray (5Y7/2), undulatory bedding planes; almost a calcarenite or calcrudite, considering high content of brachiopod, bivalve shell debris and crinoid and bryozoan fragments; Reticulatia, burrows.	.49 m
7	Mudstone, calcareous, light gray (N7), non-fossiliferous?.	.07 m
8	Mudstone, calcareous, light gray (N7), blocky; Wilkingia, Reticulatia, crinoids, gastropods, cephalopods, Pteronites.	.52 m
9	Mudstone, calcareous, light gray (N7), platy, non-fossiliferous?.	.07 m
10	Mudstone, calcareous, light gray (N7), blocky, non-fossiliferous?.	.07 m
11	Limestone, yellowish gray (5Y7/2), platy to blocky, non-fossiliferous?.	.25 m
12	Limestone, yellowish gray (5Y7/2), massive to blocky, chert nodule layer 15 cm from top, limestone continues lower, unmeasured.	.15 m
	Total	= 4.26 m

Measured Section 11

Date measured: 16 July 1973 Measured by: J. R. Griffin, Jr.

Locality: Center of NE¼, NW¼, Sec. 10, T.12S., R.5E., Geary County, Kansas; roadcut west of south access ramp to U.S. 77 from K-18; Oketo underlies base of old limestone (Fort Riley) quarry.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive to blocky, sol'n cavities in top half (approximately 1 cm in diameter), burrows (approximately 2 cm in diameter), styolites in lower 10 cm are iron-stained.	1.74 m
2	Limestone, yellowish gray (5Y7/2), thin-bedded, wavy bedding planes; crinoid, brachiopod fragments.	.29 m
3	Limestone, light gray (N7) to yellowish gray (5Y7/2), thin-bedded and wavy, similar to Bed 2; coarse (greater than 1 mm) fossil debris, mainly crinoid, echinoid, bryozoan fragments; *Reticulatia*, *Crurithyris*, fenestrate bryozoans occur periodically near base.	.29 m
4	Mudstone, calcareous, yellowish gray (5Y7/2), with some gray patches (N7), limestone	

lenses (1-2 cm thick), coiled gastropods, burrows with keels, bryozoans, Meekella, Wilkingia, Reticulatia; platy to blocky fracture. .26 m

5 Mudstone, calcareous, yellowish gray (5Y7/2) to gray (N7), 70 cm from top is dense to blocky zone more resistant than platy to blocky rock above and below; Wilkingia, Pteronites, Reticulatia, crinoid and bryozoan fragments. 1.60 m

6 Limestone, yellowish gray (5Y7/2), dense, massive; Pteronites; base covered, only surface exposed in drainage ditch at north end of outcrop. ?

Total = 4.18 m

Measured Section 12

Date measured: 19 July 1973   Measured by: J. R. Griffin, Jr.

Locality: SE¼, SW¼, SE¼, Sec. 20, T.11S., R.5E., Geary County, Kansas; at south end of Milford Dam, overlooks dam spillway, on opposite side of road (access) cut.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive, crinoid debris.	1.00 m
2	Limestone?, muddy?, yellowish gray (5Y7/2), thin-bedded; <u>Crurithyris</u>, crinoid debris.	.25 m
3	Limestone?, coarse-grained, muddy?, light gray (N7); crinoid debris.	.16 m
4	Mudstone, calcareous, light gray (N7), platy to blocky; erosion resistant zone 80 cm from top; lower 20 cm often yellowish gray (5Y7/2); <u>Reticulatia</u>, <u>Wilkingia</u>.	1.65 m
5	Limestone, yellowish gray (5Y7/2), thin-bedded, iron-stained; crinoid, bryozoan debris.	.08 m
6	Limestone, yellowish gray (5Y7/2), highly fractured; chert nodule stringer at base; below unmeasured.	.36 m
	Total	= 3.50 m

Measured Section 13

Date measured: 24 July 1973 Measured by: J. R. Griffin, Jr.

Locality: Eastern edge of SE¼, NW¼, Sec. 9, T.12S., R.6E., Geary County, Kansas; roadcut on north side of K-57, 0.5 miles southeast of K-57 and I-70 intersection.

Bed No.	Description	Thickness
1	Limestone, yellowish gray (5Y7/2), massive, sol'n cavities (1-4 cm in diameter); crinoid, brachiopod debris.	1.50 m
2	Mudstone, calcareous, yellowish gray (5Y7/2), platy to crumbly; Crurithyris, burrows (u-shaped).	.52 m
3	Limestone, gray (N7) to yellowish gray (5Y7/2), massive, continuous; Wilkingia, crinoid, echinoid debris.	.12 m
4	Mudstone, yellowish gray (5Y7/2); bryozoan debris, burrows (u-shaped); calcareous.	.14 m
5	Limestone, yellowish gray (5Y7/2), massive; crinoid, bryozoan, brachiopod debris, burrows(u-shaped).	.31 m
6	Mudstone, yellowish gray (5Y7/2), platy; Wilkingia, Reticulatia, Composita, Meekella, burrows (oblique).	.38 m

7	Mudstone, calcareous, yellowish gray (5Y7/2), blocky, intermittent limestone lenses (2-4 cm thick).	.15 m
8	Mudstone, calcareous, light gray (N7) to yellowish gray (5Y7/2), platy to blocky; *Wilkingia*, *Reticulatia*, *Pteronites*, crinoid debris.	.45 m
9	Mudstone, calcareous, light gray (N7), platy to blocky, limestone nodules; *Wilkingia*, *Derbyia*, *Reticulatia*, *Straporollus*, crinoid debris.	.25 m
10	Limestone, yellowish gray (5Y7/2), massive; crinoid, brachiopod debris; nodulose chert zone 52 cm from top--yellow, gray, white nodules.	.52 m
	Total	= 4.34 m

APPENDIX II

Appendix II contains point count data for 32 thin sections. Orthochem and allochem descriptions are on pages 29 - 32 in the text. Rock names are based on Folk's (1959) classification. Allochem mean grain sizes were estimated using Folk (1959, p. 16).

Thin Section Data For Locality 6A

Bed 1

Rock Name . . . . Fossiliferous Micrite

Orthochems - 92.3 percent of Rock

Mineral	Percentage
Micrite	46.5
Microspar	36.5
Spar	3.5
Ferrugenous Constituents	2.6
Muscovite	.3
Quartz	
Microquartz	
Pore Space	2.9

Allochems - 7.6 percent of Rock

Fossil	Percentage
Gastropods	.6
Brachiopods	2.6
Bivalves	1.3
Ostracodes	
Crinoids	.3
Foraminiferids	
Osagia sp.	.6
Phylloid Algae	.3
Echinoids	.3
Bryozoans	
Pellets	.6
Unidentified	1.0

Allochem mean grain size = .25 mm

Bed 2

Rock Name . . . . Fossiliferous Micrite

Orthochems - 94.4 percent of Rock

Mineral	Percentage
Micrite	50.1
Microspar	39.6
Spar	1.4
Ferrugenous Constituents	.7
Muscovite	.4
Quartz	2.2
Microquartz	

Allochems - 5.6 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.1
Bivalves	.7
Ostracodes	1.1
Crinoids	1.1
Foraminiferids	.4
Osagia sp.	
Phylloid Algae	.4
Echinoids	.4
Bryozoans	
Pellets	.4
Unidentified	

Allochem mean grain size = .25 mm

Bed 3

Rock Name . . . . Biomicrite

Orthochems - 84.8 percent of Rock

Mineral	Percentage
Micrite	58.4
Microspar	9.7
Spar	.6
Ferrugenous Constituents	14.8
Muscovite	.3
Quartz	1.0
Microquartz	

Allochems - 15.0 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	.6
Bivalves	
Ostracodes	.3
Crinoids	4.5
Foraminiferids	1.9
Osagia sp.	5.2
Phylloid Algae	1.0
Echinoids	.3
Bryozoans	.6
Pellets	
Unidentified	.6

Allochem mean grain size = .062 mm

Bed 4

Rock Name . . . . Fossiliferous Micrite

Orthochems - 93.9 percent of Rock

Mineral	Percentage
Micrite	54.8
Microspar	16.0
Spar	
Ferrugenous Constituents	22.8
Muscovite	
Quartz	.3
Microquartz	

Allochems - 6.1 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.4
Bivalves	1.0
Ostracodes	1.4
Crinoids	1.4
Foraminiferids	
Osagia sp.	.3
Phylloid Algae	.3
Echinoids	
Bryozoans	
Pellets	
Unidentified	.3

Allochem mean grain size = .062 mm

Bed 5

Rock Name . . . . Fossiliferous Micrite

Orthochems - 97.1 percent of Rock

Mineral	Percentage
Micrite	57.8
Microspar	24.5
Spar	.4
Ferrugenous Constituents	13.0
Muscovite	
Quartz	1.4
Microquartz	

Allochems - 3.0 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.1
Bivalves	
Ostracodes	.7
Crinoids	.4
Foraminiferids	.4
Osagia sp.	
Phylloid Algae	.4
Echinoids	
Bryozoans	
Pellets	
Unidentified	

Allochem mean grain size = .031 mm

Bed 6

Rock Name . . . . Biomicrite

Orthochems - 84.5 percent of Rock

Mineral	Percentage
Micrite	52.7
Microspar	21.3
Spar	.9
Ferrugenous Constituents	7.8
Muscovite	.3
Quartz	.9
Microquartz	.6

Allochems -15.2 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	.6
Bivalves	.6
Ostracodes	2.8
Crinoids	4.4
Foraminiferids	
Osagia sp.	4.7
Phylloid Algae	.3
Echinoids	.9
Bryozoans	.3
Pellets	.6
Unidentified	

Allochem mean grain size = .25 mm

Thin Section Data For Locality 9

Bed 1

Rock Name . . . . Biomicrudite

Orthochems - 74.8 percent of Rock

Mineral	Percentage
Micrite	52.2
Microspar	13.5
Spar	4.4
Ferrugenous Constituents	4.7
Muscovite	
Quartz	
Microquartz	

Allochems - 25.2 percent of Rock

Fossil	Percentage
Gastropods	.7
Brachiopods	4.4
Bivalves	
Ostracodes	1.7
Crinoids	6.7
Foraminiferids	1.7
Osagia sp.	.3
Phylloid Algae	3.7
Echinoids	2.7
Bryozoans	.3
Pellets	2.0
Unidentified	1.0

Allochem mean grain size = 1.00 mm

Bed 2

Rock Name . . . . Muddy* Micrite

Orthochems - 92.6 percent of Rock

Mineral	Percentage
Micrite	30.4
Microspar	19.2
Spar	1.9
Ferrugenous Constituents	40.1
Muscovite	
Quartz	1.0
Microquartz	

Allochems - 7.3 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.6
Bivalves	
Ostracodes	
Crinoids	3.8
Foraminiferids	1.0
Osagia sp.	.3
Phylloid Algae	.3
Echinoids	.3
Bryozoans	
Pellets	
Unidentified	

Allochem mean grain size = .50 mm

* Muddy refers to an admixture of silt and clay size terrigenous components.

Bed 3

Rock Name . . . . Silty Biomicrite

Orthochems - 82.9 percent of Rock

Mineral	Percentage
Micrite	39.2
Microspar	13.3
Spar	3.4
Ferrugenous Constituents	27.0
Muscovite	
Quartz	
Microquartz	

Allochems - 17.3 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	2.7
Bivalves	
Ostracodes	1.9
Crinoids	3.8
Foraminiferids	4.6
Osagia sp.	2.3
Phylloid Algae	.8
Echinoids	.8
Bryozoans	
Pellets	.4
Unidentified	

Allochem mean grain size = .50 mm

Bed 4

Rock Name . . . . Clayey Micrite

Orthochems - 95.4 percent of Rock

Mineral	Percentage
Micrite	45.8
Microspar	21.8
Spar	3.9
Ferrugenous Constituents	22.9
Muscovite	
Quartz	1.0
Microquartz	

Allochems - 4.7 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	
Bivalves	
Ostracodes	1.4
Crinoids	
Foraminiferids	1.8
Osagia sp.	.4
Phylloid Algae	.7
Echinoids	
Bryozoans	
Pellets	.4
Unidentified	

Allochem mean grain size = .125 mm

Bed 5

Rock Name . . . . Silty Biomicrite

Orthochems - 72.7 percent of Rock

Mineral	Percentage
Micrite	41.2
Microspar	13.1
Spar	1.2
Ferrugenous Constituents	17.2
Muscovite	
Quartz	
Microquartz	

Allochems - 27.1 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.9
Bivalves	
Ostracodes	1.2
Crinoids	6.6
Foraminiferids	8.4
Osagia sp.	6.6
Phylloid Algae	
Echinoids	.9
Bryozoans	1.2
Pellets	.3
Unidentified	

Allochem mean grain size = .75 mm

Bed 6

Rock Name . . . . Brachiopod Biomicrite

Orthochems - 75.1 percent of Rock

Mineral	Percentage
Micrite	61.5
Microspar	5.5
Spar	2.9
Ferrugenous Constituents	5.2
Muscovite	
Quartz	
Microquartz	

Allochems - 24.8 percent of Rock

Fossil	Percentage
Gastropods	3.6
Brachiopods	10.7
Bivalves	
Ostracodes	1.9
Crinoids	1.6
Foraminiferids	1.9
Osagia sp.	.6
Phylloid Algae	.6
Echinoids	
Bryozoans	1.6
Pellets	
Unidentified	2.3

Allochem mean grain size = .35 mm

Bed 7

Rock Name . . . . Biomicrudite

Orthochems - 66.5 percent of Rock

Mineral	Percentage
Micrite	43.1
Microspar	6.6
Spar	3.5
Ferrugenous Constituents	8.1
Muscovite	
Quartz	
Microquartz	5.2

Allochems - 33.4 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.2
Bivalves	
Ostracodes	1.4
Crinoids	9.0
Foraminiferids	5.7
Osagia sp.	4.3
Phylloid Algae	2.0
Echinoids	
Bryozoans	9.8
Pellets	
Unidentified	

Allochem mean grain size = 1.00 mm

Bed 8

Rock Name . . . . Biomicrudite

Orthochems - 72.6 percent of Rock

Mineral	Percentage
Micrite	53.6
Microspar	4.6
Spar	1.6
Ferrugenous Constituents	10.5
Muscovite	
Quartz	
Microquartz	2.6

Allochems - 27.2 percent of Rock

Fossil	Percentage
Gastropods	1.3
Brachiopods	9.2
Bivalves	
Ostracodes	.6
Crinoids	7.6
Foraminiferids	4.3
Osagia sp.	
Phylloid Algae	
Echinoids	
Bryozoans	2.6
Pellets	
Unidentified	1.6

Allochem mean grain size = 3.50 mm

Bed 9

Rock Name . . . . Muddy* Biomicrite

Orthochems - 76.4 percent of Rock

Mineral	Percentage
Micrite	29.8
Microspar	23.3
Spar	2.6
Ferrugenous Constituents	19.1
Muscovite	
Quartz	
Microquartz	1.6

Allochems - 23.5 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.3
Bivalves	
Ostracodes	3.2
Crinoids	4.8
Foraminiferids	1.3
Osagia sp.	8.1
Phylloid Algae	
Echinoids	1.9
Bryozoans	1.0
Pellets	
Unidentified	1.9

Allochem mean grain size = .35 mm

* See p. 122.

Thin Section Data For Locality 10

Bed 5*

Rock Name . . . . Silty Biomicrite

Orthochems - 79.8 percent of Rock

Mineral	Percentage
Micrite	44.2
Microspar	21.1
Spar	1.6
Ferrugenous Constituents	12.9
Muscovite	
Quartz	
Microquartz	

Allochems - 20.4 percent of Rock

Fossil	Percentage
Gastropods	.7
Brachiopods	4.3
Bivalves	
Ostracodes	.7
Crinoids	5.0
Foraminiferids	.7
Osagia sp.	4.0
Phylloid Algae	2.0
Echinoids	.7
Bryozoans	1.6
Pellets	
Unidentified	.7

Allochem mean grain size = .25 mm

* Beds 1 through 4 were not included in thin section analysis as explained on p. 9.

Bed 6G

Rock Name . . . . *Osagia* Biomicrite

Orthochems - 64.7 percent of Rock

Mineral	Percentage
Micrite	41.2
Microspar	11.9
Spar	6.6
Ferrugenous Constituents	5.0
Muscovite	
Quartz	
Microquartz	

Allochems - 35.1 percent of Rock

Fossil	Percentage
Gastropods	1.3
Brachiopods	2.0
Bivalves	2.0
Ostracodes	.3
Crinoids	5.9
Foraminiferids	4.3
Osagia sp.	12.5
Phylloid Algae	1.0
Echinoids	1.6
Bryozoans	1.6
Pellets	
Unidentified	2.6

Allochem mean grain size = .50 mm

Bed 6Y

Rock Name . . . . Biomicrite

Orthochems - 82.4 percent of Rock

Mineral	Percentage
Micrite	56.7
Microspar	15.7
Spar	.7
Ferrugenous Constituents	9.3
Muscovite	
Quartz	
Microquartz	

Allochems - 17.7 percent of Rock

Fossil	Percentage
Gastropods	.3
Brachiopods	
Bivalves	1.0
Ostracodes	.3
Crinoids	2.7
Foraminiferids	4.0
Osagia sp.	5.7
Phylloid Algae	.7
Echinoids	1.0
Bryozoans	.3
Pellets	.7
Unidentified	.3

Allochem mean grain size = .15 mm

Bed 7

Rock Name . . . . Muddy* Micrite

Orthochems - 95.9 percent of Rock

Mineral	Percentage
Micrite	63.5
Microspar	6.1
Spar	.3
Ferrugenous Constituents	24.3
Muscovite	1.4
Quartz	.3
Microquartz	

Allochems - 4.0 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	
Bivalves	
Ostracodes	1.7
Crinoids	
Foraminiferids	
Osagia sp.	
Phylloid Algae	2.3
Echinoids	
Bryozoans	
Pellets	
Unidentified	

Allochem mean grain size = .15 mm

* See p. 122.

Bed 8

Rock Name. . . . . Muddy* Biomicrite

Orthochems - 87.2 percent of Rock

Mineral	Percentage
Micrite	55.2
Microspar	11.0
Spar	.4
Ferrugenous Constituents	20.6
Muscovite	
Quartz	
Microquartz	

Allochems - 12.7 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.8
Bivalves	1.4
Ostracodes	3.2
Crinoids	2.8
Foraminiferids	2.1
Osagia sp.	
Phylloid Algae	.7
Echinoids	
Bryozoans	
Pellets	
Unidentified	.7

Allochem mean grain size = .25 mm

* See p. 122.

Bed 9

Rock Name . . . . Muddy* Micrite

Orthochems - 99.3 percent of Rock

Mineral	Percentage
Micrite	58.8
Microspar	26.4
Spar	.4
Ferrugenous Constituents	10.1
Muscovite	1.8
Quartz	1.8
Microquartz	

Allochems - .7 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	
Bivalves	
Ostracodes	.7
Crinoids	
Foraminiferids	
Osagia sp.	
Phylloid Algae	
Echinoids	
Bryozoans	
Pellets	
Unidentified	

Allochem mean grain size = .025 mm

* See p. 122.

Bed 10

Rock Name . . . . Muddy* Biomicrite

Orthochems - 89.7 percent of Rock

Mineral	Percentage
Micrite	59.2
Microspar	6.1
Spar	.5
Ferrugenous Constituents	23.0
Muscovite	.9
Quartz	
Microquartz	

Allochems - 10.3 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	3.8
Bivalves	
Ostracodes	2.3
Crinoids	1.4
Foraminiferids	.9
Osagia sp.	.5
Phylloid Algae	.9
Echinoids	
Bryozoans	.5
Pellets	
Unidentified	

Allochem mean grain size = .25 mm

* See p. 122.

Bed 11

Rock Name . . . . *Osagia* Biomicrite

Orthochems - 75.2 percent of Rock

Mineral	Percentage
Micrite	27.8
Microspar	35.9
Spar	3.0
Ferrugenous Constituents	5.9
Muscovite	.4
Quartz	.4
Microquartz	1.8

Allochems - 24.2 percent of Rock

Fossil	Percentage
Gastropods	.4
Brachiopods	.7
Bivalves	.7
Ostracodes	
Crinoids	5.6
Foraminiferids	2.6
Osagia sp.	11.8
Phylloid Algae	1.5
Echinoids	.4
Bryozoans	1.1
Pellets	
Unidentified	

Allochem mean grain size = .50 mm

Bed 12

Rock Name . . . . Biomicrite

Orthochems - 86.7 percent of Rock

Mineral	Percentage
Micrite	59.2
Microspar	20.4
Spar	.7
Ferrugenous Constituents	6.0
Muscovite	
Quartz	
Microquartz	.4

Allochems - 13.5 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	
Bivalves	3.9
Ostracodes	
Crinoids	.7
Foraminiferids	
<u>Osagia</u> sp.	5.3
Phylloid Algae	.7
Echinoids	.4
Bryozoans	2.5
Pellets	
Unidentified	

Allochem mean grain size = .125 mm

Thin Section Data For Locality 12

Bed 1

Rock Name . . . . Biomicrite

Orthochems - 77.8 percent of Rock

Mineral	Percentage
Micrite	50.5
Microspar	17.8
Spar	5.1
Ferrugenous Constituents	1.9
Muscovite	
Quartz	.3
Microquartz	
Pore Space	2.2

Allochems - 22.1 percent of Rock

Fossil	Percentage
Gastropods	.3
Brachiopods	6.7
Bivalves	
Ostracodes	
Crinoids	4.1
Foraminiferids	.3
Osagia sp.	8.9
Phylloid Algae	
Echinoids	.3
Bryozoans	.9
Pellets	
Unidentified	.6

Allochem mean grain size = .30 mm

Bed 2

Rock Name . . . . *Osagia* Biomicrudite

Orthochems - 61.7 percent of Rock

Mineral	Percentage
Micrite	44.4
Microspar	12.2
Spar	1.7
Ferrugenous Constituents	1.4
Muscovite	.3
Quartz	.3
Microquartz	
Pore Space	1.4

Allochems - 38.1 percent of Rock

Fossil	Percentage
Gastropods	1.7
Brachiopods	7.0
Bivalves	
Ostracodes	
Crinoids	7.7
Foraminiferids	3.5
Osagia sp.	15.4
Phylloid Algae	
Echinoids	1.4
Bryozoans	.7
Pellets	
Unidentified	.7

Allochem mean grain size = 1.00 mm

Bed 3

Rock Name . . . . Silty Biomicrudite

Orthochems - 77.5 percent of Rock

Mineral	Percentage
Micrite	47.1
Microspar	11.8
Spar	1.9
Ferrugenous Constituents	14.5
Muscovite	.3
Quartz	1.9
Microquartz	

Allochems - 22.4 percent of Rock

Fossil	Percentage
Gastropods	.9
Brachiopods	2.5
Bivalves	
Ostracodes	
Crinoids	4.0
Foraminiferids	3.1
Osagia sp.	8.0
Phylloid Algae	.3
Echinoids	.9
Bryozoans	1.2
Pellets	
Unidentified	1.5

Allochem mean grain size = 1.00 mm

Bed 4

Rock Name . . . . Biomicrudite

Orthochems - 74.7 percent of Rock

Mineral	Percentage
Micrite	63.6
Microspar	5.9
Spar	1.5
Ferrugenous Constituents	3.7
Muscovite	
Quartz	
Microquartz	

Allochems - 25.2 percent of Rock

Fossil	Percentage
Gastropods	1.5
Brachiopods	2.2
Bivalves	
Ostracodes	1.1
Crinoids	3.3
Foraminiferids	3.7
Osagia sp.	9.7
Phylloid Algae	
Echinoids	1.1
Bryozoans	.4
Pellets	1.1
Unidentified	.4
Intraclast	.7

Allochem mean grain size = 1.30 mm

Bed 5

Rock Name . . . . Biomicrudite

Orthochems - 70.0 percent of Rock

Mineral	Percentage
Micrite	53.9
Microspar	6.7
Spar	1.3
Ferrugenous Constituents	4.4
Muscovite	1.0
Quartz	.3
Microquartz	2.4

Allochems - 29.9 percent of Rock

Fossil	Percentage
Gastropods	.3
Brachiopods	4.4
Bivalves	
Ostracodes	2.7
Crinoids	8.1
Foraminiferids	3.7
Osagia sp.	4.4
Phylloid Algae	
Echinoids	1.0
Bryozoans	4.0
Pellets	
Unidentified	1.3

Allochem mean grain size = 1.50 mm

Bed 6

Rock Name. Biomicrite

Orthochems - 88.8 percent of Rock

Mineral	Percentage
Micrite	71.1
Microspar	12.5
Spar	.3
Ferrugenous Constituents	3.9
Muscovite	.3
Quartz	
Microquartz	1.0

Allochems - 10.9 percent of Rock

Fossil	Percentage
Gastropods	
Brachiopods	1.0
Bivalves	
Ostracodes	.7
Crinoids	3.9
Foraminiferids	1.0
Osagia sp.	3.3
Phylloid Algae	
Echinoids	
Bryozoans	1.0
Pellets	
Unidentified	

Allochem mean grain size = .50 mm

Float Sample of *Wilkingia* cf. *terminalis* Cast

Rock Name . . . . Biomicrite

Orthochems - 72.3 percent of Rock

Mineral	Percentage
Micrite	43.4
Microspar	17.5
Spar	4.8
Ferrugenous Constituents	6.0
Muscovite	
Quartz	.6
Microquartz	

Allochems - 27.6 percent of Rock

Fossil	Percentage
Gastropods	.3
Brachiopods	1.8
Bivalves	
Ostracodes	2.7
Crinoids	4.5
Foraminiferids	4.8
Osagia sp.	7.8
Phylloid Algae	1.2
Echinoids	3.6
Bryozoans	.6
Pellets	.3
Unidentified	

Allochem mean grain size = .36 mm

Transverse Thin Section of a Horizontal Burrow from Bed 4 at Locality 13

Rock Name . . . . *Osagia* Biomicrite

Orthochems - 64.4 percent of Rock

Mineral	Percentage
Micrite	40.4
Microspar	14.8
Spar	4.4
Ferrugenous Constituents	3.6
Muscovite	
Quartz	1.2
Microquartz	

Allochems - 35.6 percent of Rock

Fossil	Percentage
Gastropods	1.2
Brachiopods	2.4
Bivalves	3.2
Ostracodes	.4
Crinoids	6.4
Foraminiferids	.4
Osagia sp.	15.6
Phylloid Algae	1.2
Echinoids	2.0
Bryozoans	2.8
Pellets	
Unidentified	

Allochem mean grain size = .75 mm

APPENDIX III

Reagents and Apparatus for Phosphate Determinations

Reagents used in the procedure were prepared as follows:

1) 1 N NH_4Cl. 53.5 g solid dissolved in distilled water and diluted to a 1 L volume.

2) 0.5 N NH_4F. 18.5 g solid dissolved in 1 L of distilled water. Adjust pH to 7.0 with 4 N NH_4OH added dropwise.

3) 0.1 N NaOH. 4.1 g dissolved in 1 L of distilled water and the solution standardized to 0.1 N by addition of distilled water.

4) 0.5 N H_2SO_4. 15 ml conc. H_2SO_4 dissolved in 1 L distilled water and the solution standardized to 0.5 N by addition of distilled water.

5) Saturated NaCl solution. 400 g NaCl suspended in 1 L of distilled water.

6) Standard phosphorous solutions. 10.975 g of KH_2PO_4 is dissolved in distilled water and diluted to a 500 ml volume. 10 ml of this solution is diluted to a volume of 1 L to make a 50 ppm solution. Less concentrated solutions may be prepared as needed by further dilution of this 50 ppm stock solution.

7) Chlorostannous reductant. 25 g of $SnCl_2 \cdot 2H_2O$ is dissolved in 100 ml concentrated HCl, diluted to 1 L and stored in a brown bottle with a siphon under a 10 mm layer of mineral oil.

8) Sulfomolybdic acid solution. 25 g of $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ is dissolved in 200 ml of distilled water, heated to 60° C, and filtered if cloudy. Then 275 ml of phosphorous-free and arsenic-free concentrated sulfuric acid (35 to 36 N) is diluted to 750 ml with distilled water. After both solutions have cooled, the ammonium molybdate solution is added slowly, with stirring, to the sulfuric acid solution. The combined solution is then diluted to exactly 1 L with distilled water.

9) 2,6-dinitrophenol (or 2,4-dinitrophenol). 0.25% by weight in distilled water.

Apparatus needed for the procedure consists of 2 and 3 ml pipettes; a burette; 100 ml centrifuge tubes; 50 ml volumetric flasks; eye droppers; stirring rods; 20 ml, 100 ml, and 1 L graduated cylinders; and an array of different size beakers.

Care must be taken not to contaminate the apparatus during the phosphate tests. All glassware was cleaned following Jeppesen's procedure (Jeppesen, 1972, p. 88).

APPENDIX IV

The following pages contain estimated percentages of the different constituents found in the insoluble sand fractions from the four localities studied in detail and for selected specimens of pholadomyids and Reticulatia. Each pholadomyid sample is divided into two parts, internal cast and external matrix. Sample numbers are listed in stratigraphic order from top to bottom. For description of constituents see text, pages 26-28. Fossil fragments are listed in order of dominance.

Column headings are abbreviated and listed below:

Abbreviations

G	=	volcanic glass (shards)
LC	=	limonitic clay balls or flakes
MC	=	micaceous claystone
M	=	muscovite
OF	=	organo-phosphatic fragments
P	=	pyrite
Q	=	quartz
SF	=	silicified fossil fragments
P.	=	pholadomyid
R.	=	Reticulatia cf. huecoensis
m	=	external matrix
c	=	internal cast
B	=	brachiopod fragments
F	=	foraminiferids
By	=	bryozoan fragments
C	=	crinoid fragments
S	=	sponge spicules
E	=	echinoid fragments

Insoluble Residue Constituents

(Sand Fraction Only)

Sample No.	G	LC	MC	M	OF	P	Q	SF
6A-1		<1						99 B
6A-2		2		2				96 B,F,By
6A-3				3	2	1	1	93 B,F,By
6A-3B		<1			2	<1		97 B,By
6A-4-1		85		<1	<1		3	10 B,F
6A-4-2		2			<1	57 F		40 F,B
6A-4-3		<1		<1	10	2		86 B,F,S
6A-5		2		<1	<1	<1		96 B,F,S
6A-6	<1	1			<1			98 B,F,C,S
9-1		1		<1			1	98 F
9-2		1	98	<1				
9-3		1		1			1	97 F,B
9-4		7		<1	1		1	91 F,B
9-5		1		<1				99 F,B,By
9-6		3						97 B,By
9-7								100 B,C
9-8						<1		99 B,E,C
9-9								100 B,F,C,S,E
9-10		<1		<1				99 B,F,C,S
10-1	1	7			<1		5	86 F,B
10-2	<1	1					88	10 F,B
10-3	<1	<1		1			10	87 F,B
10-4		1		7	<1			92 B
10-5		1	<1	8			1	89 B
10-6G		5		7	<1	<1	1	86 B,F,By
10-6Y	1	5				<1	1	93 B,By
10-7				<1	40	1		59 F,B
10-8				<1	45	1		54 F,By,B
10-9	1	<1		<1		30	<1	68 F,B
10-10	1	7	5					88 B,F
10-11		<1					<1	99 B,C,E
10-12	1	<1					<1	99 B,F,S
12-1		5		<1			<1	94 F,B
12-2		<1		<1			<1	98 F,B
12-3			20	1			<1	79 F,B,By
12-4				1	2	<1	<1	96 F,B,By
12-5		<1					<1	99 F,B,By,C
12-6		<1						99 F,B,C

Sample No.	G	LC	MC	M	OF	P	Q	SF
P. 6A-6c				1	2		<1	97 F,B,S
P. 6A-6m				1	1			98 F,B,By
P. 8-9c				4	3			93 F,B
P. 8-9m				3	3	<1		94 F,B
P. 8-10c			2	<1				97 F,B
P. 8-10m		<1	7					93 F,B,S
P. 9-D-7c		2					<1	98 F,B,By
P. 9-D-7m					10	<1		90 F,B
P. 10-16c							<1	99 B,F,By
P. 10-16m			60		1			40 B,F
P. 13-0c		2	2	<1				96 F,B
P. 13-0m								100 B,F
R. 1-5m			<1		<1	<1	<1	98 B,F,By
R. 1-6&7m		<1						99 B,By,F
R. 6A-3m				<1		1	<1	98 B,By,F
R. 10-4m				<1	1	<1	<1	94 B,F
R. 11-5m		<1				<1	<1	98 F,B
R. 13-0m		1					<1	98 B,F,By

APPENDIX V

Macrofossil Angle of Repose Data

Wilkingia cf. *terminale*

Horizon from which Sample was Taken	Angle of Repose (in degrees)
1-5	11
3-C-5	8
13-3	28
13-6	27
	$\bar{X}$ = 18.5

Chaenomya cf. *cooperi*

Horizon from which Sample was Taken	Angle of Repose (in degrees)
3-C-6	17
8-4	28
	$\bar{X}$ = 22.5

Exochorhynchus cf. *altirostratus*

Horizon from which Sample was Taken	Angle of Repose (in degrees)
1-4	34
1-5	32
3-E-10	23
4-5	32
4-6	27
4-6	30
4-6	35
6A-2	31
6A-3	44
6A-3	28
6A-3	43
8-6	27
8-11	15
9-C-7	38
9-D-7	14
9-D-7	5

Horizon from which Sample was Taken	Angle of Repose (in degrees)
10-7	20
10-8	20
13-6	27

Taxonomically Undifferentiated Pholadomyids

3-B-2	36
3-C-2	34
3-C-6	7
3-D-2	35
3-D-4	0
3-D-5	38
4-5	9
4-6	11
4-6	23
4-6	29
4-6	11
4-6	20
4-6	10
4-6	28
4-6	22
4-6	35
4-7	12
6A-3	57
6A-3	17
6A-3	32
6A-3	36
6A-3	40
6A-3	25
8-1	23
8-7	29
8-12	23
9-C-6	19
10-8	24
10-8	12
10-8	10
10-8	17
10-8	30

Horizon from which Sample was Taken	Angle of Repose (in degrees)
11-4	18
11-5	7
11-5	24
11-5	23
11-5	7
11-5	3
13-3	28
13-4	25
13-7	13
13-7	31
13-7	13
13-7	15
13-8	32
13-8	34
13-9	31
	$\bar{X} = 22.5$

Reticulatia cf. huecoensis

1-4	18
1-4	9
1-5	0
1-5	10
1-5	0
1-6	6
3-B-2	0
3-B-7	20
3-C-1	53
3-C-1	18
3-C-3	31
3-C-8	0
3-C-8	0
3-D-5	5
3-E-4	20
4-6	18
4-5	1
6A-3	25
6A-3	0
8-1	38
8-3	12
8-11	0

Horizon from which Sample was Taken	Angle of Repose (in degrees)
9-C-3	35
9-C-6	0
9-D-3	0
10-8	0
10-8	0
10-8	2
10-8	0
10-8	-7
10-8	15
10-8	0
11-3	27
11-4	10
11-4	0
11-4	12
11-4	18
11-5	0
13-6	1
13-6	8
13-7	15
13-7	7
13-7	12
13-8	0
	$\bar{X} = 10.0$

APPENDIX VI

Pholadomyid Size Data

Wilkingia cf. terminale

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
1-5	87	38	22	4.0	0.6
3-C-5	59	23	27	2.2	1.2
13-3	90	38	41	2.2	1.1
13-6	100	38	27	3.7	0.7
				$\bar{X} = 3.0$	$\bar{X} = 0.9$

Chaenomya cf. cooperi

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
3-C-6	54	19	20	2.7	1.1
4-6	44	19	17	2.6	0.9
8-4	46	20	19	2.4	1.0
				$\bar{X} = 2.6$	$\bar{X} = 1.0$

Exochorhynchus cf. altirostratus

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
1-4	82	42	36	2.3	0.9
1-5	66	32	32	2.1	1.0
3-E-10	47	22	18	2.6	0.8
4-5	88	44	38	2.3	0.9
4-6	72	37	33	2.2	0.9
4-6	55	26	18	3.0	0.7
4-6	90	40	35	2.6	0.9
4-6	82	44	37	2.2	0.8
6A-2	69	28	21	3.3	0.8
6A-3	46	23	20	2.3	0.9
6A-3	72	34	35	2.1	1.0
6A-3	74	34	35	2.1	1.0

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
8-6	69	31	37	1.9	1.2
8-11	84	36	24	3.5	0.7
9-D-7	63	32	19	3.3	0.6
9-D-7	62	31	21	3.0	0.7
10-7	59	26	21	2.8	0.8
10-7	64	42	27	2.4	0.6
10-8	105	42	27	3.9	0.6
13-6	79	41	34	2.3	0.8
				$\overline{X}$ = 2.6	$\overline{X}$ = 0.8

Taxonomically Undifferentiated Pholadomyids

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
3-B-1	25	8	10	2.5	1.3
3-B-2	60	42	30	2.0	0.7
3-C-6	12	13	9	1.3	0.7
3-D-2	24	12	13	1.8	1.1
3-D-4	15	5	10	1.5	2.0
4-5	70	31	25	2.8	0.8
4-6	81	37	27	3.0	0.7
4-6	80	33	28	2.9	0.8
4-6	93	39	31	3.0	0.8
4-6	51	26	24	2.1	0.9
4-6	101	41	30	3.4	0.7
4-6	41	24	20	2.1	0.8
4-6	73	41	30	2.4	0.7
4-6	67	37	31	2.2	0.8
4-7	105	46	32	3.3	0.7
6A-3	71	39	35	2.0	0.9
6A-3	38	15	21	1.8	1.4
6A-3	38	28	30	1.3	1.1
8-1	61	35	28	2.2	0.9
8-7	54	28	20	2.7	0.7
8-12	73	33	30	2.4	0.9
9-C-6	86	31	27	3.2	0.9
10-8	77	42	41	1.9	1.0
10-8	69	27	20	3.5	0.7
10-8	106	40	25	4.2	0.6
10-8	79	33	25	3.2	0.8
10-8	106	37	29	3.7	0.8

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
11-4	35	14	14	2.5	1.0
11-5	71	18	20	3.6	1.1
11-5	48	25	21	2.3	1.4
11-5	81	26	27	3.0	1.0
11-5	17	8	5	3.4	0.6
11-5	84	30	18	4.7	0.6
11-5	77	36	25	3.1	0.7
13-4	75	37	32	2.3	0.9
13-7	73	35	21	3.5	0.6
13-7	19	8	9	2.1	1.1
13-7	68	29	20	3.4	0.7
13-7	41	13	14	2.9	1.1
13-8	82	45	36	2.3	0.8
13-8	82	39	33	2.5	0.8
13-9	57	28	16	3.6	0.6
				$\overline{X}$ = 2.7	$\overline{X}$ = 0.8

APPENDIX VII

Reticulatia cf. huecoensis Size Data

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
1-4	46	48	25	1.0	0.5
1-4	41	48	23	0.9	0.5
1-5	42	46	24	0.9	0.5
1-5	49	57	24	0.9	0.4
1-5	51	50	31	1.0	0.6
1-6	54	70	30	0.8	2.3
1-6	45	46	28	1.0	0.6
1-6	48	62	31	0.8	0.5
1-6	53	62	32	0.9	0.5
3-B-1	55	48	25	1.1	0.5
3-B-1	44	60	18	0.7	0.3
3-B-2	47	48	26	1.0	0.5
3-C-1	18	23	10	0.8	0.4
3-C-1	47	50	20	0.9	0.4
3-C-1	34	48	20	0.7	0.4
3-C-3	38	60	18	0.6	0.3
3-C-8	52	63	26	0.8	0.4
3-D-5	45	48	22	0.9	0.5
3-D-5	40	47	27	0.9	0.5
3-D-10	40	52	16	0.8	0.3
4-5	52	54	28	1.0	0.5
4-6	45	49	26	0.9	0.5
4-6	36	54	22	0.7	0.4
6A-3	48	42	26	1.1	0.6
6A-3	60	59	32	1.0	0.5
8-1	41	60	25	0.7	0.4
8-11	45	57	15	0.8	0.3
8-11	53	69	23	0.8	0.3
9-B-4	48	51	20	0.9	0.4
9-B-4	40	52	18	0.8	0.3
9-C-3	27	35	15	0.8	0.4
9-C-4	46	53	20	0.9	0.4
10-8	50	48	22	1.0	0.5
10-8	60	55	25	1.1	0.6
10-8	36	62	24	0.6	0.4
10-8	45	50	20	0.9	0.4
10-8	52	52	30	1.0	0.6
10-8	46	48	27	1.0	0.6
10-8	44	56	26	0.8	0.5
10-8	48	45	22	1.1	0.5

Sample Number	Length (mm)	Width (mm)	Height (mm)	Length/Height Ratio	Height/Width Ratio
11-3	41	44	26	0.9	0.6
11-4	45	54	22	0.8	0.4
11-4	42	36	25	1.2	0.7
11-4	37	47	25	0.8	0.5
11-4	40	25	13	1.6	0.5
11-4	41	54	18	0.8	0.3
11-4	46	48	17	1.0	0.4
11-4	50	68	30	0.7	0.4
13-6	52	51	31	1.0	0.6
13-6	40	53	22	0.8	0.4
13-7	52	58	30	0.9	0.5
13-7	49	52	28	0.9	0.5
13-7	55	57	32	1.0	0.6
13-8	46	51	24	0.9	0.5
				$\overline{X} = 0.9$	$\overline{X} = 0.5$

Basic Statistics

	Minimum	Maximum	Mean	Variance	Std. Deviation	Std. Error of Mean
Length (mm)	18	60	45	55	7.4	1.0
Width (mm)	23	70	51	81	9.0	1.2
Height (mm)	10	35	24	29	5.4	0.7

APPENDIX VIII

Sample Calculation of Rayleigh z Statistic

Test of Randomness of Fossil Orientation at Section 11

Pholadomyids

Midpoint of Class (degrees) (x_i)	Number of ind. in Class (n)	n (sin x_i)	n (cos x_i)
0	0		
30	0		
60	0		
90	0		
120	0		
150	1	0.500	-0.866
180	0		
210	2	-1.000	-1.732
240	0		
270	2	-2.000	0.000
300	2	-1.732	1.000
330	2	-1.000	1.732
	N = 9	V = -5.232	W = 0.134

$$z = \frac{V^2 + W^2}{N} = \frac{27.374 + 0.018}{9} = 3.044^*$$

Significance levels - .05 = 2.910
.01 = 4.250

*Significant at .05 level.

APPENDIX IX

Included in this appendix are graphic representations of the grid study areas at Localities 3 and 9. Accompanying each diagram is a table that lists the identity and measurement data for each fossil. Grid numbers and column abbreviations need some explanation.

Grid squares are numbered in three parts. For example, 3A1 (*i.e.*, 3-A-1), refers to Locality 3; A is the first, or lowermost, row of quarter-of-a-square-meter areas (B is the next higher row, etc.); and 1 refers to the first quarter-of-a-square-meter area in the row. Fossil data are listed by grid square; the small numbers after the fossil abbreviations on the diagram refer to the position of the fossil in the table for that particular grid square. For example, C_2 in grid square 3A9 refers to the second fossil listed under that grid number, or *Crurithyris*. The number aids in identification in the event several individuals of the same species are present in the same grid square.

Dashes indicate unmeasureable or inapplicable parameters.

An explanation of abbreviations follows:

Grid Abbreviations

B	=	bryozoan
Bw	=	burrow
C	=	*Crurithyris* sp.
Cp	=	*Composita* sp.
D	=	*Derbyia* sp.
E	=	crinoid fragment
Ec	=	echinoid fragment

M	=	*Meekella* sp.
P	=	*Pteronites* sp.
Ph	=	undifferentiated pholadomyids
R	=	*Reticulatia* cf. *huecoensis*
Sp	=	septimyalinid
Ex	=	*Exochorhynchus* cf. *altirostratus*
Ch	=	*Chaenomya* cf. *cooperi*
W	=	*Wilkingia* cf. *terminale*

Table Abbreviations

col.	=	columnal
d.	=	debris
f.	=	fenestrate
pl.	=	plate
r.	=	ramose
sp.	=	spine
o.	=	oblique
v.	=	vertical
h.	=	horizontal

Unb	=	unbroken
Art	=	articulated
PV	=	pedicle valve
BV	=	brachial valve
RV	=	right valve
LV	=	left valve
L	=	length
W	=	width
H	=	height
LP	=	in inferred life position Y = yes N = no
Sub	=	substrate color and character Y = yellowish gray (5Y7/2) G = light gray (N7) b = blocky to massive s = shaley to platy ls = limestone
CU	=	convex up
CD	=	convex down

THIS BOOK CONTAINS NUMEROUS PAGES THAT WERE BOUND WITHOUT PAGE NUMBERS.

THIS IS AS RECEIVED FROM CUSTOMER.

Locality 3

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
3A7	*Crurithyris*	X	X					10	10	8	Y	Ys	X	
3A9	*Reticulatia*			X				-	31	16	N	Ys	X	
	Crurithyris			X				8	8	7	N	Ys	X	
3A10	*Pteronites*						X	90	-	25	N	Ys		X
	Crinoid col.							-	7	7	N	Ys	-	-
	Pteronites					?	?	200	45	40	N	Ys	X	
	Bryozoan, f.							-	16	22	N	Ys	X	
3B1	*Reticulatia*		X					55	48	25	N	Ys	X	
	Crurithyris	X	X					7	8	5	Y	Ys	X	
	Reticulatia			X				44	60	18	N	Ys	X	
	Pholadomyid*		X					25	8	10	N	Ys	-	-
3B2	*Reticulatia*				X			47	48	26	N	Ys	X	
	Bryozoan, f.	X						-	16	17	N	Ys	-	-
	Meekella		X					20	24	9	Y	Ys	X	
	Crinoid col.							-	6	6	N	Ys	-	-
	Pholadomyid*		X					60	42	30	Y	Ys	-	-
3B3	*Crurithyris*	X	X					8	9	5	Y	Ys	X	
3B4	Bryozoan, f.	X						-	60	36	Y	Ys	-	-
3B5	*Pteronites*		X					-	14	75	N	Ys	X	
	Burrow, o.							-	40	20	Y	Ys	-	-
3B6	*Pteronites*					?	?	-	32	10	N	Ys		X
	Pteronites					?	?	-	55	24	N	Ys	X	
	Crinoid pl.							7	18	10	N	Ys	X	
	Burrow, o.							-	24	12	Y	Ys	-	-
3B7	*Reticulatia*			X				47	-	19	N	Gb		X

Locality 3 (continued)

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
3B8	Crinoid							-	8	8	N	Gb	-	-
	Derbyia			?	?			10	12	1	N	Gb	X	
3B9	Crinoid col.							15	6	6	N	Ys	-	-
3B10	*Pteronites*					?	?	27	-	28	N	Ys		X
3C1	*Reticulatia*			X				18	23	10	Y	Gs		X
	Derbyia				X			10	4	-	N	Gs	X	
	Chonetid?			X				4	7	1	N	Gs	X	
	Derbyia			?	?			37	-	7	N	Gb		X
	Burrow, h.							-	22	13	Y	Gs	-	-
	Straporollus(*A.*)							23	23	4	N	Gs	-	-
	Pteronites					?	?	25	-	15	N	Gs	X	
	Pteronites					?	?	-	-	42	N	Gs	X	
	Reticulatia		X					22	48	26	Y	Gs	-	-
	Reticulatia		X					47	50	20	Y	Gs	-	-
	Burrow, v.							-	32	32	Y	Gs	-	-
	Reticulatia			X				34	48	20	N	Gs	X	
	Straporollus(*A.*)							15	2	15	N	Gs	-	-
3C2	*Reticulatia*			?	?			21	-	3	N	Gb	X	
	Derbyia			?	?			26	-	2	N	Gb	X	
	Derbyia			?	?			25	-	2	N	Gb	X	
	Pholadomyid*		X					40	-	12	Y	Gb	-	-
	Pteronites					?	?	27	20	1	N	Gb	X	
	Reticulatia			?	?			20	15	3	N	Gb	X	
3C3	*Reticulatia*				X			38	60	18	N	Gs	X	
3C4	Crinoid							-	4	4	N	Gs	-	-
	Septimyalina?		X					50	25	14	Y	Gs	-	-
3C5	*Wilkingia*	X	X					100	38	27	Y	Gs	-	-

Locality 3 (continued)

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
3C6	Pholadomyid*		X					40	-	15	Y	Gb	-	-
	Pholadomyid*	X	X					12	13	9	Y	Gs	-	-
	Chaenomya		X					54	19	20	Y	Gb	-	-
	Meekella				X			-	-	20	N	Gb	X	
3C8	*Pteronites*		X					95	27	40	N	Gs	-	-
	Reticulatia		X					50	61	23	Y	Ys		X
	Reticulatia		X					52	63	26	Y	Ys		X
3C9	Burrow, v.							-	15	14	Y	Gs	-	-
	Derbyia				X			-	55	12	N	Gb		X
3C10	*Derbyia*				X			-	40	7	N	Gb	X	
3D1	*Derbyia*			X				15	18	6	N	Gs	X	
	Bryozoan, f.							-	6	10	N	Gs	-	-
	Pteronites					?	?	-	52	12	N	Gs		X
	Pteronites		X					-	32	12	N	Gs	X	
	Derbyia			X				28	20	6	N	Gs		X
	Derbyia			X				48	39	10	N	Gs	X	
	Meekella			X				24	20	4	N	Gb	X	
	Crinoid col.							-	10	10	N	Gs	-	-
	Derbyia				X			43	40	8	N	Gs	-	-
3D2	*Derbyia*			X				30	32	4	N	Gb	X	
	Burrow, o.							75	25	12	Y	Gs	-	-
	Reticulatia			X				31	52	19	N	Gs	X	
	Reticulatia			X				22	31	4	N	Gs	X	
	Crinoid col.							11	3	3	N	Gs	-	-
	Composita				X			18	15	4	N	Gs	X	
	Derbyia				X			55	52	4	N	Gb	X	
	Pholadomyid*		X					24	12	13	Y	Gs	-	-
	Reticulatia			X				55	62	20	N	Gb		X

Locality 3 (continued)

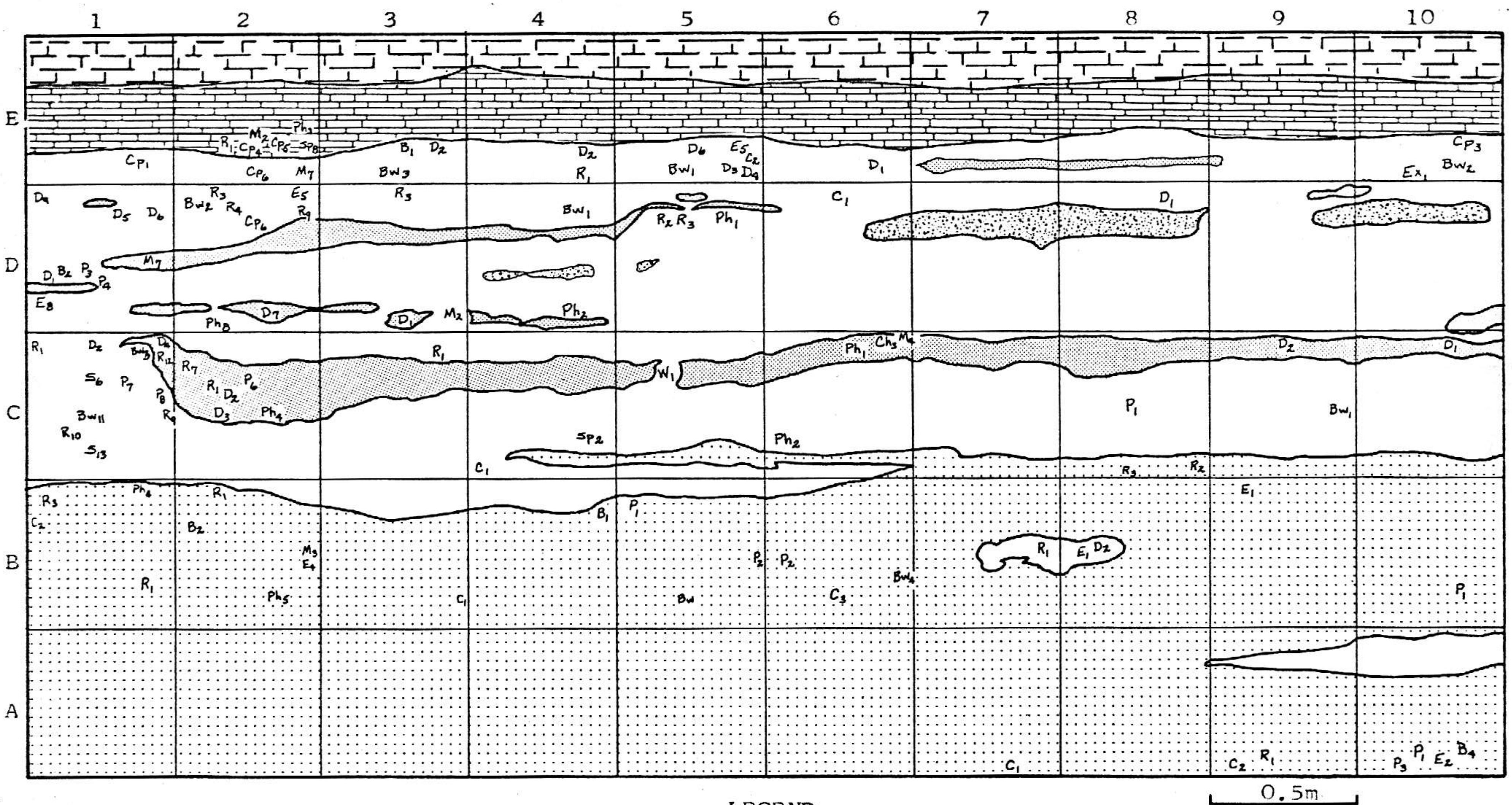
Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
3D3	*Derbyia*			X				34	12	2	N	Gb		X
	Meekella				X			21	22	9	N	Gs	X	
	Reticulatia			X				30	26	3	N	Gs	X	
3D4	Burrow, v.							20	30	19	Y	Gs	-	-
	Pholadomyid*					X		15	5	10	N	Gs	X	
3D5	Pholadomyid*		X					40	-	20	Y	Gs	-	-
	Reticulatia		X					45	48	22	Y	Gs	-	-
	Reticulatia		X					40	47	27	N	Gs	X	
3D6	*Crurithyris*	X	X					10	5	3	N	Gs	-	-
3D8	*Derbyia*		X					34	47	13	N	Gs		X
3D10	*Reticulatia*		X					40	52	16	N	Gs		X
3E1	*Composita*	X	X					22	20	10	Y	Gs	-	-
3E2	*Reticulatia*		X					42	55	29	N	Yls	X	
	Meekella				X			20	24	-	N	Yls	X	
	Pholadomyid*		X					-	12	-	Y	Yls	-	-
	Composita	X	X					9	8	6	N	Yls	X	
	Composita	X	X					8	7	5	N	Yls	X	
	Composita	X	X					6	6	4	N	Ys	X	
	Meekella				X			12	18	6	N	Ys	X	
	Septimyalina			X				27	12	-	N	Yls	-	-
3E3	Bryozoan, f.							-	9	15	N	Gs	-	-
	Derbyia			?	?			20	-	-	N	Gs	X	
	Burrow, v.							45	20	22	Y	Gs	-	-
3E4	*Reticulatia*			X				38	48	18	N	Gs		X
	Derbyia			X				22	16	2	N	Gs	X	

Locality 3 (concluded)

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
3E5	Burrow,o.							100	24	17	Y	Gs	-	-
	Crurithyris	X	X					9	8	6	N	Gs	X	
	Derbyia			?	?			22	20	2	N	Gs	X	
	Derbyia			?	?			20	26	4	N	Gs	X	
	Crinoid col.							6	4	4	N	Gs	-	-
	Derbyia			?	?			21	19	6	N	Gs	X	
3E6	*Derbyia*		X					37	48	15	N	Gs		X
3E10	*Exochorhynchus*	X	X					47	22	18	Y	Gs	-	-
	Burrow, h.							70	27	13	Y	Gs	-	-
	Composita	X	X					18	16	6	N	Gb	X	
	Total	13	36	20	11	1	1				33(Y) 82(N)	30(Ys) 0(Yb) 58(Gs) 21(Gb) 6(Yls)	53	17
	Mean							33.6	23.9	13.8				
	Percentage	11	41	64	36	50	50				29(Y) 71(N)	26(Ys) 0(Yb) 50(Gs) 18(Gb) 5(Yls)	76	24

*Undifferentiated pholadomyid.

Locality 3



LEGEND

- Limestone, muddy, yellowish gray (5Y7/2), platy
- Limestone, muddy, **light** gray (N7), platy
- Limestone, muddy, yellowish gray (5Y7/2), blocky
- Limestone, muddy, light gray (N7), blocky
- Limestone, muddy, yellowish gray (5Y7/2). thin-bedded - lower Fort Riley Limestone
- Limestone, yellowish gray (N7), thick-bedded to massive - above Oketo = Fort Riley, below Oketo = Florence

Locality 9

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
9A4	Euphemites	X						14	13	7	N	Ys		X
	Echinoid sp.							25	2	2	N	Gb	-	-
	Crinoid col.		X					10	5	5	N	Gb	X	
	Bryozoan, f.							-	5	15	N	Gb	-	-
9A5	Pteronites	X	X					75	26	36	N	Ys	X	
	Derbyia				X			50	45	5	N	Gb		X
	Composita			X				6	5	2	Y	Gs	X	
	Crinoid col.		X					75	4	4	N	Gs	X	
9B2	Derbyia				X			31	30	5	N	Ys	X	
	Bryozoan, r.	X						-	50	30	Y	Yb	X	
	Crurithyris	X	X					4	3	2	Y	Yb	X	
	Crinoid col.							15	4	4	N	Yb	X	
9B3	Derbyia			X				40	40	10	N	Ys		X
	Derbyia				X			38	-	5	N	Ys		X
	Derbyia				X			-	20	5	N	Ys		X
	Derbyia			X				10	10	6	N	Ys	X	
	Derbyia			X				-	10	2	N	Ys		X
	Crurithyris	X	X					6	5	4	N	Ys	X	
	Derbyia				X			12	-	7	N	Ys	X	
	Meekella			X				-	12	6	N	Ys		X
	Derbyia			X				10	-	3	N	Yb	X	
9B4	Reticulatia	X			X			48	51	20	N	Ys		X
	Reticulatia	X			X			40	52	18	N	Ys	X	
9B7	Crinoid d.							-	-	-	N	Yb	-	-
	Crinoid col.							2	6	6	N	Gs	X	
9B10	Derbyia				X			39	46	12	N	Ys	X	

Locality 9 (continued)

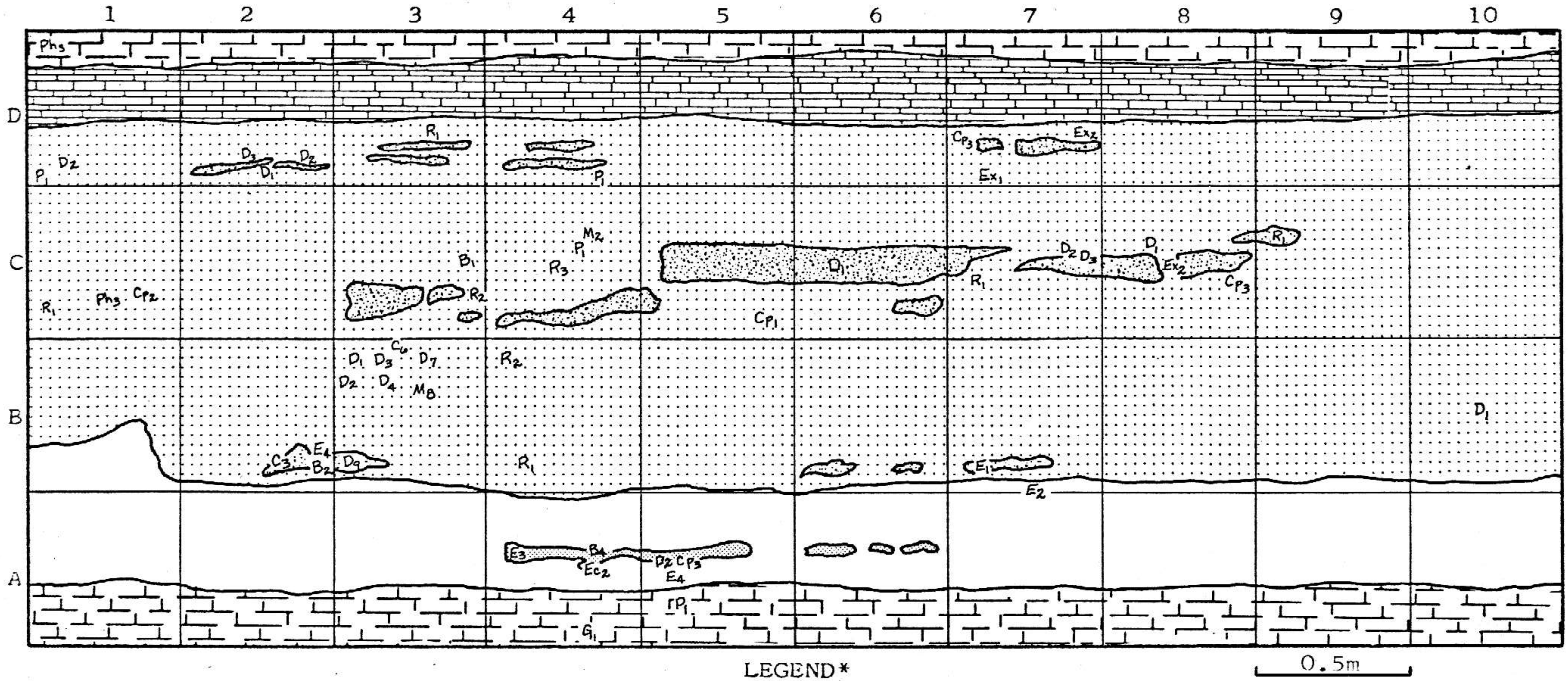
Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
9C1	*Reticulatia*			X				-	10	7	N	Ys		X
	Composita			X				22	16	8	N	Ys	X	
	Edmondia?	X	X					9	5	9	Y	Ys	-	-
9C2	Bryozoan, f.	X						-	12	20	Y	Ys	-	-
	Reticulatia			X				-	40	20	Y	Ys		X
9C3	*Pteronites*					?	?	52	-	35	N	Ys	X	
	Meekella				X			16	20	6	N	Ys	X	
	Reticulatia	X		X				27	35	15	Y	Ys		X
9C4	*Composita*	X	X					20	19	9	N	Ys	X	
9C5	*Derbyia*				X			42	48	17	N	Yb	X	
9C6	*Reticulatia*			X				46	53	20	N	Ys	X	
	Derbyia				X			18	24	6	N	Yb	X	
	Derbyia				X			20	23	10	N	Yb		X
	Pholadomyid*	X	X					86	31	27	Y	Ys	X	
9C7	*Derbyia*				X			44	40	15	N	Ys	X	
	Exochorhynchus	X	X					28	15	14	N	Yb	X	
	Composita			X				24	15	14	N	Yb	X	
9C8	*Reticulatia*				X			-	46	23	N	Yb	X	
9D1	*Pteronites*	X	X					35	6	27	N	Ys	X	
	Derbyia			X				25	20	4	N	Ys	X	
	Pholadomyid*		X?					-	-	12	Y	Yls	X	
9D2	*Derbyia*			X				32	38	12	N	Ys	X	
	Derbyia				X			21	18	4	N	Ys		X
	Derbyia				X			20	26	8	N	Ys	X	

Locality 9 (concluded)

Grid	Genus	Unb	Art	PV	BV	RV	LV	L(mm)	W(mm)	H(mm)	LP	Sub	CU	CD
9D3	Reticulatia	X		X				43	-	18	N	Ys	X	
9D4	Pteronites		X					-	36	5	N	Ys	X	
9D7	Exochorhynchus	X	X					63	32	5	N	Ys	X	
	Exochorhynchus	X	X					62	31	21	Y	Ys	X	
	Composita			X				22	20	7	N	Ys	X	
	Total	17	13	16	16	0	0				11(Y) 44(N)	37(Ys) 10(Yb) 3(Gs) 4(Gb) 1(Yls)	37	13
	Mean							30.9	23.4	11.7				
	Percentage	31	29	50	50	0	0				20(Y) 80(N)	67(Ys) 18(Yb) 5(Gs) 7(Gb) 2(Yls)	74	26

*Undifferentiated pholadomyid

Locality 9



*See p. 169.

EXPLANATION OF PLATE I*

Fig. 1. Pyritized microfossils, x 11: top left, ostracode, *Cavellina*? sp.; top right, planispiral gastropod; middle left, *Tolypammina* sp.; middle right, *Glomospira* sp.; bottom, *Ammodiscus* sp.

2. Arenaceous foraminiferids, x 11: top, three *Ammodiscus* sp.; far right, *Ammovertella* sp.; other four are *Tolypammina* sp.

3. Pyritized fecal pellets and castings?, x 11.

4. Scolecodonts, x 11.

5. Thin section (12-4) of dasycladacean alga, *Diplopora*? sp., x 10. Eight specimens are visible, each coated with *Osagia* sp.

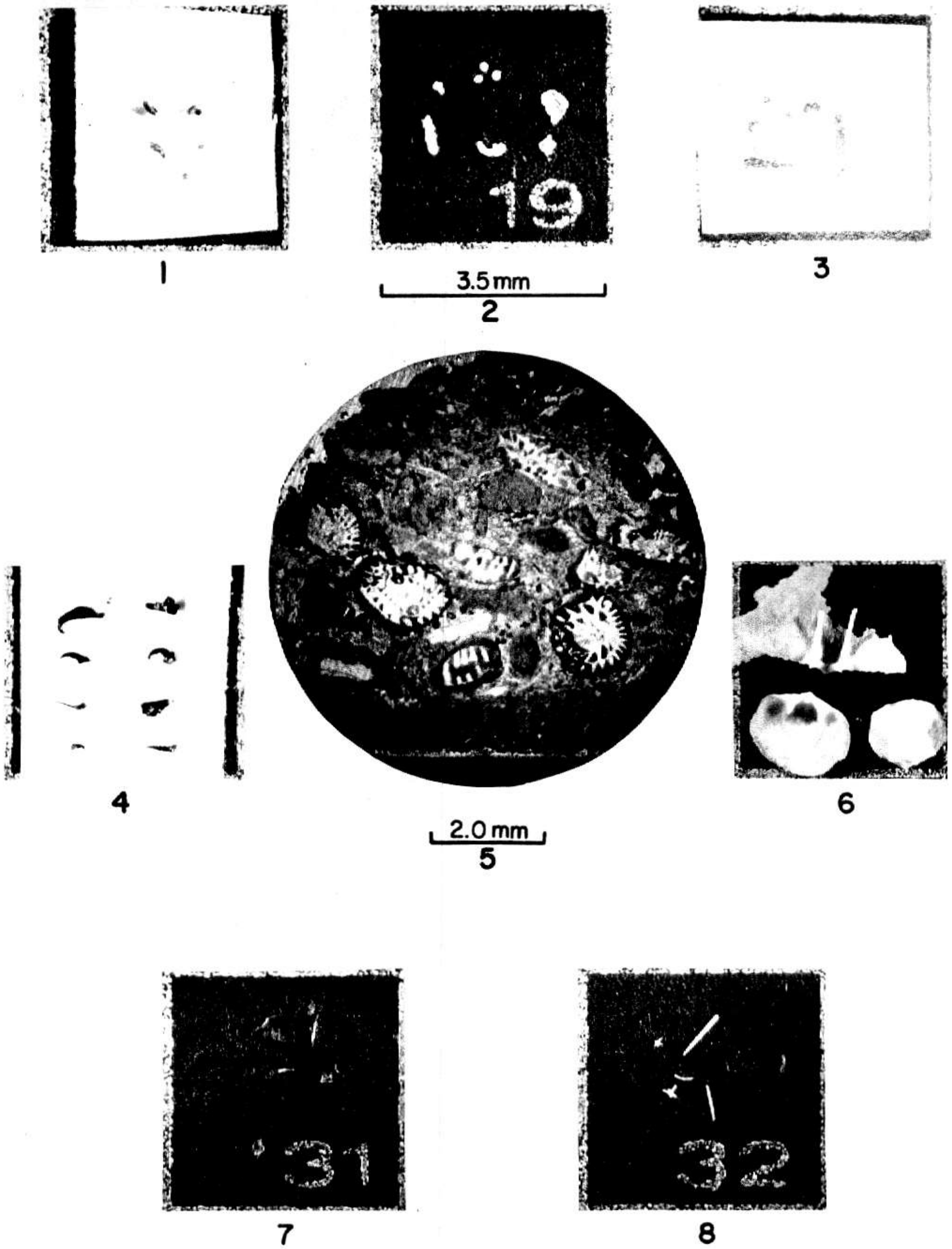
6. Silicified brachiopod valves, x 11: top, *Crurithyris* sp.; lower left, *Rhipidomella* sp.; lower right, *Crurithyris* sp.

7. Volcanic glass shards, x 12.

8. Sponge spicules, x 12.

*Specimens are composites except where noted otherwise.

PLATE I



EXPLANATION OF PLATE II

Fig. 1. *Pholadomya candida*, x 1. Right lateral view (from Waterhouse, 1969, p. 101).

2. *Chaenomya* cf. *cooperi*, x 1, (3-C-6): a, right lateral view; b, dorsal view.

3. *Wilkingia* cf. *terminale*, x 1, (13-6): a, left lateral view; b, dorsal view.

4. *Exochorhynchus* cf. *altirostratus*, x 1, (6A-3): a, right lateral view; b, dorsal view.

5. Clam burrowed bed of the Threemile Limestone, Cowley Co., Kansas. (Roadcut on N. side of K-38, 10.5 miles east of Tisdale, Kansas, near SE corner, Sec. 21, T.32S., R.7E., Cowley Co., Kansas.)

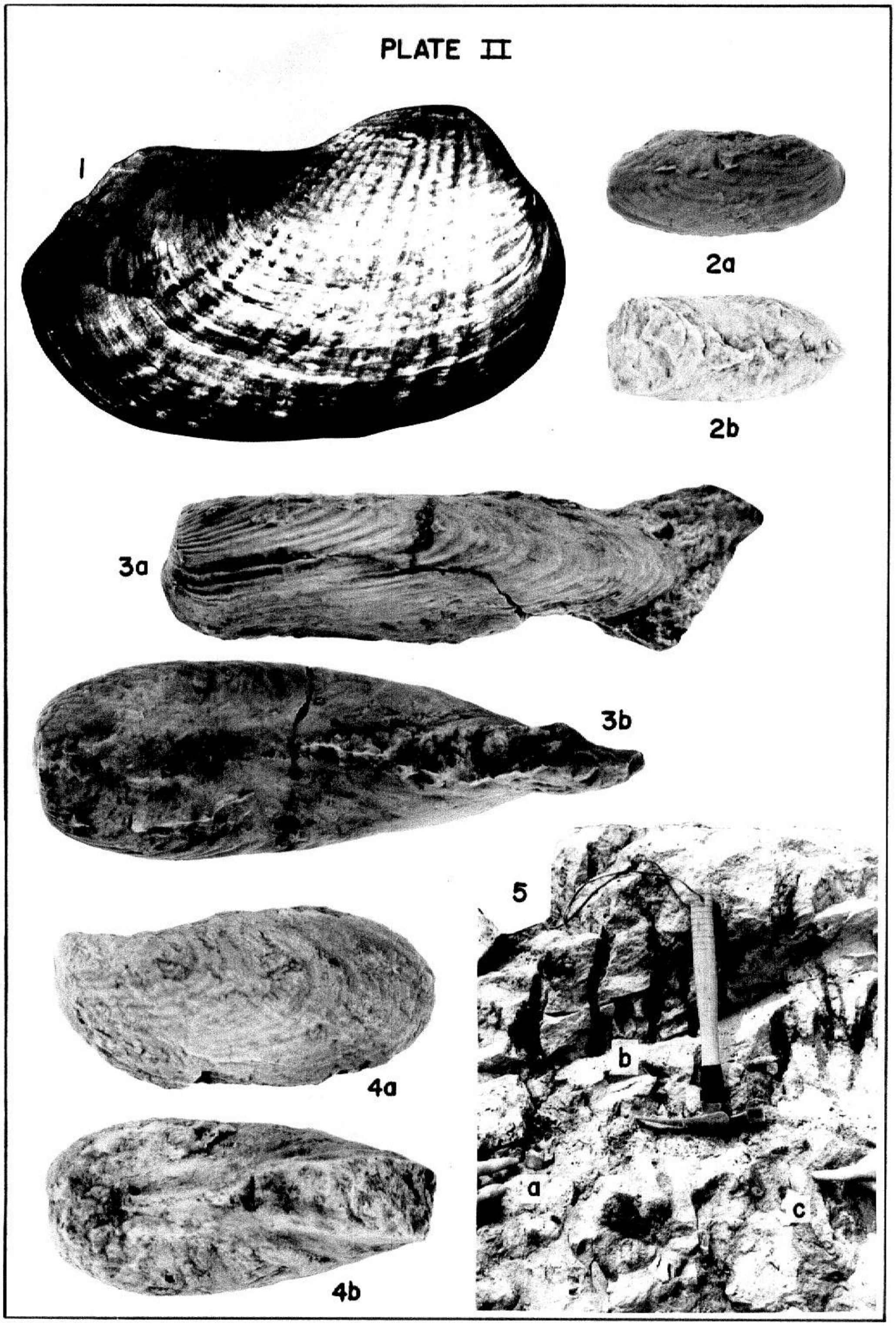


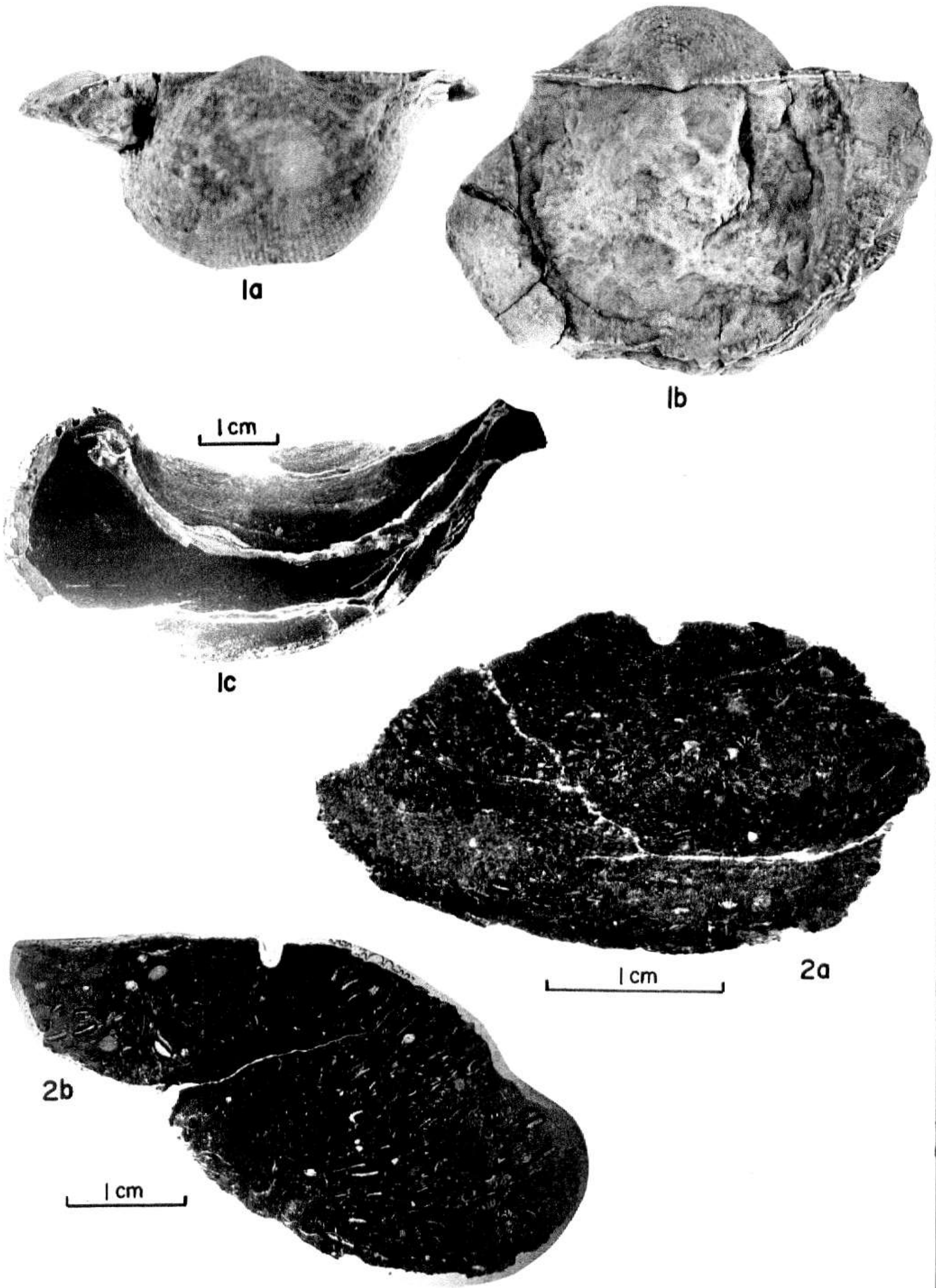
PLATE II
1
2a
2b
3a
3b
4a
4b
5
a
b
c

EXPLANATION OF PLATE III

Fig. 1. *Reticulatia* cf. *huecoensis*, x 1, (10-8): a, posterior view; b, dorsal view; c, longitudinal thin section.

2. Burrow casts: a, transverse thin section (1-4) of an oblique burrow, x 3.2; b, transverse thin section (13-4) through u-shaped bend of a horizontal burrow, x 2.4.

PLATE III



PALEOECOLOGIC STUDY OF THE
OKETO SHALE (LOWER PERMIAN)
IN NORTH CENTRAL KANSAS

by

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B. S., University of North Carolina, 1969

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ABSTRACT

A petrologic and paleoecologic investigation of the Oketo Shale Member of the Barneston Limestone (Lower Permian) was undertaken to determine (1) preferred compass orientation of in situ megafossils, (2) animal-substrate relationships, (3) comparison with animal substrate relationships of similar organisms from the Pennsylvanian (Pearce, 1973), (4) general depositional environment, and (5) temporal and spatial changes.

A Rayleigh z statistic was calculated for two suites of fossils at nine different localities to determine randomness of orientation. Eight localities showed no preferred orientation.

Pholadomyids (Bivalvia) are inferred to have been infaunal and perhaps maintained contact with the sediment-water interface. Reticulatia cf. huecoensis (Brachiopoda) is inferred to have been quasi-infaunal and lived contemporaneously with pholadomyids in a soft silty bioclastic carbonate mud. Comparison with animal substrate relationships of similar organisms from the Pennsylvanian reveals no apparent change in substrate preference during this period of time.

The Oketo Shale is believed to have been deposited on an embayed relatively shallow shelf. The only significant difference in lithologies within the study area is an increase in insoluble residues in the northern and southern sections. This increase is attributed to erosion of the Abilene and Nemaha Anticlines, respectively.