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PALEOBIOLOGY AND PALEOECOLOGY OF CRINOIDS FROM THE LOWER STANTON FORMATION (LATE PENNSYLVANIAN, MISSOURIAN) OF THE MID-CONTINENT UNITED STATES

by

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PALEOBIOLOGY AND PALEOECOLOGY OF CRINOIDS FROM THE LOWER STANTON FORMATION (LATE PENNSYLVANIAN, MISSOURIAN) OF THE MID-CONTINENT UNITED STATES

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The lower Stanton Formation is a transgressive - regressive unit that is traceable from Nebraska to Oklahoma. Changes in the crinoid assemblages coincide with lateral and vertical facies changes in the lower Stanton Formation. The dominant taxa of the different assemblages have markedly different arm morphologies, reflecting the different feeding strategies used by these crinoids.

Transgressive and early regressive deposits of the basinal terrigenous detrital facies belt are dominated by crinoids with open-mesh filtration fans. The flexibles have extremely open-mesh, non-pinnulate (ramulate) filtration fans, while the sparsely pinnulate *Apographiocrinus* has a rather open-mesh fan for poteriocrines. These crinoids probably utilized the motile-particle capture and

gravitational deposition modes of aerosol filtration.

Assemblages of the early regressive deposits of the northern carbonate shelf are rather diverse. However, they are dominated by poteriocrines with open- and intermediate-mesh, pinnulate filtration fans, such as _Apographiocrinus_ and the Erisocrinacea. These diverse assemblages probably utilized all modes of aerosol filtration.

Assemblages from the late regressive deposits of the terrigenous detrital facies belt are dominated by crinoids with closed-mesh filtration fans. These crinoids include the pirasocrinids and cromyocrinids, which have multiple branching, pinnulate arms. These closed-mesh taxa probably used the inertial impaction and direct interception modes of aerosol filtration.

Transitional assemblages of the terrigenous detrital facies belt are dominated by the diminutive, open-mesh, pinnulate poteriocrines _Exocrinus_ and _Apographiocrinus_. There is also a minor contribution to this assemblage from the ramulate flexibles. Motile-particle capture and gravitational deposition were probably the dominant modes of aerosol filtration.

The poteriocrine Paragassiz_ocrinus_ is restricted to early regressive deposits dominated by deposit-feeding molluscans. Its unique morphology indicates that it may have been a semi-infaunal deposit feeder.

This distribution pattern is consistent with aerosol filtration models proposed for Early Mississippian crinoids. Although the composition of similar assemblages is different between the Mississippian and Pennsylvanian, open- and closed-mesh forms occur in analogous facies.

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INTRODUCTION

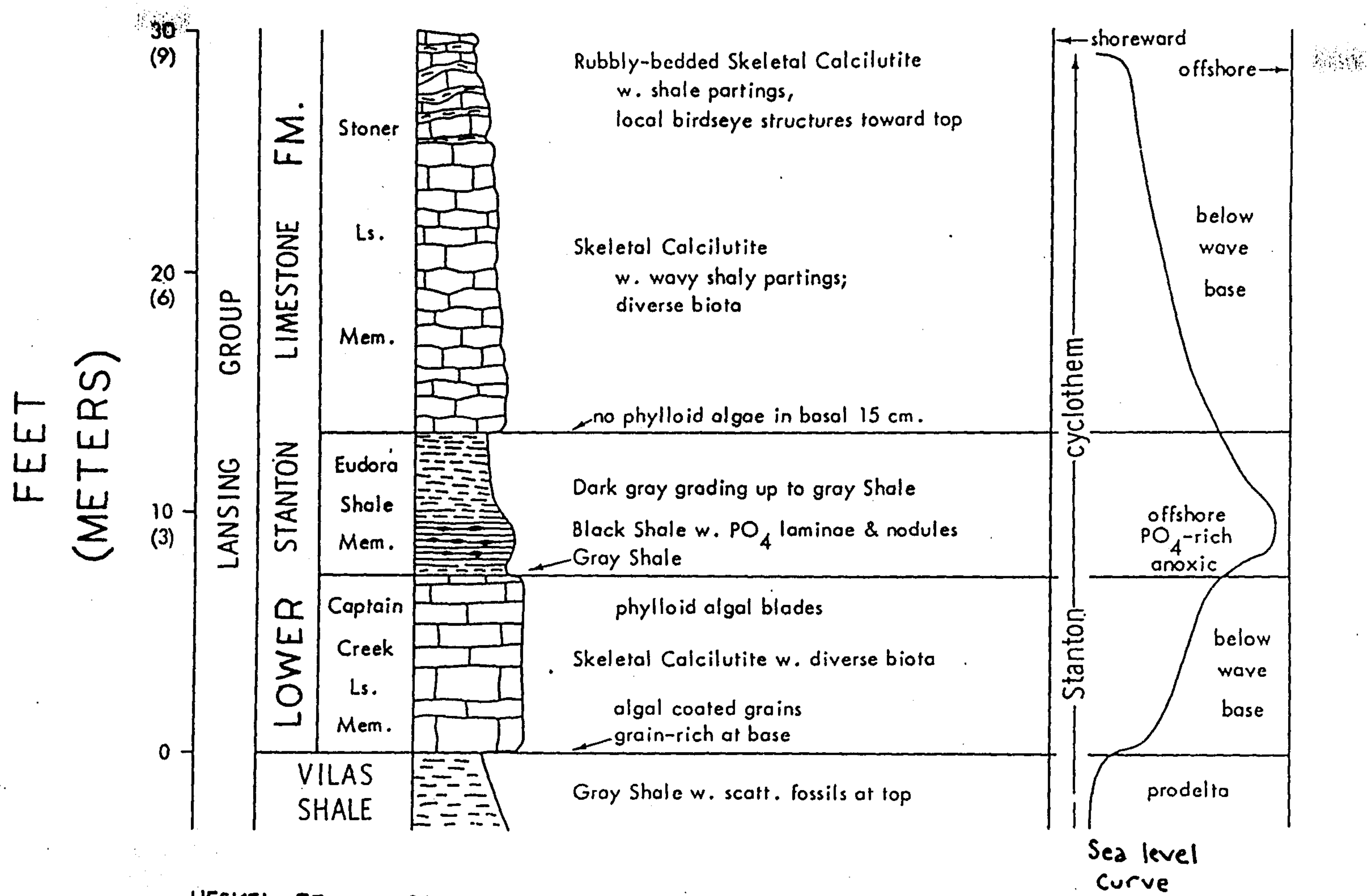
The lower Stanton Formation is composed of three members. In ascending order, these are the Captain Creek Limestone Member, the Eudora Shale Member, and the Stoner Limestone Member (Fig. 1). The Stanton Formation is the highest formation in the Lansing Group, which is the highest group of the Missourian Stage (Fig. 2).

The study area extends along the outcrop belt from the lower Platte River Valley of Cass and Sarpy counties, Nebraska into the Kansas City area of Missouri and Kansas, and into southeastern Kansas and northeastern Oklahoma (Fig. 3). Within the study area, the lower Stanton Formation extends laterally through four major facies belts (Fig. 4). These facies belts reflect the transition from basinal to shelf edge and shelf depositional environments (Heckel and Cocke, 1969; Heckel, 1975).

The lower Stanton Formation represents a single, extensive marine advance and retreat (Fig. 1). Thus the members of the lower Stanton Formation reflect deepening, and later shallowing, marine conditions (Heckel, 1977).

The stratigraphic and depositional framework of the lower Stanton Formation has been extensively studied (Heckel, 1972; 1975; 1975a; 1978; Heckel _et al._, 1979,

Figure 1 - The lower Stanton Formation as developed in the type area of the Captain Creek Limestone and Eudora Shale members near Eudora, Johnson County, Kansas. From Heckel, et al., 1979.

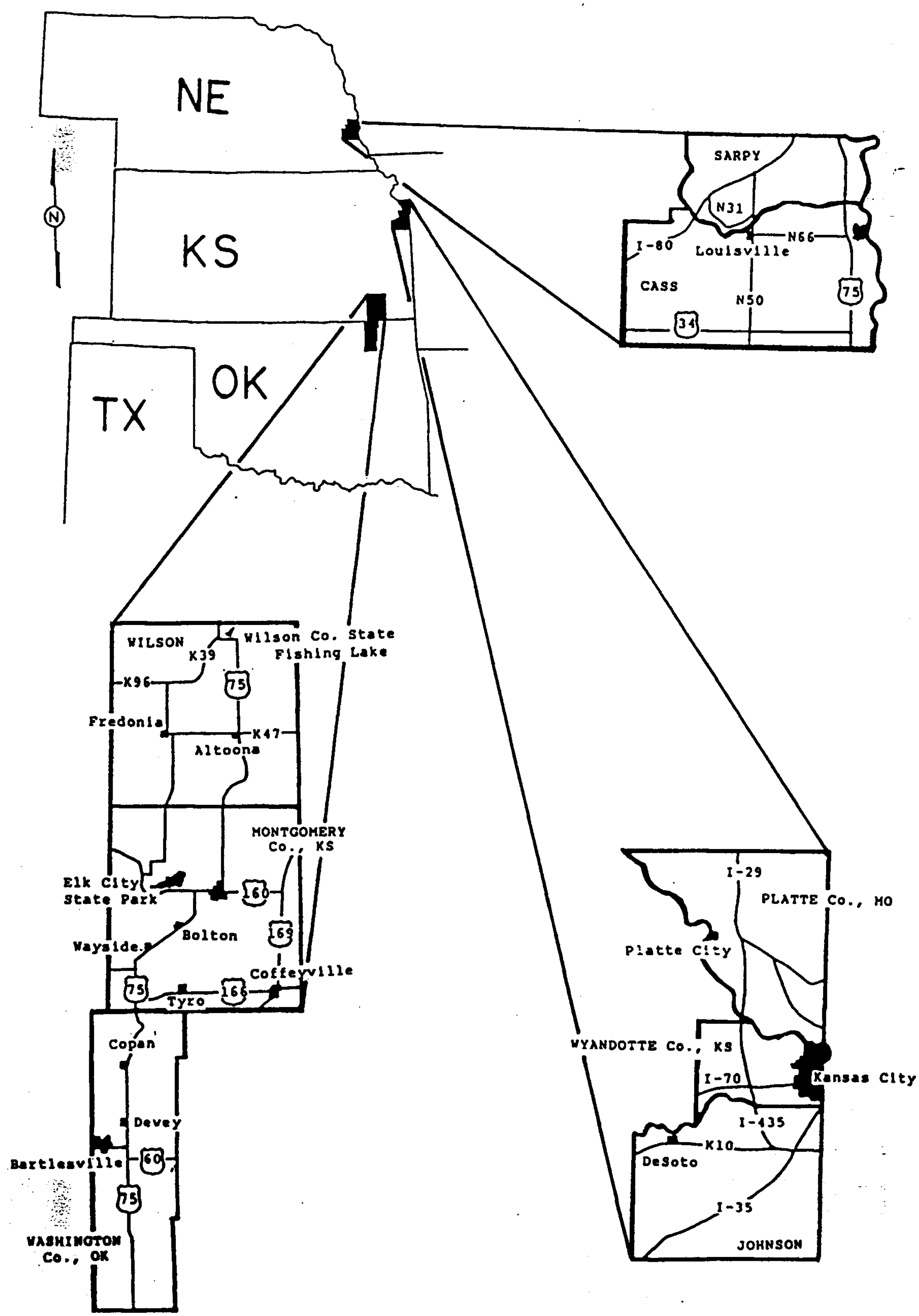


HECKEL ET AL., 1979

Figure 2 - Stratigraphic position of the Stanton and Vilas formations within the Lansing Group of the Missourian Stage.

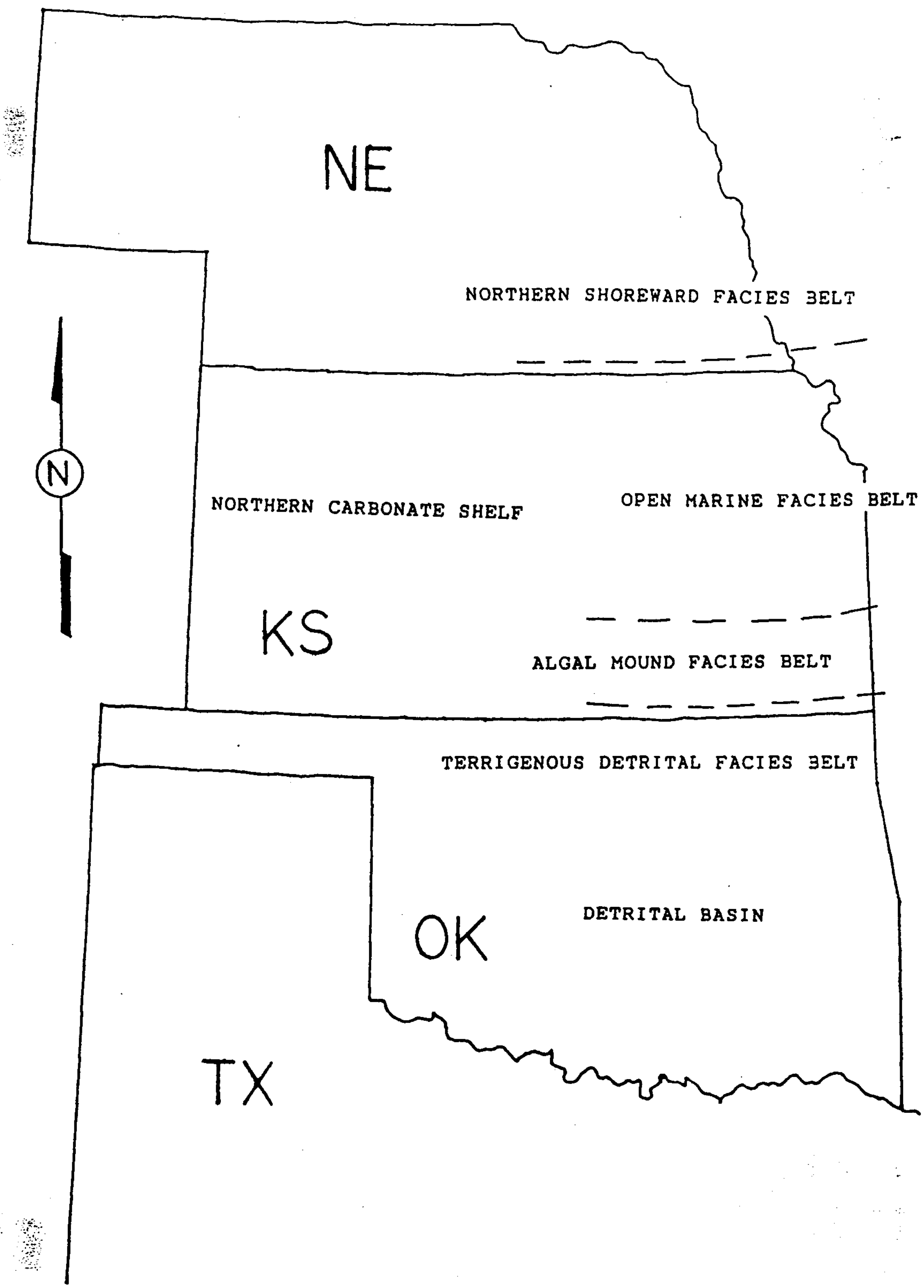
UPPER PENNSYLVANIAN	MISSOURIAN	LANS-ING	Stanton Ls.
			Vilas Sh.
			Plattsburg Ls.
		KANSAS CITY	Bonner Springs Sh.
			Wyandotte Ls.
			Lane Sh.
			Iola Ls.
			Chanute Sh.
			Drum Ls.
			Cherryvale Sh.
			Dennis Ls.
			Galesburg Sh.
			Swope Ls.
			Ladore Sh.
			Hertha Ls.
		PLEAS-ANTON	Tacket Fm.
			Checkerboard Ls.
			Seminole Fm.

Figure 3 - Location of the study area in southeastern Nebraska, northwestern Missouri, northeastern and southeastern Kansas, and northeastern Oklahoma.



NE
KS
OK
TX
N
SARPY
N31
N66
I-80
Louisville
CASS
N50
34
75
WILSON
Wilson Co. State Fishing Lake
K39
K96
75
Fredonia
K47
Altoona
MONTGOMERY Co., KS
Elk City State Park
160
169
Bolton
Wayside
75
Coffeyville
Tyro
166
Copan
Dewey
Bartlesville
60
75
WASHINGTON Co., OK
I-29
PLATTE Co., MO
Platte City
WYANDOTTE Co., KS
I-70
Kansas City
I-435
K10
DeSoto
I-35
JOHNSON

Figure 4 - Facies belts of the mid-continent Missourian.


NE
NORTHERN SHOREWARD FACIES BELT
NORTHERN CARBONATE SHELF
OPEN MARINE FACIES BELT
N
KS
ALGAL MOUND FACIES BELT
TERRIGENOUS DETRITAL FACIES BELT
DETRITAL BASIN
OK
TX

Senich, 1978, Malinky and Mapes, 1982; Mapes, 1987; Burhcett, 1971). Thus the depositional settings of the crinoid-bearing localities are well established, permitting confident interpretations of crinoid feeding behavior during the deposition of the lower Stanton Formation.

Changes in the composition of crinoid assemblages of the lower Stanton Formation coincide with these lateral and vertical facies changes. The dominant taxa of the different assemblages have divergent arm morphologies, which reflects the contrasting feeding strategies used by these crinoids.

<u>Purpose and Procedures</u> - The purpose of this study is to apply current theories of crinoid feeding mechanics (<u>sensu</u> Kammer, 1985) to crinoids of the lower Stanton Formation. It is here proposed that the crinoid assemblages are controlled by water depth related to allogenic, glacio-eustatic transgression and regression. This overriding control is modified by the assemblages' location within the detrital basin or on the carbonate shelf.

The procedures involved first examining existing collections of crinoids from the lower Stanton Formation. This included material at the Department of Geology at the University of Iowa (SUI), the University of Nebraska State Museum (UNSM), and Bartlesville Wesleyan College (BWC).

This material was tallied at the lowest taxonomic level possible. In general, articulated cups and crowns were identifiable to genus, whereas disarticulated calyx ossicles were only identifiable to family. Thus, reference to genus is made when possible, however tables and figures including all the tallied material are at the family level.

Once this was completed, the localities were recollected and the stratigraphic horizon noted to ensure the accuracy of the museum data. Surface collection of specimens was made at each locality. If the locality had not been previously bulk sampled, a large sample was taken. The bulk samples ranged from 100 to 200 lbs., and were washed, sieved, size sorted, and then picked under a binocular microscope to recover minute ossicles and microcrinoids.

Outcrop examination included the measurement of the stratigraphic interval (when possible), notation of the type of enclosing matrix, and location of the stratigraphic position of the producing horizon in relation to key beds.

Through this field investigation and through published reports, the depositional settings of the collected localities were established.

After these preliminary data were collected, statistical tests were performed. These were Q- and R-mode Pearson Correlation analyses, which identify significantly similar localities and families, respectively, and Q- and R-mode multidimensional scaling (MDS) which identifies any significant gradients upon which the data may be distributed.

Finally, the arm morphologies of the dominant crinoids in each assemblage were characterized, and this morphologic and paleoenvironmental information used to infer the modes of aerosol filtration used by these crinoids. Recognizing the inferred feeding strategies utilized by these crinoids facilitates the recognition of subtle differences in paleoenvironments of these localities more so than does gross lithologic and stratigraphic data.

STRATIGRAPHIC FRAMEWORK

Heckel (1968) and Heckel and Cocke (1969) delineated four facies belts for the mid-continent Missourian, which includes the lower Stanton Formation. These facies belts are, from north to south, the northern shoreward facies belt, the open marine facies belt, the algal mound facies belt, and the terrigenous detrital facies belt (Fig. 4). The three northern facies belts constitute the northern carbonate shelf region whereas the southern-most facies belt is the detrital basinal region.

The basin-to-shelf topography in southeastern Kansas is controlled by the development of deltaic lobes during low sea level stands prior to marine inundation (Heckel, 1988). It is thus necessary to examine the non-marine unit underlying the lower Stanton Formation.

Vilas Formation - The nearshore, or outside, shale (sensu Heckel, 1977) underlying the lower Stanton Formation is the Vilas Formation (Figs. 1 and 2). It is dominantly non-marine silty shale with the exception of the upper-most beds, which are marginal marine, calcareous shales, transitional with the overlying Captain Creek Limestone (Appendix II).

In southeastern Kansas, the Vilas Formation ranges from being absent over the Plattsburg algal mounds to being nearly 30m thick between mounds (Heckel, 1978).

Southward, in northern Montgomery County, Kansas, this thickened detrital sequence thins with increased dips toward the south (Heckel, 1975). From this data Heckel (1978) inferred that the Vilas Formation was a clastic wedge prograding to the west and south into the basinal region (Fig. 5). This clastic wedge front - basinal facies transition later defined the shelf edge break of the lower Stanton Formation. Farther south, in the Tyro, Kansas area, a small clastic lobe prograded into this area from the east during deposition of the Vilas Formation (Fig. 5; Heckel, 1975). This small, elogate lobe also affected the distribution of facies during deposition of the lower Stanton Formation.

Captain Creek Limestone - In the northern shoreward facies belt of Nebraska (Fig. 6), the Captain Creek Limestone is a thin skeletal calcilutite (Appendix II, section 1b). It thickens uniformly to 2m of skeletal calcilutite in the open marine facies belt of the Eudora, Kansas area (Fig. 6; Appendix II, section 3). Blue-green (oncolites) and phylloid algae become important allochems in the thick, dense, skeletal calcilutites of this area.

In the Wilson County, Kansas area of the algal mound

Figure 5 - Pre-lower Stanton Formation paleotopography. Note thinning of the clastic wedge in northern Montgomery County, Kansas and the small clastic lobe developed in the Tyro, Kansas area. These features were later accentuated by deposition of the Captain Creek Limestone algal mound complex and the Tyro Oolite body.

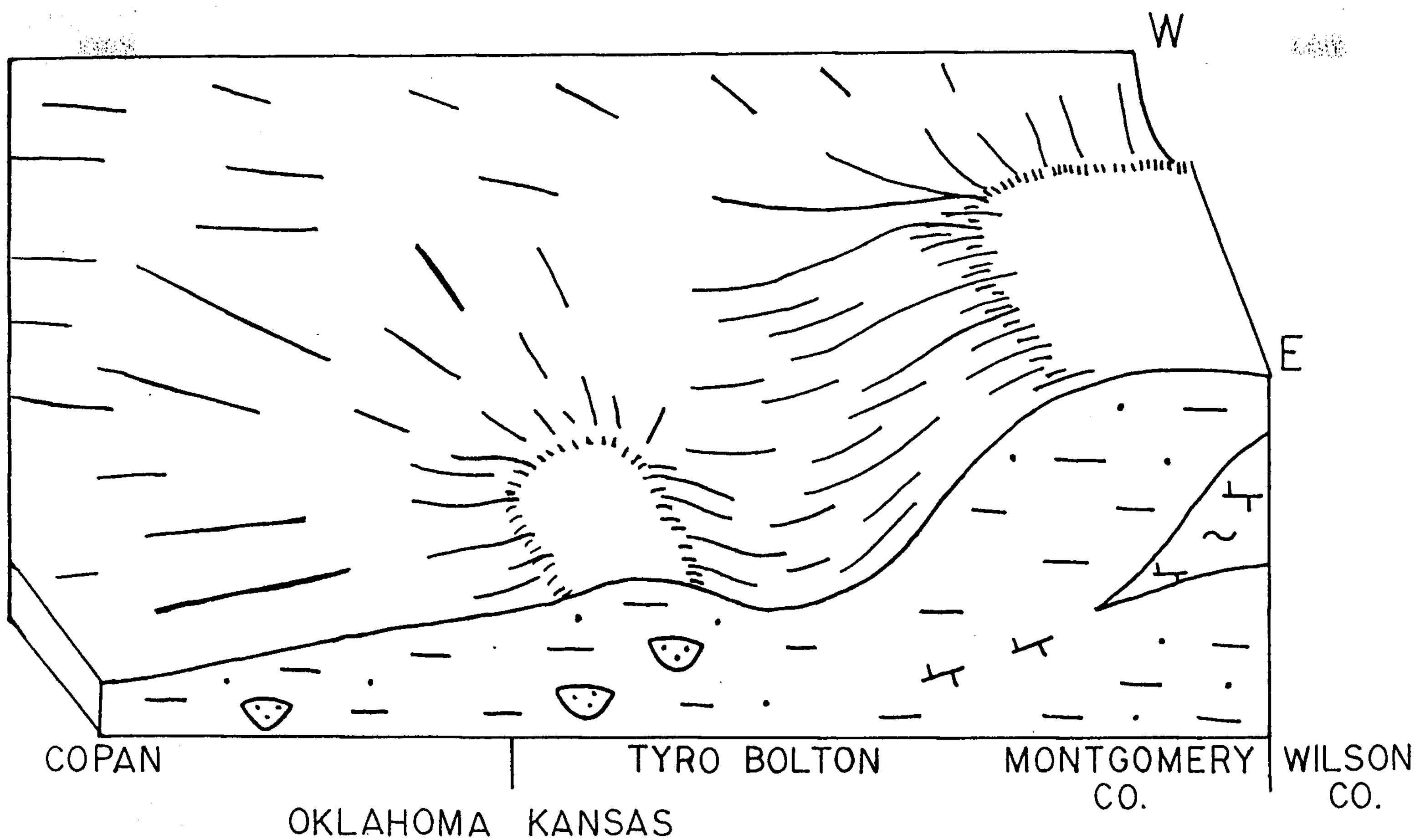
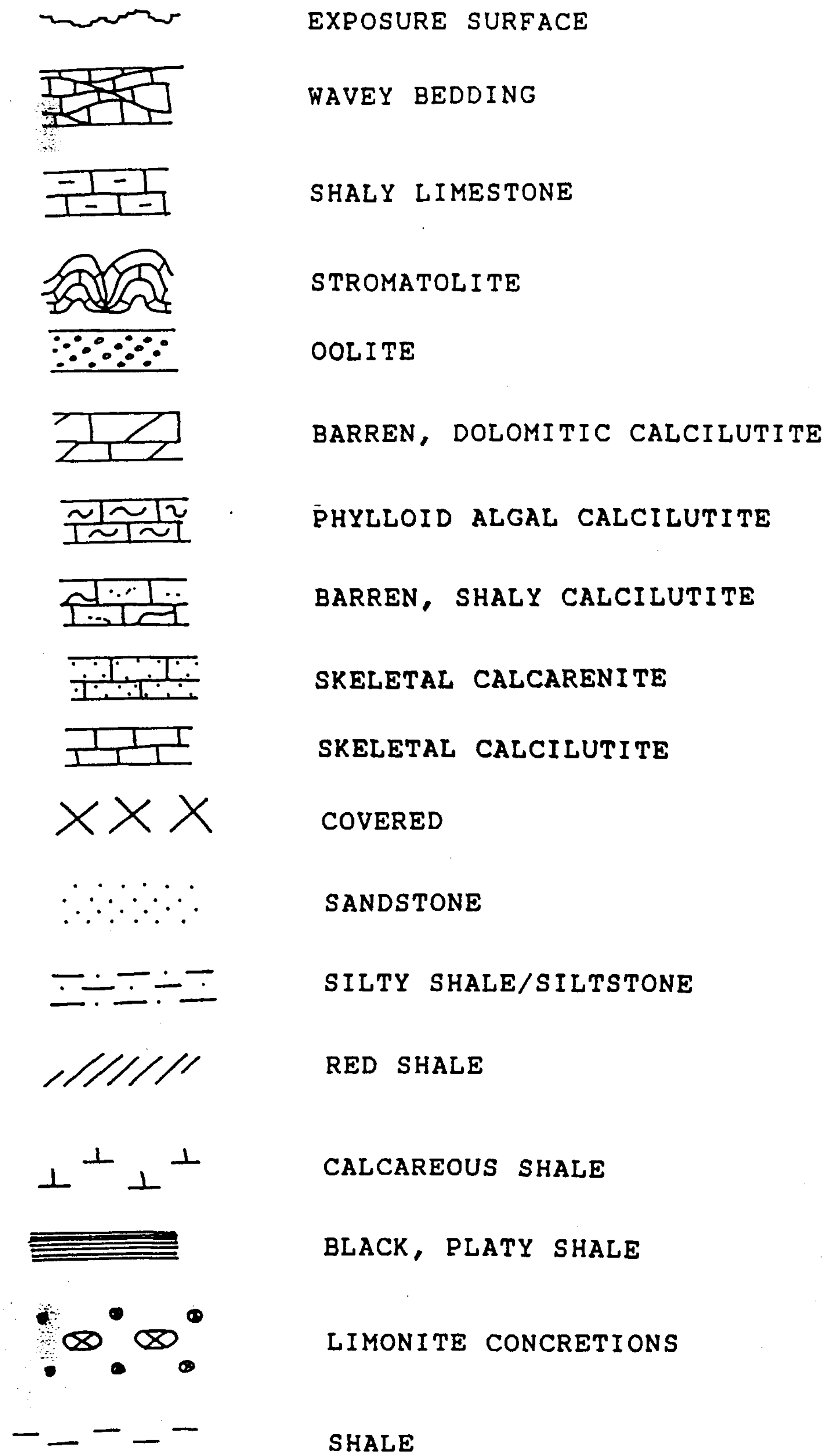
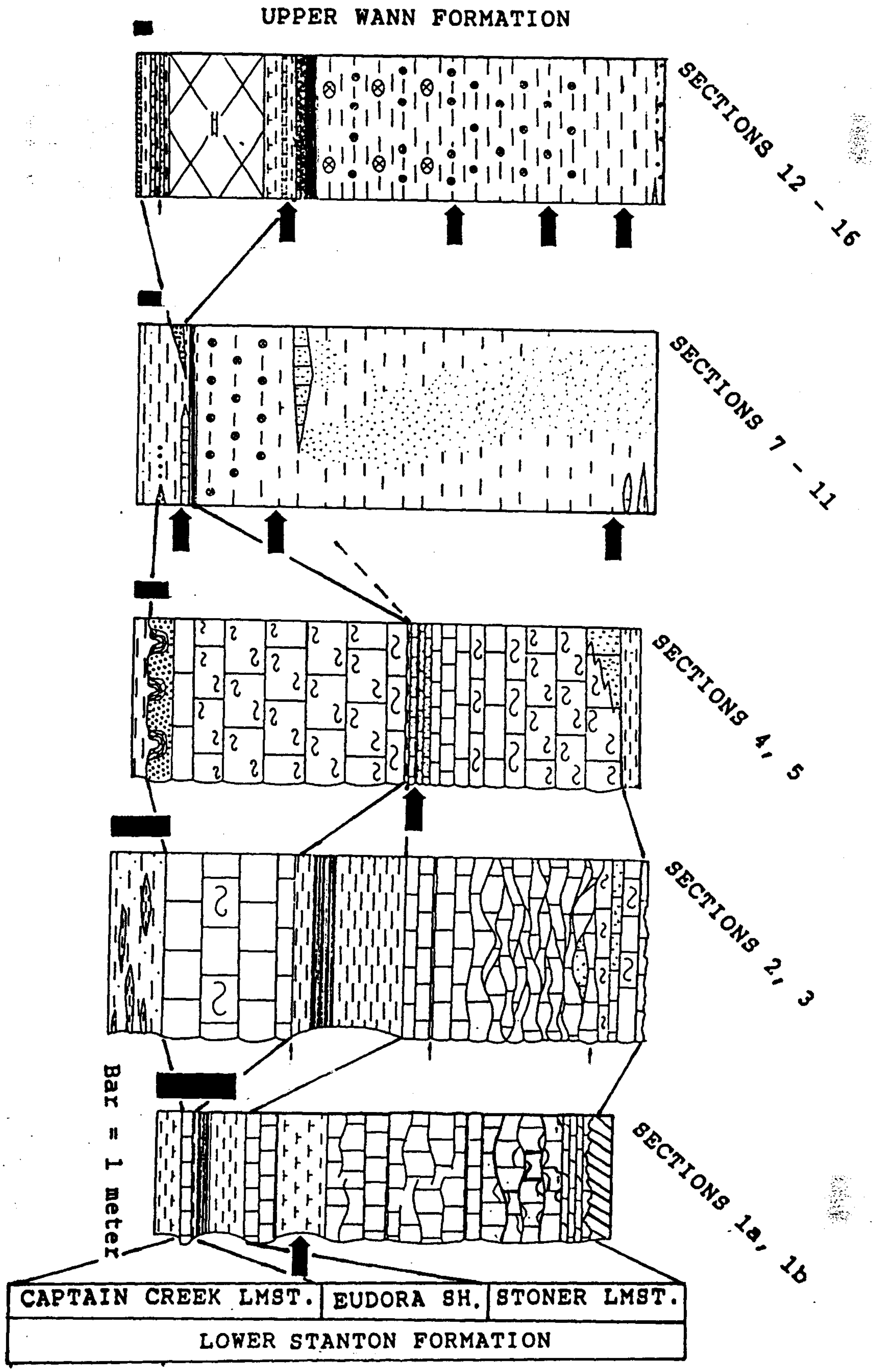

W
E
COPAN
TYRO BOLTON
MONTGOMERY CO.
WILSON CO.
OKLAHOMA KANSAS

Figure 6 - Generalized stratigraphic sections for the different facies belts of the lower Stanton Formation. The large arrows indicate the stratigraphic position of the crinoid localities used in this study, while the small arrows indicate the stratigraphic position of insufficiently large collections of crinoids.

LEGEND


EXPOSURE SURFACE
WAVEY BEDDING
SHALY LIMESTONE
STROMATOLITE
OOLITE
BARREN, DOLOMITIC CALCILUTITE
PHYLLOID ALGAL CALCILUTITE
BARREN, SHALY CALCILUTITE
SKELETAL CALCARENITE
SKELETAL CALCILUTITE
COVERED
SANDSTONE
SILTY SHALE/SILTSTONE
RED SHALE
CALCAREOUS SHALE
BLACK, PLATY SHALE
LIMONITE CONCRETIONS
SHALE



UPPER WANN FORMATION
SECTIONS 12 - 16
SECTIONS 7 - 11
SECTIONS 4, 5
SECTIONS 2, 3
SECTIONS 1a, 1b
Bar = 1 meter
CAPTAIN CREEK LMST.
EUDORA SH.
STONER LMST.
LOWER STANTON FORMATION

facies belt (Fig. 6), the Captain Creek Limestone thickens to 8.3m due to the prolific abundance of phylloid algae (Appendix II, section 4). Shoaling marine domal stromatolites, developed within oolitic limestone, are at the base of the Captain Creek Limestone in this region. In the Elk City State Park area of Montgomery County, Kansas, Heckel (1978) reports 15m of Captain Creek Member algal calcilutite.

Within these algal calcilutites are spar-filled voids that, in places, dominate the rock, producing an algal sparite. These sparites have been interpreted as relict botryoidal submarine aragonite formed in cavities sheltered by phylloid algal blades, analogous to the formation of early, submarine, botryoidal aragonite in cavities of Holocene reefs (Ravn and Heckel, 1978). Ravn and Heckel also state that a fair amount of this spar is neomorphic after micrite. In any case, this algal sparite facies supports the assertion that the Captain Creek Limestone algal mound complex was a prominent topographic feature facing a topographically lower, basinal region (Heckel, 1972; Ravn and Heckel, 1978; Heckel, 1978).

Thinning of the Captain Creek Limestone coincides with the thinning of the underlying Vilas Formation (Fig. 5). In the Elk City State Park area of Montgomery County, Kansas, the Captain Creek Limestone thins from 15m to 1.9m in five miles. With the thinning of both units, the top of the Captain Creek Limestone in the Bolton area is approximately 32m below the top of the Captain Creek Limestone in the dam area of the Elk City State Park (Heckel, 1975, Fig. 4).

Lithologies developed in the Captain Creek Limestone of the terrigenous detrital facies belt of Montgomery County, Kansas (Fig. 6) include two separate oolite bodies (one near Bolton, the other near Tyro), calcareous shales, and sponge-rich calcilutites (Appendix II, sections 8, 9, and 11). The sponge-rich calcilutite, calcareous shale, and the minor, northern, oolite body lie between the algal mound complex of the Elk City State Park and the Wayside area of Montgomery County, Kansas (Heckel, 1975, Fig. 4). South of Wayside, these lithologies pinch out up the rise in the underlying Vilas Formation (Heckel, 1975, Fig. 4). The second oolite body (Tyro Oolite) is developed over the top of this rise in the Vilas Formation (Appendix II, section 11; Heckel, 1975, Fig. 4). Although this unit cannot be traced to the Captain Creek Limestone units of the Bolton - Wayside area, the Eudora Shale Member directly overlies both the sponge-rich calcilutite of the Bolton area and the Tyro Oolite in the Tyro area (Appendix II, sections 8, 9, and 11; Heckel, 1975).

Heckel (1975) has stated that the Tyro Oolite dips steeply to the southwest, with the cross-beds also dipping consistently to the southwest. Ooid size also increases to the southwest. This, in conjunction with the rise in the Vilas Formation thickening to the northeast, led Heckel to infer that ooids forming on a shoal northeast of Tyro were periodically swept downslope into the Tyro area.

Members of the lower Stanton Formation are not formally recognized in the terrigenous detrital facies of Oklahoma. Few studies have been published on the correlation of lower Stanton Formation members with units in the upper Wann Formation. However, a marine unit west of Copan, Washington County, Oklahoma has been correlated to the Captain Creek Limestone of Kansas (Heckel, personal comm.; Fig. 6; Appendix II, section 12).

Eudora Shale - The Eudora Shale in the northern shoreward facies belt of Nebraska (Fig. 6) is composed of a lower thin, black, platy shale overlain by a thicker clay shale (Appendix II, section 1b). Southward, in the open marine facies of the Kansas City - Eudora area (Fig. 6), the Eudora Shale has generally thickened to 1.8m (Appendix II, sections 2 and 3). The lack of benthic invertebrates in the black, platy facies is indicatative of foul bottom conditions (Heckel, 1977). Coincident with this increase in thickness to the south is the appearance of phosphate in the black, platy facies, particularly the abundance of laminar phosphate (Appendix II, section 3).

South into the algal mound facies belt of northern Wilson County, Kansas (Fig. 6), the Eudora Shale has thinned to approximately 6cm (Appendix II, section 4). No black, phosphatic facies is developed over the top of the Captain Creek algal mound complex, however scattered phosphate nodules do occur in the gray, clay shale that is present. Black, platy shale is developed in local lows in the Captain Creek Limestone where the algal mound facies is not developed (Appendix II, section 6). These lows were previously formed in the Vilas Formation; this lower position inhibited development of the thick algal facies which developed along them (Heckel, 1975a, 1978). These lows became the sites of tidal channels during deposition of the Stoner Limestone Member.

South of the algal mound facies, in the terrigenous detrital facies belt of Montgomery County, Kansas (Fig. 6), the Stoner Limestone, which overlies the Eudora Shale, grades into a shale-dominated sequence (Heckel, 1975). Because this Stoner-equivalent shale sequence is considered part of the Eudora Shale, the Eudora Shale thickens greatly (Appendix II, section 7; Heckel, 1975, 1975a).

The black, platy shale facies is developed at the base of the Eudora Shale at all localities in southern Montgomery County, Kansas (Appendix II, sections 8, 9, and 11). The presence of nodular phosphate ranges from common to abundant at these localities, and also at localities in northern Oklahoma (Appendix II, sections 12 and 16).

The Eudora Shale phosphate distribution pattern is consistent with observations made by Kidder (1985) for phosphate distribution in the mid-continent Missourian. Laminar phosphate is most common in the black, platy shale facies of the open marine facies, while nodular phosphate is characteristic of the southern, basinward, black, platy shale facies. Between these two facies, nodular phosphate is developed in gray, clay, shale facies over topographic highs on the northern carbonate shelf.

The gray, clay shale sequence overlying the black, platy, shale facies near the Elk City State Park (Fig. 6), is bounded at the top by the Timber Hill Siltstone Bed. (Appendix II, section 7). Fossiliferous horizons near the top of the Eudora Shale just below this siltstone bed are equivalent to the Stoner Limestone of the northern carbonate shelf (Heckel, 1975).

In the Bolton, Montgomery County, Kansas area, the Bolton Bed defines the top of the Eudora Shale (Fig. 6).

Overlying the black, platy shale is a gray, clay shale sequence with abundant limonite concretions (Appendix II, sections 9, 10, and 11). Bennison (1985) has stated that limonite concretion-bearing shales associated with black, platy shales are characteristic for basinal sequences in the Arkoma Trough, particularly for detritally dominated regressive sequences (Fig. 6).

At Tyro, Montgomery County, Kansas, the Bolton Bed pinches out and the Eudora Shale is combined with the Rock Lake Shale (Appendix II, section 11). At the Tyro Quarry, the black shale unit is unconformably overlain by sandstones of the Rock Lake-Eudora interval (Appendix II, section 11).

South into the terrigenous detrital facies of Oklahoma (Fig. 6), the Eudora Shale is not formally recognized. However, northwest of Dewey, Washington County, Oklahoma a thick, black, platy, phosphatic shale has been identified as the Eudora Shale (Heckel, personal communication, Mapes, 1987; Appendix II, section 16). This is the southern-most confirmed lower Stanton Formation member yet identified. Bennison (1985) indicates that the thickest black, platy shales accumulate in the basinal trough axis. Thus, this area may have been the Arkoma Basin trough axis during deposition of the lower Stanton Formation.

Overlying the black, platy shale is a thick sequence of limonite concretion-bearing clay shales (Fig. 6; Appendix II, sections 13, 14, 15, and 16). At the top of this concretion-bearing shale sequence near Copan, Washington County, Oklahoma, is a concretion-free shale overlain by sandstone (Appendix II, section 14). This concretion-free shale, as well as the upper portion of the concretion-bearing shale, may be equivalent to the Stoner Limestone of the northern carbonate shelf.

Stoner Limestone - In the northern shoreward facies belt of Nebraska (Fig. 6), the Stoner Limestone is composed of skeletal calcilutites and calcareous shale in the lower half and barren calcilutites in the upper half. (Appendix II, sections 1a and 1b). A marked exposure surface with clay-filled fissures and collapse breccias is present at the top of the Stoner Limestone at section 1a (Appendix II).

South in the open marine facies belt of the Kansas City - Eudora area (Fig. 6), the Stoner Limestone is a sequence of skeletal calcilutites (Appendix II, sections 2 and 3). Phylloid algae becomes an important allochem toward the top of the Stoner Limestone at section 3 (Appendix II). Skeletal allochems become smaller up-section and are concentrated enough at some levels to produce fine skeletal calcarenites. An exposure surface is present at the top of the Stoner limestone at section 2, however it is not as pronounced as the surface at section 1a (Appendix II).

In the algal mound facies belt of northern Wilson County, Kansas (Fig. 6), the base of the Stoner Limestone is a calcarenite composed of whole, unabraded fossil allochems (Appendix II, section 4). Heckel (1978) stated that this unit was deposited below the photic zone in normal marine waters, thus the invertebrates proliferated on a bottom free of algal-carbonate mud. This lower unit is overlain by skeletal calcilutite with scattered phylloid algae (Appendix II, section 4). Up-section, the Stoner Limestone gradually becomes a phylloid algal calcilutite (Heckel, 1978).

Calcarenites of highly abraded skeletal allochems are developed within channels in depressions of the underlying units (Appendix II, section 6), and also along the basinward rim of the Stoner Limestone algal mound complex (Appendix II, section 5). Heckel (1972) interpreted these large (1 km x 30 km) channels to be tidal channels developed between mounds. He also cited the rimming calcarenite, as well as early spar cementation, as evidence that the Captain Creek/Stoner algal mound complexes were prominent, wave-resistant features on a shelf margin bordering a basinal region.

South of the Elk City State Park area, the Stoner

Limestone grades into a shale-dominated sequence and is not formally recognized (Heckel, 1975).

Rock Lake Shale - The Rock Lake Shale represents the culmination of regression at the end of the lower Stanton Formation transgression. Diagnostic features include a well developed paleosol horizon in the northern shoreward facies of Nebraska (Joeckel, 1988; Fig. 6; Appendix II, section 1a) and silty, micaceous shale with plant debris in the Kansas City area (Fig. 6; Appendix II, section 2).

In the terrigenous detrital facies of Montgomery County, Kansas and Washington County, Oklahoma (Fig. 6), shallow marine conditions continued through deposition of the Rock Lake-Eudora interval. These marine horizons may be partially equivalent to the Stoner Limestone, as stated earlier. However, a number of sandstone bodies are developed at different horizons within the Rock Lake-Eudora interval (Fig. 6; Heckel, 1975). Moussavi-Harami and Brenner (1984) observed a number of features of deltaic origin and noted that these delta lobes generally prograded to the west. They also noted that shallow marine horizons (i.e. stromatolites, oolitic sandstones, fossiliferous shales) are developed adjacent to sandstone bodies (Appendix II, sections 7 and 14). In addition, they stated that the Eudora-Rock Lake sequence becomes thicker and is shale-dominated southward into Oklahoma (Fig. 6).

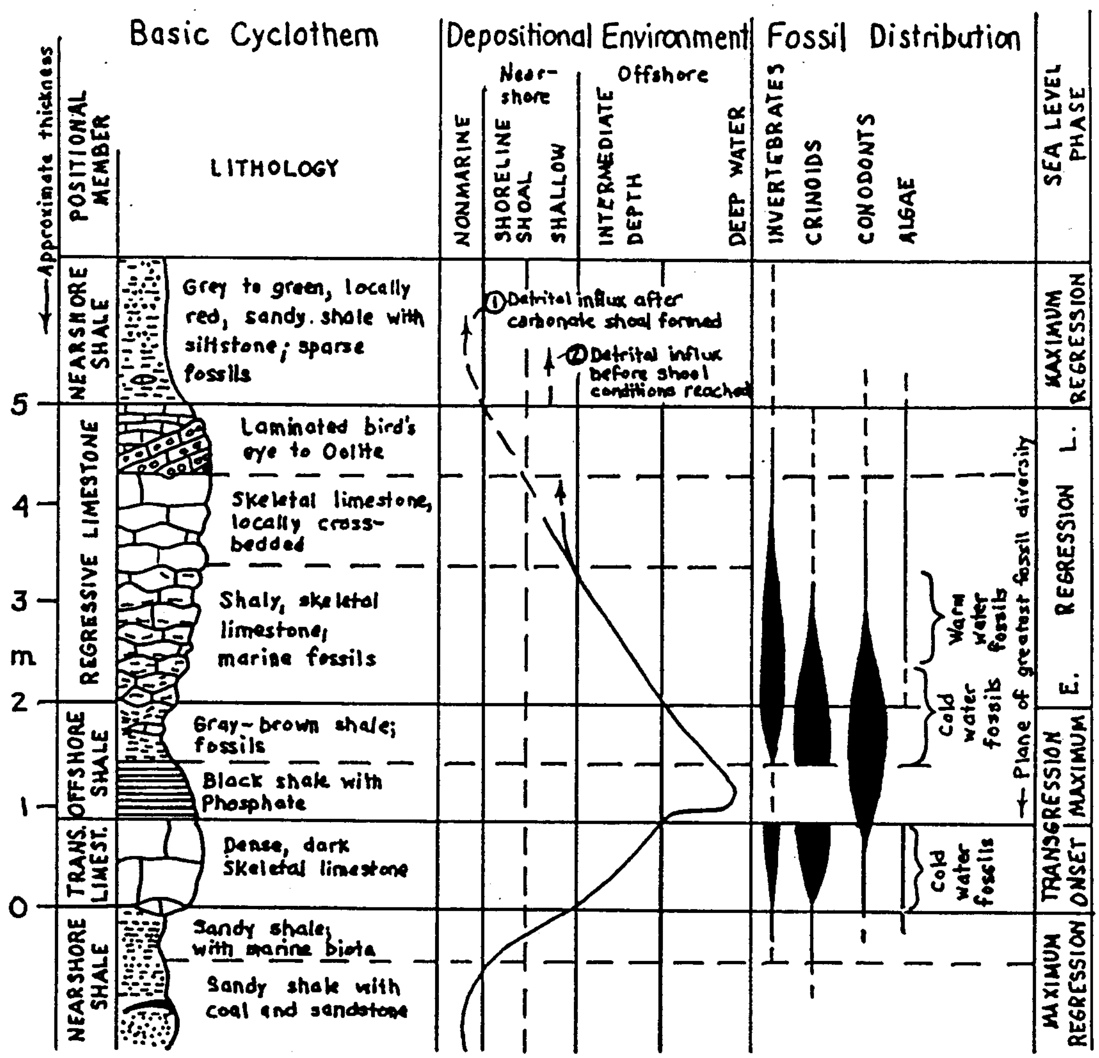
GENERAL PALEOECOLOGY

The lower Stanton Formation is typical of mid-continent Pennsylvanian marine formations in that it is composed of a limestone - black shale - limestone sequence, described by Moore (1936) as a cyclothem. Although the cyclicity of these mid-continent Pennsylvanian units is well documented, the depositional environments of these units, particularly the black, platy shale facies, has been a point of controversy.

The depositional model that best accounts for the faunal and floral distribution in the lower Stanton Formation is the deep marine black shale model proposed by Heckel (1977). In this model, the black, platy shale was deposited at maximum transgression (Fig. 7) and is the core of the cyclothem.

Boardman *et al*. (1984), using the oceanographic model outlined by Heckel (1977), proposed an allogenic faunal succession model for the cyclothems of the mid-continent Pennsylvanian. This model is based on the distribution of molluscans within the thick, detrital basinal sequences of Oklahoma. The sequence of events involved during the deposition of the lower Stanton Formation, based on these models, is enumerated below.

Figure 7 - Typical vertical succession of facies for a Missourian cyclothem on the northern carbonate shelf. Note maximum transgression at the black, phosphatic, platy shale. After Heckel, 1977 and 1978.


Basic Cyclothem
Depositional Environment
Fossil Distribution
Approximate thickness
POSITIONAL MEMBER
LITHOLOGY
Near-shore
Offshore
NONMARINE
SHORELINE SHOAL
SHALLOW
INTERMEDIATE DEPTH
DEEP WATER
INVERTEBRATES
CRINOIDS
CONODONTS
ALGAE
SEA LEVEL PHASE
NEARSHORE SHALE
Grey to green, locally red, sandy shale with siltstone; sparse fossils
1 Detrital influx after carbonate shoal formed
2 Detrital influx before shoal conditions reached
MAXIMUM REGRESSION
REGRESSIVE LIMESTONE
Laminated bird's eye to Oolite
Skeletal limestone, locally cross-bedded
Shaly, skeletal limestone; marine fossils
Warm water fossils
Cold water fossils
Plane of greatest fossil diversity
E. REGRESSION L.
OFFSHORE SHALE
Gray-brown shale; fossils
Black shale with Phosphate
TRANSGRESSION MAXIMUM
TRANS. LIMEST.
Dense, dark Skeletal limestone
ONSET
NEARSHORE SHALE
Sandy shale; with marine biota
Sandy shale with coal and sandstone
MAXIMUM REGRESSION
5
4
3
m
2
1
0

HECKEL, 1978

In these models, the nearshore (outside shale) facies was developed during maximum regression, when the global water budget was tied up as ice on Gondwana. Veevers and Powell (1987) recently bracketed the age of Permo-Carboniferous glacial deposits, and these well-dated tillites greatly support the glacial eustastic model for Pennsylvanian cyclothems. The paleosols and thick ($\pm$30m) clastic sequences of the Vilas Formation are typical of outside shale sequences (Fig. 7).

At the onset of an interglacial interval, rising sea level established marginal to fully marine conditions in the once terrestrial environment. The fossiliferous shales of the upper Vilas Formation, and the oolites and stromatolites at the base of the Captain Creek Limestone were deposited in nearshore marine environments at the onset of rising sea level (Fig. 7).

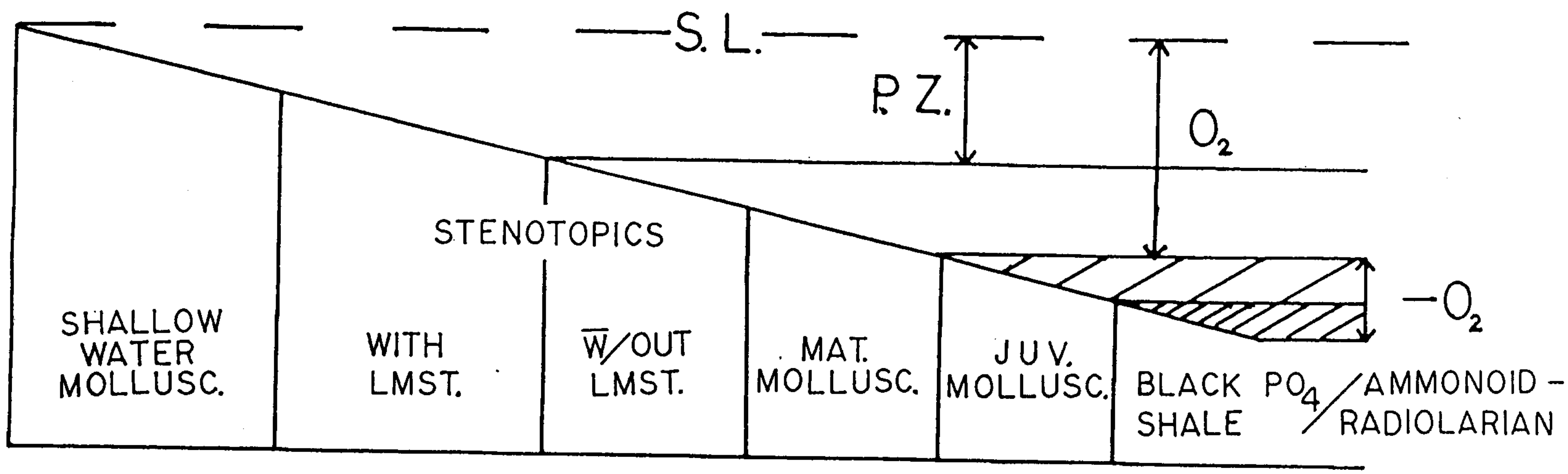
Continued rise in sea level established moderate depth, subtidal marine conditions. The sea floor remained within the photic zone and strong vertical circulation maintained well-oxygenated waters. The dense, skeletal calcilutites of the Captain Creek Limestone, with its diverse biotas and abundant phylloid algae, were deposited in normal, fully marine conditions.

Further deepening of the epicontinental sea dropped the bottom below the photic zone, effectively prohibiting photosynthesis. Algal lime-mud production ceased and fine, suspended detritus was deposited. This aphotic detrital horizon is present on the northern carbonate shelf as a thin, gray, clay shale at the base of the Eudora Shale (Fig. 1). This tall water column became stratified when a thermocline developed at the boundary between cold, oxygen-poor, nutrient-rich basinal waters and warm, oxygenated surface waters. This dysaerobic boundary zone restricted the fauna to eurytopic benthic and nektobenthic molluscans (Figs. 8 and 9). Limonite preservation after pyrite is prevalent in this facies. This restricted, limonitized, late transgressive fauna is found at the base of the Eudora Shale at locality I (Appendix I; Malinky and Mapes, 1982).

Maximum transgression was achieved at the height of the interglacial period on Gondwana. The stratified water column produced anoxic conditions over the entire mid-continent region. The distinctive black, platy shale of the Eudora Shale was deposited at this time (Figs. 1, 7, and 8). Although true benthic marine invertebrates are absent in this black, platy shale facies, planktonic, nektonic, nektobentic, and epiplanktonic invertebrates, nektonic vertebrates, and nekroplanktonic flora can be very common in

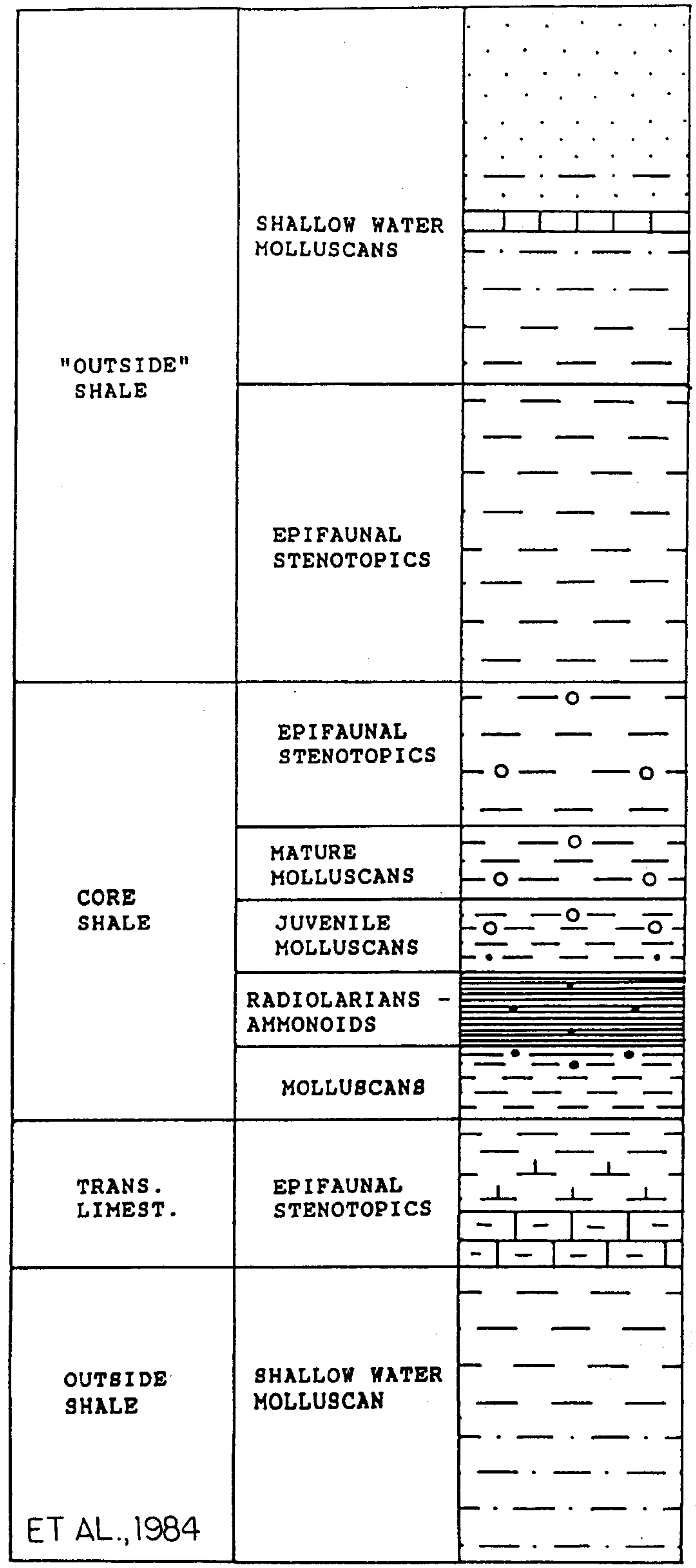
Figure 8 - Lateral development of biofacies and lithofacies controlled by allogenic sea level changes. Deep water molluscan communities are best developed in the terrigenous detrital basinal facies due to the high sedimentation rates enhancing preservation. S.L. - sea level; P.Z. - photic zone; O - oxygenated surface water; -O - reduced oxygen basinal water; MAT. MOLLUSC. - mature molluscan community; JUV. MOLLUSC. - juvenile molluscan community. After Boardman *et al.*, 1984.

DEPTH RELATED COMMUNITY SUCCESSION
IN PENNSYLVANIAN CYCLOTHEMS



BOARDMAN ET AL., 1984

Figure 9 - Vertical succession of biofacies and lithofacies in the detrital basinal region of southeastern-most Kansas and northeastern Oklahoma. This sequence is produced by the lateral migration of facies in Fig. 8 during a single marine advance and retreat. After Boardman *et al.*, 1984.



BOARDMAN ET AL., 1984

this facies. Phosphatic and carbonaceous preservation is characteristic of this black, phosphatic shale.

The presence of inorganic phosphate in the Eudora Shale was the product of nutrient-rich, oxygen-poor basinal water of the Anadarko and Midland basins upwelling up the Arkoma Trough and onto the northern carbonate shelf. Sediment-starved, anoxic conditions were essential to this phosphate accumulation (Heckel, 1977; Kidder, 1985).

The lack of a black, platy facies over the top of the Captain Creek Limestone algal mound complex was due to its elevated position, which kept the tops of the mounds above the anoxic layer. However, the presence of phosphate nodules in the gray clay shale facies indicates dysaerobic, sediment-starved conditions below the photic zone (Heckel, 1978).

At the onset of the next glacial interval, oceanic water began to, once again, be tied up as glacial ice. As sea level began to lower, the dysaerobic layer again began to impinge upon the bottom. Again, limonitized molluscan communities were developed and preserved within the thick basinal sequence of Oklahoma (Figs. 8 and 9). Keaton (1987) reports the presence of this type of molluscan fauna from the Eudora Shale interval at locality G (Appendix I). Senich (1978) also reports this molluscan-dominated community in the limonite concretion-bearing shales of the Eudora Shale at locality F. This phase is preserved as sparsely fossiliferous gray shales on the northern carbonate shelf. This gray shale above the black, platy facies of the Eudora Shale accumulated in virtually sediment starved conditions below the photic zone (Fig. 7).

Continued regression began to break down the stratified circulation system. Aerated surface water began to impinge upon the bottom, allowing benthic invertebrates to recolonize the sea floor. There is a broad transition from deposit-feeding, mollusk dominated communities to epifaunal suspension feeding communities in the Eudora Shale sequence of Oklahoma (Fig. 8 and 9). Shallowing to within the photic zone allowed the proliferation of carbonate mud-producing algae, in addition to the proliferation of benthic invertebrates (Fig. 7). Well sun-lit, shallow marine conditions are indicated by the abundance of phylloid algae and high-energy marine facies - such as the abraded grain calcarenites of the Stoner Limestone in Kansas, as well as low energy shoreline facies - such as the barren calcilutites of the Stoner Limestone in Nebraska.

In the terrigenous detrital facies, deltaic lobes began filling the basin during regression (Moussavi-Harami and Brenner, 1984). Continued regression created a mosaic of marine embayments, prodelta slopes and delta distributary channels.

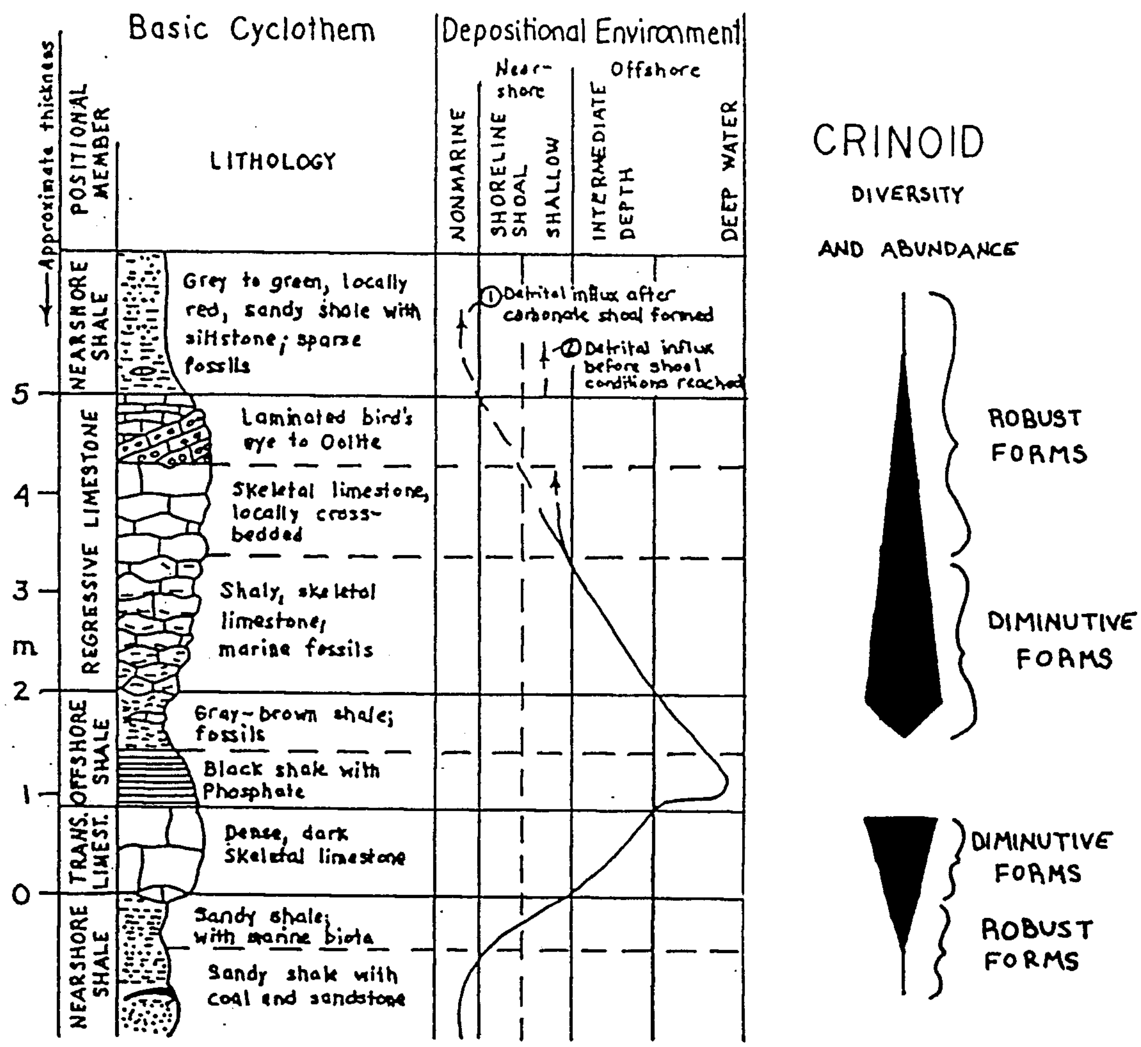
The exposure surfaces and paleosol development at the top of the Stoner Limestone, as well as coarse clastic, high-energy deltaic deposits in the Rock Lake Shale, were probably developed during maximum low-stand at the peak of this interval of Gondwana glaciation.

CRINOID PALEOBIOLOGY AND PALEOECOLOGY

The depth-related oceanographic factors that change during these glacio-eustatic transgressions and regressions have a profound effect on the distribution of crinoids within cyclothems. Pabian and Strimple (1970) noted that there are two distinct types of crinoid assemblages present in Upper Pennsylvanian cyclothems. They stated that diminutive, unornamented crinoids are probably cold water forms, while large, ornamented crinoids are warm water forms.

Heckel and Pabian (1981) integrated this data with the Heckel (1977) cyclothem model. They noted that the assemblages of diminutive crinoids are generally diverse and occur about the core shale. They suggested that this diverse assemblage developed in cold, deep, stable marine conditions near maximum transgression (Fig. 10). The assemblages of large crinoids are typically less diverse and occur at the tops of regressive limestones, within the nearshore shales, and at the base of transgressive limestones. This restricted assemblage of robust crinoids developed in warm, shallow, fluctuating conditions near maximum regression (Fig. 10). Pabian and Strimple (1979) noted that crinoids from the Kiewitz Bed of Nebraska and from the Captain Creek Limestone near Wayside, Kansas are small, deep water forms.

Figure 10 - Crinoid distribution in Late Pennsylvanian cyclothems. See text for discussion.



MODIFIED FROM
HECKEL, 1978

Pabian and Strimple (1977) and later Pabian (1979) noted the lateral variation of crinoid distribution and delineated several crinoid provinces for the mid-continent Pennsylvanian. These included: a *Delocrinus* - *Erisocrinus* province in southeastern Nebraska and southwestern Iowa; a *Delocrinus* - *Erisocrinus* - *Stenopecrinus* province rich in *Cibolocrinus* in Oklahoma and southeastern-most Kansas; a *Delocrinus* - *Erisocrinus* province with a *Lecythiocrinus* component in southeastern Kansas; and a *Stellarocrinus* - *Erisocrinus* province in Illinois.

In this study, these provinces are redefined as assemblages. This is due to the rapid lateral and vertical changes in these provinces (assemblages), which are controlled by glacio-eustatic sea level fluctuations and local topographic features rather than broad latitudinal climatic regimes.

Crinoid functional morphology and crinoid feeding strategies are of fundamental importance to understanding crinoid distribution patterns. Breimer (1969) proposed two general groups of fossil crinoids: rheophobes, or current avoiders, were crinoids that were best adapted to capturing food particles in environments void of any currents, and rheophiles, or current seekers, were crinoids that were best adapted to capturing food particles in environments of active water movement.

Lane and Breimer (1974) and Meyer and Lane (1976) compared the arm morphologies of recent pinnulate crinoids and non-pinnulate basketstars with the arms of pinnulate and non-pinnulate Paleozoic crinoids. Through these analogies, they made inferences about the different feeding strategies used by these fossil forms.

Rubenstein and Koehl (1977) proposed a theory for filter feeding organisms that they derived from studies made by industrial engineers on the removal of particles from waste gases. Aerosol filtration involves the capture of particles smaller than the pores of a filter, therefore sieving, or the capture of particles larger than the filter's pores, is not addressed in this theory. Crinoids in particular cannot feed by sieving because large particles (> pore diameter) would clog the amublacral groove system and the particle could not be ingested (Kammer, 1985).

Rubenstein and Koehl (1977) defined four modes of aerosol filtration particle capture: direct interception, inertial impaction, motile-particle capture, and gravitational deposition. (See Figure 11 for a full explanation of these modes of aerosol filtration). There are current velocity and particle size constraints upon these different modes of aerosol filtration. These relationships

Figure 11 - Modes of particle capture.

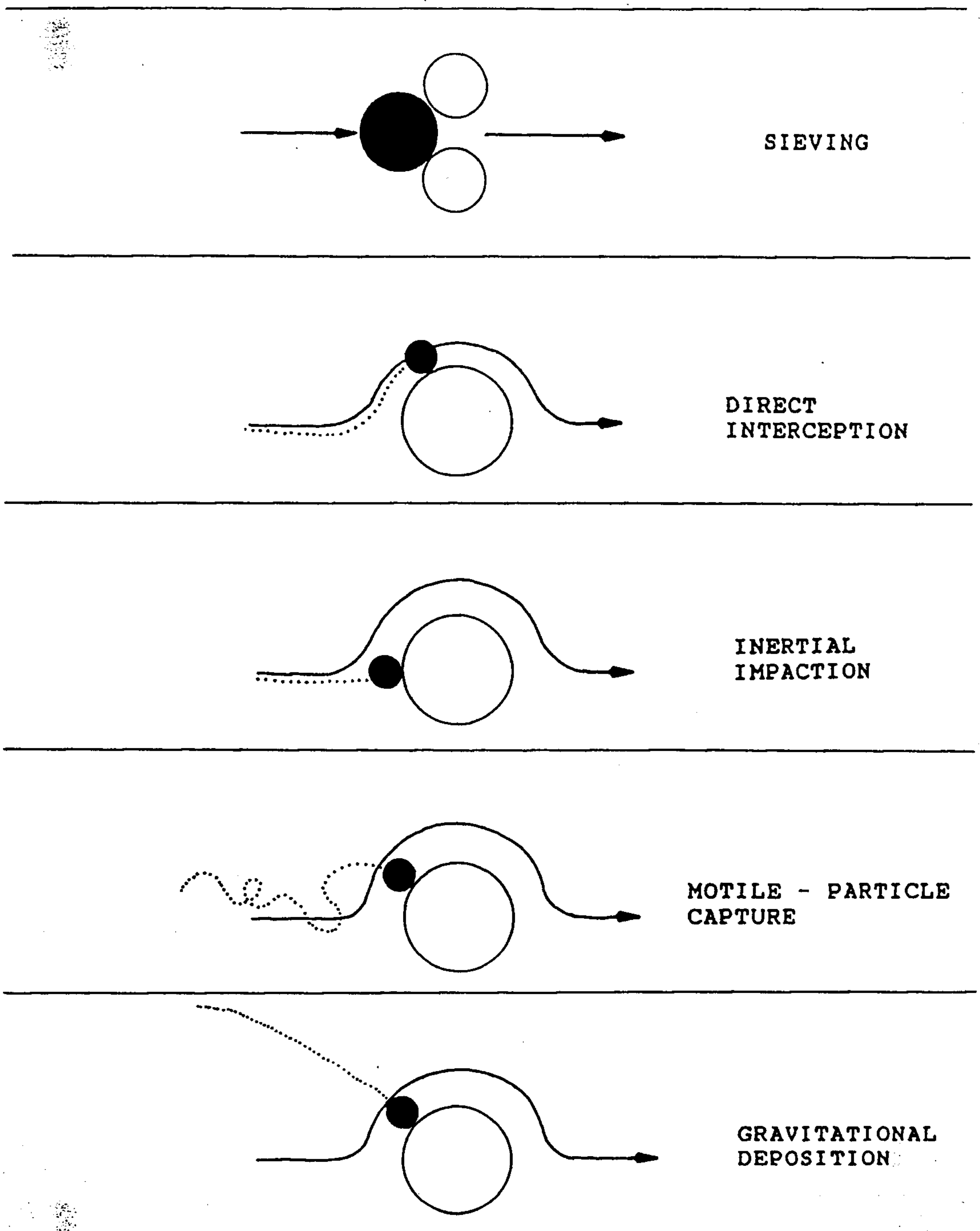
Sieving - capture of particles larger than the filter pores; not a mode of aerosol filtration; see text.

Direct interception - occurs as a neutrally bouyant particle, entrained in flow, is carried into the filter fiber. At no point does the particle separate from the flow as the flow deviates around the fiber.

Inertial impaction - occurs as a particle, entrained in flow, separates from flow as the flow deviates around the filter fiber and the inertia of the particle carries it into the filter fiber.

Motile-particle capture - involves particles (i.e. zooplankton) that are able to deviate randomly from flow. These particles are deposited (captured) on the filter fiber by their own locomotion.

Gravitational deposition - occurs as a particle, falling through a fluid, is deposited upon the filter fiber.



RUBENSTEIN + KOEHL, 1977

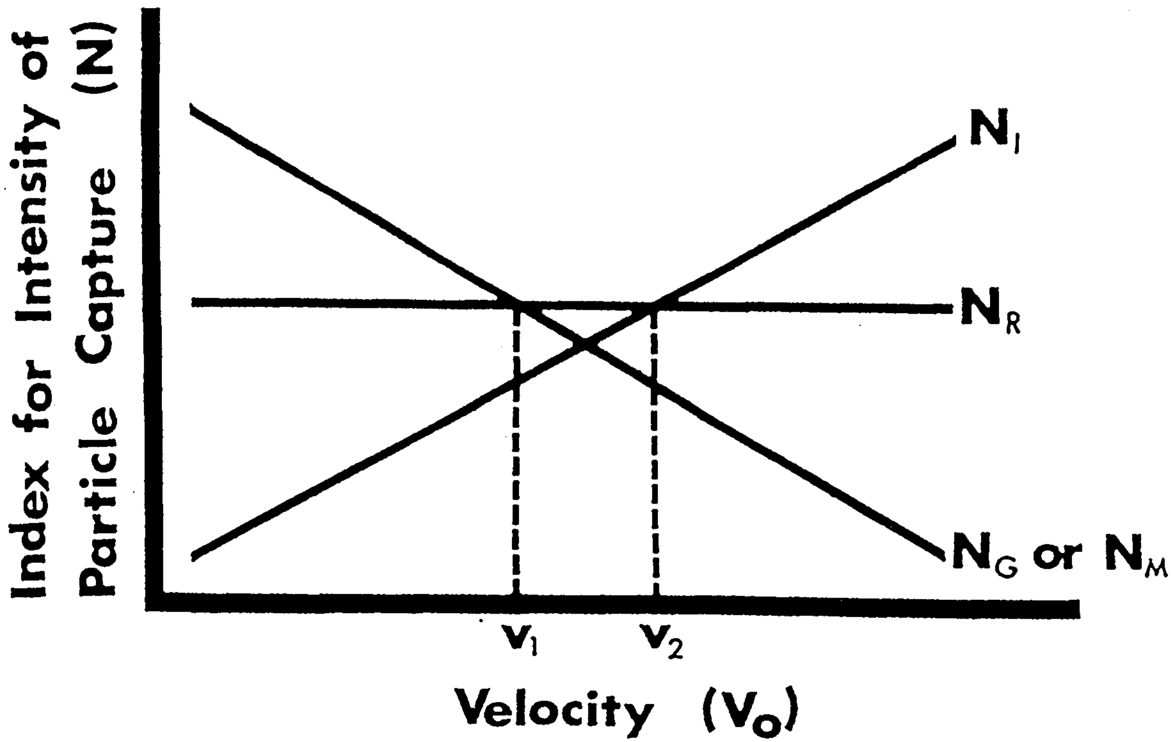
are graphically presented in Figure 12.

Meyer (1979) used this aerosol filtration theory to explain the distribution of modern crinoids on the Great Barrier Reef. He stated that most comasterid crinoids, with fairly open-mesh, pinnulate, filtration fans, feed within the reef framework in slow, multidirectional currents. The widely spaced pinnules and tube feet allow longer residence time for motile particles, thus motile-particle capture is the dominant mode of aerosol filtration feeding. In contrast, non-comasterid crinoids have closed mesh, pinnulate filtration fans and feed on reef promontories in swift, unidirectional currents. The densely packed pinnules and tube feet of these filtration fans probably facilitate inertial impaction and direct interception.

Ausich (1980) evaluated the relationship between filtration fan density and ambulacral groove width for Osagean (Early Mississippian) crinoids. In general, the dense, pinnulate, closed-mesh filtration fans have narrow groove widths, while open-mesh, non-pinnulate filtration fans have wide groove widths. It follows from Meyer's study that these crinoids used different modes of aerosol filtration, and thus fed on different sized particles.

Kammer (1985) applied aerosol filtration theory to the crinoids of the Osagean Borden delta complex studied by

Figure 12 - Comparison of effectiveness of particle capture versus flow velocity. The dimensionless parameter N, representing the intensity of particle capture, is on the vertical axis, while flow velocity is on the horizontal axis. Inertial impaction (Ni) is most effective at high flow velocities for negatively bouyant particles. Direct interception (Nr) is most effective at intermediate flow velocities for neutrally bouyant particles. Motile-particle capture (Nm) and gravitational deposition (Ng) are most effective at low flow velocities for large mobile and immobile particles, respectively



RUBENSTEIN + KOEHL, 1977

Ausich (1980). Within the prodelta facies, non-pinnulate disparid and cyathocrine inadunate crinoids and flexible crinoids are dominant, and probably fed by motile-particle capture and gravitational deposition. Pinnulate camerate and inadunate crinoids are dominant in the distributary, interdistributary, and carbonate bank facies on the delta platform. These crinoids with closed-mesh filtration fans probably utilized inertial impaction and direct interception for feeding.

In summary, crinoids with densely pinnulate, closed-mesh filtration fans (i.e. non-comasterids, camerates, some cladid inadunates) probably fed by inertial impaction and direct interception on small particles in high energy environments. Crinoids with sparsely pinnulate and non-pinnulate filtration fans (i.e. comasterids, disparid and some cladid inadunates, and flexibles) probably fed by motile-particle capture and gravitational deposition on large particles in low energy environments.

Between the Early Mississippian and Late Pennsylvanian, the Crinoidea experienced a great deal of reorganization. As a result, some of the groups of crinoids discussed by Ausich (1980), Kammer (1985), and Kammer and Ausich (1987) for the Osagean were extinct or greatly diminished by the Late Pennsylvanian. One of the greatest of these changes resulted in the virtual absence of the camerates in the mid-continent Late Pennsylvanian. This subclass had been the most prolific group of crinoids during Early Mississippian (Lane, 1971). As a consequence, the facies for which the camerates were most characteristic are populated by different groups by the Late Pennsylvanian. The inadunates also experienced a great deal of change. The disparids and cyathocrines were rather reduced by the Late Pennsylvanian compared to the Early Mississippian (Kammer, 1985). However, the disparid *Kallimorphocrinus* and the cyathocrine *Lecythiocrinus* are important members of some assemblages in the lower Stanton Formation (Tables 1 and 2).

The poteriocrine inadunates became the dominant taxa during the Late Pennsylvanian (Lane, 1971). This group explosively differentiated at lower taxonomic levels to fill niches once filled by the then diminished taxa. For the lower Stanton Formation, minor differences in arm morphologies are significant in the context of feeding strategies and facies distribution.

TABLE 1

RAW FAMILY ABUNDANCE

	NEBR	WCLQ	PHF	US75	COPW	RFP	CE75	E160	TYRO	LTD	UTD
Allagecrinidae	38	5	25	30	273	0	1	0	12	17	0
Codiacrinidae	0	31	14	25	0	0	0	0	0	1	0
Scytalocrinidae	38	8	3	2	3	0	2	3	0	13	2
Blothrocrinidae	74	15	10	4	19	0	1	1	2	4	0
Pelecocrinidae	19	2	7	14	6	0	2	1	0	3	1
Laudonocrinidae	40	45	1	5	3	0	1	0	0	0	1
Stellarocrinidae	8	9	0	0	4	0	5	5	0	34	2
Ampelocrinidae	3	3	0	0	0	0	2	0	0	11	3
Agassizocrinidae	0	0	0	8	0	80	1	0	1	0	0
Cromyocrinidae	32	4	5	0	5	0	1	6	0	2	1
Ulocrinidae	25	8	0	0	0	0	1	0	0	0	1
Erisocrinidae	141	180	35	143	52	0	2	8	7	58	4
Diphuicrinidae	82	8	0	0	13	0	0	14	0	0	0
Catacrinidae	361	77	32	79	10	2	3	17	17	11	2
Apographiocrinidae	277	73	382	159	150	2	11	1	99	275	0
Pirasocrinidae	125	108	1	2	34	0	8	17	0	49	15
Galateacrinidae	0	15	6	7	8	0	0	0	2	16	0
Cymbiocrinidae	11	5	4	0	1	0	1	6	0	7	1
Exocrinidae	32	21	0	2	0	1	1	1	213	192	0
Mespilocrinidae	8	5	241	283	196	0	5	0	5	5	0
Euryocrinidae	0	0	7	32	41	0	6	0	0	16	0
Synerocrinidae	0	0	21	25	3	0	2	0	3	1	0
	1314	622	794	820	821	85	56	80	361	715	33

TABLE 2
PERCENTAGE FAMILY ABUNDANCE

	A	B	C	D	E	F	G	H	I	J	K
	---	---	---	---	---	---	---	---	---	---	---
	NEBR	WCLQ	PHF	US75	COPW	RFP	CE75	E160	TYRO	LTD	UTD
A) SCYTALO.	2.9	1.3	0.4	0.2	0.3	0.0	4.0	3.8	0.0	1.8	6.1
B) BLOTHRO.	5.6	2.4	1.3	0.5	2.3	0.0	2.0	1.2	0.5	0.6	0.0
C) PELECO.	1.4	0.4	0.9	1.7	0.7	0.0	4.0	1.2	0.0	0.4	3.0
D) LAUDONO.	3.0	7.2	0.1	0.6	0.3	0.0	2.0	0.0	0.0	0.0	3.0
E) STELLARO.	0.6	1.5	0.0	0.0	0.5	0.0	10.0	6.3	0.0	4.7	6.1
F) AMPELO.	0.2	0.5	0.0	0.0	0.0	0.0	4.0	0.0	0.0	1.5	9.1
G) AGASSIZO.	0.0	0.0	0.0	0.9	0.0	94.1	2.0	0.0	0.3	0.0	0.0
H) CROMYO.	2.4	0.7	0.6	0.0	0.6	0.0	2.0	7.5	0.0	0.3	3.0
I) ULO.	1.9	1.3	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	3.0
J) ERISO.	10.7	28.8	4.4	17.4	6.3	0.0	4.0	10.0	1.9	8.1	12.1
K) DIPHUI.	6.2	1.3	0.0	0.0	1.5	0.0	0.0	17.5	0.0	0.0	0.0
L) CATA.	27.5	12.3	4.0	9.6	1.2	2.4	6.0	21.2	4.7	1.5	6.1
M) APOGRAPHIO.	21.1	11.7	48.1	19.4	18.2	2.4	18.0	1.2	27.4	38.5	0.0
N) PIRASO.	9.5	17.3	0.1	0.2	4.1	0.0	12.0	21.3	0.0	6.8	45.6
O) GALATEA.	0.0	2.4	0.8	0.9	1.0	0.0	0.0	0.0	0.5	2.2	0.0
P) CYMBIO.	0.8	0.8	0.5	0.0	0.1	0.0	2.0	7.5	0.0	1.0	3.0
Q) EXO.	2.4	3.4	0.0	0.2	0.0	1.2	2.0	1.2	59.0	26.8	0.0
R) ALLAGE.	2.9	0.8	3.1	3.6	33.2	0.0	2.0	0.0	3.3	2.4	0.0
S) CODIA.	0.0	5.0	1.8	3.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
T) MESPILO.	0.6	0.8	30.3	34.4	23.8	0.0	10.0	0.0	1.4	0.7	0.0
U) EURYO.	0.0	0.0	0.9	3.9	5.0	0.0	8.0	0.0	0.0	2.2	0.0
V) SYNERO.	0.0	0.0	2.6	3.0	0.4	0.0	4.0	0.0	0.8	0.1	0.0

RESULTS

The geographic distribution of the crinoid localities is given in Figure 3 and Appendix I. The stratigraphic distribution of the crinoid localities is indicated by the large arrows in Figure 6.

Locality A crinoids were all collected from the Kiewitz Bed at the base of the Stoner Limestone in the northern shoreward facies of Nebraska. Crinoid diversity is high with the poteriocrines Catacrinidae, Apographiocrinidae and Erisocrinidae most abundant (Tables 1 and 2).

Locality B crinoids were collected from the basal whole-fossil calcarenite of the Stoner Limestone in the algal mound facies of northern Wilson County, Kansas. Crinoid diversity is again high, with the poteriocrines Erisocrinidae, Pirasocrinidae, Catacrinidae, and Apographiocrinidae the most abundant families (Tables 1 and 2). The cyathocrine Codiacrinidae is also a notable element to this fauna.

Locality C crinoids are from the fossiliferous shale and sponge-rich calcilutite of the Captain Creek Limestone in the terrigenous detrital facies near Bolton, Kansas. This crinoid fauna is rather restricted and dominated by the poteriocrine Apographiocrinidae and the flexible

Mespilocrinidae (Tables 1 and 2).

Locality D crinoids are from the sponge-rich calcilutite and fossiliferous shale of the Captain Creek Limestone of the terrigenous detrital facies near Bolton, Kansas. This crinoid fauna is also rather restricted and dominated by the poteriocrines Apographiocrinidae and Erisocrinidae and the flexible Mespilocrinidae (Tables 1 and 2).

Locality E crinoids are from fossiliferous shales and shaly limestones in the terrigenous detrital facies of the upper Wann Formation (equivalent to the Captain Creek Limestone) near Copan, Oklahoma. This crinoid fauna is dominated by the disparid family Allagecrinidae, the Mespilocrinidae, and the Apographiocrinidae (Tables 1 and 2).

Locality F crinoids are from the upper Eudora Shale beneath the Bolton Bed in the terrigenous detrital facies near Bolton, Kansas. This fauna is dominated by deposit feeding and nektobenthic molluscans with a very restricted crinoid fauna (Senich, 1978). However, the unique poteriocrine Paragassizocrinus of the Agassizocrinidae is common at this locality (Tables 1 and 2).

Locality G crinoids are all from the limonite concretion-bearing shales of the upper Wann Formation (equivalent to the Eudora Shale) in the terrigenous detrital facies near Copan, Oklahoma. It should be noted that the two sub-localities may occupy different horizons within the Eudora Shale-equivalent upper Wann Formation (the section road sub-locality may be higher than the US 75 sub-locality). This rather diverse assemblage is dominated by the poteriocrine families Apographiocrinidae, Pirasocrinidae, Stellarocrinidae, and the flexibles (Tables 1 and 2).

Locality H crinoids are from the top of the Eudora Shale beneath the Timber Hill Siltstone Bed of the terrigenous detrital facies in the Elk City State Park, Kansas. This crinoid fauna is dominated by the poteriocrines Pirasocrinidae, Catacrinidae, Diphuicrinidae, and Erisocrinidae (Tables 1 and 2).

Locality I crinoids are from the base of the Eudora Shale, directly above the Tyro Oolite, in the terrigenous detrital facies near Tyro, Kansas. This restricted crinoid fauna is dominated by the poteriocrines Exocrinidae and Apographiocrinidae with a minor contribution from the flexibles and disparids (Tables 1 and 2).

Locality J crinoids are from the top of the limonite concretion-bearing shale of the upper Wann Formation (Eudora Shale-Stoner Limestone equivalent) in the terrigenous detrital facies near Copan, Oklahoma. This rather diverse crinoid fauna is dominated by the poteriocrines Apographiocrinidae and Exocrinidae with minor contributions from the flexibles (Tables 1 and 2).

Locality K crinoids are from the concretion-free shale at the top of the Stoner Limestone equivalent upper Wann Formation. This restricted crinoid fauna is dominated by the poteriocrines Pirasocrinidae and Erisocrinidae (Tables 1 and 2).

In order to ascertain the degree of similarity between the different localities and between the different crinoid families, Q- and R-mode Pearson Correlation analysis was performed on the data. The Q-mode Pearson Correlation scores that are significant at the 99% confidence interval are indicated in Figure 13. The R-mode Pearson Correlation scores that are significant at the 99% confidence interval are indicated in Figure 14. These are families that are statistically correlated to one another because they have the same distribution throughout the localities.

Multidimensional scaling (MDS) analyzes the proportional similarities between the components of a data set. In MDS analysis, the similarities and differences between the components are represented by the Euclidean distances between these data points in multidimensional

Figure 13 - Q-mode Pearson Correlation analysis. Blackened squares indicate positive statistical correlation at the 99% confidence interval.

Q - MODE PEARSON CORRELATION SCORES

- A - NEBR.
- B - WCLQ
- C - PHF
- D - US75
- E - COPW
- F - RFP
- G - CE75
- H - E160
- I - TYRO
- J - LTD
- K - UTD

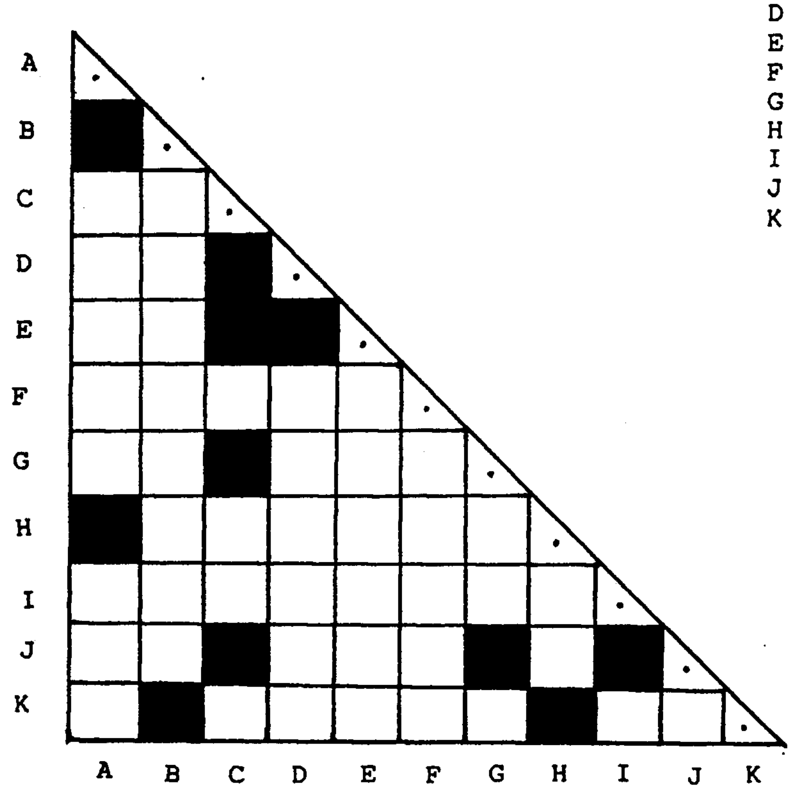
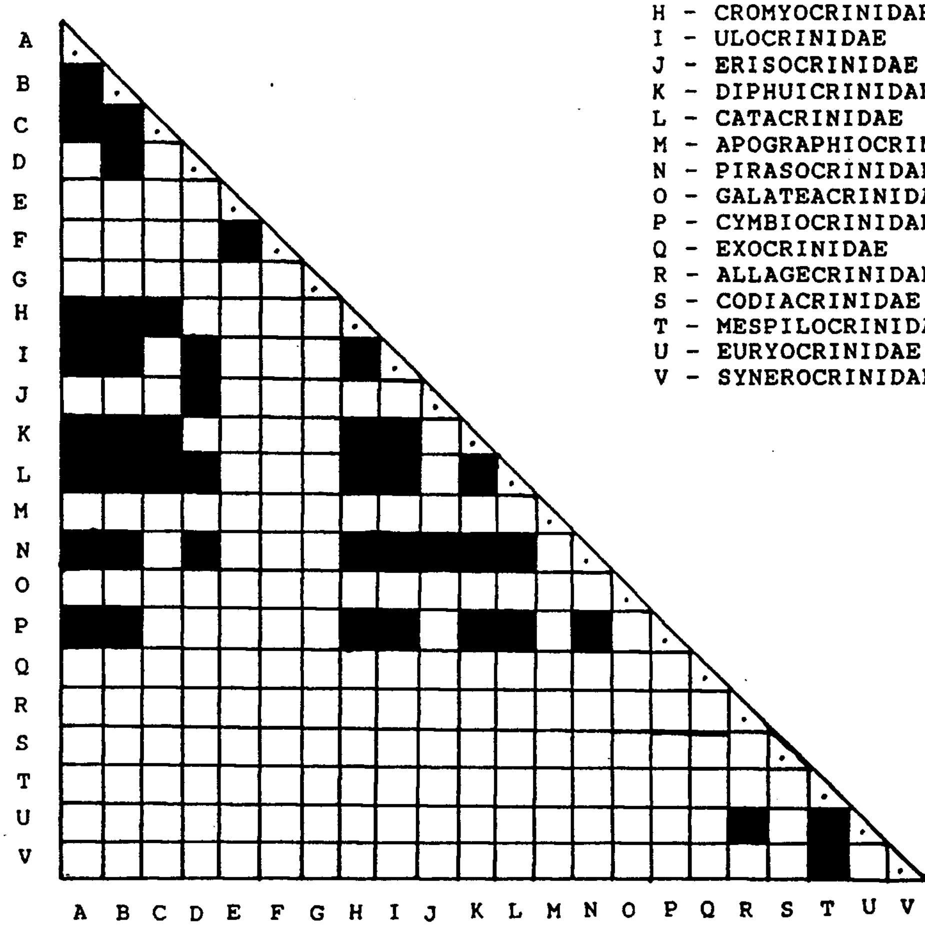


Figure 14 - R-mode Pearson Correlation analysis. Blackened squares indicate positive statistical correlation at the 99% confidence interval.

R - MODE PEARSON CORRELATION SCORES

A - SCYTALOCRINIDAE
B - BLOTHROCRINIDAE
C - PELECOCRINIDAE
D - LAUDONOCRINIDAE
E - STELLAROCRINIDAE
F - AMPELOCRINIDAE
G - AGASSIZOCRINIDAE
H - CROMYOCRINIDAE
I - ULOCRINIDAE
J - ERISOCRINIDAE
K - DIPHUICRINIDAE
L - CATACRINIDAE
M - APOGRAPHIOCRINIDAE
N - PIRASOCRINIDAE
O - GALATEACRINIDAE
P - CYMBIOCRINIDAE
Q - EXOCRINIDAE
R - ALLAGECRINIDAE
S - CODIACRINIDAE
T - MESPILOCRINIDAE
U - EURYOCRINIDAE
V - SYNEROCRINIDAE



space. This multidimensional space is projected to two dimensions. Linear trends can then be identified from the plot. The amount of distortion on the data in reducing the multidimensional space (goodness of fit) is stress. Rolf (1979) defined the stress levels between zero and one as excellent, good, fair, and poor. This method works well if the data (i.e. families or localities) are distributed along a gradient (Kammer and Ausich, 1987). Water depth, specifically the energy regimes controlled by glacio-eustatic sea level changes and modified by the shelf-to-basin topography, is here proposed as the controlling mechanism on crinoid distribution during deposition of the lower Stanton Formation. Therefore the data should be distributed along an energy gradient. A Q-mode MDS analysis was performed on the locality data (Fig. 15). The stress level was .105, which is considered good. (Rolf, 1979). In the R-mode MDS that was performed on the family data (Fig. 16), the stress level was .170, which is between good and fair according to Rolf (1979).

Discussion - Five generalized assemblages can be defined from the crinoid faunas of the lower Stanton Formation. These are the *Delocrinus* - *Erisocrinus* - *Apographiocrinus* - pirasocrinid assemblage, the *Apographiocrinus* - flexible assemblage, the

Figures 15 - Q-mode MDS. See text for explanation.

Q - MODE MULTIDIMENTIONAL SCALE

A - NEBR	EARLY REGRESSIVE, CARBONATE SHELF
B - WCLQ	EARLY REGRESSIVE, CARBONATE SHELF
C - PHF	LATE TRANSGRESSIVE, DETRITAL BASIN
D - US75	LATE TRANSGRESSIVE, DETRITAL BASIN
E - COPW	LATE TRANSGRESSIVE, DETRITAL BASIN
F - RFP	EARLY REGRESSIVE, DETRITAL BASIN
G - CE75	MIDDLE REGRESSIVE, DETRITAL BASIN
H - E160	LATE REGRESSIVE, DETRITAL BASIN
I - TYRO	LATE TRANSGRESSIVE, DETRITAL BASIN
J - LTD	MIDDLE REGRESSIVE, DETRITAL BASIN
K - UTD	LATE REGRESSIVE, DETRITAL BASIN

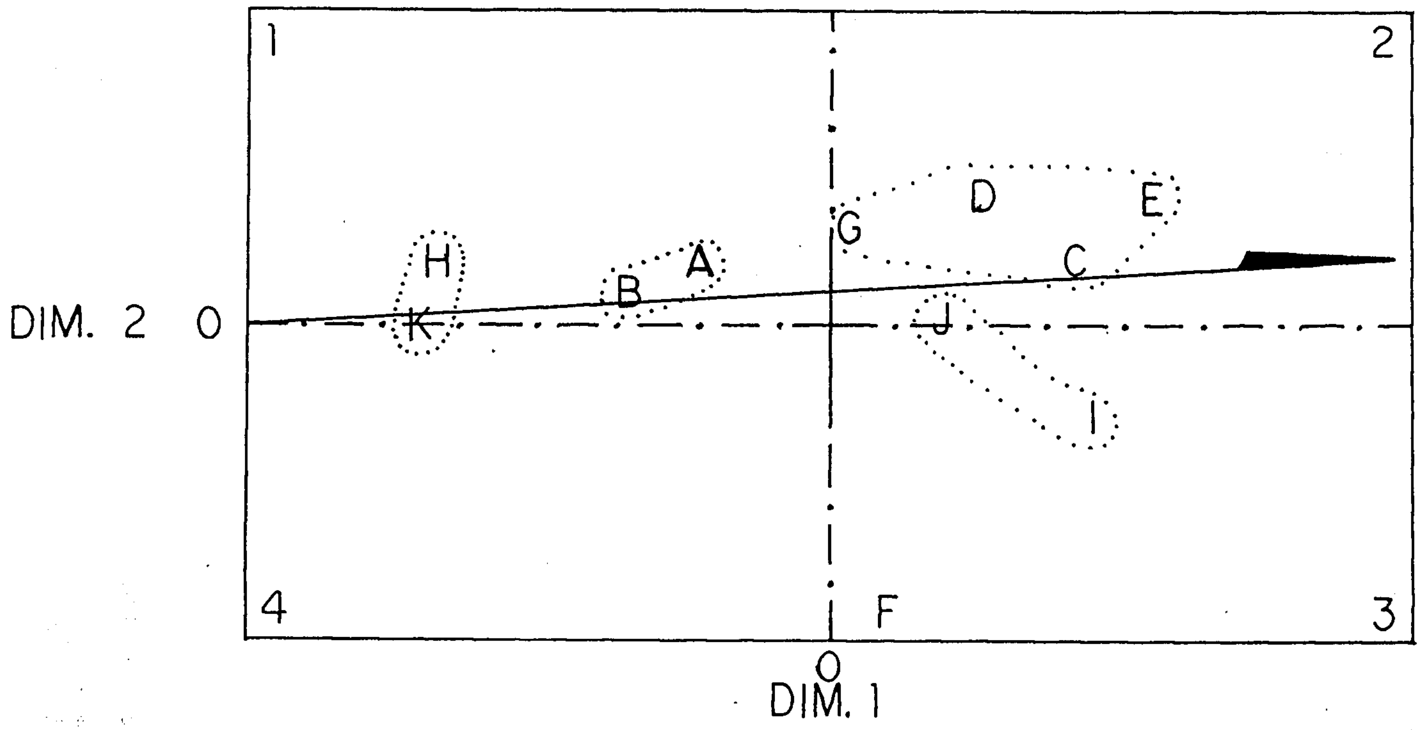
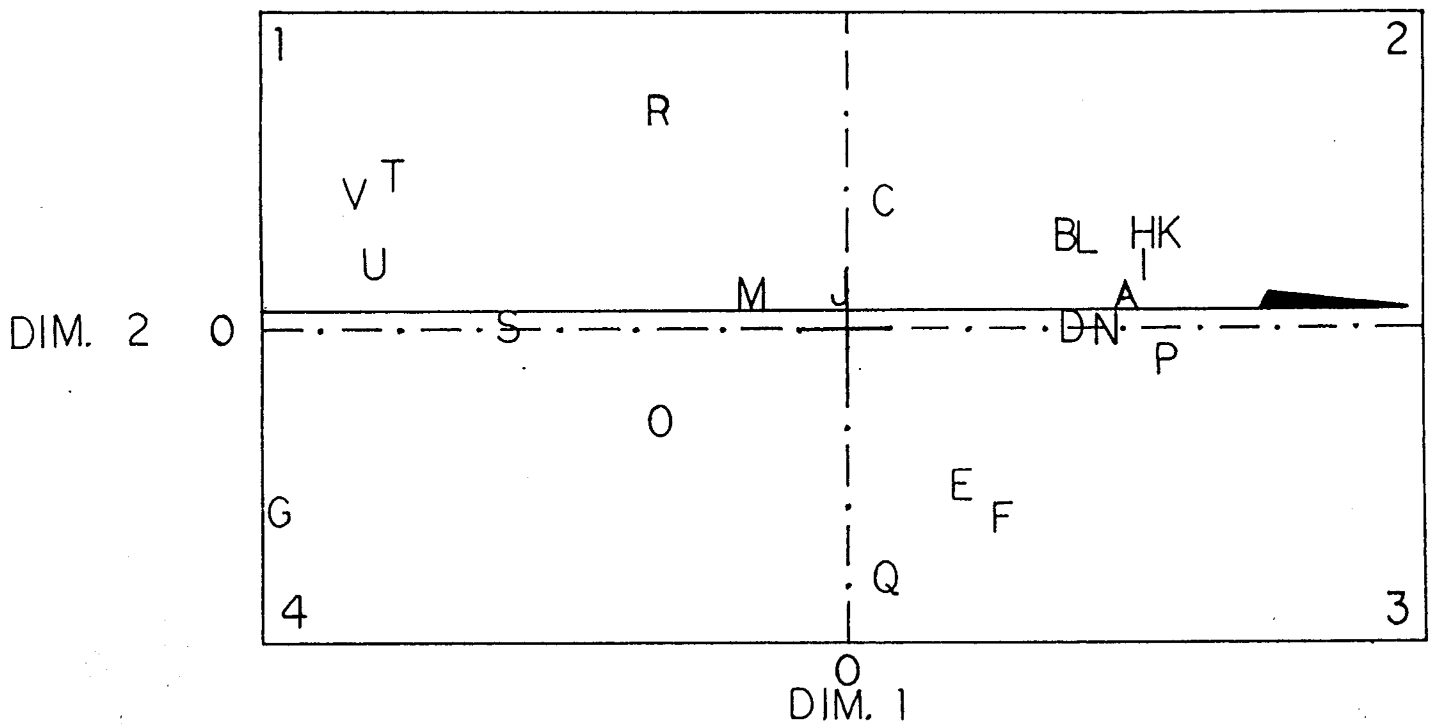


Figure 16 - R-mode MDS. See text for explanation.

R - MODE MULTIDIMENSIONAL SCALE

A - SCYTALOCRINIDAE
B - BLOTHROCRINIDAE
C - PELECOCRINIDAE
D - LAUDONOCRINIDAE
E - STELLAROCRINIDAE
F - AMPELOCRINIDAE
G - AGASSIZOCRINIDAE
H - CROMYOCRINIDAE
I - ULOCRINIDAE
J - ERISOCRINIDAE
K - DIPHUICRINIDAE
L - CATACRINIDAE
M - APOGRAPHIOCRINIDAE
N - PIRASOCRINIDAE
O - GALATEACRINIDAE
P - CYMBIOCRINIDAE
Q - EXOCRINIDAE
R - ALLAGECRINIDAE
S - CODIACRINIDAE
T - MESPILOCRINIDAE
U - EURYOCRINIDAE
V - SYNEROCRINIDAE



Paragassizocrinus assemblage, the Exocrinus - Apographiocrinus assemblage, and the pirasocrinid - Delocrinus - Erisocrinus - Graffhamicrinus assemblage.

The Delocrinus - Erisocrinus - Apographiocrinus - pirasocrinid dominated assemblage is present at localities A and B (Appendix I). These localities are both on the northern carbonate shelf, and are developed at the base of the Stoner Limestone near the maximum transgressive Eudora Shale (Fig. 6). Pearson Correlation analysis statistically correlates these localities to one another (Fig. 13). This close correlation is also indicated by Q-mode MDS, which plots these localities very closely together in quadrant 1 of Figure 15. These genera of the Catacrinidae, Erisocrinidae, and Apographiocrinidae, respectively, in addition to various genera of the Pirasocrinidae, are the most abundant taxa of these localities, and are diagnostic of this assemblage (Tables 1 and 2). Accordingly, the Catacrinidae, Erisocrinidae, and Pirasocrinidae are statistically correlated to one another by R-mode Pearson Correlation analysis (Fig. 14), however, the Apographiocrinidae is not correlated to the others. In R-mode MDS, the Apographiocrinidae and Erisocrinidae are in fairly close proximity to one another in quadrant 1, whereas the Catacrinidae and Pirasocrinidae are plotted together in quadrant 2 of Figure 16.

These crinoids all have pinnulate arm morphologies (Fig. 17; Plates 1 and 2), however the arrangement of their filtration fans is rather diverse. Apographiocrinus has the most open-mesh fan of the poteriocrines studied. It has uniserial brachials that have a single isotomous branch at PBr1 (Plate 1, 7; Fig. 17). By contrast, the Pirasocrinidae have the most closed-mesh fans of the poteriocrines studied. These crinoids (i.e. Sciadiocrinus) have uniserial to cunieform brachials with multiple axillary brachials (Plate 2, 1, 2; Fig. 17). Delocrinus and Erisocrinus, both of the Erisocrinacea, have intermediate density filtration fans. This group has biserial brachials with a single, isotomous branch at PBr1 (Plate 2, 5, 6; Fig. 17).

In this assemblage, the variety of arm morphologies indicates that the crinoids utilized a variety of feeding strategies. Direct interception and inertial impaction were probably the dominant modes of feeding, as suggested by the abundance of the more densely pinnulate crinoids (Delocrinus, Erisocrinus, pirasocrinids). However, Apographiocrinus probably fed by using some component of motile-particle capture or gravitational deposition, as indicated by its sparsely pinnulate filtration fan.

It is of particular note that the extremely open-mesh,

Figure 17 - Schematic drawings of arm morphologies.

A) Complex, non-pinnulate (ramulate) arm morphology of <u>Euonychocrinus</u> (after Strimple and Moore, 1971). <u>Paramphicrinus</u> has an equally complex, ramulate arm morphology.

B) Simple, non-pinnulate (ramulate) arm morphology of <u>Cibolocrinus</u>.

C) Atomous, non-pinnulate arm morphology of <u>Kallimorphocrinus</u>.

D) Pinnulate arms of <u>Apographiocrinus</u>. Note rectangular, uniserial brachials and single isotomous branch at PBr1.

E) Pinnulate arms of <u>Exocrinus</u>. Note elongate, uniserial brachials, fused axillaries, and two to three isotomous branches per ray.

F) Pinnulate arms of an erisocrinid (<u>Delocrinus</u>, <u>Erisocrinus</u>, and <u>Graffhamicrinus</u>). Note biserial brachials and single, isotomous branch at PBr1.

G) Pinnulate arms of a cromyocrinid (<u>Parulocrinus</u>). Note biserial brachials and axillary PBr1 and SBr1.

H) Pinnulate arms of a pirasocrinid (<u>Sciadiocrinus</u>). Note uniserial brachials and multiple branches per ray.

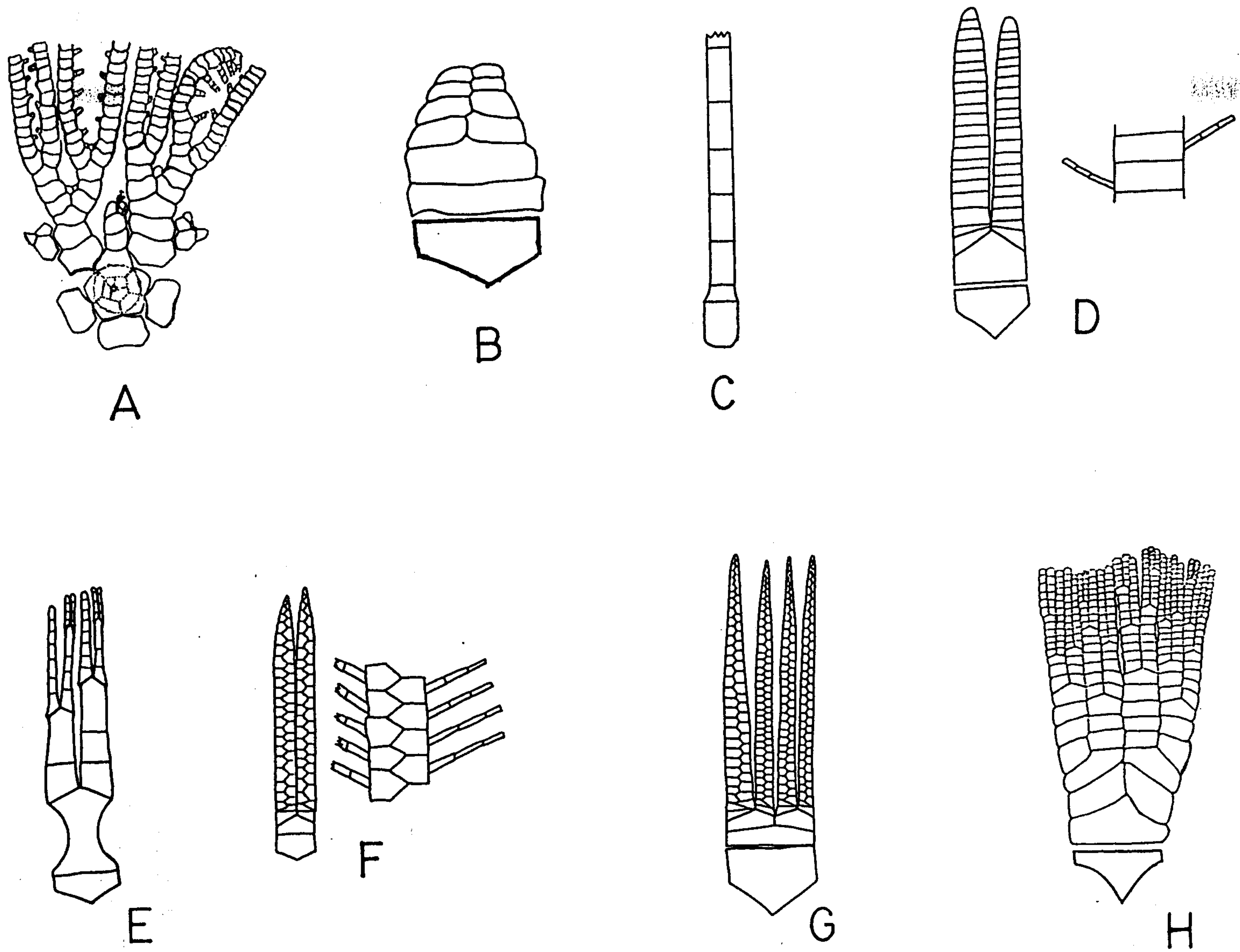

A
B
C
D
E
F
G
H

PLATE 1

1) B ray view of Paramphicrinus, note small, square brachials of complex, ramulate arms; x2.0, BWC-CH1

2) Posterior view of Euonychocrinus, note small, square brachials of complex, ramulate arms; x1.5, BWC-CH2

3) Posterior view of Cibolocrinus, note large, rectangular brachials of simple, ramulate arms ; x1.2, UNSM 13314

4) Atomous, non-pinnulate arms of Kallimorphocrinus; x2.5, BWC-CH3

5) Dorsal cup of Paragassizocrinus, note conical, fused IBB circlet; x1.5, UNSM 22113

6) C ray view of Exocrinus, note pinnulate, uniserial arms and fused axillaries; x3.0, BWC-CH4

7) D-E interray view of Apographiocrinus, note pinnulate, uniserial arms, x2.2, UNSM, un-numbered

PLATE 1

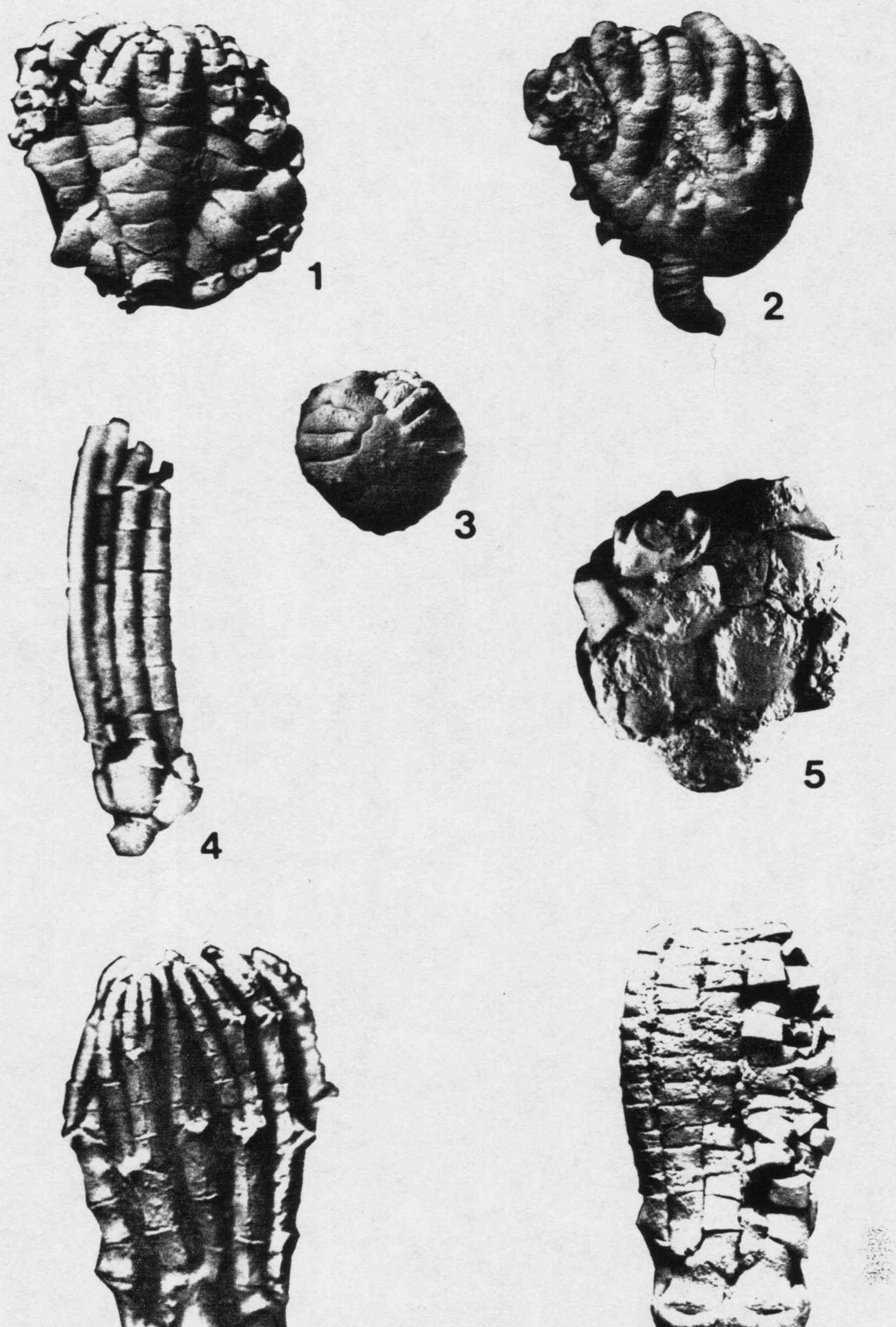


PLATE 2

1) Posterior view of *Sciadiocrinus*, note pinnulate, cunieform brachials and multiple branches per ray; x1.0, BWC-CH5

2) A-E interray view of *Sciadiocrinus*, note pinnulate, cunieform brachials and multiple branches on each ray; x0.6, BWC-CH6

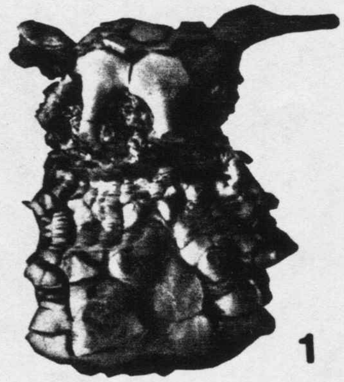
3) B ray view of *Parulocrinus*, note biserial, pinnulate brachials and axillary PBr and SBr on the A and C rays; x3.0, UNSM 16016

4) D ray view of *Graffhamicrinus*, note biserial, pinnulate brachials and single, isotomous branch at PBr1, and marked ornamentation; x0.8, UNSM 26833

5) *Erisocrinus*, note pinnulate, biserial arms and isotomous branches on PBr1; x1.0, BWC-CH7

6) C ray view of *Delocrinus*, note pinnulate, biserial brachials and isotomous branches on PBr1; x0.9, BWC-CH8

PLATE 2



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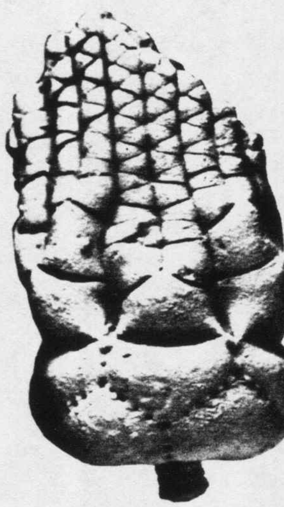

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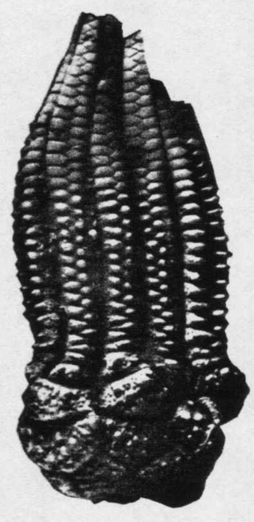

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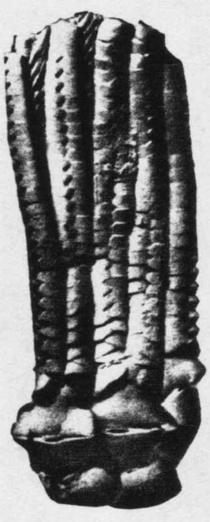


5

6

non-pinnulate crinoids are poorly represented, particularly the flexibles. The non-pinnulate inadunates (*Kallimorphocrinus* and *Lecythiocrinus*) may have been low-level crinoids feeding by motile-particle capture and gravitational deposition, however these non-pinnulate forms could not proliferate in the northern carbonate shelf environments. This may have been due to these crinoids' inability to capture particles effectively in these moderate energy, carbonate shelf facies.

The *Delocrinus* - *Erisocrinus* - *Apographiocrinus* - pirasocrinid assemblage suggests a normal, open, marine environment with moderate currents sweeping the bottom. Food particles probably consisted of small, current-entrained phytoplankton, zooplankton, and organic detritus. Water depths were moderate to deep, as indicated by the localities' proximity to the maximum transgressive Eudora Shale and position on the carbonate shelf.

The *Apographiocrinus* - flexible dominated assemblage is present a localities C, D, E, and G (Appendix I). These localities are in the terrigenous detrital facies, and are developed near the top of the Captain Creek Limestone and its equivalents, and also within the Eudora Shale-equivalent upper Wann Formation. All are near the maximum transgressive Eudora Shale (Fig. 6). Pearson Correlation analysis statistically correlates these localities to one another (Fig. 13). This close correlation is also shown by Q-mode MDS, which plots these localities within quadrant 2 (Fig. 15).

Apographiocrinus and genera of the flexible families Mespilocrinidae, Euryocrinidae, and Synerocrinidae are the most abundant taxa of these localities, and are diagnostic of this assemblage (Tables 1 and 2). The disparid allagecrinid Kallimorphocrinus is an integral component of this assemblage, however its distribution is irregular within this assemblage. The abundance of pirasocrinids at locality G is probably an artifact of mixing stratigraphic horizons during collection. These associations are confirmed by R-mode Pearson Correlation analysis, which statistically correlates these taxa (Fig. 14). R-mode MDS plots all of these taxa together within quadrant 1 of Figure 16.

Although Apographiocrinus is a pinnulate poteriocrine, its filtration fan is rather open-mesh (Plate 1, 7; Fig. 17). The remainder of the dominant taxa are all non-pinnulate. The disparid Kallimorphocrinus has a simple dorsal cup and atomous arms (Plate 1, 4; Fig. 17), while the flexibles Paramphicrinus (euryocrinid) and Euonychocrinus (synerocrinid) have small dorsal cups with large, complexly branching ramulate arms (Plate 1, 1, 2; Fig. 17). The flexible Cibolocrinus (mespilocrinid) has a large dorsal cup and arms with few branches (Plate 1, 3; Fig. 17). All of these non-pinnulate arm morphologies produce extremely open-mesh filtration fans.

In this assemblage, dominance by a sparsely pinnulate crinoid with an open-mesh fan and non-pinnulate crinoids with extremely open-mesh fans indicates that motile-particle capture and gravitational deposition were the dominant modes of feeding. The moderately pinnulate poteriocrine Erisocrinus does occur with some frequency (Tables 1 and 2), and may have been generalized enough to feed with this restricted assemblage. However, the other pinnulate poteriocrines are a minor element of this assemblage.

The Apographiocrinus - flexible assemblage suggests a restricted marine environment. The assemblage is dominated by a few opportunistic taxa that thrived in an environment of little or no current or wave action. Food particles were comparatively large, and probably consisted of sinking organic detritus and mobile zooplankton. The settings of the localities were fairly deep, as indicated by their proximity to the Eudora Shale and positions within the basin.

The Paragassizocrinus dominated assemblage is present at locality F (Appendix I). It is found within the terrigenous detrital basinal facies and is at the top of the Eudora

Shale (Fig. 6). Q-mode Pearson Correlation analysis verifies that this locality is unique (Fig. 13). Q-mode MDS plots this locality distinctly apart from the other localities (Fig. 15). This genus of the Agassizocrinidae is overwhelmingly the dominant taxon. It is unique and uncorrelated to any other crinoid taxa as indicated by the R-mode Pearson Correlation and MDS analysis (Figs. 14 and 16).

Paragassizocrinus has a dorsal cup of thick plates, particularly the fused IBB (Plate 1, *5*). Ettensohn (1980) suggested that *Paragassizocrinus* may have been a deposit feeder. He noted that the brachials of the uniserial, pinnulate arms have oblique fulcral ridges that enabled the crinoid to twist the arms. This allowed the pinnules and ambulacral grooves to make contact with the sediment surface. He also stated that the dense, cone-shaped IBB circlet allowed easy insertion into soft sediment. It seems entirely plausible for *Paragassizocrinus* to have been a semi-infaunal deposit feeder. The associated fauna is dominantly deposit-feeding, mature molluscans (*sensu* Boardman *et al*., 1984), such as gastropods, bivalves, rostroconchs, and nektobenthic ammonoids (Senich, 1978). The *Paragassizocrinus* assemblage is aberrant in that the dominant taxon probably did not filter feed. The associated molluscan fauna is typical of deep, slightly dysaerobic basinal marine settings, as described by Boardman et al., 1984 (Figs. 8 and 9).

The Exocrinus - Apographiocrinus dominated assemblage is developed at localities I and J (Appendix I). Both of these localities are within the terrigenous detrital basinal facies. Locality I is at the base of the Eudora Shale, transitional with the Tyro Oolite (Fig. 6). Locality J is at the top of the limonite concretion-bearing shale of the upper Wann Formation, equivalent to the Eudora Shale-Stoner Limestone interval (Fig. 6). Q-mode Pearson Correlation analysis statistically correlates these localities to one another (Fig. 13). This is supported by Q-mode MDS, in which these localities are plotted in quadrant 3 of Figure 15.

These genera of the Exocrinidae and Apographiocrinidae are the most abundant taxa at these localities (Tables 1 and 2). However, statistical analyses failed to show a strong correlation between these two families (Figs. 14, 16). This may be due to the ubiquitous occurrence of Apographiocrinus in the previously described normal assemblages, and the rather restricted occurrence of Exocrinus in any assemblages other than this assemblage. The non-pinnulate crinoids are notably a minor, albeit important, component of this assemblage (Tables 1 and 2). Also, differences in family richness between the two localities reflects differing ecological conditions.

Both of these pinnulate poteriocrines have rather open-mesh filtration fans compared to other poteriocrines. Apographiocrinus has uniserial brachials with a single isotomous branch at PBr1 (Plate 1, 7), while Exocrinus has uniserial brachials with two to three branches per ray. These axillary brachials are often fused with the underlying brachial (Plate 1, 6).

These crinoids probably fed by some combination of inertial impaction/direct interception and motile-particle capture/gravitational deposition. The non-pinnulate crinoids indicate that motile-particle capture and gravitational deposition may have been more effective for particle capture in these environments. This is especially true for locality I, however the more family-rich assemblage at locality J indicates that all modes of aerosol filtration were effective at food capture.

The Exocrinus - Apographiocrinus assemblage seems to represent two different environmental settings. However, both localities (I and J) are in a transitional zone between vertical facies. The assemblage at locality I is in a gray, clay shale between the Tyro Oolite and a black, clay shale of the Eudora Shale (Appendix II, section 11). This black shale contains a juvenile molluscan fauna (*sensu* Boardman *et al*., 1984), (Figs. 8 and 9), and represents a highly dysaerobic environment (Malinky and Mapes, 1982). This restricted crinoid fauna indicates a deep, probably oxygen stressed, environment swept by moderate to low energy currents.

The crinoid fauna at locality J is developed within the upper Wann Formation between the transition of limonite concretion-bearing shale below, and concretion-free shale above (Appendix II, section 14). This transition is from basinal, limonite concretion-bearing marine shales (*sensu* Bennison, 1985) to shallow marine, possibly deltaic, shales. Thus, the environment was probably only slighly oxygen stressed compared to locality I. Normal, stable marine conditions prevailed with moderate energy currents sweeping the bottom. However, shoaling marine-deltaic conditions are not indicated.

The pirasocrinid - *Delocrinus* - *Erisocrinus* - *Graffhamicrinus* dominated assemblage is present at localities H and K (Appendix I). These localities are both in the terrigenous detrital facies and are developed at the top of the Eudora Shale beneath sandstone sequences (Fig. 6). Pearson Correlation analysis statistically correlates these localities to one another (Fig. 13). Q-mode MDS also shows this relationship by plotting these localities closely together in quadrant 1 (Fig. 15). These genera of the Pirasocrinidae, Catacrinidae, Erisocrinidae, and Diphuicrinidae, respectively, are the most abundant taxa at these localities (Tables 1 and 2). Other important taxa include the Cromyocrinidae and Cymbiocrinidae. R-mode Pearson Correlation analysis shows that these families are statistically correlated to one another (Fig. 14). While R-mode MDS plots most of these families closely together, the erisocrinids are plotted farther away, but still within quadrant 2 of Figure 16.

These crinoids all have pinnulate arm morphologies. Delocrinus, Erisocrinus, and Graffhamicrinus are all biserial, and have a single isotomous branch at PBr1 (Plate 2, 4, 5, 6; Fig. 17), producing a rather closed-mesh filtration fan. The various genera of the pirasocrinids have uniserial to cuneiform brachials with multiple branches per ray (Plate 2, 1, 2; Fig. 17). The cromyocrinids (i.e. Parulocrinus) have biserial brachials with isotomous branches at PBr1 on all rays and at SBr1 on rays A, C, and D (Plate 2, 3; Fig. 17). The pirasocrinids and cromyocrinids produce a densely pinnulate, closed-mesh filtration fan.

The crinoids of this assemblage probably all fed by direct interception and inertial impaction. This is suggested by the abundance of densely pinnulate crinoid families and the absence of any non-pinnulate families.

The pirasocrinid - Delocrinus - Erisocrinus - Graffhamicrinus assemblage indicates a fairly high energy, shallow marine environment. Food particles were probably small phytoplankton and zooplankton.

Gradient Analysis - Identifiable linear trends can be discerned on the R-mode and Q-mode MDS plots (Figs. 15 and 16). The data in both plots do appear to be distributed along a depth/energy related gradient.

In the R-mode MDS, the trend starts in quadrant 1 and ends in quadrant 2 of Figure 16. All of the non-pinnulate crinoid families are within quadrant 1, while all of the most densely pinnulate crinoid families are within quadrant 2. The families with intermediate density fans are within quadrants 4 and 3. Thus, the energy gradient runs from the low energy, non-pinnulate, open-mesh filtration fan crinoids on the left of the plot to the high energy, pinnulate, closed-mesh filtration fan crinoids on the right.

The family of the Paragassizocrinus assemblage is in the lower portion of quadrant 4. For the filter feeding assemblages, the families of the Apographiocrinus - flexible assemblage are on the left side of the energy gradient. The families of the Exocrinus - Apographiocrinus assemblage are in close proximity to the middle, vertical axis of the plot. The families of the Delocrinus - Erisocrinus - Apographiocrinus - pirasocrinid assemblage are dominant along the middle horizontal axis, concentrated in quadrant 2. The families of the pirasocrinid - Delocrinus - Erisocrinus - Graffhamicrinus assemblage are concentrated together at the right end of the energy gradient plot.

For the Q-mode MDS, the phase of cyclothem deposition has been indicated with the localities of this study (Fig. 15). The late regressive, shallow marine localities H and K, containing the pirasocrinid - Delocrinus - Erisocrinus - Graffhamicrinus assemblage, are on the far left of the plot in quadrant 1. The early regressive, carbonate shelf localities, containing the Delocrinus - Erisocrinus - Apographiocrinus - pirasocrinid assemblage, are farther to the right, but still within quadrant 1. The late transgressive and middle regressive terrigenous detrital basinal localities I and J, containing the Exocrinus - Apographiocrinus assemblage, lie at the top of quadrant 3. Locality G may be plotting toward the higher energy localities of quadrant 1 because of mixing with later regressive horizons. However, the remainder of the localities containing the Apographiocrinus - flexible assemblage, the late transgressive terrigenous detrital basinal localities C, D, and E, all plot on the far right of the energy gradient in quadrant 2. The locality containing the aberrant assemblage of *Paragassizocrinus* is in the lower left corner of quadrant 3. The localities and their contained assemblages are distributed along an energy gradient from high energy, shallow marine-deltaic environments on the left of the plot to deep, low energy, basinal environments to the right of the plot.

Of note are the plots of the localities containing the *Exocrinus* - *Apographiocrinus* assemblage. Locality J, of higher family richness, plots toward the center of the figure, while the restricted assemblage of locality I plots toward the right in quadrant 3 (Fig. 15). This may reflect differing energy regimes, or possibly differences in dissolved oxygen levels between these two localities.

CONCLUSIONS

The stratigraphic and geographic distribution of these crinoid assemblages is shown in the cross section of Figure 18. At the onset of transgression, the flooded clastic lobes of the Vilas Formation developed marine oolite-stromatolite shoals. Periodically, ooids were swept downslope, off of the shoals, and into the basinal facies, as in the Tyro area. With continued transgression, this created a deep water barrier. To the north of this barrier lay the sponge-rich calcilutite of the Captain Creek Limestone with an _Apographiocrinus_ - flexible assemblage. This barrier must have created a rather stagnant, or very low energy, environment in which the non-pinnulate crinoids could thrive. South of this barrier, in the deeper portions of the basin, the shaley calcarenites of the upper Wann Formation, with an _Apographiocrinus_ - flexible assemblage, indicate a very low energy environment, possibly below the photic zone. Here the rain of fine detritus from the Ouachita and Arbuckle mountains expanded this transgessive sequence.

At the onset of water column stratification, upwelling conditions associated with maximum transgression allowed dysaerobic basinal waters to move up onto the Tyro Oolite

Figure 18 - North-south cross section showing the stratigraphic and geographic distribution of crinoid assemblages. See text for the sequence of depositional events and paleoenvironmental interpretations.

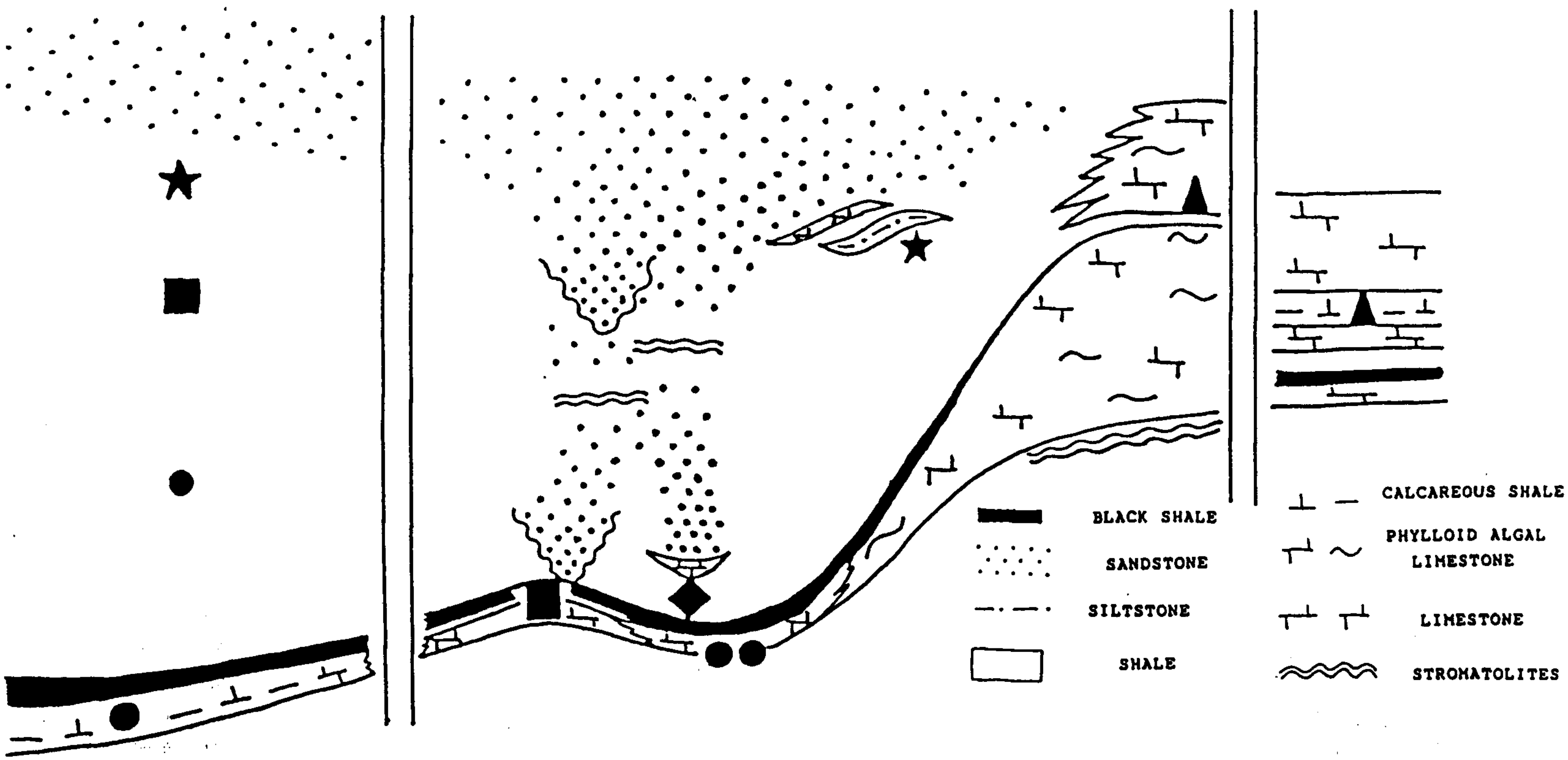
◆ *Paragassizocrinus* assemblage

● *Apographiocrinus* - flexible assemblage

■ *Exocrinus* - *Apographiocrinus* assemblage

▲ *Delocrinus* - *Erisocrinus* - *Apographiocrinus* - pirasocrinid assemblage

★ pirasocrinid - *Delocrinus* - *Erisocrinus* - *Graffhamicrinus* assemblage



barrier. Here, the restricted Exocrinus - Apographiocrinus assemblage developed in the nutrient-rich, oxygen-poor, upwelling currents. Within the Arkoma Trough of Oklahoma, anoxic conditions probably already existed, while on the northern carbonate shelf, phylloid algae production kept pace with transgression.

After maximum transgression, crinoid faunas quickly developed on the northern carbonate shelf. This Delocrinus - Erisocrinus - Apographiocrinus - pirasocrinid assemblage thrived in stable, normal marine environments with moderate to active currents, although below wave base. At this same time, within the basin to the south, molluscan faunas developed. These nektobenthic and deposit feeding mollusks were sympatric with the Paragassizocrinus assemblage. All of these deposit feeders lived in a slightly dysaerobic setting where organic detritus could collect on the sediment surface.

Continued regression allowed oxygenated surface currents to impinge on the bottom within the basin, establishing better oxygenated conditions. Filter feeding faunas became established, including the sparse development of the Apographiocrinus - flexible assemblage. Within the basin, continued regression allowed normal, subtidal marine conditions to be developed. The family-rich, transitional

Exocrinus - Apographiocrinus assemblage developed when the bottom became more actively agitated.

During the culmination of regression, delta lobes prograded into the basin. Shallow, fully marine embayments between the lobes developed a pirasocrinid - Delocrinus - Erisocrinus - Graffhamicrinus assemblage. Conditions were probably rather variable, with high wave and current energy, however salinities remained stable. Maximum regression brought fully deltaic conditions back into the basin.

Other factors, such as larval distribution patterns, turbidity, and dissolved oxygen levels may have played a part in controlling crinoid distribution, however the energy levels associated with allogenic transgression and regression and shelf/basin paleotopography seem to have been the overriding control.

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APPENDIX I

Collected Localities

Locality A - Three major collecting localities along the Lower Platte River Valley, all from the Kiewitz Shale Bed.

Rock Lake Quarry - SE1/4 SE1/4 Sec. 33, T.13 N, R.10 E, Sarpy County, Nebraska

Stone Products (Derby) Quarry - NE1/4 SE1/4 NE1/4 Sec. 16, T.12 N, R.11 E, Sarpy County, Nebraska

Ash Grove Cement Co. Quarry - SE1/4 Sec. 18, T.12 N, R.12 E, Cass County, Nebraska

Locality B - Single locality in northern Wilson County, quarry in lower Stanton Formation, collected from the basal Stoner Limestone.

Wilson County State Fishing Lake Quarry - SW1/4 SE1/4 SE1/4 Sec. 17, T.27 S, R.16 E, Wilson County, Kansas

Locality C - Single locality in central Montgomery County, dredged shale and sponge calcilutite of the Captain Creek Limestone.

Patterson's Hog Farm - C-W.Line, NW1/4 Sec. 24, T.33 S, R.14 E, Montgomery County, Kansas

<u>Locality</u> <u>D</u> - Single locality in central Montgomery County, road cut of the Captain Creek Limestone shale and sponge calcilutite.

U.S. Rt. 75 road cut - SE1/4 NW1/4 NW1/4 Sec. 36, T.33 S, R.14 E, Montgomery County, Kansas

<u>Locality</u> <u>E</u> - Single locality in northern Washington County, road cut of the Upper Wann Formation, Captain Creek equivalent shales and limestones.

Oklahoma Rt. 10 road cut, Copan West - C-W.Line, Sec. 18, T.28 N, R.13 E, Washington County, Oklahoma

<u>Locality</u> <u>F</u> - Single locality in central Montgomery County, stock pond excavation of Eudora Shale beneath Bolton Bed.

Rollins' Farm Pond - C-S.Line, SW1/4 Sec. 24, T.33 S, R.14 E, Montgomery County, Kansas

<u>Locality</u> <u>G</u> - Two collecting localities in northern Washington County, both in the Upper Wann Formation, Eudora Shale equivalent.

Section road cut, Copan East - C-E.Line, Sec. 15, T.28 N, R.13 E, Washington County, Oklahoma

U.S. Rt. 75 road cut - C-W.Line, Sec. 10, T.28 N, R.13 E, Washington County, Oklahoma

Locality H - Single locality in central Montgomery County, road cut of the upper Eudora Shale.

U.S. 160 road cut - SW1/4 NW1/4 NW1/4 Sec. 36, T.32 S, R.14 E, Montgomery County, Kansas

Locality I - Single locality in southern Montgomery County, quarry in the Stanton Formation, collected from the lower Eudora Shale.

Tyro Quarry - SW1/4 SE1/4 Sec. 30, T.34 S, R.15 E, Montgomery County, Kansas

Locality J - Single locality in northern Washington County, base of stock pond excavation in Upper Wann Formation, Eudora Shale equivalent.

Lower Tank Dike - NW1/4 NW1/4 SW1/4 Sec. 10, T.28 N, R.13 E, Washington County, Oklahoma

Locality K - Single locality in northern Washington County, top of stock pond excavation in Upper Wann Formation, Eudora Shale Equivalent.

Upper Tank Dike - NW1/4 NW1/4 SW1/4 Sec. 10, T.28 N, R.13 E, Washington County, Oklahoma

APPENDIX II

Measured Sections

This appendix includes measured sections from which collections were made and also un-collected localities. For some measured sections, previously studied sections were re-investigated, modified, and the original source noted.

Horizons from which the crinoid assemblages were collected are indicated by the asterisk (*).

Measured Section 1a - East pit of the Ash Grove Cement Company quarry, Louisville, Cass Co., Nebraska. (SE1/4 SW1/4 Sec. 18, T.12 N, R.12 E, Cedar Creek Quad.)

feet	meters	
+5.0	+1.53	Rock Lake Shale - dark red mudstone, clay rich, blocky with nodular carbonate zone approx. 3 feet (1 meter) above the base, gradational lower contact
1.75	0.53	Stoner Limestone - red to buff-green calcilutite, thinly laminated, fine grained, muddy, birds-eye structures and dessication polygons, highly root mottled and minor collapse breccias, voids filled with overlying red mudstone, barren of fossils, gradational lower contact
1.0	0.31	Stoner Limestone - light buff-gray calcilutite, thinly laminated, fine grained, muddy, birds-eye structures, <1 in. (2 cm) green shale partings, barren of fossils, gradational lower contact

2.75	0.84	Stoner Limestone - light gray calcilutite, regular beds with thin, irregular green shale partings, fine grained, more crystalline than above, scattered fossils more common towards base, 1 in. (2.5 cm) green shale at base
0.75	0.23	Stoner Limestone - light gray skeletal calcilutite, single bed, fine grained, more crystalline than above, abundant fossil grains, 1 in. (2.5 cm) green shale at base
3.5	1.07	Stoner Limestone - gray skeletal calcilutite, regular beds with thin, regular gray shale partings, fine grained, crystalline, abundant fossil grains, 1 in. (2.5 cm) gray shale at base
2.5	0.76	Stoner Limestone - gray skeletal calcilutite, regular beds with thin, regular gray shale partings, fairly dense, fine grained, large, abundant fossil grains, 2 in. (5 cm) green-gray shale at base
1.5	0.46	* Stoner Limestone, Kiewitz Bed - light

green-gray calcareous shale, abundant fossil grains, diverse, well preserved fauna

Base of Section

Measured Section 1b - Road cut on Route N-31, vicinity of Schramm Park, Sarpy Co., Nebraska.
(NW1/4 SW1/4 Sec. 18, T.12 N, R.11 E, Springfield Quad.)

feet	meters	
4.25	1.30	Stoner Limestone - weathered buff-yellow skeletal calcilutite, regular beds with thin shale partings, fine grained, abundant fossil grains, 2 in. (5 cm) shale at base
1.5	0.46	Stoner Limestone - weathered buff-yellow skeletal calcilutite, 3 beds separated by thick shale partings, lowest bed fusulinid rich, fine grained, abundant, large fossil grains, gradational lower contact
2.25	0.69	Stoner Limestone, Kiewitz Bed - light gray calcareous shale, abundant fossil grains, diverse fauna, gradational lower contact
1.75	0.53	Stoner Limestone, Dyson Hollow Bed - gray skeletal calcilutite, 2 beds with irregular shale partings, muddy, crinoidal upper horizon, sharp lower contact

1.75	0.53	Eudora Shale - dark olive green, clay shale, fissile, scattered small fossils, gradational lower contact
0.6	0.18	Eudora Shale - black, platy shale, hard, brittle, barren of macrofossils, thin olive green shale at base
0.75	0.23	Captain Creek Limestone - dark (top) to light (bottom) gray skeletal calcilutite, single bed, very dense, crystalline, scattered fossil grains more common at top, sharp lower contact
+2.0	0.61	Vilas Formation - dark gray shale, soft and fissile with sparse limonite concretions at top into calcareous, silty facies below, fossiliferous, red shale present below

Base of Section

Measured Section 2 - Road cut on north-bound entrance ramp, I-435 and county road N and T (Exit 24), Platte Co., Missouri. (Platte City Quad.)

feet	meters	
+6.0	+1.83	Rock Lake Shale - blue-gray silty shale, thin siltstone layers present, micaceous, plant fragments, sharp, irregular lower contact
0.75	0.23	Stoner Limestone - orange-yellow calcilutite, slabby to crumbly, highly root mottled, barren of fossils, sharp, uneven lower contact
1.5	0.46	Stoner Limestone - orange-yellow calcilutite, single bed, denser than above, few large root mottles on upper surface, scattered fossil grains, 1 in. (2.5 cm) orange-yellow shale at base
2.5	0.76	Stoner Limestone - yellow (top) to buff-white (bottom) micritic calcarenite, single bed, fairly dense, fine grained, sharp, even lower contact

4.6	1.40	Stoner Limestone - buff-white skeletal calcilutite, indistinctly bedded, numerous stylolites, fairly dense, abundant fossil grains, prominent thin shale parting at base
2.0	0.61	Stoner Limestone - light gray skeletal calcilutite, muddier than above, thin, anastomosing shale partings, abundant, large fossil grains, gradational lower contact
0.4	0.12	Stoner Limestone (?Kiewitz Bed) - gray calcareous shale, anastomosing to condensed, abundant, large fossil grains, gradational lower contact
1.75	0.53	Stoner Limestone - light gray skeletal calcilutite, muddy, 2 beds, abundant, large fossil grains, sharp lower contact
0.5	0.15	covered
0.3	0.09	Eudora Shale - dark gray to black clay shale, fissile, barren of macrofossils, gradational lower contact

2.0	0.61	Eudora Shale - black, platy shale, hard, brittle, barren of macrofossils, thin phosphatic laminae, gradational lower contact
0.75	0.23	Eudora Shale - dark gray shale, poorly exposed
3.75	1.14	Captain Creek Limestone - dark gray skeletal calcilutite, dense, fine grained, zones of coarse skeletal debris, abundant large fossil grains, sharp lower contact
1.25	0.38	Captain Creek Limestone - dark gray skeletal calcilutite, dense, fine grained, fusulinid-rich, sharp lower contact
+1.0	+0.3	Vilas Formation - gray shale, poorly exposed

Base of section

Measured Section 3 - Road cuts at interchange of Kansas Route 10 and Edgarton Road, vicinity of Eudora, Johnson Co., Kansas

(SE1/4 SE 1/4 Sec. 36, T.12 S, R.21 E, Eudora Quad.)

feet	meters	
+1.0	+0.3	?Rock Lake Shale - red-tan siltstone, micaceous, poorly exposed
3.0	0.91	Stoner Limestone - orange weathered skeletal calcilutite, rubbly, fine grained, muddy, irregular, thick shale partings, fine fossil grains, gradational lower contact
1.0	0.30	Stoner Limestone - buff light gray skeletal calcilutite, fine grained, thin, irregular shale partings, abundant phylloid algae, both fine and large fossil grains, sharp lower contact
2.0	0.61	Stoner Limestone - buff light gray skeletal calcilutite, fine grained, regular beds with thin, irregular shale partings, calcarenitic zones at top and bottom,

		fairly abundant phylloid algae, both fine and large fossil grains, sharp lower contact
7.5	2.29	Stoner Limestone - light gray skeletal calcilutite, fine grained, wavey to lenticular bedding with thin, irregular shale partings, scattered phylloid algae at top, replaced downward by fusulinids, abundant fossil grains, sharp lower contact
0.75	0.23	Stoner Limestone - gray skeletal calcilutite, fairly dense, fine grained, single bed, abundant large fossil grains, sparse fusulinids, 1 in. (2.5 cm) fossiliferous tan shale at base
0.75	0.23	Stoner Limestone - gray skeletal calcilutite, fairly dense, fine grained, single bed, abundant large fossil grains, sharp lower contact
0.2	0.06	Stoner Limestone (?Kiewitz Bed) - tan weathered calcareous shale, abundantly fossiliferous
1.2	0.37	Stoner Limestone - gray skeletal

		calcilutite, fairly dense, fine grained, 2 even beds, abundant large fossil grains, sharp lower contact
3.75	1.14	Eudora Shale - gray to dark gray clay shale, fissile, sparse macrofossils, gradational lower contact
0.25	0.08	Eudora Shale - dark gray to black clay shale, fissile, no macrofossils, gradational lower contact
1.2	0.37	Eudora Shale - black shale, platy, hard, brittle, no macrofossils, phosphatic laminae, lower contact sharp
1.0	0.30	Eudora Shale - dark gray-black clay shale, fissile, phosphate nodules at lower contact, lower contact sharp
1.75	0.53	Captain Creek Limestone - dark gray skeletal calcilutite, dense, fine grained, blocky, single bed, abundant large fossil grains, scattered phylloid algae, calcarenitic zone at base
1.75	0.53	Captain Creek Limestone - dark gray

		skeletal calcilutite, dense, fine grained, blocky, single bed, abundant large fossil grains, scattered phylloid algae, calcarenitic zone at base
1.75	0.53	Captain Creek Limestone - dark gray skeletal calcilutite, dense, fine grained, blocky, single bed, abundant large fossil grains, scattered phylloid algae, fusulinid rich, calcarenitic zone at base
1.5	0.46	Captain Creek Limestone - dark gray skeletal calcilutite, dense, fine grained, blocky, single bed, abundant large fossil grains, algal coated grains (oncolites), scattered phylloid algae, fusulinids, sharp lower contact
+12.0	+3.7	Vilas Formation - blue-gray shale, very silty, thin, rippled siltstone layers

Base of section

Measured Section 4 - Spillway and quarry south of Wilson County State Fishing Lake, vicinity of Buffalo, Wilson Co., Kansas.

(SE 1/4 Sec. 17, T.27 S, R.16 E, Buffalo Quad.) after Heckel, 1978, stop 4

feet	meters	
+4.0	+1.22	Stoner Limestone - buff-tan skeletal calcilutite, muddy, fine grained, slabby bedded, phylloid algae present, large fossil grains, gradational lower contact
2.75	0.84	Stoner Limestone - gray skeletal calcarenite, even bedded, coarse grained, crinoidal, dense, thin, gray shale at base
2.0	0.61	* Stoner Limestone - dark gray skeletal calcarenite, crinoidal, dense, 2 beds separated by 2 in. (5 cm) fossiliferous gray clay shale, coarse grained, abundant large fossil grains, grains unabraded, sharp lower contact
0.2	0.06	Eudora Shale - gray clay shale, fissile, scattered macrofossils, scattered phosphate

		nodules, sharp lower contact
22.0	6.71	Captain Creek Limestone - buff gray to gray algal calcilutite, dense, blocky, massively bedded, scattered horizons of skeletal calcilutite with benthic invertebrates, some spar filled voids, uniformly dominated by phylloid algae, gradational lower contact
2.0	0.61	Captain Creek Limetone - buff gray skeletal calcilutite, scattered phylloid algae, fine grained
3.0	0.92	Captain Creek Limestone (Benedict Bed) - gray oolite, spar cemented, surrounding domal stromatolites, scattered benthic invertebrate fossil grains, sharp lower contact
+25.0	+7.6	Vilas Formation - blue-gray silty shale, unit not investigated

Base of Section

Measured Section 5 - Road cut on Kansas Route 39 in the vicinity of Benedict, Wilson Co., Kansas. (NW1/4 NE1/4 Sec. 10, T.28 S, R.15 E, Buffalo Quad.)

Algal Mound Rim Facies

feet	meters	
6.75	2.06	?Stoner Limestone - complexly intertongued: gray algal calcilutite, exclusively phylloid algal grains, spar-filled voids orange stained gray skeletal calcilutite, fine grained, phylloid algae present, abundant large fossil grains dark gray calcarenite, dense, coarse grained, crinoidal, abraded grains

Base of section

Measured Section 6 - Road cut on Kansas Route 47 in the vicinity of Altoona, Wilson Co., Kansas. (NW1/4 NE 1/4 Sec. 18, T.29 S, R.16 E, Altoona Quad.) after Heckel, 1978

Algal Mound Channel Facies

feet	meters	
+16.0	+4.9	Stoner Limestone - buff-gray skeletal calcarenite, mixed fine and coarse grained, spar cemented, porous, abraded grains with scattered, unabraded fossils, large-scale cross beds with some herringbone cross beds, gradational lower contact
+2.0	+0.6	Stoner Limestone - gray skeletal calcilutite, abundant fossil grains, poorly exposed
+1.0	+0.3	Eudora Shale - black shale, platy, poorly exposed

Base of section

Measured Section 7 - Road cut on U.S. Route 160 in the vicinity of Elk City State Park, Independence, Montgomery Co., Kansas. (SW1/4 NW1/4 NW 1/4 Sec. 36, T.32 S, R.14 E, Bolton Quad.) after Heckel, 1975a

feet	meters	
+3.0	+0.92	Rock Lake Shale (Onion Creek sandstone body) - reddish-brown/orange sandstone, massive to planar bedded, well cemented to slightly friable, sharp lower contact
9.75	2.97	Rock Lake Shale - gray-tan shale, silty, barren of fossils, poorly exposed, sharp lower contact
1.25	0.38	Timber Hill Siltstone Bed - orange-tan siltstone, planar bedded, well cemented, sparsely fossiliferous, lenticular (lenses in from the west), sharp lower contact
1.4	0.43	Eudora Shale - dark gray shale, silty, fissile, sparsely fossiliferous, sharp lower contact
0.25	0.08	Eudora Shale - buff tan-orange calcilutite,

		muddy, fine grained, large fossil grains, sharp lower contact
3.25	0.99	* Eudora Shale - dark gray shale, slightly silty, fissile, highly fossiliferous, diverse fauna, gradational lower contact
14.25	4.35	Eudora Shale - dark gray shale, fissile, fossiliferous, restricted fauna, thin tan, silty shale layers
(50.0)	(15.25)	Eudora Shale - known from core at this locality

Base of section

Measured Section 8 - Road ditch up north-east side of Walker Mound, vicinity of Elk City State Park, Montgomery Co., Kansas.

(C-N.Line, NE1/4 NE 1/4 Sec. 5, T.33 S, R.14 E, Bolton Quad.)

feet	meters	
+1.5	+0.46	Eudora Shale - black shale, platy, brittle, phosphate nodules, poorly exposed
1.25	0.83	Captain Creek Limestone - orange weathered calcilutite, fine grained, muddy, abundant fossil grains, sharp lower contact
2.0	0.61	Captain Creek Limestone - gray shale, fossiliferous, mostly covered, sharp lower contact
1.5	0.46	Captain Creek Limestone - gray oolitic calcilutite, dense, fossiliferous

Base of section

Measured Section 9 - Railroad cut and adjacent road cut on U.S. Route 75, vicinity of Bolton, Montgomery Co., Kansas.

(SE1/4 NW1/4 NW 1/4 Sec. 36, T.33 S, R.14 E, Bolton Quad.)

feet	meters	
+0.75	+0.23	Rock Lake Shale - red-brown sandstone, slabby, interbedded with silty shale, poorly exposed, gradational lower contact
0.5	0.15	Bolton Bed - orange-yellow skeletal calcarenite, thin beds, slabby, some scattered oolites, fossil grains unabraded and uncoated, interbedded with shale, gradational lower contact
2.25	0.69	Bolton Bed - orange-yellow skeletal calcarenite, fairly coarse grained, single bed with irregular shale partings, abundant fossil grains unabraded, sharp lower contact
0.25	0.08	Eudora Shale - gray shale, poorly exposed
10.0	3.05	covered interval

6.0	1.83	Eudora Shale - dark gray shale, clay rich, fissile, abundant limonite concretions, scattered, restricted fauna
2.0	0.61	covered interval
3.5	1.07	* Captain Creek Limestone - orange skeletal calcilutite, muddy, fine grained, dense, phosphate nodule residuum at top, poorly exposed fossiliferous shale at base

Base of section

Measured Section 10 - Excavation at farm stock pond, the Rollins Ranch, vicinity of Bolton, Montgomery Co., Kansas

(C-S.Line, SW1/4 Sec. 24, T.33 S, R.14 E, Bolton Quad.)

feet	meters	
+3.0	+0.92	Rock Lake Shale - red-brown sandstone, thin bedded, well cemented, interbedded with silty shale, gradational lower contact
0.5	0.15	Bolton Bed - orange-yellow skeletal calcarenite, thin bedded, slabby, fairly coarse grained, fossil grains unabraded, interbedded with shale, gradational lower contact
1.0	0.30	Bolton Bed - orange-yellow skeletal calcarenite, slabby, single bed, fairly coarse grained, fossil grains unabraded, sharp lower contact
1.5	0.46	* Eudora Shale - gray shale, calcareous, fissile, hard, fossiliferous, gradational lower contact
1.0	0.30	* Eudora Shale - gray shale, clay rich,

fissile, scattered limonite concretions, fossiliferous

Base of section

Measured Section 11 - Quarry north of Tyro, Montgomery Co., Kansas.
(SW1/4 SE 1/4 Sec. 30, T.34 S, R.15 E, Tyro Quad.)
after Heckel, 1978 and Malinky and Mapes, 1982

feet	meters	
+3.0	+0.92	Eudora-Rock Lake member - gray-brown shale, silty, fissile, scattered fossils, sharp lower contact
3.75	1.14	Eudora-Rock Lake member - red-brown sandstone, well cemented, cross- and planar-bedded, lowest 1.5 ft. (0.45 m) conglomeratic with shale and oolitic limestone clasts, abraded fossils present, angular erosional lower contact
1.0	0.30	Eudora Shale - dark gray-black shale, papery, phosphate nodules at base, pyrite present, replacing scattered fossil grains, restricted fauna, gradational lower contact
1.0	0.30	* Eudora Shale - gray shale, clay rich, fissile, abundant small fossils, sharp lower contact

0.1	0.03	Tyro Oolite - tan skeletal calcitutite, muddy, fine grained, abundant fossil grains, gradational lower contact
9.25	2.82	Tyro Oolite - gray-tan oolite, spar cemented, dense, uniform southwesterly dipping cross beds, both coated and uncoated fossil grains

Base of section

Measured Section 12 - Road cut on Oklahoma State Route 10, west of Copan, Washington Co., Oklahoma. (N1/2 of W.Line, Sec. 18, T.28 N, R.13 E, Copan Quad.)

feet	meters	
+3.0	+0.92	* Upper Wann Formation (Captain Creek Limestone) - gray shale, tan weathering, fissile, highly fossiliferous, residuum at top of phosphate nodules and limonite fragments, float of orange skeletal calcilutite, muddy, abundant fossil grains, gradational lower contact
0.8	0.24	* Upper Wann Formation (Captain Creek Limestone) - orange-gray shale, calcareous, hard, blocky, abundant fossil grains, gradational lower contact
3.75	1.14	* Upper Wann Formation (Captain Creek Limestone) - gray shale, tan weathering, fissile, highly fossiliferous
10.75	3.28	covered interval
1.25	0.38	Upper Wann Formation (Captain Creek Limestone) - orange-tan skeletal

		calcilutite, muddy, poorly exposed
12.0	3.66	covered interval
5.75	1.75	Upper Wann Formation (Captain Creek Limestone) - orange-tan shale, calcareous, highly fossiliferous, interbedded with skeletal calcarenite, slabby, fairly coarse grained, abundant large fossil grains, poorly indurated

Base of section

Measured Section 13 - Road cut on U.S. Route 75, west side of hill, east of Copan, Washington Co., Oklahoma. (C-W.Line, Sec. 10, T.28 N, R.13 E, Copan Quad.)

feet	meters	
+9.0	+2.75	Upper Wann Formation (Eudora Shale) - light gray shale, poorly exposed, abundant sandstone float
3.75	1.14	Upper Wann Formation (Eudora Shale) - light gray shale, slightly silty, fissile, highly fossiliferous, single layer of dark red limonite concretions at base, concretions sparsely fossiliferous gradational lower contact
8.0	2.44	Upper Wann Formation (Eudora Shale) - light gray shale, slightly silty, fissile, fossiliferous, scattered limonite concretions, poorly exposed
17.5	5.34	covered interval
12.0	3.66	* Upper Wann Formation (Eudora Shale) - gray-dark gray shale, fissile, fossiliferous, diverse fauna, abundant

		dark red limonite concretions, concretions fossiliferous, gradational lower contact
10.0	3.05	Upper Wann Formation (Eudora Shale) - dark gray shale, fissile, sparsely fossiliferous, restricted fauna, abundant red and orange limonite concretions, concretions sparsely fossiliferous, gradational lower contact
13.0	4.0	Upper Wann Formation (Eudora Shale) - dark gray to black shale, fissile, sparsely fossiliferous to barren, prolific orange and red limonite concretions

Base of section

Measured Section 14 - Excavation for farm stock pond, south side of hill, east of Copan, Washington Co., Oklahoma (NW1/4 NW1/4 SW1/4 Sec.10, T.28 N, R.13 E, Copan Quad.)

feet	meters	
+4.0	+1.22	Upper Wann Formation (Eudora Shale) - light gray shale, very silty, barren of fossils, poorly exposed, abundant float blocks and boulders of red-brown sandstone, well cemented, sharp lower contact
0.5	0.15	Upper Wann Formation (Eudora Shale) - buff-tan skeletal calcarenite, muddy, coarse grained, abundant large fossil grains, sharp lower contact
12.5	3.81	* Upper Wann Formation (Eudora Shale) - light gray shale, silty, fissile, highly fossiliferous, gradational lower contact
5.8	1.77	* Upper Wann Formation (Eudora Shale) - gray shale, fissile, highly fossiliferous, prominent single layer of dark red limonite concretions at top, scattered dark red

concretions throughout, concretions fossiliferous

Base of section

Measured Section 15 - Road cut on section road, east of Copan, Washington Co., Oklahoma.
(C-E.Line, Sec. 15, T.28 N, R.13 E, Copan Quad.)

feet	meters	
+10.5	+3.2	* Upper Wann Formation (Eudora Shale) - gray shale, fissile, highly fossiliferous, scattered red limonite concretions, limestone float at top, gradational lower contact
6.5	1.98	* Upper Wann Formation (Eudora Shale) - gray shale, fissile, highly fossiliferous, abundant red limonite concretions, gradational lower contact
11.6	3.54	Upper Wann Formation (Eudora Shale) - gray shale, fissile, abundant red and orange limonite concretions, sparsely fossiliferous, poorly exposed

Base of section

Measured Section 16 - Hillside exposure along county road, west of Dewey, Washington Co., Oklahoma. (NW1/4 SE1/4 SW1/4 Sec. 13, T.27 N, R.12 E, Bartlesville North Quad.)

feet	meters	
+4.0	+1.22	Upper Wann Formation (Eudora Shale) - olive gray weathered shale, fossiliferous, diverse fauna, scattered orange limonite concretions, concretions fossiliferous, poorly exposed
11.75	3.58	covered interval
6.75	2.06	Upper Wann Formation (Eudora Shale) - gray-dark gray shale, fissile, sparesly fossiliferous, restricted fauna, abundant orange limonite concretions, concretions fossiliferous, sharp lower contact
2.8	0.85	Upper Wann Formation (Eudora Shale) - black shale, platy to papery, brittle, barren of macrofossils, profusely abundant phosphate nodules

Base of section

MATERIALS STUDIED

BWC: CH1 - CH715

SUI: Stratigraphic Collections, Stanton Formation material from the Tyro Quarry, Rollins' Farm Pond, and Patterson's Hog Farm.

UNSM: 7942-7945, 7948-7951, 7953-7955, 9743-9897, 9976-9998, 11856-11859, 11929-11934, 13330, 14085-14120, 14155-14220, 14251-14401, 14405-14408, 14423-14424, 14670-14798, 15254-15347, 15350, 15584-15650, 15691, 15725-15866, 15989-16347, 16352-16450, 16457-16468, 16486-16496, 17855-17917, 17962-18012, 18018-18020, 18040-18050, 18053-18086, 19546-19581, 19584-19658, 19661-19730, 22113, 22151, 22157, 22271-22272, 22348-22350 22356-22698, 26631-27036