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DEPOSITIONAL ENVIRONMENT OF THE EUDORA SHALE (MISSOURIAN, UPPER PENNSYLVANIAN) NEAR TYRO, KANSAS

by

John M. Malinky

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Kansas Geological Survey
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University of Kansas
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DEPOSITIONAL ENVIRONMENT OF THE EUDORA SHALE (MISSOURIAN, UPPER PENNSYLVANIAN) NEAR TYRO, KANSAS

A Thesis Presented to
The Graduate Faculty of
The College of Arts and Sciences of Ohio University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
John M. Malinky
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This thesis has been approved
for the Department of Geology
and the College of Arts and Sciences by

_____

Assistant Professor of Geology

_____

Dean, College of Arts and Sciences

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ABSTRACT

Detailed faunal analysis of the two distinct shale lithofacies assigned to the Eudora Shale Member of the Stanton Formation (Missourian, Upper Pennsylvanian) near Tyro, southeastern Kansas, reveals that these lithofacies were deposited in an offshore marine environment. Moderate faunal diversity and partial pyritization of certain fossils in this otherwise calcareous fauna suggest that the environment was partially oxygenated with some upwelling during deposition of the lower medium gray lithofacies. The upper dark gray lithofacies appears to have originated in a dysaerobic environment with much reduced upwelling as the majority of the predominantly molluscan fauna consists of juveniles which appear not to be native to this area. Most of these molluscs occur as pyritized molds. An offshore marine depositional model for these lithofacies is supported by the prescence of abundant phosphatic nodules at the contact between the two lithofacies. The offshore marine interpretation further supports the recently proposed model for Kansas cyclothem deposition of Heckel (1977) in which the black shale lithofacies of the "core" shale is deposited at or near the maximum transgressive phase in an offshore marine environment.

INTRODUCTION

Since the recognition of cyclic sedimentation in the Illinois basin by Udden (1912), many separate cycles have been recognized and numerous theories have been proposed for their origin. The resulting deposits, called cyclothems by Wanless and Weller (1932), are now known to characterize most Middle and Upper Pennsylvanian strata in North America (Petersen, et al. , 1973). Three types of cyclothems, each characteristic of a specific region, have been distinguished. These include the predominantly non-marine Appalachian variety, the Illinois variety which contains both marine and non-marine rock units, and the Kansas variety which consists primarily of marine rocks. Despite nearly 70 years of intensive study, the origin of these unique deposits as well as the overall mechanism of cyclic sedimentation itself is not entirely understood.

Upper Pennsylvanian sediments in Kansas are composed largely of alternating limestone and shale units. As a result, these units were initially grouped into cyclothems containing two members which are further assigned to larger units known as megacyclothems (Moore, 1936; Fig. 1). More recent investigations have demonstrated that only four units in megacyclothems, now simply termed cyclothem, are laterally continuous and recognizable over wide areas (Heckel and Baesemann, 1975) (Fig. 2). These units, the

Fig. 1 Cyclothem model and interpretation by Moore (1936) for Missourian megacyclothems in Kansas (from Heckel, 1980).

MISSOURI SERIES (MISSOURIAN) MEGACYCLOTHEM

(an incomplete megacyclothem of Moore, 1936)			Environmental interpretation (based on Moore, 1936)
.0		Sandstone or red shale, often absent	
.9		Shale, plants or no fossils	Emergent
.8		Shale; molluscs	V. nearshore marine
.7*		SUPER LS. oolitic, fragmental, algae, molluscs	Marine shoal
.6		Shale, mixed fauna, often absent	Shallowing marine
.5*		UPPER LS. Lt. gray, thin wavy bedded, molluscoids, fusulinids	Marine culmination
.2-.4		Shale, mixed fauna	Shallow marine
.1*		Black fissile Shale, conodonts, brackish molluscs	Restricted marine swamp?
.7-.5*		MIDDLE LS. dense, bluish, mixed f., fus. algae	Marine culmination
.2-.4		Shale, mixed fauna	Shallow marine
.1		Shale, plants, local thin coal	Low coastal plain
.0		Sandstone or red shale, often absent	Alluvial plain
.9		Shale, plants or no fossils	

Fig. 2 Cyclothem model and interpretation for Midcontinent cyclothems according to Heckel (1977) (from Heckel, 1980).

Basic Cyclothem
(simplified megacyclothem)
in Kansas-Iowa outcrop belt
Lithology
Positional Member
Approx. thickness
m.
OUTSIDE SHALE
UPPER LIMESTONE
CORE SHALE
MIDDLE LIMEST.
OUTSIDE SHALE
Gray to green, locally red, Sandy shale w. siltstone sparse fossils
Laminated unfoss. bird's-eye calcilutite to Oolite
loc. cross-bedded Skel. calcarenite w. marine biota
Gray shaly Skel. calcilutite w. abundant marine biota
Gray-brown Shale w. abund. to sparse mar. fauna
Black fissile Shale w. PO4, pelagic fauna
Dense, dark Skel. calcilutite w. marine biota; loc. Calcarenite at base
Sandy shale w. marine biota
Gray to brown Sandy shale w. loc Coal, Sandstone
Depositional Environment
Nonmarine
Near-shore
Offshore
Shoreline Shoal
Shallow w.
Eff. wave base
Intermediate depth
Eff. lat. limit of algal CO3 production
Deep water
Detrital influx after carbonate shoal formed
Detrital influx before shoal conditions reached
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Adetognathus spp.
Orcadella minuta
Aethotaxis adamsi
Isognathodus spp.
Isarcinoides lat.
Gondolella spp.
Phase of Deposition
Direction of sea-level change
Dominant processes
Depositional member
Maximum Regression
Regression
Transgression
Max. Regrn
Stillst
Subsid.
Detrital influx
Eustatic s.l. rise
Subsid. sedimentn.
CO3 prod
Sed. starvtn
NEARSHORE SHALE
TRANSG
LIMEST.
OFFSHORE SHALE
Stillstand
Subsid. sedimentn.
Detrital influx
Eustatic lowering of sea level
Subsidence probably < sedimentation
CO3 productn-"Basin filling"
REGRESSIVE LIMESTONE
NEARSHORE SHALE

"outside" shale, "middle" limestone, "core" shale and "upper" limestone are invariably present in Kansas cyclothems although individual cyclothems may contain additional members. Limestones and shales excluded from this model are thought to represent local depositional events and are not important to the formation of cyclothems in general (Heckel and Baesemann, 1975).

Because each lithofacies in a cyclothem including the lithically gradational units indicates a distinct depositional environment, the depositional environment and regional distribution of each unit is important to the cause of cyclic sedimentation. Two members of Kansas cyclothems are problematic: 1) the algal limestone facies which may occur in either the "middle" or "upper" limestone members, and 2) the black shale facies of the "core" shale. The study of McCrone (1964) concluded that the algal limestone facies formed in shallow marine water. However, the origin of the black (or "core") shale facies remains controversial. Some workers assign black shales to shallow, marginal marine environments such as lagoons (Zangerl and Richardson, 1963; Merrill, 1973); Heckel (1977) prefers offshore, marine environments with restricted circulation.

Scope and Purpose

The primary objective of this study is to test the two theories concerning the depositional environment of the

black shale facies of the "core" shale. The Eudora Shale Member of the Stanton Formation has been selected as a unit suitable for testing the two theories. In this study, faunal abundance and diversity and the vertical faunal succession have been used to infer changes in the depositional environment, primarily differences in available oxygen, rate of sedimentation, salinity and proximity to shore. In addition, the environmental significance of dark gray shale observed at the Tyro locality overlying medium gray shale has never been adequately explained. Furthermore, the significance of the unconformity separating the Eudora shale from the overlaying Eudora-Rock Lake interval at this locality has not been considered in relation to the depositional history represented by the rock units at this locality. The depositional environment of the Eudora shale at this locality has been incorporated into a regional depositional history.

The second portion of this report will include a description of some of the unique faunal elements discovered within the study area. The Tyro locality is the site of a rare occurrence of hyoliths and blastoids. Hyoliths have never been recovered from Upper Pennsylvanian strata in North America (Yochelson and Saunders, 1967) and their occurrence in the Eudora shale confirms their existence in North America during Upper Pennsylvanian time. Blastoids are rare in Upper Pennsylvanian rocks in North America although they are common at several localities in southeastern Asia.

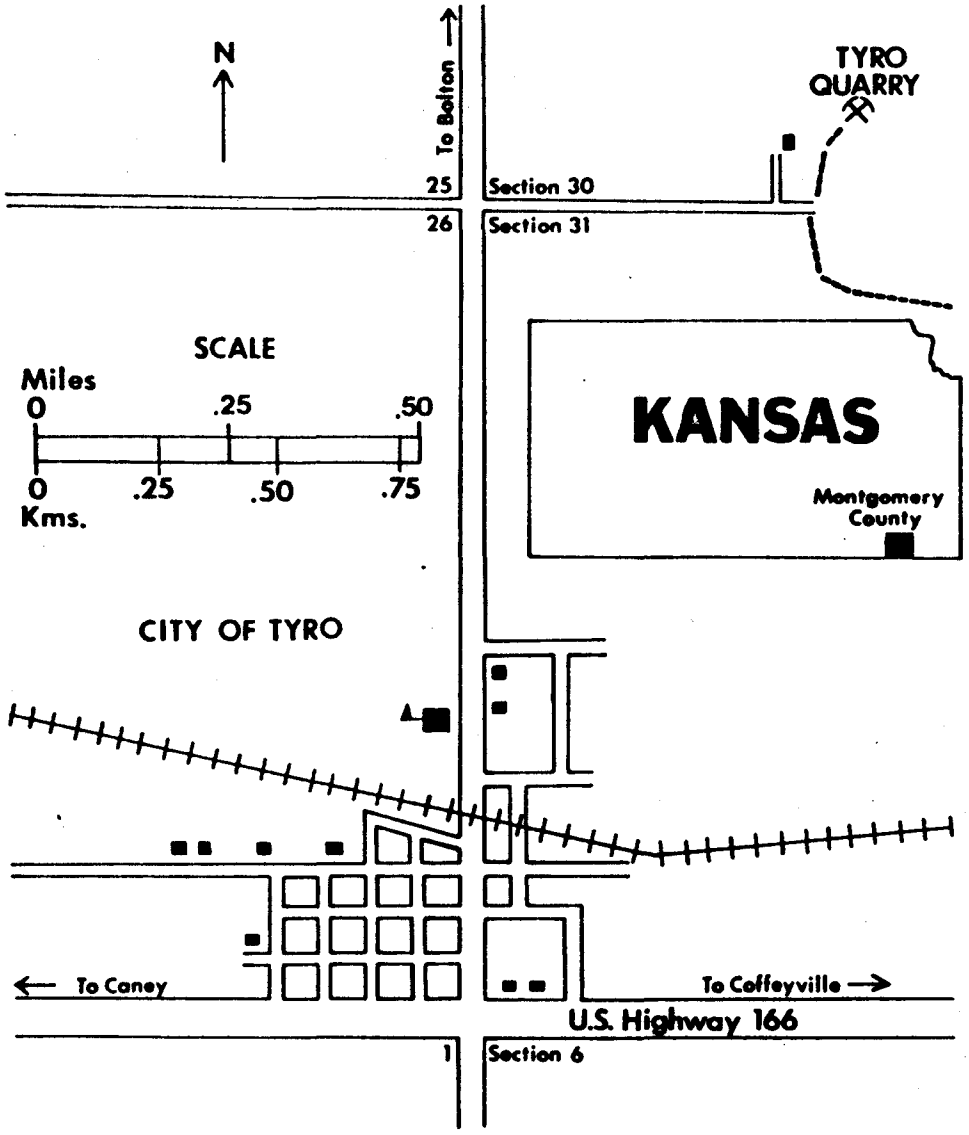
The significance of this discovery will be discussed in detail by Macurda (in preparation).

Location and Methodology

The Eudora shale is well exposed and fossiliferous in a quarry 2.7 km. (1.7 miles) northeast of Tyro, Montgomery County, Kansas. The quarry, hereafter referred to as the Tyro quarry or the Tyro locality, is located in the Tyro Quadrangle in the NE1/4, SE1/4 sec. 30, T34S, T15E and is accessible from an unimproved section road leading east from the main road connecting the communities of Tyro and Bolton, Kansas (Fig. 3).

Field investigations at this locality were undertaken during the summer of 1979. Initially, a 1.2 meter (four feet) thick sandstone overburden was removed from the shale outcrop on the southern wall of the quarry in order to expose an unweathered shale surface and to limit sample contamination. Once prepared, a detailed stratigraphic section was measured, and the shale divided into five arbitrarily selected horizons, designated in ascending order as levels One through Five. Levels Two, Three and Four were each ten centimeters thick whereas the thickness of level Five varied from ten to 15 centimeters due to the undulatory nature of the unconformity with the overlying unit. Level One had a uniform thickness of 13 centimeters extending down to the contact between the Eudora shale and the Tyro oolite.

Fig. 3 Locality map showing the Tyro quarry in the NE1/4, SE1/4, section 30, T34S, R15E in the Tyro Quadrangle Montgomery County, Kansas.


N
To Bolton
25
26
Section 30
Section 31
TYRO
QUARRY
SCALE
Miles
0
.25
.50
0
.25
.50
.75
Kms.
KANSAS
Montgomery
County
CITY OF TYRO
To Caney
To Coffeyville
U.S. Highway 166
1
Section 6

Each level was sampled using a ruler and carpenter's level, taking care that only the level in question was being sampled. During collecting, all phosphatic nodules observed in situ and 25 arbitrarily in situ nodules from level Three were marked to indicate vertical orientation in order to determine the extent of reworking. All fossils observed in situ were collected and their occurrence noted. A total of 2,022 kilograms (4,458 pounds) was collected. Distribution of the samples is shown in Table 1. The uneven distribution of sample weights among horizons is largely the result of damage to sample bags during transport. Because of potential contamination in these samples, they were utilized primarily as sources of specimens. Included as well are samples collected by R. H. Mapes of Ohio University for their diversity and abundance of bactritoids and other unusual specimens. These samples were collected from the upper one half (or dark gray shale facies) of the Eudora shale. This part of the section includes levels Four and Five and approximately the upper half of level Three of the present study.

In the laboratory all samples were weighed and several blocks of shale were chosen at random from each sample for petrographic studies. These shale samples, along with the phosphatic nodules, were sent to an independent petrographic service (Central Petrographic Service) for thin sectioning. The remaining samples were oven-dried for 18 to 24 hours then immersed in Stoddards solvent for not less

than one hour. The solvent was drained and the shale placed in water for not less than two hours. This technique effectively disaggregated the shale into clay-sized particles. The samples were then washed through a 60 mesh sieve and the residues collected. Some of the shale samples were reprocessed as above in order to reduce any shale left in the sample. Prior to processing a ten kilogram sample was arbitrarily chosen from each level for quantitative analysis. This sample was prepared using the method described above and washed through a 140 mesh sieve in order to retain the smaller microfauna. A comparison of sample weights before and after processing appears in Table 1.

Once prepared the ten kilogram samples were analyzed for their fossil content. The samples from levels Four and Five were picked under a Bausch and Lomb dissecting microscope for every fossil retained on a 40 mesh sieve. Relative abundances of fossils in the finer-sized fractions were obtained using a counting technique outlined by Dennison and Shea (1965). This technique approximates the true relative abundances of the various fossil groups through a count of 16 fossils. Relative abundances of the different fossil groups in levels One, Two and Three were obtained exclusively by this technique as the large amount of echinoderm debris prohibited complete picking of the sample.

The picked ten kilogram samples were acidized in a 10% solution of formic acid to remove pelmetazoan ossicles

TABLE 1: SAMPLE WEIGHTS (IN KILOGRAMS) OF EUDORA SHALE

LEVEL	WEIGHT BEFORE PROCESSING	WEIGHT AFTER WASHING	WEIGHT AFTER ACIDIZING
5	362.9	1.863	0.232**
4	469.5	0.828	0.480
3	306.2	1.735*	0.176
2	523.1	11.752	2.914**
1	351.5	11.979	0.232
TOTAL	2022.2	28.160	5.054
AVERAGE	404.4	5.630	1.011

WEIGHTS OF QUANTITATIVE SAMPLES AFTER PROCESSING

LEVEL	WEIGHT AFTER WASHING	WEIGHT AFTER ACIDIZING
5	0.196	0.122***
4	0.046	0.023
3	0.256	0.164
2	0.409	0.226
1	0.241	0.016***

*Weight does not include 54.057 kg. of phosphatic nodules removed prior to washing.

**Weight does not include: Level 1, 0.57 kg. of rock fragments; Level 2, 2.229 kg. of phosphatic nodules; Level 5, 0.945 kg. of phosphatic nodules.

***Weight does not include rock fragments from: Level 1, 0.053 kg.; Level 5, 0.101 kg.

and other carbonate faunal elements. This facilitated picking of any acid resistant material. The data obtained from these samples served as the basis for a qualified statement on the relative abundances of fossils in the Eudora shale at this locality. All remaining samples were simply picked and acidized in a 10% solution of formic acid to recover any unusual faunal elements. Certain fossil groups, chiefly conodonts, echinoderms, and plants, were passed onto qualified specialists for identification. All identifications are listed by higher taxon in Tables 2 through 6.

STRATIGRAPHY

Regional Stratigraphic Setting

The Stanton Formation constitutes the uppermost unit of Missourian age (Upper Pennsylvanian) in eastern Kansas (Fig. 4). This formation crops out in a belt trending northeast-southwest across eastern Kansas (Fig. 5). It has been subdivided into five members in ascending order: the Captain Creek limestone, the Eudora shale, the Stoner limestone, the Rock Lake shale and the South Bend limesone (Heckel, 1975b). These are best developed in the northern and central portions of the outcrop belt. To the south, the "middle" and "upper" limestone members thicken into biostromes of phylloid algal wackestone at the expense of the adjacent shales, which may thin to several centimeters (Heckel and Cocke, 1968) (Fig. 6). South of the mound complexes, the limestsone members intertongue with a thickened shale sequence commonly containing thin sandstone beds (Heckel, 1975b). This laterally variable sequence has been divided into four facies belts. These include, from north to the south: 1) a nearshore facies 2) an open marine facies, 3) a phylloid algal mound facies, and 4) a terrigenous detrital facies (Heckel, 1968). The cyclic nature of the Stanton Formation is no longer recognizable within the terrigenous detrital facies belt because the limestone members are absent (Heckel, 1975b).

Fig. 4 Stratigraphic succession in Upper Pennsylvanian strata in eastern Kansas showing position of the Stanton Formation and its constituent members (after Heckel, 1975b).

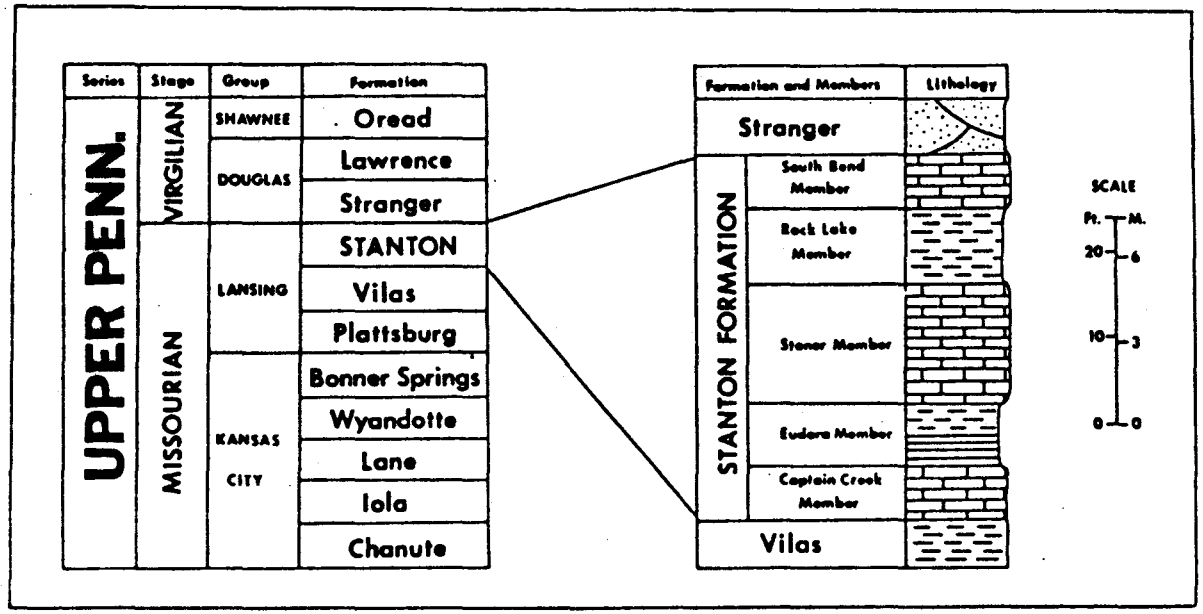

Series
Stage
Group
Formation
UPPER PENN.
VIRGILIAN
MISSOURIAN
SHAWNEE
DOUGLAS
LANSING
KANSAS CITY
Oread
Lawrence
Stranger
STANTON
Vilas
Plattsburg
Bonner Springs
Wyandotte
Lane
Iola
Chanute
Formation and Members
Lithology
Stranger
STANTON FORMATION
South Bend Member
Rock Lake Member
Stoner Member
Eudora Member
Captain Creek Member
Vilas
SCALE
Ft.
M.
20
6
10
3
0
0

Fig. 5 Generalized Stanton outcrop belt in eastern Kansas showing boundaries of facies belts (from Senich, 1978).

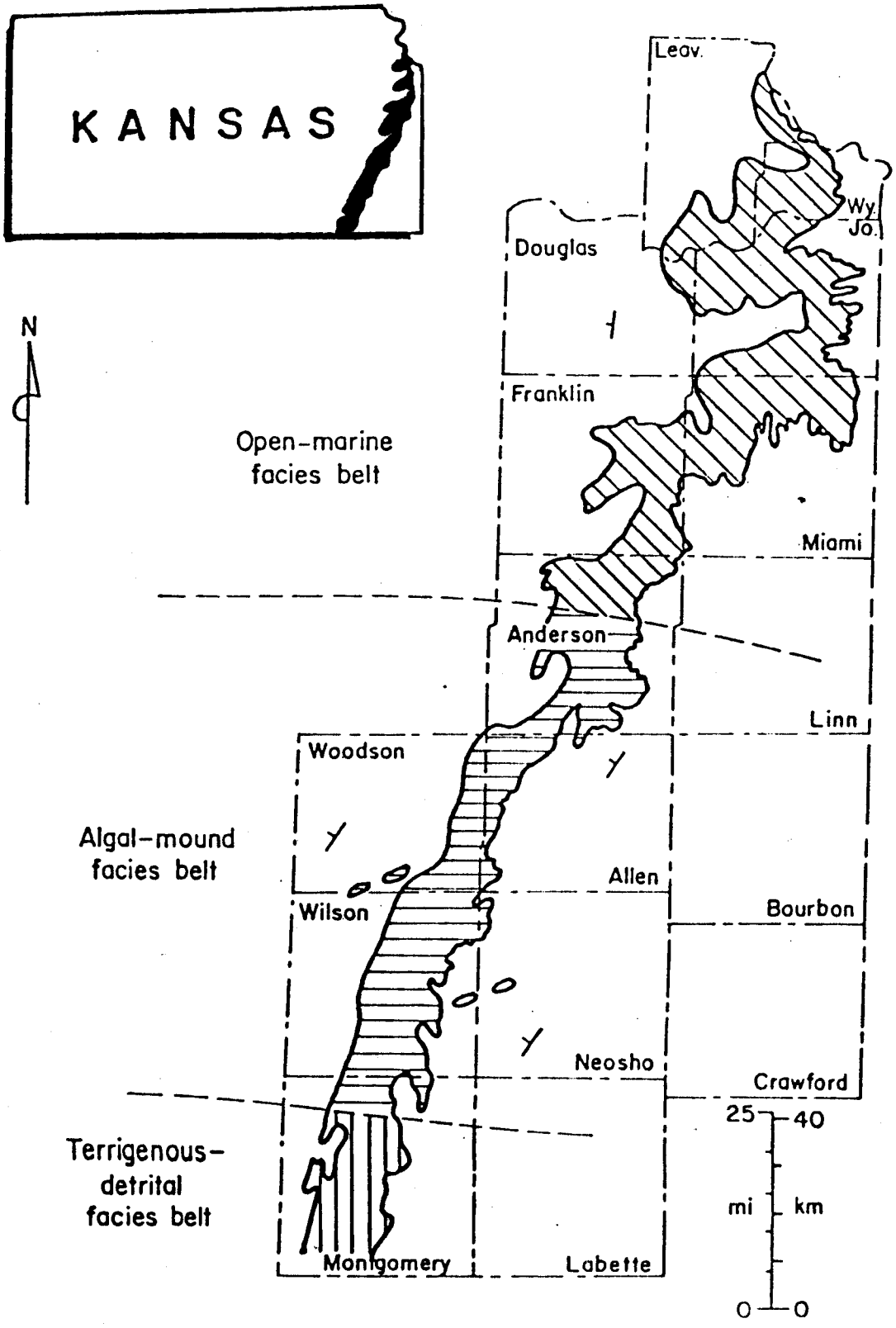
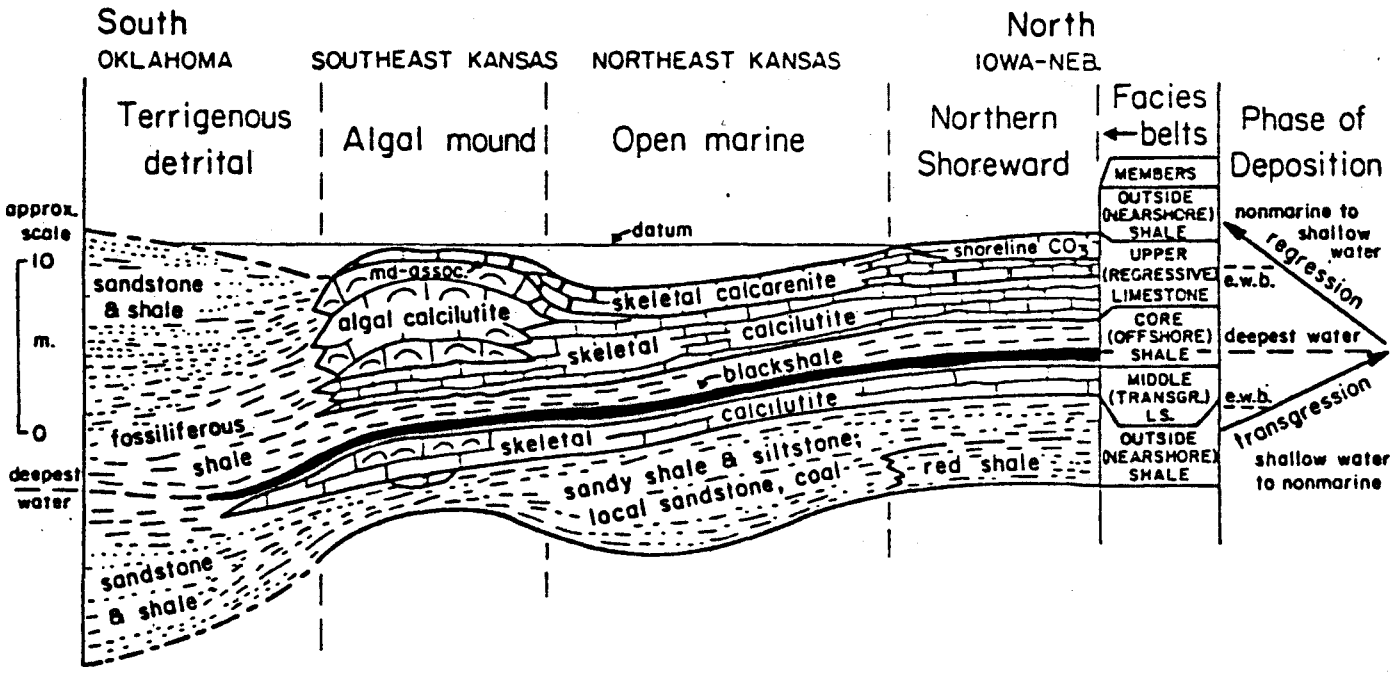

KANSAS
N
Leav.
Wy
Jo.
Douglas
Franklin
Open-marine
facies belt
Miami
Anderson
Linn
Woodson
Algal-mound
facies belt
Allen
Wilson
Bourbon
Neosho
Crawford
Terrigenous-
detrital
facies belt
Montgomery
Labette
25
40
mi
km
0
0

Fig. 6 Lateral changes among Upper Pennsylvanian cyclothem members across eastern Kansas outcrop (from Heckel, 1980).


South
OKLAHOMA
SOUTHEAST KANSAS
NORTHEAST KANSAS
North
IOWA-NEB.
Terrigenous detrital
Algal mound
Open marine
Northern Shoreward
Facies belts
Phase of Deposition
MEMBERS
OUTSIDE (NEARSHORE) SHALE
UPPER (REGRESSIVE) LIMESTONE
CORE (OFFSHORE) SHALE
MIDDLE (TRANSGR.) LS.
OUTSIDE (NEARSHORE) SHALE
nonmarine to shallow water
regression
e.w.b.
deepest water
e.w.b.
transgression
shallow water to nonmarine
approx. scale
10
m.
0
deepest water
datum
shoreline CO3
md-assoc.
algal calcilutite
skeletal calcarenite
skeletal calcilutite
blackshale
calcilutite
skeletal
sandstone & shale
fossiliferous shale
sandy shale & siltstone; local sandstone, coal
red shale
sandstone & shale

The Eudora Shale Member is present throughout the lateral extent of the Stanton Formation. In the nearshore and open marine facies belts, this member averages 2.0 meters (6.6 feet) in thickness typically including a basal black shale lithofacies (Heckel, 1975b). Within the phylloid algal mound facies belt, the Eudora shale consists largely of a fossiliferous gray shale which thins to a few centimeters over the algal mounds. The black shale facies is discontinuous, occurring in topographic lows adjacent to the biostromes. In the terrigenous detrital facies belt, the Eudora shale thickens abruptly to approximately 21 meters (70 feet) and the basal black shale portion thins markedly (Heckel, 1975b). In northern Montgomery County, the Eudora shale is separated from the normally overlaying Rock Lake shale, by the Bolton bed, a thin limestone unit. On the basis of its conodont fauna, the Bolton bed is thought to be equivalent to the lower portion of Stoner Limestone Member (Wood, 1977). Near the Oklahoma border, the Bolton bed is no longer present and the Eudora shale lies directly beneath the Rock Lake shale. Here the two shales constitute what is informally known as the "Eudora-Rock Lake" interval. Further south in Oklahoma, the Stanton Formation is replaced by the sandstone and shale units of the Wann Formation (Heckel, 1975b).

Stratigraphic Succession in the Study Area

In southern Montgomery County, the Stanton Formation occupies a centrally located northeast-southwest trending belt approximately twenty miles wide. The well developed cyclic nature of this formation, recognizable in all northern portions of the outcrop belt cannot be distinguished in southern Montgomery County, having been replaced by a thick shale (Heckel, 1975a). This shale is known to contain several thin and laterally restricted, discontinuous units including the Bolton bed and Tyro oolite. The exact stratigraphic relationship of these units to the other members of the Stanton Formation is difficult to determine. This general area, and the Tyro locality in particular, appears to represent an area of transition in terms of lithologies and depositional environments for the Eudora shale as well as for the entire Stanton Formation. In northern Montgomery County the Stanton Formation is represented by nearly 21 meters (70 feet) of shale whereas just south of the Tyro quarry the Stanton Formation grades laterally to shale and sandstone of the Wann Formation (Heckel, 1975b).

The Tyro quarry has been designated the type section of the Tyro oolite by Heckel (1975b). Based on its position in the vertical sequence, this unit, formerly assigned to the Captain Creek Limestone Member (O'Connor, 1962), has now been recognized as a distinct but correlative unit (Heckel,

1975a). The Tyro oolite comprises the base of the Stanton Formation in southern Montgomery County and is the lowermost unit exposed at the Tyro quarry. It consists of light gray, coarse grained oolitic grainstone and is characterized by large (one meter) sets of tabular cross-beds dipping to the southwest. The Tyro oolite also contains pelmetazoan ossicles and brachiopods, usually concentrated lenses. The maximum observed thickness of this unit at the Tyro quarry is 3.4 meters (11 feet).

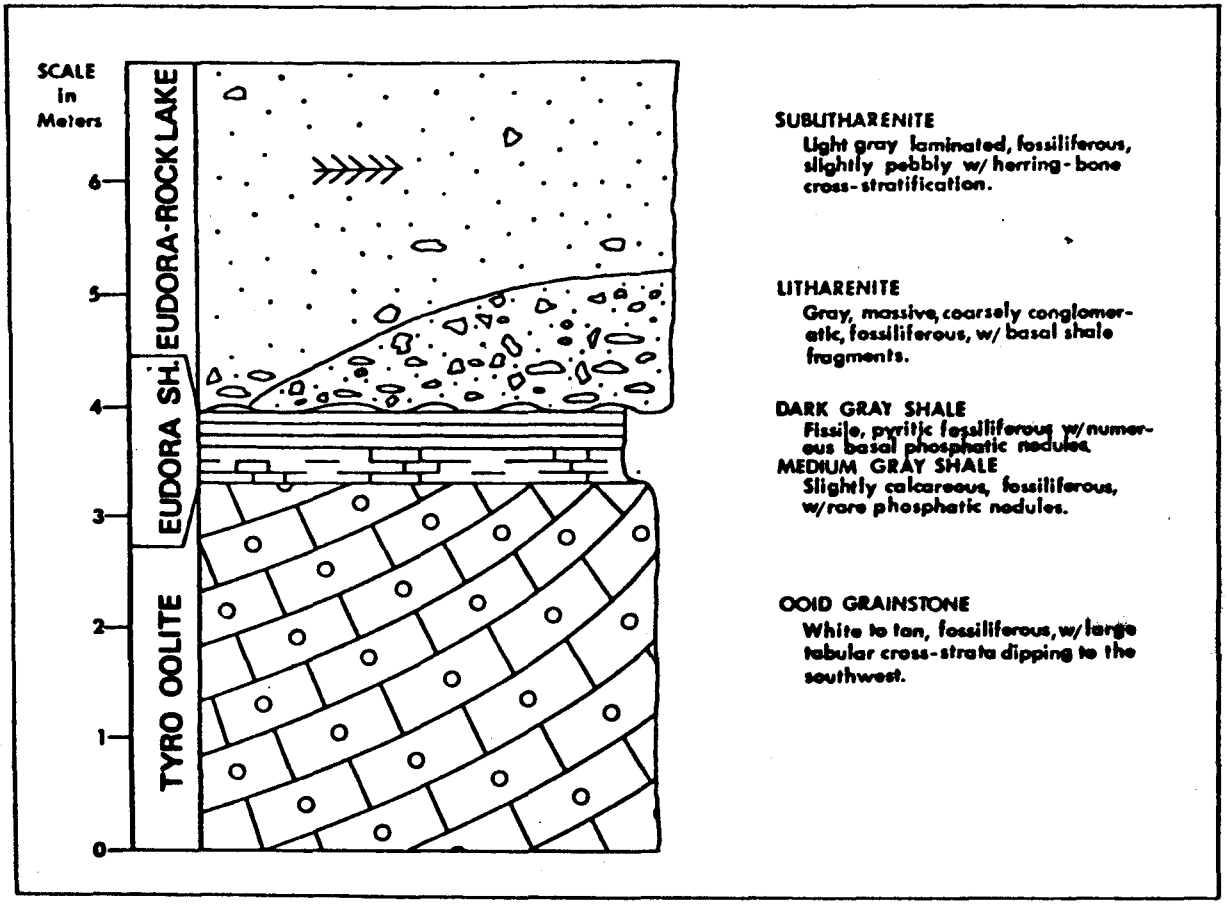
The Eudora Shale Member conformably overlies the Tyro oolite, attaining a maximum thickness of 0.63 meters (2.1 feet). The Eudora shale consists of a lower medium gray lithofacies and an upper dark gray lithofacies, both of which are lithologically and faunally distinct from the gray and black shale lithofacies of the Eudora shale in other areas (Heckel, personal communication, 1980). The thickness of the upper dark gray lithofacies averages 33 centimeters (13 inches), although it varies due to the undulatory contact with the overlying sandstone and conglomerate. The lower medium gray lithofacies retains a constant thickness of 31 centimeters (12 inches). Both shale facies at the Tyro quarry are fissile but lack other discernible bedding. An interval of phosphatic nodules roughly separates the two facies. Nodules also occur at the top of the medium gray facies and lower portion of the dark gray facies. Both lithofacies of the Eudora shale pinch out northward and are not present on the northern wall of the quarry. The basal

medium gray shale facies is dominated by echinoderms and brachiopods with lesser numbers of sponges and molluscs. In contrast, the dark gray lithofacies contains abundant molluscs and floral debris. Brachiopods and echinoderms are minor elements in this assemblage. In addition, the dark gray shale facies contains arthropods, cephalopod mandibles, and scolecodonts, as well as blastoids and hyoliths which are unique to this locality in the Pennsylvanian.

The Eudora shale is overlain by an unnamed sandstone which constitutes the upper portion of the Eudora-Rock Lake interval. It is divisible into two lithofacies: a lower conglomeratic facies which pinches out toward the west, and an upper pebbly sandstone facies which overlies and laterally intertongues with the conglomerate. In addition to numerous quartz pebbles, the conglomeratic lithofacies contains numerous shale intraclasts, presumably derived from the Eudora shale. The fauna of the conglomerate consists of abundant molluscs and brachiopods, preserved mainly in concretions, and scattered fragments of wood and pelmetazoan ossicles. The conglomerate attains a maximum thickness of 0.7 meters (2.5 feet). Intertonguing with the conglomerate is the pebbly sandstone which contains quartz pebbles and basal shale intraclasts. This sandstone is distinguished by prominent herring bone cross-stratification. Its contact with the Eudora shale is unconformable; although, the contact between the sandstone and the adjacent conglomerate is conformable. This unit contains abundant brachiopods and

pelmetazoan ossicles. The conglomerate and sandstone attain a combined maximum thickness of 3.4 meters (11.1 feet) on the northern wall of the quarry where they rest directly upon the Tyro oolite. Above this portion of the Eudora-Rock Lake interval are alternating thin sandstone and shale units. Detailed stratigraphic analysis of these units is beyond the scope of this study (Fig. 7).

Fig. 7 Stratigraphic succession at the Tyro quarry measured on southern wall of quarry.


SCALE
in
Meters
6
5
4
3
2
1
0
EUDORA-ROCK LAKE
EUDORA SH.
TYRO OOLITE
SUBLITHARENITE
Light gray laminated, fossiliferous, slightly pebbly w/ herring-bone cross-stratification.
LITHARENITE
Gray, massive, coarsely conglomeratic, fossiliferous, w/ basal shale fragments.
DARK GRAY SHALE
Fissile, pyritic fossiliferous w/numerous basal phosphatic nodules.
MEDIUM GRAY SHALE
Slightly calcareous, fossiliferous, w/rare phosphatic nodules.
OOID GRAINSTONE
White to tan, fossiliferous, w/large tabular cross-strata dipping to the southwest.

LITHIC DESCRIPTIONS

The Shale Lithofacies

Dark, gray to black shales consist of three major components: a detrital component consisting of clastic material, an authigenic fraction usually composed of sulfide minerals, and an organic component of variable composition (Carozzi, 1972). The washed residues of the Eudora shale were examined under a Bausch and Lomb binocular microscope, and estimates of the relative abundances of each constituent were made according to the technique outlined by Dennison and Shea (1966). The size divisions of the particles involved and the associated terminology are those proposed by Folk (1968). All thin sections, with the exception of nine made from phosphatic nodules were commercially prepared and cuts were made perpendicular to bedding.

The lower medium gray shale lithofacies, encompassing the lower half of level Three and levels One and Two of this report, consists predominantly (63% by weight) of fine sand-sized particles or smaller. Among the coarser fraction, pelmetazoan ossicles constitute 15.5% of the sample, and the remainder (21.5%) consists of detrital grains and authigenic minerals. These detrital grains are composed primarily of irregularly shaped, well indurated white to light gray silt/clay aggregates of medium to fine sand size. Subrounded to rounded fine quartz sand is also prominent. These grains

are usually stained yellow to brown probably by iron oxides. Few authigenic minerals are present; however, pyrite occurs as crystalline aggregates which increase in abundance toward level Three. Thin section analysis of this lithofacies reveals poorly developed lamination defined largely by the alignment of pelmetazoan debris.

The dark gray lithofacies of the Eudora shale, encompasses the upper portion of level Three and levels Four and Five of this report. Thin section analysis demonstrates that the organic matter, which occurs as very fine, structureless, widely dispersed material, constitutes more than half of the shale. Size analysis reveals that approximately 75% of the shale consists of fine sand sized particles. The detrital component in the remaining 25% varies in abundance and composition among each level. In level Five, the detrital grains consist largely of yellow to brown medium sand-sized quartz and rock fragments. These appear to be contamination from the overlying "Eudora-Rock Lake" interval as this overlaying unit contains lithically similar grains. In level Four detrital particles constitute less than 5% of the grains above fine sand size and consist predominantly of silt/clay aggregates. These aggregates are generally dark brown to black and vary from coarse to fine sand size with most being intermediate in size. Many are crudely cylindrical and exhibit pyrite encrustations. Within the upper half of level Three subrounded to rounded clear to white quartz sand is commonly present, and the silt/clay

aggregates become rarer.

The authigenic components of all level are similar and consist of euhedral overgrowths on quartz, crystalline aggregates of pyrite and sphalerite and possibly other sulfides.

The Phosphatic Nodules

Phosphate is present in the Eudora shale as nodules in both lithofacies. The nodules are most abundant at the contact between lithofacies and assume a variety of shapes and textures. Three kinds can be distinguished chiefly on the basis of internal structure.

(1) Highly calcareous and fossiliferous nodules possessing a chalky appearance and texture are most characteristic of the medium gray lithofacies. These nodules are light gray with rough, irregular exteriors. They vary from three to 50 millimeters in size and most are crudely rounded. Fauna found in the interior include brachiopods, bryozoa, and sponges, all of which retain their calcareous skeletons. Application of hydrochloric acid to the nodule reveals that the matrix surrounding the fossils is highly calcareous.

(2) Gray to black, granular nodules occurring as irregular, flattened, well rounded masses are most common at the contact between lithofacies. Many attain sizes up to 80 millimeters. Thin section analysis of these nodules

demonstrates that, despite minor external variations in shape and texture, the nodules consist of structureless masses of collophane and francolite, and possess varying amounts of organic material. The fauna of these nodules is restricted largely to aggultinated forminifera although brachiopods apparently served as the nuclei for some nodules. Many nodules seem to possess no well defined nuclei although in these cases the nuclei may simply have not been preserved. Other fauna associated with the nodules includes an organism identified as a sponge which has been observed encrusting just one side of the nodule. The only flora associated with the nodules are pieces of phosphatized wood. Sometimes this wood is observed protruding from a nodule. In other cases only the wood is present with no nodule formation.

(3) A third distinct variety of phosphate nodule, known only from the upper portion of the dark gray lithofacies, is the septarian nodule. These are similar in size and shape to the gray and black granular nodules but are transected by numerous veins of calcite and rarely sphalerite. These nodules are rare.

The presence of phosphatic nodules within the Eudora shale serves as a valuable environmental indicator. Phosphate deposition normally occurs in equatorial marine environments where phosphate rich bottom waters upwell and provide abundant phosphate for precipitation (Veeh and Burnett, 1973; Manheim, et al. , 1975; Heckel, 1977).

Stratigraphic studies and paleolatitudinal reconstructions of phosphate deposits in the geologic record indicate that the majority of these deposits originated through similar processes in equatorial environments (Blatt, et al. , 1972). The marine environments in which phosphate deposition occurs vary from nearshore to offshore, and in some instances, the environment may be estuarine (Bushinski, 1964; Pevear, 1966; Manheim, et al. , 1975). No phosphate deposits have been discovered in ancient or modern fresh water or lagoonal environments (Carozzi, 1972). These environments are inaccessible to upwelling of phosphate rich water and are usually subject to clastic sedimentation which inhibits phosphate deposition (Heckel, personal communication, 1980). Thus, phosphate deposits are considered reliable indicators of marine environments.

PALEONTOLOGY

The Medium Gray Lithofacies

The Eudora shale at the Tyro locality contains a well preserved macro- and microfauna although much of the macrofauna consisted of small-sized individuals. The terms "microfauna" and "macrofauna" are employed here in the classical sense to distinguish those groups ordinarily identifiable with and without magnification respectively. Macrofossils from this locality rarely exceed five millimeters. Because of their size, juveniles are difficult to distinguish from adults. An abundant flora is known from this unit, particularly from the dark gray lithofacies. This flora consists primarily of minute pieces of phosphatized, carbonized, or pyritized wood although leaves and reproductive organs have been recovered.

The lower half of level Three and levels One and Two encompass the entire medium gray lithofacies of the Eudora shale. Levels One and Two are considered as a single unit because they are faunally similar (Table 2). Echinoderms, represented by 13 crinoid genera, dominate the macrofauna. Exocrinus sp. is the most abundant genus, followed by Apographiocrinus sp. All remaining genera are represented by less than three specimens each. Chlidonocrinus sp., Galateacrinus sp. and Moundocrinus (?) sp., each known from a single specimen, are confined to level One. Three other

genera, Melbacrinus sp., Paramphicrinus and Seytalocrinus sp. are recognized only from level Two (Strimple, personal communication, 1980).

Other phyla include in order of decreasing abundance the brachiopods, sponges and bryozoa. The brachiopods are represented by the relatively common Rhipodomella sp., while Enteletes (?) sp., Hustedia sp. and Neospirifer sp. occur less frequently. Sponges are represented by two genera, Girtyocoelia sp. and an indeterminate genus. Girtyocoelia is the more common and specimens up to five beads long are found. Bryozoans are confined largely to the finer sized fractions of this unit. Additionally, fragmentary lophophyllid corals have been discovered although these are most common in the lower half of level Three (Table 2). With the exception of bryozoa, all these fossils are larger than the associated molluscan fauna; however, none attain the size most frequently observed for the same organisms at other localities of similar age (Mudge and Yochelson, 1962; Moore, 1964; Senich, 1978). These fossils retain their calcareous skeletal elements although the majority exhibit partial dissolution. The brachiopods and sponges display varying degrees of crushing due to compaction of the shale.

The microfaunal component of this unit includes the conodont Idiognathodus sp. (Baxter, personal communication, 1980), partially pyritized ostracods, and foraminifera (Table 4). Four vertebrate genera, identified as Agassizodus variabilis , Cladodus sp., Petalodus ohioensis ,

and Peripristis semicircularis , have been discovered (Hansen, personal communication, 1980). The remains of these shark-like organisms consist of calcified cartilage. A large quantity of the vertebrate material cannot be identified.

Levels One and Two contains little vegetal material, the majority of which is composed of pith and cortex fragments which cannot be unidentified. A single fertile pinnule, belonging to Scalecopteris sp., was recovered from the upper portion of level Two (G. Mapes, personal communication, 1980).

Level Three is a transitional unit in terms of its lithology and faunal content (Table 5). The lower portion consists of medium gray shale and contains a fauna similar to that of levels One and Two. The coelenterates are represented by lophophyllid corals, several of which have been recovered in situ but none in growth position. The echinoderm component consists solely of Exocrinus sp. (Strimple, personal communication, 1980). Brachiopods and sponges occur less frequently than the corals and bryozoans are rare. Rhipodomella sp. is the dominant brachiopod, although several specimens of ? Hustedia sp. are present. The sponge component includes Girtyocoelia sp. which occurs as segments up to five beads long. An unidentified sponge has also been observed encrusting the phosphatic nodules in this level. All non-molluscan fossils occur as calcareous individuals which exhibit partial dissolution and crushing.

The molluscan component of the lower portion of level

Three includes several bactritoids assigned to Bactrites woodi , and the rare ammonoids Eoasianites sp., Neoaganides sp. and Neodimorphoceras (?) sp. and indeterminte protoconchs. Several genera of bivalves and gastropods, including the gastropods Pseudozygopleuria (?) sp. and Straparollus (?) sp., have been recovered in small numbers. Overall, the molluscs constitute a minor group within this assemblage (Table 5).

Level Three is further charactertized by an abundant microfauna of moderate diversity. The conodont Idiognathodus sp. is numerous although a few specimens of Gondollela sp. are present (Baxter, personal communication, 1980). Additionally, numerous pyritized ostracods and foraminifera have been recovered (Table 3).

The high vertebrate abundance and diversity is unique in level Three. Agassizodus sp., A. variabilis , Cladodus sp. and Peripristis semicircularis are common in addition to Deltodus angularis and Sandalodus carbonarius which have not been recovered from any of the other levels (Hansen, personal communication, 1980) (Table 4).

The floral component of level Three consists largely of unidentifiable wood fragments and one fertile marattialean fragment possessing two synangia (G. Mapes, personal communication, 1980). Most vegetal matter is preserved as carbonized and pyritized fragments. Several phosphatized wood fragments have been discovered protruding from the phosphatic nodules.

TABLE 2: NON-MOLLUSCAN DIVERSITY IN COARSE SIZE FRACTION (0.25 MM.) IN THE EUDORA SHALE

Group	Level				
	1	2	3	4	5
CRINOIDEA					
Apographicrinus	18	60			
Chlidonocrinus	1				
Delocrinus	4	3			
Dichocrinus				2	
Elibatocrinus	1	1			
Erisocrinus	5	2			
Exocrinus	106	56	24		
Galateacrinus	1				
Melbacrinus		1			
Moundocrinus	1				
Paramphicrinus		1			
Sciadiocrinus	1	1			
Seytalocrinus		1			
Stenopecrinus	1	1			
BLASTOIDEA				X	
ECHINOIDEA				X	
HOLOTHUROIDEA				X	
BRACHIOPODA					
Chonetes				1	X
Enteletes	6.2%	6.2%			
Hustedia	6.2%	6.2%			
Neospirifer	6.2%	6.2%			
Rhipodomella	69%	69%	87%		
indeterminate			6.2%		

TABLE 2 continued.

Group	Level				
	1	2	3	4	5
PORIFERA					
Girtyocoelia	6.2%	6.2%	6.2%		
COELENTERATA					
Lophophyllid coral	4	9	26		

Numbers represent amounts recovered from the quantitative sample. The numbers of CRINOIDEA were determined by counting calyces. Percentages of BRACHIOPODA and COELENTERATA were derived using the Dennison and Shea (1966) counting technique. "X" represents the presence of the group in the bulk sample but not in the quantitative sample.

TABLE 3: FAUNAL DIVERSITY OF MOLLUSCAN AND NON-MOLLUSCAN GROUPS WITHIN THE FINE FRACTION (0.25 MM.) OF THE EUDORA SHALE

Group	Level				
	1	2	3	4	5
BIVALVIA					
indeterminate	4.7%	5.0%			
CEPHALOPODA					
Bactrites woodi			10.83%		
indeterminate	2.4%				
ARTHROPODA					
indeterminate	21.87%	21.87%			
GASTROPODA					
indeterminate	7.5%	6.2%			
FORAMINIFERA					
indeterminate	50.0%	63.75%			

Percentages for each group were derived from counting specimens in accordance with the Dennison and Shea (1966) technique.

TABLE 4: DISTRIBUTION OF VERTEBRATE SPECIES IN THE EUDORA SHALE

Species	Level				
	1	2	3	4	5
Agassizodus sp.		X			
A. variabilis			X	X	X
Cladodus sp.		X	X	X	
Deltodus angularis			X		
Petalodus ohioensis	X			X	
Peripristis semicircularis					X
Sandalodus carbonarius			X		

X = occurrence of species in bulk and quantitative samples.

TABLE 5: MOLLUSCAN DIVERSITY IN COARSE FRACTION (0.25 MM.) OF THE EUDORA SHALE

Group	Level				
	1	2	3	4	5
BIVALVIA					
Annuliconchia				9	
Nuculana				X	
Paleoenilo				X	
Paleoyoldia				X	
Promytilus				X	
Selemyalina				4	
Septimyalina				3	16
Wilkingia				1	
indeterminate	X	X	X	40	20
CEPHALOPODA					
Bactrites woodi			X	58	59
Eoasianites			X	27	50
Moorecoceras			X		
Orbobactrites				X	
Turbobactrites				X	
marathanitid			X		
thalassoceratid indeterminate			X		
GASTROPODA					
Euomphalus					3
Ianthinopsis				6	7
Leptogyma			X		
Pseudozygopleuria			63	41	
Straparollus			6	39	
Worthenia			3	1	
beelerophontid indeterminate			43	5	14
				22	

TABLE 5 continued.

Group	Level				
	1	2	3	4	5
HYOLITHA					
Hyolithes wilsoni				X	X
SCAPHOPODA					
indeterminate				13	44

Numbers represent counts of specimens from the quantitative samples.
X = presence of fossil in the bulk sample and not in the quantitative samples.

TABLE 6: ABUNDANCE OF MISCELLANEOUS GROUPS FROM THE DRK GRAY FACIES OF THE EUDORA SHALE

Group	
CRINOIDEA	
Apographicrinus	10
Delocrinus	2
Dichocrinus	1
Erisocrinus	2
Euonychocrinus	2
Exocrinus	1
ARTHROPODA	
indeterminate	1
CONULARIA	
indetermonate	1
GASTROPODA	
Cyclioscapha	1

Data has been derived from samples collected by R.H. Mapes as part of a study on bactritoid diversity within the Eudora shale. Numbers of CRINOIDEA were determined by counting calyces.

The Dark Gray Lithofacies

The dark gray shale lithofacies of the Eudora shale encompasses the upper half of level Three and levels Four and Five which are considered as a single unit. Molluscs are particularly abundant and diverse in this unit, whereas non-molluscan groups decrease in abundance and diversity (Table 2). Among the molluscs, cephalopods are especially common, represented by numerous indeterminate protoconchs and abundant bactritoid fragments including Bactrites woodi , Dilatobactrites sp., and more rarely Orbobactrites sp. and Turbobactrites sp. The ammonoids include Eoasianites sp., Neoaganides sp. and Neodimorphoceras (?) sp. and an unidentifiable marathonitid and thalassoceratid. The nautiloid component, represented by uncommon specimens of Mooreoceras (?) sp., is largely insignificant in terms of the overall composition of the assemblage. Bivalves, the next most abundant molluscan group, are more diverse than the cephalopods. Specimens recovered have been assigned to Annuliconchia (?) sp., Selenimyalina (?) sp., Septimyalina (?) sp. and Wilkingia (?). The gastropod component is neither as diverse nor abundant as the other molluscan groups. Ianthinopsis (?) sp., Pseudozygopleuria (?) sp., Straparollus (?) sp. and Worthenia (?) sp. numerous genera and species whose identities have not been determined have also been recovered. Scaphopods, the least diverse molluscan group, have been recovered in small quantities

from this unit. All molluscs are preserved as pyritized internal molds. They appear not to have attained the size most frequently observed for adult members of their representative genera as no mollusc exceeds five millimeters (Mudge and Yochelson, 1962; Moore, 1964; Senich, 1978).

Rare non-molluscan components from this unit include brachiopods, bryozoans, echinoderms and sponges. Some of these specimens are pyritized while others, especially the bryozoa, retain their calcareous skeletal elements. The mobile echinoderms are represented by a single echinoid spine in addition to one holothurian plate. A single radial plate from the crinoid Dichocrinus sp. has also been discovered (Strimple, personal communication, 1980). Blastoids, which are rare in Upper Pennsylvanian strata in North America, have been discovered at this locality. These blastoids are important as they extend the known geographic range of this order during the Upper Pennsylvanian Period (Table 3). Their occurrence at this locality will be discussed elsewhere (Macurda, in preparation).

The microfaunal component of this assemblage is more diverse than that of the medium gray lithofacies, and includes the conodont Idiognathodus sp. (Baxter, personal communication, 1980), in addition to pyritized foraminifera and ostracods. The most unusual fossil among the microfaunal elements, a bivalved organism questionably identified as an arthropod, occurs in abundance. Agglutinated foraminifera are very common (Table 3).

Two vertebrate species, Agassizodus variabilis and Petalodus ohioensis , were recovered from levels Four and Five (Table 4). The majority of the vertebrate material is too fragmentry to be identifed with confidence.

Vegetal matter attributed to four major groups including conifers, seed ferns, cordaitaleans, and true ferns have been identified. The conifer remains, some of which possess leaf fragments and fertile scales, are particularly abundant. Medullosan seed ferns are represented by a single section of Myeloxylon sp. and miscellaneous fragments including radially symmetrical ovules. Cordaitaleans are represented by a decorticated partial axis with septate pith and well developed wood; most of the indeterminate fragments are probably assignable to this group as well. True ferns in this assemblage include Scolecopteris and (possibly) Millaya sp. The fern remains also include partially fertile pinnules, numerous isolated synangia, and isolated megaspores. Trilete megaspores may represent the genus Triletes sp. A second group, possessing equatorial ridges or sutures and poles may be remnants of unidentifiable seed ferns (G. Mapes, personal communication, 1980).

Several unusual fossils characterize the dark gray lithofacies of the Eudora shale. These include common hyoliths, cephalopod mandibles, and scolecodonts. The hyoliths are preserved as internal pyritized molds and several possess well preserved opercula. The cephalopod

mandibles and scolecodonts, which are more abundant than the hyoliths, are more uniformly distributed throughout the dark gray shale (Table 5).

Other fossils collected from this shale as part of a study by R. H. Mapes include a normal sized specimen of the gastropod Cycilioscapha sp. and a conularid, both of which retain their original tests. Other fossils include several small spiriferids, fragments from a rostroconch, and a questionable trilobite spine (Table 6).

Paleontologic Interpretation

The primary objective of studying the flora and fauna of the Eudora shale is to infer the depositional environment of this unit on the basis of its fossil content. Specifically, fossils will be employed in interpretting proximity to shore, salinity, rate of sedimentation and oxygen levels during deposition. Determination of the first two parameters will allow the Eudora shale to be assigned to either an offshore marine environment or a nearshore lagoonal environment. Many environmental parameters cannot be known with certainty as the environmetal preferences of the organisms involved are not well known.

There are several lines of evidence which can be used to determine proximity to shore and salinity. A model for conodont distribution within Upper Pennsylvania strata recognizes two distinct biofacies: an offshore Idiognathodus

biofacies and a nearshore Cavusgnathus biofacies (Merrill, 1973). The distribution of these biofacies is suggested as a function of proximity to shore and salinity. The organisms of the Cavusgnathus biofacies supposedly prefer reduced or fluctuating salinities associated with nearshore areas whereas the Idiognathodus biofacies fauna is apparently more stenohaline, preferring the stable salinities characteristic of offshore areas (Merrill, 1973). Alternate models for conodont distribution suggest that conodonts are pelagic organisms with a distribution that is strongly depth controlled (Seddon and Sweet, 1971; Heckel and Baesemann, 1975). As a result conodont diversity is believed to increase in progressively deepening water. Other workers suggest that conodonts are benthic or nektobenthic organisms which are influenced by substrate rather than depth (Barnes and Fahraeus, 1975; Klapper and Barrick, 1978). These two alternate models have been proposed for the distribution of conodonts in Ordovician strata. If the models for conodont biofacies in Pennsylvanian strata is correct, conodonts are particularly useful in distinguishing nearshore from offshore marine environments.

Normal marine salinities may also be inferred from many other organisms. Many taxa within the Eudora shale, including the brachiopods, echinoderms and vertebrates are known only from normal marine environments (Heckel, 1972; Hansen, personal communication, 1980; Strimple, personal communication, 1980).

Other environmental parameters may also be inferred from the faunal content of this unit. These include degree of oxygenation and rate of sedimenation during deposition. An increase in faunal diversity probably indicates an increase in the amount of oxygen in the water if salinity and other environmental parameters, such as food supply, have remained unchanged (Heckel, 1972). The presence of numerous filter-feeding organisms suggests a low rate of sedimentation as suspended sediment in the water will suffocate these organisms will clog their feeding and breathing mechanisms (Heckel, 1972).

The fauna recovered from the Eudora shale at the Tyro locality presents certain problems in terms of environmental interpretation. For example, the small size of the majority of the organisms, particularly the molluscs, does not allow direct observation of fossils in situ. Taxonomic identification and distinguishing juveniles from mature organisms is extremely difficult. In addition, some of the fauna, especially the molluscs, may not have lived in this area because small organisms are easily transported by floating despite the fact that as adults they may have a benthonic life mode (Heckel, 1972).

The medium gray shale lithofacies of the Eudora shale encompasses the lower portion of level Three and levels One and Two. The fauna, with the possible exception of the molluscs, appears to be native to this area. Even delicate structures, such as echinoderm calyces, are preserved. This

assemblage is dominated by brachiopods, echinoderms and sponges, and includes Idiognathodus sp. This fauna is indicative of an offshore, normal marine environment rather than a nearshore lagoon with sediment influxes and fluctuating salinities (Heckel, personal communication, 1980). The moderate diversity in this lithofacies may be a function of reduced oxygen within the water. A moderately dysaerobic condition may be inferred from the pyrite aggregates in the sediment and the partial pyritization of certain fossils (Heckel, 1972), although this could be a diagenetic feature. A moderate rate of sedimentation is suggested by the presence of numerous filter-feeding organisms, such as abundant echinoderms and less common brachiopods.

Conodonts and vertebrate remains suddenly increase in abundance in proportion to the other fauna in level Three. The abundance of these fossils indicates a diastem as their abundance may be due to non-dilution by sediment (Heckel, personal communication, 1980). Decreased sedimentation is further suggested by the occurrence of numerous phosphatic nodules, which are characteristic of diastems (Heckel, 1972). The sudden appearance of abundant filter-feeding lophophyllid corals is probably related to the low rate of sedimentation as well. At this interval of level Three molluscs become abundant and diverse. These organisms may have floated to this area as their small size lends itself to easy transport (Heckel, personal communication, 1980). If

the small size of these organisms is due to immaturity rather than stunting, they do not constitute an ecologically coherent, indigenous population as the adult members of the population are absent. Therefore, some biological or sedimentological mechanism must be invoked to explain their presence.

There are essentially three mechanisms by which an assemblage of small individuals may originate. These mechanisms include: 1) true stunting ; 2) concentrating immature individuals with sub-normal lifespans or 3) mechanical sorting of individuals so that only small individuals remain (Dunbar and Rogers, 1957).

Population studies of Recent molluscan assemblages reveal that a variety of age groups, and therefore a variety of different sized organisms (skewed toward larger mature individuals) are typical of an ecologically coherent, indigenous population of several species (Raup and Stanley, 1971). According to the preservational model proposed for such a population by Raup and Stanley (1971), a size distribution of organisms similar to that of the living assemblage will be preserved assuming that the assemblage has not been reworked by currents. In an indigenous assemblage of stunted organisms the size frequency distribution of a normal population will be absent although the age distribution of the organisms remains the same (Raup and Stanley, 1971).

Stunted faunas consisting largely of molluscs have

long been known from pyrite-bearing horizons in the Devonian aged Tully Limestone of eastern North America (Loomis, 1903; Heckel, 1973). A similar fauna from the Devonian aged Ludlowville Formation has been recovered from the same region (Fisher, 1951). Recognition of the stunted nature of the individuals in these faunas rests solely on various morphologic parameters modified during ontogeny (Fisher, 1951). Such features include growth lines on molluscs or ammonoid suture patterns, which indicate the degree of maturity of the organism despite its size. Because the stunted faunas of the Devonian black shales are associated with pyrite, the high iron and sulfur content of the water was at first thought to be responsible for growth retardation. More recent investigations suggest that reduced oxygen levels in the water are responsible for interferring with certain metabolic processes which in turn inhibit feeding and growth (Hallam, 1965). The association of small individuals, dark gray shale, pyrite and other sulfide minerals seems to indicate stunting; however, other evidence indicates that this is almost certainly not the case.

The Eudora molluscan fauna is preserved mainly as pyritized internal molds, therefore most of the morphologic features by which age determinations can be made are absent. However, with one exception, the ammonoids possess sutures which do not reflect the sutural configurations observed much larger and presumably more mature specimens from other

localities. Additionally, cephalopod protoconchs constitute the most abundant fossil in this lithofacies. This strongly suggests that all the cephalopods are juveniles, therefore, the other molluscs are probably immature as well.

If the juvenile nature of the molluscan component is accepted, the problem of faunal interpretation becomes one of explaining the concentration of immature individuals with sub-normal lifespans. These small-sized organisms may have been planktonic larvae and drifted or swam into this environment where they could not survive for very long, possibly due to reduced oxygen in the water. A possible point of origin for these molluscs is the more shoreward, oxygenated environment represented by the medium gray lithofacies. This environment probably coexisted with the highly dysaerobic dark gray shale environment in accordance with Walther's Law of Facies.

An alternate mechanism by which small fossils may be concentrated is through hydrodynamic sorting, that is, through selected transport and deposition of small organisms. Evidence for sorting such as mechanical concentration could not be observed in the small fauna of the Eudora shale.

The dark gray shale lithofacies of the Eudora shale, encompassing the upper half of level Three and levels Four and Five, is considered as a single unit due to lithologic and faunal similarities between levels. The brachiopod and echinoderm assemblage of the lower lithofacies is replaced

upward by a molluscan dominated assemblage. The scarce brachiopods, bryozoa, echinoderms and sponges, as well as the conodonts and hyoliths, indicate continued offshore marine sedimentation during the deposition of this unit. The faunal changes between lithofacies are explained as a result of greatly reduced levels of oxygen in the water. Most of the fauna consists of small molluscs, which did not live in this area (Heckel, personal communication, 1980). The abundant non-marine flora in this lithofacies is thought to have floated from shore. Upon sinking the lack of oxygen prevented decomposition and helped promote preservation. The decrease in the abundant benthic foraminifera and ostracods and vertebrates suggests that the rate of sedimentation had increased since the deposition of level Three.

Although the depositional environment of the Eudora shale in the Tyro quarry is marine, it differs in several respects the Eudora shale in Kansas and from Pennsylvanian black shales in the Illinois basin. Faunal diversity within both lithofacies at the Tyro locality, particularly among the echinoderms and molluscs, is much greater than that reported by Senich (1978) for the Eudora shale at other localities. Additionally, a high proportion of Gondollela sp. and Idiognathodus sp. among the conodonts, which is thought to be characteristic of the Eudora shale (Baesemann, 1973; Heckel and Baesemann, 1975; Wood, 1977; Wood and Heckel, 1977; von Bitter and Heckel, 1978) has not been observed at the Tyro locality. The faunal differences

observed at the study area as compared to those previously cited may be in part a function of this area's proximity to the edge of the basin of deposition rather than the center (Heckel, personal communication, 1980).

The Eudora shale at the Tyro locality resembles, in general, the black shales of the Illinois basin more closely in terms of faunal content, particularly conodont diversity. Molluscan diversity within the Eudora black shales is similar in diversity to the shales of the Mecca and Logan Quarries studied by Zangerl and Richardson (1963). Additionally, as in the Eudora shale at the Tyro locality, Gondollela sp. and Idioprionodus sp. are rarely encountered in the Illinois basin shales (Merrill, 1973; Merrill and Martin, 1976; Merrill, et al. , 1978).

DEPOSITIONAL ENVIRONMENT OF THE EUDORA SHALE

Depositional Models for Black Shales

Several depositional environments for black muds have been recognized. However, black mud deposition will occur in any marine or non-marine environment where water circulation and therefore oxygenation has been restricted (Trask, 1939). Each black shale should be considered individually based on its own intrinsic characteristics. This is particularly true for the black shales of the Illinois basin and the Midcontinent region. Two depositional models for black shale facies in the "core" shales of Kansas cyclothems particularly the Eudora Shale will be considered. The differences between models involve salinity and proximity to shore with consequent variations in faunal content and associated facies. These variations ideally should serve as the distinguishing criteria for black shales from the two different depositional environments (Heckel, 1977).

The first model involves black mud deposition in a restricted basin with inferred patterns of water circulation, depth and salinity similar to those of an epicontinental sea. Black muds are known to be forming in a number of restricted basins such as the Black Sea, basins along the coast of southern California, the Baltic Sea and

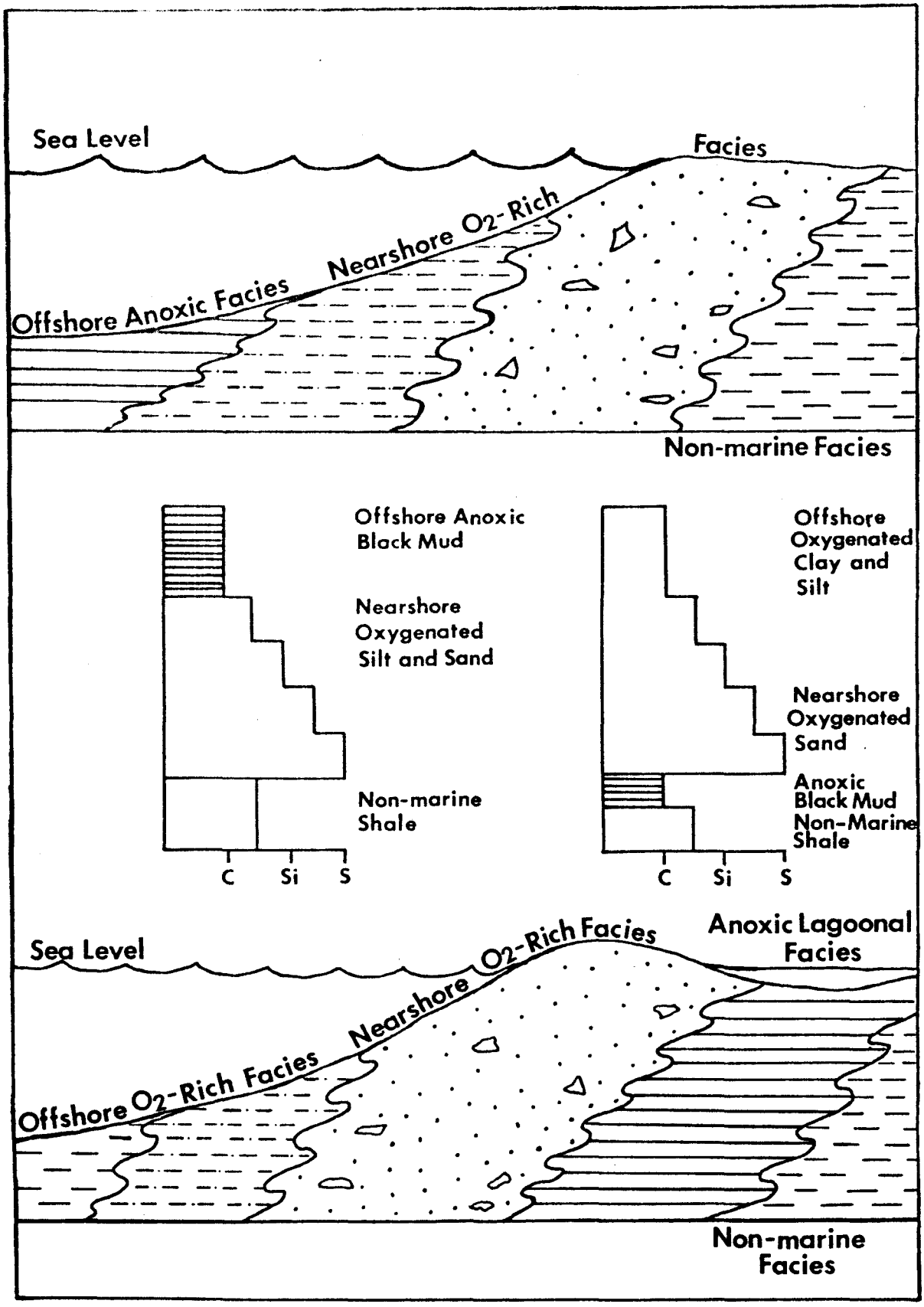
in a number of fjords along the Norweigian coast (Dunbar and Rogers, 1957), although none of these basins is strictly analogous to an epicontinental sea. Black muds are presently being deposited in the Baltic Sea at depths exceeding 80 meters (Manheim, 1961). The anoxic conditions at this depth are thought to result from warm, oxygenated surface water overriding cold, oxygen poor bottom water creating a vertical density stratification and therefore inhibiting vertical circulation of oxygenated water (Twenhofel, 1915; Manheim, 1961). The lack of oxygen in the bottom water coupled with a yearly plankton bloom further enhances anoxic conditions on the sea bottom by supplying organic debris for decomposition (Segerstrale, 1957). The resulting black mud has been observed to grade laterally into progressively finer grained and more oxygenated facies represented by blue-gray sandy clay which in turn grades into coarse beach sands and gravels (Manheim, 1961). The black mud facies is characterized by a scarce pelagic fauna, abundant anaerobic bacteria and numerous floral remains (Segerstrale, 1957). Immediately adjacent to the black mud, a marine and brackish fauna inhabits the bottom sediment. The adult members of this fauna appear not to have attained the size most frequently observed for their species a other localities (Segerstrale, 1957). In the stratigraphic record, a black shale from a marine environment will occur in association with progressively more oxygenated and larger grained facies containing abundant and diverse faunas in a shoreward

direction (Heckel, 1977) (Fig. 8).

The model described above, based largely upon the Baltic Sea, differs in several respects from the model postulated by Heckel (1977) for anoxic Midcontinent basins. Salinities in the Baltic Sea vary from brackish to normal marine (Manheim, 1961) whereas in the Midcontinent basins, salinities are thought to have remained near normal marine (Heckel, 1977). Furthermore, the Baltic Sea is a large basin with restricted access to the sea whereas the Midcontinent basins are believed to have possessed unrestricted access to the open ocean (Heckel, 1977). A depositional environment exactly analagous to a Paleozoic epicontinental sea has not been recognized at present. Therefore, the Baltic Sea, and similar restricted large bodies of water are the most closely analagous situations to epicontinental seas currently available.

The second depositional model for black muds involves deposition in shallow, shoreline embayments parallel to the strandline with restricted access to the sea. These environments are characterized by brackish water and periodic influxes of sediment, resulting from the periodic influx of water from the landward side of the lagoon (Heckel, personal communication, 1980). These environments include lagoons adjacent to the coasts of the Baltic Sea (Twenhofel, 1915), the New Jersey coast (Fischer, 1961), the Gulf Coast (Zangerl and Richardson, 1963) and the coast of southern California (Reineck and Singh, 1975). Anoxic

Fig. 8 Generalized vertical and lateral facies relationships for black shales forming in offshore marine and lagoonal environments.


Sea Level
Facies
Nearshore O2-Rich
Offshore Anoxic Facies
Non-marine Facies
Offshore Anoxic Black Mud
Nearshore Oxygenated Silt and Sand
Non-marine Shale
C
Si
S
Offshore Oxygenated Clay and Silt
Nearshore Oxygenated Sand
Anoxic Black Mud
Non-Marine Shale
C
Si
S
Sea Level
O2-Rich Facies
Anoxic Lagoonal Facies
Nearshore
Offshore O2-Rich Facies
Non-marine Facies

shallow water embayments may originate through two mechanisms: (1) barrier beach complexes, which serve as restrictions to uninhibited circulation, as along the coasts of New Jersey and southern California (Fischer, 1961; Reineck and Signh, 1975) and (2) the presence of vegetation, which either grows on the floor of the lagoon or floats on the surface, as in the Baltic Sea or in the bayous along the Gulf Coast (Twenhofel, 1915; Zangerl and Richardson, 1963). Black muds from a lagoonal environment can be distinguished from marine black muds by lateral gradation into shoreline and shallow marine facies including beach facies, tidal flat facies and tidal channel facies (Reineck and Singh, 1975; Heckel, 1977) (Fig. 8). Furthermore, the abundance and diversity of the fauna is restricted to those organisms which favor brackish environments (Reineck and Singh, 1975).

The marginal marine embayment model has been widely used to explain the origin of black shales in the Illinois basin (Moore, 1936; Weller, 1957, 1958; Zangerl and Richardson, 1963; Merrill, 1973). Unlike the black shale units of the Kansas cyclothem, the Illinois basin black shales directly overlay coals and are therefore thought to represent the initial stage of transgression (Weller, 1957, 1958; Zangerl and Richardson, 1963; Merrill, 1973). The restricted circulation in these lagoons has been ascribed to vegetation floating on the surface (Zangerl and Richardson, 1963), or vegetation growing on the bottom (Weller, 1957) or to the extremely shallow depths associated with the initial

transgression (Wanless and Shepard, 1936). The general absence of a benthic fauna and the presence of exclusively pelagic organisms such as cephalopods and aquatic vertebrates attest to the anoxic bottom conditions. However, extremely shallow depths of water are suggested by the presence of local, dense accumulations of molluscan shells which are thought to indicate periodic ponding and drying of water in the lagoon (Zangerl and Richardson, 1963). Based on the changing faunal content of these shales, the salinity during deposition is thought to have varied from fresh to normal marine. In this respect, the lagoonal model of Zangerl and Richardson (1963) differs from those of the Recent in which brackish water dominates.

A final depositional model for black mud is considered. This model illustrates that a black shale in itself is not necessarily indicative of an anoxic environment. Certain Recent black muds, such as the black mud in Chesapeake Bay, are being deposited in fully oxygenated water. The high organic content of the mud is not the result of anoxic conditions but of an overabundance of organic debris which is buried before decomposition is complete (Dunbar and Rogers, 1957). A black shale deposited in an oxygenated environment would be recognizable in the stratigraphic record not so much by the associated facies but more so by a high faunal diversity.

Depositional Models for Kansas Cyclothems

The origin of the cyclothems of Kansas and the generation of the black shale, are interrelated. The original cyclothem model of Moore (1936) was initially interpretted by him as several underdeveloped Illinois cyclothems originating through several transgressive events. According to this model, the black shale was deposited at the start of transgression which culminated with the deposition of the fusiline-bearing limestone member in an offshore marine environment (Moore, 1936; Weller, 1957, 1958; Mudge and Yochelson, 1962) (Fig. 1). In a similar depositional model, the Eudora Shale and certain portions of the limestone members of the Stanton Formation, were assigned to protected lagoonal environments in which the phylloid algal mounds served as barriers to restrict water circulation (Wilson, 1957). Although neither of these models is presently favored, an alternate depositional model for Kansas cyclothems cannot be constructed until the origin of the black shale facies is thoroughly understood.

A more recent depositional model for Kansas cyclothems favors an offshore, marine origin for the black shale facies of the "core" shale (Heckel, 1977). According to this model, the black shale originates during the maximum transgressive phase when the water near the sea bottom becomes anoxic due to temperature stratification associated with the changing patterns of water circulation.

This model has been derived from the eastern equatorial Pacific Ocean where oceanographic and climatic

conditions similar to those thought to characterize the Pennsylvanian Midcontinent, are known to exist. The prevailing northeasterly wind, characteristic of the equatorial regions, displaces the warm, oxygenated surface water laterally to the west. This warm water forces cold, oxygen poor water to migrate laterally to the east, replacing, and therefore underlaying, the warm surface water. The pattern of circulation resulting from this movement is known as quasi-estuarine circulation. The differences in density due to temperature prohibit vertical circulation, thereby inhibiting oxygenation of the sea bottom. This establishes a temperature stratification known as a thermocline. Anoxic conditions on the bottom are enhanced when organic debris from the surface sinks and utilizes any remaining oxygen during decomposition. The bottom water is rich in nutrients and upwells to the surface, causing extensive plankton blooms. This plankton generates most of the organic debris which falls to the sea floor and decomposes (Fig. 9).

A reconstruction of the depositional sequence in Kansas cyclothems following this model suggests that the predominantly non-marine "outside" shale unit marks the maximum regression, as these units are thought to represent largely fluvial and deltaic environments. The uppermost marine portion of the "outside" shale denotes the beginning of transgression. Greater water depths are attained during the deposition of the "middle" limestone, a shallow marine

wackestone containing current produced structures and a abundant and diverse fauna. Above this unit is the "core" shale. This shale possesses a a black facies which was deposited at the maximum extent of transgression, overlain in turn by a gray facies that marks the onset of regression. The "upper" limestone is lithologically and depositionally similar to the "middle" limestone and suggests shallowing water. This limestone is in turn overlain by an "outside" shale unit, delineating the base of the next cyclothem (Fig. 2).

A depositional model featuring a single transgressive-regressive package for Kansas cyclothems makes possible a reasonable time-stratigraphic correlation between the cyclothems of Kansas and the Illinois basin. According to Heckel (1977), the "outside" shale is equivalent to the fluvial and deltaic portion of the Illinois cyclothem. These non-marine strata are better developed in terms of lithologic diversity and thickness in the Illinois basin as this region is thought to have been located further east of the strandline during regression. Consequently, fluvial and deltaic conditions prevailed in the Illinois basin for longer periods of time, permitting a more lithologically diverse section to develop. The "middle" transgressive limestone is equivalent to the depositional surface separating the coal horizon from the overlaying black shale. Decaying vegetation of a partially submerged coal swamp would prevent carbonate formation due to the acidity or low

oxygen of the water. The shallow transgressive phase is not represented in the Illinois cyclothem. The coal is directly overlain by a black shale unit, thought to be depositionally similar to the black shale facies of the "core" shale. The "upper" limestone is believed to be equivalent to the marine strata of the Illinois cyclothem or possibly to the lowermost non-marine strata in the next cyclothem (Heckel, 1977) (Fig. 10). Laterally restricted, seemingly additional strata in the Illinois cyclothem which cannot be correlated to any units in Kansas cyclothems represent the local progradation of deltas and their associated facies (Wanless, 1964).

Depositional History of the Eudora Shale

The fauna of the Eudora shale indicates that both lithofacies originated under marine conditions. The calcareous brachiopod and echinoderm dominated fauna of the medium gray lithofacies is indicative of a normal marine environment. The dominantly juvenile molluscan fauna of the upper dark gray lithofacies, which appears to have been floated to this area, is not in itself suggestive of marine conditions. However, a lagoonal environment with fluctuating salinities and clastic influxes would not be conducive to the survival of the few brachiopods, bryozoans, echinoderms and conodonts recovered from this lithofacies (Heckel, personal communication, 1980). Additionally, a lagoon is

Fig. 9 Patterns of circulation in a west facing epicontinental sea at A, low stand of sea level, and B, high sea level stand. At high sea level stand, depth is sufficiently great to establish a regional thermocline preventing sea floor oxygenation, and allowing black shale to be deposited (from Heckel, 1980).

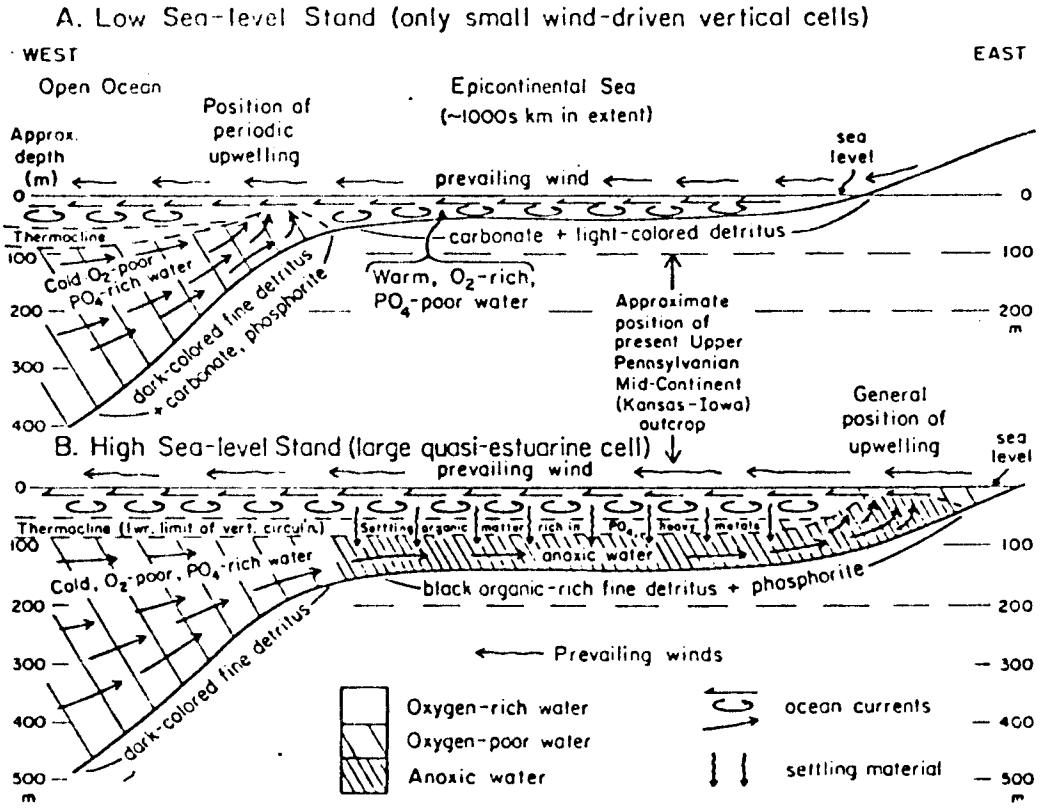

A. Low Sea-level Stand (only small wind-driven vertical cells)
WEST
EAST
Open Ocean
Position of periodic upwelling
Epicontinental Sea (~1000s km in extent)
Approx. depth (m)
sea level
prevailing wind
Thermocline
carbonate + light-colored detritus
Cold, O2-poor, PO4-rich water
Warm, O2-rich, PO4-poor water
dark-colored fine detritus + carbonate, phosphorite
Approximate position of present Upper Pennsylvanian Mid-Continent (Kansas-Iowa) outcrop
General position of upwelling
B. High Sea-level Stand (large quasi-estuarine cell)
prevailing wind
Thermocline (lwr. limit of vert. circ'n)
Settling organic matter rich in PO4, heavy metals
anoxic water
Cold, O2-poor, PO4-rich water
black organic-rich fine detritus + phosphorite
dark-colored fine detritus
Prevailing winds
Oxygen-rich water
Oxygen-poor water
Anoxic water
ocean currents
settling material
0
100
200
300
400
500
m

Fig. 10 Proposed depositional relationship between cyclothems of Midcontinent and Illinois basin. The black shale is thought to be a deep water transgressive deposit in both areas (from Heckel, 1980).

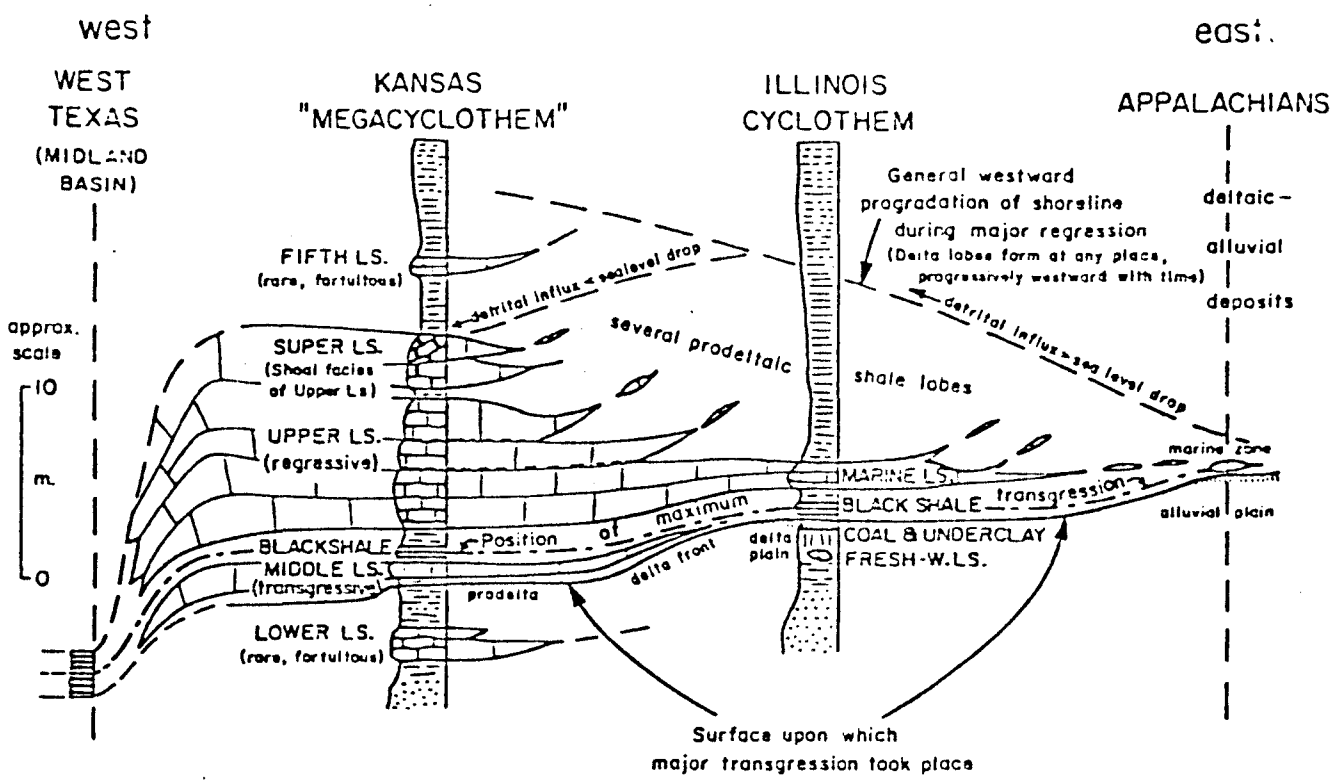
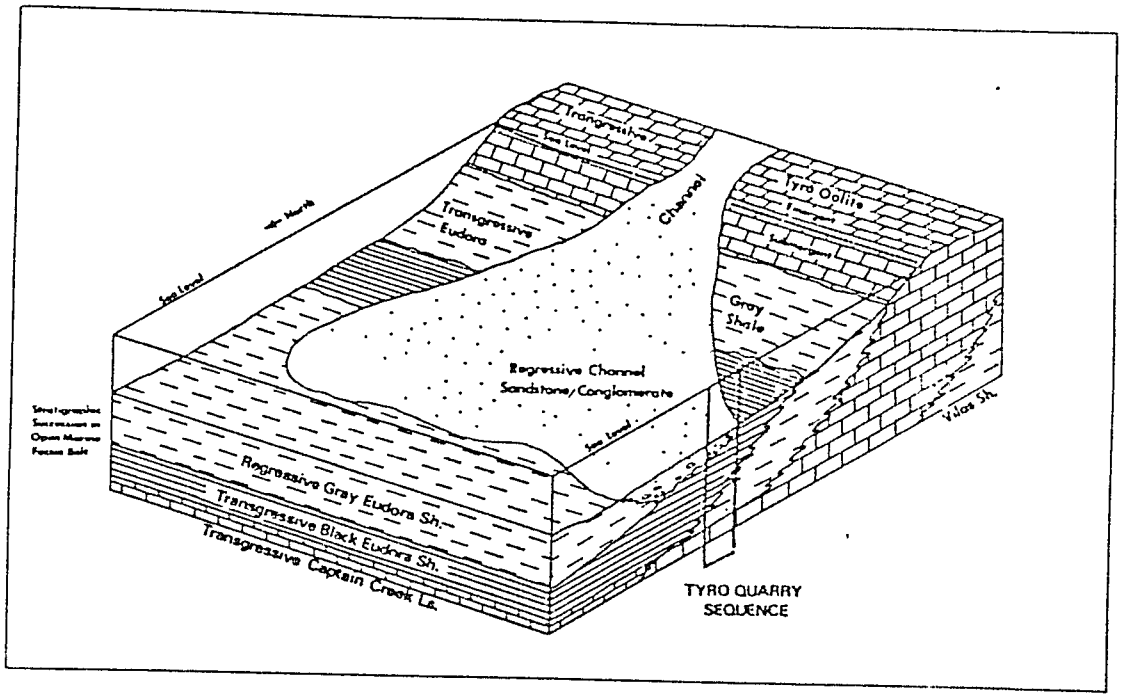

west
east
WEST TEXAS (MIDLAND BASIN)
KANSAS "MEGACYCLOTHEM"
ILLINOIS CYCLOTHEM
APPALACHIANS
deltaic – alluvial deposits
General westward progradation of shoreline during major regression
(Delta lobes form at any place, progressively westward with time)
FIFTH LS.
(rare, fortuitous)
detrital influx < sealevel drop
detrital influx > sealevel drop
several prodeltaic shale lobes
approx. scale
10
m.
0
SUPER LS.
(Shoal facies of Upper Ls)
UPPER LS.
(regressive)
MARINE LS.
marine zone
BLACK SHALE
transgression
alluvial plain
maximum
Position of
BLACKSHALE
MIDDLE LS.
(transgressive)
delta front
delta plain
COAL & UNDERCLAY
FRESH-W.LS.
prodelta
LOWER LS.
(rare, fortuitous)
Surface upon which major transgression took place

Fig. 11 Diagram showing inferred facies relationships during deposition of the "Eudora-Rock Lake" interval at the Tyro quarry. The intrastratal transition between the Captain Creek limestone and Tyro oolite has not been directly observed. The intertonguing between the medium gray regressive Eudora shale and the sandstone of the "Eudora-Rock Lake" interval is inferred.


Transgressive
Tyro Oolite
Channel
Transgressive
Eudora
Gray
Shale
Regressive Channel
Sandstone/Conglomerate
Regressive Gray Eudora Sh.
Transgressive Black Eudora Sh.
Transgressive Captain Creek Le.
TYRO QUARRY
SEQUENCE

beyond the influence of upwelling, which is necessary for phosphate deposition (Carozzi, 1972; Heckel, personal communication, 1980). Thus, the fauna and the presence of phosphatic nodules suggest that an offshore depositional environment is the most satisfactory explanation for the origin of the Eudora shale at this locality.

With the onset of transgression, deposition at the Tyro locality was initiated with the formation of the Tyro oolite. According to Heckel (1975b), this rock unit originated in a broad, open shoal environment characterized by shallow, agitated water that was free of clastic influx. The lithology of the Tyro oolite suggests shallow marine deposition at the margin of the basin, as the correlative units of the Tyro oolite are deeper water wackestones.

Within the basin, temperature stratification of the water occurred altering the overall pattern of vertical circulation. As a result, the bottom waters became oxygen poor, and a dark gray or black shale was deposited in the basin. Initially, at the Tyro locality, the water was sufficiently shallow for the area to remain oxygenated. Limited circulation and oxygenation resulted in the deposition of a medium gray shale containing a fauna of moderate diversity characterized by brachiopods, echinoderms and sponges. With continued transgression, the thermocline and the associated anoxic conditions migrated further eastward, enveloping the Tyro area in oxygen-poor water. Numerous phosphatic nodules were accreted, indicating a

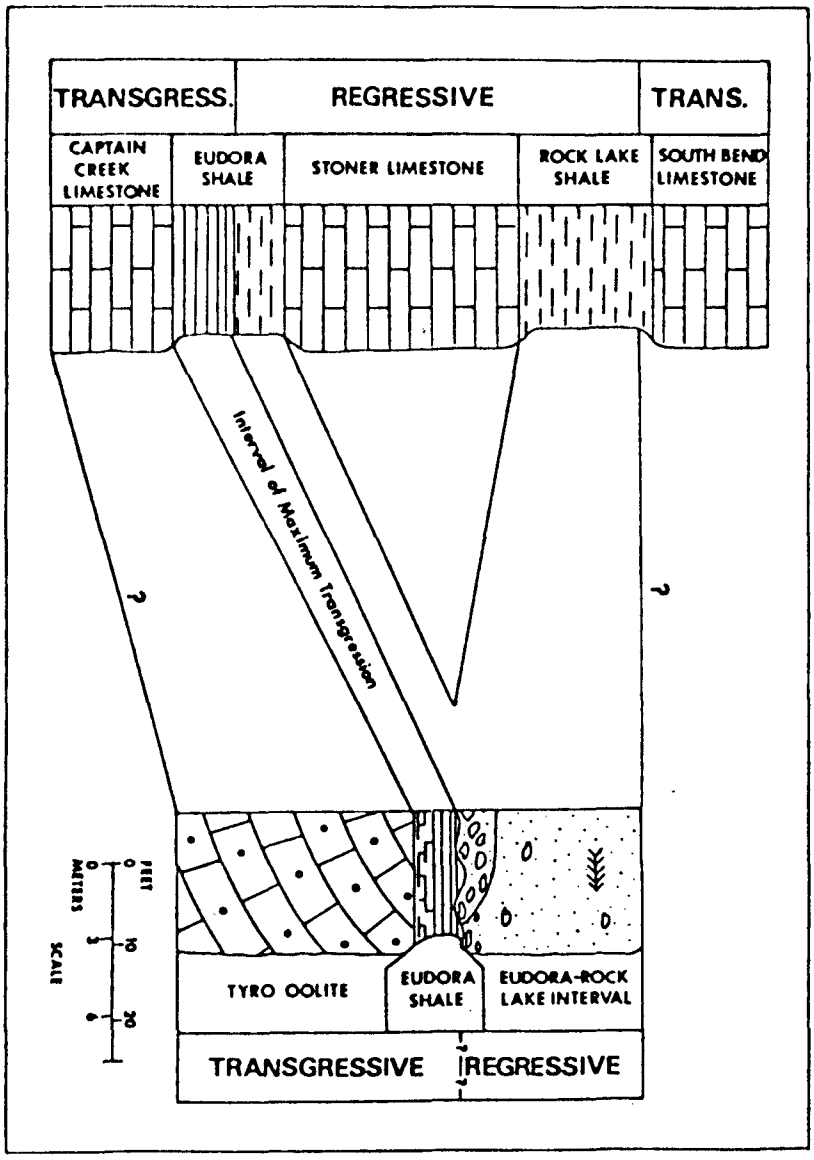
temporary cessation of sedimentation (Heckel, 1972). Afterward, a dark gray shale, similar in certain aspects to the black shale in the center of the basin, was deposited. The fauna of this dark gray shale indicates a marked dysaerobic environment rather than completely anoxic conditions, possibly as a result of proximity to well oxygenated and agitated waters near wave base toward shore. The onset of regression ended black shale deposition by destroying the temperature stratification and allowing resumption of vertical circulation, and a light gray shale, similar to the lower transgressive gray shale at the Tyro locality, was deposited throughout the basin. In the Tyro area, this upper regressive light gray shale is absent and an unconformity separates the dark gray shale from the overlying unit. This suggests that water depths were very shallow in this area, probably as a result of this area's proximity to the basin margin.

With continued regression, the Tyro area became a marginal marine environment very near to the strandline. The conglomeratic lithofacies in the "Eudora-Rock Lake" interval may represent a lag deposit on the floor of a tidal channel. The remaining conglomeratic sand lithofacies suggests tidal channel deposition, as this facies contains bidirectional current structures (Fig. 11). The marginal-marine interpretation is supported by the fact that other transitional environments, such as tidal flats, have been recognized within the Rock Lake shale in other areas

(Russell, 1972).

The black lithofacies of the Eudora shale in the open marine facies belt and both Eudora shale lithofacies at the Tyro quarry are transgressive and time-equivalent. Since the "Eudora-Rock Lake" interval is a regressive unit, it may be equivalent to all or part of the regressive light gray shale and the lower regressive portion of the Rock Lake shale in the northern portions of the outcrop belt (Fig. 12). The emplacement of this tidal channel facies was followed by the deposition of the thin alternaing sandstone and shale units in the upper portion of the "Eudora-Rock Lake" interval. Detailed environmental analysis of these units is beyond the scope of this report.

Fig. 12 Possible correlation between the sequence at the Tyro quarry and the members of the Stanton Formation in the open marine facies belt. Both lithofacies of the Eudora shale at the Tyro area are thought to be equivalent to the Eudora black shale facies observed at other areas. The "Eudora-Rock Lake" interval at this locality is thought to have originated simultaneously with the formation of the upper regressive medium gray Eudora shale. Water depths at this area were probably too shallow for the formation of the moderately dysaerobic regresive gray Eudora shale, instead, a tidal channel sequence developed during regression.


TRANSGRESS.
REGRESSIVE
TRANS.
CAPTAIN CREEK LIMESTONE
EUDORA SHALE
STONER LIMESTONE
ROCK LAKE SHALE
SOUTH BEND LIMESTONE
Interval of Maximum Transgression
?
?
METERS
FEET
SCALE
TYRO OOLITE
EUDORA SHALE
EUDORA-ROCK LAKE INTERVAL
TRANSGRESSIVE
REGRESSIVE

SUMMARY AND CONCLUSIONS

The salient points of this study may be summarized as follows:

1) The lower medium gray shale lithofacies of the Eudora shale near Tyro, Kansas contains a fauna dominated by brachiopods, echinoderms, and sponges. Moderate diversity, and the presence of pyrite aggregates, suggests moderately dysaerobic normal marine conditions during the deposition of this unit. While this transgressive unit was being deposited at the basin margin, anoxic conditons prevailed in the center of the basin resulting in black shale deposition in the basin. This medium gray shale is therefore time equivalent to the black Eudora shale in the center of the basin.

2) The dark gray shale lithofacies of the Eudora shale differs in certain respects from the Eudora shale at other localities. The differences involve the high molluscan diversity in the dark gray facies at the Tyro locality, and the extremely low conodont diversity in both lithofacies. These faunal changes, as well as the dark gray, rather than black color, may be related to the greater degree of oxygen at this locality during deposition. The absence of complete anoxic conditions may in part result from close proximity of this area to the basin margin. With continued transgression following medium gray shale deposition, this area was enveloped in deeper, oxygen poor water. However, this

area's proximity to the basin margin (and therefore to wave base) prohibited the development of totally anoxic conditions.

3) The upper dark gray lithofacies contains a highly diverse, juvenile, pyritized molluscan fauna which may have floated or swum from an adjacent oxygenated area. The remainder of the fauna consists of rare brachiopods, echinoderms, sponges and foraminifera and ostracods, indicating dysaerobic, normal marine conditions. A normal marine depositional environment is further supported by the prescence of numerous phosphatic nodules, known to occur only in marine environments. A restricted lagoonal embayment, subject to fluctuating salinities and occasional influxes of clastic sediment, is not conducive to the survival of a extensive marine fauna or the accretion of phosphatic nodules.

4) The Eudora shale at the Tyro locality is distinguished by its unusual fossil content, particularly the blastoids and hyoliths. The blastoids are significant as they extend the known geographic range of this group during the Upper Pennsylvanian Period. Formerly, blastoids were believed to be confined largely to occurrences on the Asian continent. The hyoliths are important as previously this group was unknown from Pennsylvanian strata in North America. This suggests that hyoliths were more widespread during Pennsylvanian time than was formerly believed.

5) An offshore, marine depositional environment for

the dark gray lithofacies of the Eudora shale supports the depositional model proposed by Heckel (1977) for black shale deposition and the deposition of Kansas cyclothems. This model states that the Kansas cyclothems are the result of a single transgressive-regressive event with black shale deposition occurring during maximum transgression.

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APPENDIX

SELECTED SYSTEMATIC PALEONTOLOGY

APPENDIX A

SELECTED SYSTEMATIC PALEONTOLOGY

A NEW OCCURRENCE OF HYOLITHS FROM THE MISSOURIAN OF KANSAS

Abstract. The recovery of fifty-five specimens of hyoliths from the Missourian (Upper Pennsylvanian) Eudora Shale Member of the Stanton Formation in southeastern Kansas constitutes the first known occurrence of hyoliths from Pennsylvanian strata in North America. The specimens are preserved as pyritized internal molds which impedes precise generic determination; however, the cross-sectional shape and the pattern of ornamentation indicate that these specimens are a new species within the genus Hyolithes. The name Hyolithes wilsoni is proposed. These hyoliths were recovered from the dark gray shale lithofacies of the Eudora shale in which certain molluscs, such as the ammonoids, are known to be juvenile on the basis of sutural configuration. This suggests that all molluscs from this unit, including the hyoliths, are immature as well.

INTRODUCTION

Hyolith occurrences become progressively less frequent in strata of Upper Paleozoic age. Hyoliths are

known from six Mississippian localities and one Permian locality in North America (Yochelson and Saunders, 1967). Additional reports of hyoliths from Europe and Australia include three from strata referred to as Carboniferous and not differentiated into Mississippian or Pennsylvanian, and three Permian occurrences in Europe and Australia (Sinclair, 1946; Fisher, 1962; Downie, et al. , 1967). The discovery of hyoliths in Missourian (Upper Pennsylvanian) strata in the Mid-Continent region of North America constitutes the first known hyolith occurrence from Pennsylvanian strata in this region and possibly the world.

The stratigraphic horizon which has yielded the hyoliths is the Missourian (Upper Pennsylvanian) Eudora Shale Member of the Stanton Formation in southeastern Kansas. The hyoliths were initially discovered by R.H. Mapes while sampling the Eudora shale to determine its bactritoid cephalopod content. Later, additional specimens were recovered by J.M. Malinky during sample collection for a study of the depositional environment of this stratigraphic unit. All hyoliths were recovered from the upper dark gray lithofacies of the Eudora shale at this locality (Malinky, 1980). Associated faunal groups include abundant and diverse ammonoids, bactritoids, bivalves, gastropods and foraminifera and less commonly occurring scaphopods, brachiopods, bryozoa and echinoderms. Additionally, an abundant and diverse flora is known from this locality

(Malinky, 1980). All molluscan fossils from this locality, including the hyoliths, are preserved as pyritized internal molds.

The lack of a well preserved test on the hyolith specimens precludes easy comparison of genera which have been assigned to this family. Thus, the specimens are assigned to Hyolithes with reservations. However, several morphologic features on the internal mold are distinctive, and on that basis, the name Hyolithes wilsoni n. sp. is proposed. The internal molds of this taxon exhibit an array of morphologic features and the procurement of well preserved specimens possessing tests may demonstrate that the specimens assigned to H. wilsoni actually constitute several new genera and species.

SYSTEMATIC PALEONTOLOGY

Phylum MOLLUSCA

Class HYOLITHA Marek, 1963 and Marek and Yochelson, 1964

Family HYOLITHIDAE Nicholson, 1872

Genus HYOLITHES Eichwald, 1840

Discussion. The assignment of H. wilsoni to the genus Hyolithes based primarily upon the absence of cuts on the lips of the ventral face. The lack of a well preserved test, as well as the generally poor preservation associated with pyritization, prevent a more precise taxonomic determination. Precise generic identification is further impeded by the fact that Hyolithes is defined to include a wide array of cross-sectional shapes and other morphologic features which overlap with other genera (Fisher, 1962). For example, H. wilsoni possesses noticeable lips and a subtriangular cross-section which have also been observed within the genus Linevitus. This genus differs from Hyolithes to the extent that it has been assigned to the family Sulcavitidae by Syssoiev (1958). Linevitus is differentiated from Hyolithes by small cuts on the lipped ventral face which have not been observed in H. wilsoni. The absence of these cuts may either be a taxonomic characteristic or a preservational artifact.

The variations in curvature, as well as differences in cross-sectional shape among the specimens assigned to H. wilsoni may indicate several genera and species among specimens referred to this taxon. Until well preserved specimens are procured, the assignment of this species to Hyolithes seems most appropriate at this time.

The extremely low frequency at which hyoliths are recovered from Upper Pennsylvanian strata results in an

uncertain age range for this taxon. Fisher (1962) reports that hyoliths occur in strata ranging in age from Lower Cambrian to Middle Permian. However, a specimen tentatively identified as a hyolith has been reported from the Upper Productus Limestone in the Salt Range of India (Waagen, 1880). Should this specimen prove to be a hyolith, this occurrence will extend the age range for this group into the Upper Permian (Downie, et al. , 1967).

Hyoliths have been reported twice from post-Paleozoic strata. One occurrence, from a supposed Triassic unit in Austria (Gugenberger, 1934) has been shown to be Permian aged (Fisher, 1962). An occurrence of hyoliths from Miocene strata in Libya (Chiesa, 1931) is now considered doubtful (Fisher, 1931).

Six Mississippian hyolith occurrences have been reported in the North America. These include H. carbonaria (Walcott, 1884) from Eureka County, Nevada and H. parvulus Girty (1926) from San Saba County, Texas. Other hyoliths recovered include H. aculeatus (Hall), discovered in 1860 in the "Goniatite Limestone" near Rockford, Indiana and later discovered in the Marshall Formation in Hillsdale, Michigan (Winchell, 1862, 1865) and H. lancelotus Miller (1894) from a locality in Missouri. The most recent hyolith occurrence from Mississippian strata is the discovery of H. waverliensis Hyde (1953) from the Byer Member of the Logan Formation near Sciotoville, Ohio.

Three hyolith occurrences are known from Carboniferous strata in Europe. These include H. roemeri Koenen (1879) from Germany, H. sicala Koninck (1883) from Belgium and H. sturi Klebelsberg (1912) from Austria. The strata which have yielded the hyoliths has not been differentiated into Mississippian or Pennsylvanian, therfore it is not known whether one or more of these hyoliths actually occurs in Pennsylvanian strata.

A single Permian hyolith has been recovered in the United States. This hyolith, referred to as Hyolithes sp., was discovered in the Leonard Bone Springs Limestone in Texas (Fisher, 1962). Other Permian hyolith occurrences include H. kirkbyi (Howse, 1857) from the "Magnesian Limestone Series" in Great Britain, H. richteri Geinitz (1861) from the Lower Zechstein in Germany and H. lancelotus (Morris, 1845) from New South Wales, Australia. A fossil presumed to be a hyolith has been recovered from the Upper Productus Limestone in India and may constitute the final occurrence of this taxon.

HYOLITHES WILSONI n. sp.

Plate 1

Diagnosis. Hyolithes wilsoni is distinguished by a subtriangular cross-section and transverse lirae on the dorsal face (Fig. 1).

Description. All species within the genus Hyolithes possess a strongly projecting lipped ventral face with cross-sections of variable shape. Hyolithes wilsoni is distinguished by its subtriangular cross-section and pattern of ornamentation which includes closely spaced transverse lirae confined to a triangular area on the dorsal face.

The holotype of H. wilsoni (SUI 40045) consists of a pyritzed internal mold approximately 10 mm. long with an apical angle of 11 degrees. The holotype is well preserved retaining an operculum and ornamentation. Hyolithes wilsoni is known from fifty-four specimens in addition to the holotype. All specimens occur as internal molds and many lack the adoral and apical margins. Two specimens retain fragments of an operculum which appears to have slipped during fossilization and now is preserved at a wide angle to the rest of the specimen. The conch of H. wilsoni is broadly convex to flat on the ventral face and narrowly rounded on the dorsal face. The point of maximum curvature on the dorsal face is marked by an elevated ridge which spans the length of the specimen and coincides with the plane of bilateral symmetry. The flanks of the dorsal face adjacent to the elevated area are slightly inflated. As a result, the cross-sectional shape is subtriangular. The point of intersection of the dorsal ridge and the aperature is marked by a small furrow along the margin of the aperature. The ventral face is strongly lipped. On the

ventral face, H. wilsoni possesses two longitudinal grooves which become less prominent toward the apex. The apex of several specimens appears to curve dorsally; this may be a preservational artifact or a slightly greater expression of the logarithmic curvature all hyoliths are thought to possess (Marek and Yochelson, 1976) This feature may be taxonomically significant. Hyolithes wilsoni possesses a well defined ornament on the dorsal and ventral faces. The dorsal face contains prominent transverse lirae which occupy a triangular area with the apex of the triangle pointing toward the apex of the specimen. These lirae are closely spaced with a centrally located sinus on the dorsal ridge. Several specimens possess lirae on the ventral face adjacent to the aperature. The presence of these lirae on only a few specoimens may be a preservational artifact or possibly a taxonomic characteristic (Fig. 2). The triangular area extends for three-quarters the length of the specimen. The remainder of the specimen is covered by matted ornamentation.

The holotype of H. wilsoni retains most of an operculum. The operculum is sub-triangular in shape and contains fine growth lines parallelling the edge.

Discussion. Hyoliths are believed to exhibit a preference for environments associated with argillaceous facies (Fisher, 1962). H. wilsoni occurs in the dark gray shale

facies of the Eudora shale which is thought to have originated a low oxygen, offshore marine environment (Malinky, 1980). A synecological analysis of the fauna from this unit suggests that all molluscs, including the hyoliths, during early ontogeny, floated or swam into this oxygen poor area from an adjacent, more oxygenated region, and were than killed by the oxygen poor water (Malinky, 1980). This interpretation is supported by the fact that many ammonoids possess sutures which do not reflect sutural configurations on more mature specimens from localities of similar age. This indicates that the ammonoids, and probably all other molluscs including the hyoliths, are immature.

The immaturity of the hyoliths is further supported by the absence of muscle scars on the internal mold. We believe muscle scars to be a mature modification as they have been observed on larger and presumably more mature specimens from other localities. The absence of muscle scars on all specimens from the Eudora shale is most likely an indication of immaturity rather than a preservational artifact as muscle scars have not been observed on any of the 55 specimens. The occurrence of numerous, juvenile hyoliths in association with other juvenile molluscs in a dark gray shale indicate that hyoliths probably experience a planktonic mode of life during early ontogeny, followed by a benthic life mode as an adult, as suggested by Marek and Galle (1976).

The taxonomic status of the hyoliths, as well as their mode of life, is controversial. Some authorities refer hyoliths to the Mollusca (Marek and Yochelson, 1964, 1976) whereas others assign them to a new phylum: Hyolitha (Runnegar, et al., 1975; Runnegar, 1980). The transverse lirae on H. wilsoni closely resembles the runzelschicht, or wrinkled layer, characteristic of many ammonoid cephalopods (House, 1971, Plate 1, Fig. 4 and Plate 2, Fig. 6; Tozer, 1972, Plate 124, Figs. 7 and 8 and Plate 127, Fig. 3). The presence of this feature on the hyoliths suggests molluscan affinities for this group.

Locality. Hyolithes wilsoni has been recovered from the Eudora Shale member of the Stanton Formation in a quarry 2.7 km. (1.7 mi.) northeast of Tyro, Montgomery County, in southeastern Kansas (Fig. 3). The quarry is located in the NE1/4, SE1/4, sec. 30, T34S, R15E in the Tyro Quadrangle, and is accessible from an unimproved section road leading east from the main road connecting the communities of Tyro and Bolton, Kansas.

Etymology. Hyolithes wilsoni is named in honor of Mr. Robert Wilson, the landowner who kindly permitted us access to the Eudora shale exposure on his property. The species is named for him in recognition of his commitment to the advancement of higher education within the geological sciences.

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Fig. 13 Cross-section and Diagrammatic View of Ornament on Hyolithes wilsoni (SUI 40045)

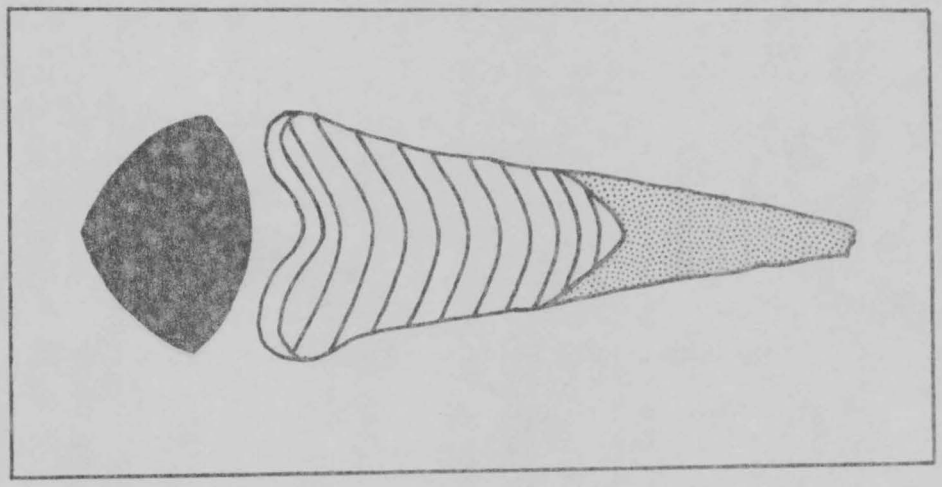


Fig. 14 Scanning Electron Photo-micrograph of Transverse Ornament on *Hyolithes wilsoni* (SUI 40045).

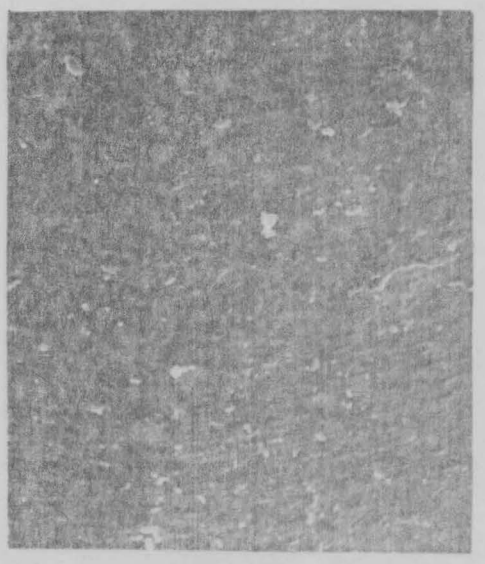
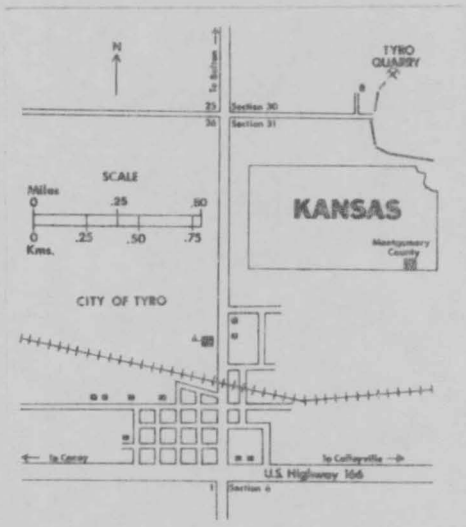


Fig. 15 Map of Hyolith Locality near Tyro, Kansas.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EXPLANATION OF PLATE 1

All specimens are Hyolithes wilsoni recovered from the Eudora shale near Tyro, Kansas. The magnification on each specimen is 30x, with the exception of Fig. 8, which is magnified at 100x.

Fig. 1 Oblique view of SUI 40054 showing lipped dorsal and ventral faces and prominent shelf on ventral face (right side of specimen.)

Fig. 2 Dorsal view of SUI 40057.

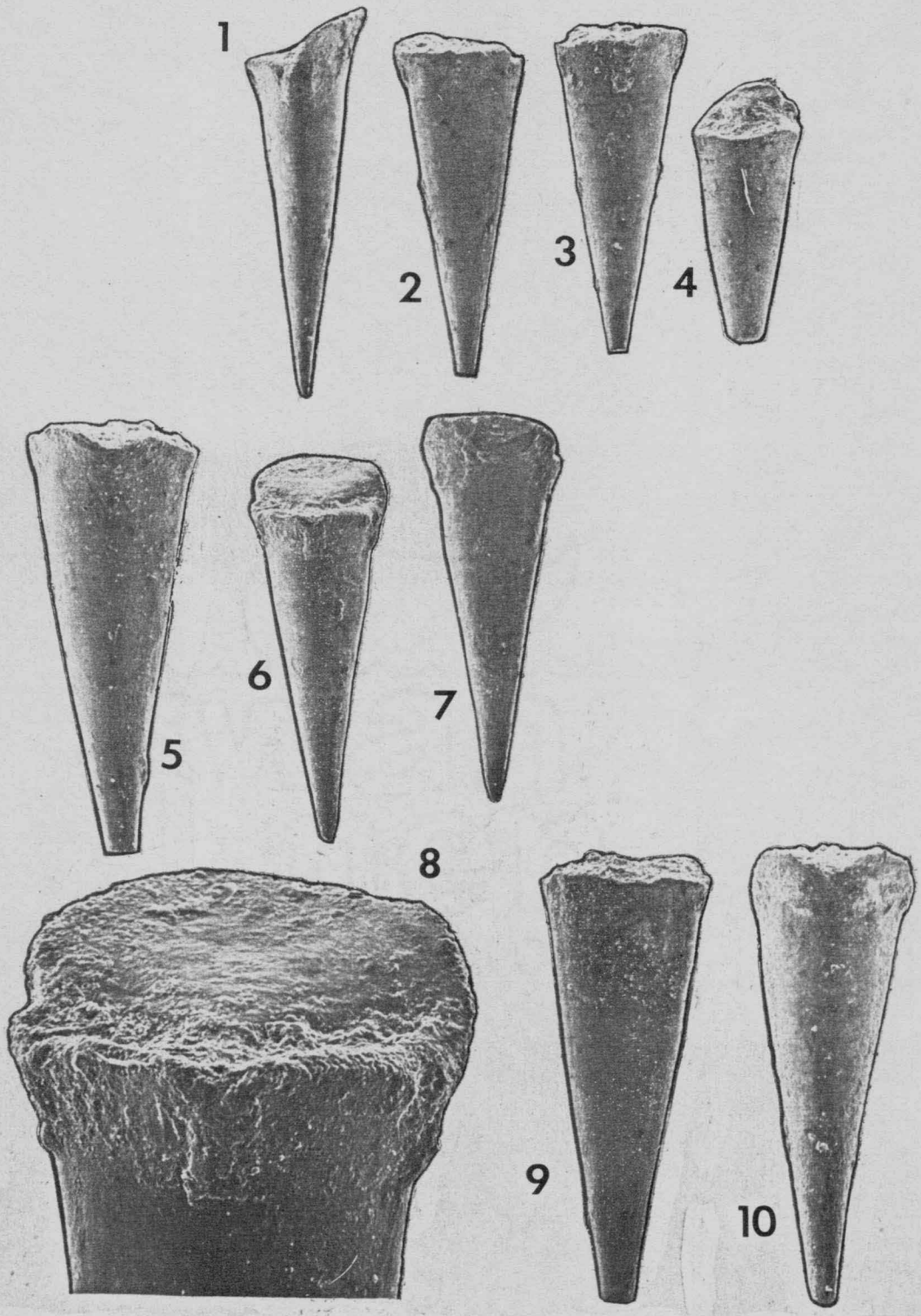
Fig. 3 Dorsal face of SUI 40058.

Fig. 4 Dorsal face of SUI 40056.

Fig. 5, 10. Dorsal view of SUI 40045 showing furrow at junction of aperature and dorsal ridge.

Fig. 6, 7,8 Holotype SUI 40045 with operculum showing dorsal, ventral and enlarged dorsal views respectively.

Fig. 9 Dorsal face of SUI 40059.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