CONODONT DISTRIBUTION, PALEOECOLOGY, AND PRELIMINARY BIOSTRATIGRAPHY OF THE UPPER CHEROKEE AND MARMATON GROUPS (UPPER DESMOINESIAN, MIDDLE PENNSYLVANIAN) FROM TWO CORES IN SOUTH CENTRAL IOWA

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Geology at the May, 1982 graduation.

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INTRODUCTION

Studies of Middle and Upper Pennsylvanian conodonts in the Midcontinent region have not proceeded toward the goal of developing an effective biostratigraphy as rapidly as have conodont studies in other parts of the geologic column. Early work summarized by Ellison (1941) showed that almost all of the ramiform elements he identified range unchanged from the upper Cherokee Group of the Desmoinesian Stage to the lower Shawnee Group of the Virgilian Stage (Fig. 1). Although considerable variation was noted among the platform elements, their use in discrimination of strata below the group level was considered to be unreliable. In part, this resulted from the observation that within any one formation, there exist striking variations in the vertical distribution of the conodont faunas. Merrill (1962, 1968, 1973) postulated that the observed variation was the result of a high degree of environmental control. This concept ran contrary to the generally accepted view that conodonts were probably pelagic, and because of this, their distribution was likely to be facies independent (e.g., Müller, 1962).

Merrill (1973) described empirical biofacies for groups of Pennsylvanian conodont taxa, which are now known to represent multielement apparatuses rather than provincial faunas as he had implied. Von Bitter (1972) studied collections spanning the Shawnee Group of the lower

Figure 1

Pennsylvanian stratigraphic nomenclature in south-central Iowa (after Ravn *et al.*, in prep.).

PENNSYLVANIAN STRATIGRAPHIC NOMENCLATURE IN SOUTH CENTRAL IOWA

SYSTEM	STAGE (Time)	SUPERGROUP (Rock)	GROUP	FORMATION
PENNSYLVANIAN	VIRGILIAN	VIRGIL	WABAUNSEE	
			SHAWNEE	TOPEKA
				CALHOUN
				DEER CREEK
				TECUMSEH
				LECOMPTON
				KANWAKA
				OREAD
			DOUGLAS	
	MISSOURIAN	MISSOURI	LANSING	STANTON
				VILAS
				PLATTSBURG
			KANSAS CITY	BONNER SPRINGS
				WYANDOTTE
				LANE
				IOLA
				CHANUTE
				DRUM
				CHERRYVALE
			BRONSON	DENNIS
				GALESBURG

cont.

SYSTEM	STAGE	SUPERGROUP	GROUP	FORMATION	MEMBER
PENNSYLVANIAN	MISSOURIAN	MISSOURI	BRONSON	SWOPE	Bethany Falls Hushpuckney Middle Creek
				LADORE	
				HERTHA	
				PLEASANTON	
	DESMOINESIAN	DES MOINES	MARMATON	"LENAPAH"	Cooper Creek Unnamed Sh. Unnamed Ls.
				NOWATA	
				ALTAMONT	Worland Lake Neosho Amoret
				BANDERA	
				PAWNEE	Coal City Mine Creek Myrick Sta. Anna
				LABETTE	Mystic C.
				STEPHENS FOREST	Higginsville Unnamed Sh. Houx Little Osage
				MORGAN SCHOOL	Summit C.
				MOUSE CREEK	Blackjack Cr. Excello
			CHEROKEE	SWEDE HOLLOW	Mulky C. Bevier C. Wheeler C. Ardmore Ls. Oakley Sh. Whitebreast C.
				FLORIS	Carruthers C. Unnamed C. Laddsdale C.
	DESMOINESIAN/ATOKAN			KALO	Cliffland C. Blackoak C.
				KILBOURN	

unconformity

Figure 1.

Virgilian Stage in northeastern Kansas in an effort to evaluate and quantify Merrill's biofacies. His cluster analyses revealed enough systematic variation to permit the partial reconstruction of at least six multielement apparatuses and showed a high degree of mutual exclusion between platform elements of Cavusgnathus (=Adetognathus of this paper) and those of Streptognathodus (included in Idiognathodus of this paper). Baesemann (1973) studied collections spanning the Missourian Stage of northeastern Kansas and used restricted mutual occurrences to delineate the apparatus constituents of the genera Adetognathus, Aethotaxis, Ozarkodina (=Anchignathodus of this paper, =Pennsylvanian and younger Hindeodus of Sweet, 1977), Idiognathodus, and Idioprioniodus. Heckel and Baesemann (1975) used the distributional data from Baesemann (1973) in combination with a newly integrated environmental interpretation of the Missourian sequence to produce a model for Missourian conodont paleoecology that was largely patterned after the general model of vertical stratification of living zones proposed by Seddon and Sweet (1971). They briefly discussed the probable relationship of their model to the upper Desmoinesian Marmaton Group, but noted both the lack of good understanding of the environmental sequence and the lack of comprehensive study of upper Desmoinesian conodonts since Ellison (1941). Merrill (1975) published an extensive study of Desmoinesian conodont faunas from northwestern Illinois, which showed certain aspects of their distribution in rocks equivalent to the Marmaton Group of the Midcontinent outcrop, but applied a different environmental interpretation to the lithologic succession.

It therefore seems appropriate to extend detailed knowledge of the succession of conodont faunas and lithotopes in which they are found downward from the work of Baesemann (1973) into the upper Desmoinesian strata of the Midcontinent sequence. The purpose of this study is threefold: 1) A detailed description of the succession of lithotopes and conodont faunas from the upper Cherokee Group through the Marmaton Group (late Desmoinesian) in a continuous stratigraphic section derived from two overlapping core segments in south central Iowa; 2) Interpretation of paleoenvironments, leading to the development of a working model for late Middle Pennsylvanian conodont paleoecology in light of recent depositional models for the origin of the cyclic Pennsylvanian sequence; 3) To describe in preliminary fashion the succession of conodont faunas found in the six exceedingly conodont-rich shales that occur in the sequence, which may be used as the basis for establishing definite correlation of the formations in which they are found along the Midcontinent outcrop and perhaps into adjacent basins.

Toward these goals, portions of two cores made available by the drilling program of the Iowa Geological Survey Coal Project have been extensively sampled for conodonts. The two cores studied are CP #22, drilled at SE¼, SW¼, SE¼, section 36, T70N, R19W, Appanoose County, and CP #37, drilled at NE¼, SE¼, NE¼, section 2, T72N, R26W, Clarke County, Iowa. They are situated about 40 miles (65 km) apart on the northeast side of the Forest City Basin (Fig. 2). The present erosional outcrop

Figure 2

Midcontinent Desmoinesian isopachous and outcrop map showing core locations and Pennsylvanian structural features (modified after O'Brien, 1977, Figure 2).

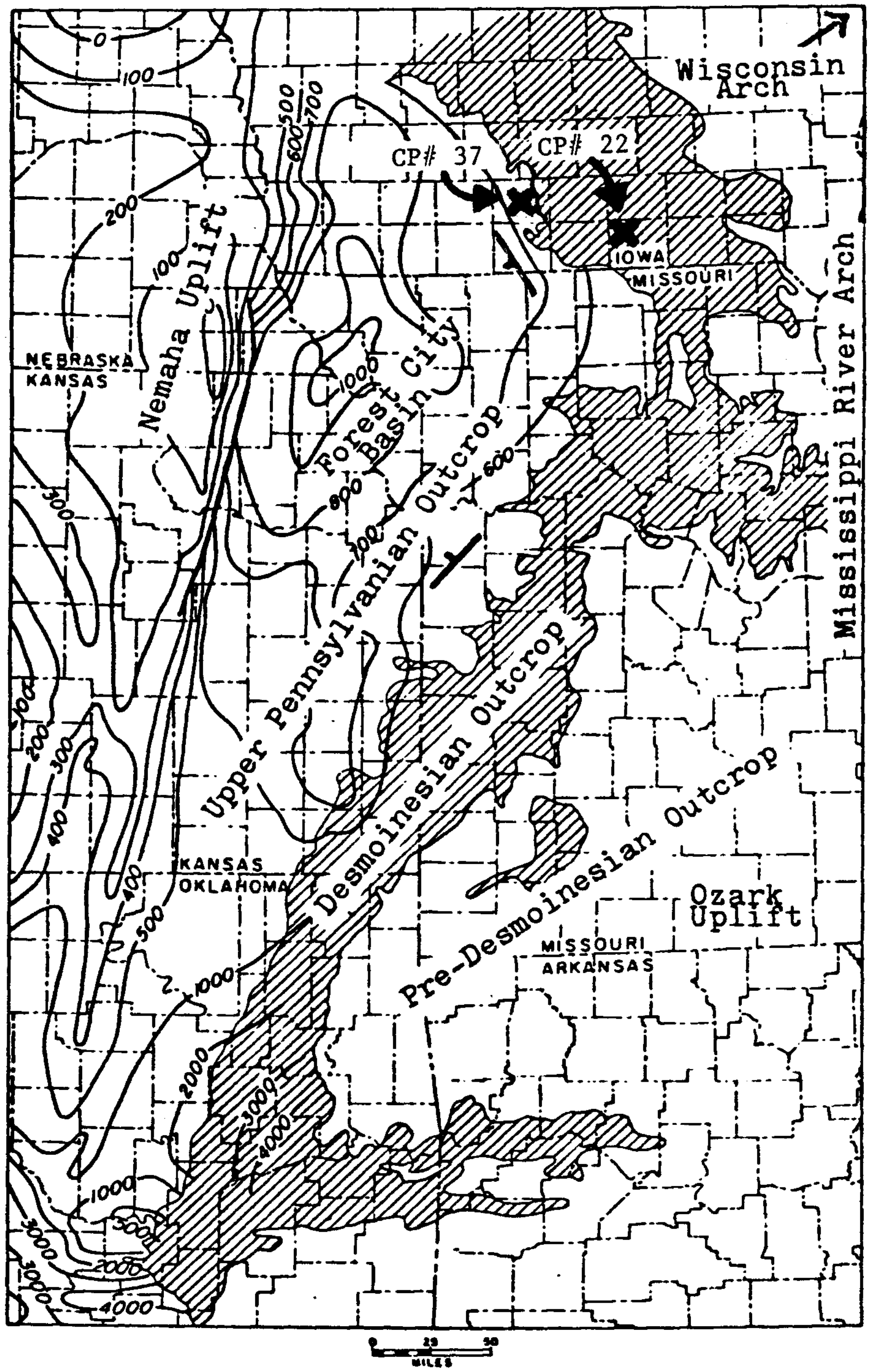

Wisconsin Arch
CP# 37
CP# 22
IOWA
MISSOURI
Mississippi River Arch
NEBRASKA
KANSAS
Nemaha Uplift
Forest City Basin
Upper Pennsylvanian Outcrop
Desmoinesian Outcrop
Pre-Desmoinesian Outcrop
KANSAS
OKLAHOMA
Ozark Uplift
MISSOURI
ARKANSAS
MILES

Figure 2.

roughly parallels the trend of depositional strike in south-central Iowa (Schenk, 1967) where basinward dip is to the southwest.

CP #22 encountered 425.5 feet of Pennsylvanian strata ranging from the Atokan Kilbourn Formation (Cherokee Group) to the Desmoinesian Altamont Formation (Marmaton Group) (Fig. 1). Ravn et al. (in prep.) illustrated portions of CP #22 as reference sections for the Kilbourn, Swede Hollow, Mouse Creek, Morgan School, and Stephens Forest Formations. The upper 204.5 feet were examined in this study, and include the latter four formations listed above, and the overlying Labette, Pawnee, Bandera, and Altamont Formations (Fig. 3). CP #37 encountered 636 feet of section ranging from the Desmoinesian Kalo Formation (Cherokee Group) to the Missourian Swope Formation (Bronson Group). The succession of Pawnee, Bandera, Altamont, Nowata, and "Lenapah" Formations overlaps with CP #22 to complete the Marmaton Group section examined for this study.

Individual conodont samples generally consisted of one-half of the 2-inch (5.4-cm) core, in continuous 0.5-foot vertical segments through portions thought to represent marine deposits, although smaller sample intervals were used where indicated by lithologic breaks. Spot samples at 1- or 2-foot intervals were taken from probable marginally marine shales. Samples ranged in weight from 200 to about 500 grams. Limestones were processed in a 9% Formic Acid solution; grey shales in Stoddard Solvent, and organic shales in commercially available sodium hypochlorite bleach. All samples were washed using a U.S. Standard Sieve Series 18 mesh (1 mm) upper screen and U.S. Standard Sieve Series 200

Figure 3.

Generalized columns showing stratigraphic intervals studied in cores CP# 22 and CP# 37, their correlation, and the cyclothems recognized. Intervals in brackets to right of columns show approximate sections illustrated in detail along with summary data on the distribution of conodonts and other fossil groups.

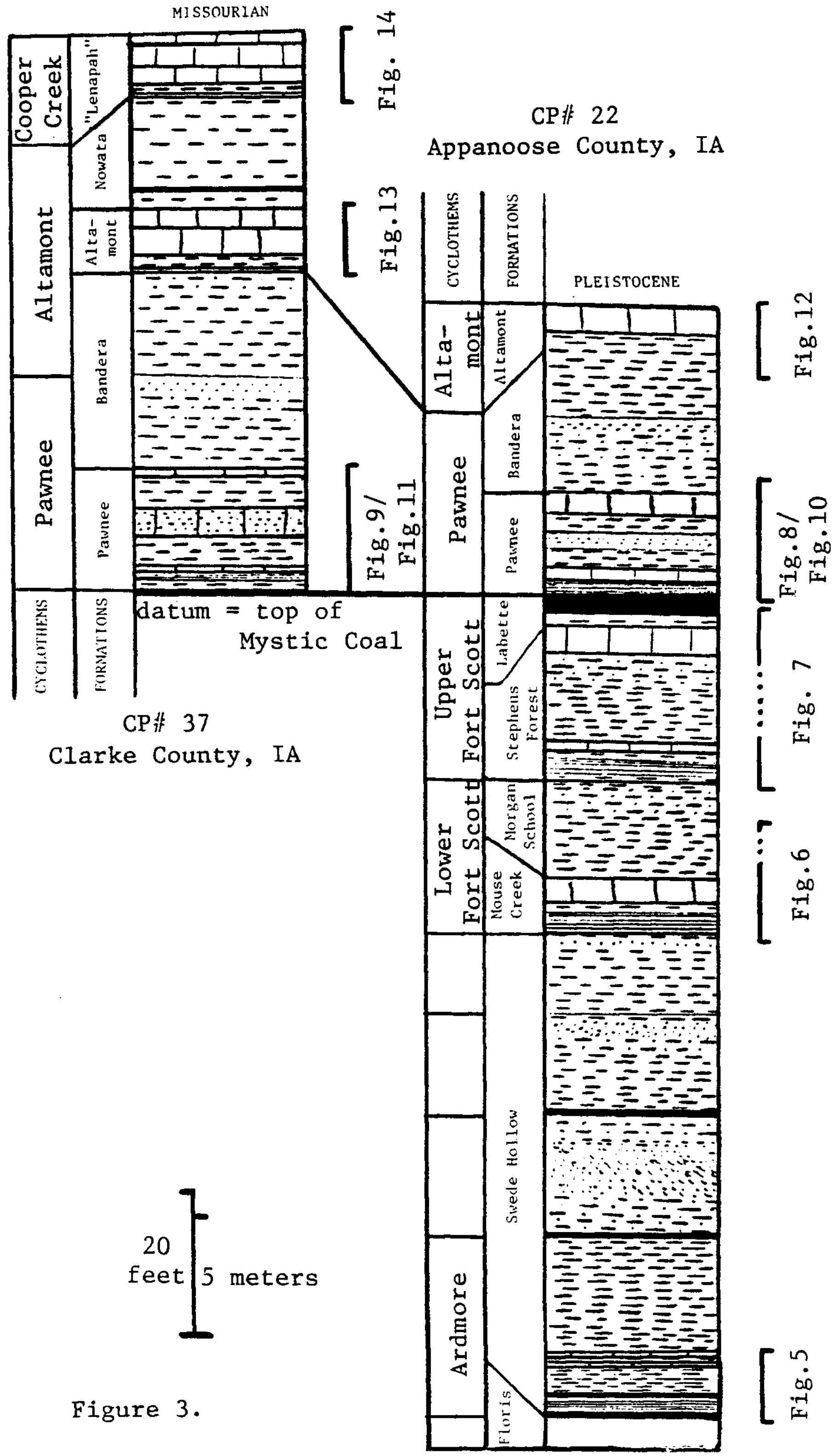

MISSOURIAN
Cooper Creek
"Lenapah"
Nowata
Altamont
Alta-mont
Bandera
Pawnee
Pawnee
CYCLOTHEMS
FORMATIONS
datum = top of Mystic Coal
CP# 37
Clarke County, IA
Fig. 14
Fig.13
Fig.9/ Fig.11
CP# 22
Appanoose County, IA
CYCLOTHEMS
FORMATIONS
PLEISTOCENE
Alta-mont
Altamont
Bandera
Pawnee
Pawnee
Upper Fort Scott
Labette
Stephens Forest
Lower Fort Scott
Morgan School
Mouse Creek
Swede Hollow
Ardmore
Floris
Fig.12
Fig.8/ Fig.10
Fig. 7
Fig.6
Fig.5
20 feet
5 meters

Figure 3.

mesh (0.075 mm) lower screen. Separation of large volume residues with tetrabromoethane greatly eased the burden of picking. A total of 208 samples have been examined, and in excess of 22,000 identifiable conodont elements assigned to nine multielement genera were recovered. Detailed element distribution is compiled on Plates 1-3. Conodont data are also presented in summary form along with the graphic section and information on distribution of other fossil groups in figures included in the descriptive portion of the text, as indicated on Figure 3.

STRATIGRAPHY

Many individual Pennsylvanian stratigraphic units occur in orderly vertical lithic sequences, and many such sequences are repeated through the succession. These sequences have historically been considered to represent cycles of sedimentation (Udden, 1912), and the basic repeating package of sediments is termed a cyclothem (Wanless and Weller, 1932). A cyclothem, particularly the ideal cyclothem as conceptualized by workers in the Illinois Basin (e.g., Willman and Payne, 1942), is considered to reflect a fluctuation in the relative stand of sea level. A number of recent studies (e.g., Crowell, 1978) have demonstrated widespread glaciation in the southern hemisphere during the late Paleozoic, and most modern Midcontinent workers accept the hypothesis of Wanless and Shepard (1936) that individual sea level fluctuations are related to episodic glacial maxima and minima, although the geometry and rate of subsidence of the depositional basins clearly exert broad control over the individual patterns of sedimentation that result. In any one area, in this case south-central Iowa, the succession of Middle Pennsylvanian strata is characterized by an increase in the effects of marine invasion upwards in the section that corresponds with the early "transgressive" portion of the Absaroka Sequence (Sloss, 1966).

Cherokee Group

Four formations of the Cherokee Group have recently been proposed by Ravn and others (in prep.), which reflect four major episodes of sedimentation, each characterized by different depositional regimes, and each showing the progressively increased effects of marine sedimentation. The base of the Kilbourn Formation (Fig. 1) is marked by a pronounced unconformity that separates the Absaroka Sequence from the underlying Kaskaskia Sequence of Late Devonian and Mississippian age. The Kilbourn is characterized by alluvial, fluvial and estuarine sediments that essentially represent the infilling of the erosional topography developed on the Mississippian surface. Fully marine sediments are apparently restricted to former valley axes and include dark shales and argillaceous skeletal calcilutites that occasionally contain thin zones of non-skeletal phosphate nodules.

The base of the overlying Kalo Formation is marked by the Blackoak Coal which is the lowest bed in the section that is traceable over most of south-central Iowa. The Kalo is characterized by two widespread coal horizons, the Blackoak and the Cliffland, which are split by localized detrital wedges and are usually overlain by marginally marine "prodeltaic" shales. The few, localized limestones that occur in the Kalo are generally argillaceous and/or arenaceous skeletal calcarenites.

In some areas, the lower portion of the overlying Floris Formation is similar to the Kalo, with several coals split by detrital wedges, but the coals are often overlain by thin marine shales and occasionally by skeletal calcilutites. The Floris is quite complex laterally, however, and includes thick channel sandstones that locally have replaced earlier Pennsylvanian strata. The upper part of the Floris, above the major channelling horizons, contains at least one and perhaps as many as three marine intervals that are somewhat more laterally extensive and appear to foreshadow the upper Desmoinesian eustatic cylcothems that are the subject of the present study.

The Swede Hollow Formation is the uppermost of the four subdivisions of the Cherokee Group proposed by Ravn and others (in prep.). The basal member, the Whitebreast Coal, is overlain by the Oakley Shale and Ardmore Limestone Members, a marine interval that has long been recognized as the most reliable marker horizon within the Cherokee Group (e.g., Moore, 1936). This interval is traceable across the Midcontinent from Oklahoma to Iowa and across the Illinois Basin into Indiana. The sequence of beds remains relatively constant across this large area and may be considered archetypical of the Illinois-type cyclothem discussed by Heckel (1977, pp. 1060-61). The stratigraphic sequence in the upper part of the Swede Hollow is characterized by two or more deltaic clastic wedges separated by coals that are generally less persistent and more variable laterally, but which, as a whole, form a package of relatively constant thickness across the larger Midcontinent area.

Marmaton Group

The stratigraphic sequence in the Marmaton Group and younger Pennsylvanian strata in the Midcontinent is characterized by formations dominated by marine limestones that alternate with detrital formations that represent nearshore to terrestrial environments. Cycles of sedimentation in these repeating deposits were recognized early by Moore (1936, 1949), who termed them megacyclothems. The Marmaton Group cycles have generally been less well known than Upper Pennsylvanian examples, in part due to the thinner limestones present and consequent lack of continuous exposures. Weller (1958) had difficulty relating the Marmaton cycles to younger Pennsylvanian cycles and considered them to be incompletely developed. Part of the difficulty may have arisen owing to his recognition of only four megacyclothems which corresponded with the then-recognized Fort Scott, Pawnee, Altamont and Lenapah limestone formations. In actuality, the Fort Scott in south-central Iowa contains the marine portions of two major depositional cycles and thus, five such cycles are present in the group. The revised stratigraphic nomenclature proposed by Ravn and others (in prep.) was designed to reflect this new understanding and is followed herein (Fig. 1). Major revisions are the inclusion of the Excello Shale Member with the Blackjack Creek Limestone in the lowermost Marmaton Mouse Creek Formation and the division of the remainder of the former Fort Scott into the Morgan School and Stephens Forest Formations.

Upper Desmoinesian Eustatic Cyclothems

Recent interpretations of the cyclothemic sequence in the Midcontient Middle and Upper Pennsylvanian stress the central position of the black phosphatic shale facies. Heckel (1977) presented a synthesis of arguments based on a wide variety of lithologic and paleontologic criteria in support of a deep water, yet still epicontinental, origin for the black phosphatic shale sandwiched between two marine limestones that characterizes typical "Kansas" cyclothems (Fig. 4), which are developed also along the Midcontinent outcrop into Iowa. More recently, Heckel (1980) presented a major regional synthesis of the paleogeography during deposition of a typical Upper Pennsylvanian cyclothem as a result of one complete eustatic rise and fall of sea level and described the manner in which the environmental model may be applied to the Illinois-type cyclothems (Fig. 4) that characterize the Marmaton Group. The basic cycle of 1) transgressive shale or limestone, 2) deepest-water shale, 3) regressive limestone, followed by 4) detrital influx (usually delta progradation) is supported by studies of carbonate petrology and diagenesis (Heckel, in review) and clay mineralogy (Schutter, in prep.) and has been applied to many Upper Pennsylvanian cycles (Ravn, 1981; Mitchell, 1981; Heckel, 1978; Heckel et al., 1979) and to some Middle Pennsylvanian cycles (Schenk, 1967; Price, 1981) along the Midcontinent outcrop belt.

The actual lithologic sequence in the six Upper Desmoinesian eustatic cyclothems that form the basis of this study contains some variations to the basic cycle that can readily be described in terms of the megacyclothemic nomenclature of Moore (1936) and Heckel and Baesemann (1975). In the idealized case of maximum cyclic development, Moore recognized five limestone members, which he designated by relative position as "lower", "middle", "upper", "super", and "fifth". The middle and upper limestone are separated by the most distinctive shale member, which usually contains the black, fissile, phosphatic facies,

Figure 4.

Generalized restored cross section of typical Upper Pennsylvanian eustatic cyclothem along axis of Midcontinent Sea. Shown are relations of members and facies between Kansas- and Illinois-type cyclothems and with marine deposits in Appalachian area and west Texas Basins. (after Heckel, 1980, Fig. 4).

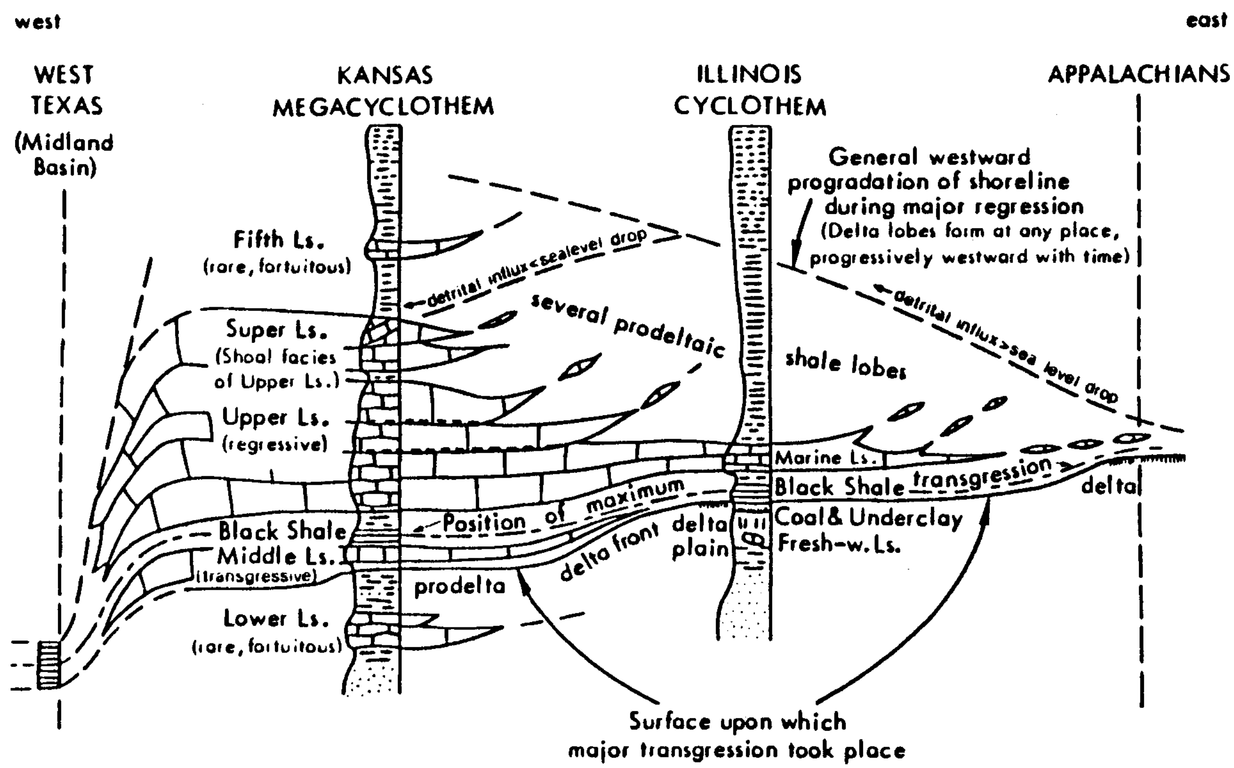

west
east
WEST TEXAS (Midland Basin)
KANSAS MEGACYCLOTHEM
ILLINOIS CYCLOTHEM
APPALACHIANS
General westward progradation of shoreline during major regression
(Delta lobes form at any place, progressively westward with time)
Fifth Ls.
(rare, fortuitous)
detrital influx<sealevel drop
several prodeltaic
shale lobes
detrital influx>sea level drop
Super Ls.
(Shoal facies of Upper Ls.)
Upper Ls.
(regressive)
Marine Ls.
Black Shale
transgression
delta
Position of maximum
Coal & Underclay
Fresh-w. Ls.
Black Shale
Middle Ls.
(transgressive)
delta front
delta plain
prodelta
Lower Ls.
(rare, fortuitous)
Surface upon which major transgression took place

Figure 4.

the only position this facies occupies in the sequence. In deference to its central position, Heckel (1977) referred to this member as the "core" shale, an appropriate term, especially in cyclothems in which the black facies is poorly developed or absent. Heckel and Baesemann (1975, p. 5067) noted that the "lower" and "fifth" limestones are rarely developed in Upper Pennsylvanian cyclothems. "Super" limestones occur in less than half of the Missourian cyclothems and were regarded by Heckel and Baesemann (ibid.) either as separate marine incursions or as parts of the upper limestone separated by fortuitous shales. Detrital units that separate the marine-dominated limestone-formation portions of the sequence are termed "outside" shales.

Each individual lithologic sequence in the six Upper Desmoinesian cyclothems studied generally contains three limestone members: middle, upper, and super. Lower limestones do not occur in these cyclothems, and a possible fifth limestone equivalent is noted in only one of the six cyclothems. In the ideal cyclothem, the lower boundary is usually marked by an unconformity, but in the cores examined only the lower four cycles (up through the Labette Shale in CP #37) contain obvious breaks in sedimentation (O'Brien, 1977). Generally, cyclothemic deposition is considered to commence with the formation of the rooted seat-rock below the coal horizon. Significant coals usually occur only at the top of the outside shale below the middle limestone, but local coals have also been noted below the super limestones, in particular, below the Higginsville and Coal City Members (Van Eck, 1965). The horizon of the transgressive middle limestone is readily apparent, but the precise character of the bed changes markedly upward in the Iowa section, progressing from thin marine shales to thicker shales and finally marine limestone. The core shale, which represents maximum inundation, is also readily apparent. All are phosphatic, but black, fissile facies are well-developed in only the lower four cyclothems studied. The upper limestone members are the most persistent laterally, and historically are the best recognized in the sequence. This study also indicates that super limestones are developed in five of the six cyclothems. Rather than merely parts of the upper limestone separated by the intervention of shales during relative stillstand of sea level, most of these apparently resulted from minor eustatic transgressive events.

LITHOLOGIC SUCCESSION
AND CONODONT DISTRIBUTION

Swede Hollow Formation

The Swede Hollow Formation is the uppermost of four subdivisions of the Cherokee Group recognized by Ravn and others (1982). It consists of strata associated depositionally with the youngest major eustatic marine cyclothem of the Cherokee Group along with several overlying deltaic cyclothems. In southeastern Iowa, the unit is generally consistent in thickness, averaging about 100 feet (31 m), and the base is marked by the laterally persistent Whitebreast Coal Member. Overlying the Whitebreast Coal are the Oakley Shale and Ardmore Limestone Members, a couplet that represents the marine eustatic core of a cyclothem analogous to the Excello Shale-Blackjack Creek Limestone couplet of the lower Marmaton Group. The remainder of the formation includes at least three clastic wedges of probable deltaic origin that are separated by two laterally traceable coals, the Wheeler and Bevier Coal Members. The top of the formation is marked by the Mulky Coal Member and/or the base of the overlying Excello Shale Member of the Mouse Creek Formation.

Whitebreast Coal Member

The Whitebreast Coal is notable for its lateral persistence and uniformity of thickness in southeastern Iowa. In CP #22, it is approximately one foot thick (Fig. 5), which is an average value for the area. R. L. Ravn (pers. comm.) examined the miospore assemblage of the unit and biostratigraphically confirmed the previous lithostratigraphic correlations of the Whitebreast with the Colchester (No. 2) Coal of the Illinois Basin, and with the Croweburg Coal in Kansas and Missouri.

Oakley Shale Member

The Oakley Shale in CP #22 is 2.2 feet thick and consists of black, fissile shale with common nonskeletal phosphate in small granular nodules and lamellae, especially in the middle portion. Just above the base is a 0.3-foot thick heavily pyritic dolomite nodule or lenticular bed with septarian calcite fracture fillings. This sample (22Y) could be only partially disaggregated, and the residue contains only fragments of conodonts. The basal sample of the shale yielded about 1200 conodont elements/kilogram. The abundance increases in a three-inch zone in the lower middle portion of the shale (sample 22W) to an extrapolated 2770 elements/kilogram. The increase is largely due to the abundant and restricted occurrence of platform and ramiform elements of *Gondolella*, which constitute about 75 percent of the total recovered in that sample. The lower portion of the shale also contains *Idiognathodus* and *Neognathodus* with their platform elements present in a ratio of just over three to one except in sample 22V which, despite an overall lower extrapolated abundance, yielded a ratio approaching 1:1. *Idioprioniodus* elements make up the remainder of the fauna.

The upper portion of the Oakley in CP #22 differs from lower Marmaton Group black shales in that the contact with the overlying Ardmore

Figure 5

Distribution of conodonts and other fossils in the Swede Hollow Formation CP# 22. Lithologic symbols standard except for;

Phosphorite nodules -

Root traces -

Chondrites-type burrows -

Conodont genera are abbreviated as follows:

Adetognathus - Ad, *Aethotaxis* - At, *Anchignathodus* - An, *Diplognathodus* - Di, *Gondolella* - Go, *Idiognathodus* - Ig, *Idioprioniodus* - Ip, *Neognathodus* - Ng, *Stepanovites* - St.

Note change in scale at left side of logarithmic abundance curve. Weighted distribution of the conodont genera was calculated on the basis of the maximum abundance of platform or any other paired element in the apparatus reconstruction. Distribution of other fossil groups is based on observations from coarse residues of conodont samples and, in part, from thin section descriptions of O'Brien (1977) for CP #37.

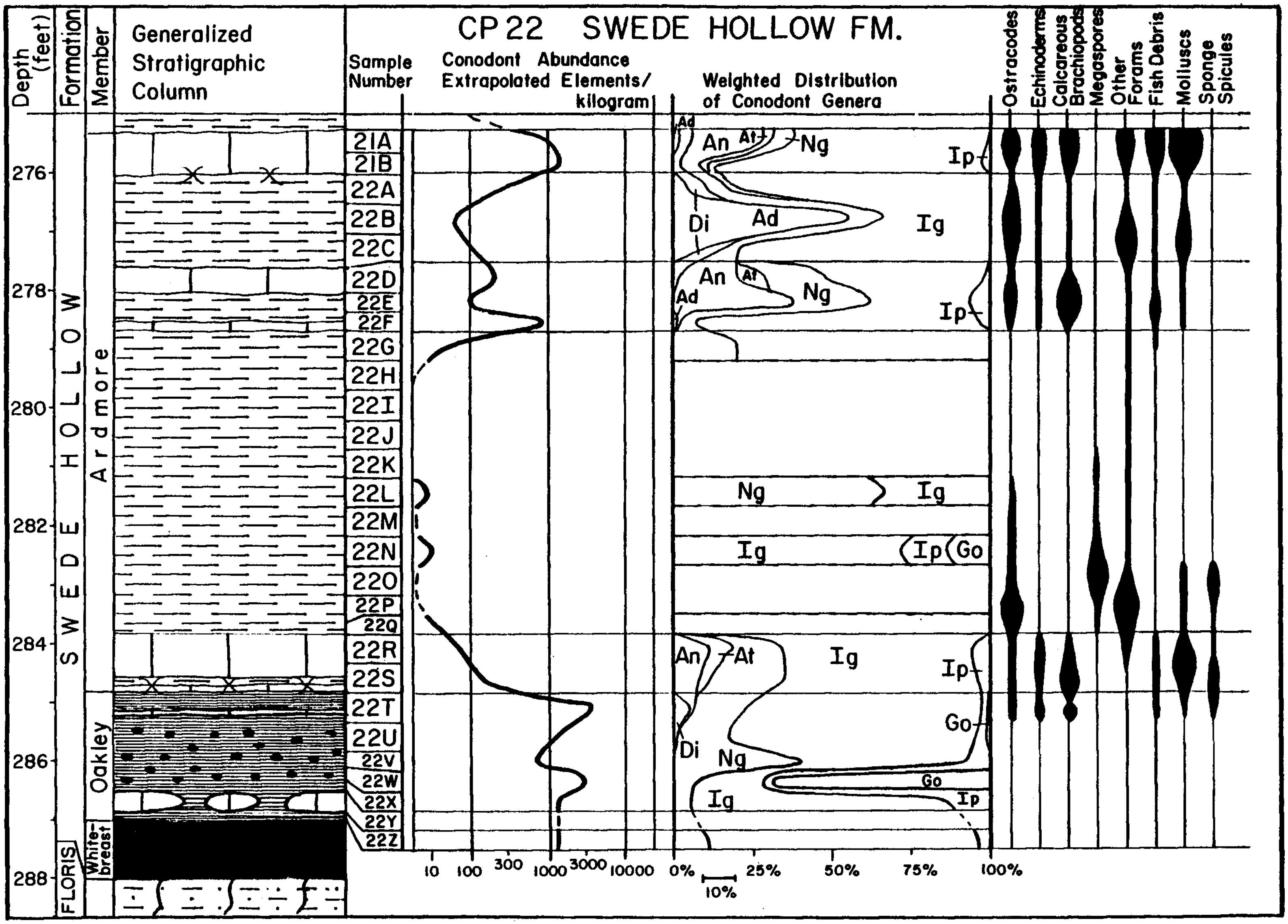

CP 22 SWEDE HOLLOW FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Megaspores
Other Forams
Fish Debris
Molluscs
Sponge Spicules
276
278
280
282
284
286
288
SWEDE HOLLOW
FLORIS
Ardmore
Oakley
White-breast
21A
21B
22A
22B
22C
22D
22E
22F
22G
22H
22I
22J
22K
22L
22M
22N
22O
22P
22Q
22R
22S
22T
22U
22V
22W
22X
22Y
22Z
10
100
300
1000
3000
10000
0%
10%
25%
50%
75%
100%
Ad
An
At
Ng
Ip
Di
Ig
Go

Figure 5.

Limestone is interbedded. The uppermost sample from the black facies (22T) contains a thin, lenticular, medium grey, skeletal calcarenite composed largely of brachiopod fragments with common bryozoans, echinoderm debris, molluscs and ostracodes. The shale in this sample yielded a second peak of abundance, containing an extrapolated 3500-plus elements/kilogram. The fauna from the upper portion of the black shale is dominated by platform elements of *Idiognathodus* and *Neognathodus* in a ratio of about 3.5:1. *Diplognathodus* elements form a conspicuous part of the fauna with lesser numbers of *Idioprioniodus* elements, and rare *Gondolella* and *Anchignathodus* platforms.

Ardmore Limestone Member

The Ardmore Limestone in southeastern Iowa usually displays a three-part subdivision consisting of two limestone horizons separated by a laterally persistent shale (Ravn *et al.*, 1982). In CP #22, both the upper and lower limestones are represented by multiple beds (Fig. 5). The lower limestone is one foot thick and consists of two beds of medium grey, skeletal calcilutite separated by a thin bioturbated, dark grey, slightly silty shale parting. The extrapolated conodont abundance decreases upward, from over 100 to about 50 elements/kilogram. In addition to *Idiognathodus*, *Neognathodus* and minor *Idioprioniodus*, *Anchignathodus* and *Aethotaxis* are present.

The middle shale interval of the Ardmore Limestone is about five feet thick, dark grey, sparsely fossiliferous in the lower portion, and increasingly silty upward. The lower portion sporadically yielded *Idiognathodus*, *Neognathodus*, and minor *Gondolella* platforms and

Idioprioniodus elements, as well as ramiform fragments. Extrapolated abundance is very low, however, only about 10/kilogram. Conodont elements are absent in the upper middle portion of the shale, but small numbers of Idiognathodus and Neognathodus platforms were found in the uppermost sample.

The upper limestone horizon of the Ardmore in CP #22 includes three limestone beds. The lower two thin beds are medium grey, slightly argillaceous, skeletal calcilutite that are separated by 0.5 feet of medium dark grey, calcareous, fossiliferous shale. The upper bed is nine inches thick, massive, light medium grey skeletal calcilutite, mottled by bioturbation, with a diverse macrofauna including corals and trilobites, and chondrites-type burrows affecting the lower contact. It is separated from the lower two beds by 1.7 feet of medium grey, silty shale that contains abundant ostracodes, forams, and molluscs.

Conodont elements range throughout the upper limestone interval of the Ardmore. Extrapolated abundances, however, vary greatly. The lower-most sample (22F) yielded about 800 elements/kilogram but the overlying calcareous shale and limestone contained only about 100 and 200 elements/kilogram, respectively. This interval yielded Idiognathodus, Neognathodus, Anchignathodus and minor Idioprioniodus elements with rare Adetognathus in only the lowermost sample. Diplognathodus and Aethotaxis elements occur in the upper of the two limestone beds. The middle shale bed of the upper limestone interval contains a sharply different fauna. Adetognathus increases to dominance relative to Idiognathodus in the central portion, with minor Anchignathodus ranging throughout. This central zone yielded the lowest extrapolated abundance, only about 40 elements/kilogram. Minor Diplognathodus occur near the base of the shale and also near the top with rare Neognathodus. Extrapolated abundance increases from about 200 elements/kilogram in the upper portion of the shale to about 1400/kilogram in the lower portion of the upper limestone bed. This bed yielded a well-preserved fauna which, although dominated by Idiognathodus platform and ramiform elements, contains representatives of all the individual element types included in Anchignathodus and Aethotaxis, as well as minor Neognathodus, Diplognathodus, and Idioprioniodus elements. Rare Adetognathus occur only in the upper one-half of the bed, and total abundance decreases slightly upward.

Wheeler, Bevier and Mulky Coal Members and Associated Strata

Overlying the Ardmore Limestone are three clastic wedges, each with a named coal member at the top. The first wedge overlies the uppermost bed of the Ardmore and consists of approximately 19 feet of medium grey, silty shale with the Wheeler Coal at the top. The lower 2.0 feet contain sparse fossil debris, but unfortunately, this shale was not sampled initially, and the core has since been rendered unavailable due to other research purposes.

The middle portion of this grey shale is mottled maroon in color suggesting partial oxidation related to subaerial weathering, probably related to soil formation. Near the top, the shale becomes poorly stratified and rooted, grading upward to the mudstone seatrock of the

Wheeler Coal. The Wheeler in CP #22 is 1.4 feet thick. It is overlain by the second clastic wedge, which consists of approximately 18 feet of thinly interbedded medium grey, argillaceous siltstone and light grey, fine grained, slightly argillaceous sandstone. This unit is cross-bedded and sole-marked in the lower portion, and coarsens slightly upward, grading to massive, argillaceous, rooted sandstone in the upper portion. Near the top, the sandstone grades into the rooted mudstone seatrock of the Bevier Coal. The Bevier is 1.25 feet thick in the core.

The Bevier Coal is overlain by the third clastic wedge, which includes in the lower portion a 35-foot-thick coarsening-upward sequence that grades from medium dark grey, silty shale through thinly interbedded shale and cross-laminated sandstone to massive light grey, fine grained, calcareous cemented sandstone. The shale in the lower 4.0 feet contains plant fossils and pyritized pelecypods. A spot sample taken immediately above the Bevier Coal (16A, Plate 1) confirms the presence of small numbers of conodont elements. The fauna consists mainly of Idiognathodus elements, but includes Adetognathus elements and Neognathodus platforms. The massive sandstone grades upward through a rooted siltstone to a silty mudstone that contains several poorly defined smut zones, probably equivalent to a coal horizon farther basinward. The upper portion of the third clastic wedge includes an additional coarsening-upward clastic sequence that grades from mottled maroon shale by thin interbedding to fine grained, argillaceous, calcareous sandstone that in turn grades upward into rooted mudstone seatrock of the Mulky Coal. The Mulky, however, is represented by only a thin coal smut in this core.

Mouse Creek Formation

The Mouse Creek Formation (Ravn et al., 1982) has recently been defined to include marine strata associated with the lowermost depositional cycle of the Marmaton Group (the lower Fort Scott Cyclothem of O'Brien, 1977). In southeastern and south central Iowa, the Mouse Creek is a thin unit, ranging from about 4.0 to 7.0 feet, which includes two laterally persistent members, the distinctive black Excello Shale and the overlying Blackjack Creek Limestone.

Excello Shale Member

In CP #22, the Excello Shale is 2.7 feet thick and rests, apparently conformably, on a thin coal smut considered to be equivalent to the horizon of the Mulky Coal (Fig. 6). The Excello exhibits a three-part subdivision which parallels that described throughout the southern Midcontinent by James (1970), although he did not examine the unit in Iowa. The lower portion, considered by James to be transgressive in nature, is represented in the core by less than 0.2 foot of dark grey, slightly silty shale with minor carbonaceous plant debris. The middle portion, 1.5 feet thick, is dark green-grey to black, laminated clay-shale with abundant lenses and lamellae of granular, nonskeletal phosphate and no apparent macrofauna. The contact between the middle and upper portions is a rapid gradation. The upper portion is 1.0 foot thick and consists of mottled medium grey and light to medium grey-green, silty shale with common calcareous brachiopod debris. James described the upper portion of the Excello as a bioturbated interval and this in part may account for the mottled coloration and slightly

Figure 6.

Distribution of conodonts and other fossils in the Mouse Creek Formation in CP# 22. See figure 5 for explanation.

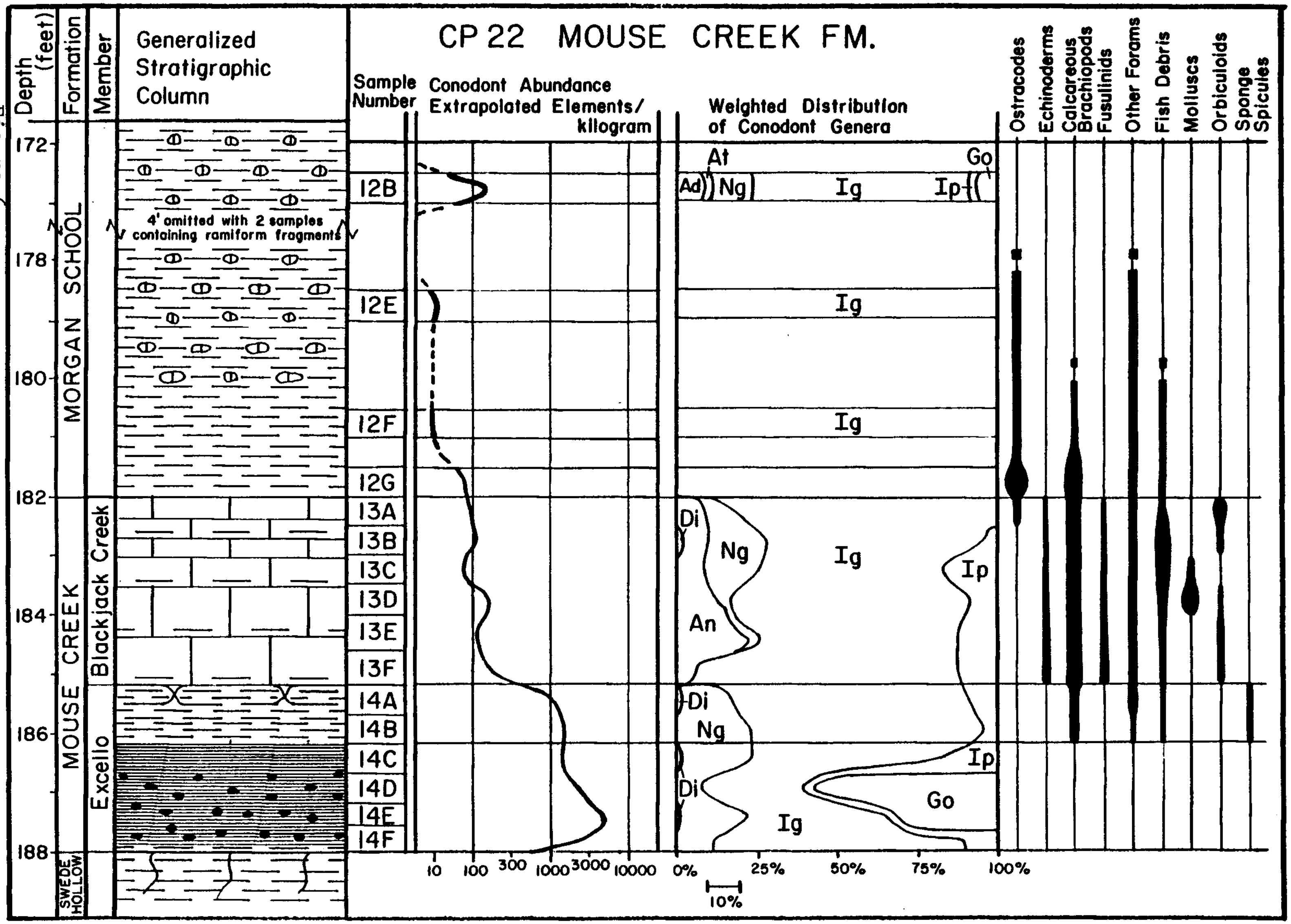

CP 22 MOUSE CREEK FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/ kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Orbiculoids
Sponge Spicules
172
178
180
182
184
186
188
MORGAN SCHOOL
MOUSE CREEK
SWEDE HOLLOW
Blackjack Creek
Excello
4' omitted with 2 samples containing ramiform fragments
12B
12E
12F
12G
13A
13B
13C
13D
13E
13F
14A
14B
14C
14D
14E
14F
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
10%
At
Go
Ad
Ng
Ig
Ip
Di
An

Figure 6.

disturbed bedding observed in the core, but the only indisputable bioturbation noted is a zone of chondrites-type burrows that extend downward from the base of the overlying Blackjack Creek Limestone.

The Excello Shale yielded an extrapolated abundance in excess of 1000 elements/kilogram in each of six samples. Idiognathodus, Neognathodus and Idioprioniodus occur through the entire interval. The ratio of Idiognathodus platforms to Neognathodus is over 5:1 near the top and bottom, but drops to about 2:1 in zones in the middle of the shale. Gondolella has a narrower vertical range, occurring only in the middle two samples from the black phosphatic clayshale facies. The presence of Gondolella in those samples coincides with an increase in the overall abundance to an extrapolated maximum of 5130 elements/kilogram in sample 14E. In the overlying sample, 14D, Gondolella elements constitute in excess of 50% of the total number recovered, and elements of the other three genera are slightly decreased in abundance relative to the other Excello samples. Diplognathodus occurs sporadically in the Excello, but is extremely rare, represented by a total of three specimens.

Blackjack Creek Limestone Member

The Blackjack Creek Limestone Member in CP #22 is 3.2 feet thick (Fig. 6). It is dominantly a massive green-grey, argillaceous, skeletal calcilutite with a diverse macrofauna and probable bioturbation expressed by light green-grey, argillaceous mottling. The upper portion includes two thin beds of light medium grey, slightly argillaceous calcilutite with contacts disturbed by soft sediment deformation and/or bioturbation.

The extrapolated total number of elements recovered from the Blackjack Creek Limestone is greatly reduced compared to the underlying shale, averaging only about 100 elements/kilogram, and abundance tends to decrease slightly upward in the unit. The conodont fauna is numerically dominated by *Idiognathodus* elements. *Anchignathodus* also ranges throughout the Blackjack Creek, but is not found in the overlying or underlying shales. *Idioprioniodus* elements form a minor, but consistent part of the fauna in the lower and middle portions of the member, but diminish rapidly to absence in the uppermost sample examined. *Neognathodus* P elements, on the other hand, occur in significant numbers only in the upper one-half of the member, and diminish downward to absence in the lowermost sample. *Diplognathodus* again is a rare element of the fauna, represented by only a single specimen.

Morgan School Shale

The Morgan School Shale (Ravn *et al.*, 1982) constitutes the terrestrial to marginally marine clastic part of the Little Osage Shale as previously defined, and is associated depositionally with the Mouse Creek Formation. It is a laterally variable unit in south central Iowa, ranging from 1.0 foot to about 20.0 feet thick. The Summit Coal Member, at the top of the formation, is usually poorly developed in Iowa, but a laterally persistent smut zone distinctly marks its horizon.

In CP #22, the Morgan School Shale is 16.3 feet thick and consists of a single, coarsening upward clastic sequence (Fig. 6). The lower 2.0 feet are light green-grey, slightly silty shale with common calcareous brachipod debris and ostracodes. Extrapolated conodont abundance diminishes rapidly from about 80/kilogram at the base to less than 10/kilogram, and the fauna consists almost entirely of *Idiognathodus* platform elements. The next approximately 10 feet grades imperceptibly upward through silty shale to argillaceous siltstone and contains common carbonate nodules. The nodules are dominantly light grey calcilutite, locally dolomitic, up to three inches thick, some of which may represent disrupted lenticular beds. Spot samples through this interval yielded small numbers of *Idiognathodus* elements in most shale samples, but one sample, 12B, yielded an unusual conodont fauna from both the shale and carbonate nodules. The total of 64 elements recovered is dominated by *Idiognathodus* platforms, but includes platform elements of *Adetognathus*, *Anchignathodus*, and *Neognathodus*, as well as platform and ramiform elements of *Gondolella* and rare *Idioprioniodus* elements. All specimens in this mixed fauna are quite small and most are incomplete. The largest specimen recovered is an *Idiognathodus* P element 0.57 mm in length, which includes most of the blade.

The upper portion of the Morgan School consists of light green-grey argillaceous, rooted siltstone with small carbonate nodules that did not yield conodonts. About 0.75 foot below the top, the siltstone grades to a rooted, silty mudstone seatrock that fines upward and darkens in color. The top of the formation is marked by the half-inch thick, vitrain-rich Summit Coal bed (Fig. 7).

Stephens Forest Formation

The Stephens Forest Formation, as defined by Ravn and others (1982), encompasses the marine-dominated phase of the second depositional cycle

Figure 7.

Distribution of conodonts and other fossils in the Stephens Forest Formation in CP# 22. See figure 5 for explanation.

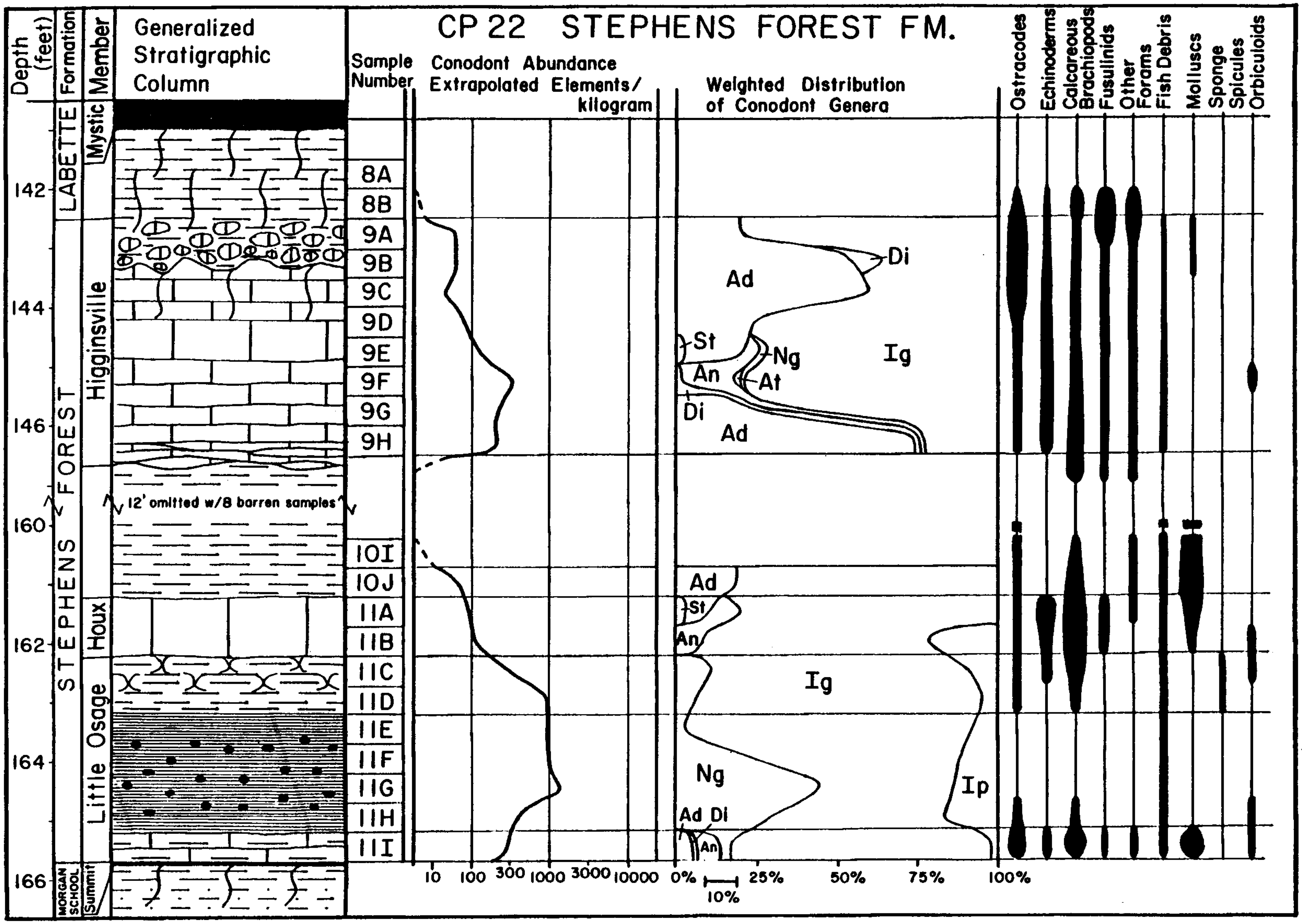

CP 22 STEPHENS FOREST FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Sponge Spicules
Orbiculoids
142
144
146
160
162
164
166
LABETTE
STEPHENS FOREST
MORGAN SCHOOL
Mystic
Higginsville
Houx
Little Osage
Summit
12' omitted w/8 barren samples
8A
8B
9A
9B
9C
9D
9E
9F
9G
9H
10I
10J
11A
11B
11C
11D
11E
11F
11G
11H
11I
10
100
300
1000
3000
10000
0%
10%
25%
50%
75%
100%
Ad
Di
St
Ng
Ig
An
At
Ip
Ad Di

Figure 7.

above the base of the Marmaton Group (the Upper Fort Scott cyclothem of O'Brien, 1977). In southeastern Iowa, the Stephens Forest is generally consistent in thickness, ranging from 23 to 27 feet, and contains four laterally persistent members, in ascending order, the Little Osage Shale, Houx Limestone, an unnamed shale, and Higginsville Limestone Members. The upper two members are more variable in character laterally than the lower two and are included in the Stephens Forest because, as Ravn and others (1982) indicate, the Higginsville constitutes a "super" limestone analogous to the Coal City Limestone Member of the Pawnee Formation (Price, 1981).

Little Osage Shale Member

The Little Osage Shale, as redefined by Ravn and others (1982), includes a three-part subdivision paralleling that observed in the Excello Shale. In CP #22, the lower, "transgressive" interval consists of 0.5 foot of thinly interbedded lenticular, medium grey, argillaceous skeletal calcilutites and calcarenites, and medium dark grey, silty shale with carbonaceous plant debris in the lower portion (Fig. 7). This grades rapidly upward into 2.0 feet of black, fissile clayshale with abundant non-skeletal phosphate nodules and lamellae. The middle portion grades rapidly to the upper, bioturbated interval, which consists of approximately one foot of dark grey, slightly silty, fossiliferous shale with chondrites-type burrows carrying lighter colored, slightly coarser argillaceous material downward from the base of the overlying Houx Limestone Member.

The conodont fauna of the lower, transgressive portion of the Little Osage Shale is dominated by Idiognathodus elements, with small numbers of platform elements of Adetognathus, Neognathodus and Anchignathodus elements present. Diplognathodus is rare, represented by a single specimen. The extrapolated abundance is approximately 300 elements/kilogram. The abundance increases upward through the lower portion of the black phosphatic shale facies to about 1000 elements/kilogram through the upper half of the black shale and lower half of the grey shale, and decreases upward into the Houx Limestone. The black shale and the overlying bioturbated grey shale contain only three genera, Idiognathodus, Neognathodus, and Idioprioniodus. Neognathodus platforms show an increase in proportion relative to Idiognathodus, which approaches 1:1 in the zone of maximum abundance, but this ratio decreases upward as Idiognathodus platforms become more abundant. Idioprioniodus is also most abundant in the lower portion of the black shale, and decreases slightly upward.

Houx Limestone Member

The Houx is represented in CP #22 by nearly one foot of light medium grey, slightly argillaceous, skeletal calcilutite that is mottled with calcareous, argillaceous siltstone by probable bioturbation (Fig. 7). Conodont abundance in the Houx averages about 100 elements/kilogram decreasing slightly upward, and the fauna is dominated by Idiognathodus elements. Anchignathodus also ranges throughout the Houx, but is absent in both the overlying and underlying shales.

Idioprioniodus elements occur only in the lower one-half, and minor *Adetognathus* and *Stepanovites* elements are found only in the upper one-half.

Unnamed Shale Member

The unnamed shale member overlying the Houx includes in the lower half approximately six feet of dark grey, slightly silty shale, which contains obvious macrofossil debris only in the lower one foot. Identifiable conodonts were found only in the lowermost of 10 samples, and consist mostly of small numbers of *Idiognathodus* platforms and minor *Adetognathus* elements. The dark grey shale grades upward over about four feet by interlamination to light grey, argillaceous, micaeous, cross-laminated siltstone. Sample residues from this portion contained abundant fine-grained, granular siderite. The upper one foot of the member grades to green-grey, slightly silty, calcareous mudstone below the upper contact, which shows relief in the core and may be disconformable.

Higginsville Limestone Member

The Higginsville Limestone in CP #22 is approximately 4.5 feet thick and consists dominantly of light brown and green-grey, slightly argillaceous skeletal calcilutite (Fig. 7). The lower portion is lenticularly interbedded with green clay partings and becomes more thickly bedded and fossiliferous upward. The middle portion is massive, but contains common vertically anastomosing clay partings along which carbonaceous root impressions are observed to penetrate in the upper half.

Near the top, the unit grades to fractured limestone beds or nodules in a matrix of medium green, silty mudstone. The contact with the overlying Labette Shale is gradational, but placed in the core at the uppermost limestone nodule.

Conodont faunas through the Higginsville in this core vary vertically in such a way as to suggest three subdivisions. The lower, lenticularly bedded portion yielded dominantly Adetognathus elements near the base, but with Idiognathodus increasing and Adetognathus diminishing upward. Anchignathodus and Diplognathodus are minor elements in the fauna. The middle portion, represented in the core by sample 9F, had the highest extrapolated abundance of elements in the unit, 330/kilogram. This fauna is dominated by Idiognathodus, but Adetognathus is conspicuously absent. Anchignathodus reaches its maximum, forming about 15% of the fauna. Diplognathodus, Aethotaxis, and Neognathodus are minor elements of the fauna. The upper portion (sample 9E and above) has extrapolated abundances that diminish from approximately 100/kilogram at the bottom to an average of about 30/kilogram toward the top. The faunas recovered contain minor Anchignathodus, Neognathodus, and Stepanovites elements at the bottom, with Adetognathus increasing upward in relation to Idiognathodus P elements. Most of the individual samples from the upper portion yielded conondonts from both the clay and limestone fractions, but in numbers too small to produce statistically valid comparative ratios between the genera. Nevertheless, Adetognathus and Idiognathodus are roughly subequal and minor Diplognathodus elements are present as well.

The laterally variable lithology of the Higginsville Member is reflected also in conodont faunas. Samples from three feet of Higginsville in another core (CP #10) located approximately ten miles to the southeast yielded a sharply different conodont fauna (Swade, 1977). There, conodonts are present only in the lower one-half of the Higginsville. In addition to Idiognathodus, Neognathodus, Anchignathodus, and Diplognathodus elements, Idioprioniodus elements were recovered, whereas Adetognathus was not found.

Labette Shale

The Labette Shale in Appanoose County is much reduced from its thickness and character elsewhere in the state (Van Eck, 1965). In CP #22 it consists entirely of the 2.4 feet thick Mystic Coal Member and its 1.5 foot thick, mudstone seatrock. The mudstone is medium green-grey, silty, and calcareous in the lower portion, becoming finer and darker in color, with poorly preserved pyritic root traces increasing upward. The lowermost sample (8B) yielded only fragments of ramiform conodont elements, but also contained a diverse and abundant micro- and macrofauna. Most of the material is preserved as pyritic replacements and casts and includes ostracodes, fusulinids, and other calcareous forams, as well as brachiopods and echinoderms.

Pawnee Formation

The Pawnee Formation consists of the marine-dominated portion of the third of the five major eustatic cyclothems present in the Marmaton Group. In Iowa, it includes four laterally persistent members, in ascending order: Anna Shale, Myrick Station Limestone, Mine Creek Shale, and Coal City Limestone. Price (1981) has recently demonstrated that, although variable in thickness and character, these same subdivisions are recognizable across virtually the entire Midcontinent. The Anna Shale and Myrick Station Limestone form the marine-eustatic core of the cyclothem, analogous to the Little Osage Shale-Houx Limestone couplet of the Stephens Forest Formation, whereas the Coal City Limestone is a super limestone, analogous to the Higginsville Limestone Member. The Mine Creek Shale is the most laterally variable member of the Pawnee, ranging from six to almost forty feet in thickness. Locally along the Iowa outcrop belt, a coal smut is present at or near the top (VanEck, 1965).

The Pawnee is included in the overlapping interval of the two cores examined in this study (CP #22, CP #37), and thus, some measure of the lateral variability of the members in south-central Iowa is illustrated. The Pawnee in CP #37 has been examined in detail petrologically by O'Brien (1977), and the lithologic descriptions below are derived in part from his study.

Anna Shale Member

The Anna Shale in southeastern Iowa displays a three-part subdivision that parallels the sequence observed in the Excello and Little Osage Shale Members. In CP #22 the lower, transgressive portion is 0.5 foot thick and consists of dark grey, slightly silty, calcareous shale with fossil debris increasing, grading downward to lenticularly bedded, argillaceous skeletal calcarenite near the bottom (Fig. 8).

Figure 8.

Distribution of conodonts and other fossils in the lower Pawnee Formation in CP# 22. See figure 5 for explanation.

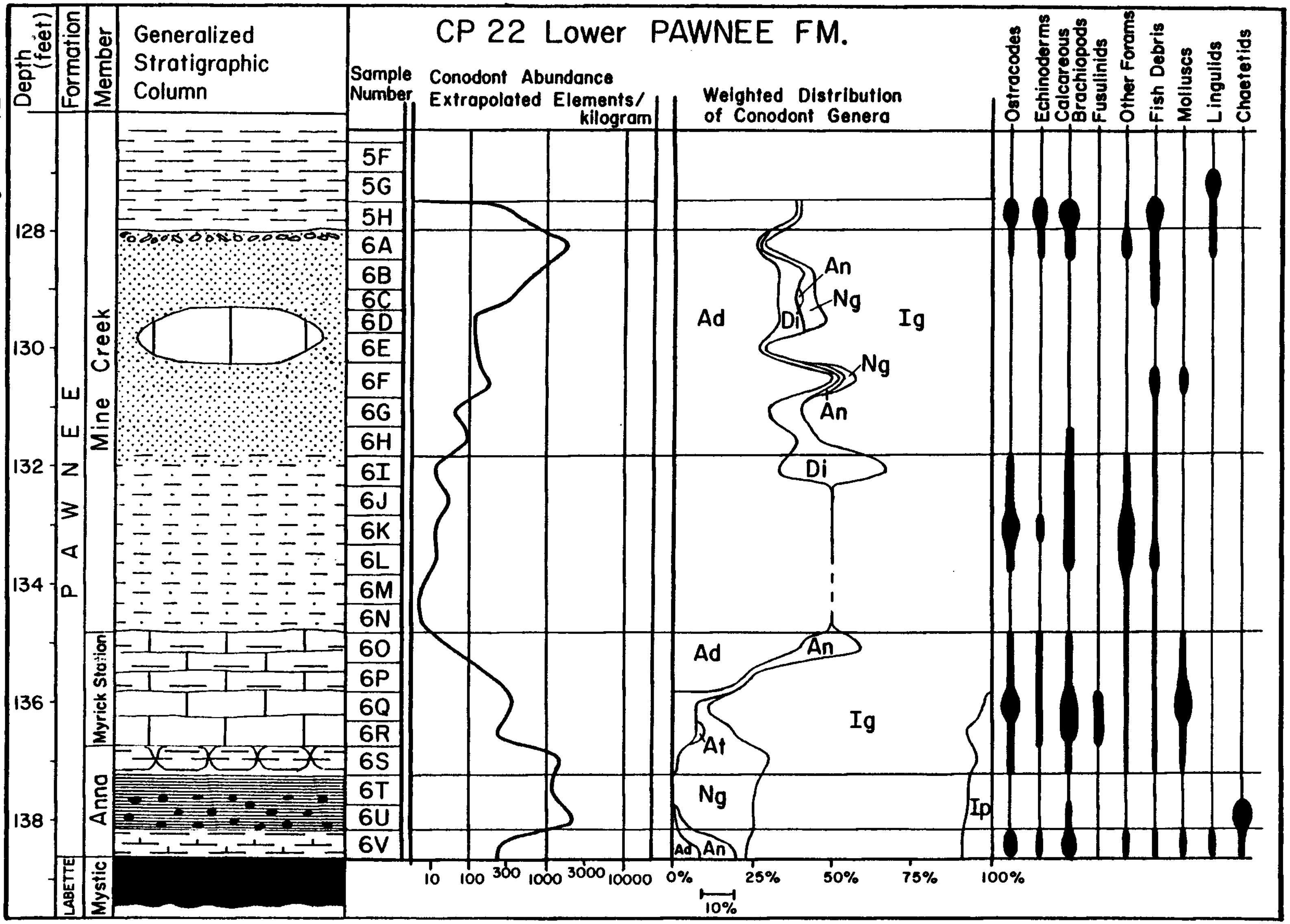

CP 22 Lower PAWNEE FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Lingulids
Chaetetids
PAWNEE
Mine Creek
Myrick Station
Anna
LABETTE
Mystic
128
130
132
134
136
138
5F
5G
5H
6A
6B
6C
6D
6E
6F
6G
6H
6I
6J
6K
6L
6M
6N
6O
6P
6Q
6R
6S
6T
6U
6V
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
10%
Ad
Ig
An
Ng
Di
At
Ip

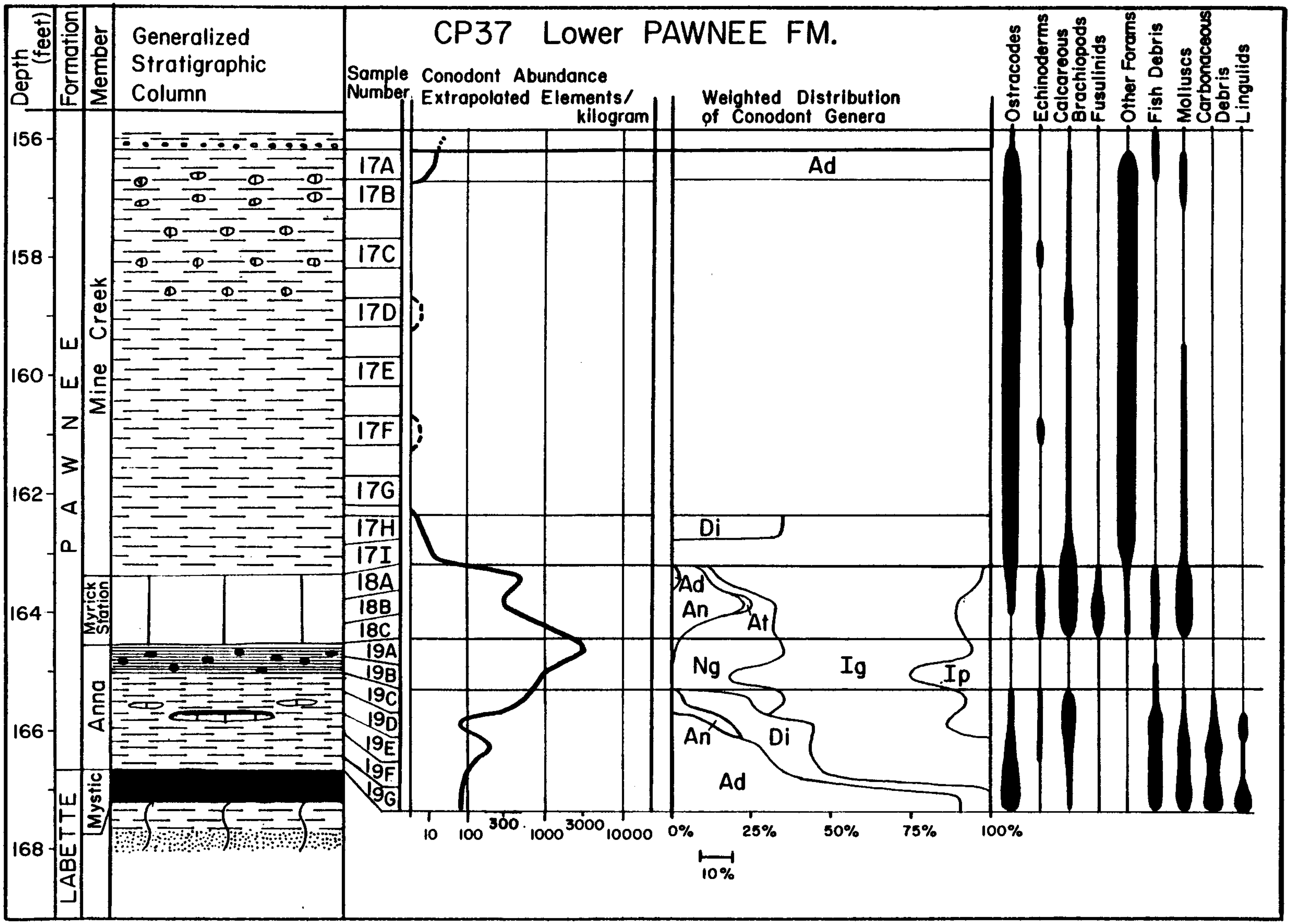
Figure 8.

A diverse macrofauna including common calcareous brachiopods and ostracodes is present, with several fragments of chaetetids toward the top. The middle black, fissile, non-calcareous clay shale is one foot thick and contains abundant non-skeletal phosphate lenses and lamellae. The upper "bioturbated" portion is 0.5 foot thick and is dark grey, slightly silty calcareous shale with sparse fossil debris. The only obvious bioturbation consists of chrondrites-type burrows that extend downward from the overlying Myrick Station Limestone.

Only the lower two subdivisions present in the above sequence are represented in the Anna Shale in CP #37 (Fig. 9). The lower, transgressive portion consists of 1.5 feet of fossiliferous, dark brown to black, slightly silty shale with abundant minute carbonaceous particles. A thin zone of fossil debris, including pyritized pelecypods, lingulid brachiopods, ostracodes and minor calcareous brachiopod debris is present just above the base and may represent the "middle limestone" of this cycle. All but the calcareous brachiopods decrease upward in this shale, and echinoderm debris is first noted several inches above the base. The local occurrence of thin, lenticular limestones in the middle of the unit is indicated by a whole-shell gastropod calcilutite, which is immediately overlain by a millimeter-thick cleated vitrain band. A thin, argillaceous, skeletal calcarenite occurs at the top, just below the sharp contact with the upper portion of the unit which consists of a 0.7-foot thick, dark grey to black, calcareous, laminated shale with common nodules and thin lenses of granular non-skeletal phosphate in the lower two-thirds, and no obvious macrofauna.

Figure 9.

Distribution of conodonts and other fossils in the lower Pawnee Formation in CP# 37. See figure 5 for explanation.


CP37 Lower PAWNEE FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/ kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Carbonaceous Debris
Lingulids
156
158
160
162
164
166
168
PAWNEE
LABETTE
Mine Creek
Myrick Station
Anna
Mystic
17A
17B
17C
17D
17E
17F
17G
17H
17I
18A
18B
18C
19A
19B
19C
19D
19E
19F
19G
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
10%
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Ng
Ig
Ip

Figure 9.

The third portion of the Anna recognized in CP #22, the upper, bioturbated shale, is not present in CP #37. Instead, the contact between the black shale and overlying limestone is sharp, and is inclined at about 20 degrees. This contact is not slickensided and probably is conformable, perhaps suggesting that the Myrick Station is wavy bedded in the core.

The conodont faunas from the Anna Shale are similar in both cores. However, CP #37, which shows an apparent lithologic transition between the two types of black shale described by Heckel and Swade (1977), also shows a more completely developed transition in the faunas. The lowermost sample (19G) contains only small numbers of Adetognathus elements and a single Diplognathodus element. In the remainder of the unit, Idiognathodus constitutes about 50% of the fauna. Adetognathus elements diminish upward and disappear below the top of the lower bed, and Diplognathodus is restricted to the lower shale bed. Anchignathodus occurs only in the upper portion, whereas Neognathodus and Idioprioniodus increase upward into the black, fissile facies. Extrapolated abundances average about 100 elements/kilogram in the lower portion, increasing to over 500/kilogram in the uppermost sample (19C) from the lower shale and to approximately 3200/kilogram in the uppermost sample of upper Anna (19A). The fauna from the black, phosphatic shale consists mainly of only three genera, Idiognathodus, Neognathodus, and Idioprioniodus, with Idiognathodus dominant over Neognathodus by 2:1. Anchignathodus occurs as a minor element near the top, increasing upward into the overlying Myrick Station.

The sequence of faunas in CP #22 is similar, but, especially in the lower portion, is condensed (Fig. 8). The fauna of the lower bed is dominated by Idiognathodus elements, with Adetognathus and Anchignathodus (which diminish upward into the lower portion of the black facies) and Neognathodus and Idioprioniodus (which increase upward). A maximum abundance of about 2200 elements/kilogram was noted in the lower portion of the black facies, and the abundance remains high upward into the upper bioturbated shale. The black shale fauna consists mainly of Idiognathodus, Neognathodus, and Idioprioniodus, and small numbers of Anchignathodus and Adetognathus. The upper shale bed yielded the same four genera as the uppermost sample from the black shale in CP #37; Idiognathodus, Neognathodus, Idioprioniodus, and Anchignathodus, and in virtually the same proportions.

Myrick Station Limestone Member

The Myrick Station Limestone in southeastern Iowa is typically represented by a single, laterally persistent, massive limestone bed ranging from one to two feet thick. In CP #22, the Myrick Station is two feet thick and consists of medium dark grey, slightly argillaceous, skeletal calcilutite that becomes increasingly argillaceous upward (Fig. 8). The unit is somewhat mottled by bioturbation and the upper contact is a rapid gradation. In CP #37, the Myrick Station is one foot thick (Fig. 9). The lower 0.2 foot is faintly interlaminated non-abraded skeletal calcarenite with a diverse macrofauna that grades upward to skeletal calcilutite, mottled by bioturbation.

The conodont faunas from the Myrick Station are closely parallel in CP #22 and CP #37. In CP #22 (Fig. 8), extrapolated abundance increases upward from about 230 elements/kilogram to a secondary peak of about 550/kilogram and then diminishes to less than 10/kilogram near the base of the overlying shale. The fauna is dominated by *Idiognathodus* elements and the secondary abundance peak is due to an increase in their abundance. *Anchignathodus* ranges through the unit. *Neognathodus* and *Idioprioniodus* diminish upward and are absent in the upper half of the unit. *Aethotaxis* is a minor element of the fauna, restricted to the sample with slightly lower abundance at the base of the bed. *Adetognathus* occurs only in the upper half and appears to increase upward in relation to *Idiognathodus*.

In CP #37 (Fig. 9), the extrapolated abundance in the lower portion of the Myrick Station is high, about 1100 elements/kilogram, but there is a second peak in the upper portion of about 500 elements/kilogram, with a relative low of about 270/kilogram in the middle. *Idiognathodus*, *Neognathodus*, *Idioprioniodus*, and *Anchignathodus* range throughout, with *Neognathodus* diminishing upward relative to dominant *Idiognathodus*. *Aethotaxis* again is a minor element of the fauna, restricted to the middle of the bed, and *Adetognathus* occurs only in the uppermost sample.

Mine Creek Shale Member

The Mine Creek Shale is a complex and laterally variable unit in southeastern Iowa. It comprises a minor clastic wedge developed during a eustatic regression (Price, 1981). In both CP #22 and CP #37, a sequence of three distinct subdivisions are present: a lower and an upper argillaceous unit, and a middle arenaceous unit, but both sequences differ in particulars.

CP #22

In CP #22, the lower argillaceous unit is represented by approximately three feet of medium grey, argillaceous siltstone (Fig. 8). This grades rapidly to the middle arenaceous unit, which consists of about four feet of medium green-grey, argillaceous, calcite-cemented, very fine to fine grained sandstone that coarsens slightly upward. There is a one-foot-thick septarian calcilutite nodule/bed in the middle, and near the top, the unit becomes conglomeratic, containing subrounded limestone clasts, small angular shale clasts and abraded brachiopod debris. There is a sharp contact with the upper argillaceous unit (Figs. 8 and 10), which consists of approximately seven feet of silty, noncalcareous shale that grades from medium grey in the lower one-half to mottled green and maroon in the upper one-half. Macrofossil debris occurs scattered throughout the lower two units, but extends only into the base of the upper unit, which has a poorly preserved coal smut at the top.

Conodont elements generally occur in beds with macrofossil debris. They range throughout the lower two units of the Mine Creek in CP #22, but occur only at the very top and bottom of the upper shale bed. The lower shale unit (Fig. 8) yielded a low abundance of Adetognathus and Idiognathodus platform elements, generally increasing upward from about 10/kilogram, and in roughly subequal numbers. Extrapolated abundance

Figure 10.

Distribution of conodonts and other fossils in the upper Pawnee Formation in CP# 22. See figure 5 for explanation.

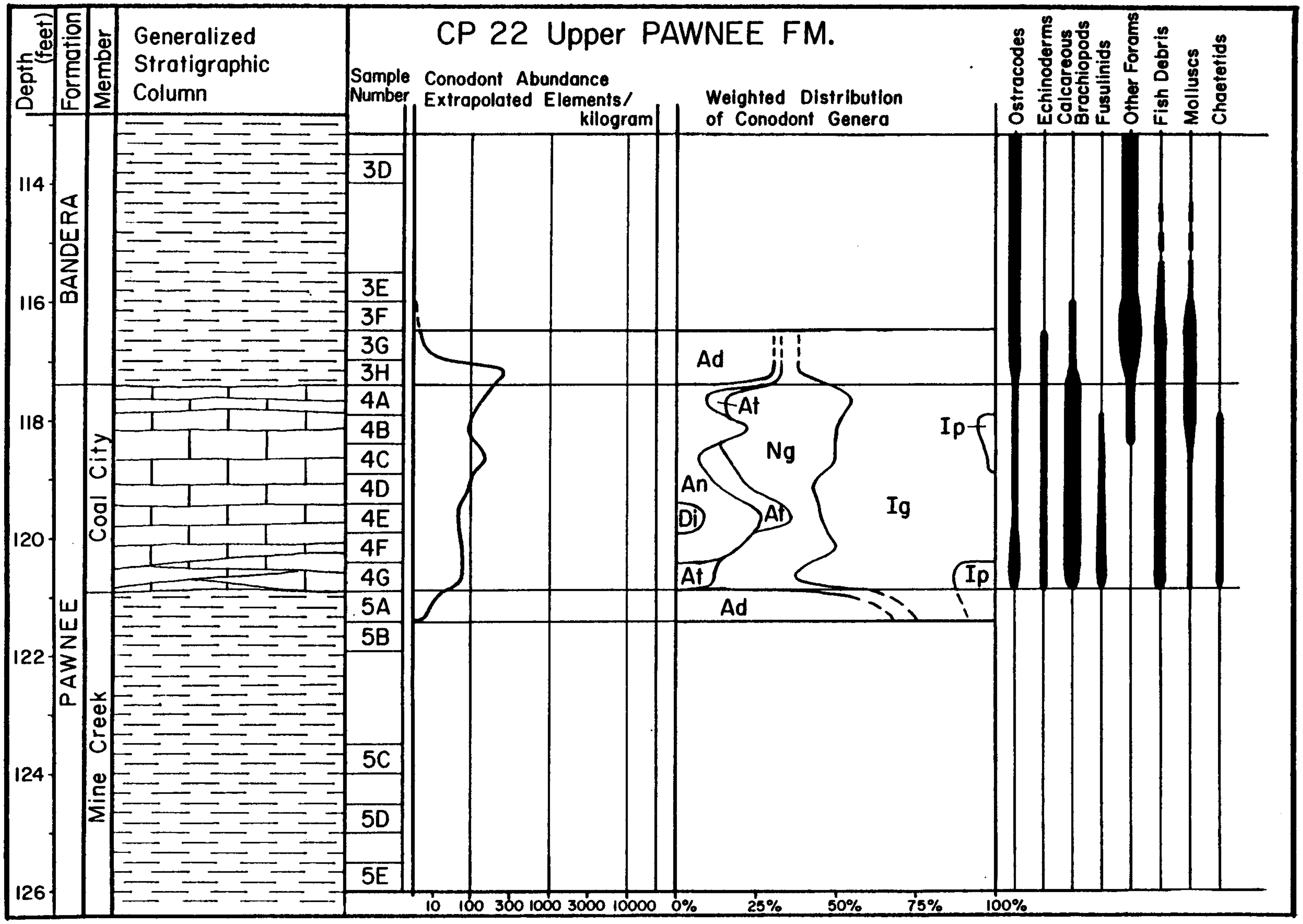

CP 22 Upper PAWNEE FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/ kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Chaetetids
114
116
118
120
122
124
126
BANDERA
PAWNEE
Coal City
Mine Creek
3D
3E
3F
3G
3H
4A
4B
4C
4D
4E
4F
4G
5A
5B
5C
5D
5E
Ad
At
Ng
Ip
An
Di
Af
Ig
At
Ip
Ad
10 100 300 1000 3000 10000
0% 25% 50% 75% 100%

Figure 10.

averages about 100 elements/kilogram in the lower half of the sandstone and increases dramatically to about 1700/kilogram in the uppermost sample, which contains the limestone clasts. The sandstone fauna also is dominated by subequal amounts of Idiognathodus platforms and Adetognathus platform and ramiform elements. Diplognathodus elements are a minor constituent throughout, and Neognathodus platforms are minor in the upper portion. Anchignathodus occurs sporadically and in only small numbers. The major elements of the fauna extend only into the base (sample 5H) of the overlying shale.

The unusually high abundance at the top of the sandstone is probably a winnowed accumulation brought about by hydrodynamic sorting. In particular, almost all of the Idiognathodus platforms recovered are small in size and abraded in appearance with the blade broken off.

CP #37

The lithologic sequence in the Mine Creek Shale in CP #37 is more complex than in the sequence in CP #22, but three similar units are recognizable (Figs. 9 and 11). The lower argillaceous unit is about 7.0 feet thick and consists of sparsely fossiliferous, variegated, slightly silty, mudstone with small calcilutite nodules in the upper portion (Fig. 9). The middle arenaceous unit in the Mine Creek is 5.0 feet thick and is comprised of two distinct facies. The lower 2.0 feet consist of several interbedded grey mudstones with a zone of intraclast and sedimentary lithoclast conglomerates near the base. A thin vitrain lamella overlies one of the conglomerates, and other carbonaceous debris is present throughout the mudstone. Thin sandy

Figure 11.

Distribution of conodonts and other fossils in the upper Pawnee Formation in CP# 37. See figure 5 for explanation.

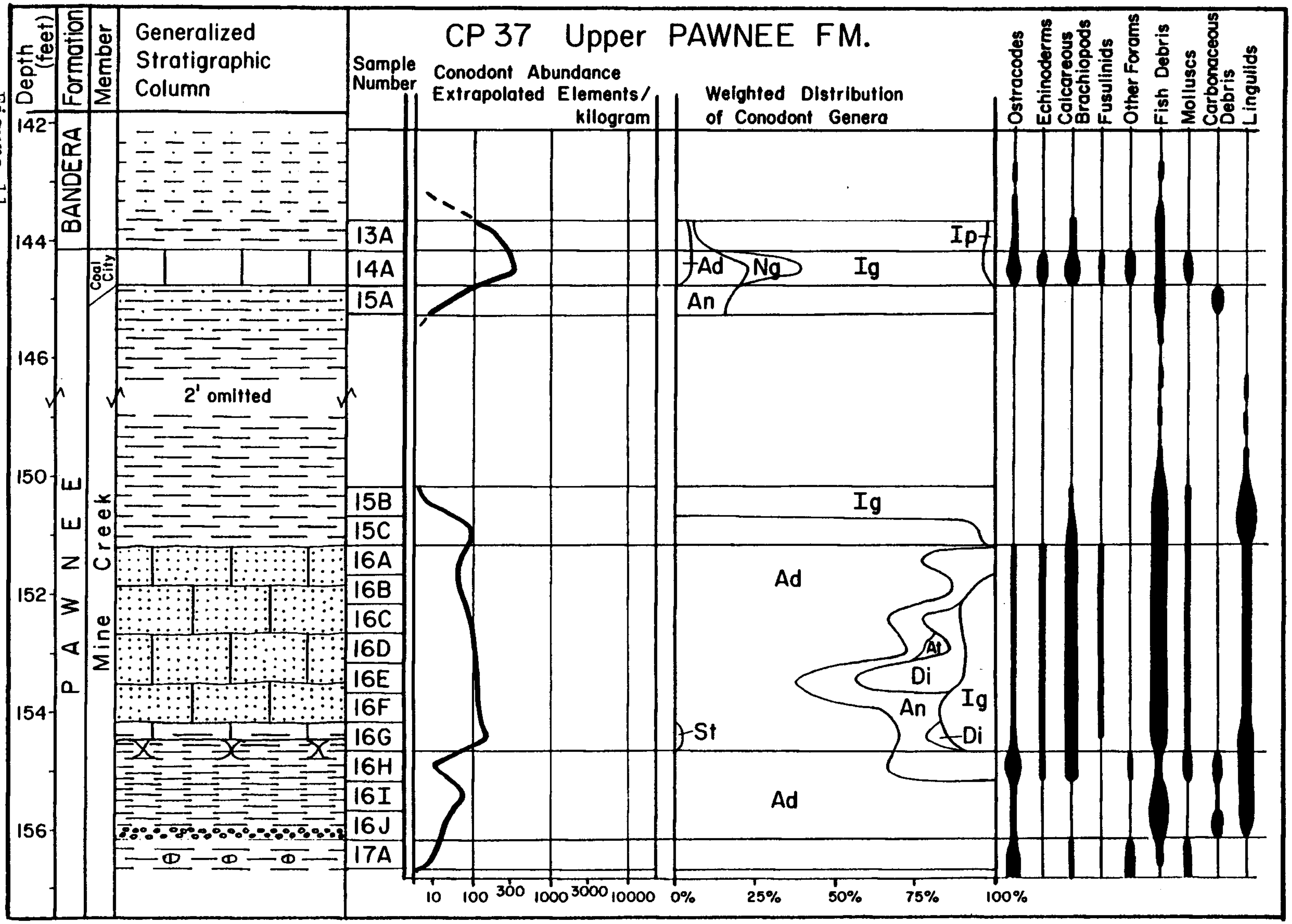

CP 37 Upper PAWNEE FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/ kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fusulinids
Other Forams
Fish Debris
Molluscs
Carbonaceous Debris
Lingulids
142
144
146
150
152
154
156
BANDERA
PAWNEE
Coal City
Mine Creek
2' omitted
13A
14A
15A
15B
15C
16A
16B
16C
16D
16E
16F
16G
16H
16I
16J
17A
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
Ad
Ng
Ig
An
Ip
At
Di
St

Figure 11.

lamellae that yield a weak positive reaction when tested for phosphate are present in two zones in the middle portion. The contact with the overlying upper calcareous unit is gradational over 0.2 foot, in part by bioturbation. The upper part of the arenaceous unit is gradational between bioturbated, sandy skeletal calcilutite and calcareous, very fine-grained sandstone. Two thin calcilutite beds with disturbed bedding are present at the bottom, from which chondrites-type burrows originate. The upper argillaceous unit of the Mine Creek Shale consists of 6.5 feet of mottled green and grey mudstone with lingulids and minor molluscs and calcareous brachiopods only in the lower one foot, and zones of maroon and gold staining in the middle. Just below the top are thin, interlaminated sandy siltstones and silty shale, some of which are carbonaceous.

Conodont distribution in the Mine Creek in CP #37 varies somewhat from the pattern observed in CP #22. The shale immediately overlying the Myrick Station yielded very small numbers of _Idiognathodus_ platforms and a single _Diplognathodus_ element, although sporadic occurrences of ramiform fragments were noted in the middle portion. The mudstones at the base of the middle unit yielded dominantly _Adetognathus_ platforms in abundances ranging up to an extrapolated 50/kilogram, with minor _Anchignathodus_ overlapping from the limestone above. The sandy limestone unit yielded an extrapolated abundance of about 140 elements/kilogram at the base, which declines upward to about 50/kilogram at the top. The fauna is dominated by delicately preserved _Adetognathus_, with all six element types represented. _Anchignathodus_ also ranges throughout, but Idiognathodus and Diplognathodus elements occur only in the middle. Stepanovites elements are rare at the base and Aethotaxis is rare in one sample in the middle.

The upper shale bed of the Mine Creek was only sampled for conodonts in the lower one foot and at the top. In the base, conodonts diminish in abundance from just under 100 elements/kilogram to less than 10/kilogram, and the fauna is dominated by Adetognathus and low numbers of Idiognathodus. The interlaminated interval at the top yielded only seven elements, mostly small Idiognathodus platforms.

Coal City Limestone Member

The Coal City Limestone in outcrop in southeastern Iowa is usually a single massive limestone bed ranging from 1.0 to about 4.5 feet thick. In CP #22 (Fig. 10), it is 3.5 feet thick and consists dominantly of light grey skeletal calcilutite that is lenticularly bedded near the base and becomes irregularly interbedded upward with slightly more argillaceous calcilutites. A diverse macrofauna includes fusulinids and chaetetids, and the upper contact is a rapid gradation.

Farther west of the outcrop belt in CP #37 (Fig. 11), the Coal City is reduced to a single bed 0.6 foot thick. The lower 0.1 foot is argillaceous non-abraded skeletal calcarenite that is gradational from the underlying shale. The remainder is skeletal calcilutite that grades rapidly into the overlying shale. The bed is fractured subvertically and the opening is filled with green mudstone and blocky calcite. The gradational zones at top and bottom contain thin lenses of granular glauconite and fine grained phosphate.

Conodont faunas from the Coal City in CP #22 are dominated by _Idiognathodus_, _Neognathodus_ and _Anchignathodus_. Extrapolated abundance in the lower portion averages about 50 elements/kilogram, but increases to about 150/kilogram in the upper middle. The overall increasing upward trend culminates in a second abundance peak of about 250/kilogram at the base of the overlying shale. _Aethotaxis_ is present sporadically throughout the Coal City, whereas _Idioprioniodus_ occurs both at the base and in the high abundance zone in the upper portion. _Diplognathodus_ is represented by a single element. _Adetognathus_ is absent in the limestone, but does occur in both the overlying and underlying shales.

In CP #37, the fauna appears to be condensed, as is the limestone. Extrapolated abundance in the limestone is about 350 elements/kilogram and the fauna is dominated by the same three genera, _Idiognathodus_, _Neognathodus_, and _Anchignathodus_. Both _Adetognathus_ and _Idioprioniodus_ are present in small numbers, and both extend into the overlying shale which contains a fauna dominated by _Idiognathodus_ platform elements.

Bandera Shale

The Bandera Shale consists of a major clastic wedge developed during the episode of regression that closed Pawnee deposition and preceded the eustatic transgression that was responsible for the Altamont Formation. In southeastern Iowa, the Bandera usually has two distinct subdivisions: a lower coarsening upward sequence of deltaic clastics, and an upper mudstone that is red in the lower portion and locally includes a coal near the base.

In CP #22, the lower deltaic sequence is about 15.5 feet thick. It grades upward from green-grey, silty shale by interlamination to light grey, very fine to fine-grained sandstone at the top. The middle portion has lenticular and cross lamination, flame structures and sole markings, and common carbonate nodules, most of which are siderite. The lower few feet of the shale (Fig. 10) are fossiliferous, including calcareous brachiopods and molluscs, which diminish upward, and ostracodes and forams, which continue upward. Conodont elements in an extrapolated abundance of about 250/kilogram diminish rapidly upward from the lowermost sample. The fauna is dominated by *Idiognathodus* and *Adetognathus* elements with minor *Neognathodus* and *Anchignathodus* extending from the underlying limestone.

The upper mudstone portion of the Bandera in CP #22 is 14 feet thick and has minor molluscs and plant debris just above the base. There is a two-foot zone of maroon mottled, silty, noncalcareous mudstone two feet above the base, above which the mudstone grades to green-grey, slightly silty, noncalcareous shale. The upper contact with the overlying Amoret Member of the Altamont Formation is completely gradational and arbitrarily placed in the core below the lowest limestone nodule (Fig. 12). Very small numbers of conodont elements are present in the upper shaly portion, but in the uppermost sample below the limestone nodules, abundance increases to about 65 elements/kilogram, mostly *Neognathodus* and *Idiognathodus* platform elements.

In CP #37, the lower deltaic sequence is 14.5 feet thick and grades rapidly from shale at the base through light medium green siltstone to

Figure 12.

Distribution of conodonts and other fossils in the Altamont Formation in CP# 22. See figure 5 for explanation.

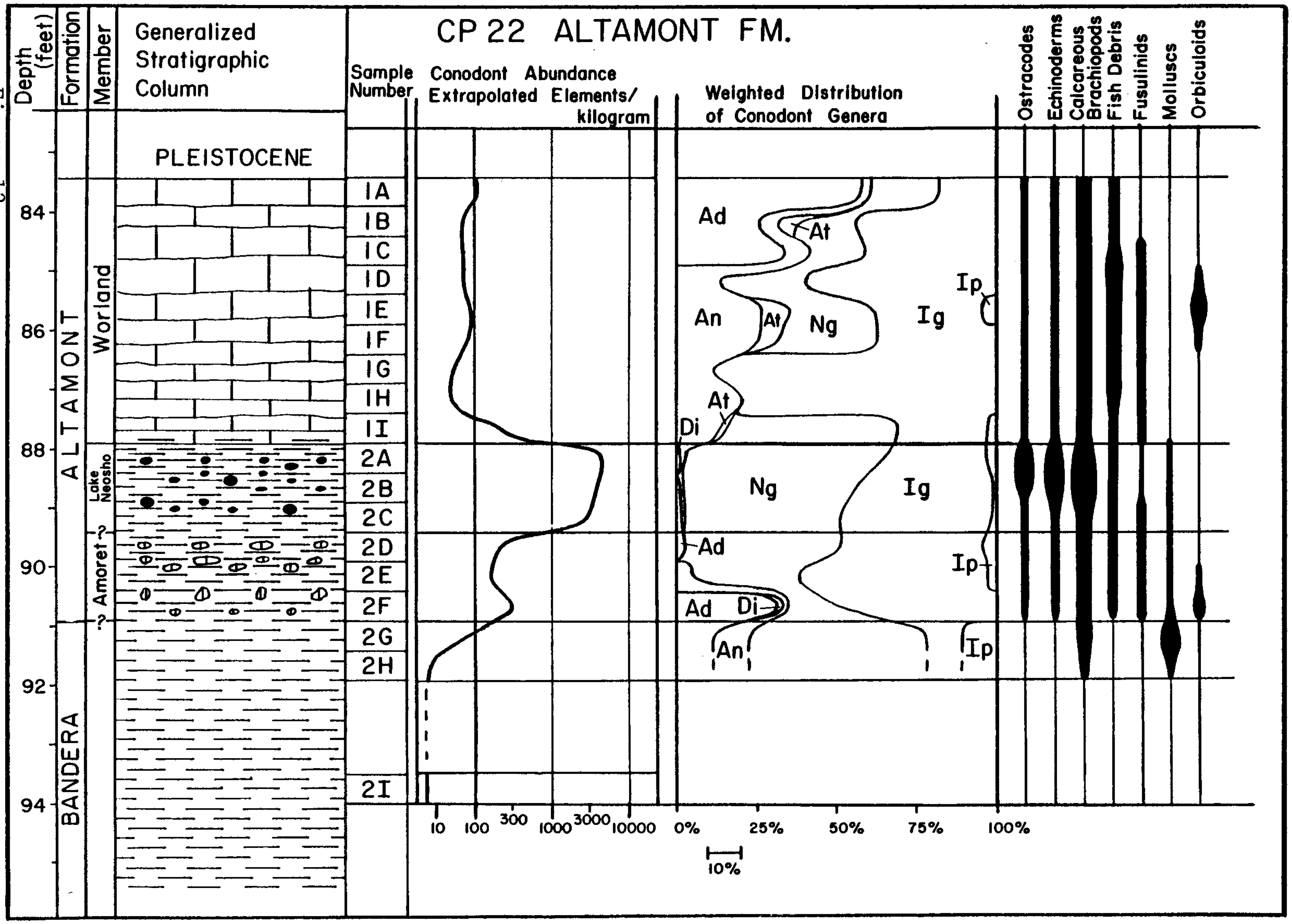

CP 22 ALTAMONT FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/ kilogram
Weighted Distribution of Conodont Genera
Ostracodes
Echinoderms
Calcareous Brachiopods
Fish Debris
Fusulinids
Molluscs
Orbiculoids
PLEISTOCENE
ALTAMONT
BANDERA
Worland
Lake Neosho
Amoret
84
86
88
90
92
94
1A
1B
1C
1D
1E
1F
1G
1H
1I
2A
2B
2C
2D
2E
2F
2G
2H
2I
Ad
At
An
Ng
Ip
Ig
Di
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
10%

Figure 12.

interlaminated and interbedded siltstone and argillaceous, very fine grained, cross-bedded sandstone. The upper portion has thin, lenticular, fine grained, calcareous sand lamellae below the slickensided upper contact. Only the lowermost six inches was sampled (Fig. 11), which was found to contain *Idiognathodus* platforms and minor *Adetognathus*, *Neognathodus* and *Anchignathodus* elements in an extrapolated abundance of over 200/kilogram. Presumably, abundance would diminish rapidly upward.

The upper mudstone-dominated portion of the Bandera in CP #37 is about 19 feet thick. Just above the base is 3.5 feet of brick red mudstone, which grades upward through maroon and gold mottled mudstones that have a brecciated texture to about 3.5 feet of grey, argillaceous, sandy siltstone with brown-stained root traces at the top (Fig. 13).

Altamont Formation

The Altamont Formation encompasses the marine-dominated portion of the fourth of the five major eustatic cyclothems in the Marmaton Group. The Altamont is the only formation in the cores upon which a detailed outcrop study has been published. Schenk (1967) described lateral and vertical variations in the three recognized members--Amoret Limestone, Lake Neosho Shale, and Worland Limestone--and interpreted their depositional environments. As a whole, the Altamont averages about 10 feet in thickness in southcentral Iowa.

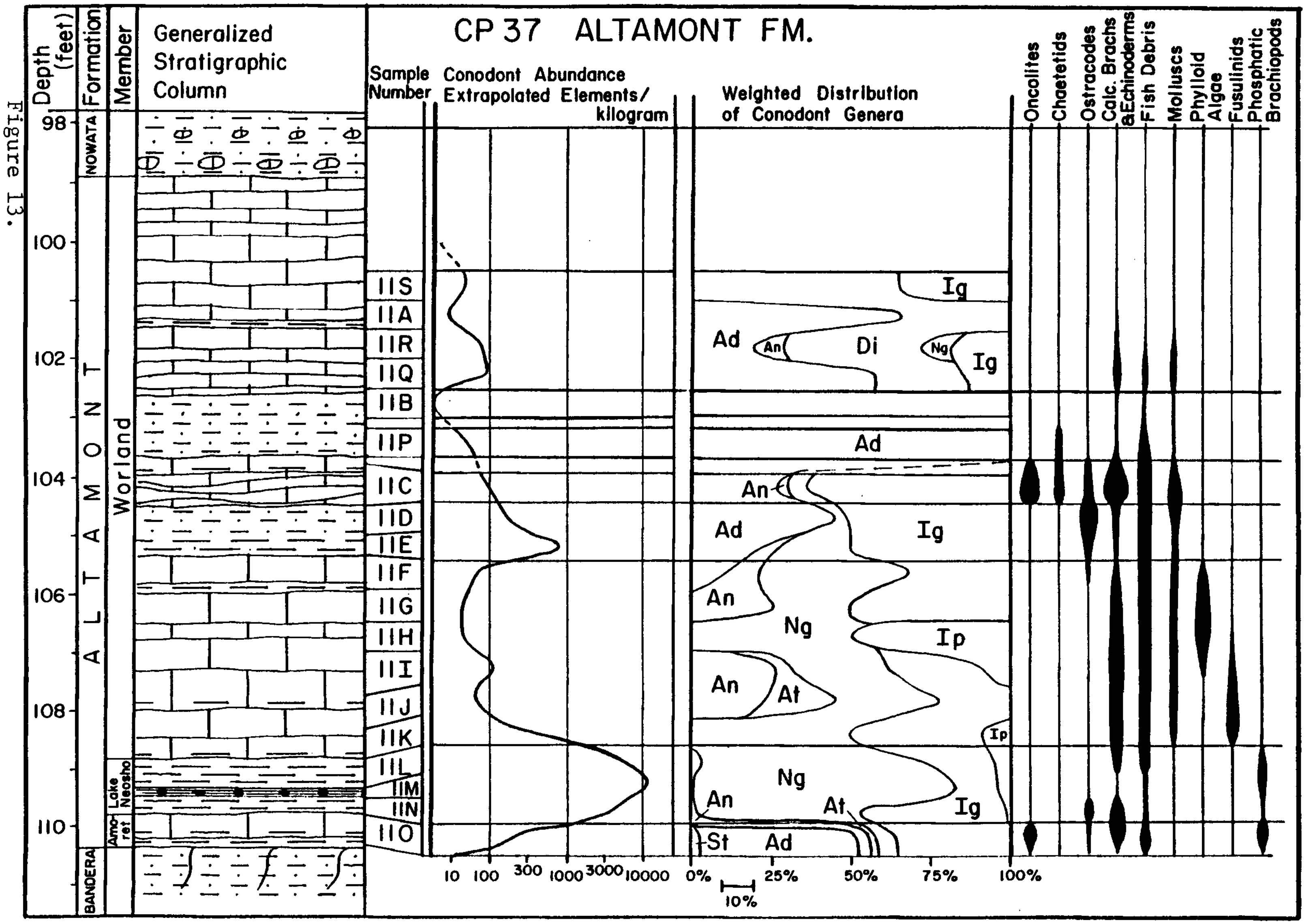
Amoret Limestone Member

The Amoret Limestone is the first well developed "transgressive" limestone in the Iowa Desmoinesian section. In southcentral Iowa it

Figure 13.

Distribution of conodonts and other fossils in the Altamont Formation in CP# 37. See figure 5 for explanation.

Figure 13.


CP 37 ALTAMONT FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extrapolated Elements/kilogram
Weighted Distribution of Conodont Genera
Oncolites
Chaetetids
Ostracodes
Calc. Brachs &Echinoderms
Fish Debris
Molluscs
Phylloid Algae
Fusulinids
Phosphatic Brachiopods
98
100
102
104
106
108
110
NOWATA
ALTAMONT
BANDERA
Worland
Lake Neosho
Amoret
IIS
IIA
IIR
IIQ
IIB
IIP
IIC
IID
IIE
IIF
IIG
IIH
III
IIJ
IIK
IIL
IIM
IIN
IIO
10 100 300 1000 3000 10000
0% 25% 50% 75% 100%
10%
Ig
Ad
An
Di
Ng
At
Ip
St

attains a maximum thickness of two feet in Madison County (Van Eck, 1965), and although the unit grades laterally into shale, its horizon is laterally traceable. In CP #22 (Fig. 12), the Amoret is developed as a zone of fossiliferous calcilutite nodules about 1.5 feet thick in light green-grey, slightly silty, calcareous shale that is gradational at top and bottom. Conodonts occur in both the nodules and the shale in extrapolated abundances that average about 200 elements/kilogram. Near the bottom, *Adetognathus* constitutes over 25% of the fauna, but only a few rare platform elements were found in the upper portion. *Idiognathodus* platforms are dominant near the bottom, but *Neognathodus* increases in relative abundance upward. *Anchignathodus* and *Diplognathodus* are minor elements in the lower part, whereas *Idioprioniodus* is minor only in the upper part.

In CP #37 (Fig. 13), the Amoret is represented by a 0.4-foot-thick bed of slightly argillaceous, bioturbated, skeletal calcilutite with common abraded fossil debris, some with thin oncolitic grain coatings. The lower portion is interlaminated with thin sandstones and green shales that become carbonaceous at the base. Extrapolated conodont abundance is about 200/kilogram, and the fauna is similar to that in the lower portion of the Amoret in CP #22. *Adetognathus* platforms constitute 50% of the fauna, *Idiognathodus* dominates over *Neognathodus*, and *Idioprioniodus* is absent. *Anchignathodus*, *Aethotaxis*, and *Stepanovites* are minor faunal elements.

Lake Neosho Shale Member

The Lake Neosho Shale represents the core shale of the Altamont cyclothem. Compared to lower Marmaton Group cyclothem cores, it shows a slightly reduced lateral extent of its black fissile phosphatic facies. It is characterized in northern Oklahoma and southeastern Kansas by a three-part subdivision; grey shale with a medial black phosphatic bed (Schenk, 1967). To the north, however, in the Iowa outcrop area, the Lake Neosho rarely contains the same fissile black lithology that characterizes the cores of older Desmoinesian cyclothems. In CP #22, it consists of 1.5 feet of green-grey, slightly silty, calcareous, laminated shale with an abundant and diverse macrofauna (Fig. 12). Thin, irregular granular nonskeletal phosphate lenses and lamellae increase upward, and the upper contact is a rapid gradation to limestone.

The Lake Neosho in CP #37 (Fig. 13), situated farther basinward of the Iowa outcrop, displays the three-part subdivision of the Kansas sequence, although somewhat condensed. The dark medial shale is 0.15 foot thick and does contain common thin granular phosphatic lamellae, but instead of being black and fissile, it is dark grey and weakly laminated. The upper and lower shale beds are 0.5 and 0.3 foot thick, respectively, and are green, silty, calcareous, and fossiliferous.

Conodont faunas from the Lake Neosho apparently display only slight lateral variability and are, in general, quite distinctive. In both cores, faunas are dominated by <u>Neognathodus</u> and <u>Idiognathodus</u> elements. In CP #22 (Fig. 12), extrapolated abundance averages about

3300 elements/kilogram, increasing slightly upward, and *Neognathodus* platform elements increase upward relative to *Idiognathodus* platforms from a ratio of about 1:1 to over 3:1 near the top. In CP #37 (Fig. 13), the upper and lower shale display a similar abundance and ratio of *Neognathodus* to *Idiognathodus* platforms, but the thin medial phosphatic shale yielded in excess of 12000 elements/kilogram and the ratio exceeded 4:1. Both cores contain common *Idioprioniodus* and rare *Anchignathodus* elements throughout the Lake Neosho. In addition, CP #22 yielded rare *Adetognathus* platforms, and near the top, a single *Diplognathodus* element.

Worland Limestone Member

The Worland Limestone is one of the thickest limestones in the Marmaton Group in Iowa, reaching 8 feet in Appanoose County, and is characterized especially in the upper portion by green shale partings and rapidly changing litho- and biofacies. In CP #22 (Fig. 12) from Appanoose County, only approximately 5 feet of Worland was recovered, the upper portion having been lost to pre-Pleistocene erosion. It consists of light grey, skeletal calcilutite that is greenish and argillaceous in irregular zones and has three thin clay partings in the upper portion.

In core CP #37 from Clarke County (Fig. 13), the Worland is considerably more complex and contains two distinct subunits: the lower, which probably represents the usual "upper" limestone, and the upper, which may represent a "super"-type limestone development. The lower unit is about 3.5 feet thick and consists of non-abraded skeletal calcilutite with interbedded argillaceous limestone and a macrofauna that includes fusulinids near the bottom and common phylloid algae near the top. The upper unit of the Worland actually consists of four distinct beds. The lowest bed is 0.9 foot of green, argillaceous, calcareous siltstone with minor fossil debris that, at the base, grades to shale and contains irregular, fine-grained phosphatic lenses. The second bed is 0.9 foot of mottled argillaceous calcilutite and nodular, abraded skeletal calcarenites with common oncolitic grain coatings. The third bed is 1 foot of sparsely fossiliferous, green, calcareous siltstone. The uppermost bed is about 3.5 feet thick and consists dominantly of barren, thinly bedded calcilutites that become less argillaceous and more arenaceous upward and, in the upper 1.5 feet, become cross-laminated and lenticular with thin pelletoidal beds and zones of sedimentary boudinage. The upper contact is rubbly and nodular, in part gradational to limestone nodules in the lower portion of the Nowata Shale.

The conodont faunas from the Worland in CP #22 and from the lower unit of the Worland in CP #37 are quite similar. Extrapolated abundance decreases from about 200 elements/kilogram in the lowermost sample to less than 100/kilogram and in some zones, as few as 20/kilogram. Both cores show, in general, *Idiognathodus*, *Neognathodus* and *Anchignathodus* throughout, with occasional *Aethotaxis* in certain zones. *Idioprioniodus* occurs in low abundance only in the lowermost sample and again in a zone about 2 feet above the base. *Adetognathus* occurs only near the top, increasing to over 50% in the uppermost sample recovered in CP #22 (1A). It occurs only in the uppermost sample of the lower Worland (11F) in CP #37, although it does increase in relative abundance upward into the overlying shale.

The upper portion of the Worland Limestone, studied only in CP #37 (Fig. 13), yielded a sequence of conodont faunas that bear heavily on its environmental interpretation. The phosphatic shale at the base yielded an extrapolated abundance of 790 elements/kilogram, which diminishes upward to zero at the top of the second siltstone bed. *Adetognathus* generally increases upward in relation to *Idiognathodus*, and *Neognathodus* decreases. *Anchignathodus* is present in the phosphatic shale, and rarely in the oncolitic limestone (sample 11C). The second siltstone bed yielded only 7 *Adetognathus* platforms near the bottom. The second limestone bed was sampled only in the lower portion, but the fauna appears to be distinctive. Extrapolated abundance generally decreases upward from about 90 elements/kilogram to about 20/kilogram in the middle of the bed (sample 11S). The small number of elements recovered is dominated by *Adetognathus* platforms and ramiforms, and *Diplognathodus* elements, with minor *Idiognathodus* and in one sample rare *Anchignathodus* and *Neognathodus*.

Nowata Shale

The Nowata Shale is a terrestrial or marginally marine clastic sequence that records the regressive episode that followed deposition of the Altamont Formation. A maximum thickness of about 80 feet is observed in Madison County, and the unit thins southeastward along outcrop to Appanoose County, where a thin coal may be present at the top

(VanEck, 1965). In CP #37, the Nowata is 18 feet thick and displays two distinct parts: the lower is possibly a thin soil profile, and the upper is an incompletely developed, possibly only local, cyclothem with a thicker soil developed at the top.

The lower unit, 4 feet thick, is barren mudstone that grades rapidly from green to brick red in the middle and to grey with maroon mottling near the top. Irregular carbonate nodules diminish upward and most have a brecciated appearance and no internal structure. The contact with the upper part of the Nowata is sharp and undulatory, probably burrowed. The lower approximately 4 feet of the 14-foot upper unit is grey, silty shale that becomes increasingly calcareous, fossiliferous and well laminated downwards. Just above the base is a 0.2-foot thick bed of skeletal calcilutite that includes calcareous brachiopods, molluscs and echinoderm debris. The remainder of the unit grades rapidly upward to about 10 feet of barren, red silty mudstone with common irregular carbonate nodules in the lower portion.

The minor marine incursion in the Nowata in this core occurs at approximately the same horizon as the Lenapah Formation in northern Oklahoma (see discussion below). It remains to be demonstrated whether or not they are genetically related.

Unnamed Formation ("Lenapah")

Recent work by R.W. Parkinson (M.S. thesis in prep.) and P.H. Heckel has revealed a long-standing miscorrelation of the Lenapah Formation. In its type area in northern Oklahoma, the Lenapah constitutes a rather localized three-part limestone-shale-limestone sequence.

Although this sequence resembles that of a cyclothem, R.W. Parkinson has demonstrated that the central shale does not contain a phosphatic facies or a zone of high conodont abundance, both of which characterize the core shales of other more widespread eustatic cyclothems. The black fissile phosphatic shale that does occur in this part of the Oklahoma section overlies the Dawson Coal, several feet above the top of the type Lenapah.

Previous workers have applied the name Lenapah widely across the Midcontinent for the uppermost laterally traceable limestone formation in the Desmoinesian. In Iowa, this limestone is represented by the Cooper Creek Member, named for outcrops in Appanoose County. Ravn et al. (1982), recognizing the miscorrelation, refer the Cooper Creek to the "Lenapah" Formation, but this widespread limestone formation actually remains unnamed, pending a proposal by P.H. Heckel.

Lithologic examination by O'Brien (1977) and this study demonstrate the existence of the three-part nature of this limestone formation in the subsurface of Clarke County, Iowa (CP #37). The lower two units, which Ravn et al. (1982) recognized as unnamed members, are very thin, but they clearly represent the transgressive "middle" limestone and the core shale of the unnamed cyclothem. The Cooper Creek is the "upper" limestone member.

The results of this study indicate also that the Exline Limestone, known to occur above the Cooper Creek in Appanoose County, is present in CP #37. It apparently represents a "super" limestone development and, as Ravn et al. (1982) suggest, probably should be recognized as a member of this unnamed limestone formation.

Unnamed Limestone Member

The unnamed transgressive "middle" limestone member is represented in CP #37 by a 0.1- to 0.15-foot thick, light grey, abraded skeletal calcilutite (Fig. 14). The lower contact is rapidly gradational by interlamination. The top of the Nowata Shale was included in the sample (9X) with the limestone, and the results are composited on Plate 3. Both the shale and limestone fractions yielded conodonts with an overall extrapolated abundance of about 160 elements/kilogram and the fauna seems to be mixed. Idiognathodus dominates, with minor Neognathodus, Gondolella, Adetognathus, Idioprioniodus, and Diplognathodus elements.

Unnamed Shale Member

The unnamed "core" shale member is represented in CP #37 by less than 0.1 foot of green, calcareous, fossiliferous shale. The lower contact is sharp, irregular, and draped by a 5 mm thick band of fine grained nonskeletal phosphate. Granular phosphate also occurs in the middle of the shale. Extrapolated conodont abundance approaches 11000 elements/kilogram. The fauna is dominated by Idiognathodus elements and the ratio relative to Neognathodus platforms is about 4.5:1. Gondolella and Idioprioniodus elements combined constitute about 15% of the fauna. Overlapping from the limestones are rare constituents:

Figure 14.

Distribution of conodonts and other fossils in the "Lenapah" Formation in CP# 37. See figure 5 for explanation.

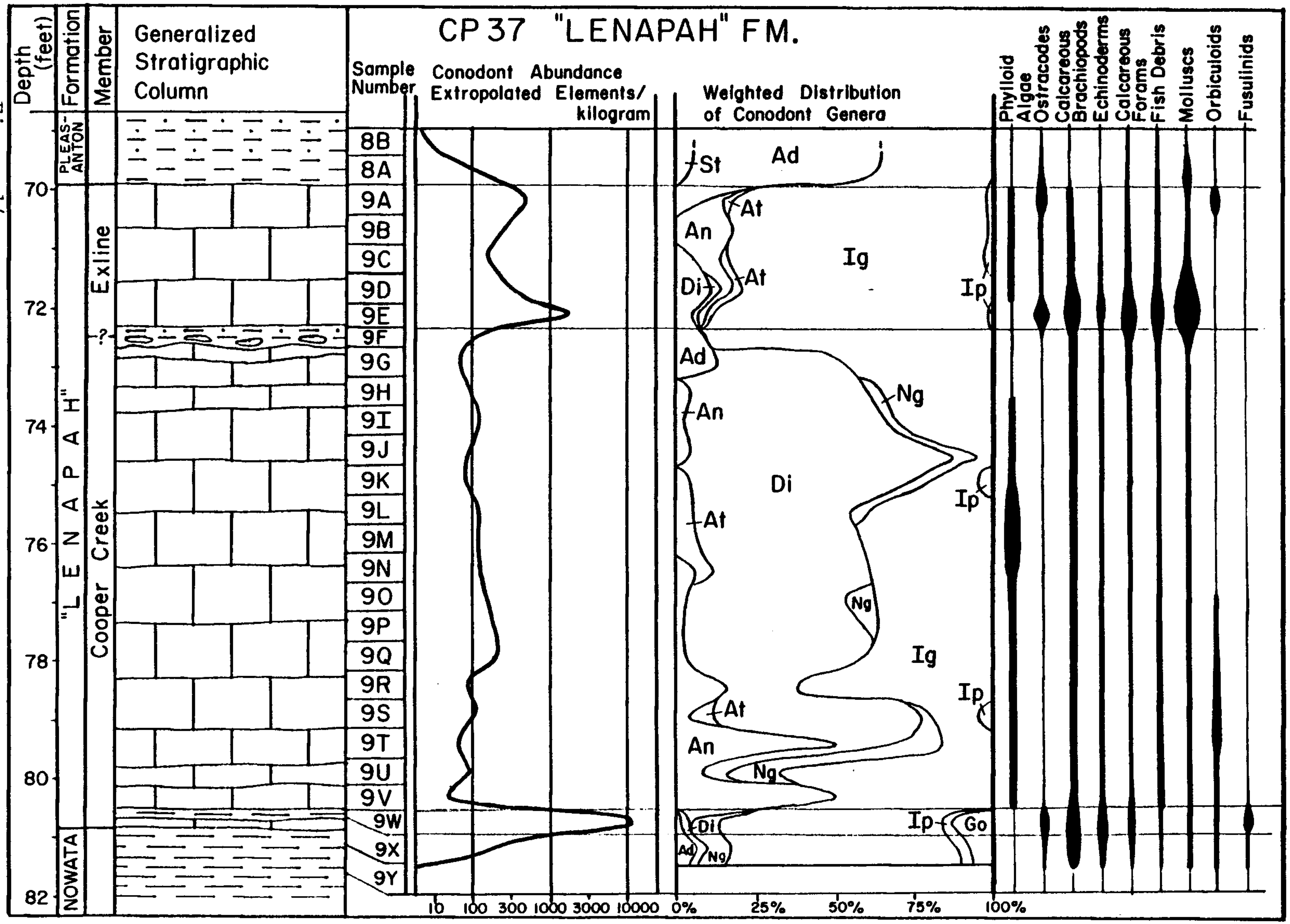

CP 37 "LENAPAH" FM.
Depth (feet)
Formation
Member
Generalized Stratigraphic Column
Sample Number
Conodont Abundance Extropolated Elements/kilogram
Weighted Distribution of Conodont Genera
Phylloid Algae
Ostracodes
Calcareous Brachiopods
Echinoderms
Calcareous Forams
Fish Debris
Molluscs
Orbiculoids
Fusulinids
PLEASANTON
"LENAPAH"
NOWATA
Exline
Cooper Creek
70
72
74
76
78
80
82
8B
8A
9A
9B
9C
9D
9E
9F
9G
9H
9I
9J
9K
9L
9M
9N
9O
9P
9Q
9R
9S
9T
9U
9V
9W
9X
9Y
10
100
300
1000
3000
10000
0%
25%
50%
75%
100%
St
Ad
At
An
Ig
Di
Ip
Ng
Go

Figure 14.

two specimens each of <u>Adetognathus</u> platforms and <u>Anchignathodus</u> elements, and a single <u>Diplognathodus</u> element were recovered.

Cooper Creek Limestone Member

The Cooper Creek Limestone attains a maximum thickness of about 7 feet in outcrop in Appanoose County, and is characterized by a brecciated appearance, with darker-colored limestone "clasts" in a lighter, more argillaceous matrix (Van Eck, 1965). The lower two members of the formation have not yet been located in Appanoose County.

In CP #37 (Fig. 14) from Clarke County, the Cooper Creek is 8.5 feet thick. The unit is dominated by skeletal calcilutite with the characteristic mottling, bioturbation independent of mottling, and a diverse, unabraded macrofauna including common red and green phylloid algal blades. The lower 1.5 feet are generally more argillaceous and thin mudstone partings increase downward. The upper portion is more nodular in appearance, with irregular mudstones increasing upward to a 0.3 foot green, arenaceous mudstone parting at the top.

Conodonts occur throughout the Cooper Creek, but abundances are quite low near the base and near the top. A maximum extrapolated abundance of 220 elements/kilogram occurs in the lower middle portion (sample 9Q) and abundance decreases upward to 50/kilogram in the top mudstone (9F). In general, a sequence of three faunas seem to be represented. The lower, slightly more argillaceous portion is dominated by <u>Idiognathodus</u>, with minor to subequal <u>Anchignathodus</u> and minor <u>Neognathodus</u>. <u>Diplognathodus</u> increases upward relative to <u>Idiognathodus</u>, and rare <u>Aethotaxis</u> and <u>Idioprioniodus</u> occur only in a slightly higher abundance zone (9S). The thick middle portion yielded unusual collections dominated by Diplognathodus elements. Idiognathodus is secondary throughout, with minor Anchignathodus, Aethotaxis, and Neognathodus, and rare Idioprioniodus more sporadic in occurrence. The upper portion, represented by the top two samples, is restricted faunally to three genera. Idiognathodus platforms dominate, with minor Adetognathus. Diplognathodus diminishes and is absent in the top mudstone.

Exline Limestone Member

The Exline Limestone, named from outcrop in Appanoose County, is a thin discrete bed that occurs stratigraphically close above the Cooper Creek. It can be traced southward into Missouri, where it occurs below the erosional unconformity used there to mark the top of the Desmoinesian Series. In Iowa, no pronounced unconformity is present, and the top of the Desmoinesian has historically been placed at the top of the Cooper Creek. Based on the recognition of the "super" limestone nature of the Exline determined in this study, it is proposed that it be recognized formally as a member of the unnamed formation referred to herein as "Lenapah". Consequently, the series boundary is placed herein at the top of the Exline. Clastic wedges locally intervene to separate the Exline and Cooper Creek Limestones on outcrop in Iowa, northern Missouri, and northwestern Illinois, and these may eventually also be accorded member status.

In CP #37 in Clarke County, Iowa, the Exline is represented by a 2.5-feet-thick, irregularly bedded, abraded skeletal calcilutite with grey argillaceous partings similar to the overlying shale and generally increasing upward (Fig. 14). The macrofauna is diverse, and especially in the lower portion, is dominated numerically by small molluscs, most of which are preserved as phosphatic internal molds.

Extrapolated conodont abundance increases dramatically in the lowermost sample (9E), which also appears to contain the most non-skeletal phosphate, to a maximum of over 1700 elements/kilogram. Abundance decreases to about 150 elements/kilogram in the middle of the unit, and increases again at the top to over 750/kilogram. Idiognathodus elements dominate the fauna, and Neognathodus is conspicuously absent. Anchignathodus is far better represented than in the underlying Cooper Creek and Adetognathus is prominent near both the bottom and top. Rare Aethotaxis and Idioprioniodus generally range throughout, and rare Diplognathodus elements occur only in the lower part.

Pleasanton Formation

Although Missourian strata are present in CP #37 and have been examined petrographically by O'Brien (1977), time constraints did not permit their inclusion in the present study. The base of the Pleasanton Formation was sampled, however, in conjunction with the Exline Limestone Member (Fig. 14). It consists of green, silty, weakly laminated shale, which becomes increasingly arenaceous upward. Conodont elements diminish upward from the lowermost sample which yielded an extrapolated 85 elements/kilogram. The fauna is dominated by Adetognathus platforms, with lesser numbers of Idiognathodus platforms and rare Stepanovites elements.

DEVELOPMENT OF A MODEL FOR UPPER DESMOINESIAN CONODONT PALEOECOLOGY

Review of Eustatic Model for Pennsylvanian Cyclothems

Heckel (1980) attributed the nature of Middle and Upper Pennsylvanian cyclothems as resulting from eustatic fluctuations of sea level and described the paleogeography of the Midcontinent during one cycle in terms of six phases of deposition. The Upper Cherokee and Marmaton Group cyclothems in south-central Iowa display a vertical sequence of basically eight members (Fig. 15) that can be related to the generalized model in the following manner.

Early Transgression

The top of the underlying outside shale is considered to represent deposition during the earliest phase of transgression. Generally, these deposits show evidence of rising water tables prior to incursion of marine water. They overlie the deltaic clastics that closed the preceding depositional cycle, which represent terrestrial environments that range from the active delta plain to low uplands that experienced processes of soil formation, and usually consist of sandy rooted mudstones. Locally where channeling affected the deposits of the preceding cycle, fluvial sandstones may fill the channels, stranded in

Figure 15.

Relationship of the cyclic phases of deposition in the six cyclothems studied.

	CYCLIC PHASES \ CYCLOTHEMS	ARDMORE	LOWER FORT SCOTT	UPPER FORT SCOTT	PAWNEE	ALTAMONT	COOPER CREEK
NONMARINE	CLASTICS	Deltaic Clastic Wedge (Interbedded)	MORGAN SCHOOL SHALE Deltaic Clastic Wedge	LOWER LABETTE Deltaic Clastics or Underclay	LOWER BANDERA Deltaic Clastics	LOWER NOWATA (Including Fifth Ls.?)	PLEASANTON FORMATION Deltaic Clastics
MARINE	SUPER LS.	UPPER ARDMORE LIMESTONE		HIGGINSVILLE LIMESTONE	COAL CITY LIMESTONE	UPPER WORLAND LIMESTONE	EXLINE LIMESTONE
MARINE	MARGINALLY MARINE CLASTICS	Dark Grey Sh.		Deltaic Clastic Wedge	MINE CREEK SHALE Clastic Wedge	Thin Clastics or diastem	Thin Clastics or Diastem
MARINE	UPPER LS. - REGRESSIVE	LOWER ARDMORE LIMESTONE (Grey Sh. or interbedded	BLACKJACK CREEK LIMESTONE (Grey Sh.)	HOUX LIMESTONE (Grey Sh.)	MYRICK STATION LIMESTONE (Grey Sh.)	LOWER WORLAND LIMESTONE (Green Sh.)	COOPER CREEK LIMESTONE
MARINE	MAXIMUM INUNDATION	Black Fissile Phosphatic OAKLEY SHALE	Black Fissile Phosphatic EXCELLO SHALE	Black Fissile Phosphatic LITTLE OSAGE SHALE	Black Fissile Phosphatic ANNA SHALE	Dark Phosphatic LAKE NEOSHO SHALE	Green Phosphatic UNNAMED SHALE
MARINE	MIDDLE LS. - TRANSGRESSIVE	(Sharp Contact)	Thin Grey Sh.	Fossiliferous Shale Wedge	Fossiliferous Shale Wedge	(Green Sh.) AMORET LIMESTONE (or Sh. =)	UNNAMED LIMESTONE
NONMARINE	COAL	WHITEBREAST C.	MULKY COAL	SUMMIT COAL	MYSTIC COAL	Marginally Marine Sh. or Local Coal UPPER BANDERA	UPPER NOWATA
NONMARINE	CLASTICS	(Rooting)	(Rooting)	(Rooting)	(Rooting) UPPER LABETTE Fluvial Clastics		

Figure 15.

response to the rise in water level. The top of the rooted mudstone represents the time at which the elevation of the local water table caused formation of extensive marginal swamps upon the previously well-drained soil. These swamps migrated away from the basin centers depositing a blanket of peat which, if not later destroyed, formed the significant coal that characterizes some Upper Desmoinesian cyclothems. The top of the coal marks the change from nonmarine to marine environments with sufficient water depths and/or salinities to prevent accumulation of the peat-forming plant material.

Late Transgression

The middle limestone or its shale equivalent represents deposition during the later, marine phase of transgression. The degree of development of the middle limestone is one of the principal differences between the conceptualized Illinois- and Kansas-type cyclothems. In the Missourian cyclothems in Kansas, it is usually represented by dark skeletal calcilutites, some of which grade upward from thin shoal-water calcarenites. In the Desmoinesian cyclothems of south-central Iowa, there is a pronounced trend upward in the section toward increased development of the middle limestone. The sharp contact between the Oakley Shale and underlying Whitebreast Coal is typical of the Illinois-type cyclothem, and is thought to result from the rate of transgression being sufficiently rapid to prevent the establishment of carbonate-producing algae upon a widespread peat (Heckel, 1977). In the three succeeding cyclothems (lower and upper Ft. Scott, Pawnee), the marine transgression is represented by thin, probably wedge-shaped, dark fossiliferous shales. These vary laterally, grading locally into lenticular skeletal calcarenites, dense nodular calcilutites, or zones of pyritic shell hash in black shale. These clearly represent deposition from above to below effective wave base, but not necessarily below the photic zone or resulting from exceedingly rapid transgression. Bottom conditions resulting from the proximity of a thick bed of peat may also have been responsible for inhibiting much algal carbonate production. The upper two cyclothems (Altamont, Cooper Creek) are more reminiscent of the Kansas-type, with thin, skeletal calcilutites having diverse macrofaunas and common oncolitic grain coatings. Evidently these later two transgressions were slow enough and did not deposit enough peat to prevent algal carbonate deposition in sporadically agitated, clear water marine environments.

Maximum Transgression

The core shale, and in particular, the black, fissile, phosphatic facies that it usually contains, represents deposition at maximum eustatic transgression. This facies developed when water in the epicontinental sea became deep enough to develop a thermocline that prevented bottom oxygenation by wind-driven vertical circulation (Heckel, 1977). Orientation of the Midcontinent sea in the trade wind belt north of the Pennsylvanian paleoequator resulted in establishment of large-scale quasi-estuarine circulation in which cold, oxygen-poor, phosphate-rich water from intermediate depths of the western ocean was drawn in along the bottom through deep basins in West Texas to upwell in the Midcontinent. A circulatory trap resulted, in which settling phosphatic and organic matter derived from phytoplankton blooms enriched the incoming deep water and further depleted its oxygen content, and eventually resulted in anoxic conditions above the sediment-water interface and in precipitation of non-skeletal phosphate.

The lower four of the six cyclothems studied contain well-developed black phosphatic facies dominating their cores. Each of these shales grades vertically into thin nonsandy grey shales with sparse benthic faunas representing low-oxygen conditions peripheral to the anoxic bottom, which record the breakup of the thermocline across the basin as eustatic regression began.

The core shales of the upper two cyclothems studied apparently left smaller areas of the basin affected by anoxic bottom conditions. The Lake Neosho Shale in CP #37 probably represents deposition near the margin of the anoxic conditions at maximum transgression as reflected by the thin, dark phosphatic bed sandwiched between green, fossiliferous shale. Eastward in CP #22 and elsewhere along the outcrop in south-central Iowa, only green phosphatic shale is present, whereas in other parts of the basin, a central black fissile facies is well developed (Schenk, 1967). The extremely thin phosphatic shale below the Cooper Creek Limestone evidently represents conditions of nearly complete sediment-starvation at maximum transgression in a basin insufficiently deep to develop an extensive thermocline. The black fissile facies in that cyclothem is restricted to the central and southern Midcontinent area (P.H. Heckel, pers. commun., 1982).

Opposing models focusing on an alternative interpretation of the depositional environment of the black, phosphatic shale facies still exist (esp. Merrill, 1975; Merrill and Martin, 1976). Merrill and Von Bitter (1976) summarized the delta-algal bank model in which the black shale facies was deposited in shallow-water, nearshore environments, either in restricted lagoons behind algal banks or between delta lobes, probably beneath an algal flotant such as had been described by Zangerl and Richardson (1963) for Middle Pennsylvanian black shales in Indiana. These models are largely discounted for the Midcontinent Desmoinesian black phosphatic shales studied owing to their great lateral continuity and usual position between fully marine beds. Local occurrences of dark shallow-water shales are noted in the Midcontinent (e.g., the lower Anna Shale in CP #37), but as Heckel and Swade (1977) indicated, they are laterally discontinuous and further distinguished by containing sandy lamellae and sparse benthic faunas, and by lacking nonskeletal phosphorite.

Early Regression

The upper limestone members of the cyclic sequence record marine deposition following the maximum transgressive phase. The grey or green shale that immediately underlies this limestone probably represents the return of at least partially oxygenated bottom conditions following the retreat of the thermocline, but perhaps at depths still sufficient to be below the effective photic zone. The base of the limestone represents the establishment of carbonate mud-producing algae in the lower photic zone. Carbonate deposition continued through most of the eustatic regression under fully marine conditions below effective wave base. The Desmoinesian upper limestones studied are generally uniform skeletal calcilutites and lack the shoal-water facies common in the upper parts of thicker Missourian upper limestones. In the lower four cyclothems (Ardmore through Pawnee), the upper limestones are generally thin, argillaceous, mottled by bioturbation and lack phylloid algae. The upper two cyclothems (Altamont, Cooper Creek) contain thicker upper limestones that are generally wavy-bedded, skeletal calcilutites with green clay partings that increase upward and common phylloid algae, and are more reminiscent of younger Pennsylvanian upper limestones. Carbonate production in the upper limestones generally was terminated by fine detrital influx that marked the approach of shoreline later during eustatic regression, although in all six cyclothems, these prodeltaic deposits still represent marine environments.

Late Regression

The late phase of marine regression is represented by the super limestone member in five of the six Upper Desmoinesian cyclic sequences. These super limestones represent a resumption of carbonate mud production and return of more fully marine conditions. Unlike the upper limestones, the super limestones are laterally variable in thickness and character, and in addition to below-wave-base carbonates, often include common abraded and coated-grain skeletal calcarenites, carbonate tidal flats and other shoal-water deposits. Their relatively great lateral extent seems to support the interpretation that they resulted from minor eustatic transgressive events instead of from fortuitous events of delta progradation and abandonment. For example, Price (1981) has demonstrated the lateral persistence of the Coal City (and equivalent Laberdie) Limestone over most of the Midcontinent. He also determined that in parts of the basin, the Coal City is underlain by dark grey to black shale that merges laterally in Oklahoma with the upper portion of the Anna Shale. The increase in the area affected by low-oxygen bottom conditions prior to and during deposition of the Coal City is more easily accounted for by eustatic transgression than by delta abandonment models. The latest stage of regression is represented by the progradation of deltaic clastics that rapidly overwhelm marine conditions and close out the depositional cycle.

Maximum Regression

The maximum phase of regression is represented in the cyclic sequence by an episode of subaerial exposure that typically left little sedimentary record. Local erosion may have produced unconformities, but more commonly, the effect of subaerial exposure was in-place weathering of the underlying strata and formation of paleosols represented in the cyclic sequence by the rooted, sandy mudstone seatrock of the next higher coal, or in the case of the top of the Altamont cyclothem, where the exposed surface was limestone instead of clastic materials, by the red, weathered residuum and possible caliche that overlies the Worland Limestone.

Summary of Depositional Trends and Conodont Distribution

Application of the eustatic model of Heckel (1980) to the six Upper Desmoinesian cyclothems studied permits recognition of analogous cyclic phases in each vertical sequence (Fig. 15). The vertical cyclic sequence was related by Heckel (1977) to a series of laterally contiguous depositional environments that develop in the epicontinental sea under the influence (at higher sea level stands) of an upwelling water mass. The well established interpretation of marine depositional environments provides a firm basis for the development of a model for conodont paleoecology. Identification of analogous cyclic phases also reveals a series of trends developed within the individual members of successive cyclothems that may lead to the interpretation of larger-scale trends in the pattern of Pennsylvanian depositional history.

Middle Limestones

As previously noted, the lithologic character of the middle limestone changes markedly upward in the Upper Desmoinesian cyclothems studied. The lower two cyclothems (Ardmore, lower Fort Scott) have little or no equivalent of the middle limestone developed. The thin grey shale below the black, phosphatic facies in the lower Fort Scott in CP #22 was not sampled independently, but the basal sample (14F) contained only Idiognathodus, Neognathodus and Idioprioniodus.

The middle two cyclothems (upper Fort Scott, Pawnee) have fossiliferous shale wedges that are equivalent to the "middle limestone" member of the sequence. Conodont abundance in these shales averages about 300 elements/kilogram. Where thin, as in the Little Osage or Anna in CP #22, the faunas are dominated by Idiognathodus, but appear somewhat mixed, containing minor Neognathodus and Idioprioniodus, as well as Adetognathus, Anchignathodus and Diplognathodus.

Where the shale is thicker, as in the lower Anna Shale in CP #37, a more complete record of the succession of conodont faunas during transgression is recorded (Fig. 9). Only Adetognathus and minor Diplognathodus occur at the base; Adetognathus diminishes upward as Idiognathodus increases; Anchignathodus, Neognathodus and Idioprioniodus occur only in the upper part and are associated with a more normal marine macrofauna. This sequence is mirrored above the core shale (upper Anna) in the upper limestone (Myrick Station), and thus bears heavily on the interpretation of the vertical and lateral relationships in the paleoecologic model.

In the upper two cyclothems (Altamont, Cooper Creek) the middle limestone consists of thin skeletal calcilutites that yield an average of about 200 conodont elements/kilogram. The same six genera are present, and a similar sequence of faunas is observed where the bed is thick, as in the Amoret Member of the Altamont in CP #22 (Fig. 12).

Core Shales

The greatest abundance of conodonts in the entire cyclic sequence occurs in the core shales. As indicated previously, the cores of the lower four cyclothems are dominated by black, fissile, phosphatic facies. Each of these four black shales (Oakley, Excello, Little

Osage, and Anna) yields conodonts in abundances ranging from 1000 to over 3000 elements/kilogram. The faunas are principally restricted to four genera: Idiognathodus, Neognathodus, Idioprioniodus, and Gondolella. Idiognathodus platforms generally dominate over Neognathodus by ratios of 2:1 to 5:1, but both the Oakley and Little Osage contain zones in the central part of the bed in which the ratio decreases to approximately 1:1. Idioprioniodus is a consistent faunal element averaging 5 to 10% of the totals. Gondolella occurs in only the lower two of the four black core shales, the Oakley and the Excello, and its abundant occurrence is restricted to thin, central zones within these shales. Its abundance seems to be superimposed upon the numbers of the other three genera, which remain generally constant in all four shales. Diplognathodus elements are extremely rare in the black shale, represented by only two specimens from the Excello shale. D. coloradoensis is also found in the uppermost sample from the Oakley, but as indicated, that sample contained interbedded calcarenites probably indicating deposition marginal to the fully anoxic bottom. The grey shales above the black facies in the Excello, Little Osage, and Anna Shales contain only the same three genera, Idiognathodus, Neognathodus and Idioprioniodus, in similar abundance in the lower part, about 1000 elements/kilogram, but generally decreasing upward.

The Lake Neosho, the core shale of the Altamont Cyclothem, also represents deposition marginal to the area of anoxic bottom and generally, consists of green fossiliferous shale. Conodont abundance averages about 3500 elements/kilogram and the fauna is dominated by Neognathodus and *Idiognathodus* with minor *Idioprioniodus*. *Neognathodus* platforms dominate over *Idiognathodus* by a ratio of 3:1. Rare elements of *Anchignathodus*, *Diplognathodus* and *Adetognathus* were observed. In CP #37, a central, thin, dark phosphatic facies is developed, and it yielded about 12,000 elements/kilogram with the ratio of *Neognathodus* to *Idiognathodus* platforms exceeding 4:1.

The unnamed phosphatic shale below the Cooper Creek Limestone represents extremely slow deposition during maximum transgression. It yielded in excess of 10,000 conodont elements/kilogram, dominated by *Idiognathodus* elements, but with a restricted common occurrence of *Gondolella*, lesser numbers of *Neognathodus* and *Idioprioniodus*, and rare elements of *Diplognathodus* and *Adetognathus*.

Upper Limestones

Although the upper limestones in the lower four cyclothems (Ardmore-Pawnee) differ somewhat lithologically from the upper limestones in the upper two cyclothems (Altamont, Cooper Creek), the conodont faunas are generally similar in all six. In general, abundances in the lower four average about 100 elements/kilogram, ranging as high as 300/kilogram in some samples, and generally diminishing upward. In the upper two cyclothems it is usually lower, from 20 to 100 elements/kilogram through most of the bed. The faunas are perhaps the most diverse of any in the cyclic sequence, as representatives of eight of the nine genera recognized are found in the upper limestones, and generally a distinctive sequence is observed. *Idiognathodus* dominates, and

Neognathodus and *Anchignathodus* also range throughout; *Anchignathodus* is often restricted to the limestone. Where the limestone is thin, *Idioprioniodus* and *Aethotaxis* may also range throughout, but where the bed is thicker, *Idioprioniodus* decreases upward and disappears below the top, whereas *Aethotaxis* occurs in more sporadic zones, often only in the middle of the bed. *Adetognathus* and very rare *Stepanovites* occur only in the upper portion of the upper limestones. *Diplognathodus* is absent in most upper limestones. It is represented by only a single specimen from the Blackjack Creek, but in the lower-abundance faunas from the Cooper Creek Limestone in CP #37, it numerically dominates in most samples.

Marginally Marine Clastics

The detrital unit that separates the upper and super limestones in five of the six cyclothems studied generally consists of deltaic clastics that are of variable character. In the Ardmore cyclothem, it consists of dark grey shale that probably represents a distal "prodeltaic" deposit. Scarce conodonts occur in the lower half of the unit and just below the top, dominantly small *Idiognathodus* and *Neognathodus* platform elements, with scarce *Gondolella* and *Idioprioniodus* elements. The Morgan School Shale is a single, coarsening upward, deltaic clastic wedge. A super limestone is not developed in the lower Fort Scott cyclothem, although a zone of limestone nodules several feet above the top of the Blackjack Creek Limestone did yield a diverse group of small conodont elements. The Houx and Higginsville Limestones of the upper

Fort Scott cyclothem are also separated by a single deltaic clastic wedge. Conodonts occur only in shale in the lower 0.5 foot and consist of scarce Adetognathus platforms.

The most complex detrital unit in the cyclothems studied is the Mine Creek Shale. The three subunits it contains (pp. 50-51) apparently represent an incomplete prodelta wedge, a delta-abandoned, sandy carbonate unit, and a second prodeltaic wedge. The sequence is well developed in CP #37 and contains a sequence of conodont faunas that are important in the formulation of the paleoecologic model. The lower prodeltaic shale contained scarce Idiognathodus and Diplognathodus elements in only the lower 1.0 foot. The middle subunit begins with lagoonal shales and a thin carbonaceous zone at the base, which yield only Adetognathus elements. These shales are overlain by quartz-sandy calcilutite that represents a winnowed deposit at or just below effective wave base (O'Brien, 1977). Its conodont fauna is dominated by Adetognathus, but also contains Idiognathodus, Anchignathodus and Diplognathodus throughout, and rare Aethotaxis and Stepanovites in some samples. Neognathodus and Idioprioniodus are absent. The third subunit, the upper prodeltaic shale, contains only Adetognathus and Idiognathodus in the lower 1.0 foot.

In the upper two cyclothems, the upper and super limestones are separated by thin shales. In the Altamont cyclothem, a 0.9 foot shale overlies the "upper" limestone portion of the Worland. A ten-fold increase in conodont abundance may indicate the presence of a diastem at the base of the shale and a change in conodont fauna also occurs across this interval. For the present, however, little can be inferred concerning the lateral relations of this horizon as the "super" portion of the Worland has not been located in outcrop. In core CP #37, a 0.3 foot silty shale separating the Cooper Creek and Exline Limestones yielded small numbers of Idiognathodus and Adetognathus platforms. This shale may represent the thin edge of a delta wedge, as the Exline is known to become increasingly separated from the Cooper Creek southward into Missouri (Cline, 1941).

Super Limestones

The super limestone members of the cyclic sequence, as noted earlier, are perhaps the most variable of the cyclic sequence. Lateral variations in thickness, lithotype, and conodont fauna are particularly well developed in the Higginsville Limestone (Swade, 1977) and in the Coal City Limestone in this study. As a whole, the five super limestones contain diverse conodont faunas, including the same eight genera found in the upper limestones and in a similar sequence of faunas.

The super limestone portion of the Ardmore Limestone consists of interbedded limestone and shale. Conodont faunas indicate two peaks of abundance in limestones dominated by Idiognathodus separated by a shale with lower abundance dominated by Adetognathus. The two peaks probably indicate episodes of slower deposition although it cannot be determined whether these are related to fluctuations in sea level or in rate of clastic influx.

The Higginsville Limestone in CP #22 contains a sequence of three faunas (p. 40). The lower and upper parts are dominated by Adetognathus and Idiognathodus, with minor Diplognathodus and rare Stepanovites.

The thin middle zone, which contains the greatest abundance, is dominated by Idiognathodus, with Anchignathodus, Aethotaxis, Neognathodus, and Diplognathodus, but no Adetognathus. The fauna in the Coal City Limestone in CP #22 contains the same five genera as in the middle Higginsville, plus minor Idioprioniodus. Adetognathus occurs only in the over- and underlying shales.

The super limestone portion of the Worland in CP #37 consists of limestone and interbedded shale (p. 59). A thin phosphatic shale at the base yielded the greatest abundance of conodonts. The shale and the overlying shoal water carbonate contain Idiognathodus and Adetognathus, and minor Neognathodus and Anchignathodus. The second shale bed yielded only Adetognathus. The upper part of the Worland consists of lagoonal or tidal-flat carbonates and yielded a different fauna, dominated by Adetognathus and Diplognathodus, with minor Idiognathodus, and rare Anchignathodus and Neognathodus.

The Exline Limestone in CP #37 represents a carbonate environment at or just below wave base (O'Brien, 1977) with the greatest conodont abundance at the base. The fauna is mixed, dominated by Idiognathodus elements with Anchignathodus, Adetognathus, and minor Aethotaxis, Diplognathodus, and Idioprioniodus.

Outside Shales

Five of the six cyclothems concluded with the deposition of deltaic clastics, except for the Altamont, in which the Worland Limestone was exposed to subaerial weathering with little or no clastic deposition. In general, only the basal portion of the prodeltaic shales contains conodonts, as is the usual case with the detrital unit between the upper and super limestones. These sparse faunas are dominated by *Adetognathus* and *Idiognathodus* platforms, with minor *Neognathodus* and *Anchignathodus*, and rare *Diplognathodus* and *Stepanovites*.

Model for Conodont Paleoecology

Application of the eustatic model elaborated by Heckel (1977, 1980) to the lithologic succession in the six Upper Desmoinesian cyclothems studied permits the identification of marine depositional environments and their relationship to the overlying water masses present in the epicontinental sea (Fig. 16A). Klapper and Barrick (1978) reviewed the ecologic models proposed to explain the distribution patterns of conodonts. They examined possible modern analogues and concluded that it is not possible to distinguish between a pelagic or benthic mode of life solely on the basis of preserved distributional patterns. They did conclude, following Seddon and Sweet (1971), Heckel and Baesemann (1975) and Merrill and von Bitter (1976), that a pelagic mode was strongly indicated for those genera observed to occur in black shales that lack benthic faunas and are interpreted as representing anoxic bottom conditions. The well developed black shales in the cyclothems studied yielded four genera, *Idiognathodus*, *Neognathodus*, *Idioprioniodus* and *Gondolella*, and therefore, these are considered to have been pelagic organisms.

Two other Middle Pennsylvanian genera were possibly also pelagic, *Diplognathodus* and *Adetognathus*. *Diplognathodus coloradoensis* occurs

Figure 16.

Generalized restored cross sections of Midcontinent sea at maximum transgression. A, Relation of water masses involved in quasi-estuarine circulation to sedimentary lithotopes. Vertical scale greatly exaggerated. B, Interpreted paleoecological distribution of conodont genera. Idiognathodus, Neognathodus, Idioprioniodus, and Gondolella are pelagic organisms; remainder may be either pelagic or benthic.

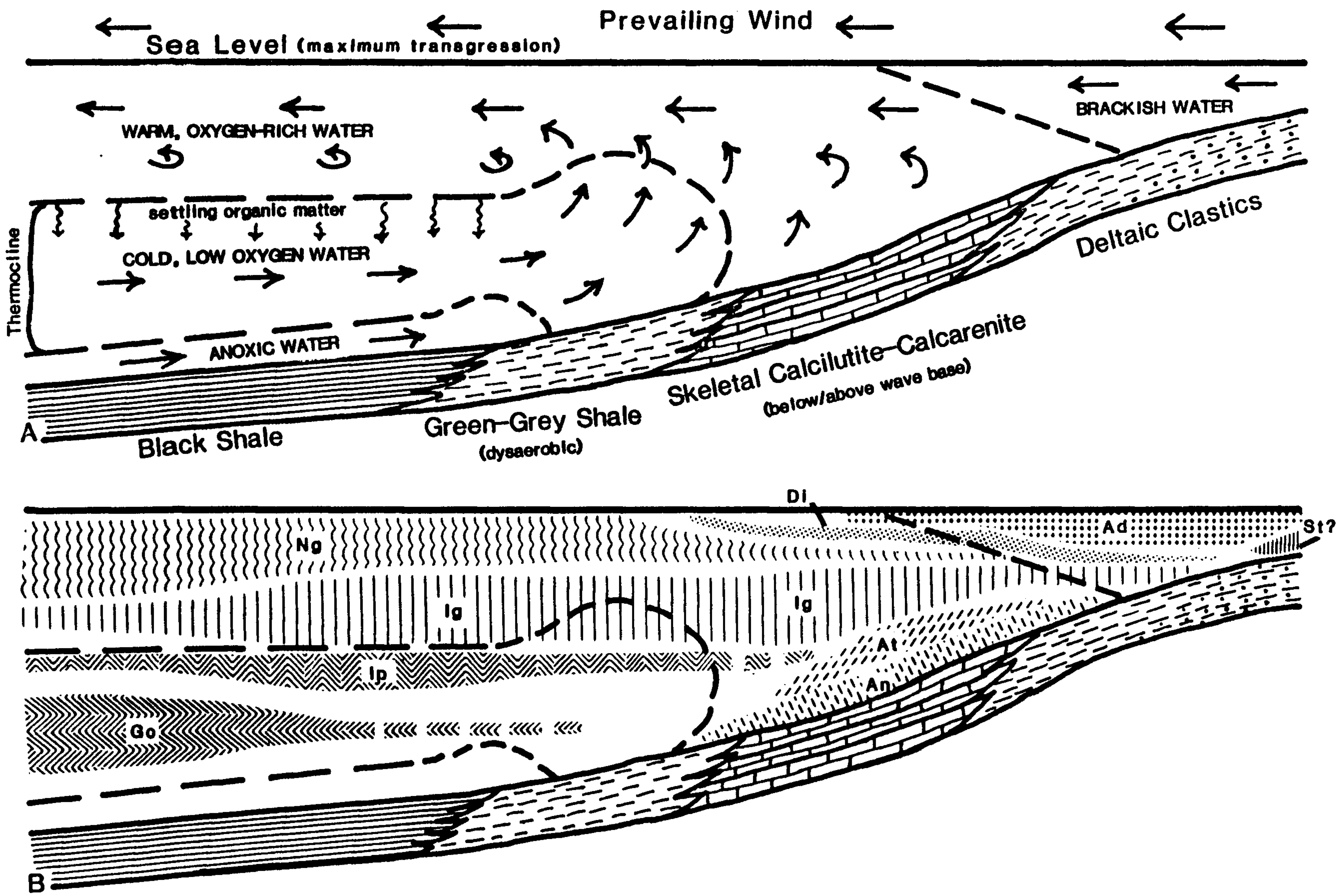

Prevailing Wind
Sea Level (maximum transgression)
BRACKISH WATER
WARM, OXYGEN-RICH WATER
settling organic matter
COLD, LOW OXYGEN WATER
ANOXIC WATER
Thermocline
Deltaic Clastics
Skeletal Calcilutite-Calcarenite
(below/above wave base)
Green-Grey Shale
(dysaerobic)
Black Shale
A
Dl
Ad
St?
Ng
Ig
Ig
At
An
Ip
Go
B

Figure 16.

in the uppermost sample of the Oakley Shale and is also known to occur in a phosphatic black shale in the Floris Formation in CP #22. D. n.sp.1 is rare in the Excello Shale and D. n.sp.2 occurs with Adetognathus elements in the lower part of the Anna Shale in CP #37. Elsewhere, however, Diplognathodus elements seem conspicuously absent in some of the black shales, for example, the black phosphatic facies of the upper Anna in CP #37. Adetoganthus is also considered to have been possibly pelagic, based on suggestive evidence offered by the occurrence of Cavusgnathus, a closely related Mississippian genus, in bedding plane assemblages in black shales (Norby, 1976). If these two genera were pelagic, their absence in the black phosphatic shales may be related to the extremely low bottom gradients in the epicontinental sea, and the resulting great distance from their preferred nearshore habitats out to the anoxic basin centers.

Having established a pelagic mode of life for four, and possibly six of the nine genera recognized, it is then possible to relate their distribution pattern to the three water masses present in the Midcontinent Sea, following the model proposed by Klapper and Barrick (1978, Fig. 3). Idiognathodus and Neognathodus were offshore surface-dwelling conodonts adapted to warm, well oxygenated waters (Fig. 16B). Idiognathodus apparently dominated in the onshore area, whereas Neognathodus became relatively more abundant offshore, but both are widely distributed, possibly in part by post-mortem transport while settling. Idioprioniodus and Gondolella were offshore, deep-dwelling conodonts adapted to colder, low-oxygen water. The occurrence of Gondolella in two of the black shales, and not in two others suggests it may have inhabited a different deep, cold water mass than Idioprioniodus and that its migration into the Midcontinent Sea was only possible when that mass became involved in the upwelling. The occurrence of Gondolella in marginally marine shales in the same two cyclothems is limited to scarce, small-sized elements thought to have been transported while settling. Adetognathus exhibits a distribution pattern compatible with life in the nearshore water mass that is characterized by fluctuating environmental conditions, particularly the brackish salinities that result from fresh-water influx. Diplognathodus is rare enough in the present study that firm conclusions regarding its distribution cannot be drawn, but its occurrence seems to range from onshore to offshore environments, near the area affected by anoxic bottom conditions. This wide distribution may result from its small size and greater susceptibility to transport while settling.

Two other Middle Pennsylvanian genera exhibit distribution patterns that may indicate a nektobenthic habitat following the reasoning of Barnes and Fahraeus (1975), but as Klapper and Barrick (1978) indicated, this can by no means be proved. Anchignathodus and Aethotaxis are both strongly restricted to carbonate lithotopes representing oxygenated conditions in the photic zone. Anchignathodus generally appears to range farther onshore than Aethotaxis, and its occurrence in calcareous shales that separate limestone beds may suggest that it was somewhat more tolerant of turbid waters. These interpretations of the habitats of Adetognathus, Anchignathodus, and Aethotaxis are consistent with interpretations made for them by previous workers (e.g., Merrill, 1975; Merrill and Von Bitter, 1976; Heckel and Baesemann, 1975), but the interpretation for Gondolella and Idioprioniodus differs sharply from that of Merrill (1975) or Merrill and Von Bitter (1976, Fig. 11).

Stepanovites is the only other genus represented in the present collections and it is too rare to permit any firm conclusions regarding its paleoecology. Its occurrence, however, appears closely linked to that of Adetognathus.

BIOSTRATIGRAPHIC ASPECTS OF THE CONODONT FAUNAS

Precise correlation of Upper Cherokee and Marmaton Group strata of the Midcontinent can be based on conodont faunas from the six laterally persistent phosphatic shales present in the section. These are, in ascending order, the Oakley Shale, Excello Shale, Little Osage Shale, Anna Shale, Lake Neosho Shale, and the unnamed phosphatic shale associated with the Cooper Creek Limestone. Each of these shale horizons can be traced over the entire Midcontinent region and, with the possible exception of the Lake Neosho, each supposedly has a direct lithostratigraphic equivalent in the Illinois Basin. Detailed lithologic characteristics of these shales and associated strata are observed to change laterally, particularly near the margins of the depositional basins, and more pronounced variation may be expected in attempting to correlate between basins. Previous interstate correlations have generally been based on knowledge of the sequence of formational units, and misidentification of key shale horizons has resulted in errors (e.g., Hertha Limestone/Tacket Shale: Ravn, 1981; Lenapah Limestone/supposed northern equivalents: Parkinson, in prep., and P.H. Heckel, pers. commun., 1981). An independent means of confirming correlations such as may be provided by the conodonts is thus highly desirable.

The conclusions of Heckel (1977) regarding the offshore origin and depositional environment of these phosphatic shale units lead directly to the interpretation that these beds represent the closest approximation of stratigraphic timelines available in the sequence, as developed by Israelsky (1949) for the Gulf Coast Tertiary. The faunas from these shales, although restricted to only four genera, are abundant and from preliminary data apparently laterally consistent, reflecting the condensed nature of their deposition under offshore, sediment-starved conditions. As has been elaborated earlier, these shale faunas are dominated by platform elements of *Idiognathodus*, *Neognathodus* and *Gondolella*, and by *Idioprioniodus* elements. No uniformly applicable system for the recognition of species has yet been proposed for Middle and Upper Pennsylvanian *Idiognathodus* (see Merrill, 1975), and although a system has been proposed for *Neognathodus* (Merrill, ibid.), its application to the present collections is considered beyond the scope of this study. Further biostratigraphic research will focus on these genera and it is hoped that biometric analyses may help resolve problems of species identification. Pennsylvanian *Gondolella* are currently being examined (Von Bitter and Merrill, 1980), but revision of the broad-platformed species has not yet been published. At present, elements of *Idioprioniodus* are useful only for discrimination between the Desmoinesian and Missourian Stages (Merrill and Merrill, 1974). Nevertheless, vertical variation in the detailed nature and proportions of the three platform genera can be used to describe assemblage biozones that are practical for the identification of the six phosphatic shales for intrabasinal correlation (Fig. 17).

Figure 17.

Assemblage biozones of *Idiognathodus*, *Neognathodus* and *Gondolella* platform elements based on collections from the phosphatic core shales. All conodonts are enlarged approximately 28X. Numbers in parentheses below indentify the core and sample from which illustrated specimens were taken.

Unnamed shale below Cooper Creek Limestone:
- 1,2-*Gondolella* sp.3 (37-9W)
- 3-*G. denuda* (37-9W)
- 4,5-*Idiognathodus* sp.1 (37-9W)
- 6,7-I. sp.6 (37-9W)
- 8-*Neognathodus roundyi* (37-9W)
- 9-*N. medexultimus* (37-9W)

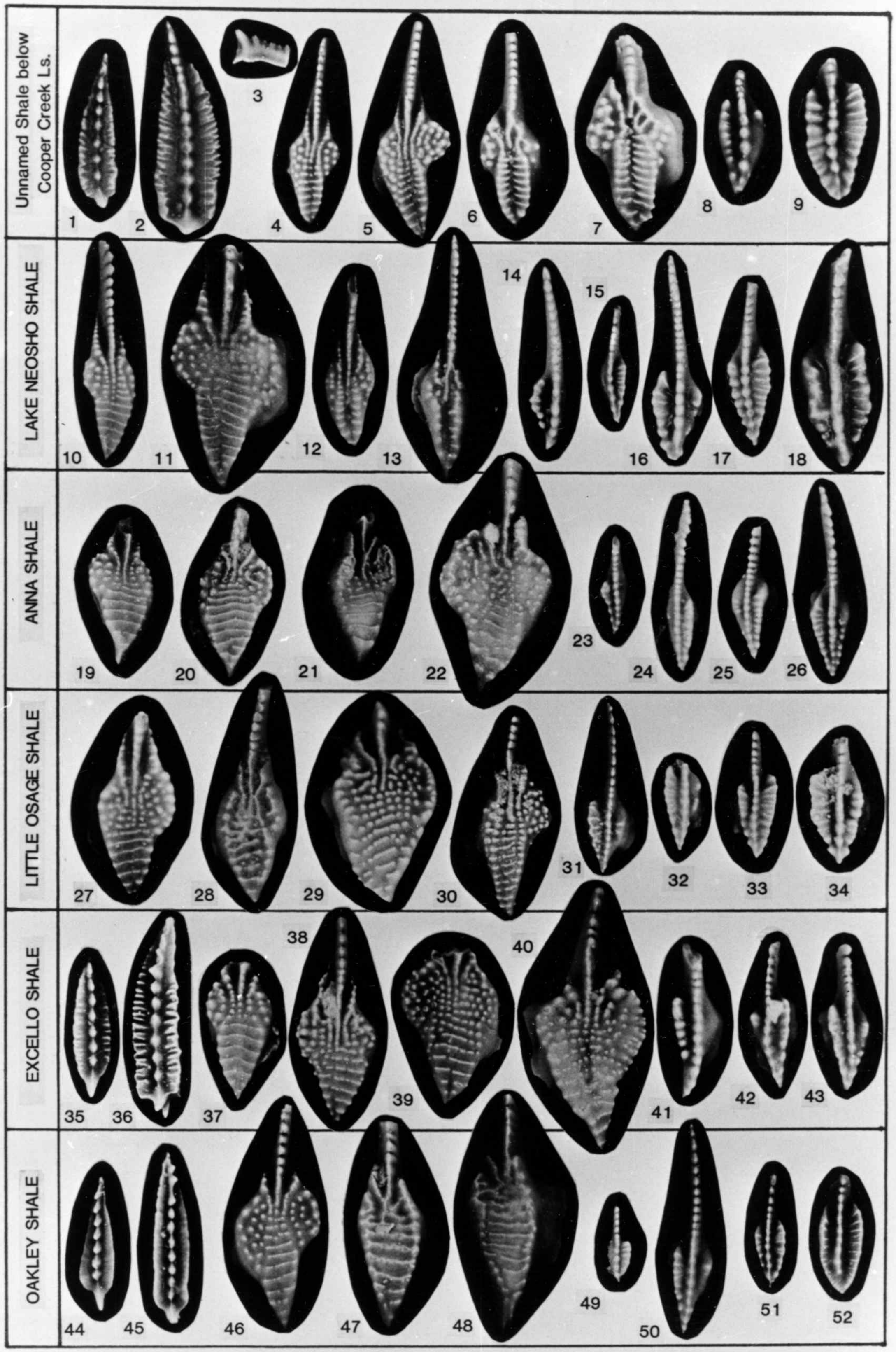
Lake Neosho Shale:
- 10,11-*Idiognathodus* sp.1 (22-2A)
- 12,13-*I.* sp.5 (22-2B, 22-2C)
- 14-*Neognathodus polynodosus* (22-2B)
- 15-*N. dilatus* (22-2A)
- 16-*N. roundyi* (22-2A)
- 17-*N. medexultimus* (22-2A)
- 18-*N. medalultimus* (22-2A)

Anna Shale:
- 19-*Idiognathodus* sp.1 (22-6U)
- 20-*I.* sp.1 (37-19A)
- 21-*I.* sp.2 (22-6U)
- 22-*I.* sp.3 (22-6U)
- 23-*Neognathodus dilatus* (22-6U
- 24,25-*N. roundyi* (37-19A)
- 26-*N. medexultimus* (37-19A)

Little Osage Shale:
- 27-*Idiognathodus* sp.1 (22-11G)
- 28-*I.* sp.2 (22-11H)
- 29-*I.* sp.3 (22-11H)
- 30-*I.* sp.4 (22-11D)
- 31-*Neognathodus roundyi* (22-11H)
- 32-*N. roundyi* (22-11G)
- 33-*N. medexultimus* (22-11G)
- 34-*N. medadultimus* (22-11G)

Excello Shale:
- 35,36-*Gondolella* sp.2 (22-14D)
- 37,38-*Idiognathodus* sp.1 (22-14E)
- 39,40-*I.* sp.3 (22-14E)
- 41-*Neognathodus polynodosus* (22-14D)
- 42-*N. roundyi* (22-14D)
- 43-*N. medexultimus* (22-14D)

Oakley Shale:
- 44,45-*Gondolella* sp.1 (22-22W)
- 46-*Idiognathodus* sp.1 (22-22T)
- 47,48-*I.* sp.2 (22-22T)
- 59-*Neognathodus dilatus* (22-22T)
- 50-*N. roundyi* (22-22T)
- 51-*N. medexultimus* (22-22T)
- 52-*N. medadultimus* (22-22T)


Unnamed Shale below Cooper Creek Ls.
LAKE NEOSHO SHALE
ANNA SHALE
LITTLE OSAGE SHALE
EXCELLO SHALE
OAKLEY SHALE

Diplognathodus, a rare conodont in the black shales, is only a little more common in nearer-shore lithotopes, but where present, it appears to exhibit a zonation useful for biostratigraphy (Fig. 18). *D*. *coloradoensis* is the only species present in the Ardmore cyclothem and in upper Floris Formation cyclothems. It ranges up to the lower Fort Scott cyclothem where it is rare (Merrill, 1975). *D*. n.sp.1 ranges from the lower Fort Scott through the Cooper Creek cyclothem. *D*. n.sp.2 ranges from the Pawnee cyclothem through the Cooper Creek and and *D*. *illinoisensis* occurs only in the Cooper Creek.

Each of the six Upper Desmoinesian cyclothems can be uniquely characterized by means of its conodont fauna, using the assemblage biozones for the three pelagic platform genera in conjunction with the *Diplognathodus* zonation. It is hoped that further work will demonstrate the applicability of these characterizations to interbasinal correlation.

Ardmore Cyclothem

The Ardmore cyclothem can be recognized by the conodont fauna of the Oakley Shale. Most characteristic is the occurrence of *Gondolella* sp.1, a relatively narrow, smooth platformed variety that Von Bitter and Merrill (1980) regard as transitional between *G*. *laevis* and *G*. *bella*. Among the *Idiognathodus* platforms, two distinct types are noted with few intermediates. *I*. sp.1 represents the longest-ranging type and generally conforms to conservative *I*. *delicatus* of many workers. *I*. sp.2 is a short- or narrow-platformed variety, with ridges instead of nodes on the small accessory lobes. Large specimens usually have poorly defined ornamentation on the upper surface. *Neognathodus* platforms in the

Figure 18.

Stratigraphic range chart for species of *Diplognathodus*. Vertical scale approximate. Conodonts are enlarged approximately 40X. Illustrated specimens: *D*. *coloradoensis* from sample 22-22T, *D*. n.sp.1 from samples 22-9f and 37-9I, *D*. n.sp.2 from sample 37-9H, and *D*. *illinoisensis* from 37-9X.

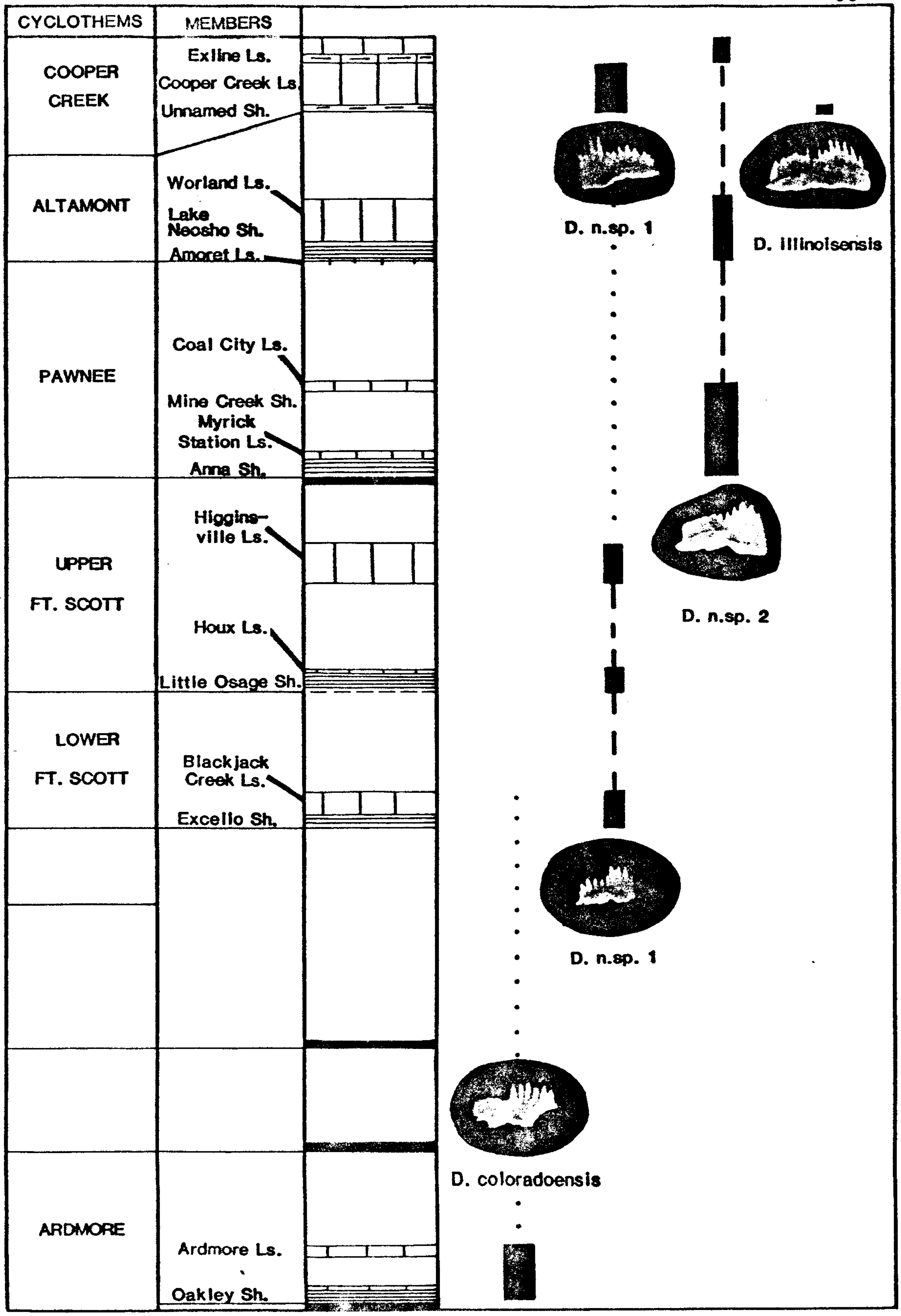

CYCLOTHEMS
MEMBERS
COOPER CREEK
Exline Ls.
Cooper Creek Ls.
Unnamed Sh.
ALTAMONT
Worland Ls.
Lake Neosho Sh.
Amoret Ls.
PAWNEE
Coal City Ls.
Mine Creek Sh.
Myrick Station Ls.
Anna Sh.
UPPER FT. SCOTT
Higgins-ville Ls.
Houx Ls.
Little Osage Sh.
LOWER FT. SCOTT
Blackjack Creek Ls.
Excello Sh.
ARDMORE
Ardmore Ls.
Oakley Sh.
D. n.sp. 1
D. illinoisensis
D. n.sp. 2
D. n.sp. 1
D. coloradoensis

Figure 18.

Oakley are dominantly N. medexultimus and N. roundyi, with a few N. medadultimus among the largest specimens and a few N. dilatus among the smallest. Faunas similar in each of these regards have also been recovered from the Oakley in three additional cores (CP# 53, Monroe County; CP# 41, Marion County; CP# 37,Clarke County) and in outcrop in Lucas County at the type locality of the Swede Hollow Formation. The Ardmore cyclothem can also be recognized by the youngest common occurrence of Diplognathodus coloradoensis.

Lower Fort Scott Cyclothem

The lower Fort Scott cyclothem can be identified on the basis of conodonts from the Excello Shale. Most characteristic is the occurrence of abundant Gondolella sp. 2, a broad-platformed species that has parallel transverse ridges. The Idiognathodus are mostly conservative I. sp. 1, but among the largest specimens there are many that have only a few, generally incomplete transverse ridges, and instead, most of the upper surface is occupied by rows of nodes, often arranged in concentric arcs on both accessory lobes. This variety could probably be called I. cf. claviformis as it is transitional to that species, which is characterized by a completely nodose upper surface. Herein, it is referred to as I. sp. 3. Neognathodus platforms in the Excello generally range from small specimens of the N. metanodosus-N. dilatus type to larger N. roundyi-N. medexultimus, with a few N. polynodosus. The Excello also contains the youngest, rare occurrence of Diplognathodus coloradoensis and the oldest, rare occurrence of D. n.sp. 1. Additional samples of the Excello that are known to contain Gondolella sp. 2 are available from four additional cores in Iowa (CP #10, Appanoose County; CP #37, Clarke County; CP #41, Marion County; CP #53, Monroe County), from outcrop in Lucas County, Iowa, at the type locality of the Mouse Creek Formation, and from outcrops at Fort Scott, Bourbon County, Kansas, and at Jubilee College Park, Fulton County, Illinois.

Upper Fort Scott Cyclothem

The upper Fort Scott cyclothem is difficult to characterize in regard to its conodont faunas. The Little Osage Shale contains *Idiognathodus* and *Neognathodus* platforms similar to those in both Excello and Anna Shale faunas. The most common ididognathodids are generalized *I.* sp. 1, and among the larger specimens, the *I.* sp. 3 types are common; but a few specimens of the narrow *I.* sp. 2 type are present, as are rare *I.* sp. 4, a variant with pits on the upper surface instead of nodes. The *Neognathodus* are dominantly *N. medexultimus* and *N. roundyi*, but instead of *N. polynodosus* as in the Excello, the Little Osage contains a few *N. medadultimus*. The only *Diplognathodus* species present in the upper Fort Scott is *D.* n.sp. 1. *Gondolella* is absent in the Little Osage Shale. Additional samples from the Little Osage, which yield similar faunas, are available from two cores (CP #10, Appanoose County; CP #37, Clarke County), and from outcrop in Lucas County, Iowa, at the type locality of the Stephens Forest Formation, and from outcrop at Fort Scott, Bourbon County, Kansas, not far from the type section of the Little Osage Shale.

Pawnee Cyclothem

The Pawnee is perhaps the most difficult cyclothem to characterize by its conodont faunas. The Anna Shale, like the Little Osage, does not contain Gondolella, and the variations in the other two genera are similar to those in either the Little Osage or the Excello. Most are generalized I. sp. 1, and the large specimens are usually nodose I. sp. 3, but examples of both other types, I. sp. 2 and I. sp. 4 are also noted among the samples available. Neognathodus platforms in the Anna in both CP #22 and CP #37 are generally small specimens, dominated by N. roundyi and N. medexultimus, with N. dilatus and N. metanodosus among only the smallest examples. Diplognathodus n.sp. 2 is the only species observed from the Pawnee cyclothem in the two cores, but as D. sp. 1 also occurs in the Cooper Creek cyclothem, it may range through the Pawnee interval as well. An additional outcrop sample of the Anna from near its type locality in Bourbon County, Kansas, has been examined that contains similar Idiognathodus and Neognathodus platforms.

Altamont Cyclothem

The Altamont cyclothem can be identified by the conodont fauna of the Lake Neosho Shale. Although it does not contain Gondolella, the Idiognathodus and Neognathodus platforms are quite distinctive. Two types of Idiognathodus are present and exhibit sharp vertical variation in their distribution. The uppermost sample of the Lake Neosho in CP #37 and the overlying Worland Limestone yielded only the generalized I. delicatus-type, I. sp. 1, whereas the thin, dark, phosphatic shale and underlying green shale and limestone yielded only a "strepto-gnathodus"-type element, *I.* sp. 5. *I.* sp. 5 is characterized by a shallow trough that runs the length of the narrow platform, leaving two ridges with short transverse ridges or a row of nodes on either side.

The Lake Neosho is the only phosphatic shale unit in the entire sequence in which platform elements of *Neognathodus* are numerically dominant over those of *Idiognathodus*. The *Neognathodus* show a complete intergradational series from small *N. dilatus*-*N. metanodosus* through through *N. roundyi* and *N. medexultimus* to the largest specimens, which are *N. medadultimus*. Two other distinctive varieties also occur among intermediate-sized elements: *N. polynodosus*, and a variety with a single node on one side like *N. roundyi*, but with the other parapet also greatly reduced. Additional samples of the Lake Neosho have been examined from outcrop at the type locality in Neosho County, Kansas, and from core in Sarpy County, Nebraska, which generally support these observations.

Cooper Creek Cyclothem

The Cooper Creek cyclothem can be readily recognized by its conodont fauna, in particular, that of its unnamed phosphatic shale member. Most characteristic is the occurrence of *Gondolella* sp. 3 and the rare occurrence of *G. denuda* (*G.* cf. *gymna* of Von Bitter and Merrill, 1980). *G.* sp. 3 is a broad-platformed species with the upper margins of the platform ornamented by transverse ridges, many of which bifurcate.

Idiognathodus platforms in the Cooper Creek are diverse and appear to completely intergrade between two end members, I. sp. 1, the flat-platformed I. delicatus-type, and a deep-troughed "streptognathodus"-type, I. sp. 6. I. sp. 6 has large nodose accessory lobes on both sides and a centrally located trough that separates two rows of distinct, parallel ridges. It generally conforms to the form species, S. excelsus of Ellison (1941) and others.

Neognathodus platforms in the Cooper Creek in CP #37 are neither as common nor as diverse as they are known to be elsewhere (e.g., Swade, 1973; Merrill, 1975). In general, they are similar to those in the Altamont cyclothem, ranging from small N. metanodosus to large N. medexultimus, but a significant number of intermediate- to large-sized specimens present in other collections represent the morphologically-simple varieties, N. polynodosus, N. oligonodosus, and N. anodosus.

Diplognathodus is represented in the Cooper Creek cyclothem by three morphotypes that appear to exhibit sharp differences in habitat. D. n.sp. 1 is abundant in the Cooper Creek Limestone, D. n.sp. 2 occurs at the top of the Cooper Creek and in the lower part of the Exline Limestone, and D. illinoisensis is a rare element in the thin core shale and underlying limestone (Fig. 18).

Another platform element that has its occurrence restricted to the Cooper Creek is Anchignathodus ellisoni, which is distinguished from the long-ranging A. minutus by its greater number of denticles and the angle at which they lie with respect to the cusp. Adetognathus lautus (in the sense of Baesemann, 1973) occurs only in the Exline Limestone in the upper Desmoinesian of this study, although Baesemann (ibid.) indicates that it ranges throughout the Missourian.

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