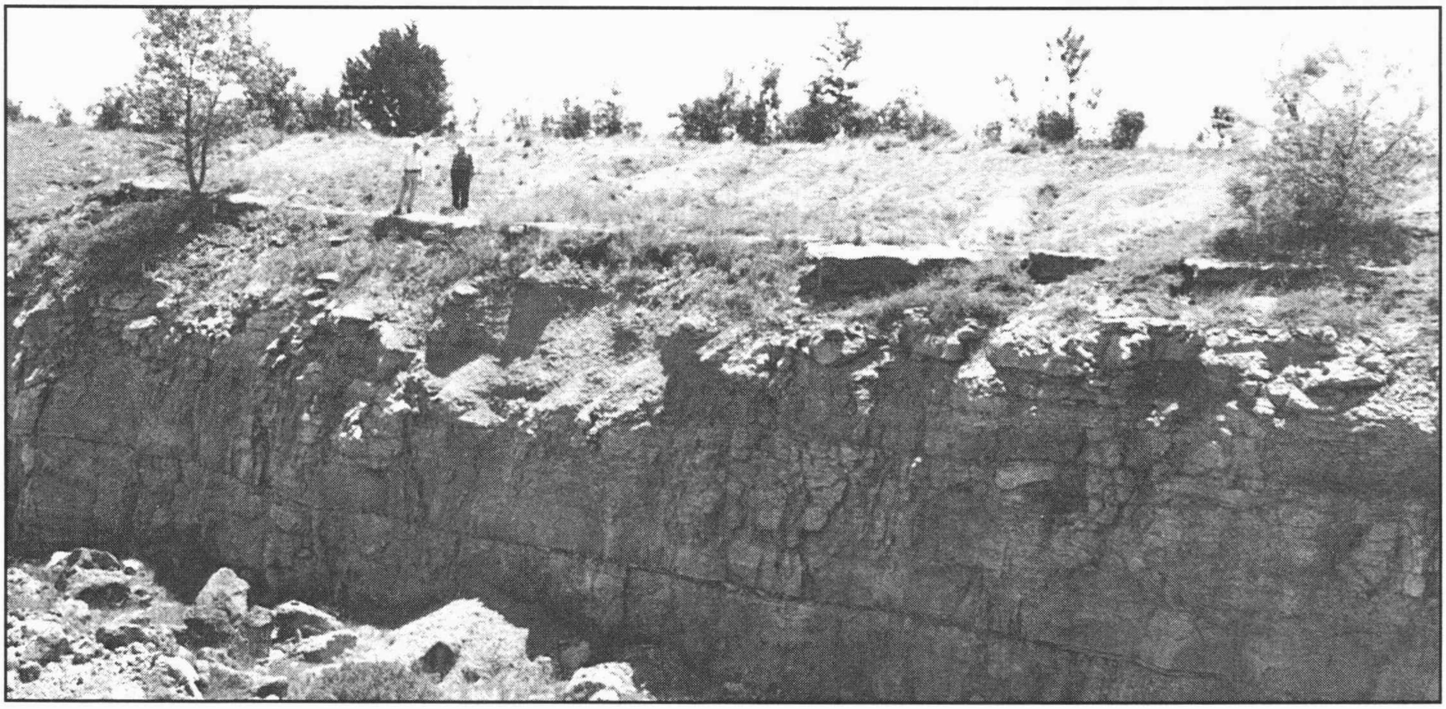
AUGUST 12-15, 1999 KGS OPEN-FILE REPORT 99–27

FIELD TRIP #8:

Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A.



Philip H. Heckel, editor

Leaders—Philip H. Heckel, Darwin R. Boardman, W. Lynn Watney, James E. Barrick, John P. Pope

Honorary Leader—Allan P. Bennison

Held in association with XIV International Congress on the Carboniferous–Permian, Calgary, Canada, August 17–21, 1999

Sponsored by the Kansas Geological Survey and The University of Kansas Energy Research Center

Front cover photo: Quarry near Farlington, Kansas; Karsted Pawnee Limestone overlain by Mulberry Coal and Farlington Limestone.
Back cover photo: Little California Creek, Nowata County, Oklahoma: Checkerboard Limestone with South Mound Shale Member, overlain by Tacket Formation.

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Leaders:

Philip H. Heckel, Department of Geology, University of Iowa, Iowa City, Iowa
Darwin R. Boardman, School of Geology, Oklahoma State University, Stillwater, Oklahoma
W. Lynn Watney, Kansas Geological Survey, Kansas University, Lawrence, Kansas
James E. Barrick, Department of Geosciences, Texas Tech University, Lubbock, Texas
John P. Pope, Department of Geology, University of Iowa, Iowa City, Iowa

Honorary Leader:

Allan P. Bennison, Independent Geologic Consultant, Tulsa, Oklahoma

A note about our honorary leader:

Allan P. Bennison is a recently retired consultant in petroleum geology living in Tulsa, Oklahoma. In addition to his consulting business, he has for several decades maintained an intense interest in the Pennsylvanian stratigraphy of eastern Oklahoma and eastern Kansas. He has continually updated the old geological mapping of this region and has continually shared his significant discoveries with all of us. He discovered the outcrops that will be visited at Stops B4, B6, B7, B8, C1, C2, C3 and C5, having found and recognized the significance the roadcuts while they were still under construction. For these reasons we have named him as honorary leader of this field trip.

Acknowledgments:

In addition to the colleagues (many of them students) mentioned in the credits for the individual field trip stops and in the papers that follow, we are indebted to many other persons without whom this field trip and guidebook would not have been possible, including:

Melanie Cromwell (Kansas University Energy Research Center) organized field trip logistics;
Marla Adkins-Heljeson and Jennifer Sims (Kansas Geological Survey) shepherded final printing of the guidebook;
Richard Atkinson (Midwest Minerals, Inc.) allowed access to Stops B2 and B4;
Bill and Lorene Swanson allowed access to Stop B8;
Joyce Chrisinger (Dept. of Physics and Astronomy, Univ. of Iowa) drafted the ink diagrams in the Heckel articles;
Adrian Goettemoeller (Dept. of Geology, University of Iowa) computer-drafted the stop diagrams.

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It can be obtained by contacting the Kansas Geological Survey, Publications/Sales Office, 1930 Constant Avenue, Lawrence, KS 66047–3726 or at telephone (785) 864–3965.

GUIDEBOOK FOR XIV-ICCP FIELD TRIP #8: MIDDLE AND UPPER PENNSYLVANIAN (UPPER CARBONIFEROUS) CYCLOTHEM SUCCESSION IN MIDCONTINENT BASIN, U.S.A.

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Edited by Philip H. Heckel

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ITINERARY FOR XIV-ICC FIELD TRIP #8

SCHEDULE OF STOPS

Day 1 (A): Top of Desmoinesian; Missourian in its type region on lower mid-shelf; basal Virgilian

Leave Comfort Inn north of KCI Airport at 7:30 AM
Drive 61 miles (I-29, 435, 70, County Road F) — 80 min.

Stop A1: Creek bank south of Sni Mills: **Lost Branch** cyclothem (**Nuyaka Creek** core shale) — 30 min.
8:50-9:20 AM
Drive 26 miles (Co. Rd. F, US-50, MO-350, 63rd St.) — 40 min.

Stop A2: 63rd St. at I-435: **Hertha, Swope**, Dennis cyclothems (**Mound City, Hushpuckney** core shales)+**snack** — 100 min.
10:00-11:40 AM
Drive 8 miles (I-435) — 10 min.

Stop A3: I-435 E of Blue R.: **Dennis, Cherryvale** cyclothems (**Stark** core shale, **Block Ls**. Condensed interval) — 60 min.
11:50 AM-12:50 PM
Drive 22 miles (I-435, US-69, I-35, 635, 70, Park/Kaw Drive) — 30 min.

Stop A4: Park/Kaw Drive roadcut: **Dewey** and Iola cyclothems (**Quivira** core shale; Muncie Ck – Day 4)+**lunch** — 60 min.
1:20-2:20 PM
Drive 8 miles (Kaw Drive, I-435) — 10 min.

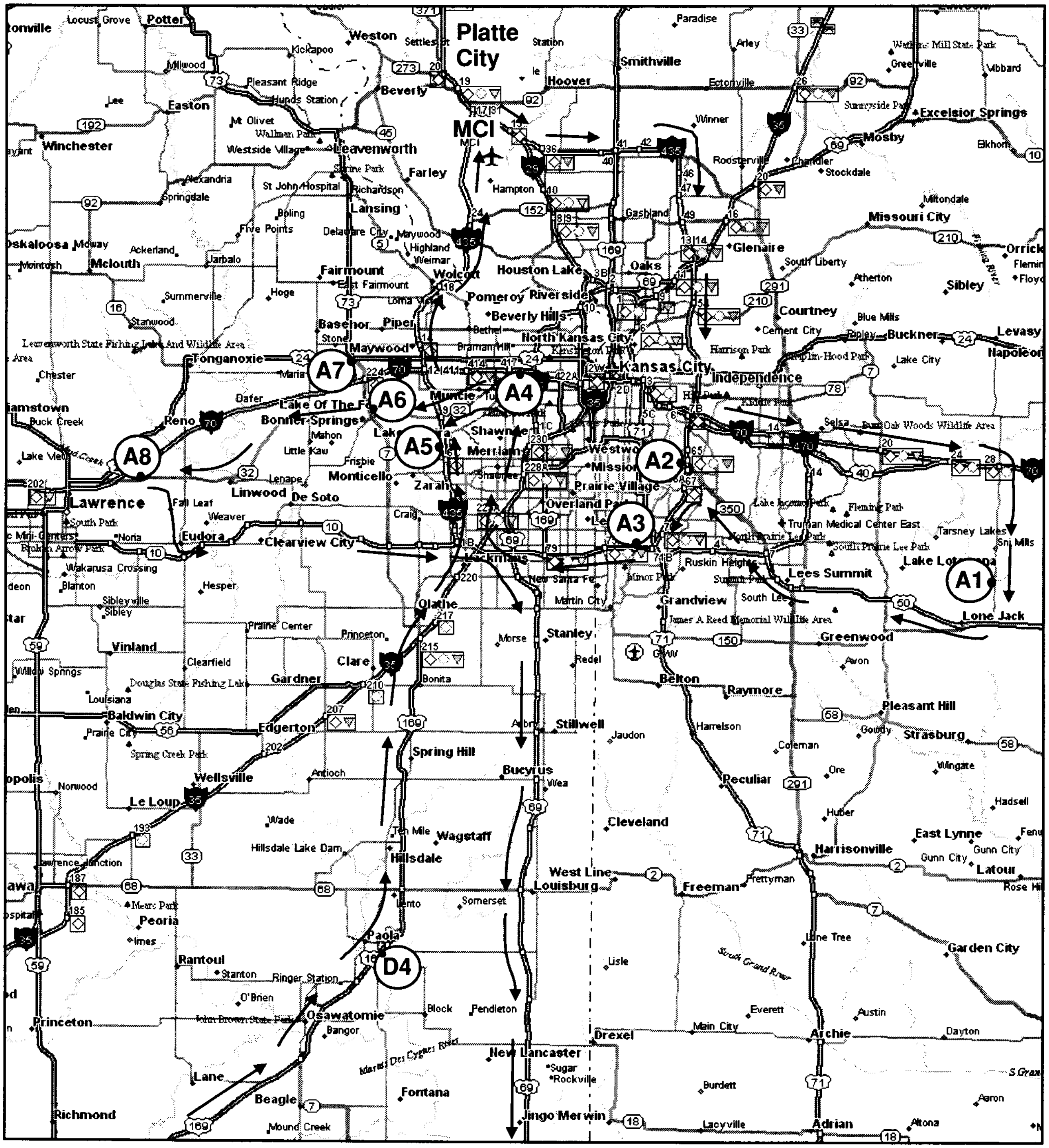
Stop A5: I-435-Holliday Rd. offramp: **Wyandotte** cyclothem (**Quindaro** core shale) — 30 min.
2:30-3:00 PM
Drive 7 miles (I-435, K-32, 7) — 10 min.

Stop A6: Bonner Spgs K-7 Rdcut: **Plattsburg** & Stanton cyclothems (**Hickory Ck**. Core shale; Eudora – Day 4) — 30 min.
3:10-3:40 PM
Drive 3.5 miles (K-7) — 10 min.

Stop A7: K-7 Roadcut S of US 40: **South Bend** cyclothem (**Gretna** core shale) — 30 min.
3:50-4:20 PM
Drive 20 miles (K-7, 32) — 30 min.

Stop A8: K-32 Roadcut W of Linwood: **Cass** cyclothem (**Little Pawnee** core shale) (Virgilian) — 40 min.
4:50-5:30 PM
Drive 105 miles (K-32, Linwood-DeSoto, K-10, US-69) — 120 min.

Dinner and overnight: Best Western Fort Scott Inn, Fort Scott, Kansas



to Ft. Scott

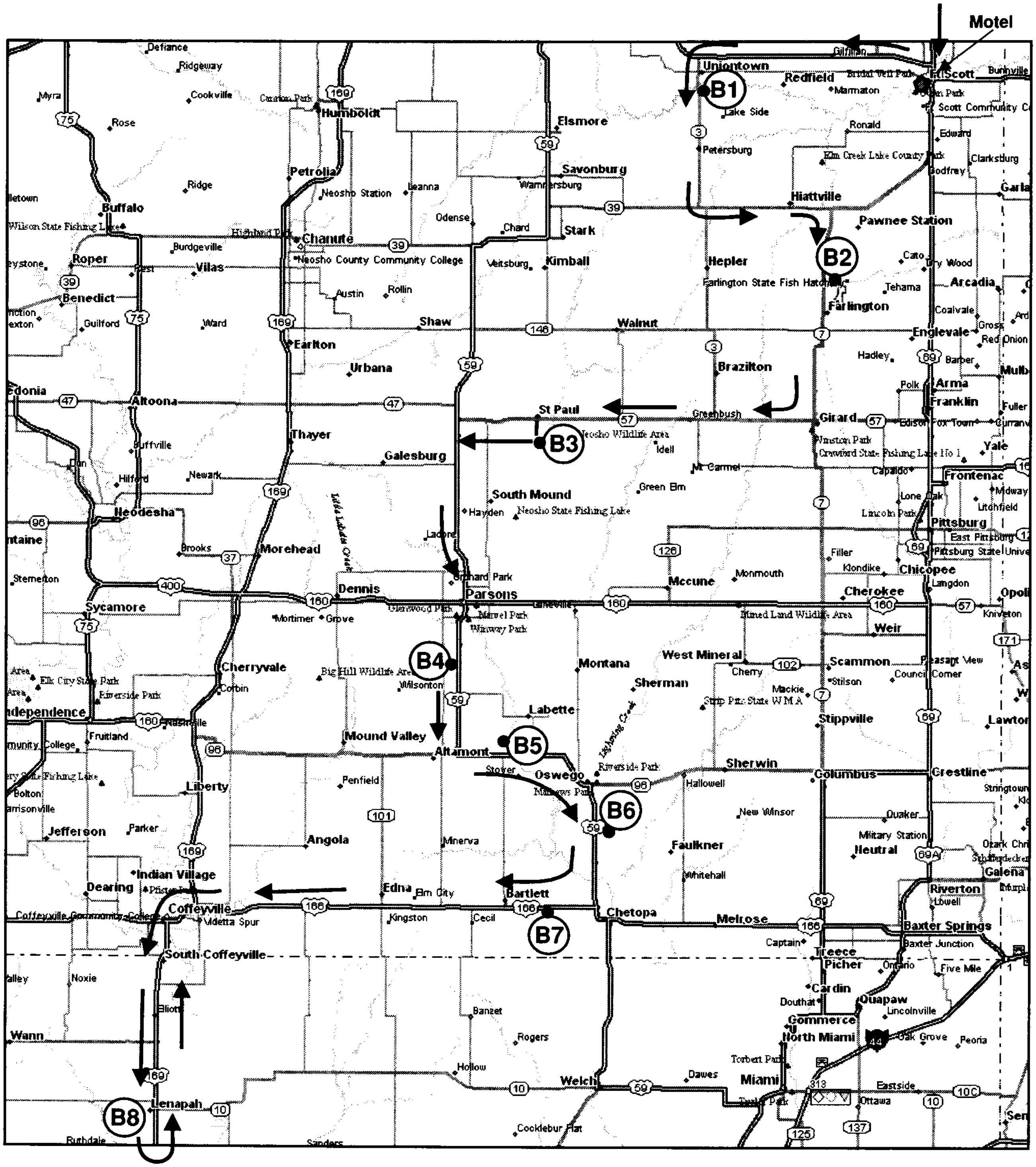
Field Trip Route for First Day (A) and End of Fourth Day (D)

SCHEDULE OF STOPS

Day 2 (B): Lower Missourian and upper Desmoinesian on lower shelf; proposed Desm.-Missourian boundary

Leave Fort Scott Best Western Inn at 7:30 AM	
Drive 18 miles (US-69, 54, K-3)	30 min.
Stop B1: Uniontown Roadcut: **Exline, Critzer,** Hertha cyclothems (**Mound City** core shale)	50 min.
8:00-8:50 AM	
Drive 22 miles (K-3, 39, 7, 277)	30 min.
Stop B2: Farlington Quarry: **Pawnee** cyclothem (top of **Anna**; **Joe** core shales) **Farlington** cyclothem + **snack**	70 min.
9:20-10:30 AM	
Drive 30 miles (K-277, 7, 57, county road)	40 min.
Stop B3: Roadcut S of St. Paul: **Altamont** cyclothem (**Lake Neosho** core shale)	30 min.
11:10-11:40 AM	
Drive 22 miles (county roads, US-59)	30 min.
Stop B4: Qy. S Parsons: **Lenapah** cyclothem (**Norfleet** Ls, basal **Perry Farm** Sh. Condensed interval)+ **lunch**	50 min.
12:10-1:00 PM	
Drive 10 miles (US-59, county road)	15 min.
Stop B5: Roadditch SW of Labette: base of **Pawnee** cyclothem (**Anna** and **Joe** core shales)	30 min.
1:15-1:45 PM	
Drive 12 miles (county road, US-59, county road)	20 min.
Stop B6: Overman bridge: **Fleming** and **Verdigris** cyclothems (**Oakley** core shale)	40 min.
2:05-2:45 PM	
Drive 9 miles (county road, US-59, 166)	15 min.
Stop B7: US-166 Rdcut E Bartlett: **Lwr & Upr Fort Scott** cyclothems (**Excello & Little Osage** core shales)	60 min.
3:00-4:00 PM	
Drive 46 miles (US-166, 169, county roads)	60 min.
Stop B8: Little California Creek: **South Mound, Exline, Mound City, Hushpuckney** core shales, and proposed **Desmoinesian-Missourian stage boundary stratotype**	120 min.
5:00-7:00 PM	
Drive 18 miles (county roads, US-169)	30 min.

Dinner and overnight: Super-8 Motel, Coffeyville, Kansas



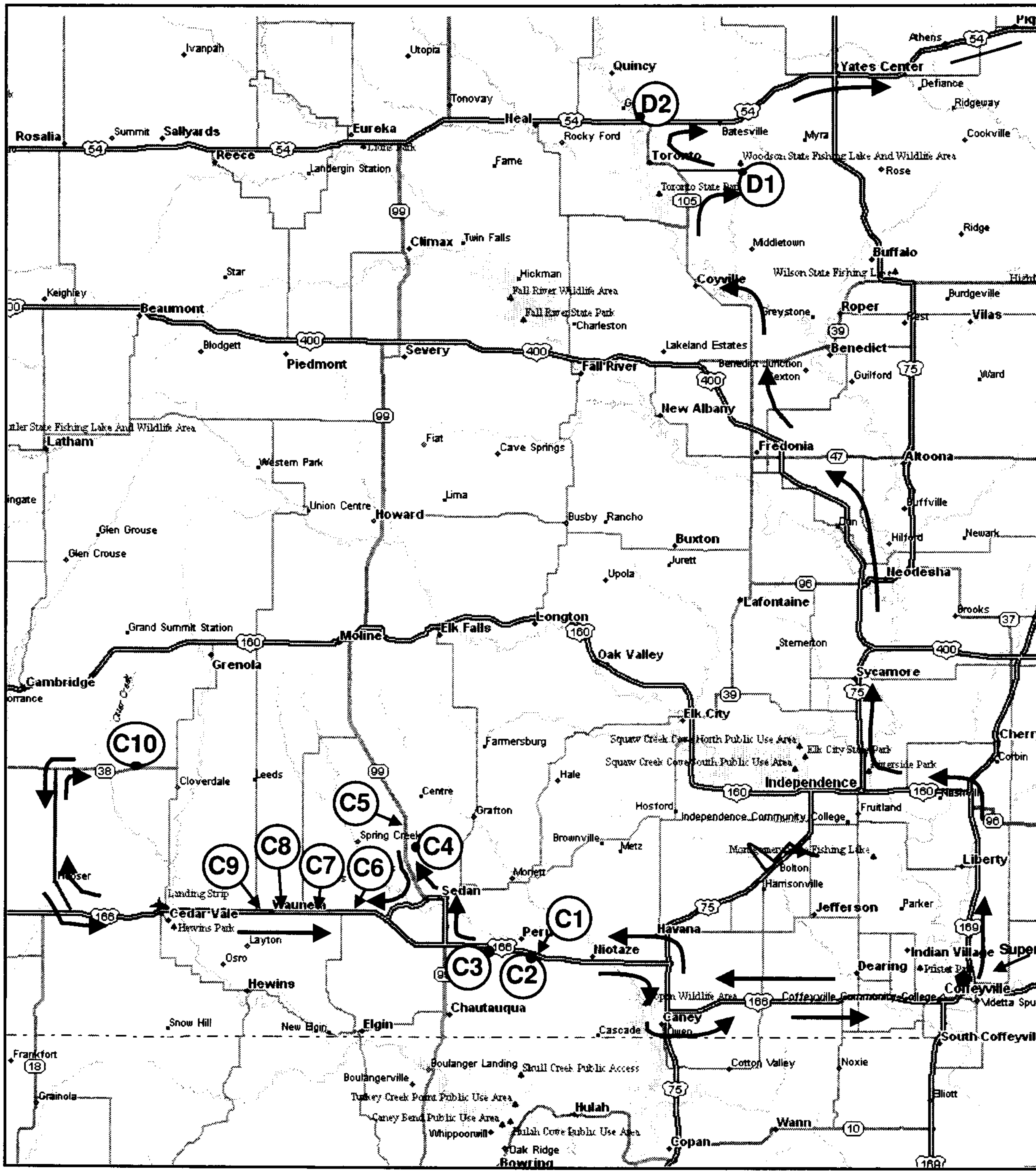
Field Trip Route for Second Day (B)

SCHEDULE OF STOPS

Day 3 (C): Primarily Virgilian in type region; uppermost Missourian; correlated base of Permian

Leave Coffeyville Super-8 Motel at 7:30 AM	
Drive 28 miles (US-166)	40 min.
Stop C1: US-166 Roadditch W of Niotaze: **Iatan** cyclothem	30 min.
8:10-8:40 AM	
Drive 0.5 mile (US-166, sideroad)	10 min.
Stop C2: Sideroad off US-166 SE of Peru: **Westphalia Limestone**	30 min.
8:50-9:20 AM	
Drive 2.4 miles (sideroad, US-166)	10 min.
Stop C3: US-166 Roadcut W of Peru: **Cass** cyclothem (**Little Pawnee** core shale)	60 min.
9:30-10:30 AM	
Drive 12 miles (US-166, K-99, entrance road)	20 min.
Stop C4: Sedan City Lake spillway: **Oread** cyclothem (**Heebner** core shale) + **lunch**	90 min.
10:50 AM-12:20 PM	
Drive 2 miles (K-99)	10 min.
Stop C5: K-99 Roadditch NW of Sedan: **Lecompton** cyclothem (**Queen Hill** core shale)	40 min.
12:30-1:10 PM	
Drive 10 miles (K-99, business US-166, 166)	20 min.
Stop C6: US-166 W of Cedar Ck: upper **Deer Creek** and lower **Hartford** cyclothems	40 min.
1:30-2:10 PM	
Drive 2 miles (US-166)	10 min.
Stop C7: US 166 E of Sycamore Ck: lower **Deer Creek** cyclothem (**Larsh** core shale)	30 min.
2:20-2:50 PM	
Drive 2.3 miles (US 166)	10 min.
Stop C8: US-166 Roadcut E of Wauneta: **Howard** cyclothem (**Aarde/Shanghai Creek** core shale)	40 min
3:00-3:40 PM	
Drive 1 mile (US-166)	10 min
Stop C9: US-166 Roadcut W of Wauneta: **Topeka** cyclothem (**Holt** core shale)	30 min.
3:50-4:20 PM	
Drive 29 miles (US-166, county road, Rte 38)	40 min.
Stop C10: Rte 38 Roadcut W of Cloverdale: **Five Point—Red Eagle** succession, and **base of Permian System**	60 min.
5:00-6:00 PM	
Drive 75 miles (US-166)	90 min.

Dinner and overnight: Super-8 Motel, Coffeyville, Kansas



Field Trip Route for Third Day (C) and Start of Fourth Day (D)

SCHEDULE OF STOPS

Day 4 (D): Provisional Missourian-Virgilian boundary; plus core shales not readily collectable elsewhere

Leave Coffeyville Super-8 Motel at 7:30 AM

Drive 75 miles (US-169, 160, 75, 400, county roads & K-105) — 100 min.

Stop D1: Woodson Co. State Lake Spillway: **Westphalia** and **Cass** cyclothems (**Little Pawnee** core shale), and provisional **Missourian-Virgilian Stage boundary stratotype + lunch** — 140 min.
9:10-11:30 AM

Drive 10 miles (county road, K-105, US-54) — 20 min.

Stop D2: US-54 Roadcut N of Toronto: **Toronto** cyclothem with thin core shale — 30 min.
11:50 AM-12:20 PM

Drive 74 miles (US-54, 169, county roads) — 100 min.

Stop D3: Roadcut N of Pottawatomie Creek, NW of Garnett: **Stanton** cyclothem (**Eudora** core shale) — 40 min.
2:00-2:40 PM

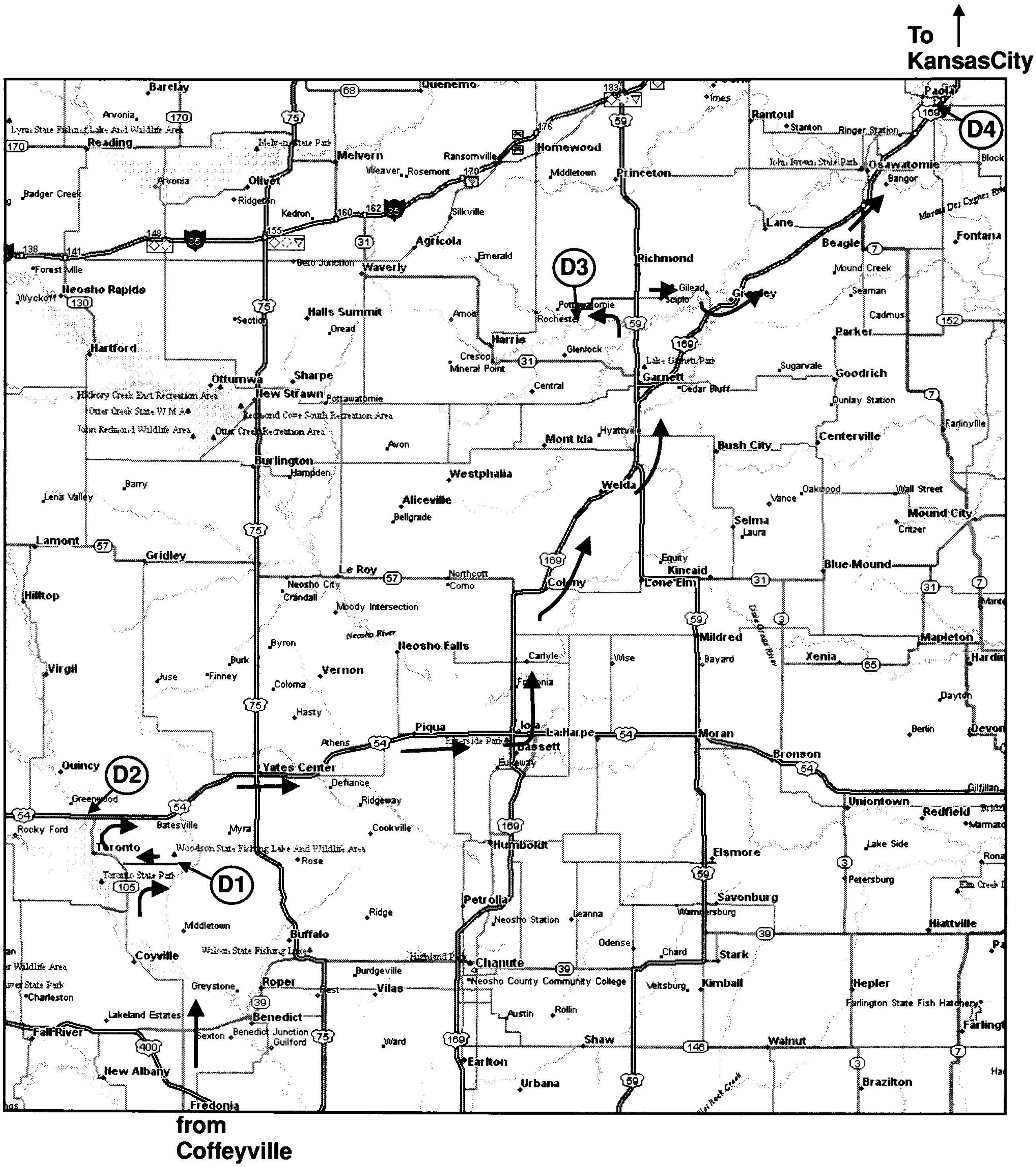
Drive 40 miles (county roads, US-169) — 60 min.

Stop D4: Roadcut SE of Paola: **Iola** cyclothem (**Muncie Creek** core shale) — 30 min.
3:40-4:10 PM

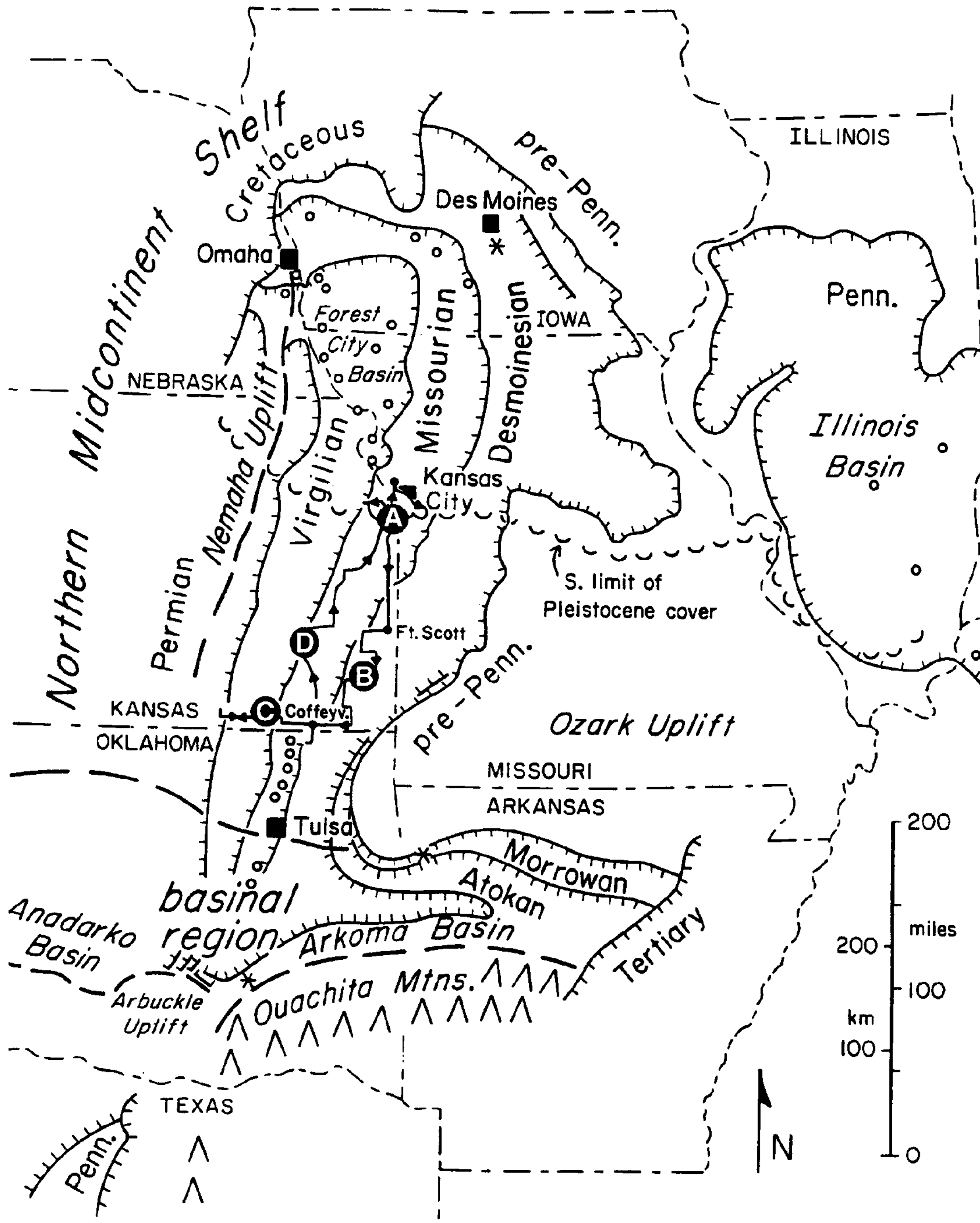
Drive 65 miles (US-169, I-35, 435, 29) — 80 min.

Arrive at Comfort Inn north of Kansas City International Airport about 5:30 PM

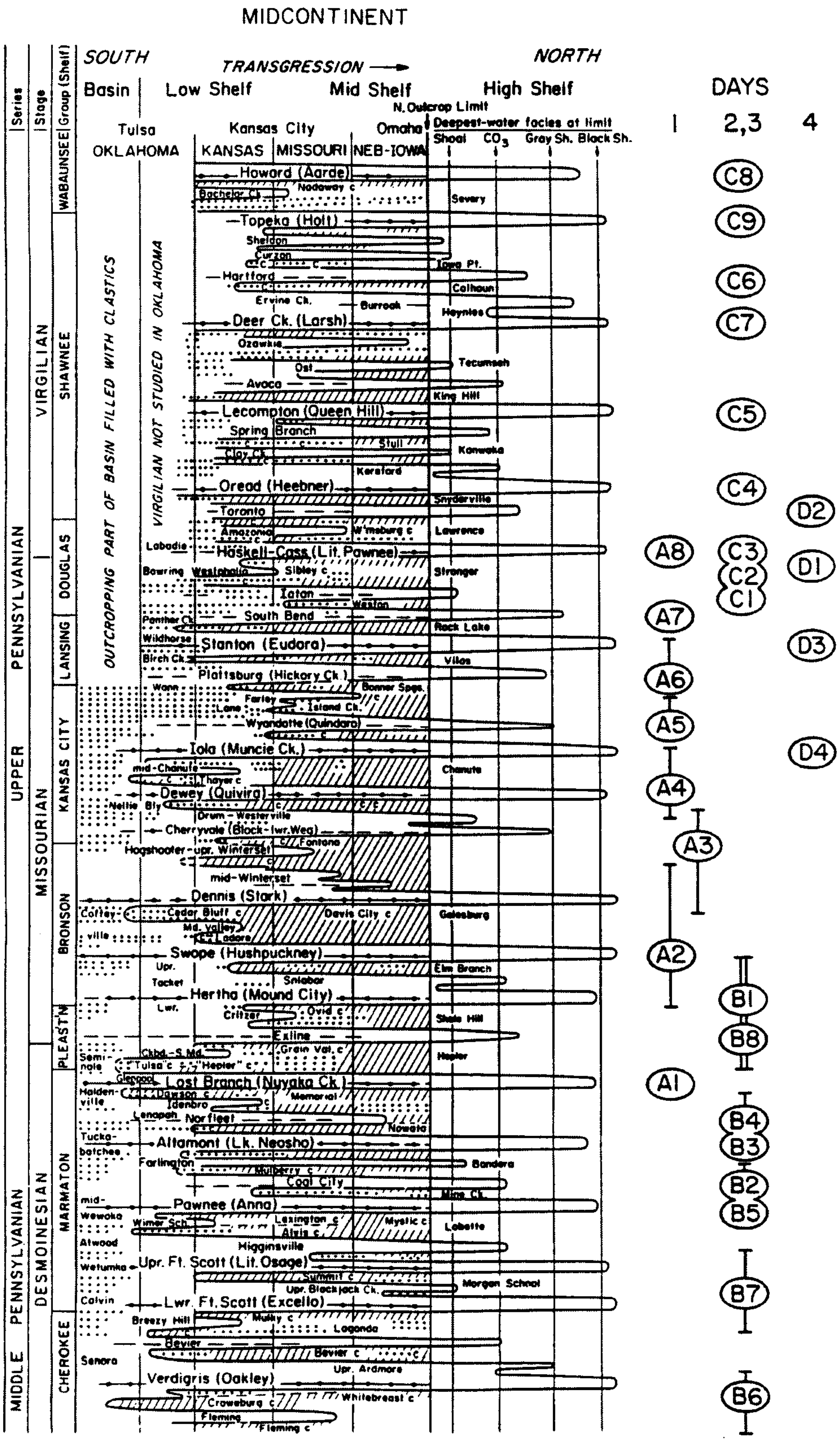
There will be facilities available for packing and shipping rock samples at the motel



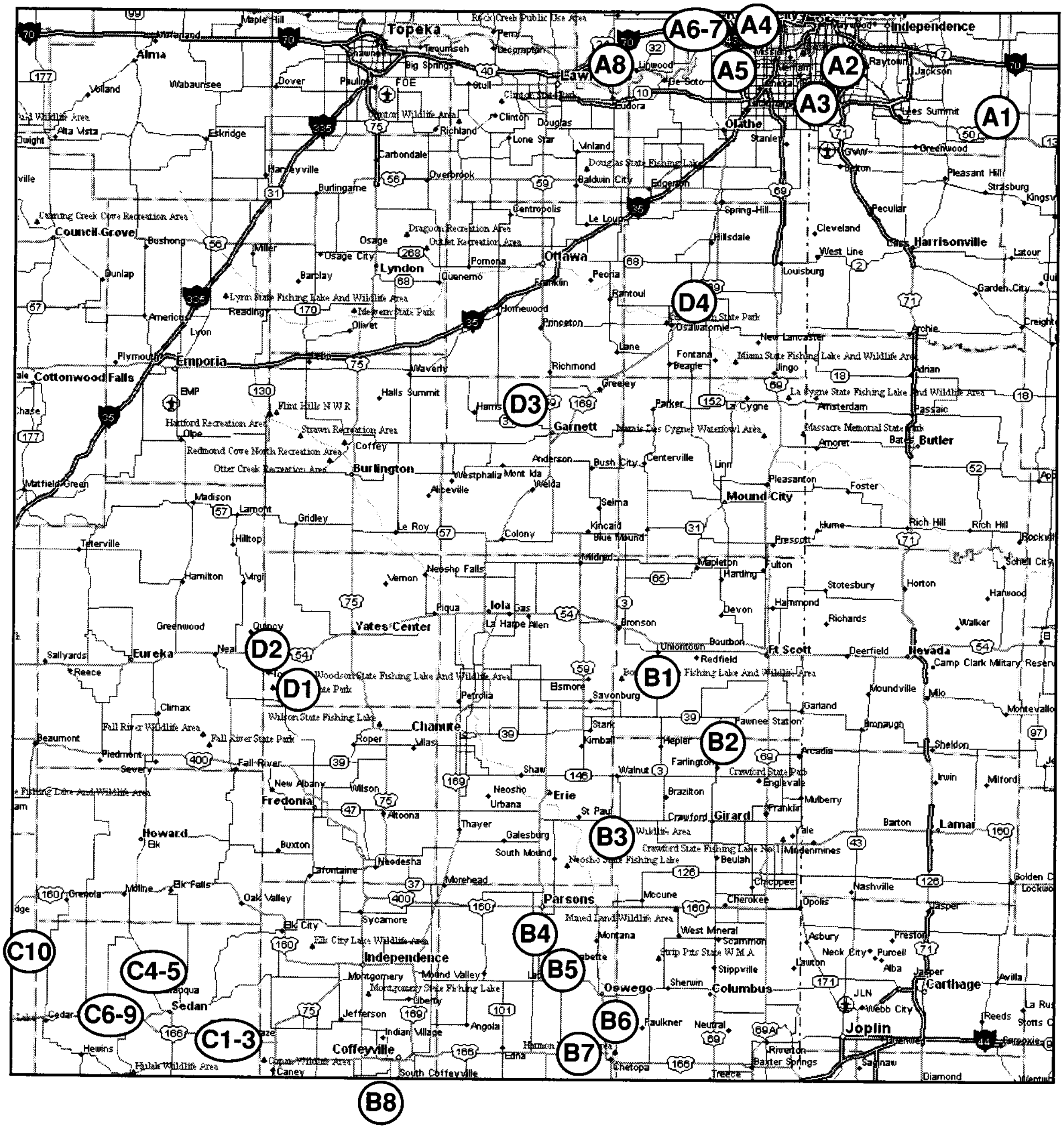
Field Trip Route for Fourth Day (D)



Field trip route on geologic map, with each day's travel indicated by letters A-D, and overnight stays (Kansas City, Fort Scott, and Coffeyville) indicated by solid circles



Stratigraphic position of field trip stops



Location of All Field Trip Stops

DESCRIPTION OF FIELD TRIP STOPS

Philip H. Heckel, Darwin R. Boardman, and others

Listing of Stops with credits for utilized descriptions:

Stop A1 (Lost Branch): Phil Heckel, John Pope
Stop A2 (Hertha, Swope, Dennis): Lynn Watney, John French, Phil Heckel, John Pope
Stop A3 (Dennis, Cherryvale): Phil Heckel, John Pope
Stop A4 (Westerville, Dewey, Iola): Phil Heckel, John Pope
Stop A5 (Wyandotte): Phil Heckel
Stop A6 (Plattsburg, Stanton): Phil Heckel, John Pope
Stop A7 (South Bend): Phil Heckel
Stop A8 (Cass): Phil Heckel
Stop B1 (Exline, Critzer, Hertha, Swope): Phil Heckel, Darwin Boardman, Jim Barrick
Stop B2 (Pawnee, Farlington): Rex Price, Phil Heckel, John Pope
Stop B3 (Altamont): Phil Heckel, John Pope
Stop B4 (Altamont, Lenapah): Phil Heckel, Lynn Watney, John Pope
Stop B5 (Pawnee): Rex Price, Phil Heckel, John Pope
Stop B6 (Fleming, Verdigris): Darwin Boardman, Tom Marshall, Phil Heckel, John Pope
Stop B7 (Fort Scott): Phil Heckel, John Pope, Darwin Boardman, Tom Marshall
Stop B8 (Checkerboard, S. Md., Tacket): Darwin Boardman, Joe Hall[#], Ryan Birkenfield[#], Phil Heckel, John Pope
Stop C1 (Iatan): Darwin Boardman, Phil Heckel
Stop C2 (Westphalia): Darwin Boardman, Phil Heckel
Stop C3 (Cass): Darwin Boardman, Phil Heckel, Jim Barrick
Stop C4 (Oread): Darwin Boardman, Tim Walsh, Mark Bryan, Phil Heckel
Stop C5 (Lecompton): Darwin Boardman, Tim Walsh, Mark Bryan, Phil Heckel
Stop C6 (Deer Creek, Hartford): Darwin Boardman, Tim Walsh, Mark Bryan, Phil Heckel
Stop C7 (lower Deer Creek): Darwin Boardman, Tim Walsh, Mark Bryan, Phil Heckel
Stop C8 (Howard): Darwin Boardman, Phil Heckel, John Pope
Stop C9 (Topeka): Darwin Boardman, Tim Walsh, Mark Bryan, Phil Heckel
Stop C10 (Five Point, Foraker, Red Eagle): Darwin Boardman
Stop D1 (Westphalia, Cass): Phil Heckel, Darwin Boardman, Jim Barrick, John Pope
Stop D2 (Toronto): Phil Heckel, Tim Walsh, Mark Bryan
Stop D3 (Stanton): Bob Wood, Phil Heckel
Stop D4 (Iola): Phil Heckel, John Pope

[#] Supported by the Oklahoma Louis Stokes AMP Program, Cooperative Agreement Number NSF/HRD-9450355

Two stops on the same diagram are shown in stratigraphic order, even if the lower (older) one is visited first.

Explanation of symbols and abbreviations for field-trip stop diagrams:

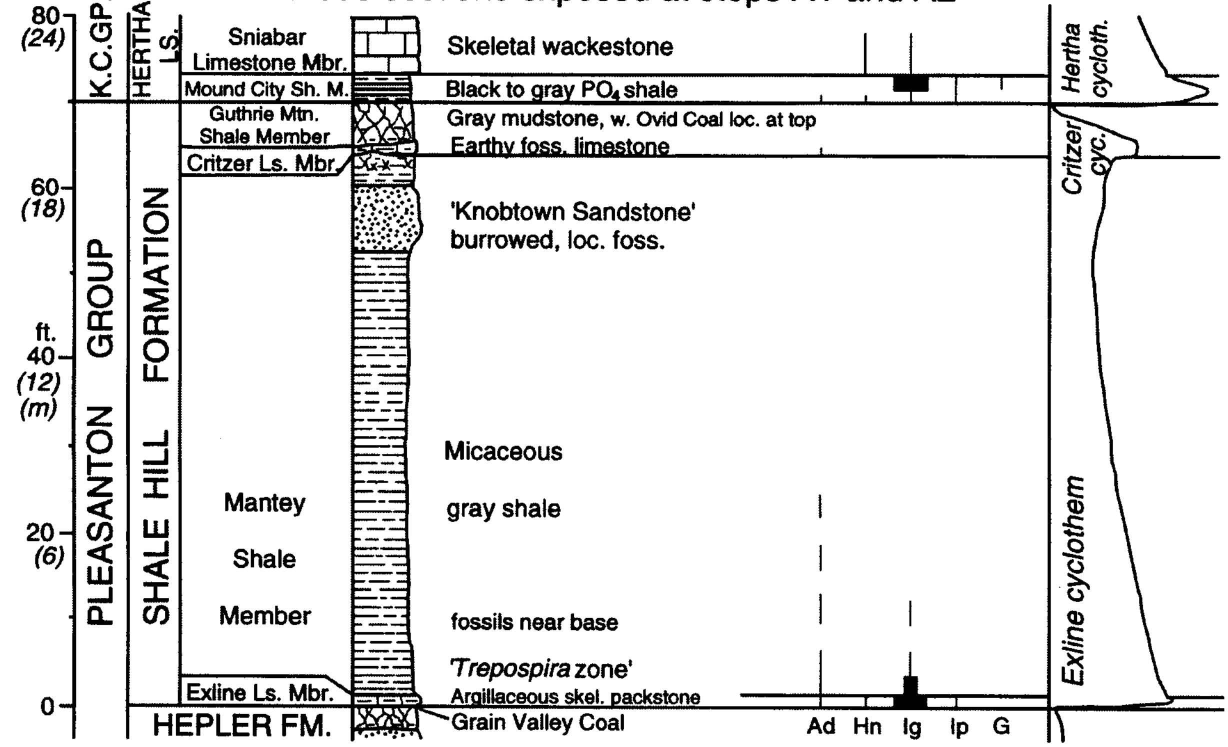
* denotes positions at which conodont samples were taken (for which detailed data were readily available). Conodont distribution shown beyond these samples is based on interpolation or extrapolation from data in von Bitter (1972), Heckel and Baesemann (1975), and in various theses, dissertations, and personal communications.

Width of lines shows relative abundance of taxa indicated.

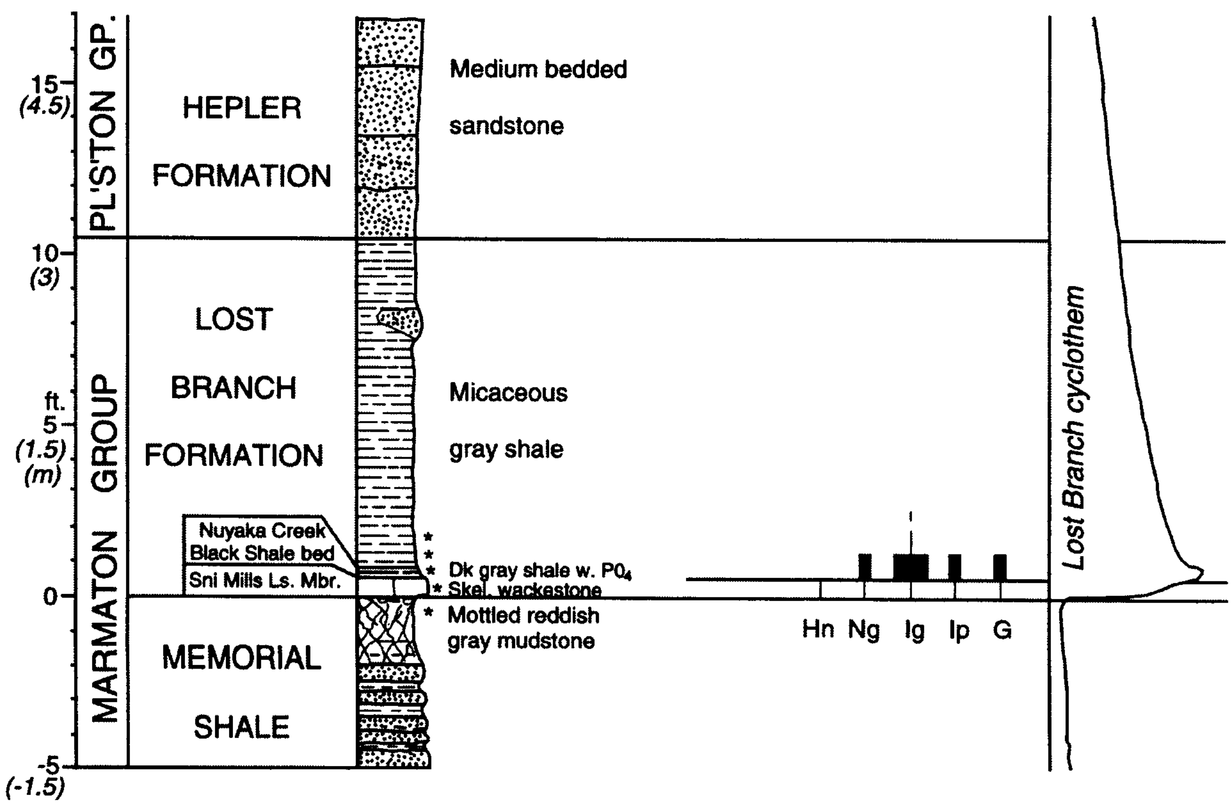
Abbreviations: fus = fusulinids; Ad = *Adetognathus*; Hn = *Hindeodus*; Ng = *Neognathodus*; Ig = idiognathodids, including *Idiognathodus, 'Idiognathodus'*, and *Streptognathodus*; Ip = *Idioprioniodus*; G = *Gondolella*

References cited in descriptions for stops are included in reference list for 'Overview...' article by Heckel

Generalized stratigraphic succession between those sections exposed at stops A1 and A2



Stop A1: Creek bank south of Sni Mills



DESCRIPTION OF FIELD TRIP STOPS

Day 1 (A): Top of Desmoinesian; Missourian in its type region on lower mid-shelf; basal Virgilian.
Leave Comfort Inn at 7:30 AM
[Drive 61 miles: S on I-29, E & S on I-435, E on I-70, S on Co. Rd. F 7.5 miles] (80 min.)

STOP A1: Creek bank south of Sni Mills. (E half NE-SE sec. 5, T 47 N, R 29 W, Jackson Co., MO) (30 min.)

*[**Beware of poison ivy,** especially along creek bank and terrace to south]*

This stop shows the **Lost Branch Formation** and **cyclothem** (named from southeastern Kansas), which is the **youngest Desmoinesian major marine unit in the Midcontinent**, in one of its best exposed and most easily accessible exposures. It was named and described by Heckel (1991) to provide stratigraphic coherency to an important unit that had previously been grouped with other units or overlooked because, as a shale-rich cyclothem, it is rarely well exposed. It forms the top of the Marmaton Group and contains the youngest distinctly Desmoinesian fauna in the Midcontinent Basin.

Nowata Shale (named from northern Oklahoma, where it is several hundred feet of paralic and slope detrital clastics) consists here of bedded sandstone overlain by slightly reddish mottled blocky mudstone, which is a paleosol. This unit is the shelf facies of the lowstand deposits, extending northward into Iowa, and capping the upper Lenapah (Idenbro) minor cyclothem, with the sequence boundary at the top of the paleosol.

Sni Mills Limestone Member (in its type area) is a thin, diversely fossiliferous skeletal wackestone that rests disconformably on the exposure surface at the top of the paleosol and represents the transgressive limestone of the Lost Branch cyclothem. It extends northward 180mi. (300 km) into south-central Iowa, but disappears southward at the Missouri-Kansas border. Its southward equivalent in central Oklahoma, the Homer School limestone bed, contains the youngest *Chaetetes* in the Midcontinent Basin.

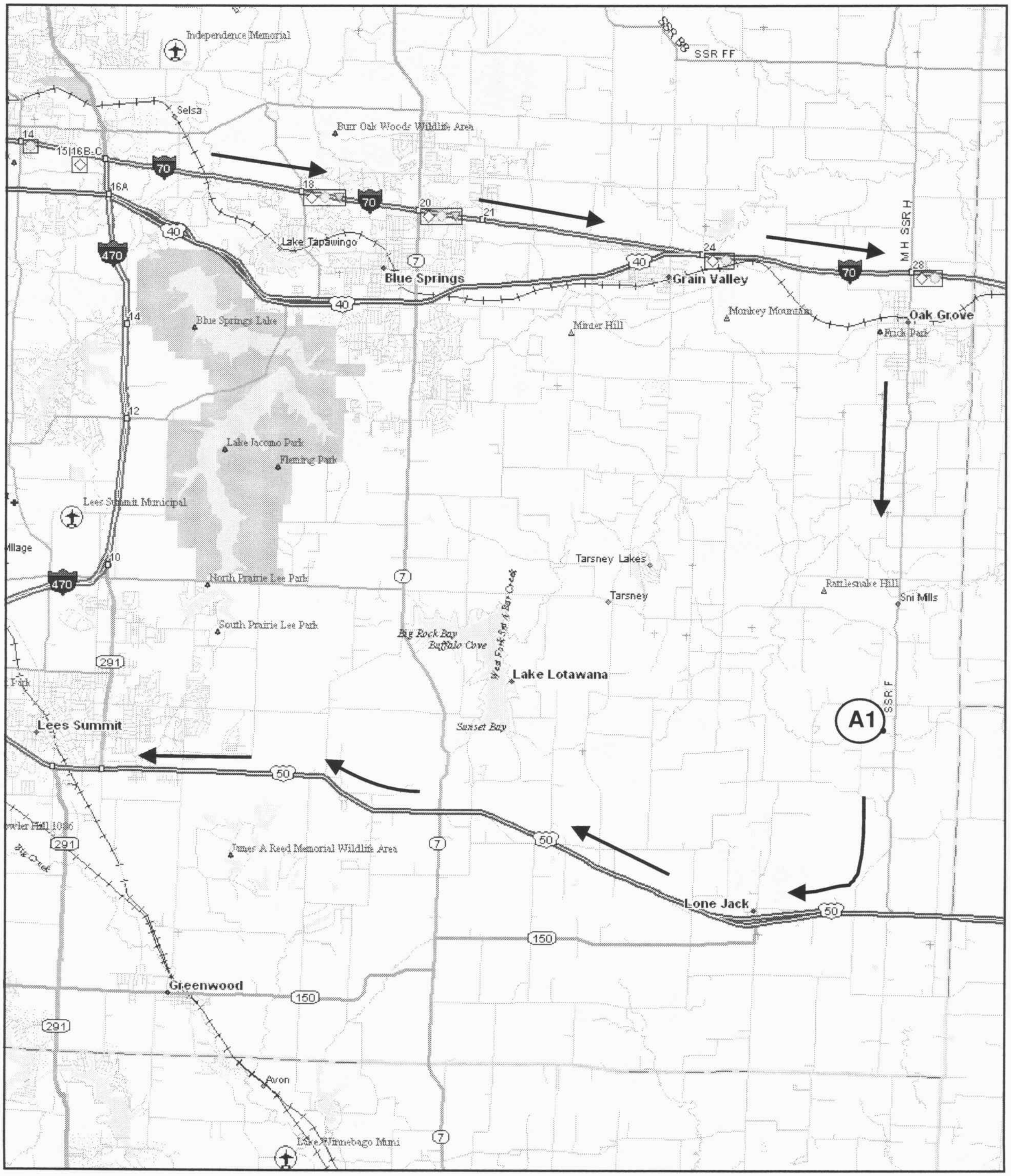
Nuyaka Creek Black Shale bed (named from central Oklahoma) is a very thin dark gray shale here that contains abundant conodonts and small granules of nonskeletal phosphorite. It is the condensed interval that represents sea-level highstand. The conodonts include nearly the youngest *Neognathodus* and youngest species (Swade sp. 6 = '*Idiognathodus*' *nodocarinatus*) of the pre-*Streptognathodus* troughed clade of idiognathodids recognized by Swade (1985), along with *Idioprioniodus* and *Gondolella magna*. This bed thickens southward to 6 to 7 ft (~2 m) in central Oklahoma, and its distinctive character and conodont fauna allows correlation of the Lost Branch cyclothem along 500 miles (800 km) of outcrop. It contains ammonoids at some localities.

Upper part of Lost Branch Formation (not divided into members) is nearly 10 ft (~3 m) of gray micaceous shale that contains sparse fossils in the base and becomes sandy upward with small sandstone lenses. It represents at least the lower part of the forced-regressive systems tract. Northward 130 miles (220 km) in Iowa, its position is occupied by the Cooper Creek Limestone Member, the regressive limestone of the Lost Branch cyclothem, which contains the youngest species of *Beedeina* in the Midcontinent basin, *B. eximia*, described from this unit by Thompson (1934) in Iowa. Influx of detrital clastics overwhelmed carbonate production southward at this time.

Hepler Formation (named from southeastern Kansas) is over 10 ft (3 m) of medium-bedded micaceous quartz sandstone here. Although it appears to be a coarser-grained upward continuation of the FRST here, it contains a diversity of detrital facies elsewhere, some of which appear to be paleovalley fillings, including tidal-laminated facies in at least one exposure. It contains a blocky mudstone paleosol at the top nearly everywhere from east-central Kansas northward (but not exposed here), which is capped by a coal (Grain Valley) in some places. In southeastern Kansas it contains at the top a fossiliferous marine shale, the South Mound Shale Member (named from there), which extends into northern Oklahoma where it grades into the Checkerboard Limestone (named from central Oklahoma). The South Mound Shale and Checkerboard Limestone represent a minor marine transgressive-regressive cyclothem that did not extend north of southeastern Kansas. We will see this unit at Stop B8 tomorrow. The Hepler Formation (including the South Mound Shale Member) is overlain by the Exline Limestone Member (named from south-central Iowa) of the Shale Hill Formation (named from north-central Missouri). In this area and southward throughout Kansas, the Exline Limestone is a thin argillaceous, conodont-rich, skeletal packstone to wackestone that is rarely exposed, but it represents both the transgressive member and condensed interval of a cyclothem that is continuous from Oklahoma into west-central Iowa. The Exline contains the first appearance of the conodont *Idiognathodus eccentricus*. We will see it at Stop B1 and its southward equivalent black shale at Stop B8 tomorrow. The disconformity below the Exline Limestone, which was recognized by previous geologists by means of the lenticular sandstones of the Hepler Formation, has been regarded as the traditional base of the Missourian Series (now Stage). We are selecting the base of the Missourian Stage at the base of the Exline-equivalent black shale where it overlies the marine South Mound Shale in a continuous marine succession in northern Oklahoma, as will be seen at Stop B8 tomorrow.

Leave Stop A1 at 9:20 AM

[Drive 26 miles: S on Co. Rd. F, W on US 50, NW on Mo. 350, W on 63rd St. past I-435 entrance] (40 min.)

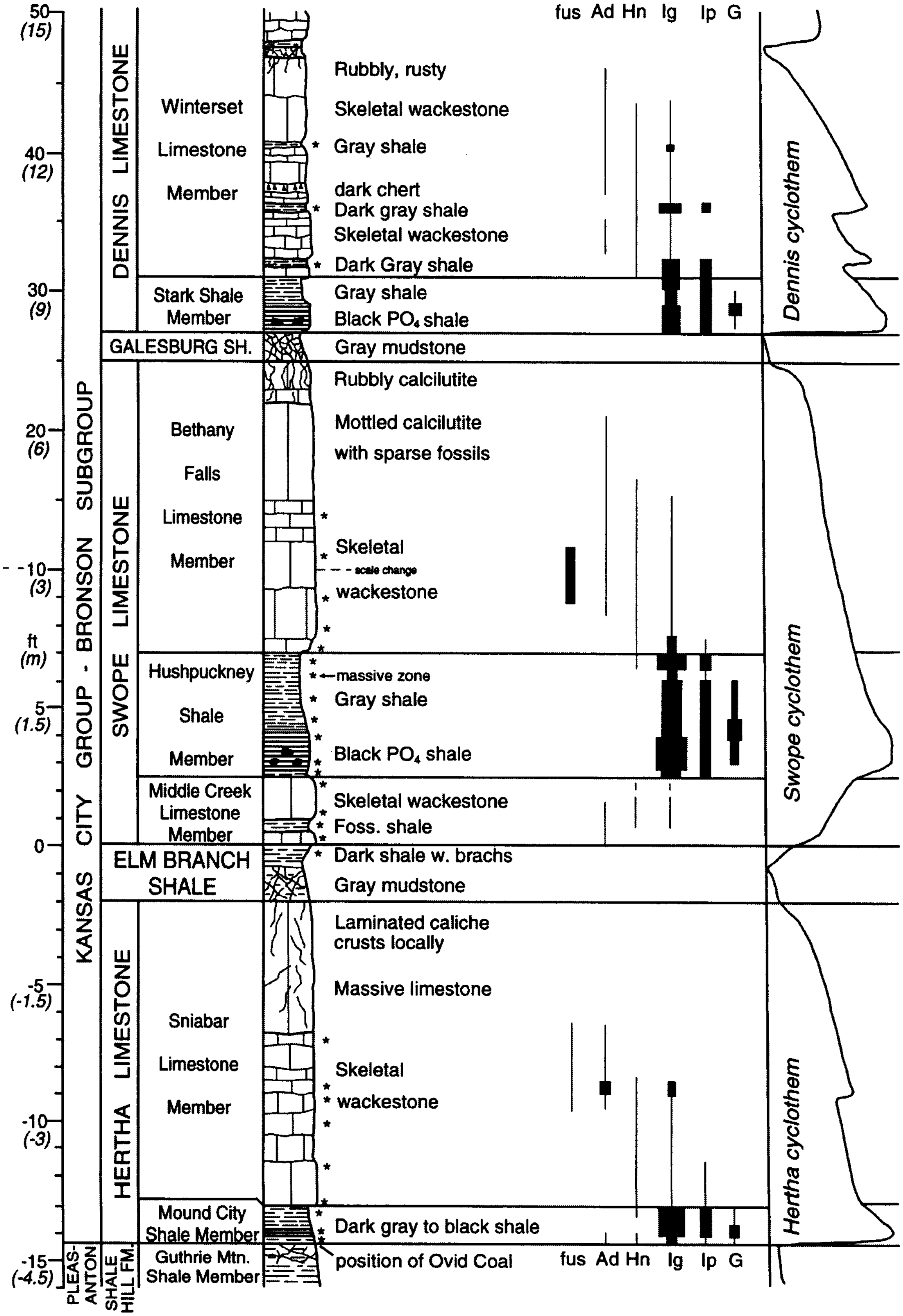

Independence Memorial
SSR BB
SSR FF
Selsa
Burr Oak Woods Wildlife Area
14
15
16B-C
70
16A
18
20
21
40
Lake Tapawingo
470
Blue Springs
24
Grain Valley
M H SSR H
28
Oak Grove
Frick Park
Monkey Mountain
Minter Hill
Blue Springs Lake
12
Lake Jacomo Park
Fleming Park
Lees Summit Municipal
10
Tarsney Lakes
Tarsney
North Prairie Lee Park
Rattlesnake Hill
Sni Mills
South Prairie Lee Park
Big Rock Bay
Buffalo Cove
Lake Lotawana
291
Lees Summit
Sunset Bay
SSR F
A1
50
James A Reed Memorial Wildlife Area
Lone Jack
150
Greenwood
Avon
Lake Winnebago Muni

Stop A1


A4
A2
A3
Kansas City
North Kansas City
Sugar Creek
Maywood
Raytown
Westwood Hills
Roeland Park
Mission Woods
Mission
Fairway
Mission Hills
Countryside
Prairie Village
Overland Park
Leawood
Grandview
Braman Hill
Baptist Mission
Turner
Glenn
Elmhurst
Indian Village
Little Santa Fe
New Santa Fe
Martin City
Red Bridge
Ruskin
Ruskin Heights
Hickman Mills
Truman Corners
Jeffreys
Bryant
Flinn
Dodson
Melville
Holmes Park
Waldo
Baptist Medical Center
St Lukes Hospital
Menorah Medical Center
Linda Hall Library
Truman Medical Center
Little Blue
Unity
Vale
Centropolis
Rock Creek Junction
Fairmount
Air Line Junction
Ft Cavagnolle
Mt Washington
The Lagoon
Swope Park
Kansas River
ROE
HOLMES RD
METCALF
W 135TH

Stops A2-A4

Stop A2: Creek along 63rd St. and onramp to I-435



STOP A2: Creek along 63rd St. at I-435. (SW-NW sec. 6, T 48 N, R 32 W, Jackson Co., MO) (100 min.)

[Proceed east along creek bank, or in creek bed where possible; please avoid 63rd St]

This stop shows the **Hertha Limestone** and **cyclothem**, the **Swope Limestone** and **cyclothem**, and part of the **Dennis Limestone** and **cyclothem**, the **second, third**, and **fourth major marine units** of the **Missourian Stage**. The Swope is named from this area, whereas the Hertha and Dennis are named from southeastern Kansas. These three formations dominate the limestone-rich Bronson Subgroup of the Kansas City Group, which forms steep-walled valleys here and a conspicuous escarpment across east-central Kansas.

Mound City Shale Member (named from east-central Kansas) is a thin dark shale beneath the first small waterfall. Its lower contact (above a blocky mudstone) is the lower sequence boundary of the Hertha cyclothem. The Mound City represents both transgressive and highstand deposits of the Hertha cyclothem and extends from Iowa to Oklahoma. It contains abundant conodonts that include the first appearance of *Idiognathodus clavatulus* and n. sp. A, both more nodose descendants of *I. eccentricus*, along with *Idioprioniodus* and *Gondolella*.

Sniabar Limestone Member (named from this area) is the regressive limestone of the Hertha cyclothem, extending from Iowa to southeastern Kansas, where it grades into basinal dark shales of the Tacket Formation (seen at Stop B8 tomorrow).The conodont concentration below the middle records the minor transgressive Sniabar cycle. The Sniabar contains only the small fusulinids *Schubertella* and *Oketaella inflata*, described by Thompson (1957) from the upper part in an old quarry nearby. The top of the Sniabar is pedogenic Pennsylvanian caliche.

Elm Branch Shale (named from east-central Kansas) is exposed beneath the next small waterfall. It comprises a blocky mudstone paleosol overlain by thin gray fossiliferous shale (dominated by derbyiid brachiopods) with a sharp contact, which is the sequence boundary between the Hertha and Swope cyclothems. The Elm Branch extends from Iowa to southern Kansas, and its paleosol extends to Stop B1 in east-central Kansas.

Middle Creek Limestone Member (named from east-central Kansas) forms the lip of the waterfall. It is the classic transgressive limestone of the Swope cyclothem, extending from Iowa to southeastern Kansas. The 'transgressive systems tract' of this 'stratigraphic sequence' includes the top of the underlying Elm Branch Shale and the base of the overlying shale as well as the Middle Creek Limestone.

Hushpuckney Shale Member (named from east-central Kansas) consists of black fissile shale with phosphorite nodules and laminae, and has thin gray shale at the base and thicker gray shale at the top. It extends from Iowa to central Oklahoma and is the classic 'core shale' of the Swope cyclothem, which contains the condensed interval deposited at highstand. Its abundant conodont fauna (most easily obtained from the upper gray facies) is dominated by species of *Idiognathodus*, includes *Idioprioniodus* and *Gondolella* (including *G. denuda*), and contains the first appearance of *Streptognathodus cancellosus*, the earliest member of this genus that dominates most higher Missourian and Virgilian faunas. Road-building that exposed this and several other dark shales in and around Kansas City in the early 1930s led to the collections of conodonts from which Gunnell (1933) described about 70 species of *Idiognathodus* and *Streptognathodus*, most of which were later synonymized by Ellison (1941), but several of which are determined to be valid today (Barrick et al., 1996; also this guidebook).

Bethany Falls Limestone Member (named from northern Missouri) forms the walls of the 'canyon' and is the classic regressive limestone of the Swope cyclothem, extending from Iowa to southeastern Kansas. It consists of bedded subtidal marine skeletal wackestone in the lower part grading upward into more massive mottled sparsely fossiliferous wackestone that represents peritidal facies at the top. Oolite is present locally in the upper part. The top is marked in various places by laminar caliche, solution tubes, and microkarstic features that all reflect subaerial exposure at the top of this cyclothem. The Bethany Falls contains the only occurrence of the distinctive fusulinid *Eowaeringella ultimata* in the Midcontinent, which is abundant above the base at this locality. Thompson et al. (1956) described associated *Fusulina fallsensis* from this area (in reported sparse abundance), which is the youngest occurrence of this genus known.

Galesburg Shale (named from southeastern Kansas, and no longer well exposed here) is a thin gray blocky mudstone paleosol with the sequence boundary at its top.

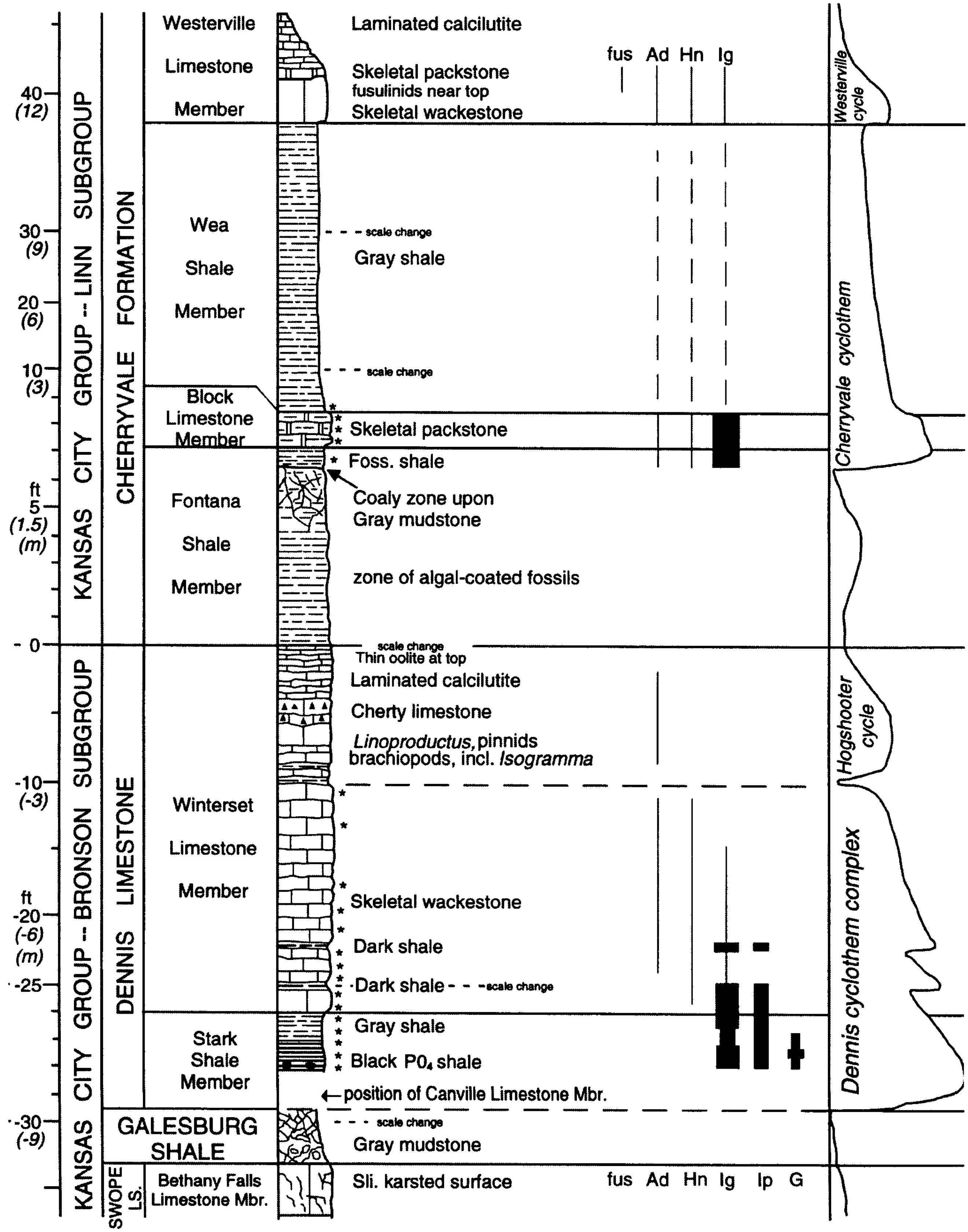
Stark Shale Member (named from southeastern Kansas, and better exposed at Stop A3) is a black phosphatic shale that is the core shale of the next higher Dennis cyclothem.

Winterset Limestone Member (named from Iowa) is the complex regressive limestone of the Dennis cyclothem. It contains two conodont-rich dark shales in the lower part, which represent minor transgressions that interrupt the 'phased regression' (Felton and Heckel, 1996) to form the bases of 'parasequences' and are more easily collected here than at Stop A3. The third shale up contains the lowest known more deeply troughed forms of *Streptognathodus*. The Winterset contains the first appearance of triticitid fusulinids in the Midcontinent, *Triticites ohioensis* and *Kansanella winterensis*, described by Thompson (1957) from Iowa, but have not been seen here.

Leave Stop A2 at 11:40

[Drive 8 miles, south on I-435, pulling off on downgrade approaching Blue River] (10 min.)

Stop A3: I-435 east of Blue River (north side)



STOP A3: I-435 east of Blue River. (S line SW-NW sec. 34, T 48 N, R 33 W, Jackson Co., MO) (60 min.)
[Start at exposure low in ditch; be careful of cliff at lower end]

This stop shows the **Dennis Limestone** and **cyclothem** and the **Cherryvale Formation** and **cyclothem**, the **fourth** and **fifth major marine units** of the **Missourian Stage**. Both formations are named from southeastern Kansas, where the Dennis is similar to its appearance here, but the Cherryvale consists largely of lowstand, thick sparsely fossiliferous marine shale overlain by thin highstand units.

Bethany Falls Limestone Member forms the bluff along the river.

Galesburg Shale (named from southeastern Kansas, and poorly exposed here) is a thin gray blocky mudstone paleosol with the sequence boundary at its top. It is a paleosol from Iowa (where it is capped by a thin coal) to southeastern Kansas, where it thickens greatly and contains sandstone bodies and at least two coals as it extends into Oklahoma. There it is the top of the Coffeyville Group, which replaces most of the Bronson Subgroup as shales replace limestone southward. It is a complex lowstand systems tract in the southern basin-marginal area.

Stark Shale Member (named from southeastern Kansas) is exposed low in the road ditch. It consists of black fissile shale with phosphorite nodules and laminae grading up into gray shale at the top. It is the classic 'core' shale of the Dennis cyclothem and contains the condensed interval deposited at highstand. Like the Hushpuckney, it extends essentially unchanged from Iowa to central Oklahoma. It is underlain by the Canville Limestone Member (named from southeastern Kansas), the transgressive limestone of the Dennis cyclothem, which first appears southward in east-central Kansas and is present as small lenses in Iowa. The abundant conodont fauna of the Stark (most easily obtained from the top of the gray facies) includes *Idiognathodus, Idioprioniodus, Gondolella*, and the first northern appearance of *Streptognathodus confragus*, a descendant of *S. cancellosus* (neither of which contains very deep troughs). *S. confragus* first appears in the Mound Valley Limestone, a minor cycle between the Swope and the Dennis that extends southward from east-central Kansas.

Winterset Limestone Member (named from Iowa) comprises two major parts. The lower part (in the road ditch) is the regressive limestone of the Dennis cyclothem. The two conodont-rich shales exposed in the vertical section at Stop A2 are less easily seen in this gentle slope. They are traceable from southern Iowa, descending in the section into east-central Kansas where they merge into the top of the underlying Stark Shale (Felton and Heckel, 1996; see figure 10 in Overview article). These shales are minor condensed intervals that represent minor transgressions during the general phase of forced regression. They separate individual regressive carbonate wedges ('parasequences') that progressively overstep the previous one southward. Furthermore, the upper two wedges disappear northward into the overlying major sequence boundary, indicating that the entire type Winterset Limestone at Winterset, Iowa, which is a single regressive unit, is represented in just the lower 1 foot (30 cm) of the Winterset here. Thompson (1957) reported the fusulinids *Triticites* and *Kansanella* only from Winterset, Iowa (which may help explain the scarcity of fusulinids here). The shaly zone in the terrace contains blocky mudstone (seen in good exposures) locally capped by coal in Kansas City, Kansas, thus is a sequence boundary (which extends southward to east-central Kansas). The upper Winterset in the ledge above the shaly zone (cherty sparsely skeletal wackestone capped by thin-bedded peritidal facies) is a separate T-R cycle bounded by subaerial exposure surfaces. It shows abrupt facies changes around Kansas City, has no condensed interval and only a sparse conodont fauna dominated by the nearshore genus *Adetognathus* in this region, and thus appears to be the nearshore end of the intermediate Hogshooter cycle (named from northern Oklahoma).

Fontana Shale Member (named from east-central Kansas) is mainly blocky mudstone abruptly overlain by marine shale above a coaly zone near the top, thus contains the major sequence boundary. This paleosol extends southward into east-central Kansas The zone of algal-coated clams, brachiopods, and other fossils in the middle may record a minor transgression at the top of the complex Dennis cyclothem. The Fontana thickens into 100 ft (30 m) of lowstand marine shale in southeastern Kansas.

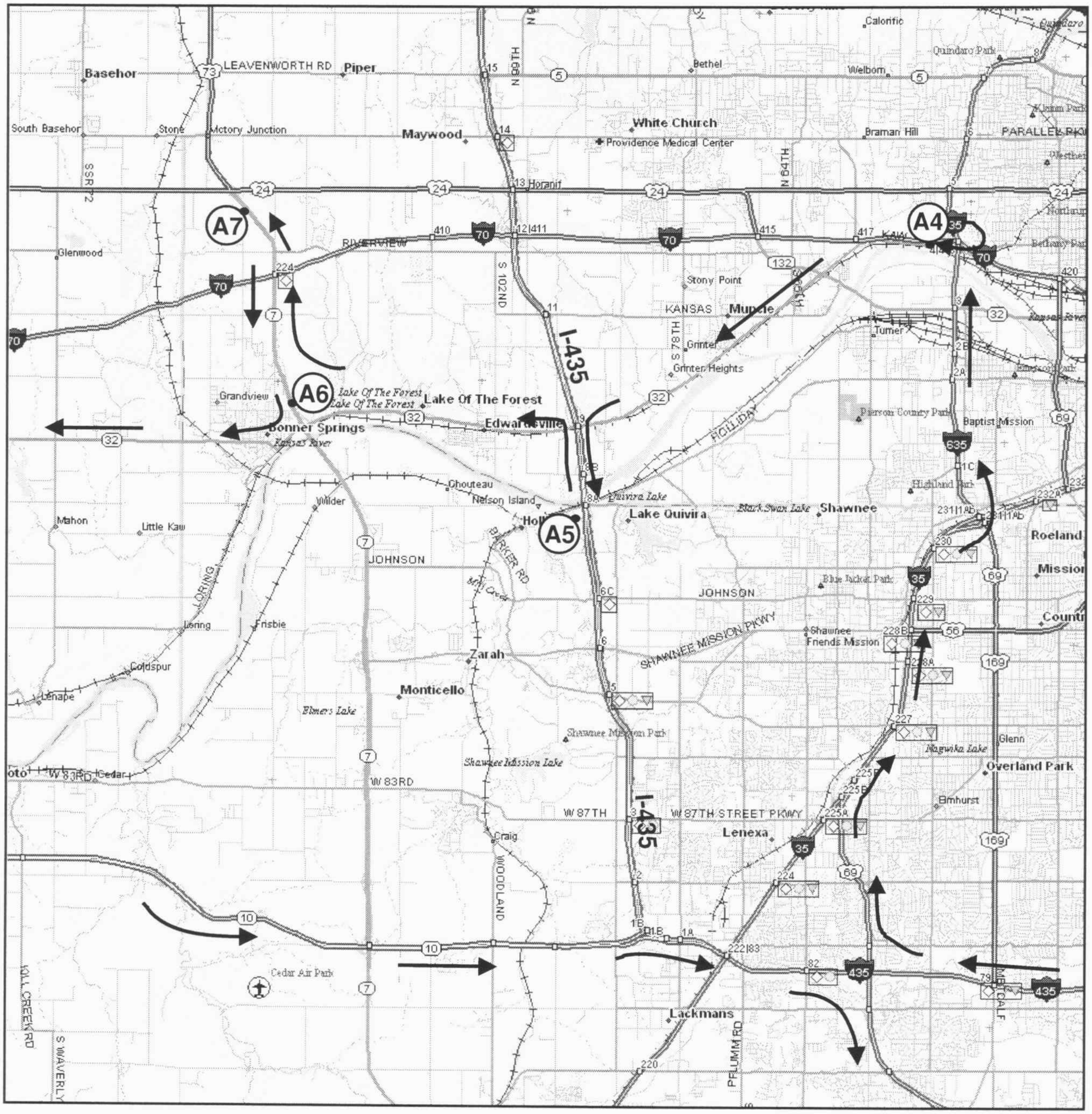
Block Limestone Member (named from east-central Kansas and extending from Iowa to southern Kansas) is a conodont-rich skeletal packstone. Along with the upper Fontana shale, it represents the transgressive to highstand condensed interval of the intermediate-scale Cherryvale cyclothem, which has a dark shale facies only in Oklahoma. Its conodont fauna is dominated by the first abundant northern appearance of deeply troughed *Streptognathodus gracilis, S corrugatus, S. excelsus*, and *S. elegantulus* in the Midcontinent (some first appear in the Hogshooter Limestone in northern Oklahoma), and includes *Idioprioniodus* and *Idiognathodus*.

Wea Shale Member (named from east-central Kansas) is thick sparsely fossiliferous regressive shale here, but includes the top of the condensed interval elsewhere in scarce exposures from Iowa to southern Kansas.

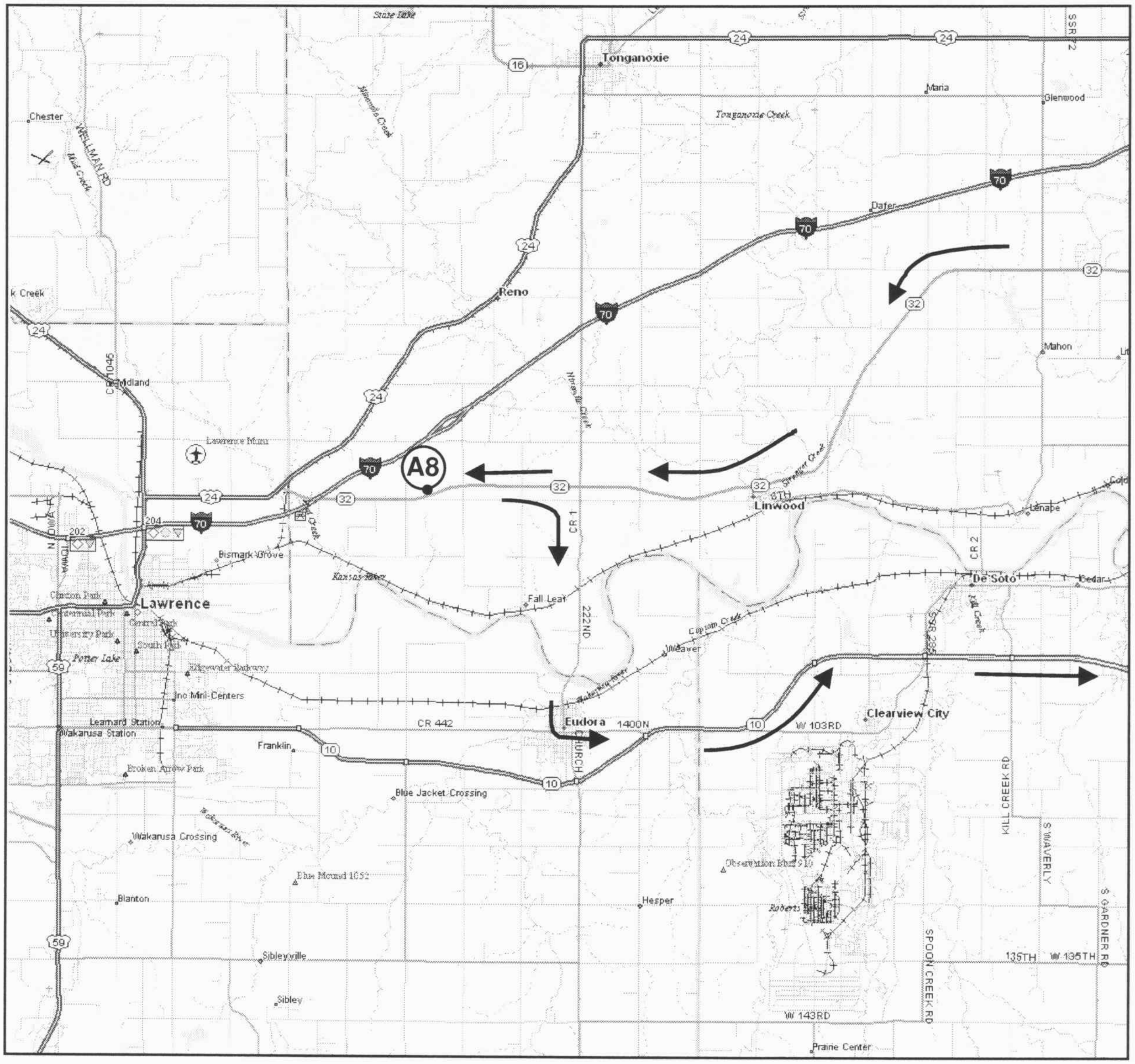
Westerville Limestone Member (named from Iowa and traced to just south of Kansas City) is a regressive limestone, locally with oolite and tidal flat facies at the top. It contains a slightly more conodont-rich condensed interval in its base nearby, thus represents a minor cycle ('parasequence') at the top of the Cherryvale cyclothem. It contains fusulinids, possibly *Triticites burgessae*, reported by Thompson (1957) from this unit in Iowa.

Leave Stop A3 at 12:50

Drive 22 mi: W on I-435, N on US-69, I-35, & I-635, E on I-70, exiting on Park/Kaw Drive to W, 1 mi] (30 min.)

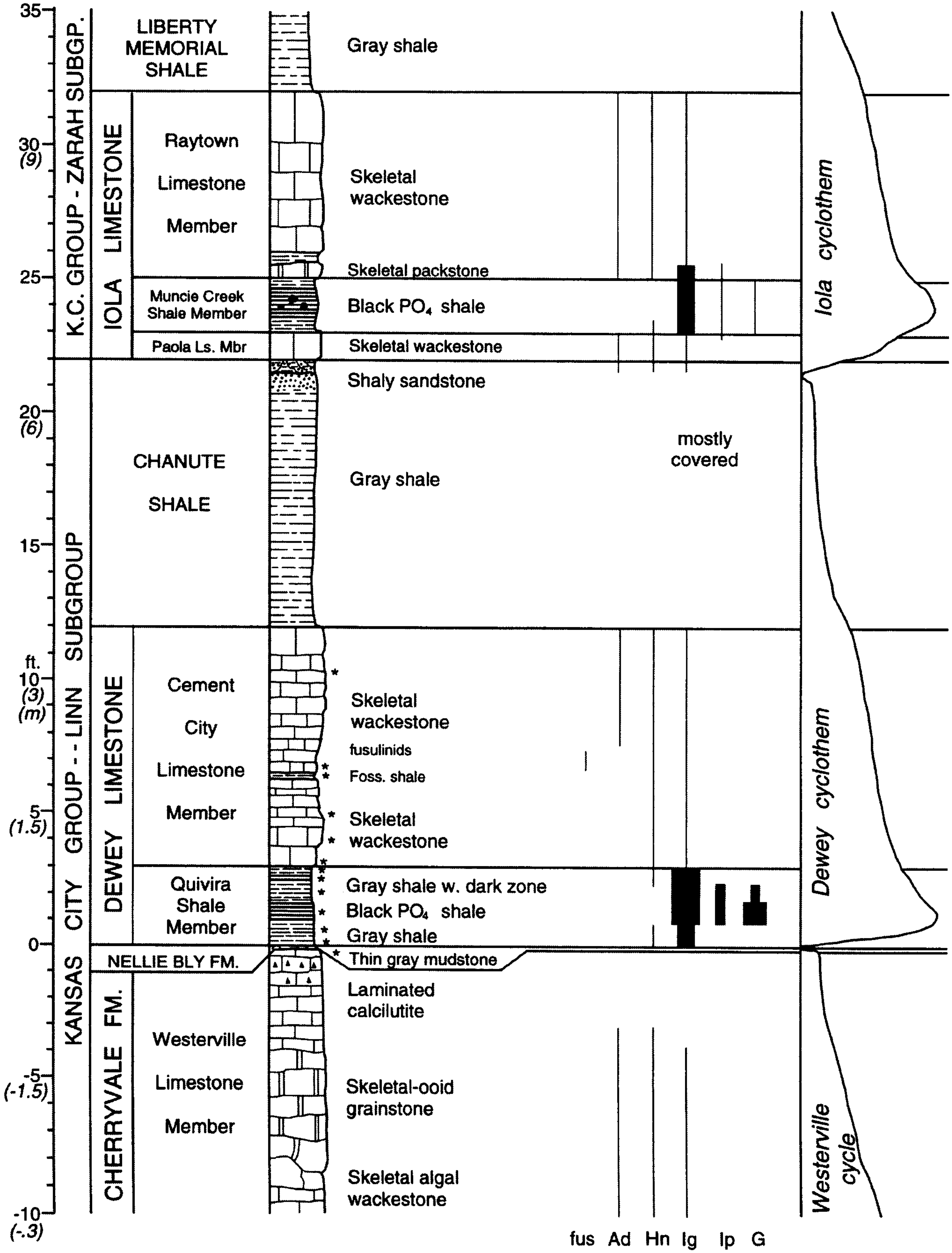

A4
A5
A6
A7
I-435
Basehor
Piper
Maywood
White Church
Providence Medical Center
Bonner Springs
Edwardsville
Lake Of The Forest
Lake Quivira
Shawnee
Lenexa
Overland Park
Roeland
Monticello
Zarah
Lackmans
KANSAS
JOHNSON
LEAVENWORTH RD
RIVERVIEW
SHAWNEE MISSION PKWY
W 87TH STREET PKWY
W 83RD

Stops A4-A7


Tonganoxie
Reno
Lawrence
Linwood
De Soto
Eudora
Clearview City
A8
Fall Leaf
Franklin
Blue Jacket Crossing
Wakarusa Crossing
Blanton
Sibleyville
Sibley
Hesper
Prairie Center
Chester
Maria
Glenwood
Dafer
Mahon
Lenape
Cedar
Weaver
Bismark Grove
Kansas River
Tonganoxie Creek
Lawrence Muni
Midland
Lakeview Station
Wakarusa Station
Broken Arrow Park
Blue Mound 1052
Observation Bluff 910
CR 442
CR 1
CR 2
222ND
1400N
W 103RD
W 143RD
135TH
W 135TH
KILL CREEK RD
S WAVERLY
S GARDNER RD
SPOON CREEK RD
WELLMAN RD

Stop A8

Stop A4: Kaw Drive Roadcut, west of I-635 overpass



STOP A4: Kaw Drive roadcut. (ctr. W half, SE-SE sec. 12, T 11 S, R 24 E, Wyandotte Co., KS) (60 min.)

*[Be very careful while crossing this narrow highway; we will have **lunch** here]*

This stop shows the **Dewey Limestone** and **cyclothem**, with a brief look at the **Iola Limestone** and **cyclothem**, the **sixth** and **seventh major marine units** above the base of the **Missourian Stage**. The Dewey is named from northern Oklahoma, and the Iola is named from east-central Kansas. Both are traceable from Iowa to Oklahoma, and long-standing miscorrelations in this more shale-rich part of the succession in both areas have recently been rectified by examining the conodont faunas of their 'core' shales.

Westerville Limestone Member (named from Iowa) is the regressive limestone of a minor cycle ('parasequence') at the top of the Cherryvale cyclothem. Here it displays skeletal-algal wackestone overlain by skeletal-ooid grainstone capped by peritidal laminated lime mudstone, a classic shallowing-upward sequence.

Nellie Bly Formation (named from Oklahoma) is only 0.1 foot (3 cm) of mudstone (possibly paleosol) here, with the sequence boundary between the Cherryvale and Dewey cyclothems at the top. Westward, the Nellie Bly thickens to 1.5 ft (45 cm) of caliche-bearing mudstone. A thin coal bed has been reported at this horizon elsewhere in the Kansas City area. The Nellie Bly in its type region in northern Oklahoma is about 165 ft (50 m) of sandy shale and sandstone deposited at lowstand. The paleosol extends from just south of here northward to Iowa.

Quivira Shale Member (named from this area) is phosphatic gray to black shale that extends from Iowa to central Oklahoma. It represents the transgressive and highstand deposits of the Dewey cyclothem and locally has a very thin transgressive limestone at the base, which is thick enough to be named in Iowa (Pammel Park) and Oklahoma (Wekiwa). The Quivira carries an abundant conodont fauna that is dominated by *Idiognathodus* and *Streptognathodus*, with larger numbers of *Gondolella* than are typical of other Missourian cyclothems, and smaller numbers of *Idioprioniodus*. This fauna is characterized by the first appearance (at least in any abundance) of a large-lobed morphotype of finely ribbed *Idiognathodus magnificus* (s.s.), and contains more coarsely ribbed forms, including a somewhat triangular morphotype. These are accompanied by *Streptognathodus elegantulus, gracilis, excelsus,* and *corrugatus*. The holotype of *S. oppletus* (as *I. multinodosus*) was collected from this unit in Missouri.

Cement City Limestone Member (named from nearby in Missouri) is the regressive limestone of the Dewey cyclothem, and extends from Iowa to Oklahoma. It is typical skeletal wackestone in the exposure here, with a thin shale at 3.5 ft (~1 m) up that carries a fauna dominated by small brachiopods. Fusulinids are found just above. Thompson (1957) described *Triticites collus* from the Cement City Limestone in Iowa, but this may be from the Westerville because correlation with Iowa at that time was uncertain.

Chanute Shale (named from southeastern Kansas, and not accessible here) is a relatively thin coarsening-upward sequence in this area with mudstone near the top, possibly a paleosol, which would mark the sequence boundary at the top of the Dewey cyclothem. The Chanute is mainly a paleosol farther northward onto the shelf in Iowa, but thickens southward toward the basin in its type area and in Oklahoma to a complex sandstone-dominated lowstand detrital unit with a persistent coal bed (Thayer) near the middle.

[The following units can be seen in a roadcut to the west, but will be collected on the fourth day to the south]

Paola Limestone Member (named from east-central Kansas) is the transgressive limestone of the Iola cyclothem, and can be traced from Iowa to Oklahoma.

Muncie Creek Shale Member (named from this area) is the gray to black phosphatic shale that represents the condensed interval deposited at highstand. It also can be traced from Iowa to Oklahoma. Across much of east-central Kansas, it is a thin 0.1-0.2-ft (3-6 cm) truly sediment-starved gray shale with phosphate nodules and an abundant conodont fauna, which can be collected at a locality there (Stop D4) on the last day of the trip. This fauna is similar to that of the Quivira Shale except that it contains far fewer *Gondolella* and a descendant smaller-lobed morphotype of *Idiognathodus magnificus* (s.s.), which we are informally calling 'postmagnificus'. So far as we can tell at this point, the species of *Streptognathodus* are similar to those below in the Quivira Shale.

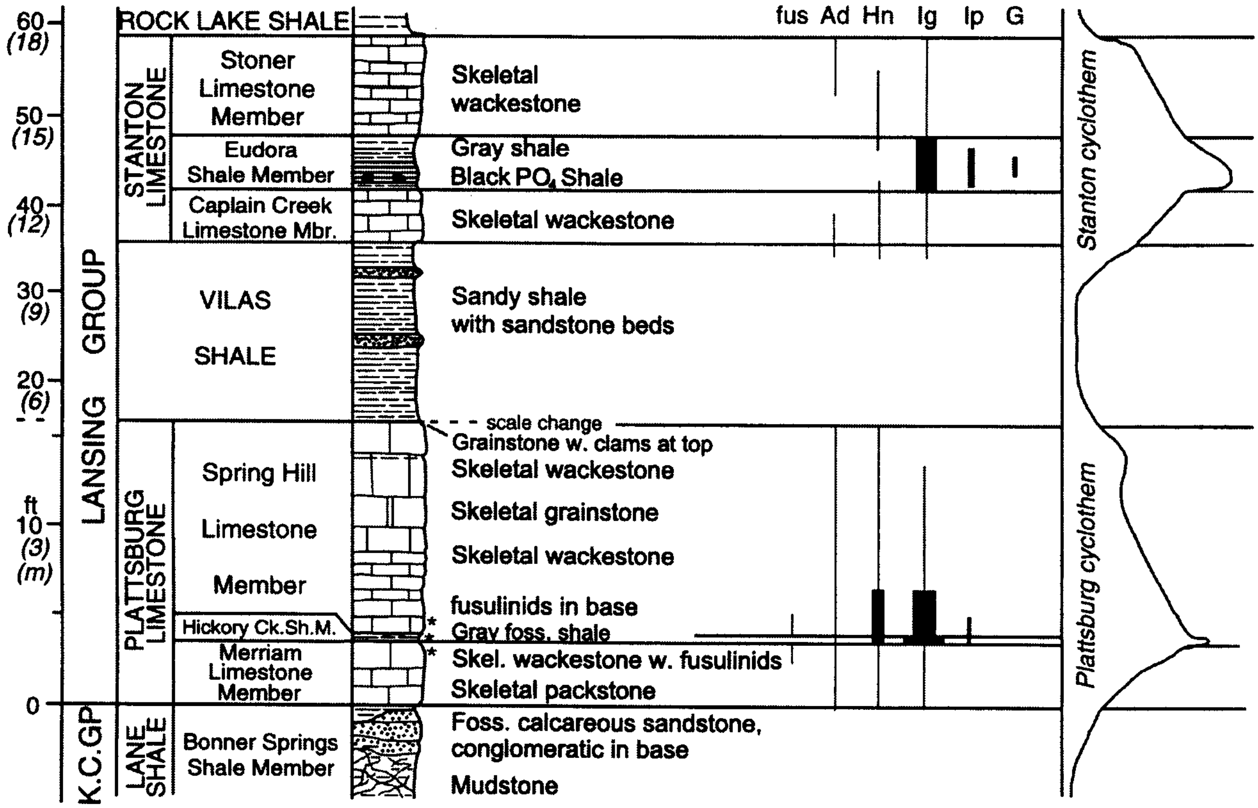
Raytown Limestone Member (named from nearby in Missouri) is the regressive limestone of the Iola cyclothem, and also can be traced from Iowa to Oklahoma. Its basal bed is a conodont-rich skeletal packstone that represents the top of the condensed interval. The entire unit is relatively thin throughout this region where it lacks shallow-water deposits at the top, but it thickens northward in Iowa, where it is a shallowing-upward unit with shoal-water deposits and an exposure surface at the top. In the Kansas City region it is overlain by a thick coarsening-upward prodeltaic sequence that interrupted carbonate deposition in the central part of the outcrop belt.

Liberty Memorial Shale (named from Kansas City, Missouri, and exposed in its entirety at the next stop) is the prodeltaic shale that forms the top of the Iola cyclothem in this region.

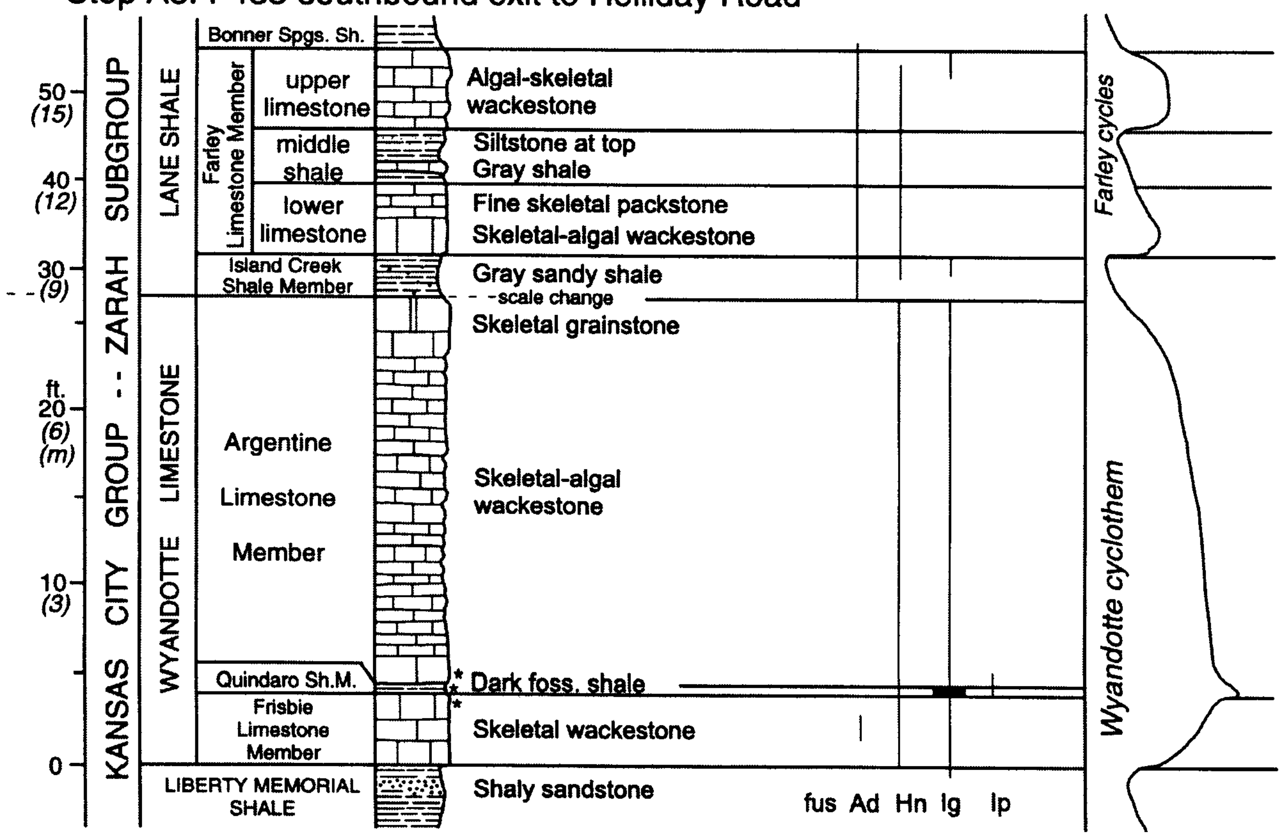
Leave Stop A4 at 2:20 PM

[Drive 8 miles: W on Kaw Drive, S on I-435, exiting and stopping on the offramp to Holliday Road] (10 min.)

Stop A6: Bonner Springs K-7 Roadcut



Stop A5: I-435 southbound exit to Holliday Road



STOP A5: I-435 exit to Holliday Road. (S half, NE-NW sec. 6, T 12 S, R 24 E, Johnson Co., KS) (30 min.)

[Please do not cross the highway here; we will visit only the south-facing exposure]

This stop shows the **Wyandotte Limestone** and **cyclothem**, the **eighth major marine unit** above the base of the **Missourian Stage**, but a cyclothem of only intermediate scale as it is well developed only in this region. Across the ramp we can view the overlying **Farley Limestone**, which contains two minor cycles ('parasequences'). Both these units are named from this area. The Iola Limestone crops out down-section.

Liberty Memorial Shale (named from Kansas City, Missouri) represents coarsening-upward prodeltaic influx that forms the top of the Iola cyclothem. The sequence boundary is at the top of the sandstone containing only plant fragments, and shows evidence of exposure where a thin coal appears at the top northeastward in Missouri. The unit ultimately becomes a thin paleosol northward. Southward, its distal end thins to disappearance as the Wyandotte and Iola cyclothems merge in east-central Kansas (Arvidson, 1990).

Frisbie Limestone Member (named from this area) is the transgressive limestone of the Wyandotte cyclothem, which extends from north-central Missouri to east-central Kansas.

Quindaro Shale Member (named from this area) is a thin fossiliferous conodont-rich dark gray shale that represents the condensed highstand deposit. It was deposited in oxygenated water that did not attain enough depth to develop a long-term thermocline. The Quindaro carries a conodont fauna dominated by *Streptognathodus elegantulus* and its relatives, and it contains a distinctive *S.* morphotype in which the trough line is bent laterally at a slight angle from the free blade, along with *Idioprioniodus* and rare *Idiognathodus*. This conodont-rich zone extends from Iowa to Oklahoma, in the base of the overlying limestone away from this area.

Argentine Limestone Member (named from this area) is the regressive limestone of the Wyandotte cyclothem, mainly skeletal wackestone capped by packstone. The Argentine carries only *Streptognathodus* whereas the higher Farley Limestone carries only *Adetognathus*, which allowed Baesemann (1973) to differentiate ramiform elements of these two genera. Fusulinids include *Kansanella tenuis*, named from the Wyandotte nearby. The Argentine is traced from Iowa to southeastern Kansas where it thins above the disappearance of underlying units and rests with the thin Quindaro Shale in basinal facies on top of the Raytown Limestone.

Island Creek Shale Member (named from this area) is sandy shale that is the distal end of a prodeltaic influx centered just a few miles to the north, and contains a minor sequence boundary at its top.

Farley Limestone Member (named from nearby in Missouri) comprises two limestone beds separated by a coarsening-upward shale widespread enough (and with coal at the top in Missouri), that the Farley is considered to represent two minor cycles of transgression ('parasequences') at the top of the Wyandotte cyclothem.

Leave Stop A5 at 3:00 PM

[Drive 7 miles: E on Holliday Road, then re-enter I-435 northward, W on K-32, N on K-7, 0.5 mile) (10 min.)

STOP A6: Bonner Springs K-7 Roadcut. (ctr. S half, NE sec. 29, T 11 S, R 23 E, Wyandotte Co., KS) (30 min.)

[Do not cross this highway]

This stop shows the **Plattsburg Limestone** and **cyclothem**, and we will view the **Stanton Limestone** and **cyclothem** (which we will collect on the last day), the **ninth** and **tenth major marine units** above the base of the **Missourian Stage**. The Plattsburg is named from nearby in Missouri, and the Stanton from east-central Kansas.

Bonner Springs Shale Member (named from here) is a variable unit locally with well developed reddish calcareous paleosol that forms the sequence boundary between the Wyandotte and Plattsburg cyclothems. Here it contains early transgressive sandy conglomeratic limestone with both marine shells and plant debris at the top.

Merriam Limestone Member (named from this area) is the transgressive limestone of the Plattsburg cyclothem, extending from southeastern Nebraska to southeastern Kansas. Here it is skeletal packstone grading up to wackestone, displaying a deepening-upward sequence not often this distinct in these units.

Hickory Creek Shale Member (named from east-central Kansas) is a thin fossiliferous conodont-rich gray shale (like the Quindaro) that represents the condensed highstand deposit of this intermediate cyclothem. It is traced from Nebraska into northern Oklahoma beyond the extent of the two limestone members. Its conodont fauna is dominated by the same species of *Streptognathodus* as below, with the bent morphotype more abundant.

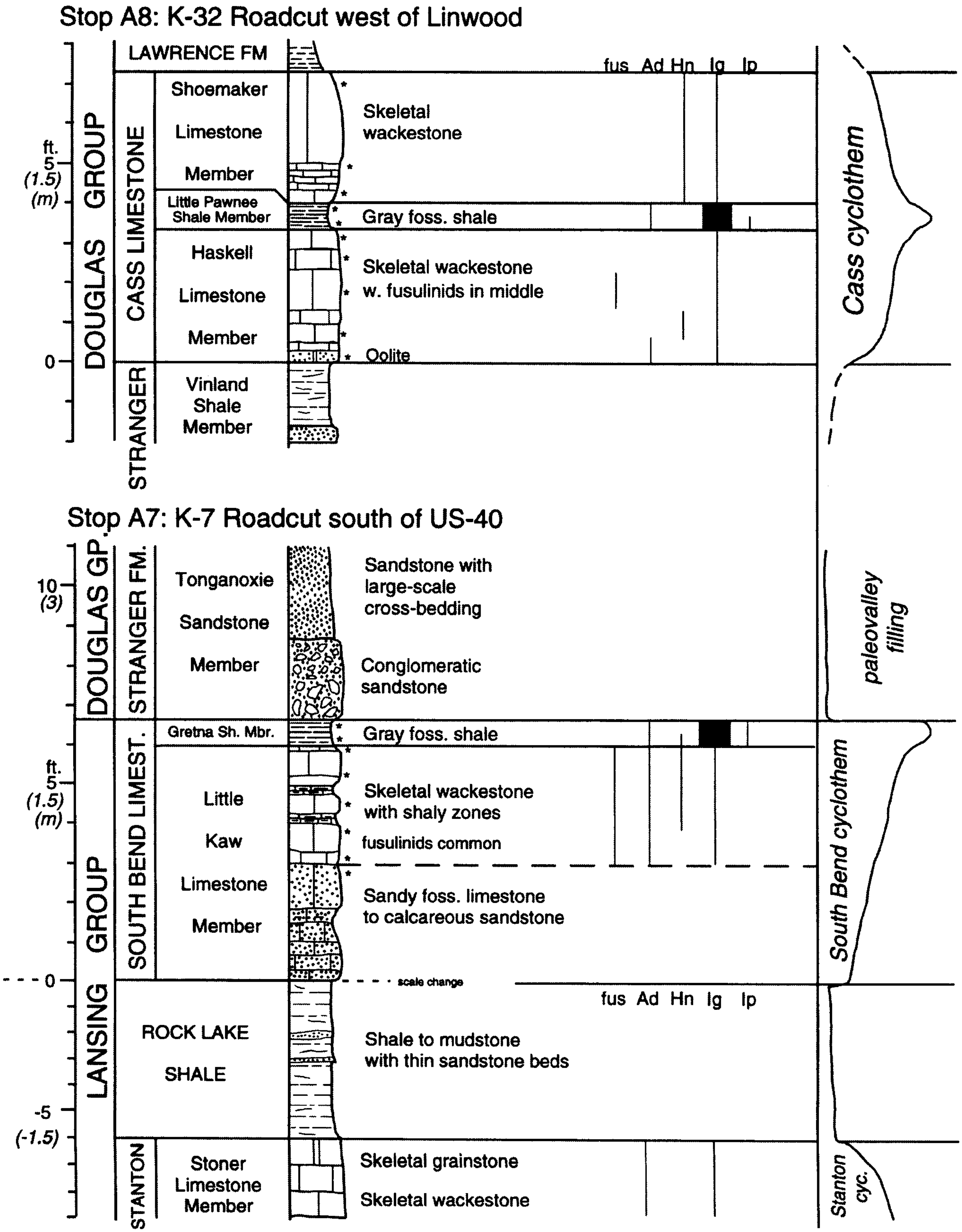
Spring Hill Limestone Member (named from this area) is the regressive limestone of the Plattsburg cyclothem grading from skeletal wackestone upward to packstone, and extending from Iowa to southeastern Kansas. Thompson (1957) described the fusulinid *Kansanella plicatula* From the Spring Hill in eastern Kansas.

Vilas Shale (named from southeastern Kansas) is a complex lowstand shale that locally contains paleosol mudstone and plant-debris-bearing sandstone and thus contains the sequence boundary between the Plattsburg and Stanton cyclothems. Here it contains early transgressive fossiliferous shale and sandstone at the top.

Captain Creek Limestone is the transgressive limestone; Eudora Shale is the 'core' shale (containing the first appearances of *Idiognathodus simulator* and *Streptognathodus firmus*, and the last appearances of *S. gracilis, elegantulus, corrugatus* and *excelsus*); and Stoner Limestone is the regressive limestone of the Stanton cyclothem.

Leave Stop A6 at 3:40 PM

[Drive 3.5 miles: N along K-7, pulling left into sideroad just beyond outcrop on left] (10 min.)


Stop A8: K-32 Roadcut west of Linwood
LAWRENCE FM
fus Ad Hn Ig Ip
DOUGLAS GROUP
CASS LIMESTONE
Shoemaker Limestone Member
Skeletal wackestone
Little Pawnee Shale Member
Gray foss. shale
Haskell Limestone Member
Skeletal wackestone w. fusulinids in middle
Oolite
STRANGER
Vinland Shale Member
ft. 5 (1.5) (m)
0
Cass cyclothem
Stop A7: K-7 Roadcut south of US-40
DOUGLAS GP.
STRANGER FM.
Tonganoxie Sandstone Member
Sandstone with large-scale cross-bedding
Conglomeratic sandstone
paleovalley filling
10 (3)
Gretna Sh. Mbr.
Gray foss. shale
LANSING GROUP
SOUTH BEND LIMEST.
Little Kaw Limestone Member
Skeletal wackestone with shaly zones
fusulinids common
Sandy foss. limestone to calcareous sandstone
South Bend cyclothem
ft. 5 (1.5) (m)
0
scale change
fus Ad Hn Ig Ip
ROCK LAKE SHALE
Shale to mudstone with thin sandstone beds
-5 (-1.5)
STANTON
Stoner Limestone Member
Skeletal grainstone
Skeletal wackestone
Stanton cyc.

STOP A7: K-7 Roadcut S of US-40. (NW-SW-NW sec. 8, T 11 S, R 23 E, Wyandotte Co., KS) (30 min.)

[Please do not cross this busy highway]

This stop shows the **South Bend Limestone** and **cyclothem**, the **eleventh major marine unit** above the base of the **Missourian Stage**. The South Bend is named from southeastern Nebraska.

Stoner Limestone Member (exposed across the highway to the northeast) shows a shallowing-upward sequence from skeletal wackestone to grainstone, and is the regressive limestone of the Stanton cyclothem.

Rock Lake Shale (named from Nebraska and extending into northern Oklahoma) was once well exposed across the highway above the Stoner. It is largely unfossiliferous shale to mudstone paleosol with local sandstone beds and lenses, and contains the sequence boundary between the Stanton and South Bend cyclothems.

Little Kaw Limestone Member (named from this area) is the transgressive limestone of the South Bend cyclothem, which can be traced from Nebraska to northern Oklahoma. Here it contains sandy limestone to calcareous, fossiliferous sandstone at the base, which carries derbyiid and other brachiopods and myalinid clams, and represents a shoal-water environment developed during early transgression. This part is overlain by skeletal wackestone that represents a quiet, more offshore environment that is more typical of transgressive limestones and completes the deepening-upward sequence. The limestone carries moderately abundant fusulinids, probably *Triticites kawensis* and *T. newelli*, both described or reported by Thompson (1957) from this unit in this region.

Gretna Shale Member (named from Nebraska) is a thin fossiliferous conodont-rich gray shale that represents the condensed interval of the South Bend cyclothem deposited at highstand. Its conodont fauna is dominated by *Streptognathodus firmus* and contains the first appearance of *S. pawhuskaensis*. It also includes *Idioprioniodus*, and rare *Idiognathodus simulator*. The Gretna is overlain by a regressive limestone (Kitaki) only in Nebraska. Although rarely exposed southward, the Gretna has been traced to northern Oklahoma by means of the conodont-rich zone above the top of the Little Kaw Limestone wherever it is exposed.

Tonganoxie Sandstone Member (named from this area) is a classic paleovalley filling consisting of conglomerate overlain by sandstone here and tidal deposits upward, described by Archer et al. (1994). The bottom of the paleovalley forms the upper sequence boundary of the South Bend cyclothem in this region.

Leave StopA7 at 4:20 PM

[Drive 20 miles: S on K-7, W on K-32 to nearly 6 miles past Linwood] (30 min.)

STOP A8: K-32 Roadcut W of Linwood. (ctr. S line, SW 13, T 12 S, R 20 E, Leavenworth Co., KS (40 min.)

[Please stay off this busy highway]

This stop shows the **Cass Limestone** and **cyclothem**, the **basal unit of the Virgilian Stage**. The Cass was named from Nebraska. Between the South Bend and Cass cyclothems is the Iatan Limestone and cyclothem (named from Missouri), the twelfth major Missourian marine unit, which is cut out in this area by the Tonganoxie paleovalley, but will be seen in southern Kansas at Stop C1. Southward, the Westphalia Limestone (to be seen at Stops C2 and D1), representing a minor marine transgression, appears between the Iatan and Cass.

Vinland Shale Member (named from this area and extending into northern Oklahoma) is a detrital unit that coarsens upward to sandstone here. It contains the lower sequence boundary of the Cass cyclothem, and the upper beds are typically fossiliferous, representing the early transgressive phase of the Cass cyclothem.

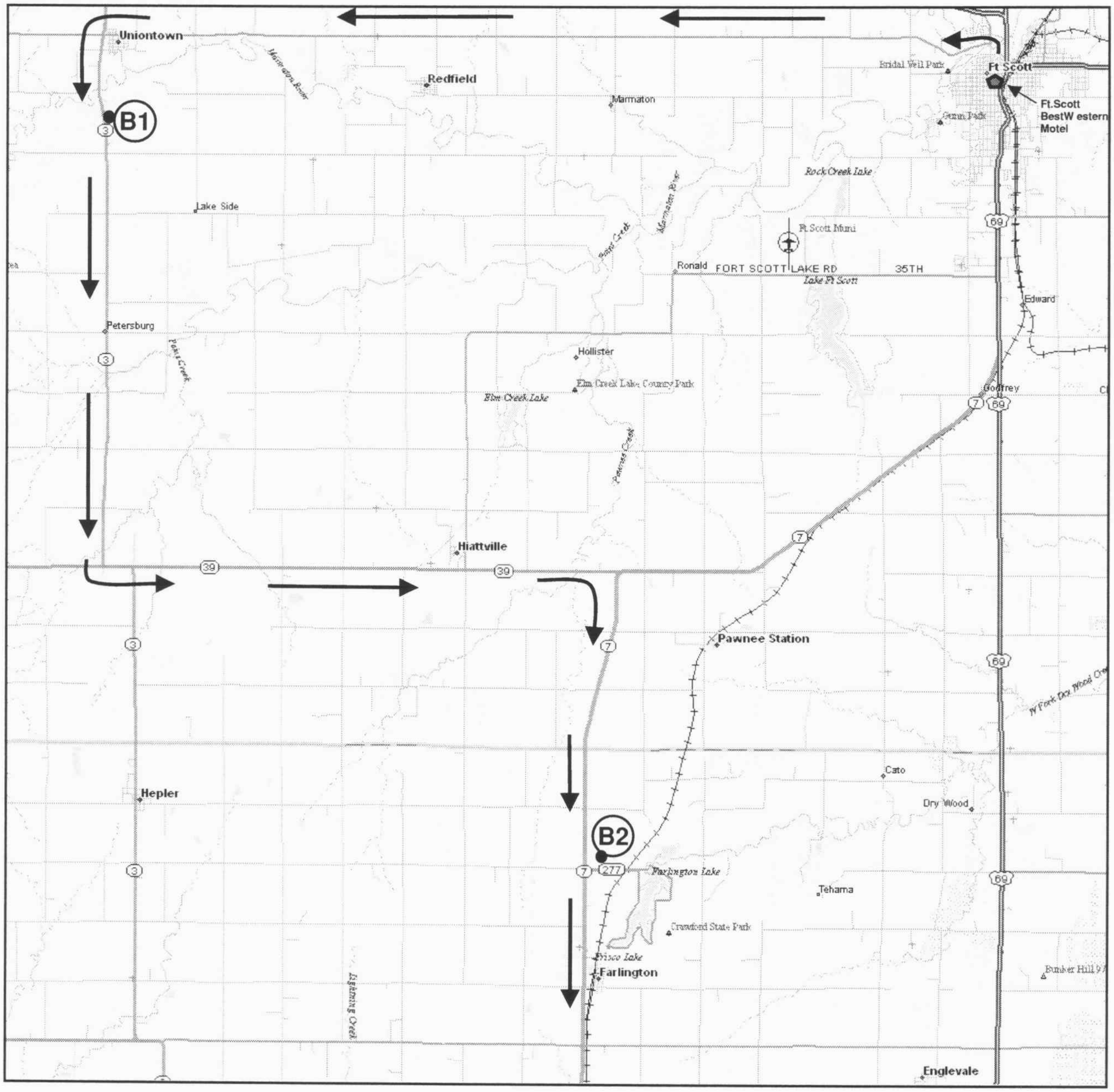
Haskell Limestone Member (named from this area, and extending from Nebraska to northern Oklahoma) is the transgressive limestone of the Cass cyclothem (which has previously been termed Haskell-Cass cyclothem because of the dominance of the Haskell Limestone in it south of Nebraska). Here the Haskell is oolitic grainstone at the base, grading up to typical skeletal wackestone, reflecting the deepening-upward sequence. The Haskell contains scattered fusulinids, which are not known to have been identified in publications.

Little Pawnee Shale Member (named from Nebraska and traced into Oklahoma) is a thin fossiliferous conodont-rich shale that represents the condensed interval deposited at highstand. The conodont fauna is dominated by *Streptognathodus pawhuskaensis*, and contains the first appearance of its probable descendant *S. zethus*; this event is used to define the base of the Virgilian Stage, as will be explained at Stops C3 and D1. *S. firmus* and *Idioprioniodus* are also present.

Shoemaker Limestone Member (named from Nebraska) is the regressive limestone of the Cass cyclothem and is known only at this locality south of there. It, like the regressive limestone of the South Bend cyclothem, was apparently overwhelmed by detrital influx across most of the mid- to low-shelf position south of Nebraska.

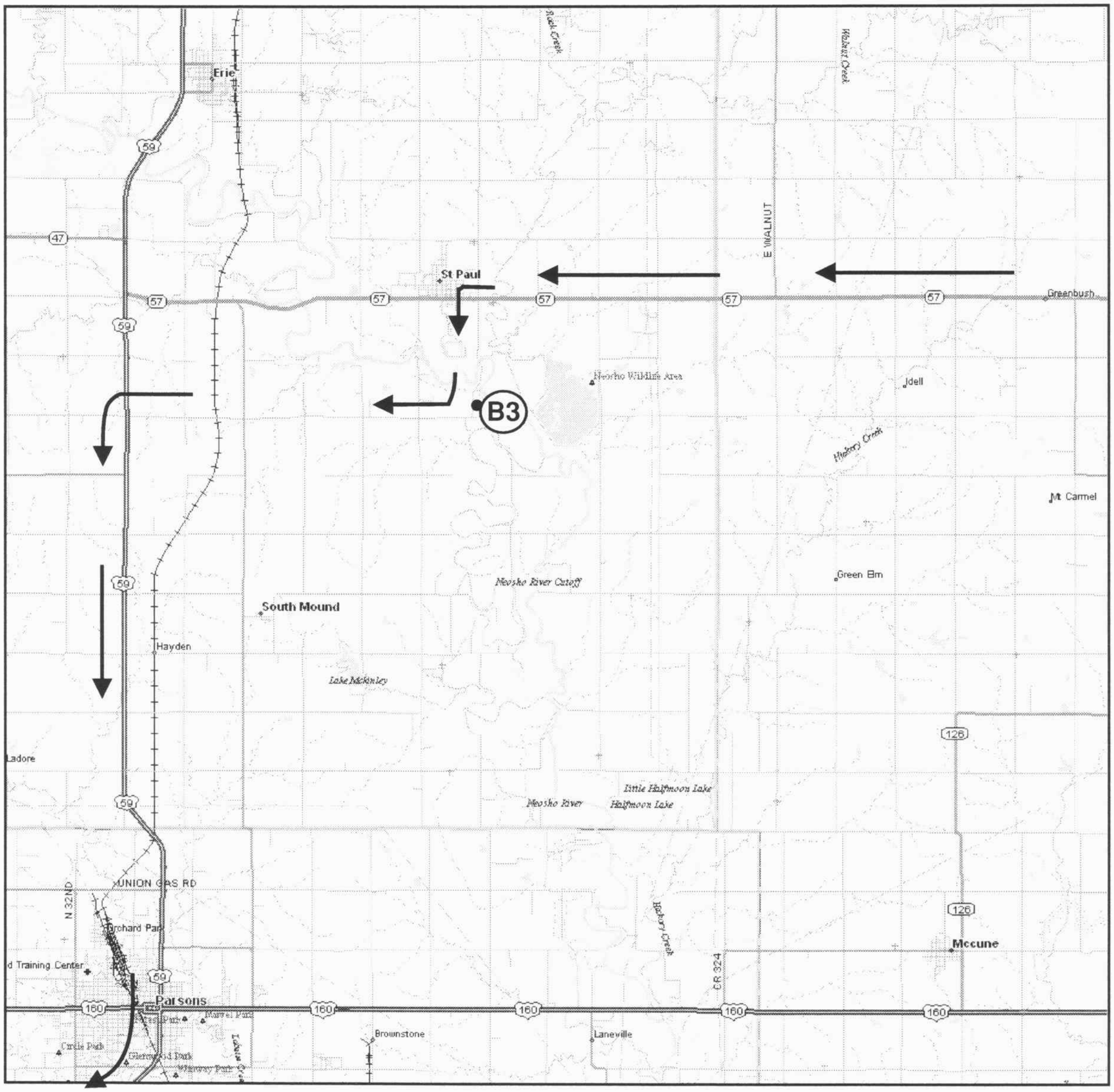
Leave Stop A8 at 5:30 PM

[Drive 105 miles: E on K-32, 3 miles, S on Co. Rd., E on K-10, E on I-435, S on US-69 to Fort Scott] (120 min.)



Uniontown
Redfield
Marmaton
B1
Lake Side
Petersburg
Hollister
Elm Creek Lake
Hiattville
Pawnee Station
Hepler
B2
Farlington Lake
Crawford State Park
Frisco Lake
Farlington
Tehama
Cato
Dry Wood
Englevale
Ft Scott
Ft.Scott
BestW estern
Motel
Bridal Veil Park
Rock Creek Lake
Ft Scott Muni
Ronald
FORT SCOTT LAKE RD
35TH
Lake Ft Scott
Edward
Godfrey
Lightning Creek
Bunker Hill

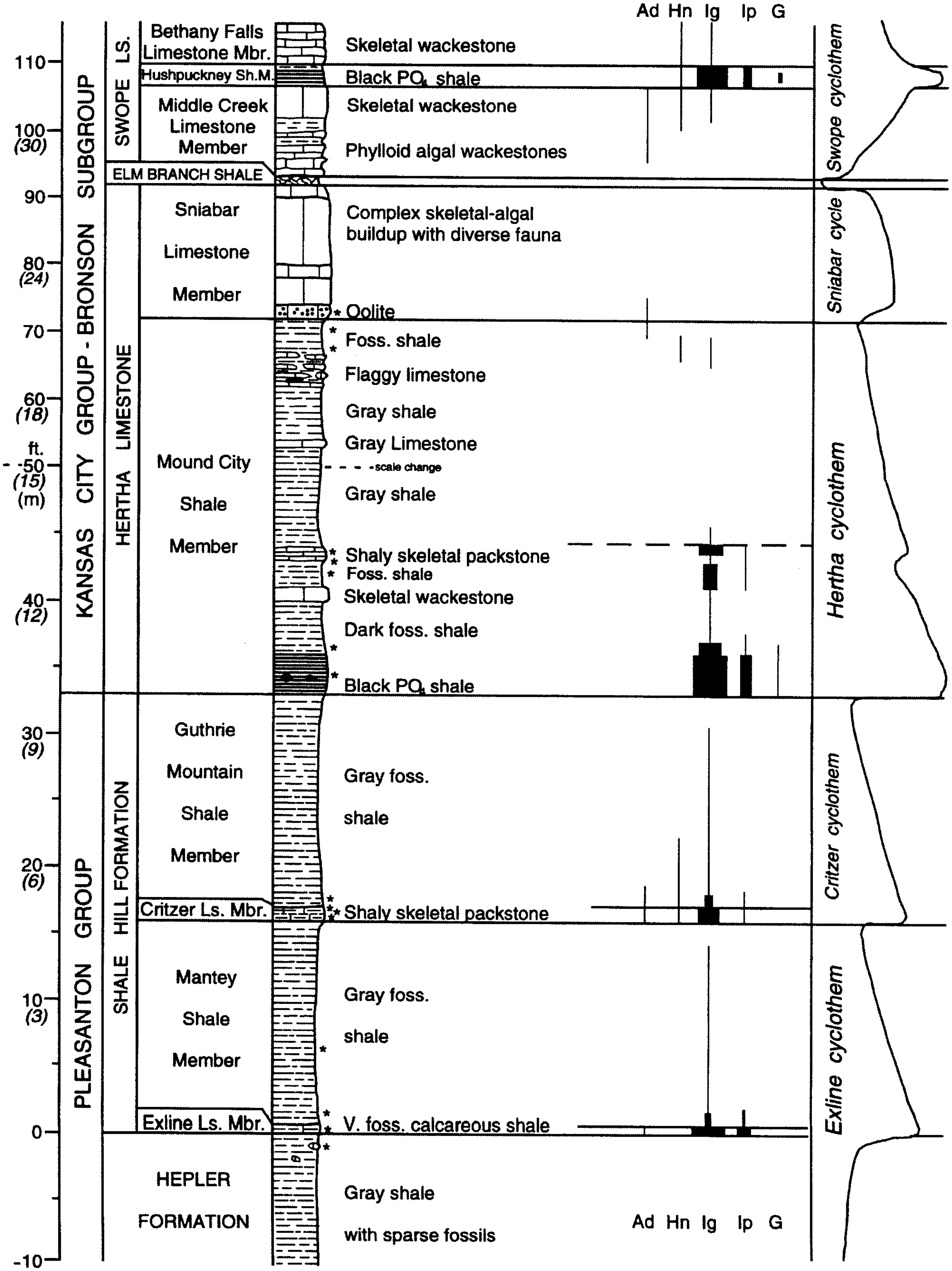
StopsB1-B2



Erie
47
57
59
St Paul
Greenbush
E WALNUT
B3
Neosho Wildlife Area
Idell
Hickory Creek
Mt Carmel
Green Elm
Neosho River Cutoff
South Mound
Hayden
Lake Mckinley
126
Ladore
Little Halfmoon Lake
Neosho River
Halfmoon Lake
UNION GAS RD
N 32ND
Orchard Park
Mccune
CR 324
Parsons
160
Brownstone
Lanewille

Stop B3

Stop B1: K-3 Roadcut south of Uniontown



Day 2 (B): Lower Missourian and upper Desmoinesian on lower shelf; proposed Desm.-Missourian boundary
Leave Best Western Fort Scott Inn at 7:30 AM
[Drive 18 miles, N on US-69, W on US-54, S on K-3, 2.2 miles] (30 min.)

STOP B1: K-3 Roadcut S of Uniontown. (E half SE-NW sec. 34, T 25 S, R 22 E, Bourbon Co., KS) (50 min.)

[Be very careful crossing this highway, which has limited visibility uphill to the south]

This stop shows the **Exline Limestone** and **cyclothem**, the **Critzer Limestone** and **minor cyclothem**, the **Hertha Limestone** and **cyclothem** (here shale-dominated), and the **Swope Limestone** and **cyclothem**, the latter two seen at Stop A2 yesterday. The **Exline is the lowest Missourian marine unit in the Midcontinent**; it lies at the base of the Shale Hill Formation in the shale-dominated Pleasanton Group, for which the complex internal stratigraphy was worked out by tracing the conodont-rich black shale and underlying thin limestones seen in this outcrop.

Hepler Formation (named from just south of here) is sparsely fossiliferous marine shale in its upper part (in gully east of road). This appears to be transgressive because the lower Hepler contains mudstone capped with coal overlain by thin sandstone, all above the Lost Branch Formation in the wooded ravine to the northwest. The separate minor marine cycle at the top represented by the South Mound Shale Member southward (to be seen at Stop B8 late today) is not present this far north, because there is no apparent shallowing at the top of the Hepler here.

Exline Limestone Member (named from Iowa; exposed in gully east of road) is a thin, conodont-rich, very shaly skeletal packstone to calcareous shale that represents the condensed interval of the Exline cyclothem, deposited at highstand; (the early transgressive part of the Exline cyclothem is recorded in the sparsely fossiliferous upper Hepler shale here). The Exline cyclothem can be traced from west-central Iowa to east-central Oklahoma, although in southeasternmost Kansas and northern Oklahoma it consists almost entirely of dark fossiliferous shale. The conodont fauna of the Exline Limestone includes *Idioprioniodus*, but it is dominated by *Idiognathodus sulciferus* (which first appears in the top of the Desmoinesian toward the south), and it also contains the first appearance of the descendant *I. eccentricus* everywhere it has been studied in the Midcontinent. This event is used to define the base of the Missourian Stage in North America. The proposed boundary stratotype will be seen at Stop B8 later today.

Mantey Shale Member (named from northeast of here) is the distal portion of a prodeltaic shale that records the regressive phase of the Exline cyclothem. It thickens substantially northeastward, where it contains sandstone in the top near the Missouri border, and contains the Locust Creek coals in a deltaic complex northeast of Kansas City.

Critzer Limestone Member (named from northeast of here; exposed downstream from culvert) is a thin shaly, conodont-rich skeletal packstone that records a minor transgression. It is traced from skeletal grainstone shelf facies near Kansas City southward through flaggy calcilutite slope facies ('Bourbon flags') above thinning Mantey Shale to this more basinal facies that converges southward with the Exline cyclothem in northern Oklahoma. It contains the same species of *Idiognathodus* as the Exline here, but its fauna becomes dominated by *Adetognathus* northward on the shelf.

Guthrie Mountain Shale Member (named from northeast of here) is the distal portion of a prodeltaic shale that represents the regressive phase of the Critzer cyclothem. Like the Mantey Shale, it too thickens substantially northeast-ward, then thins and becomes a mudstone paleosol capped locally by the Ovid coal east of Kansas City.

Mound City Shale Member (named from northeast of here) represents the major transgressive phase and, here, part of the regressive phase of the Hertha cyclothem. It is much thicker here than at Stop A2 (higher on the shelf) because here it is near the foot of the slope formed by the substantial southward thinning of the two underlying shale members, where more accommodation space allowed accumulation of much more sediment. The basal phosphatic black shale bed (top exposed southwest of the paved lane intersection) records the major transgressive highstand, which can be traced from Iowa to Oklahoma. It contains abundant conodonts dominated by *Idiognathodus*, including the first appearance of *I. clavatulus* and n. sp. A, and it carries *Idioprioniodus* and *Gondolella*, just as at Stop A2. Above the black shale are *Trepospira*- and *Crurithyris*-bearing dysoxic shale and limestone, followed by conodont-rich shale and skeletal limestone, which represent recurrences of sediment starvation in the early regressive phase. Above these are more sparsely fossiliferous lighter gray shales and flaggy limestones that record shallowing later during regression and contain sparse *Adetognathus* at the top. The succession of distinctive beds in the Mound City Shale in this area may possibly represent shorter-period sea-level fluctuations that are normally masked by monotonous lithology.

[There probably will not be much time to visit the following higher units]

Sniabar Limestone Member (named from the Kansas City area) represents the late regressive phase of the Hertha cyclothem. Because it is pure carbonate in this area distinct from the thick underlying, shallower detrital facies of the Mound City Shale, it probably records a minor transgression that stymied the detrital influx before final regression, and may be equivalent to only the upper Sniabar at Stop A2. Its conodont fauna here is unstudied.

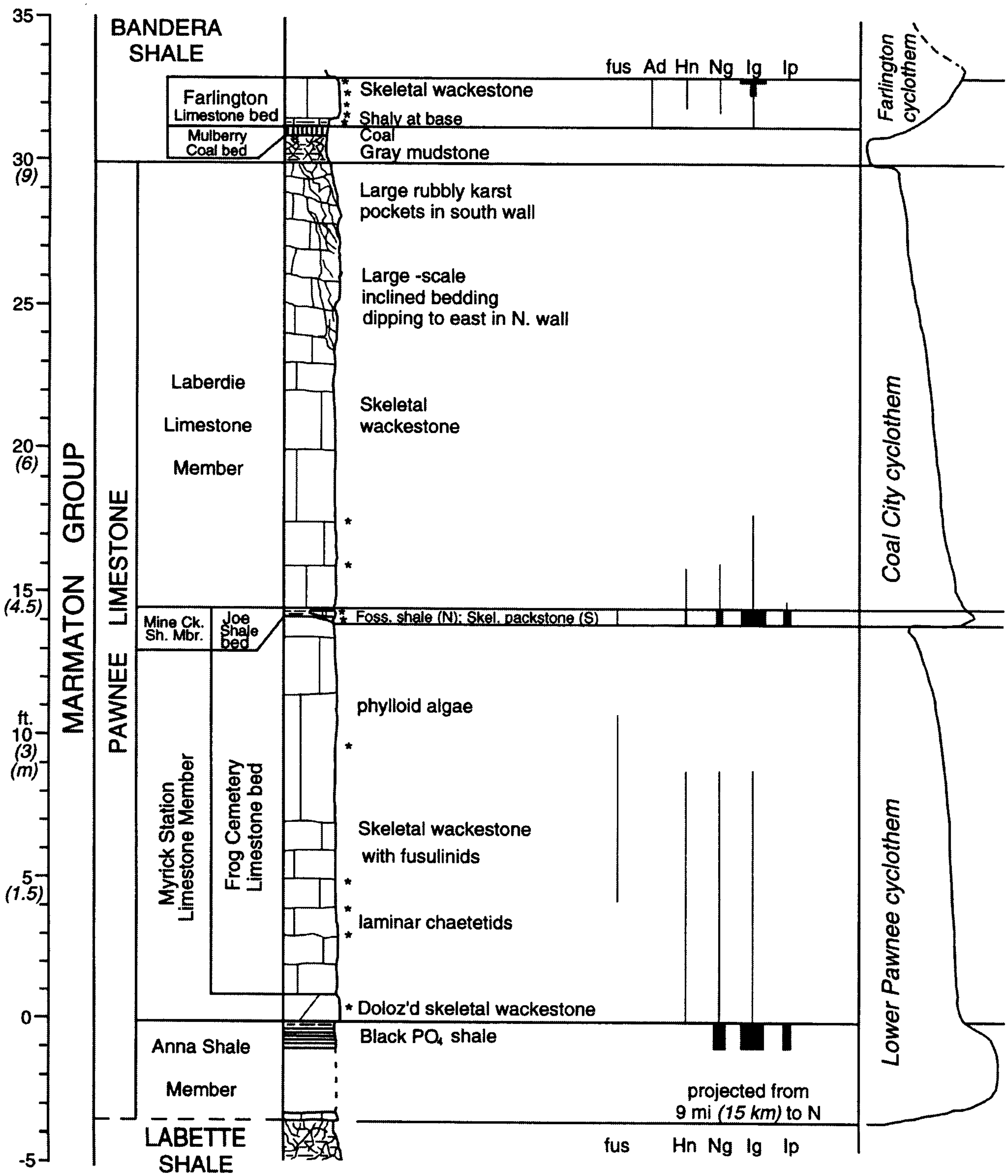
Elm Branch Shale (named from east-central Kansas) is a thin blocky mudstone paleosol visible on the east side of the highway. Southward, the mudstone is replaced by thicker sparsely fossiliferous shale and sandstone.

Middle Creek Limestone is thicker here, but Hushpuckney Shale and base of Bethany Falls Limestone are about the same as they were northward at Stop A2, where seen west of the highway southward at the top of the hill.

Leave Stop B1 at 8:50 AM

[Drive 22 miles: S on K-3, E on K-39, S on K-7, E on K-277, 0.3 mile] (30 min.)

Stop B2: Quarry north of Farlington



STOP B2: Farlington Quarry (Midwest Minerals #4). (S half, SW 31, T 27 S, R 24 E, Crawford Co., KS) (70 min.)

*[**You must wear hardhats and boots** here; start at bottom of quarry, then work around to top of south side]*

This stop shows the **Pawnee Limestone** and its two component **cyclothems (Lower Pawnee** and **Coal City)**, and also the overlying **Farlington Limestone bed** and **cyclothem**. These are the **fourth, fifth,** and **sixth major marine units below the top of the Desmoinesian**, in the middle of the upper Desmoinesian Marmaton Group. The Pawnee is named from this area, and the Farlington from this quarry, but the Coal City is named from Iowa, where the cyclothem includes a coal. The middle shale of the Pawnee Limestone, where it is thicker in west-central Missouri, is the unit from which Gunnell (1931) named the conodont genus *Idiognathodus* and three of its species, including *I. delicatus*.

Anna Shale Member (named from this area) is exposed in places in the floor of the quarry. It is a hard phosphatic black shale that extends from Iowa to south-central Oklahoma and here represents the condensed interval of the Lower Pawnee cyclothem. It is more completely exposed at Stop B5 later today.

Myrick Station Limestone Member (named from west-central Missouri, and continuous from Iowa to southern Kansas) is the early regressive limestone of the Lower Pawnee cyclothem. The Pawnee Limestone was shown by Price (1981, 1984) to comprise two cyclothems (Lower Pawnee and Coal City). Northward, the thin Myrick Station Limestone is overlain by the thick Mine Creek Shale, which is a coarsening-upward regressive sequence that is overlain by another condensed interval (represented by the Joe Shale bed in this quarry). Southward, the Mine Creek Shale grades laterally into carbonate facies represented here by the Frog Cemetery Limestone bed (which is classified lithostratigraphically as part of the Myrick Station even though it is equivalent to most of the Mine Creek Shale northward). Only the thin lower bed is equivalent to type Myrick Station Limestone.

Frog Cemetery Limestone bed (named from south of here by Price, 1981, 1984) is found only in southeastern Kansas, and its south end will be seen at Stop B5. It is the later regressive limestone of the Lower Pawnee cyclothem, consisting of skeletal wackestone with conspicuous chaetetids in the lower part, followed upward by more conspicuous phylloid algae. It contains fusulinids throughout, probably *Beedeina* (formerly *Fusulina*). Midcontinent Desmoinesian fusulinids from several Iowa localities were the subject of M.L. Thompson's first work in 1934. He recognized two species, *B. girtyi* and *B. stookeyi*, in the Coal City Limestone, which overlies the equivalent Mine Creek Shale in Iowa. Alexander (1954) named *B. tumida* from the Pawnee Limestone in northern Oklahoma. Bebout (1963) named *B. marmatonensis* from, and recognized *B. knighti, B. girtyi,* and *B. haworthi* in the Pawnee Limestone in Missouri.

Joe Shale bed (named from south of here by Price 1981, 1984) is the thin transgressive unit and condensed interval of the Coal City cyclothem. It is continuous from Missouri to the Kansas-Oklahoma border, where it merges with the top of the Anna Shale southward into central Oklahoma. It contains a thin bed of glauconitic skeletal packstone (which includes fusulinids) in the south part of this quarry. Both this limestone and the enclosing shale facies (most easily collected in the north wall) carry an abundant conodont fauna that is dominated by *Idiognathodus delicatus* and includes *Neognathodus* and *Idioprioniodus*. The Joe Shale grades into the base of the thin Coal City Limestone in Iowa, which overlies a coal formed on a paleosol at the top of the Mine Creek Shale. This marks the sequence boundary between the Coal City and Lower Pawnee cyclothems, but extends only partway into Missouri. The submarine extent of this sequence boundary is the top of the Frog Cemetery Limestone bed in this quarry.

Laberdie Limestone Member (named from north of here) is the southern extent of the Coal City Limestone (given a different name in Kansas, and extending into Oklahoma as the thick upper unit of the Oologah Limestone), and is the regressive limestone of the Coal City cyclothem. It is skeletal wackestone with large-scale cross-beds in the upper part. The top is degraded locally to large rubbly pockets (seen along the south wall of the quarry) that appear to represent Pennsylvanian karstic weathering because they are overlain by the unaffected Farlington Limestone bed.

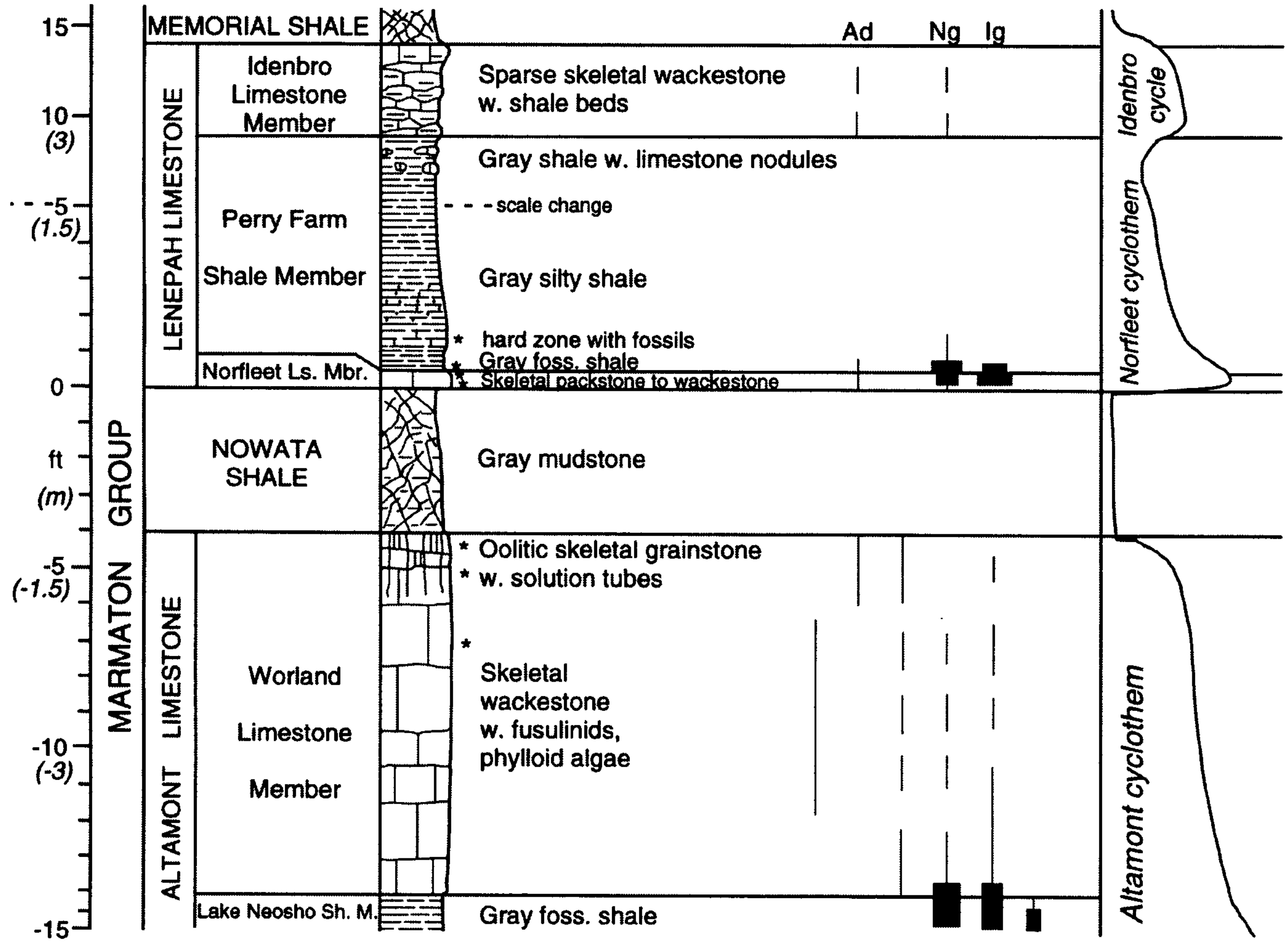
Bandera Shale (named from north of here) has a basal bed that consists of a thin paleosol and overlying Mulberry Coal bed (named from western Missouri), which extends from northern Oklahoma to Iowa and forms the sequence boundary at the top of the Coal City cyclothem. It is considered to be a major disconformity because of both the associated karstic weathering and the abrupt change in conodont faunas in the overlying Farlington Limestone bed.

Farlington Limestone bed (named from this quarry) extends from northern Oklahoma into Missouri. It is the transgressive limestone (with the condensed interval in the top) of the Farlington cyclothem (previously termed post-Mulberry), which extends as marine shale into the subsurface of Iowa and Nebraska. The Farlington contains a conodont fauna (abundant in the top) that is dominated by the abrupt first appearance of a distinctive troughed clade of idiognathodids represented by *'Idiognathodus'* sp. 5 of Swade 1985. These were recognized as distinct from *Streptognathodus* (which first appears in the lower Missourian) by Swade, for whom the new genus will be named (see Lambert and Heckel, this guidebook). This fauna nearly lacks *I. delicatus*, whose apparent descendants do not become common again until the middle of the next higher cyclothem (Altamont) to be seen at the next stop. This new genus has no known ancestor in older Desmoinesian strata in this region and therefore must be an immigrant. This is the most abrupt break in conodont faunas at an exposure surface known in this part of the Midcontinent succession.

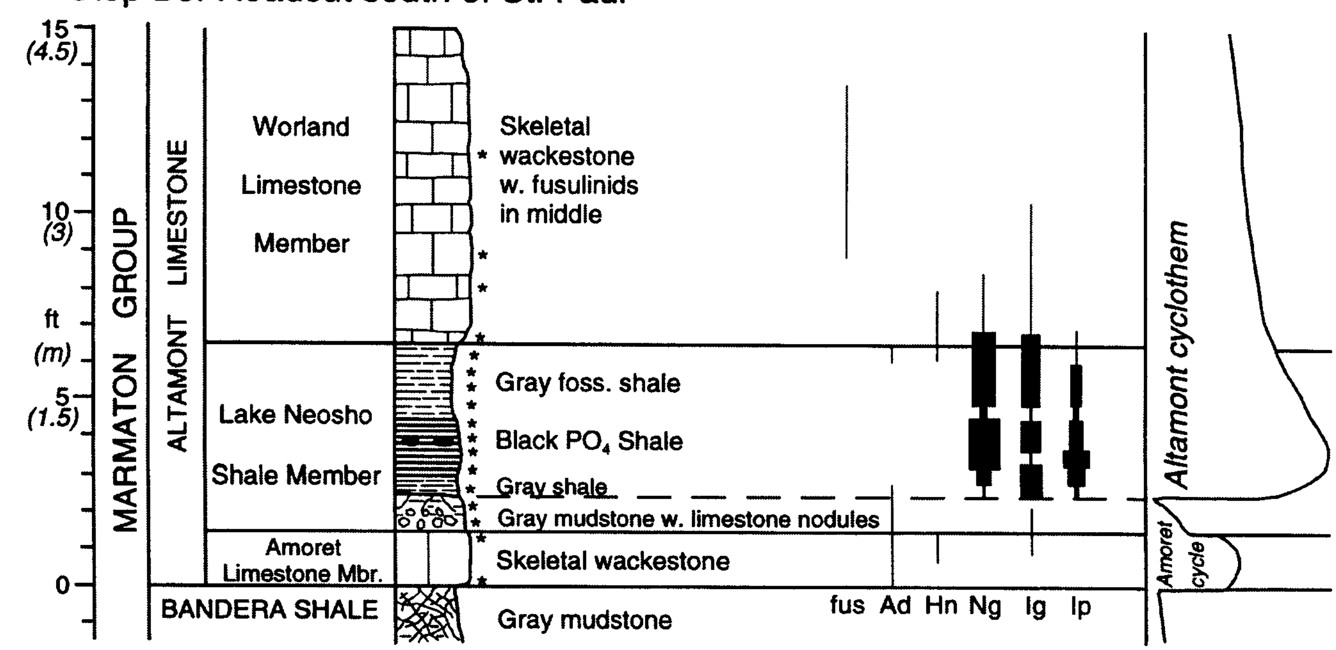
Leave Stop B2 at 10:30 AM

[Drive 30 miles: W on K-277, S on K-7, W on K-57 to church on E side of St. Paul, S on Co. Rd., 1.6 mi.] (40 min.)

Stop B4: SW Quarry southwest of Parsons



Stop B3: Roadcut south of St. Paul



STOP B3: Roadcut south of St. Paul. (NE-NE-SE sec. 25, T 29 S, R 20 E, Neosho County, KS) (30 min.)

[Be careful of traffic coming over hill from north]

This stop shows the **Altamont Limestone** and **cyclothem**, the **third major marine unit below the top of the Desmoinesian Stage**. The Altamont was named from south of here, and extends from Iowa to central Oklahoma.

Amoret Limestone Member (named from west-central Missouri) extends from Iowa to Oklahoma. Although traditionally considered the transgressive limestone of the Altamont cyclothem, the Amoret locally undergoes abrupt thickness changes, unlike most other limestones in this position. Because the Altamont was interpreted early (Schenk, 1967) as a simple transgressive-regressive cyclothem with the highstand phase in the middle shale unit, and Swade's (1985) conodont analysis of it in Iowa far to the north supported that interpretation, it was not subject to the detailed attention given the other units. Analysis of lithology and conodont faunas for this field trip revealed that the Amoret in this outcrop has low conodont abundance with *Adetognathus* dominance in the top, which is maintained into the base of the overlying shale, where small corroded limestone nodules in a mudstone matrix suggest subaerial weathering. Thus the Amoret here represents a minor T-R cycle ('parasequence') prior to the main Altamont transgression, and is older than the 'Amoret' of Iowa, which is the transgressive limestone of the Altamont cyclothem there.

Lake Neosho Shale Member (named from this area, and extending from Iowa to central Oklahoma) includes both the capping nodular mudstone of the underlying minor Amoret cycle at its base, and the transgressive condensed interval and highstand deposit of the Altamont cyclothem above this. The latter extends from a probable sequence boundary above the middle of the lower gray shale bed up through the black phosphatic shale and the upper gray shale. It carries an abundant conodont fauna of idiognathodids, *Neognathodus*, and *Idioprioniodus*. In the transgressive portion up to the lower middle of the black shale, the idiognathodids are almost entirely the troughed clade (*'I'*. sp. 5 of Swade, 1985) that first appeared in the Farlington Limestone below, but from this point up (above a sample nearly devoid of idiognathodids) they are all flat larger-lobed morphotypes of *Idiognathodus* that probably are descendants of *I. delicatus*. Possible reasons for this abrupt changeover in idiognathodid faunas are only speculative at this point.

Worland Limestone Member (named from western Missouri, and extending from Iowa to Oklahoma) is the regressive limestone of the Altamont cyclothem. It is a diverse skeletal wackestone that contains scattered fusulinids above the base, possibly *Beedeina megista* and *B. mysticensis* named by Thompson (1934) from the Worland in Iowa., and *B. haworthi, B. tumida, B. acme,* and *B. marmatonensis*, recognized by Bebout (1963) in the Worland in Missouri.

Leave Stop B3 at 11:40

[Drive 22 miles: S 0.4 mile, W on gravel road, S on US-59 to 3 miles S of Parsons, W 0.5 mi. on gravel road] (30 min.)

STOP B4: Quarry SW of Parsons (Midwest Minerals #3B). (NE-NW 12, T 32 S, R 19 E, Labette Co., KS) (50 min.)

[You must wear hardhats and boots here]

This stop shows the top of the **Altamont Limestone** and **cyclothem** and the lower (and most important) part of the shale-rich **Lenapah Limestone** and its lower, **Norfleet cyclothem**, the **second major marine unit below the top of the Desmoinesian Stage**. The Lenapah is named from northern Oklahoma, and the Norfleet is named from this area.

Worland Limestone Member is completely exposed here. It is mainly skeletal wackestone with scattered fusulinids in the upper middle and contains oolite at the top, recording the shallowing-upward sequence.

Nowata Shale (named from northern Oklahoma) is a mudstone paleosol here with the upper sequence boundary of the Altamont cyclothem at its top. This paleosol extends from Iowa to the Oklahoma border. Southward the Nowata thickens greatly, reaching over 400 ft (120 m) around Tulsa, where it represents lowstand deposits that filled in around the south end of the limestone banks and deltaic clastics that dominate the Marmaton Group in Kansas.

Norfleet Limestone Member (named from this area) is the transgressive limestone of the lower Lenapah or Norfleet cyclothem. Here it contains the highstand condensed interval in the top. Because the Norfleet marine unit extends only from the Iowa-Missouri border to central Oklahoma (as the Eleventh Street Limestone), it is a cyclothem of intermediate scale, and thus lacks the dark phosphatic shale facies. In most localities, it contains a moderately abundant conodont fauna consisting almost entirely of *Neognathodus*, with *Adetognathus* increasing northward to dominate the shelfward faunas of Missouri. At this outcrop, however, it carries a diverse fauna of the troughed clade of idiognathodids in the top (and base of overlying shale), including *'I'*. sp. 5 and *'I'*. sp. 6 [=*nodocarinatus*] and a form that resembles one described by Alekseev and Goreva from the basal Kasimovian of the Moscow region of Russia.

Perry Farm Shale Member (named from this area and extending from east-central Kansas into northeastern Oklahoma) is the regressive shale of the Norfleet cyclothem. It has fossils only in the base and becomes siltier upward. Thompson et al. (1956) described *Oketaella lenensis* from this unit in northern Oklahoma.

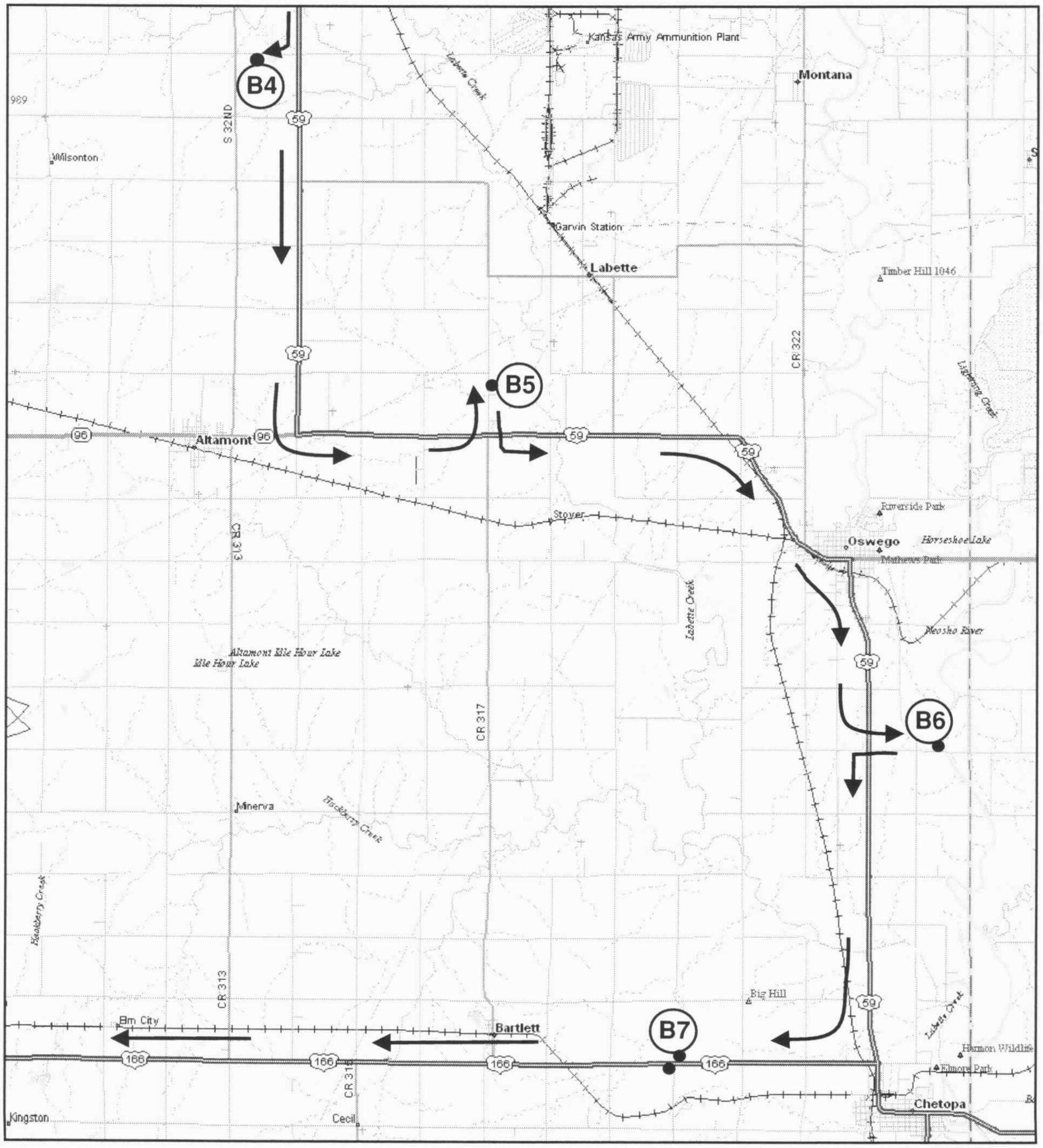
Idenbro Limestone Member (named from this area) is visible at the west end of this quarry and represents a minor transgressive-regressive cycle that is traced from east-central Kansas to northeastern Oklahoma.

Memorial Shale is a mudstone paleosol, which is overlain by type Lost Branch Formation just to the southwest.

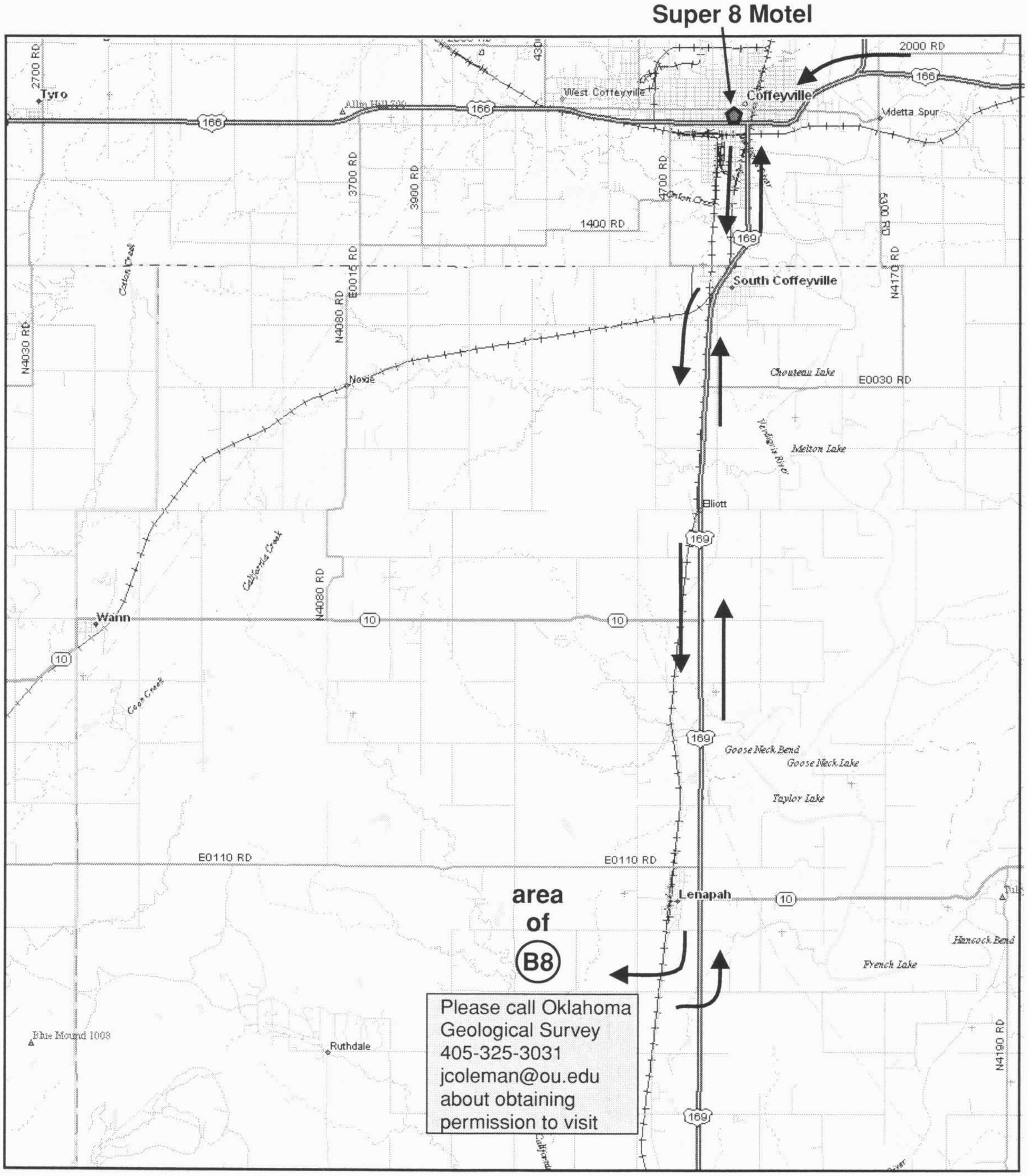
Leave Stop B4 at 1:00 PM

[Drive 10 miles: E to US-59, S on US-59, then E 3 miles, and N on gravel road 0.7 mile] (15 min.)

from Parsons

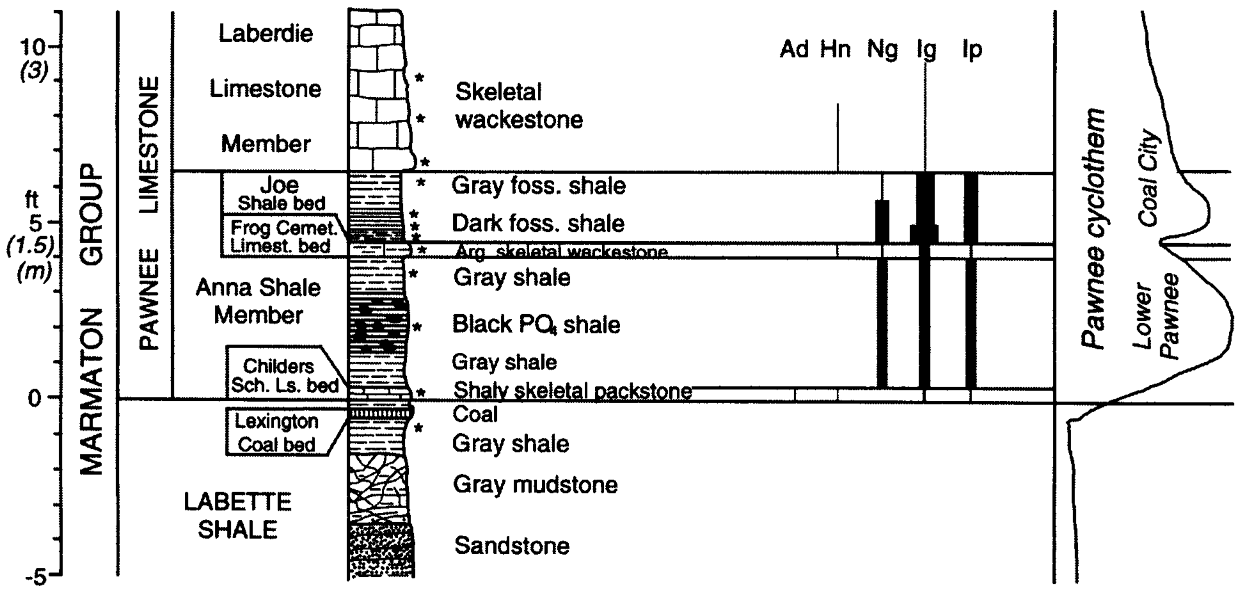


Stops B4-B7

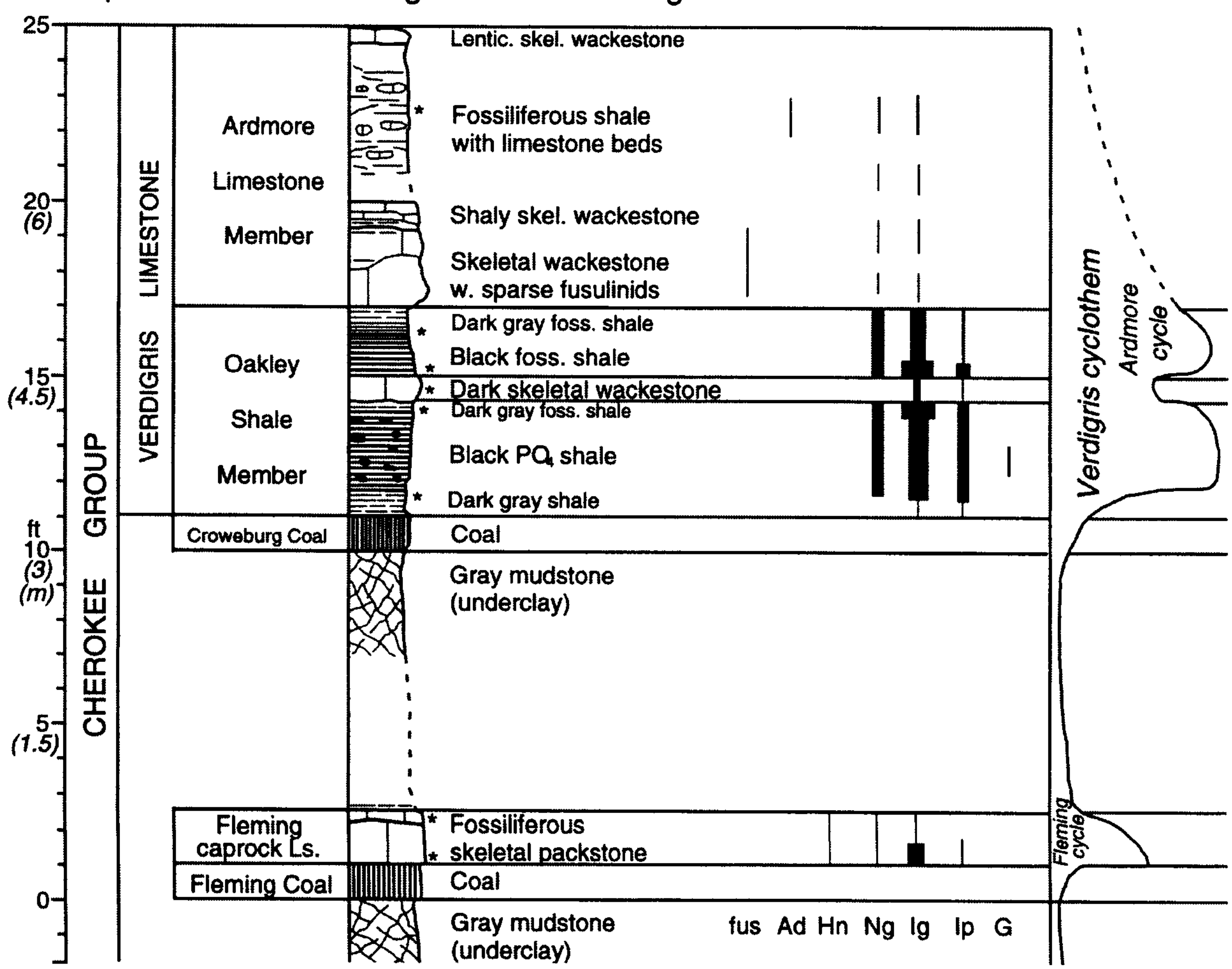

Super 8 Motel
Coffeyville
West Coffeyville
2000 RD
166
Tyro
2700 RD
Mdetta Spur
3700 RD
3900 RD
4700 RD
1400 RD
169
South Coffeyville
N4170 RD
E0015 RD
N4080 RD
N4030 RD
Nowata
Chouteau Lake
E0030 RD
Melton Lake
Elliott
Wann
10
Goose Neck Bend
Goose Neck Lake
Taylor Lake
E0110 RD
Lenapah
area
of
B8
French Lake
Hancock Bend
Please call Oklahoma
Geological Survey
405-325-3031
jcoleman@ou.edu
about obtaining
permission to visit
Blue Mound 1003
Ruthdale
N4190 RD

Stop B8

Stop B5: Roadditch southwest of Labette



Stop B6: Overman Bridge south of Oswego



STOP B5: Roadditch SW of Labette. (W line NW-SW-NW sec. 3, T 33 S, R 20 E, Labette Co., KS) (30 min.)

[Beware of poison ivy growing to bush size, at and downstream from the small waterfall]

This stop shows the lower part of the **Pawnee Limestone**, 42 miles (70 km) southwest of Stop B2, in a more basinward position where the **Lower Pawnee** and **Coal City cyclothems** (seen earlier today) have nearly converged, as the Frog Cemetery Limestone has greatly thinned, and the Anna and Joe 'core' shales have nearly merged.

Labette Shale (named from this area) is a thick detrital siliciclastic succession between the Fort Scott Limestone (to be seen at Stop B7 later this afternoon) and the Pawnee. It consists largely of lowstand deposits with perhaps several minor marine transgressive-regressive cycles developed mainly in Oklahoma, and at least one (Wimer School) extending into southeastern Kansas. The top here is a mudstone paleosol, with the sequence boundary at its top.

Lexington Coal bed (named from western Missouri) extends from Iowa (where it is called Mystic Coal) to northern Oklahoma. It represents the early phase of transgression when rising sea level in a generally wet climate kept the water table high enough to form a peat bed. The thin overlying shale is marginal marine.

Childers School Limestone bed (named from northern Oklahoma) forms the lip of the small waterfall. It is the transgressive limestone of the Lower Pawnee cyclothem, which extends only into east-central Kansas.

Anna Shale Member (named from north of here) lithostratigraphically includes four beds here (from the Childers School to the Joe Shale), which represent the transgressive and highstand deposits of both cyclothems associated with the Pawnee Limestone. The main bed is the core shale of the Lower Pawnee cyclothem (and is equivalent to the entire Anna Shale northward). It carries a conodont fauna (most easily collected from the upper gray shale) dominated by *Idiognathodus delicatus* and related forms, and includes *Neognathodus* and *Idioprioniodus*.

Frog Cemetery Limestone bed (named from northeast of here) is the regressive limestone of the Lower Pawnee cyclothem, thinned to a small fraction of its thickness at stop B2. It has become argillaceous in its gradation to calcareous shale just south of here, and it contains the sequence boundary between the two cyclothems.

Joe Shale bed (named from north of here) is the highstand condensed interval of the Coal City cyclothem, which extends from Iowa to this area, then merges with the top of the Anna Shale southward into central Oklahoma. It carries an abundant *I. delicatus*-dominated conodont fauna similar to that of the main bed of the Anna.

Laberdie Limestone Member (named from eastern Kansas) is the regressive limestone of the Coal City cyclothem, and extends into the Tulsa area of Oklahoma where it forms the thick upper unit of the Oologah Limestone.

Leave Stop B5 at 1:45 PM

[Drive 10 miles: S to US-59, E to Oswego, then S 3 miles, and E 1.2 miles on gravel road] (15 min.)

STOP B6: Overman Bridge (center S line, SW sec. 35, T 33 S, R 21 E, Labette County, KS) (40 min.)

[Be careful in the steep gully along the north side of the road where the lower part of the section is exposed]

This stop shows the mid-Desmoinesian **Fleming** and **Verdigris cyclothems** in the upper part of the Cherokee Group. The **Verdigris** is the **tenth major marine unit below the top of the Desmoinesian Stage**. The cyclothemic classification shown is sequence-stratigraphic and centered on the marine transgressive-regressive unit, thus each cyclothem extends from the sequence boundary at the top of the paleosol underclay upward to the top of the next underclay. Previous cyclothemic classifications used here included the named coal with the underlying underclay.

Fleming Coal bed (named from northeast of here) extends from western Missouri into eastern Oklahoma and represents the peat bed formed during the early phase of transgression. It lies upon the exposure surface and sequence boundary developed on its underclay paleosol (which along with the underlying shale has been included in the Fleming cyclothem as a strictly lithostratigraphic unit, even though they genetically belong in the underlying cyclothem).

Fleming caprock is a limestone bed that represents the marine culmination of the Fleming cyclothem. Its base contains a conodont fauna dominated by species of *Idiognathodus*, including *I. delicatus*. Alexander (1954) and Bebout (1963) reported the fusulinids *Wedekindellina euthysepta*, *Beedeina kayi, B. euryteines,* and *B. leei* from this bed in Oklahoma and Missouri. The overlying shale and mudstone paleosol represent the regressive phase of this cyclothem.

Croweburg Coal bed (named from northeast of here) extends from Iowa (where it is called the Whitebreast Coal) to northeastern Oklahoma, and represents the early phase of the next major transgression.

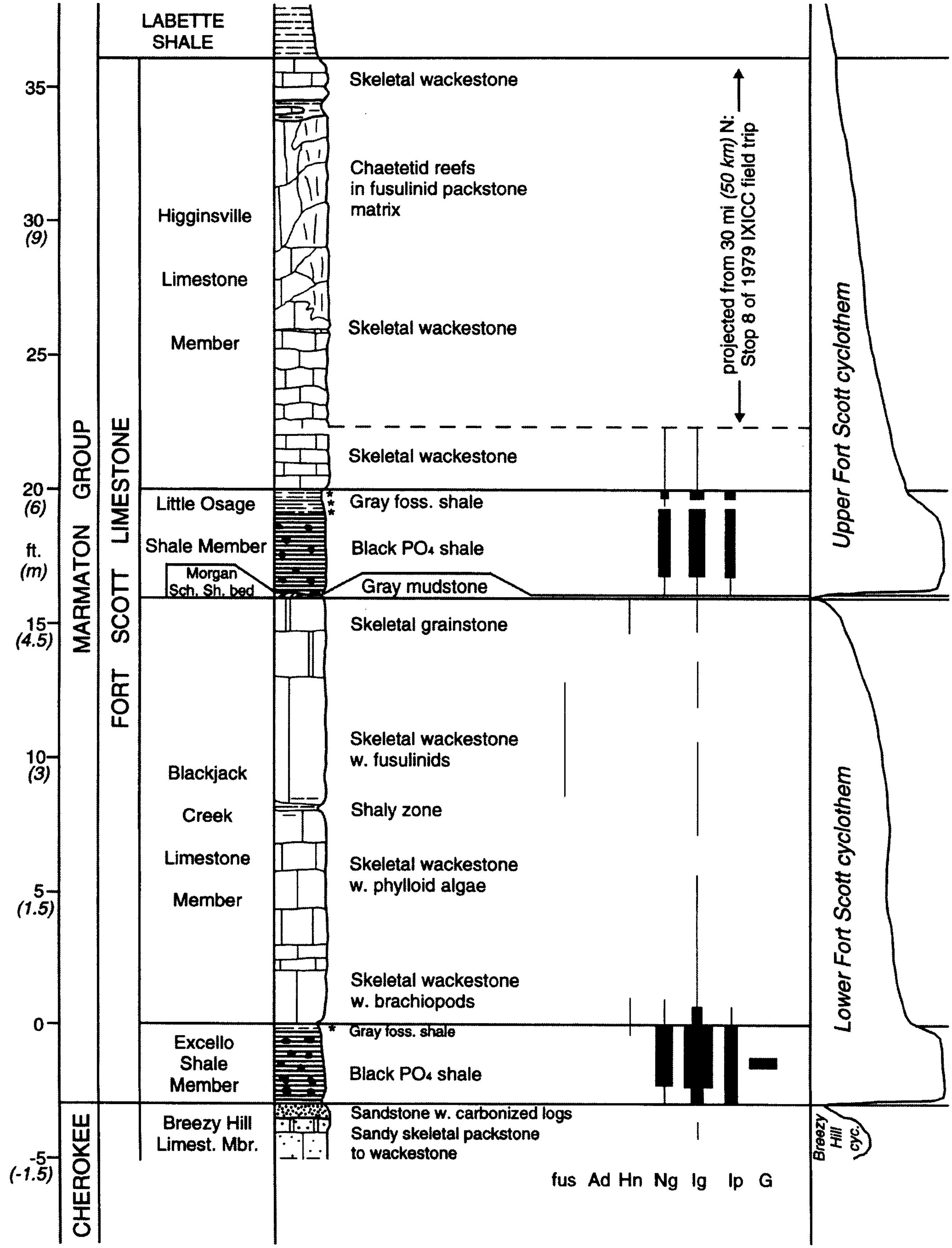
Oakley Shale Member (named from Iowa) extends from Iowa to Oklahoma and represents the transgressive and highstand phases of the Verdigris cyclothem (named from Oklahoma), the most widespread Cherokee cyclothem. The abrupt increase in conodont abundance in the base of the upper Oakley Shale above the mid-Oakley limestone may reflect the transgression detected by Swade (1985) in the Ardmore Limestone in Iowa. The Oakley carries conodonts dominated by *Idiognathodus delicatus* and *I. acutus*, and also includes a smooth-platformed species of *Gondolella*.

Ardmore Limestone Member (named from Missouri) is the regressive limestone of the upper (Ardmore) cycle of the Verdigris cyclothem. The fusulinid *Wedekindellina euthysepta* was reported from this unit by Thompson (1934) and Bebout (1963) in Iowa and Missouri. Bebout also reported *Beedeina euryteines, B. boonensis, B. cadyi,* and *B. leei* from it in Missouri, and Alexander (1954) reported *B. equilaqueata* from Oklahoma.

Leave Stop B6 at 2:45 PM

[Drive 9 miles: return W to US-59, S on US-59, then W on US-166, 3 miles) (15 min.)

Stop B7: US-166 Roadcuts east of Bartlett



STOP B7: US-166 Roadcuts E of Bartlett. (S line SW-SW 30, T 34 S, R 21 E & adj. pts., Labette Co., KS) (60 min.)
[Be very careful crossing this busy highway]

This stop shows the **Fort Scott Limestone** and its two component **Lower Fort Scott** and **Upper Fort Scott cyclothems**, the **seventh and eighth major marine units below the top of the Desmoinesian Stage**. The Fort Scott is named from east-central Kansas and extends from Iowa to east-central Oklahoma. The Fort Scott Limestone is the lowest thick limestone formation in the Midcontinent Pennsylvanian, and forms the base of the Marmaton Group (named from the Marmaton River, running through Fort Scott), which contains all the thick limestone formations at the top of the Desmoinesian Stage. The underlying Cherokee Group (named from this area) is characterized by thick shale, mudstone, and sandstone sequences with numerous coal beds and only thin limestones. The uppermost 100 feet (30 m) of the Cherokee (above the Verdigris Limestone) are mostly terrigenous siliciclastics with up to 3 or 4 coal beds in places. The Bevier Coal bed (named from Missouri) in the lower part, is overlain by a marine shale across much of the region, which is the ninth major marine unit below the top of the Desmoinesian, but has not yet received detailed study.

Breezy Hill Limestone Member (named from northeast of here) is a sandy limestone that represents a minor marine incursion at the top of the Cherokee Group, which extends from the Kansas-Missouri border southward into east-central Oklahoma, where it locally overlies the Iron Post Coal bed. Northward from this area, the Breezy Hill is overlain by the Mulky Coal bed and its underclay paleosol, which mark it as a separate cycle there. It thickens southward in Oklahoma where the overlying coal and other evidence of subaerial exposure disappear, and its upper part apparently becomes the transgressive limestone to the overlying lower Fort Scott cyclothem.

Mulky Coal unit is represented here by sandstone with carbonized logs formed near a lowstand shoreline.

Excello Shale Member (named from north-central Missouri and extending from Iowa to central Oklahoma) is the transgressive and highstand condensed interval, the classic black phosphatic 'core' shale of the Lower Fort Scott cyclothem. It carries an abundant conodont fauna (most easily collected from the thin gray facies at the top) dominated by *Idiognathodus delicatus* and containing *I. acutus* (named from this unit) and more nodose morphotypes, some with a small longitudinal groove. This fauna also includes *Idioprioniodus* and *Neognathodus* and a ribbed-platformed species of *Gondolella* confined to a zone in the middle. The genus *Gondolella* occurs only in the lowest (this one) and highest (Lost Branch) cyclothems of the Marmaton Group, even though the black shale facies appears in three other cyclothems between them, where presumably migration from deeper basinal water was impeded for some reason.

Blackjack Creek Limestone Member (named from west-central Missouri) extends from Iowa to east-central Oklahoma. It is the regressive limestone of the Lower Fort Scott cyclothem. It carries fusulinids, probably *Beedeina*, including *B. lucasensis*, described by Thompson (1934) from Iowa, *B. boonensis, B. haworthi, B. girtyi,* and *B. occultifons* reported by Bebout (1963) and Alexander (1954) from Missouri and Oklahoma. The upper Blackjack Creek cycle recognized northward where the top grades laterally into Morgan School Shale, is not yet detected here.

Morgan School Shale bed is named from Iowa, where it is a sequence of coarsening-upward clastics capped by coal. Here it is a thin mudstone paleosol that thickens slightly into lows on top of the underlying limestone. Its top marks the sequence boundary between the Lower and Upper Fort Scott cyclothems. The Summit Coal bed (named from Missouri) caps this exposure surface locally toward the north and is represented by coalified plant debris just south of here. Southward the Morgan School Shale disappears, and the base of the overlying marine shale rests on top of the underlying marine limestone, showing that the lowstand shoreline must have stood near the Kansas-Oklahoma border.

Little Osage Shale Member is named from east-central Kansas. The main part (above the Morgan School Shale bed) is black phosphatic shale with a thin gray shale facies at the top. This marine part represents the transgressive and highstand deposits of the Upper Fort Scott cyclothem, a 'core' shale that extends from Iowa to east-central Oklahoma. The Little Osage carries a moderately abundant conodont fauna (most easily collected at the top of the upper gray facies) that is dominated by *Idiognathodus delicatus* and related more nodose morphotypes (*I. fustiformis*), and includes *Neognathodus* and *Idioprioniodus*. This fauna is similar to that of the Anna Shale Member and Joe Shale bed of the Lower Pawnee and Coal City cyclothems, the next two higher major marine units upward (seen at Stops B2 and B6 earlier today). These three faunas also resemble (in the dominance of *I. delicatus* and presence of *Neognathodus*) the fauna of the Myachkovian Substage at the top of the Moscovian Stage in the Moscow region of Russia. Further supporting this general correlation is the occurrence of the fusulinid *Protriticites* in both the upper Myachkovian of Russia and, in the western U.S., at the Honaker Trail section in Utah (Ritter et al, this guidebook) in equivalents to marine units in the overlying Labette Shale or lower Pawnee Limestone of this region.

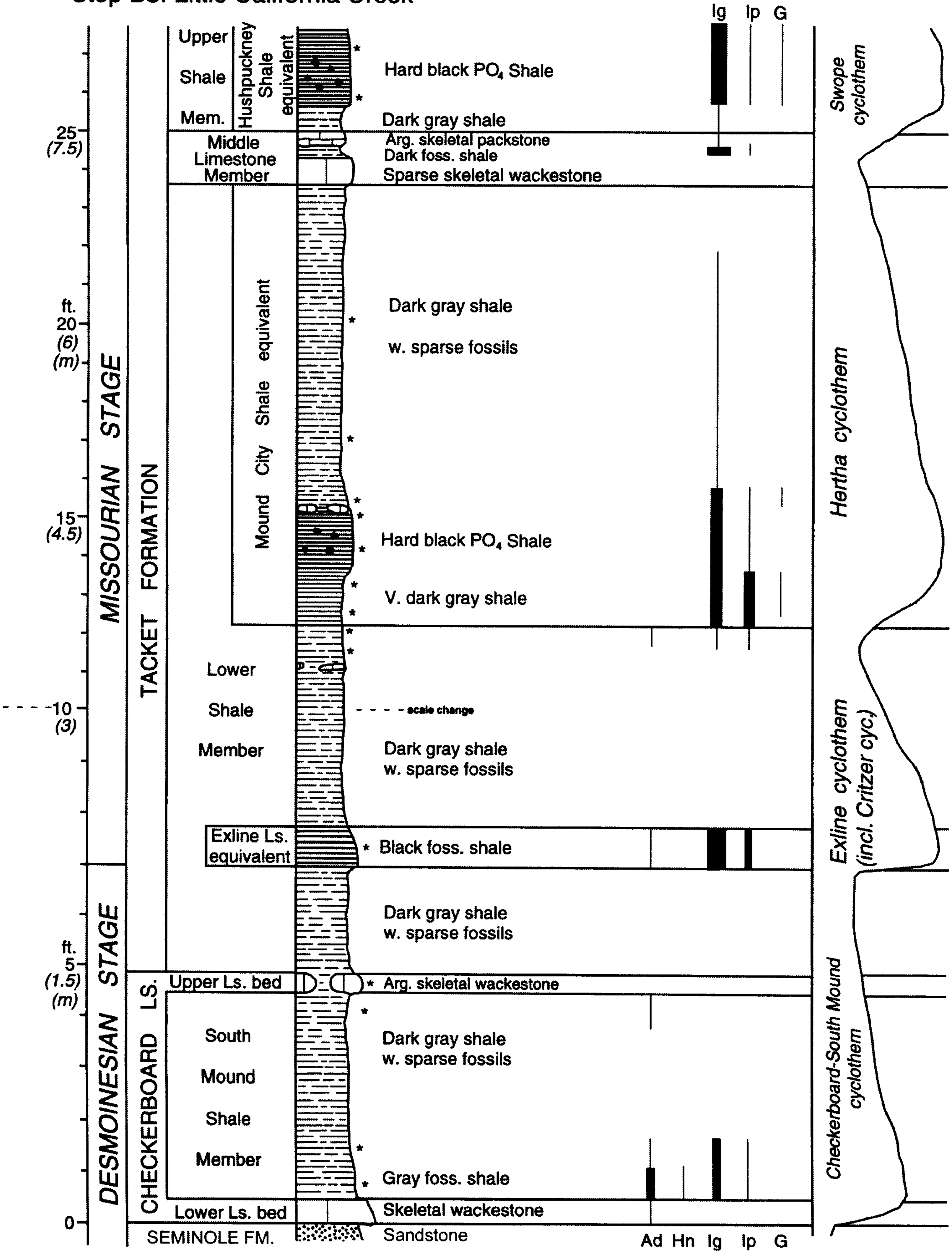
Higginsville Limestone Member (named from Missouri) is the regressive limestone of the Upper Fort Scott cyclothem. Only the lower part is exposed here, but 30 miles (50 km) to the north in an isolated quarry, the middle of this limestone contains chaetetid reefs up to 2.4 m thick and 3 m across, developed in a matrix of fusulinid packstone. Fusulinids reported from the Higginsville include *Beedeina lucasensis, B. haworthi, B. girtyi, B. higginsvillensis,* and *B. marmatonensis* in Missouri (Bebout, 1963) and *B. occultifons* in Oklahoma (Alexander, 1954).

Labette Shale (not exposed here) is mainly clastics deposited from late regression to lowstand.

Leave Stop B7 at 4:00 PM

[Drive 40 to 50 miles: W on US-166 to Coffeyville, S on US-169 to gravel roads] (60 min.)

Stop B8: Little California Creek



STOP B8: Little California Creek. (Nowata Co., OK; contact Oklahoma Geological Survey for access) (120 min.)
[This locality is on private property, so please sign waiver form, and adhere to all guidelines on the printed sheet]

This stop shows the proposed **Desmoinesian-Missourian Stage boundary stratotype**. It is placed near the base of the **Tacket Formation**, which includes the basinward shale-dominated facies of the **Exline**, **Hertha**, and **Swope cyclothems**, the **first, second**, and **third major marine units of the Missourian Stage**, and it lies above the **Checkerboard Limestone**, which here contains the **South Mound Shale Member** and together constitute the minor **Checkerboard-South Mound cyclothem**. The Tacket Formation is named from southeastern Kansas and includes all the basinward, southern shale-dominated strata equivalent to the Shale Hill Formation, Hertha Limestone, Elm Branch Shale, and Swope Limestone, which we have seen previously at Stops A2 and B1. The Checkerboard Limestone is named from east-central Oklahoma, where it is a single bed extending northward through Tulsa. Halfway between Tulsa and here, it splits into two beds as it is penetrated by the South Mound Shale, which was derived from a northeasterly source in Kansas. The Checkerboard and South Mound Shale are equivalent to the top of the Hepler Formation.

Seminole Formation (named from east-central Oklahoma) comprises the generally coarser detrital strata that are equivalent to the lower part of the Hepler Formation and represent the lowstand deposits above the Lost Branch Formation and below the Checkerboard Limestone. Sandstone at the top is exposed upstream. The Seminole contains as many as 3 coal beds around Tulsa, the lower of which contains a few typically Desmoinesian palynomorphs.

Lower Checkerboard Limestone bed is the transgressive limestone of the Checkerboard-South Mound cyclothem, and contains a sparse *Adetognathus*-dominated conodont fauna.

South Mound Shale Member (named from southeastern Kansas) here grades from richly fossiliferous shale at the base up to sparsely fossiliferous shale at the top. In its type region around Parsons, Kansas, it is similarly richly fossiliferous at the base locally approaching a shaly limestone in appearance, the northern equivalent of the Lower Checkerboard Limestone, which overlies sandstone and coal there as well. There it also grades upward into sparsely fossiliferous shale, which is overlain north of Parsons by sandstone beneath the Exline equivalent, overlain south of Parsons by a coal beneath the Exline equivalent, and overlain farther southward by the north end of the Upper Checkerboard Limestone, as it is here. Therefore, the South Mound Shale is abruptly transgressive at the base and regressive upward to subaerial exposure from its type region southward to the area north of Mound Valley, Kansas, where the capping coal disappears and the limestone appears. Southward from there to east-central Oklahoma, there is no evidence of subaerial exposure at the top of the Checkerboard-South Mound cyclothem (though southward from east-central Oklahoma, a coal again appears above the Checkerboard Limestone and below the southern Exline-equivalent limestone). Here, in the bank of Little California Creek, the lower 1.5 ft (45 cm) of South Mound Shale contains a conodont fauna of moderate abundance (~50/kg) dominated by *Adetognathus* at the base, and by *Idiognathodus sulciferus* upward, with a few *Hindeodus, Ellisonia,* and *Idioprioniodus*. Some of the *I. sulciferus* have an anterior eccentric groove in apparent initial transition to *I. eccentricus*, which first appears upward in the Exline-equivalent dark shale. The upper South Mound Shale here contains only sparse conodonts, mainly *Adetognathus*.

Upper Checkerboard Limestone bed is lenticular here. It contains conspicuous brachiopods, but only sparse conodonts (*Adetognathus*) as it does near its north end at Mound Valley, Kansas, and thus continues the regression.

Lower Shale Member of Tacket Formation comprises several units of gray to black, and soft to hard fissile shale. The lowermost 2.3 ft (70 cm) is soft dark gray shale with sparse fossils and no conodonts, thus appears to represent a thin marine lowstand deposit at the end of the regression.

The overlying black, slightly harder 0.5 ft (8 cm) shale contains a more abundant conodont fauna (~100/kg) dominated by *Idiognathodus sulciferus*, and containing some *Adetognathus*, *Ellisonia*, *Idioprioniodus*, and the first appearance of *I. eccentricus*, a descendant of *I. sulciferus* (allowing recognition of this black shale bed as the Exline equivalent)**. This first appearance marks the base of the Missourian Stage, and the boundary stratotype is designated at the base of the black Exline-equivalent shale bed** in this continuous marine sequence extending upward from the base of the Lower Checkerboard Limestone (Heckel, Boardman and Barrick, this guidebook).

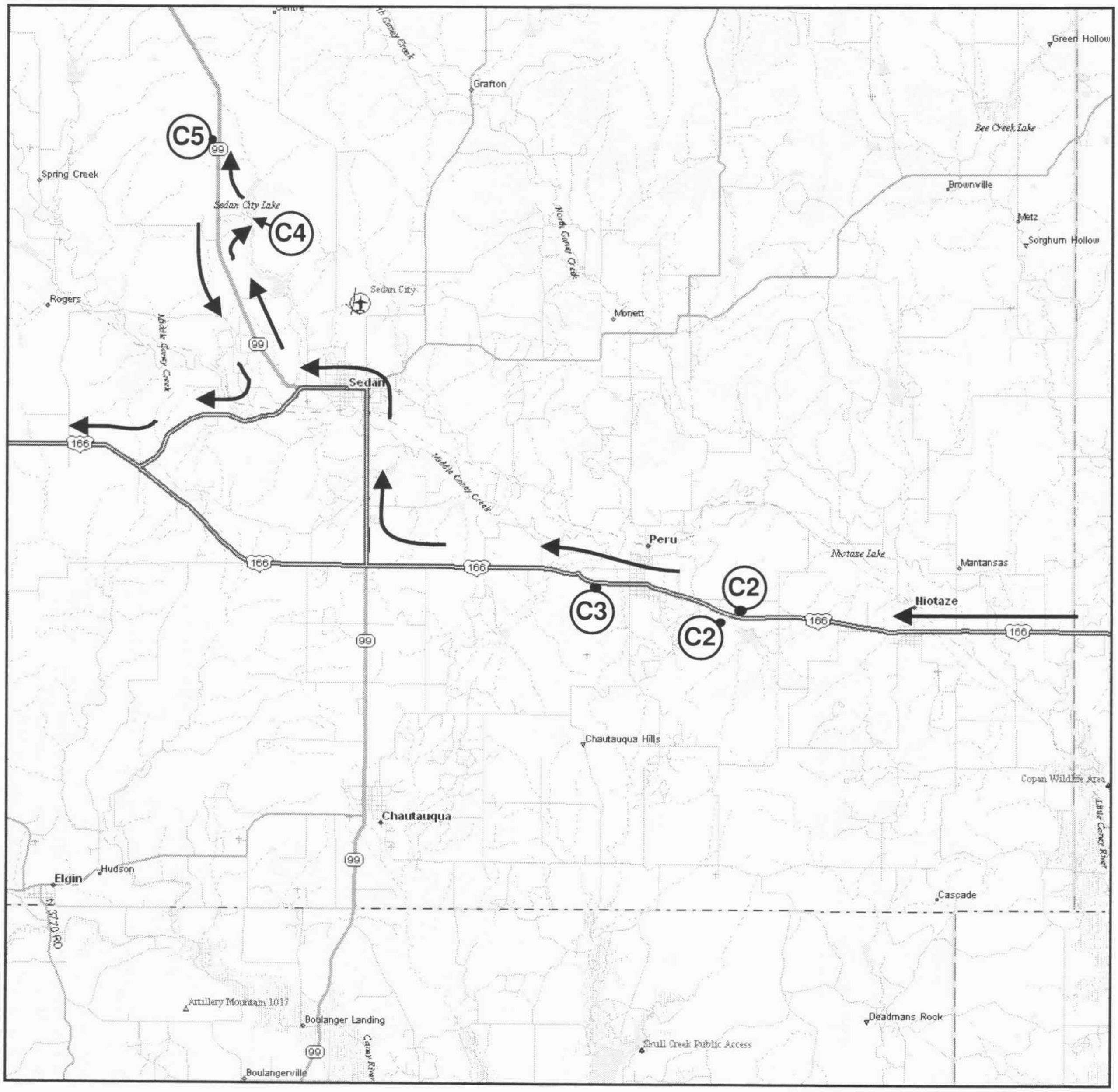
The overlying 4 ft (1.2 m) of sparsely fossiliferous dark gray shale is by position the basinward equivalent of the upper Shale Hill Formation. The horizon of the Critzer cyclothem is not known here, but it may be merged with the top of the Exline (though it becomes separated again southward from east-central Oklahoma). The next 3 ft (90 cm) of darker gray upward to hard black fissile shale contains phosphorite nodules and a moderately abundant conodont fauna that includes the first appearance of *Idiognathodus clavatulus* and n. sp. A, thus identifying it as the base of the Mound City Shale, seen at Stop B1 this morning. The dark gray shale above this is the upper Mound City.

Middle Limestone Member of Tacket Formation (better exposed downstream) comprises two thin limestone beds separated by a thin shale bed. These beds appear to represent the basinward equivalent of the Sniabar Limestone, Elm Branch Shale, and Middle Creek Limestone, and contain a condensed interval or lag bed in the middle.

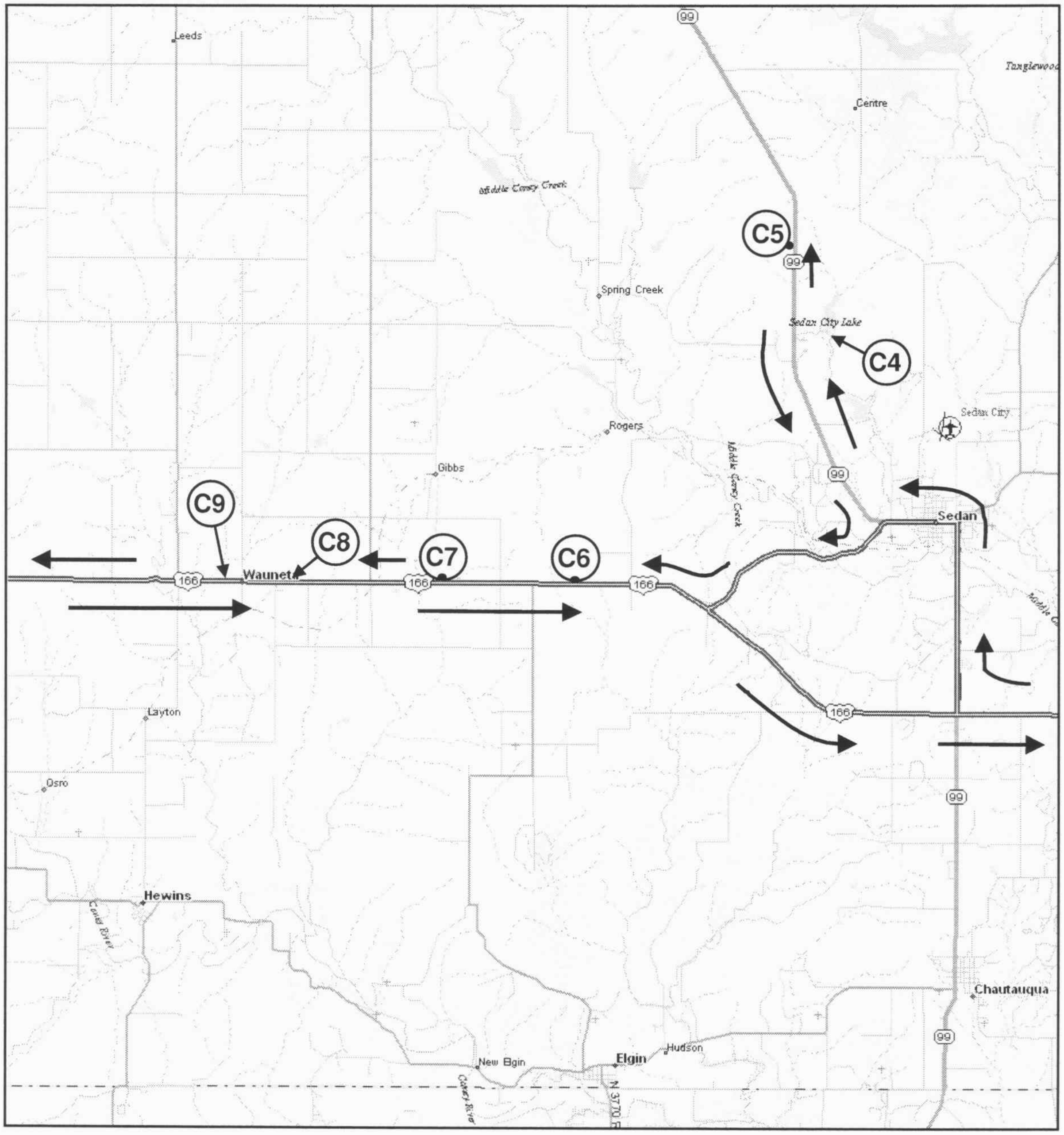
Upper Shale Member of Tacket Formation (better exposed downstream) comprises dark gray shale overlain by black hard fissile shale that has phosphorite nodules and an abundant conodont fauna that includes the first appearance of *Streptognathodus cancellosus*, thus identifying it as the Hushpuckney Shale, little changed from the north.

Leave Stop B8 at 7:00 PM

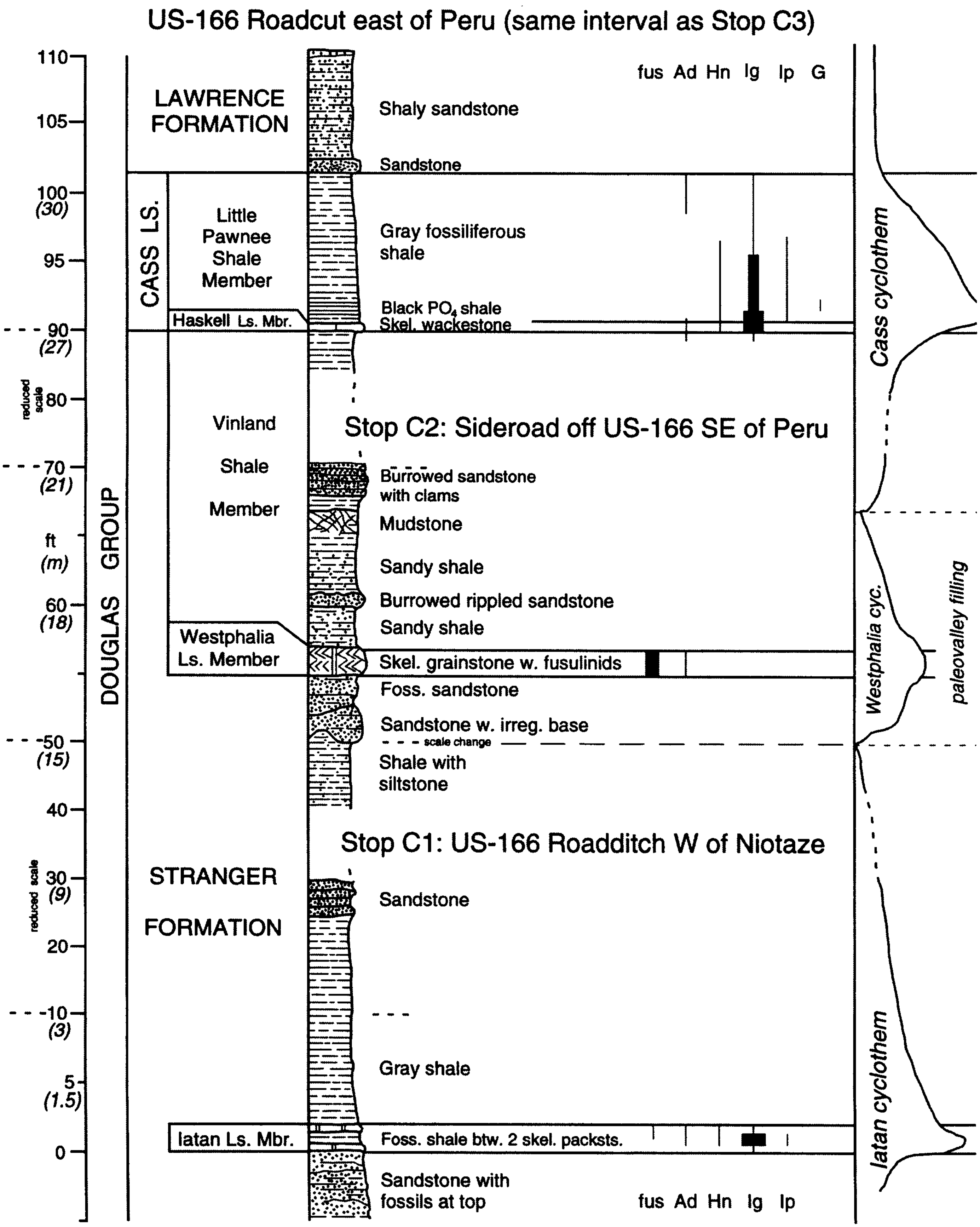
[Drive about 20 miles: gravel roads to US-169, N to Super-8 Motel in Coffeyville] (30 min.)


C5
C4
C3
C2
C2
Grafton
Green Hollow
Bee Creek Lake
Spring Creek
Sedan City Lake
Brownville
Metz
Sorghum Hollow
Rogers
Sedan City
Monett
North Caney Creek
Middle Caney Creek
Sedan
Peru
Hlotaze Lake
Mantansas
Hlotaze
Chautauqua Hills
Copan Wildlife Area
Little Caney River
Chautauqua
Elgin
Hudson
Cascade
Artillery Mountain 1017
Boulanger Landing
Deadmans Rook
Skull Creek Public Access
Caney River
Boulangerville
166
99

Stops C1-C5


Leeds
Tanglewood
Centre
Middle Caney Creek
C5
C4
Spring Creek
Sedan City Lake
Sedan City
Rogers
Gibbs
Middle Caney Creek
C9
C8
C7
C6
Sedan
Wauneta
Layton
Osro
Hewins
Chautauqua
New Elgin
Elgin
Hudson

Stops C4-C9


US-166 Roadcut east of Peru (same interval as Stop C3)
fus Ad Hn Ig Ip G
LAWRENCE FORMATION
Shaly sandstone
Sandstone
CASS LS.
Little Pawnee Shale Member
Gray fossiliferous shale
Black PO_4 shale
Haskell Ls. Mbr.
Skel. wackestone
Vinland Shale Member
Stop C2: Sideroad off US-166 SE of Peru
Burrowed sandstone with clams
Mudstone
Sandy shale
Burrowed rippled sandstone
Sandy shale
Westphalia Ls. Member
Skel. grainstone w. fusulinids
Foss. sandstone
Sandstone w. irreg. base
scale change
Shale with siltstone
DOUGLAS GROUP
Stop C1: US-166 Roadditch W of Niotaze
STRANGER FORMATION
Sandstone
Gray shale
Iatan Ls. Mbr.
Foss. shale btw. 2 skel. packsts.
Sandstone with fossils at top
fus Ad Hn Ig Ip
Cass cyclothem
Westphalia cyc.
paleovalley filling
Iatan cyclothem
110
105
100 (30)
95
90 (27)
reduced scale
80
70 (21)
ft (m)
60 (18)
50 (15)
40
reduced scale
30 (9)
20
10 (3)
5 (1.5)
0

Day 3 (C): Primarily Virgilian in type region; uppermost Missourian; correlated base of Permian
Leave Super-8 Motel, Coffeyville at 7:30 AM

[Drive 28 miles: W on US-166, to slight northward bend in road about 3 miles W of Niotaze] (40 min.)

STOP C1: US-166 roadditch W of Niotaze. (NE-SE-SW sec. 23, T 34 S, R 12 E, Chautauqua Co., KS) (30 min.)
[Please stay off this highway]

This stop shows the **Iatan Limestone** and **cyclothem**, the **twelfth major marine unit above the base of the Missourian Stage**. The Iatan is named from northwestern Missouri, and has been traced from northeastern Kansas northward to Nebraska, but only recently has this unit in Chautauqua County (which was once mapped as the Haskell Limestone) been recognized as the Iatan.

Underlying clastic unit is the top of a thick complex coarsening-upward, perhaps deltaic detrital sequence that at least in the lower part, represents the regressive phase of the South Bend cyclothem. The sandstone exposed here contains crinoids and other marine fossils in the top and thus represents the early phase of the Iatan transgression.

Iatan Limestone here comprises two thin beds of argillaceous skeletal packstone with a fossiliferous conodont-rich shale in the middle, which represents the condensed interval of this intermediate-scale cyclothem. This shale carries a fauna that includes *Idioprioniodus, Hindeodus,* and *Adetognathus*, but is dominated by morphotypes of *Streptognathodus pawhuskaensis*, a few of which have incipient nodes on the sides of the platform that appear to be ancestral to *Streptognathodus zethus*, which first appears in the higher Cass cyclothem. This is the same fauna that that occurs in the thin 'core' shale in the thicker type Iatan Limestone in northwestern Missouri, and forms the basis for correlation of this thin unit here with the type Iatan. Fusulinids occur in the upper limestone here. Thompson (1957) described *Triticites iatensis* and *Kansanella joensis* from the type Iatan of Missouri. Nearly two miles (3 km) to the north, in an isolated quarry, fusulinids are present with crinoids in a packstone that overlies a local phylloid-algal buildup that apparently is equivalent to the lower thin limestone bed at this locality.

Overlying clastic unit is a coarsening-upward deltaic sequence that completes the Iatan cyclothem.

Leave Stop C1 at 8:40 AM

[Drive 0.5 mile: W on US-166, S on gravel sideroad] (10 min.)

STOP C2: Sideroad off US-166, SE of Peru. (ctr. W line, SW 23, T 34 S, R 12 E, Chautauqua Co., KS)(30 min.)

This stop shows the **Westphalia Limestone**, a minor cyclothem named from east-central Kansas and extending from northeastern Kansas into northern Oklahoma. **It is the highest marine unit in the Missourian Stage** (as currently recognized with the base of the Virgilian placed in the overlying Cass cyclothem).

Underlying unit is mainly silty shale and siltstone in the lower part. This is abruptly overlain by a dominantly sandstone unit with an irregular sharp basal contact, which may represent the base of a paleovalley filling.

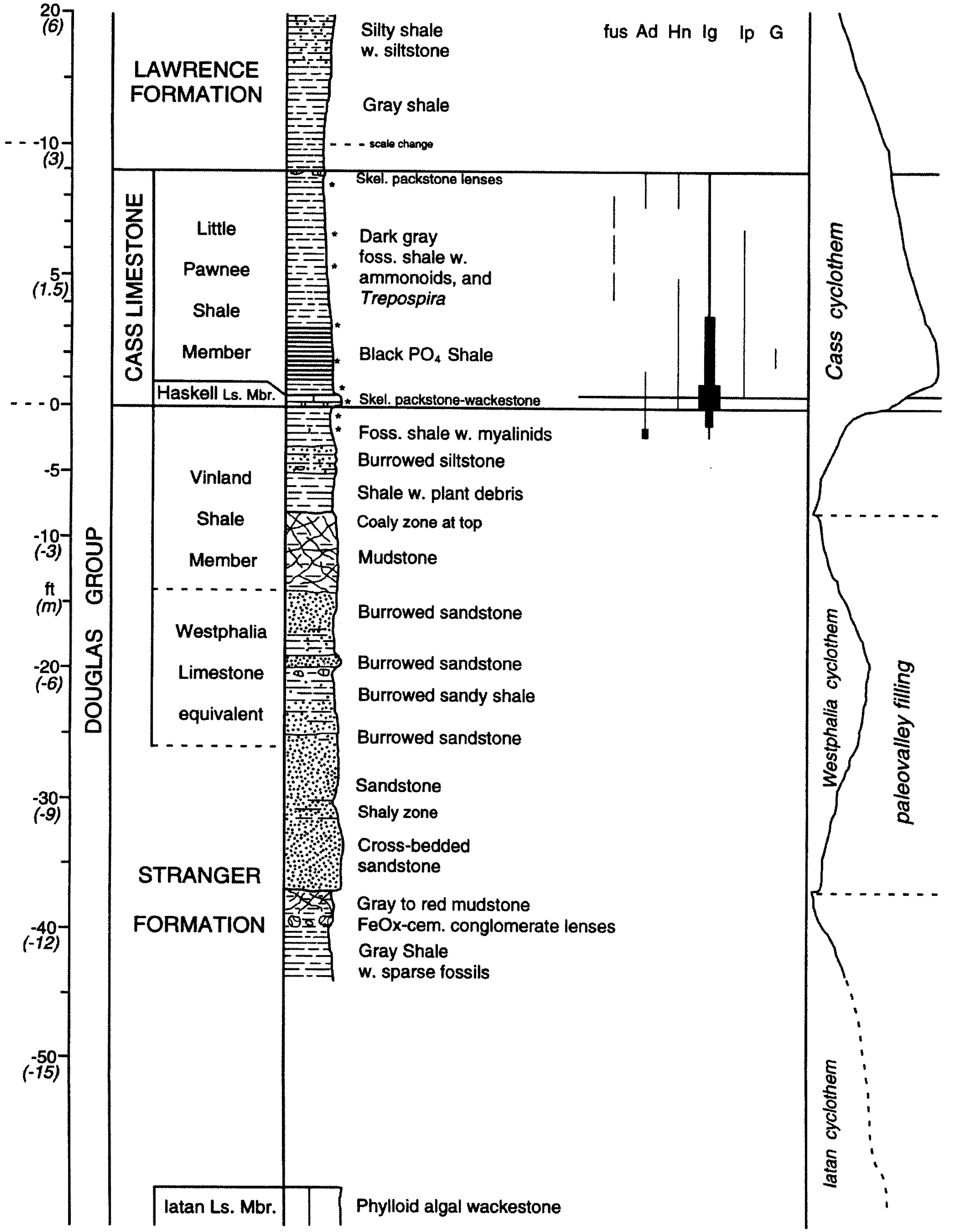
Westphalia Limestone Member here is a sandy fusulinid grainstone with 'herringbone' cross-bedding that suggests tidal-dominated deposition at the edge of a marine transgression up the paleovalley. The fusulinids are probably *Triticites oryziformis*, named by Newell (1934) from the type Westphalia. The sparse conodont fauna includes only *Adetognathus*.

Vinland Shale Member (named from northeastern Kansas) comprises a clastic unit that here continues the paleovalley filling upward through sandy shales with a bed of burrowed, ripple-marked sandstone to a mudstone that may represent an exposure surface. Above this is a thicker set of burrowed sandstones that contain clams and appear to represent the early phase of the next transgression. This next marine unit is the Cass Limestone, which is now regarded as the base of the Virgilian Stage. It is exposed just around the corner to the northwest along US-166, but we will visit it at another good exposure about 2 miles to the west.

Leave Stop C2 at 9:20 AM

[Drive 2.4 miles: N to US-166, W on US 166, 2.3 miles] (10 min.)

Stop C3: US-166 Roadcut west of Peru



STOP C3: US 166 roadcut W of Peru. (NE NE sec. 20, T 34 S, R 12 E, Chautauqua Co., KS) (60 min.)

[Be very careful when crossing this highway]

This stop shows the **Cass Limestone** and **cyclothem**, the **basal marine unit of the Virgilian Stage**, in a more basinal facies than at Stop A8 on the first day. We will see this unit again at Stop D1 tomorrow at an outcrop that has a more complete conodont record and is provisionally proposed as a regional stage boundary stratotype for the base of the Virgilian Stage. **The variety of fossils that are available here, however, make it appropriate that this exposure be designated a supplementary stratotype**.

Iatan Limestone Member is exposed in the bed of the small stream a half mile to the east. This is the phylloid algal wackestone facies that is well developed from northeast to west of Peru.

Overlying unit is mostly covered in the lower part, but its top is exposed in the base of the exposure in the roadditch gully leading eastward down the hill on the south side of US-166, where it is gray shale with sparse marine fossils that represents the regressive phase of the Iatan cyclothem. It is overlain by iron-oxide-cemented shale-pebble conglomerate lenses that may represent buried slump from a cutbank. This is overlain by gray to red mudstone that probably represents subaerial exposure, and is abruptly overlain by cross-bedded sandstone that begins the paleovalley fill sequence. Partway up is a succession of burrowed sandstone and sandy shale that represents shoreline development of a marine unit, presumably the Westphalia cyclothem by position as the only marine unit in the paleovalley fill seen a little over 2 miles to the east at Stop C2.

Vinland Shale Member (named from northeastern Kansas) here is a complex detrital unit in which the lower part is a thick reddish mudstone that appears to be a well developed paleosol, and is overlain by a coaly shale. Although the lithostratigraphic boundary (if even recognized) might be placed at the top of the Westphalia-equivalent burrowed sandstone, the sequence boundary that separates the Westphalia sequence from the base of the Cass cyclothem is placed at the top of the mudstone paleosol. The upper Vinland here becomes fossiliferous (including myalinid clams) and marks the early transgressive phase of the Cass cyclothem.

Haskell Limestone Member (named from northeastern Kansas and seen at Stop A8) is the transgressive limestone of the Cass cyclothem, which here contains the lower half of the condensed interval. It is a thin dark skeletal wackestone that had been overlooked in this region until these roadcuts were made. It contains the brachiopod *Crurithyris*, which is tolerant of dysoxic environments and abundant conodonts, dominated by *Streptognathodus pawhuskaensis*.

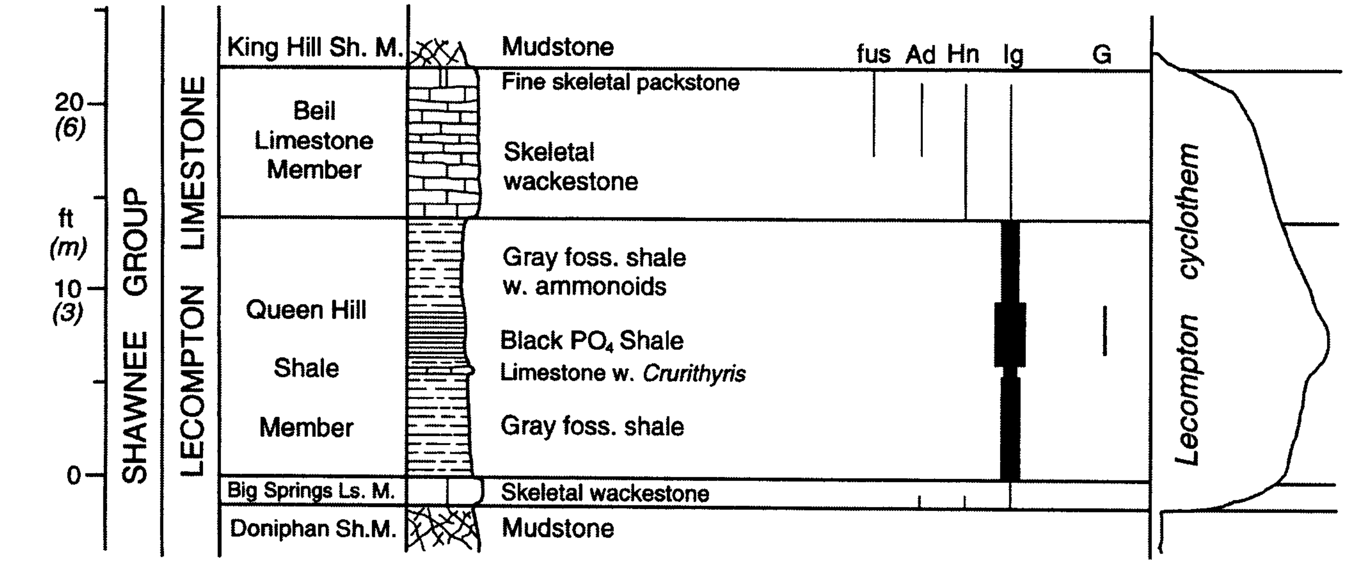
Little Pawnee Shale Member (named from Nebraska) is a thick dark gray fossiliferous shale here with a black phosphatic zone just above the base. This reflects its position in deeper, more oxygen-deficient water in this more basinal region in contrast to the lighter colored, more abundantly fossiliferous nature of the thin equivalent shale northward on the shelf as seen at Stop A8. The Little Pawnee here contains abundant conodonts in the lower part, which are dominated by *Streptognathodus pawhuskaensis* and include the first appearance of *S. zethus* (as elsewhere along the outcrop belt). It contains more *Idioprioniodus* here than northward and also includes a small number of the deeper-water genus *Gondolella*. The deeper-water gastropod *Trepospira* is present above the black facies, and the upper part is very fossiliferous, containing groups that are not commonly well represented in the limestone-dominated cyclothems of the north. For example, the Little Pawnee here contains the first appearance of ammonoids of the genus *Vidrioceras*, which characterizes Virgilian faunas on a more regional scale. Just as significantly, the upper part carries fusulinids that have not yet been studied, but which can provide the basis for characterization of the base of the Virgilian when compared to the fusulinid fauna of the underlying Westphalia Limestone, seen at Stop C2 just to the east (and to be seen again at Stop D1 tomorrow where it is particularly well developed as well as rich in fusulinids). For these reasons, this exposure will be designated as a supplementary stratotype to whatever exposure contains the appropriate succession to be designated the Missourian-Virgilian boundary stratotype.

Overlying clastic unit is a coarsening-upward deltaic sequence that represents overwhelming detrital influx of an approaching shoreline during the regressive phase of the Cass cyclothem. The upper sequence boundary can be seen up-section, southward along the gravel road to the west.

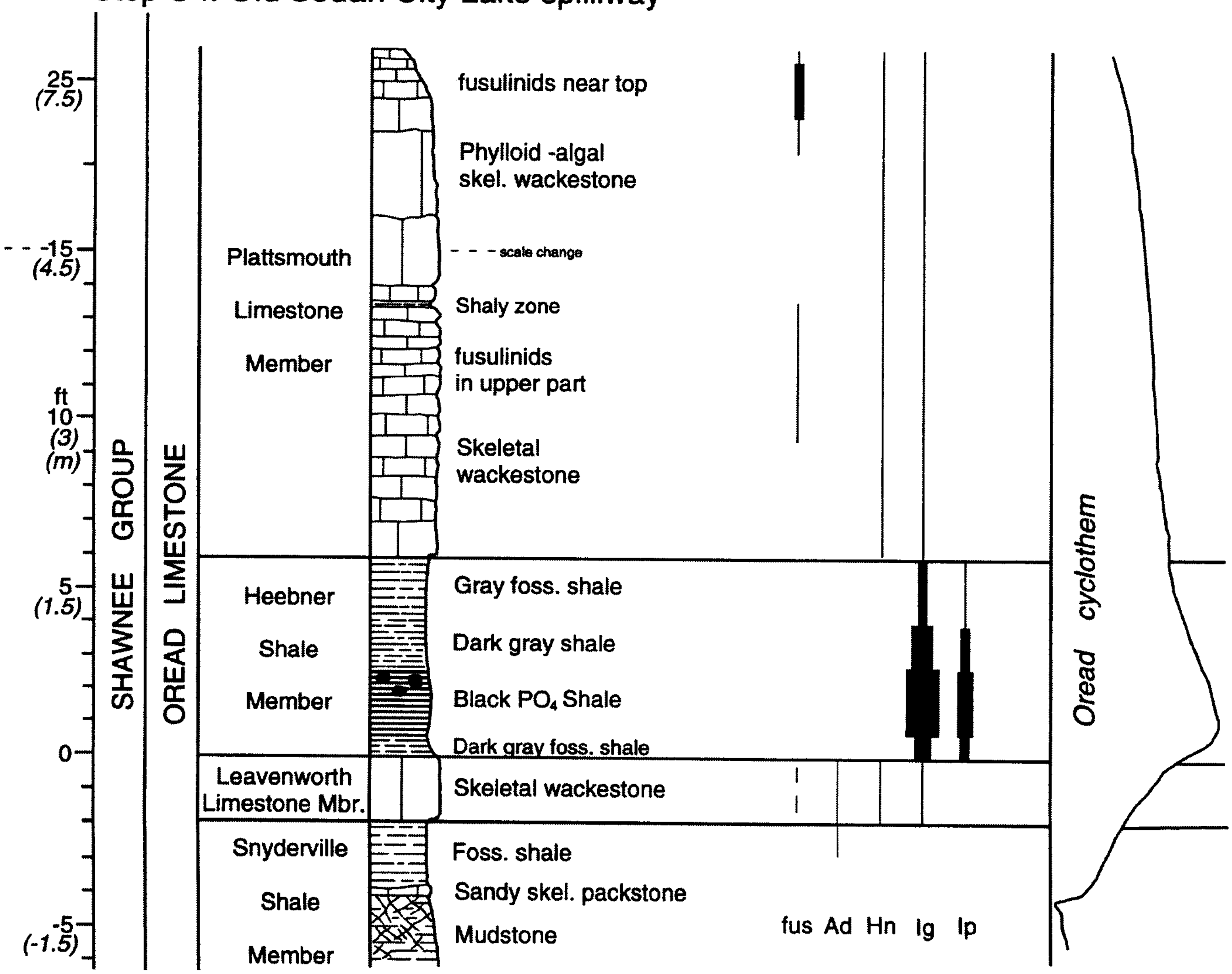
Leave Stop C3 at 10:30 AM

[Drive 12 miles: W on US-166, N on K-99, 3 miles beyond jct. W of Sedan, E on entrance road] (20 min.)

Stop C5: K-99 Roadditch northwest of Sedan



Stop C4: Old Sedan City Lake spilllway



STOP C4: Sedan City Lake spillway. (SW-NW-NW sec. 21, T 33 S, R 11 E, Chautauqua Co., KS) (90 min.)

*[Watch out for **poison ivy**, and be very careful climbing down the cliff; we will have **lunch** here]*

This stop shows the **Oread Limestone** and **cyclothem**, the **second major cyclothem** (but **third major marine unit**) above the base of the **Virgilian Stage**. The Oread was named from northeastern Kansas (from the hill upon which Kansas University is situated), and this cyclothem was used by R.C. Moore as the prototype of his original 'Kansas' cyclothem in the 1930s. The Oread extends from Nebraska southward into Oklahoma. The 'Kansas' cyclothem soon became the 'Shawnee megacyclothem' named after the group that includes this and the next three higher limestone formations. The 'lower limestone' of this original cyclothem/megacyclothem (in this case the Toronto Limestone) is not exposed at this locality, but we will visit it at Stop D2 tomorrow.

Snyderville Shale Member (named from Nebraska) is a thick sequence of detrital clastics with a mudstone paleosol at the top here and throughout southern Kansas. It thins north of east-central Kansas to entirely a mudstone paleosol. The Snyderville paleosol marks the sequence boundary that separates the Oread cyclothem above from the Toronto cyclothem (one of only intermediate scale) below, confirming the depositional artificiality of grouping the 'lower limestone' (Toronto) with the two higher ('middle' and 'upper') limestones in the old 'Shawnee megacyclothem'. This original grouping was an artifact of the fortuitous occurrence of T-R units of intermediate or minor scale with similar physical characteristics below all four major cyclothems (those containing the distinctive black shale facies) in the Shawnee Group. The thin marine top of the Snyderville is the initial transgressive phase of the Oread cyclothem.

Leavenworth Limestone Member (named from northeastern Kansas) is the classic transgressive limestone of the Oread cyclothem, which was deposited in deepening water. It extends from Nebraska to northern Oklahoma with little change in appearance. In addition to fusulinids of the common triticitid lineages, it also carries the unique occurrence of the genus *Waeringella* in the Midcontinent (Toomey, 1964). The Leavenworth was the 'middle limestone' of the old Shawnee megacyclothem, a term now falling into disuse because the limestone in this position is the transgressive (or lower) limestone of the depositionally significant major cyclothem.

Heebner Shale Member (named from Nebraska) is a gray to black phosphatic shale, the classic 'core' shale of the Oread cyclothem that represents the condensed interval developed at sea-level highstand. It also extends with little apparent change from Nebraska southward (but farther) into Oklahoma. The Heebner carries an abundant conodont fauna subequally dominated by *Idiognathodus simulator* and *Streptognathodus pawhuskaensis*; it also includes *S. firmus* and the highest occurrence of the genus *Idioprioniodus* in the Midcontinent.

Plattsmouth Limestone Member (named from Nebraska) is the classic regressive limestone member of the Oread cyclothem (as well as the more appropriately termed 'upper limestone' of the old 'Shawnee megacyclothem'). It displays a typical a shallowing-upward sequence into phylloid-algae-dominated wackestone here. The first appearance of the conodont *Idiognathodus tersus* was reported by von Bitter (1972: data sheets) from the lower part of the Plattsmouth Limestone in northeastern Kansas. The fusulinids of the Plattsmouth are of the common triticitid lineages. The Plattsmouth is overlain in this region by the fossiliferous Elgin Sandstone, which represents an encroaching detrital shoreline in the late regressive phase of the Oread cyclothem, but the exact relations with the higher members of the northern Oread have not yet been worked out.

Leave Stop C4 at 12:20 PM

[Drive ~2 miles: back to K-99, then N 1.25 mile, turning left into the lane leading into an oil field] (10 min.)

STOP C5: K-99 Roadditch NW of Sedan. (NE-SE-SW sec. 8, T 33 S, R 11 E, Chautauqua Co., KS) (40 min.)

[Please stay off of the highway and away from the oilfield facilities]

This stop shows the middle of the **Lecompton Limestone** and **cyclothem**, the **third major cyclothem** (but the **sixth major marine unit**) above the base of the **Virgilian Stage**. The Lecompton was named from northeastern Kansas, and extends from Nebraska into northern Oklahoma.

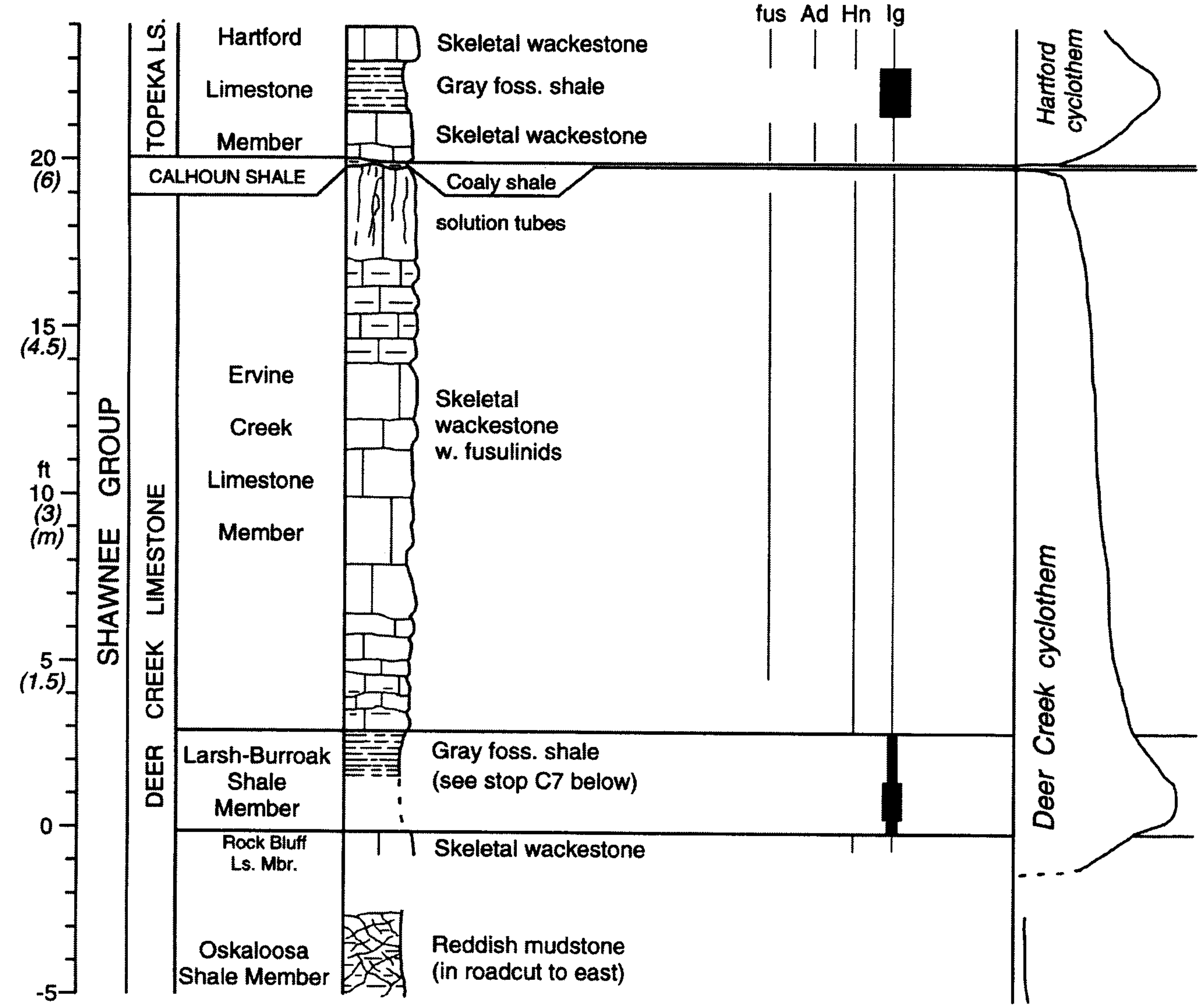
Big Springs Limestone Member (named from northeastern Kansas, extending southward from Nebraska and not well exposed here) is the transgressive limestone of the Lecompton cyclothem.

Queen Hill Shale Member (named from Nebraska and extending into Oklahoma) is the condensed interval deposited at highstand, the typical dark gray to black phosphatic 'core' shale of the Lecompton cyclothem. Macrofauna includes conulariids, ammonoids, and snails (*Trepospira, Strobeus*). It contains an abundant conodont fauna subequally dominated by *Idiognathodus tersus* and *Streptognathodus pawhuskaensis* and contains the first appearance of *S. virgilicus* Ritter 1995. The black facies also contains rare specimens of platformless *Gondolella*.

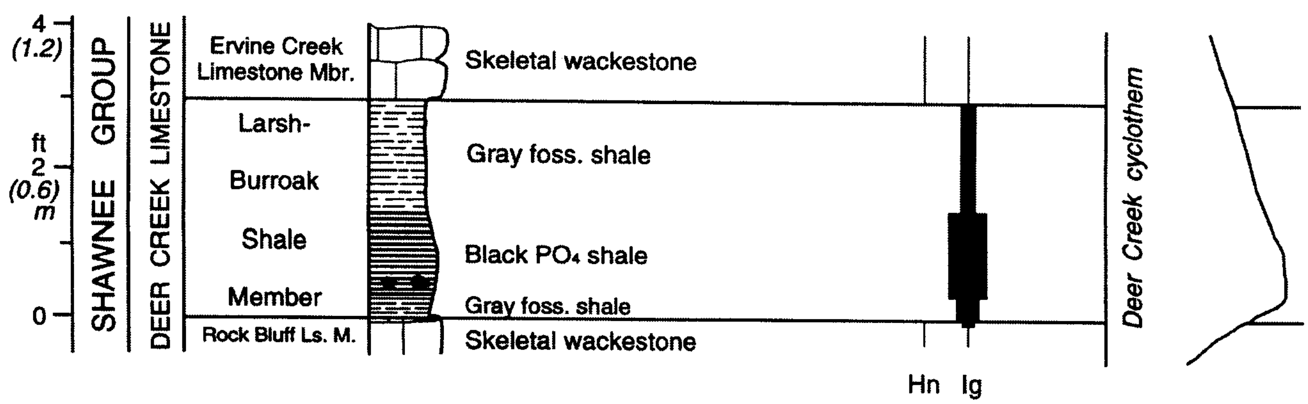
Beil Limestone Member (named from Nebraska and extending into Oklahoma) is the regressive limestone of the Lecompton cyclothem. Its macrofauna is dominated by corals (*Syringopora, Cladochonus*, caniniids) and it contains fusulinids (of the common triticitid lineages) in the upper part.

Leave Stop C5 at 1:10 PM

Stop C6: US-166 Roadcut west of Cedar Creek



Stop C7: Creekbed east of Sycamore Creek



[Drive 10 miles: S on K-99, SW on Business US-166, W on US-166, 2 miles to roadcut] (20 min.)

STOP C6: US-166 Roadcut W of Cedar Creek. (S line SW 2, T 34 S, R 10 E, Chautauqua County, KS (40 min.)

[Please stay off the highway at this and the next three stops]

This stop shows the **Deer Creek Limestone** and **cyclothem**, the **fourth major cyclothem** (and the **eighth major marine unit**) above the base of the **Virgilian Stage**, and also the overlying **Hartford Limestone** and **cyclothem**, the **ninth major marine unit** (a cyclothem of intermediate scale) above the base. The Deer Creek is named from northeastern Kansas and extends from Nebraska into Oklahoma. The **next stop (C7)** better shows the **middle** of the **Deer Creek cyclothem**, and these units will be described here for that stop as well.

Oskaloosa Shale Member (named from northeastern Kansas and recognized from Nebraska to Oklahoma) contains reddish paleosol mudstone and the lower sequence boundary of the Deer Creek cyclothem at the top, above a thick detrital succession in this region.

Rock Bluff Limestone Member (named from Nebraska and extending into Oklahoma) is the transgressive limestone of the Deer Creek cyclothem. It is characterized by large fusulinids of the common triticitid lineages along much of the outcrop, but the unit is not well exposed here. Its top is broadly exposed in the bed of the creek at Stop C7, where it represents a surface of nondeposition and initial condensation after carbonate production and preservation ceased prior to the slow accumulation of fine clays of the overlying 'core' shale in deep water.

Larsh-Burroak Shale Member (named from Nebraska and Iowa and extending into northern Oklahoma) is the 'core' shale of the Deer Creek cyclothem, the condensed interval deposited at highstand. It is much better exposed at Stop C7. It has a double name in Kansas because in Iowa and Nebraska, the lower black phosphatic shale facies (named Larsh, from Nebraska) is separated from the upper lighter shale facies (named Burroak from Iowa) by the thin Haynies Limestone Member (named from Iowa) which disappears southward in Kansas. The Haynies represents a minor sea-level drop during the generally highstand phase. The Larsh-Burroak carries an abundant conodont fauna dominated by *Streptognathodus pawhuskaensis*, which was named from this unit by Harris and Hollingsworth (1933) from Pawhuska, Oklahoma, about 30 miles (50 km) south of here.

Ervine Creek Limestone Member (named from Nebraska, and extending into northern Oklahoma) is the regressive limestone of the Deer Creek cyclothem. It contains fusulinids of the common triticited lineages. Its well exposed top at Stop C6 displays birdseye structures and solution tubes that record subaerial exposure and mark the sequence boundary at the top of this cyclothem.

Calhoun Shale (named from northeastern Kansas) is only a thin local coaly shale bed here, marking the sequence boundary between the Deer Creek and Hartford cyclothems. It thickens northward to a substantial coarsening-upward detrital succession in its type area around Topeka.

Hartford Limestone Member (named from east-central Kansas and extending from Nebraska into Oklahoma) rests in places directly upon the exposure surface at the top of the Ervine Creek. The thick probably deltaic Calhoun Shale that separates them in northeastern Kansas (where the Hartford is classified as a member of the Topeka Limestone) nearly disappears southward, and the thin terrestrial facies that developed here may have been partly eroded by the Hartford transgression. The lowest bed with pinnid clams is transgressive, and the overlying shale carries an abundant conodont fauna dominated by *S. pawhuskaensis*, and thus represents the core shale condensed interval of the Hartford cyclothem, deposited at highstand. The highest bed exposed here appears to be regressive.

Leave Stop C6 at 2:10 PM

[Drive 2 miles: W along US-166] (10 min.)

STOP C7: Creekbed E of Sycamore Creek. (SE-SW-SW sec. 4, T 34 S, R 10 E, Chautauqua Co., KS) (30 min.)

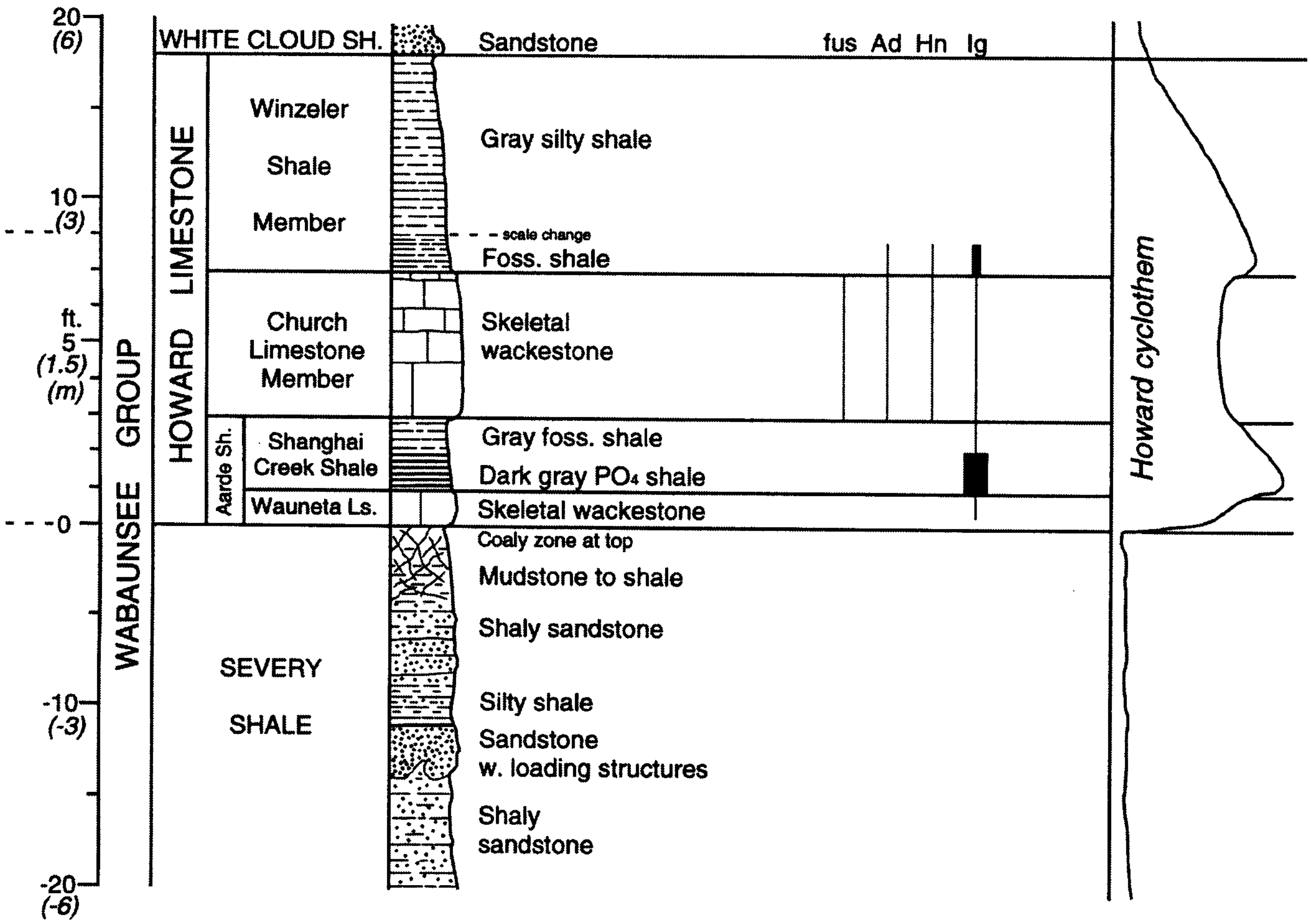
[Please do not cross this highway]

This stop shows a better exposure of the **condensed interval** of the **Deer Creek cyclothem** (see above).

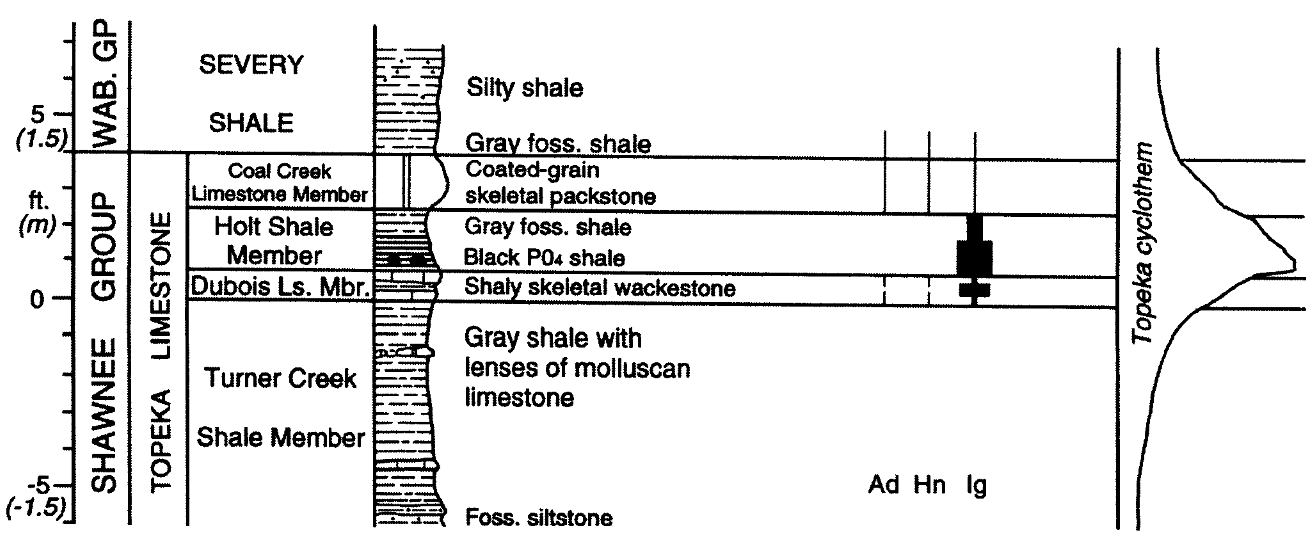
Leave Stop C7 at 2:50 PM

[Drive 2.3 miles: W on US-166 to steep hill] (10 min.)

Stop C8: US-166 Roadcut east of Wauneta



Stop C9: US-166 Roadcut west of Wauneta



STOP C8: US-166 roadcut E of Wauneta. (NE-NE sec. 12, T 34 S, R 9 E, Chautauqua Co., KS) (40 min.)

[Please do not cross this highway]

This stop shows the **Howard Limestone** and **cyclothem**, the **sixth major cyclothem** (and probably the **twelfth major marine unit**) above the base of the **Virgilian Stage**. The Howard is named from this region and extends from Nebraska to northern Oklahoma. This is the highest cyclothem with black shale in the Virgilian and the lowest limestone formation in the shale-dominated Wabaunsee Group.

Severy Shale (named from this region) is a well exposed complex coarse detrital unit with a mudstone paleosol at the top that marks the sequence boundary at the base of the Howard cyclothem. It is capped by a coaly zone that is the south end of the Nodaway coal, the most important Virgilian coal, which extends into Nebraska.

Wauneta Limestone bed (named from here) is the transgressive limestone of the Howard cyclothem, which extends from southern Kansas into northern Oklahoma.

Shanghai Creek Shale bed (named from here) is the dark gray to black 'core' shale condensed interval of the Howard cyclothem, deposited at highstand and extending from northern Oklahoma to Nebraska. Both can be considered beds in the Aarde Shale Member (named from north of here). The Shanghai Creek carries an abundant conodont fauna dominated by *Streptognathodus pawhuskaensis* and *S. virgilicus*.

Church Limestone Member (named from Nebraska) is the early regressive limestone of the lower part of the Howard cyclothem, but does not display a shallowing-upward sequence.

Winzeler Shale Member (named from north of here) has a conodont-rich gray fossiliferous shale at the base that represents another condensed interval. This shows that the Howard cyclothem has a double core interval like the Deer Creek cyclothem, but with a stronger early regressive phase represented by the Church Limestone, which is much more widespread than the Haynies Limestone in the Deer Creek. It carries both *S. pawhuskaensis* and *S. virgilicus*. The upper part of the Winzeler here is a coarsening-upward detrital sequence.

Utopia Limestone Member (named from east-central Kansas and extending into Nebraska) is not developed here, but is a coated-grain skeletal packstone to grainstone that represents the late regressive shoal-water limestone of the Howard cyclothem.

White Cloud Shale (named from northeastern Kansas) is a coarse detrital-dominated unit that contains sandstone just north of here in the position of the Utopia Limestone, and contains the upper sequence boundary of the Howard cyclothem.

Leave Stop C8 at 3:40 PM

[Drive 1 mile: west on US-166 to small hill past Wauneta] (10 min.)

STOP C9: US-166 roadcut W of Wauneta. (NW-NE-NE sec. 11, T 34 S, R 9 E, Chautauqua Co., KS) (30 min.)

[Please do not cross this highway]

This stop shows the shaly basinward facies of the **Topeka Limestone** and **cyclothem** (also called upper Topeka cyclothem), the **fifth major cyclothem** (and probably the **eleventh major marine unit**) above the base of the **Virgilian Stage**. The Topeka is named from northeastern Kansas, where it comprises 5 limestone and 4 shale members, and is the highest, most complex, and least studied of the limestone formations in the Shawnee Group.

One of the lower members of the Topeka, the Curzon Limestone Member (named from northwestern Missouri), which lies above the Hartford Limestone and extends from north of here into Nebraska, contains a conodont-rich shale in east-central Kansas and appears to be an intermediate cyclothem, the **tenth major marine unit** above the base of the **Virgilian Stage**. The Sheldon Limestone Member (named from Nebraska in the middle of the Topeka), which appears to be a minor cycle in the Topeka region (where von Bitter, 1972, reported its sparse conodont fauna) is not known in this region.

Turner Creek Shale Member (named from Nebraska) is here largely sparsely fossiliferous shale with thin molluscan limestones that probably represent the early transgressive facies of the Topeka cyclothem.

Dubois Limestone Member (named from Nebraska) is the transgressive limestone of the Topeka cyclothem extending at least to here, and it contains a condensed interval in the shale within it.

Holt Shale Member (named from Nebraska) is the dark phosphatic 'core' shale condensed interval of the Topeka cyclothem deposited at highstand, and can be recognized from Nebraska to northern Oklahoma. Its abundant conodont fauna is dominated by *Streptognathodus pawhuskaensis, S. virgilicus*, and is the unit from which *S. holtensis* Ritter 1994 was described.

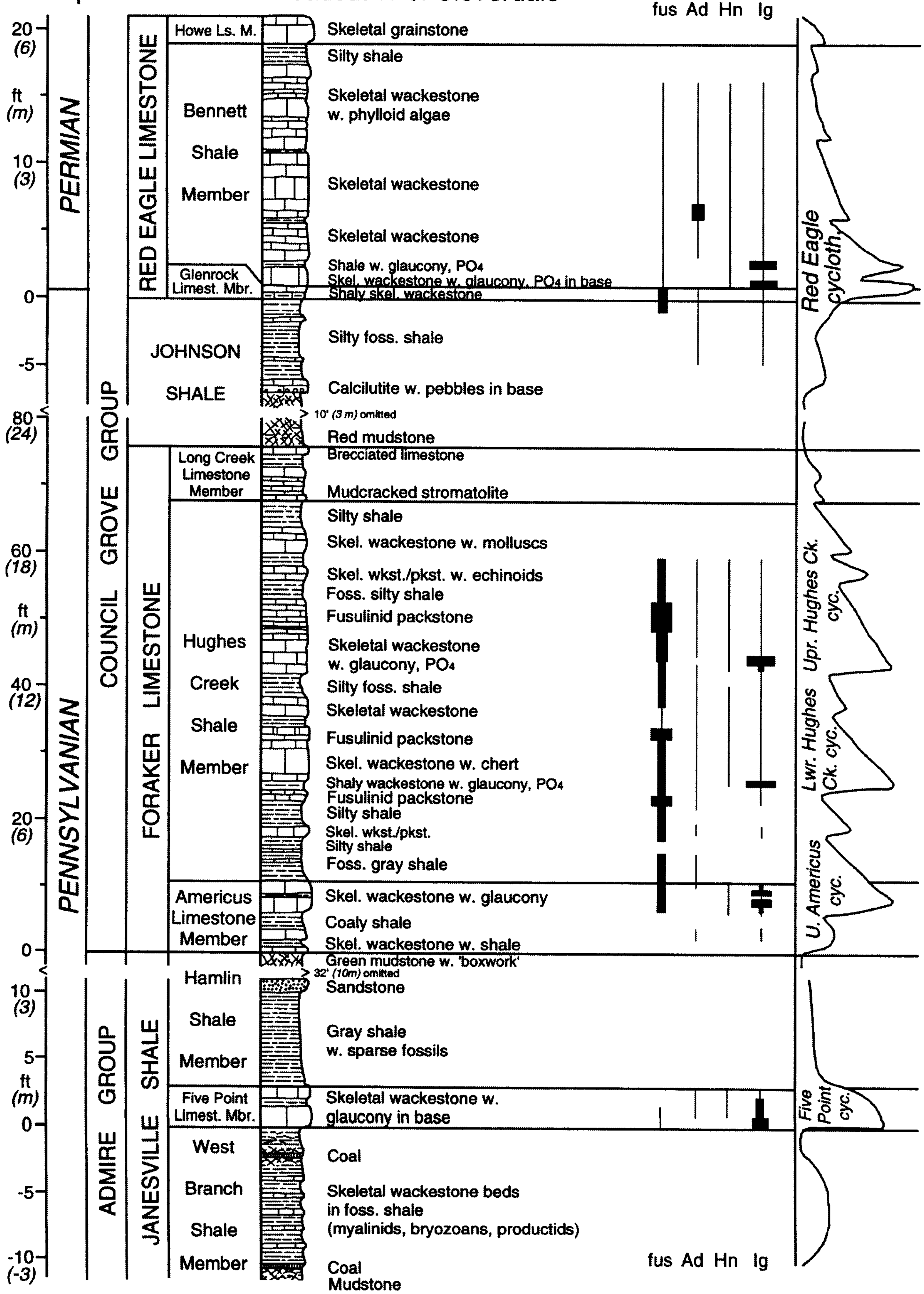
Coal Creek Limestone Member (named from northeastern Kansas) is a skeletal packstone with algal-coated grains. It is the regressive limestone of the Topeka cyclothem, extending from Nebraska at least to here.

Severy Shale (named from this region) contains the sequence boundary in its upper part.

Leave Stop C9 at 4:20 PM

[Drive 29 miles: W on US-166 to 6 miles beyond Cedar Vale, N on gravel road, E 5 miles on Rte. 38] (20 min.)

Stop C10: Route 38 Roadcut W of Cloverdale



STOP C10: Rte. 38 Roadcut W of Cloverdale. (NW-NE) sec. 28, T 32 S, R 8 E, Cowley Co., KS) (60 min.)

[Please stay off this highway as there is heavy truck traffic from a nearby quarry]

This stop shows the **Five Point Limestone** and **cyclothem** and the **Foraker Limestone**, which contains a very complex succession of **cyclothems** ('composite sequence') at the **top of the Virgilian Stage** (and the top of the Pennsylvanian [Upper Carboniferous] Subsystem), and the **Red Eagle Limestone** and **cyclothem**, which now marks the base of the **Permian System** in the Midcontinent Basin, based on correlation of the ratified boundary from the southern Ural Mountains. Both the Foraker and Red Eagle are named from northern Oklahoma and extend northward into Nebraska. Most members are named from Nebraska where they are better differentiated..

West Branch Shale Member (named from Nebraska) contains a small cycle of shallow-water marine deposition between two coals in its upper part. No conodonts were recovered from this unit

Five Point Limestone (named from Nebraska) represents an intermediate-scale cyclothem that can be traced from southeastern Nebraska to northern Oklahoma. It contains the condensed interval in its base, which contains glaucony as well as abundant conodonts.

Hamlin Shale Member (named from the same region as the lower two) includes the upper regressive phase of the Five Point cyclothem in its base, and is mostly a well developed paleosol across the Midcontinent.

Americus Limestone Member (named from east-central Kansas) includes the basal transgressive and early highstand phases of the complex Foraker succession. The lower part is a minor cycle regressing to coaly shale. The upper part is a major cyclothem culminating in a highstand condensed interval containing glaucony and phosphatized molluscs. This is the unit from which *Streptognathodus wabaunsensis* was described.

Hughes Creek Shale Member (named from Nebraska where it is mainly shale) is mainly limestone facies here. It includes two major highstand condensed intervals, both of which contain glaucony, phosphatized molluscs and abundant conodonts. Both shallow upward through limestone facies containing abundant fusulinids to silty lowstand shales. The conodont fauna includes *S. wabaunsensis, S. conjunctus*, and related forms. The abundant fusulinid fauna includes advanced triticitids, *Leptotriticites*, and *Schwagerina*. Other macrofauna includes a wide variety of invertebrates. The Hughes Creek is mainly shale from east-central Kansas northward.

Long Creek Limestone Member (named from Nebraska) is the final late regressive limestone of the complex Foraker succession. It is mainly mudcracked laminar stromatolite capped by highly brecciated limestone.

Johnson Shale (named from Nebraska) is a reddish paleosol mudstone in the lower part, which contains the sequence boundary at the top. The upper part contains an early transgressive limestone bed with pebbles in the base, overlain by marine shale that represents the early transgressive phase of the Red Eagle cyclothem.

Glenrock Limestone Member (named from Nebraska) is the transgressive limestone of the Red Eagle cyclothem from east-central Kansas northward where the overlying Bennett is manifest as shale facies. It is possible that most of the Glenrock has graded southward into the marine top of the Johnson Shale in this area.

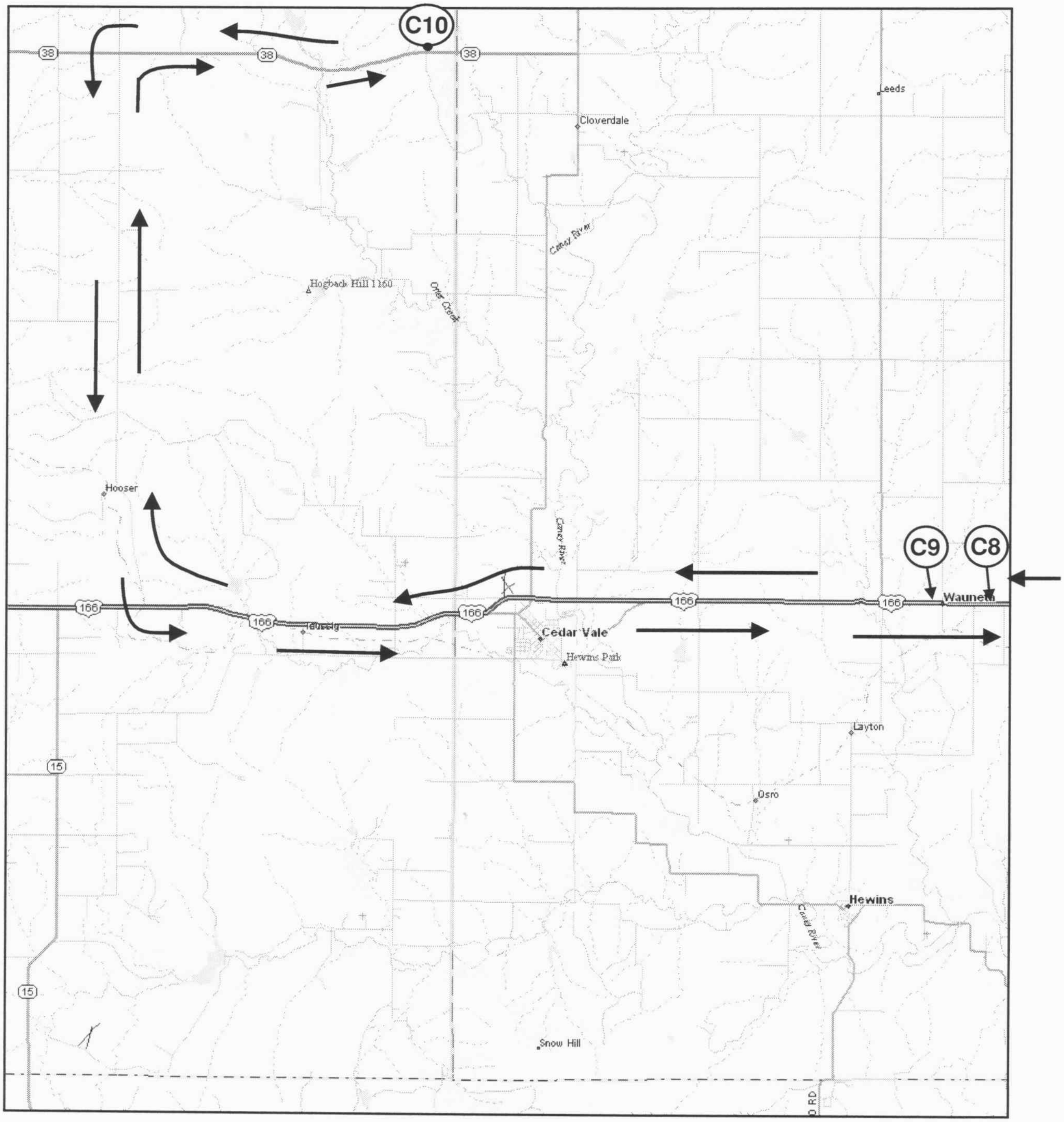
Bennett Shale Member (named from Nebraska where it is mainly shale) contains the double condensed interval of the Red Eagle cyclothem in its base. Here these intervals are represented by two conodont-rich zones that also contain glaucony and phosphatized molluscs, the lower one in the base of the limestone, and the upper one in the overlying shale. The upper part is a generally regressive sequence involving phylloid-algal limestone and silty shale, but including a couple of minor reversals, the lower of which is marked by a zone of abundant *Adetognathus*. The Bennett is mainly dark gray to black shale (like the older Pennsylvanian core shales) in Nebraska and northeastern Kansas, but contains increasing amounts of limestone southward into this area. This may reflect the change in regional depositional dip from southward during the Pennsylvanian to northward as the former basin in Oklahoma became completely filled by orogenic detritus. The condensed intervals contain an abundant conodont fauna that includes (in addition to *Streptognathodus wabaunsensis*) *S. isolatus* (which defines the base of the Permian System in the southern Urals), *S. nodulinearis, S. fuchengensis*, and *S. invaginatus*. Fusulinid faunas of the Red Eagle include advanced triticitids, *Leptotriticites*, and *Schwagerina*, which should provide material for distinguishing Pennsylvanian from Permian fusulinids in the Midcontinent.

Howe Limestone Member (named from Nebraska) is the final regressive limestone of the Red Eagle cyclothem and is a shoreline skeletal grainstone that contains no conodonts.

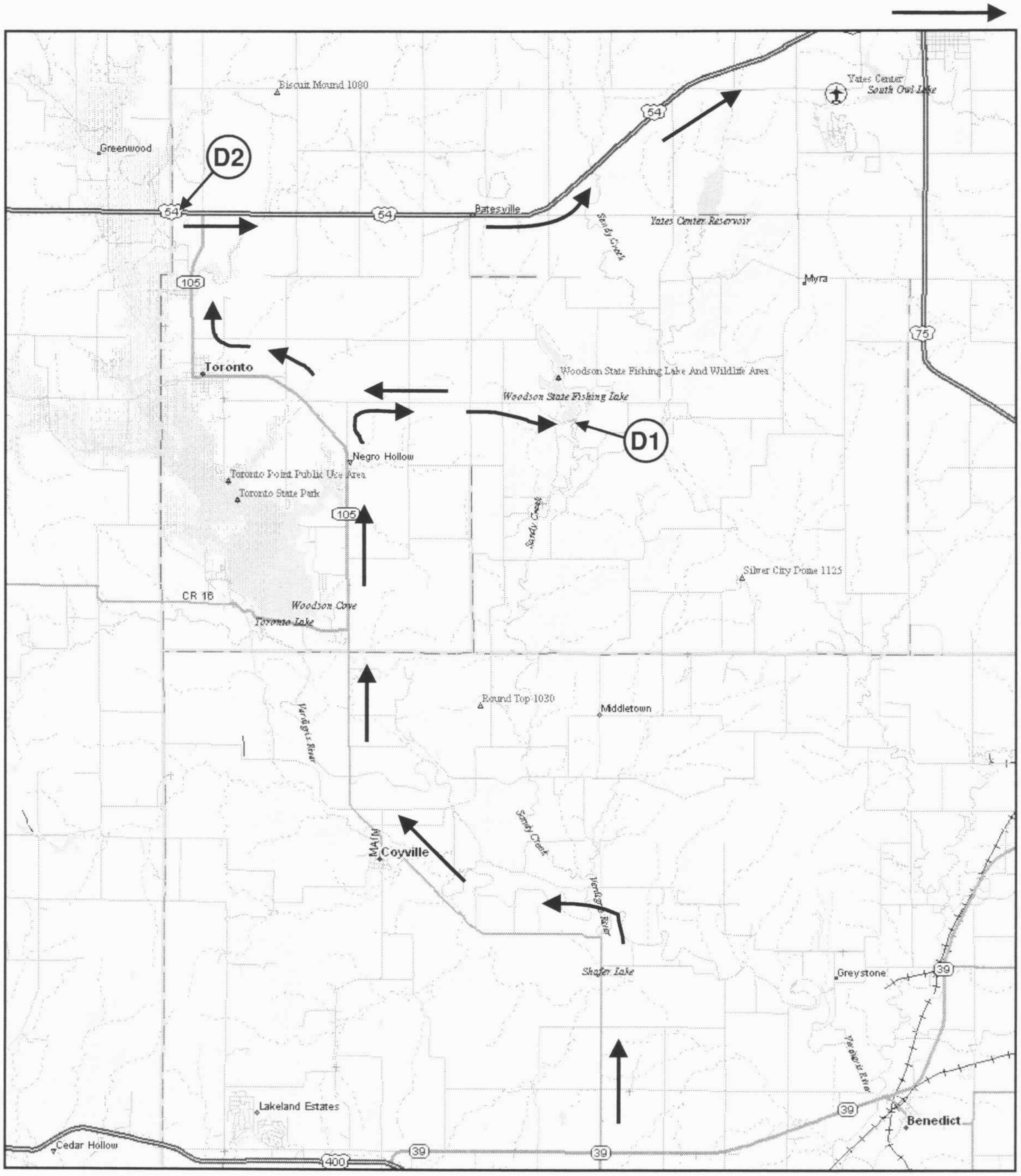
Roca Shale (named from Nebraska) overlies the Howe Limestone and consists of reddish mudstone paleosol that contains the sequence boundary at the top of the Red Eagle cyclothem.

Leave Stop C10 at 6:00 PM

[Drive 75 miles: W 6 miles, S on gravel road and E on US-166 to Super 8 Motel in Coffeyville, Kansas] (90 min.)

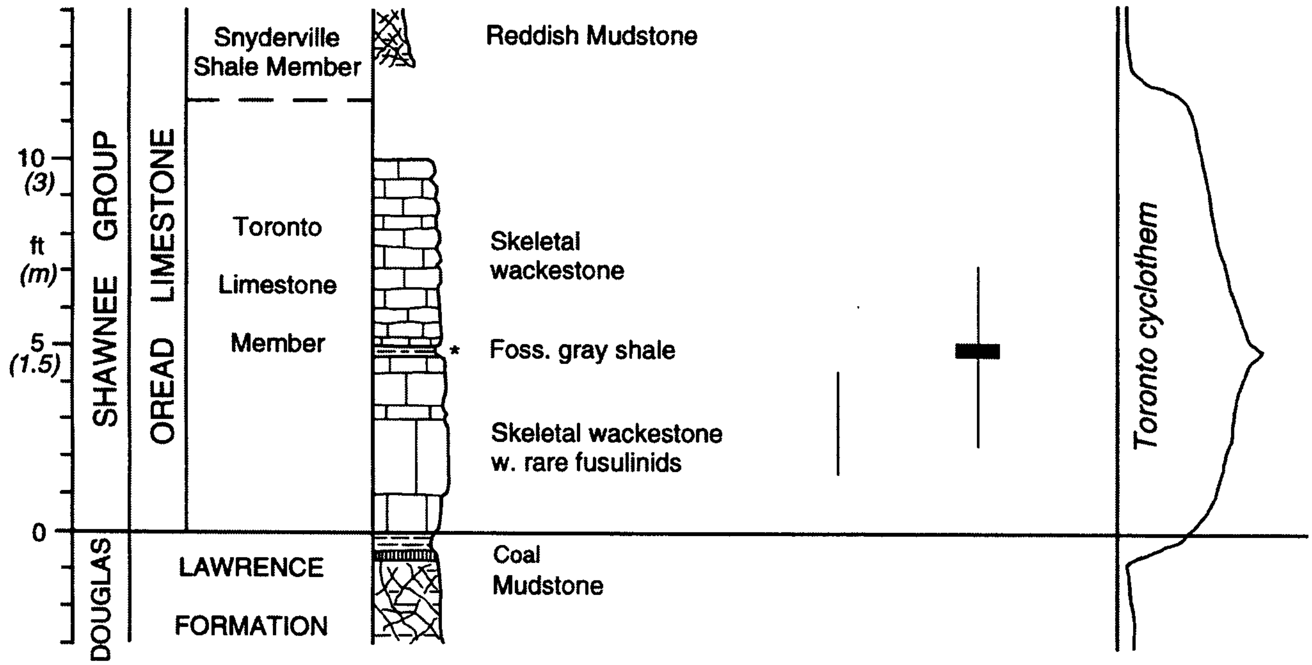

C10
38
38
38
Leeds
Cloverdale
Caney River
Hogback Hill 1160
Otter Creek
Hooser
Caney River
C9
C8
166
166
166
166
166
166
Wauneta
Cedar Vale
Hewins Park
Layton
Osro
15
15
Hewins
Caney River
Snow Hill

Stops C8-C10

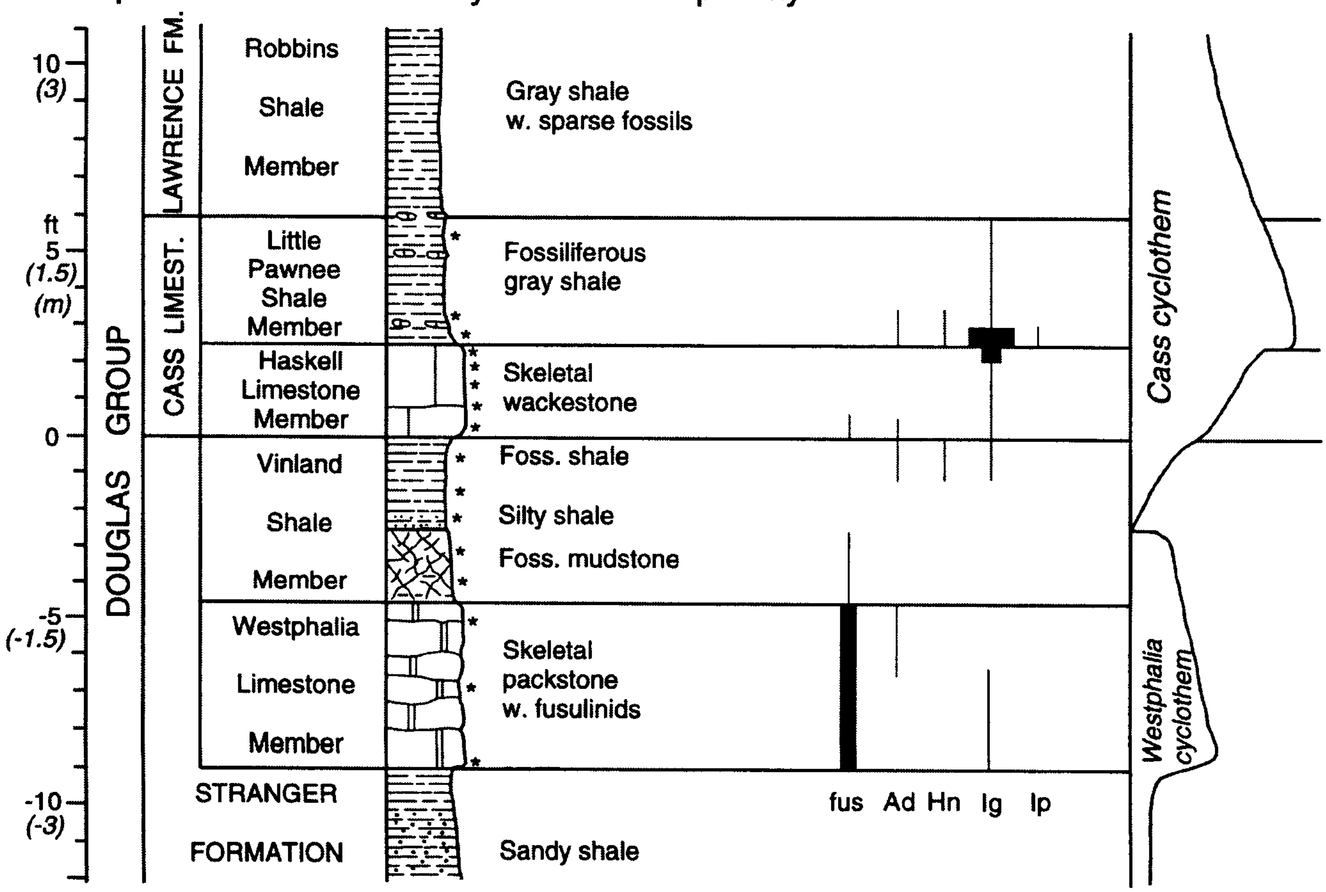

Biscuit Mound 1080
Greenwood
D2
54
Batesville
Yates Center
South Owl Lake
Yates Center Reservoir
Sandy Creek
Myra
75
105
Toronto
Woodson State Fishing Lake And Wildlife Area
Woodson State Fishing Lake
D1
Negro Hollow
Toronto Point Public Use Area
Toronto State Park
Silver City Dome 1125
CR 16
Woodson Cove
Toronto Lake
Round Top 1030
Middletown
Verdigris River
Coyville
MAIN
Shafer Lake
Greystone
39
Benedict
Lakeland Estates
Cedar Hollow
400

Stops D1-D2

Stop D2: US-54 Roadcut, north of Toronto



Stop D1: Woodson County State Lake spillway



Day 4 (D): Provisional Missourian-Virgilian Stage boundary; core shales not readily collectable elsewhere.
Leave Super-8 Motel at 7:30 AM

[Drive ~75 miles: N on US-169, W on US-160, N on US-75, NW on US-400 to N side of Fredonia, N on Co. Rd., then W to Coyville, N to K-105, N 3 miles, then straight at bend, E 3.8 miles, across dam] (100 min.)

STOP D1: Woodson County State Lake spillway. (SE-SW-NE 14, T 26 S, R 14 E, Woodson Co., KS) (140 min.)

[Be careful of poison ivy, steep bluffs, steep gullies, and fallen blocks at the waterfall]

This stop shows the **Westphalia Limestone** and **cyclothem**, the **Cass Limestone** and **cyclothem**, and a **provisional Missourian-Virgilian boundary**. The Cass Limestone is named from Nebraska but is represented here mainly by the prominent Haskell Limestone Member (named from northeastern Kansas), and the Westphalia is named from this area, about 30 miles (50 km) to the northeast. The Westphalia Limestone and Vinland Shale are members of the detrital-clastic-dominated Stranger Formation (named from northeastern Kansas).

Upper Stranger detrital beds (exposed some distance downstream) consist mainly of sandy shale, with scattered fossils at the top representing the early transgressive beds of the Westphalia cyclothem.

Westphalia Limestone Member (forming the creek bed below the falls) is mainly skeletal packstone with a diverse fauna including abundant fusulinids. These include *Triticites oryziformis*, named by Newell from this unit in its type area. The Westphalia is a minor marine unit, extending only from northeastern Kansas (where it is a very marginal marine ostracode-bearing lime mudstone) into northern Oklahoma (where it called the Bowring Limestone). It is fully marine only from east-central Kansas southward and is in a tidally influenced paleovalley at Stop C2. Its generally sparse conodont fauna is dominated by *Adetognathus* nearly everywhere, except around here where the lower part contains a slightly more abundant (12 per kg) *Streptognathodus*-dominated fauna; thus this area appears to have the most offshore development of this minor cyclothem. The fauna here is mainly *S. pawhuskaensis*, but some specimens contain tiny incipient nodes on the sides of the platform that appear to be ancestral to the small lobes that typify *S. zethus*, which first appears in the Cass cyclothem, and which we regard as marking the base of the Virgilian Stage. This form with incipient nodes (referred to informally as 'prezethus') first appears in the more abundant faunas in the slightly older Iatan Limestone (seen at Stop C1).

Vinland Shale Member (named from northeastern Kansas) is thicker and coarse-detrital-dominated both northward (Stop A8) and southward (Stop C2-3). Here it is thin with a mudstone at the base that contains weathered fossils and has an abrupt top that marks it as a paleosol, the sequence boundary separating the Westphalia and Cass cyclothems. The upper Vinland is fossiliferous shale with silty laminae at the base, the early transgressive phase of the Cass cyclothem, which carries a sparse *Adetognathus*-dominated conodont fauna.

Haskell Limestone Member (forming the waterfall) is the transgressive limestone of the Cass cyclothem. Its conodont fauna is dominated by *Streptognathodus pawhuskaensis* throughout, with sparse *Adetognathus* in the base, and a few *S.* 'prezethus' and its descendant *S. zethus* at the top where abundance increases. It also contains fusulinids of the common triticitid lineages. **The Missourian-Virgilian boundary is provisionally placed within the Haskell Limestone**, the unit in which *S. zethus* (defining the base of the Virgilian) first appears at the top (in places), along with its ancestor (which occurs in both the Iatan and Westphalia cyclothems below).

Little Pawnee Shale Member (named from Nebraska) is thin medium gray conodont-rich phosphatic shale that represents the condensed interval of the Cass cyclothem from Nebraska into northern Oklahoma wherever the top of the Haskell Limestone is exposed. It contains *S. pawhuskaensis* and *S. zethus*, along with *S. firmus* and *Idioprioniodus*. It also contains rare ammonoids.

Robbins Shale Member (named from here) is a sparsely fossiliferous gray shale coarsening upward eventually to sandstone, and represents the regressive phase of the Cass cyclothem in this region.

Leave Stop D1 at 11:30 AM

[Drive 10 miles: back to K-105, W into Toronto, then N, W on US-54, 0.3 mile] (20 min.)

STOP D2: US-54 roadcut N of Toronto. (S line SW-SW sec. 26, T 25 S, R 13 E, Woodson Co., KS) (30 min.)

[Please do not cross this highway]

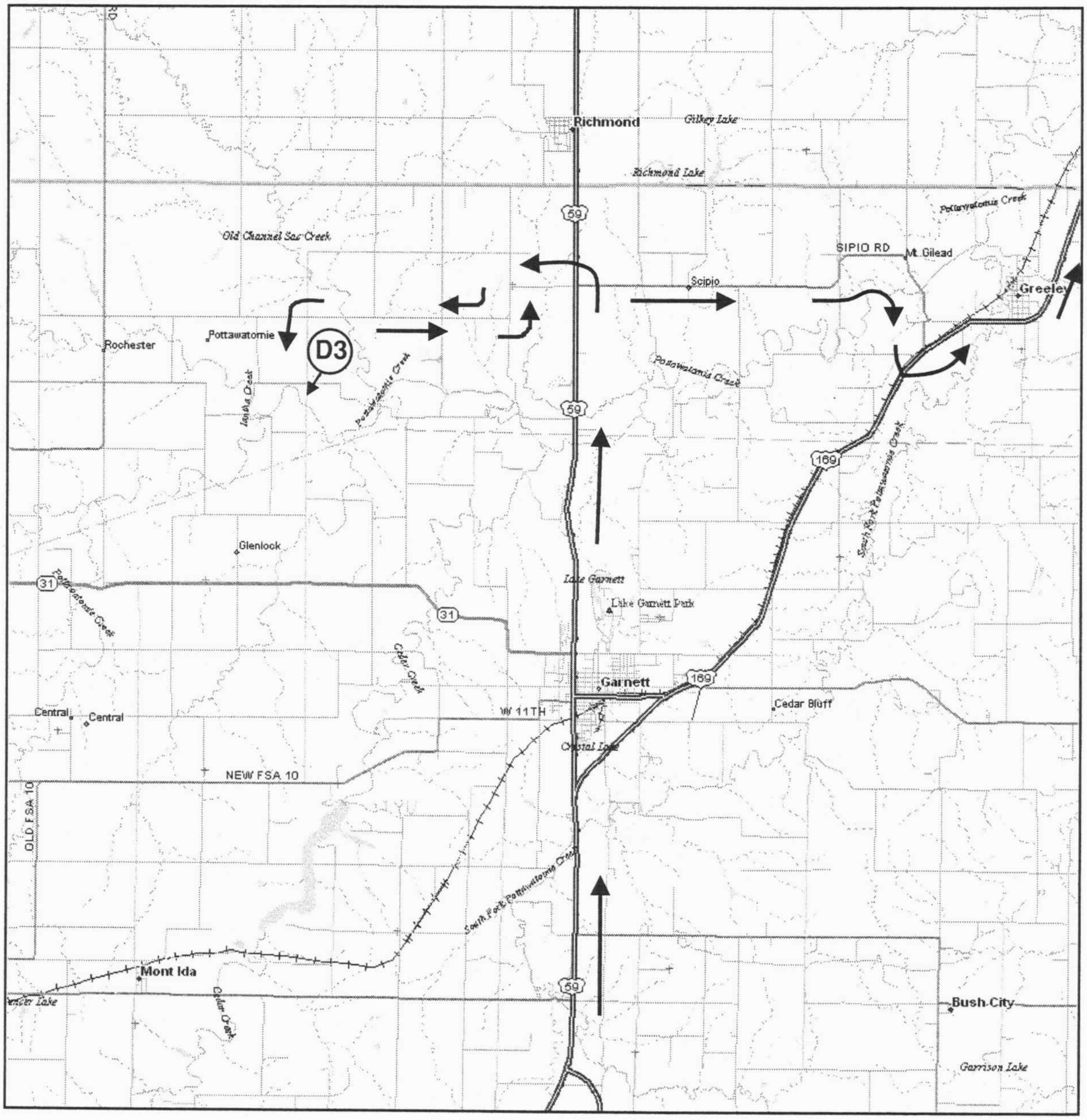
This stop shows the **Toronto Limestone** and **cyclothem** (named from here), the **second major marine unit** of the **Virgilian Stage**.

Top of Lawrence Formation (named from northeastern Kansas) is a paleosol overlain by a coal and marks the lower sequence boundary of the Toronto cyclothem.

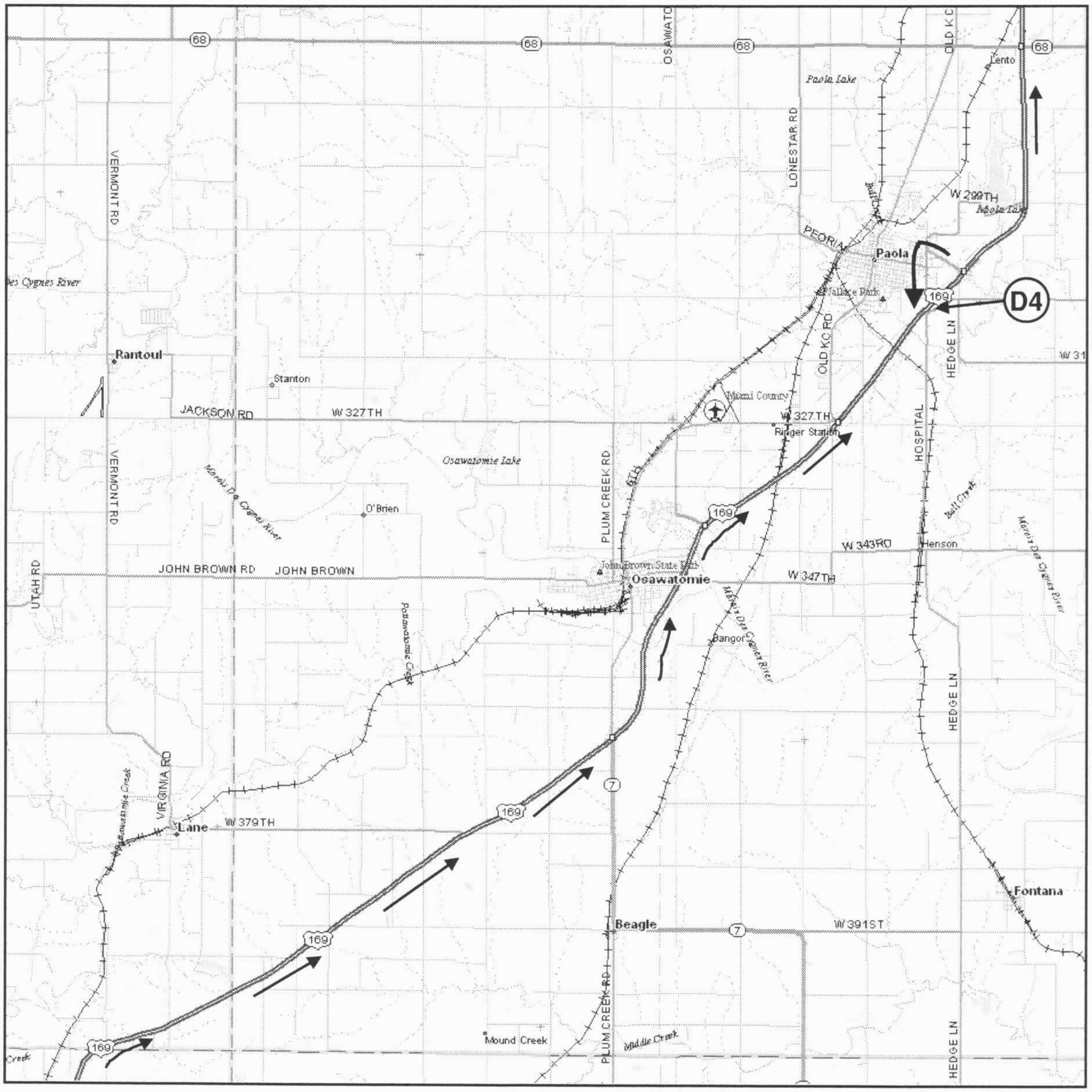
Toronto Limestone is continuous from Nebraska to southern Kansas. It is transgressive in the lower part and contains a thin fossiliferous conodont-rich shale (dominated by *S. pawhuskaensis*) in the middle, the condensed interval that marks it as an intermediate cyclothem. The upper part shallows upward to mollusc-dominated wackestone (Troell, 1969) which is not exposed here.

Snyderville Shale (exposed nearby) is red paleosol mudstone that marks the upper sequence boundary.

Leave Stop D2 at 12:20 PM


Richmond
Gilkey Lake
Richmond Lake
59
Old Channel Sac Creek
SIPIO RD
Mt. Gilead
Pottawatomie Creek
Scipio
Greeley
Rochester
Pottawatomie
D3
Pottawatomie Creek
169
Glenlock
31
Lake Garnett
Lake Garnett Park
Garnett
W 11TH
Cedar Bluff
Central
Central
NEW FSA 10
OLD FSA 10
South Fork Pottawatomie Creek
Mont Ida
Bush City
Garrison Lake

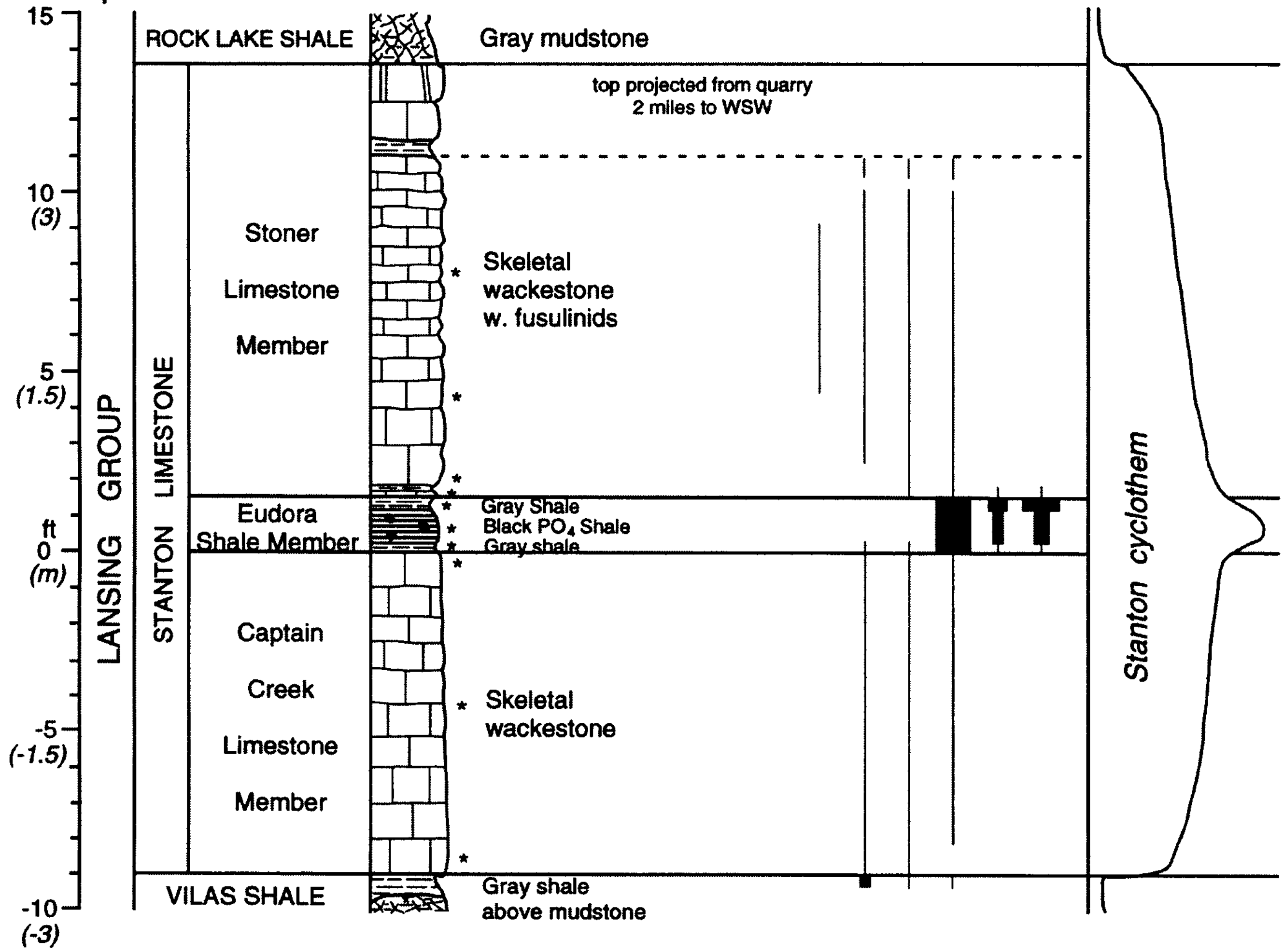
Stop D3



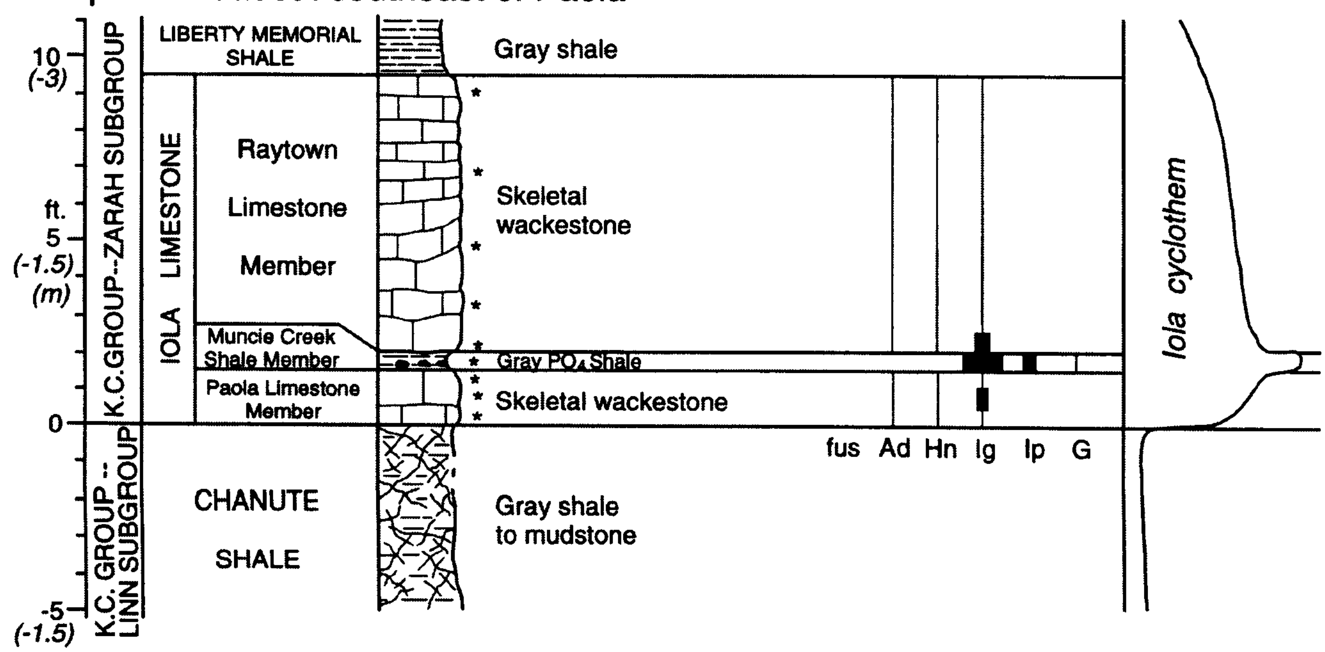
68
OSAWATO
Paola Lake
OLD K C
Lento
LONESTAR RD
VERMONT RD
W 299TH
Paola Lake
PEORIA
Paola
Des Cygnes River
Wallace Park
169
D4
OLD KC RD
HEDGE LN
W 31
Rantoul
Stanton
Miami County
JACKSON RD
W 327TH
W 327TH
Ranger Station
Osawatomie Lake
PLUM CREEK RD
HOSPITAL
VERMONT RD
Marais Des Cygnes River
O'Brien
Bull Creek
W 343RD
Henson
UTAH RD
JOHN BROWN RD
JOHN BROWN
John Brown State Park
Osawatomie
W 347TH
Pottawatomie Creek
Bangor
Marais Des Cygnes River
HEDGE LN
VIRGINIA RD
W 379TH
Lane
7
Fontana
Beagle
W 391ST
PLUM CREEK RD
Mound Creek
Middle Creek
HEDGE LN

Stop D4

Stop D3: Roadcut north of Pottawatomie Creek



Stop D4: Roadcut southeast of Paola



[Drive 74 miles: E on US-54 to Iola, N on US-169, N on US-59 through Garnett, 5.5 miles N of K-31 jct., W 4.5 miles (with S-ward jog) on gravel roads, S 1.3 miles to bluff above Pottawatomie Creek] (100 min.)

STOP D3: Roadcut N of Pottawatomie Creek. (ctr. W line NW 4, T 20 S, R 19 E, Anderson Co., Ks) (40 min.)

[Beware of poison ivy]

This stop shows the middle of the **Stanton Limestone** and **cyclothem**, the **tenth major marine unit above the base of the Missourian Stage**, which we viewed above the Plattsburg Limestone at Stop A6 on the first day. At this locality the core shale is thinner and the black facies somewhat easier to disaggregate.

Vilas Shale (named from southeastern Kansas) is a thin mudstone (not exposed here) above an algal-mound complex in the upper part of the Spring Hill Member of the Plattsburg Limestone, and is probably mostly a paleosol marking the sequence boundary between the Plattsburg and Stanton cyclothems.

Captain Creek Limestone Member (named from northeastern Kansas and extending from Iowa and Nebraska to northern Oklahoma) is the transgressive limestone of the Stanton cyclothem. It is generally thicker than all other transgressive limestones in Kansas and it contains more phylloid algae, suggesting that it resulted from a slower than usual transgression that allowed a longer time in the photic zone for algae to produce more carbonate mud. It contains conspicuous brachiopods (including *Enteletes*) and fusulinids (most common in the base), including *Kansanella neglecta*, described by Newell (1934) from this unit northeast of here.

Eudora Shale Member (named from northeastern Kansas) is the 'core' shale condensed interval of the Stanton cyclothem deposited at highstand, which is traceable from Iowa and Nebraska some distance into Oklahoma. It comprises lower and upper gray shale facies separated by black phosphatic facies in the middle that disappears southward in Kansas above the thickest, most algal facies of the Captain Creek. The lower gray shale bed contains the first appearance of *Idiognathodus simulator* along with ungrooved possibly ancestral forms, and the last appearances of *Streptognathodus elegantulus, S. gracilis, S. corrugatus,* and *S. excelsus*. The middle black facies is strongly dominated by *I. simulator*. The upper gray shale bed is dominated by *I. simulator* and large numbers of *Gondolella*, and contains the first appearance of *Streptognathodus firmus*.

Stoner Limestone Member (named from Nebraska and continuous into southern Kansas) is the regressive limestone of the Stanton cyclothem, generally skeletal wackestone shallowing upward to grainstone or mudstone, often with rooting structures at the top. It contains abundant brachiopods and echinoderm debris in the thin shale just above the base, and fusulinids of the common triticitid lineages about 3 to 5 ft (1.5 m) above.

Rock Lake Shale (named from Nebraska and traced into Oklahoma) is not exposed here, but typically is a thin mudstone paleosol that contains the sequence boundary between the Stanton and South Bend cyclothems. Just northwest of here, in a channel eroded into the Stoner, the notable Garnett biotic assemblage that includes plants and vertebrates classified in the Rock Lake Shale, is actually preserved in the early transgressive deposits of the South Bend cyclothem where they were protected by the channel morphology from transgressive erosion.

Leave Stop D3 at 2:40 PM

[Drive 40 miles: N 1.2 mile, E 4.5 miles (jogging N) on gravel roads, across US-59 on paved road, joining US-169 N, continuing to exit W on K-263 ~0.75 mile, S on Hospital St., E across bridge over US-169] (60 min.)

STOP D4: Roadcut SE of Paola. (E half NW-NW sec. 22, T 17 S, R 23 E, Miami Co., Ks) (30 min.)

[Please be careful crossing this road]

This stop shows the **Iola Limestone** and **cyclothem**, the **seventh major marine unit of the Missourian Stage**, in an exposure that is more easily collected than where we viewed it near Stop A4.

Chanute Shale (named from southeastern Kansas) is thicker here and southward than where we first saw it at Stop A4 in northeastern Kansas. It contains mudstone with fractured limestone nodules near the top, probably a paleosol marking the sequence boundary at the base of the Iola cyclothem.

Paola Limestone Member (named from here and traced from Iowa to Oklahoma) is the transgressive limestone of the Iola cyclothem, with skeletal packstone at the base and skeletal wackestone upward.

Muncie Creek Shale Member (named from northeastern Kansas and the condensed interval 'core' shale of the Iola cyclothem) is a thin fossiliferous gray shale with abundant phosphate nodules over the area of thicker Chanute in east-central Kansas, apparently positioned above the thermocline even at highstand. Its invertebrate fauna includes diverse brachiopods. Its abundant conodont fauna is dominated by *Streptognathodus gracilis, S. excelsus*, and *S. elegantulus* (which were described from its Texas equivalent), and includes at least 2 lineages of *Idiognathodus* ('postmagnificus' and a coarsely ribbed triangular form) along with *Idioprioniodus* and *Gondolella*.

Raytown Limestone Member (named from Missouri) is the regressive limestone of the Iola cyclothem. Thompson (1957) reported *Kansanella tenuis* from the Iola nearby, but fusulinids are sparse at this exposure.

Leave Stop D4 at 4:10 PM

[Drive 65 miles: back to & N on US-169, N on I-35, W & N on I-435, N on I-29 to **Comfort Inn** by 5:30 PM]

OVERVIEW OF PENNSYLVANIAN (UPPER CARBONIFEROUS) STRATIGRAPHY IN MIDCONTINENT REGION OF NORTH AMERICA

Philip H. Heckel, Department of Geology, University of Iowa, Iowa City, Iowa 52242

PALEOGEOGRAPHIC AND PALEOCLIMATIC SETTING

During Pennsylvanian (Late Carboniferous) time, North America and most of Europe (Euramerica) were joined with 'Gondwana' by means of the Appalachian-Hercynian orogeny, to become the northern part of the assembling supercontinent 'Protopangaea'. On the northwestern side of this large continent (Fig. 1A), the North American Midcontinent Sea at sea-level highstand covered the greater part of the present United States from the Appalachian Basin across the Midwest through the Rocky Mountain states and opened westward to northwestward into the Protopacific Ocean ('Panthalassa'). On the northeastern side of this continent, the somewhat analogous Russian Platform Sea covered most of European Russia up to the rising Uralian highlands. These two large epicontinental seas were connected around the north end of Protopangaea via Spitsbergen and Arctic and western Canada. South of the Russian Platform was the rapidly subsiding Dniepr-Donets Basin, at least partly separated from the southeastern ocean ('Tethys') by orogenic land. Along the rim of this ocean, Pennsylvanian rocks exposed today were deposited in the area of the Carnic Alps in the Austrian-Slovenian border region and in the Cantabrian Basin of north-central Spain. Marginal marine rocks of the Sydney Basin of Nova Scotia may have been connected with the open ocean via the Cantabrian Basin.

At sea-level lowstand, most of the Midcontinent and Russian Platform seas, along with the Donets Basin and the marginal areas around the north end of Protopangaea were subaerially exposed, as indicated by widespread surfaces of subaerial exposure with various combinations of paleosols, coals, and terrestrial clastic deposits. Only the region of the Carnic Alps and deeper parts of the Cantabrian Basin, the foredeep along the Urals, and the Arkoma-Anadarko and Midland Basin complex along the orogenic Ouachita end of the Appalachian highlands at the southwestern end of the North American Midcontinent Sea, remained continually under marine water.

Detrital clastics and coals dominate the Appalachian, Sydney and Donets Basins, and the west end of the Cantabrian Basin, near orogenic highlands along or near the paleoequator in the humid equatorial zone. Thick carbonates dominate the east end of the Cantabrian basin and the Carnic Alps, away from the sources of detrital influx in this zone. Carbonates that locally contain evaporites dominate the Russian Platform, Spitsbergen, Arctic and western Canada, and the northern to western ends of the North American Midcontinent Sea in the tropical trade-wind to subtropical zone north of the equator. Alternating carbonate and terrestrial clastic deposits characterize the central eastern part of the Midcontinent Sea from Kansas to Illinois, and much of the Donets Basin in the transition zone between the humid equatorial and the dry trade-wind belts.

BASINS OF CENTRAL AND EASTERN UNITED STATES

Pennsylvanian deposits of the North American Midcontinent Sea are now exposed in several separate large, shallow structural basins in the eastern and central United States (Fig. 1B), and in a number of smaller, more tectonically disturbed structural basins in the western United States. The larger basins include the Appalachian Basin, Michigan Basin, Illinois Basin, and Midcontinent Basin. In addition, a series of basins extending across the subsurface of west Texas (including the Midland Basin) were deep enough to have provided the main connection between the other basins and the Panthalassan Ocean at all stands of sea level. The eastern shelf of the Midland Basin is exposed in north-central Texas. It is apparent from the similarities of marine faunas that all these basins were connected at higher stands of sea level (Fig. 1A).

The **Appalachian Basin** comprises essentially the western half of the state of Pennsylvania (from which the name of the subsystem is derived), southeastern Ohio, nearly all of West Virginia, eastern Kentucky, central eastern Tennessee, north-central Alabama (where it is called the Warrior Basin), and small parts of adjacent states (Fig. 1B). The early to early middle Pennsylvanian succession of mainly shale, sandstone, and coal, with a number of sparsely to richly fossiliferous marine zones, is particularly thick, well-developed and fairly complete in

Heckel, P. H., 1999, Overview of Pennsylvanian (Upper Carboniferous) stratigraphy in midcontinent region of North America; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 68–102.

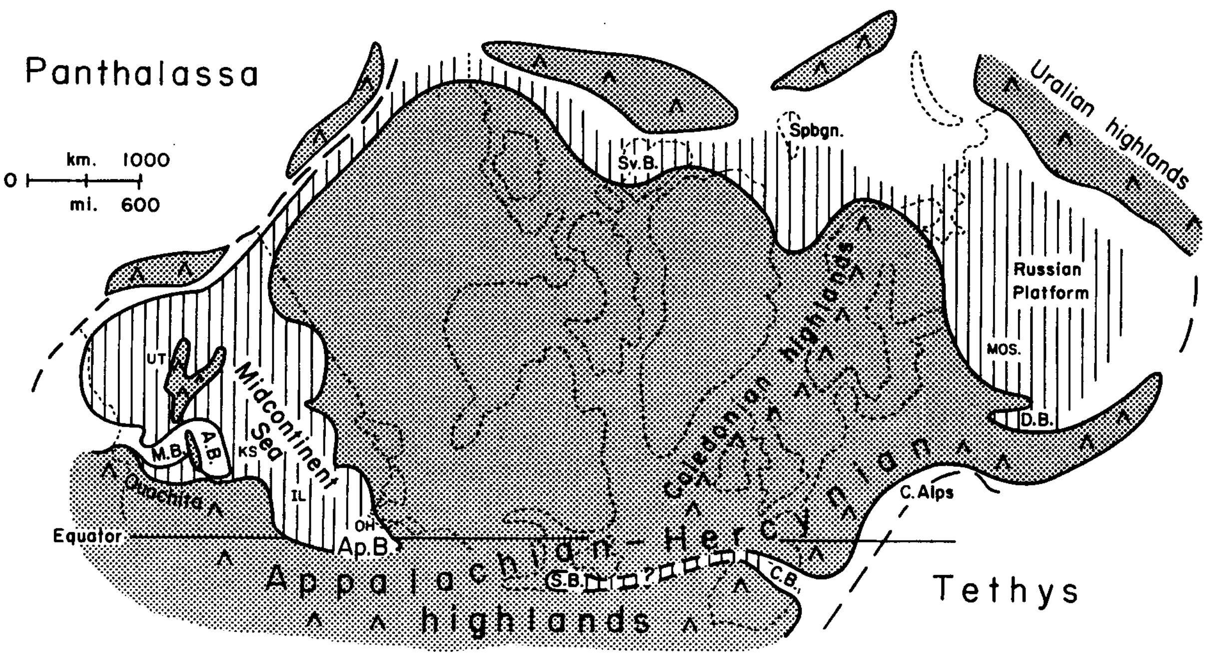


Fig. 1A: Interpreted paleogeography of northern (Euramerican) end of Protopangaea during late Middle to Late Pennsylvanian time, showing land (dots), maximum extent of epicontinental seas at highstand (lines), and minimum extent at lowstand (blank), modified from Heckel (1995) by Nikishin et al. (1996) for east Europe. A.B.= Arkoma-Anadarko Basins; Ap.B= Appalachian Basin; C.Alps= Carnic Alps; C.B.= Cantabrian Basin; D.B.= Dniepr-Donets Basin; M.B.= Midland Basin; Spbgn= Spitsbergen; Sv.B.= Sverdrup Basin.

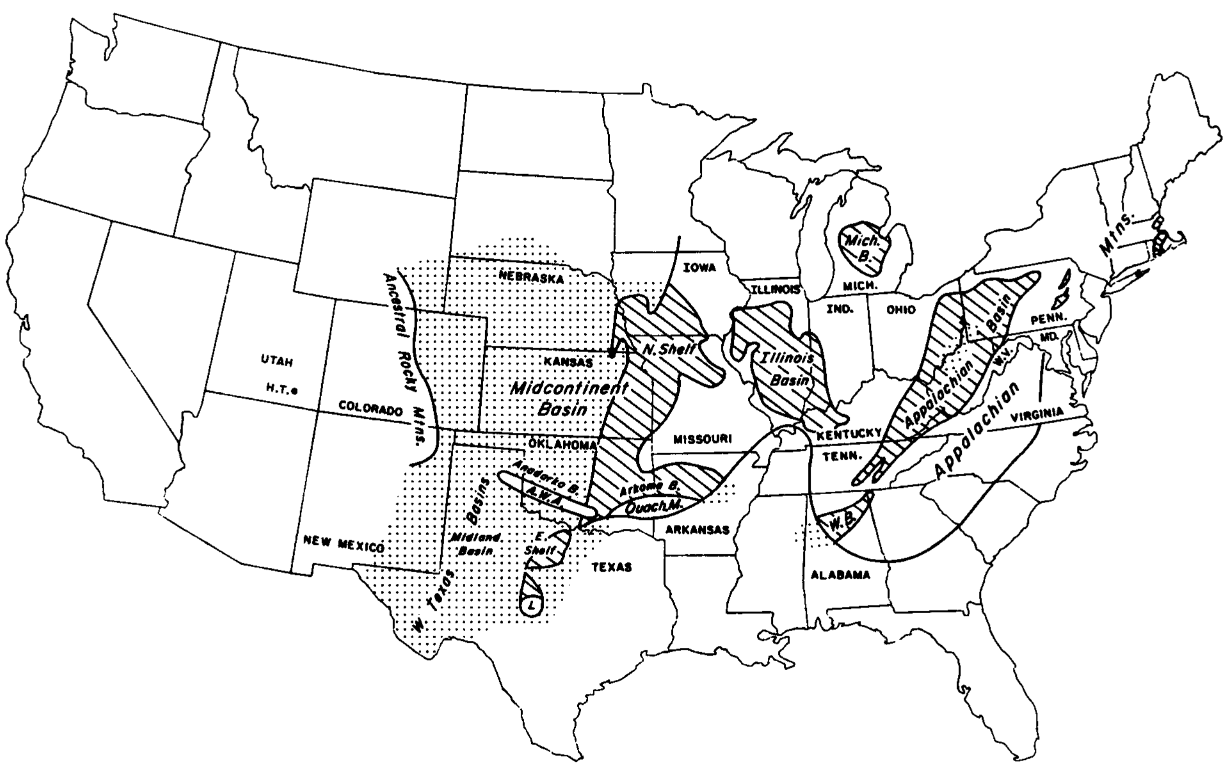


Fig. 1B: Distribution of Pennsylvanian rocks in outcrop (lined) and subsurface (dots) in basins of central and eastern United States, compiled from U.S. Geological Survey Professional Paper 1110 and Moore (1958, p. 236-237). AWA= Amarillo-Wichita-Arbuckle Uplift; L= Llano Uplift; H.T.= Honaker Trail; W.B.= Warrior Basin.

the southern part of the Appalachian Basin from Alabama through eastern Kentucky into southern West Virginia. This reflects the major filling of the foreland basin that developed adjacent to the rising Appalachian highlands during this time. The late middle to late Pennsylvanian succession also consists mainly of shale, sandstone, and coal, but is overall much thinner, contains more thin marine to nonmarine (upward) limestones, and is confined to the northern part of the basin in Pennsylvania, Ohio, northeastern Kentucky, northern West Virginia, and westernmost Maryland. It is also characterized by widespread well-developed paleosol mudstones (with and without overlying coals) that attest to large-scale subaerial disconformities throughout the basin during this time. Combined with the thinness of the overall succession, these paleosols reflect a lessening of subsidence and net accommodation space throughout the later part of Pennsylvanian time in this basin.

The **Michigan Basin** covers the middle of the lower part of Michigan. The Pennsylvanian succession here is very poorly exposed, and consists mainly of shale and sandstone with local coal beds in cyclical sequences. The one marine limestone that has been dated is early middle Pennsylvanian in age.

The **Illinois Basin** (sometimes called the Eastern Interior Basin) covers most of the state of Illinois (Fig. 1B, 2) and adjacent parts of southwestern Indiana and western Kentucky. The early to early middle Pennsylvanian succession here is mainly sandstone and shale with some coal, and is thickest and best developed in the southern, deeper part of the basin. The late middle to late Pennsylvanian succession consists largely of alternating sequences of shale, mudstone, coal, limestone, and more local sandstone, which are well developed throughout the basin but thicker in the southern part. This is the succession from which cyclothems were first described and named.

The **Midcontinent Basin** (sometimes called the Western Interior Basin) covers the entire state of Kansas, most of Nebraska, southwestern Iowa, northwestern Missouri, northern and central Oklahoma, west-central Arkansas (fig. 2), and extends westward into eastern Colorado up the east side of the Ancestral Rocky Mountains (Fig. 1B), which is essentially the east side of the current Front Range. The northern and central part of this basin was relatively shallow, and is referred to as the 'Northern Midcontinent Shelf' (Fig. 2). Structural features denoted within this region (Nemaha Uplift, Forest City Basin, and Bourbon Arch) were active mainly during the earlier part of Pennsylvanian time, and the latter two exerted only very subtle, if any, influence over later Pennsylvanian deposition. Southward in central Oklahoma and adjacent Arkansas, this basin became a foredeep, a truly basinal region, which is termed Arkoma Basin to the east, north of the Ouachita orogenic Mountains, and Anadarko Basin to the west, north of the Arbuckle Uplift and its westward extension, the Wichita-Amarillo Uplift. These two basins were filled with sediment from east to west during Pennsylvanian time. South of the Arbuckle Uplift is the Ardmore Basin, which, although small (and not shown on Figure 2), was active throughout Pennsylvanian time.

PENNSYLVANIAN REGIONAL STAGES

The Midcontinent Basin is the region in which the North American regional series/stage names became established. Through study of various fossil groups, these subdivisions have become recognized throughout much of the United States and in some nearby regions. Early work used fusulinids, then ammonoids and palynomorphs, when and where they were recovered, and most recently, conodonts are being used to refine the previous correlations. Although initially regarded as series by most workers, these subdivisions were regarded as stages by Moore and Thompson (1949) and by the Kansas Geological Survey since the 1960s (Zeller, ed., 1968). I am regarding them as regional stages based on proposals made to the Calgary meeting of the SCCS (Heckel, Villa, and others, 1999). The regional stages are, in ascending order: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The Morrowan has generally been considered lower Pennsylvanian, the Atokan and Desmoinesian considered middle Pennsylvanian, and the Missourian and Virgilian considered upper Pennsylvanian, but in keeping with the proposals mentioned above, exact boundaries of the Lower, Middle, and Upper Pennsylvanian Series will not be selected until global correlation is established.

The **Morrowan Stage** was derived from the Morrow formation named by Adams and Ulrich (1904) from a town in northwestern Arkansas. It comprises about 300-400 ft (~100 m) of fossiliferous shale, sandstone and limestone in its type region, thinning westward to mainly limestone in northeastern Oklahoma. It is a thicker succession of shale, limestone and sandstone on the north side of the Arbuckle Uplift in south-central Oklahoma. It is largely confined to the more basinal region of the Midcontinent Sea (Fig. 2). On the Northern Midcontinent Shelf, it is known mainly in local exposures of coal-bearing shale and sandstone that appear to be paleovalley fillings, and which are identified as Morrowan by means of palynomorphs. This distribution reflects the widespread Mississippian-Pennsylvanian unconformity in the shelf areas of North America, and is analogous to the absence of Bashkirian (~lower Pennsylvanian) deposits across the Moscow region of the Russian Platform (Fig. 1A).

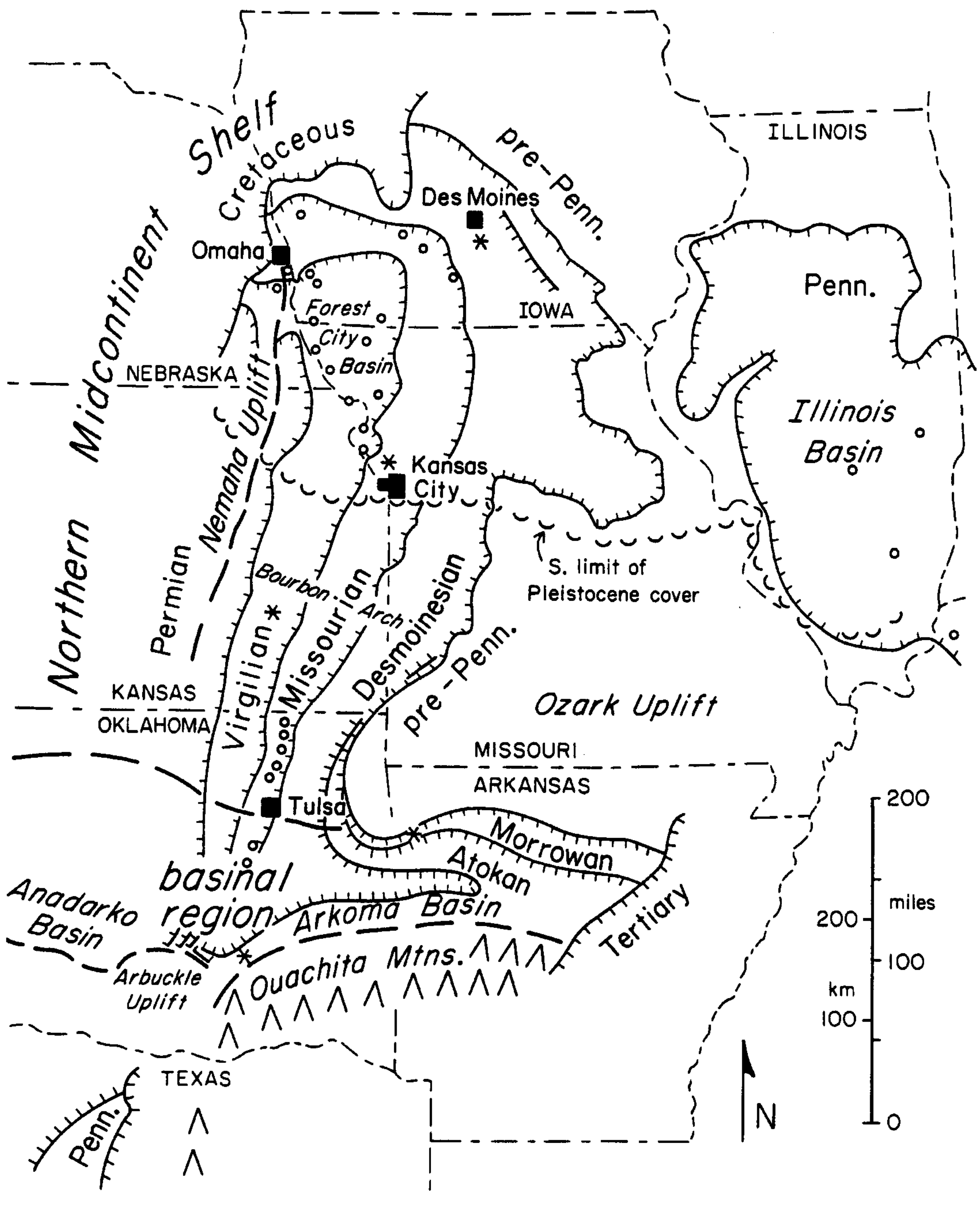


Fig. 2: Midcontinent Pennsylvanian outcrop belt showing outcrop of regional stages, with hachures in direction of dip, asterisks showing type areas, and circles showing location of long cores. Nemaha Uplift and Forest City Basin were formed in Early Pennsylvanian, remained active through much of Middle Pennsylvanian, and became part of Northern Midcontinent Shelf by Late Pennsylvanian time (modified from Heckel, 1990).

The Morrowan was regarded as a series in the 1930s to 1940s (e.g., Moore et al., 1944; Cheney et al., 1945) or a stage of a lower Pennsylvanian series termed Ardian (Moore and Thompson, 1949), a designation that never attained common usage. It has been considered the zone of *Millerella* in which this primitive fusulinid occurs by itself, and it also is characterized by reticuloceratid and schistoceratid ammonoids. Its base in its type region appears to be disconformable, but its base is now defined by the Mid-Carboniferous boundary in Nevada.

The **Atokan Stage** was derived from the Atoka formation, named by Taff and Adams (1900) from a town in southeastern Oklahoma. It dominates the foreland

Arkoma Basin (Fig. 2), where it comprises up to 12,000 to 20,000 ft (3600-6000 m) of sparsely fossiliferous shale, with sandstone and coals particularly to the east. It thins abruptly northward in northeastern Oklahoma, and has been recognized in places on outcrop in Missouri and Iowa, where it is manifest as cyclothems and has been identified by palynomorphs and scattered marine fossils. Although primarily basin filling, Atokan rocks show a certain amount of transgression of the northern shelf.

The Atokan was regarded as a series (Moore, 1948) or a stage of a middle Pennsylvanian series termed Oklan (Moore and Thompson, 1949), another designation that never attained common usage. The terms Bendian, Lampasan and Derryan were used for a while for rocks of this age based on more fossiliferous exposures in Texas and New Mexico. The Atokan has been considered to comprise the zones of *Profusulinella* and *Fusulinella* (Moore and Thompson, 1949). Its base appears to be disconformable in its type region, and the problems with both lower and upper boundaries of the Atokan have been extensively discussed in a symposium edited by Sutherland and Manger (1984).

The **Desmoinesian Stage** was derived from the Des Moines formation named by Keyes (1893) from outcrops along the Des Moines River in central Iowa. This unit comprises a succession of cyclic shales, limestones, coals, and sandstones that cover the Northern Midcontinent Shelf (Fig. 2). It ranges from 600 to 750 ft (180-225 m) in thickness along outcrop in Kansas, thinning slightly northward along outcrop into Iowa, but thickening into the subsurface Forest City Basin of southwestern Iowa and adjacent Missouri (Fig. 2). It thickens southward substantially to perhaps 6600 ft (2000 m) in the Arkoma Basin in central Oklahoma where it is dominated by shale and sandstone.

The Desmoinesian was regarded as a series by most authors in the 1940s, and as the upper stage of the little used middle Pennsylvanian Oklan Series by Moore and Thompson (1949). It has been considered the zone of *Fusulina (Beedeina)*, and is also characterized by the presence of arborescent lycopods and their palynomorphs (Peppers, 1996), the brachiopod *Mesolobus*, the conodont *Neognathodus*, and the coral-like chaetetid sponges (all of which appeared earlier), and by various ammonoid genera. Its base is disconformable upon rocks that are biotically determined to be Atokan in its type area in Iowa (Lambert and Heckel, 1990), but it may be able to be designated more rigorously in a more basinal and continuous marine section in east-central Oklahoma (D.R. Boardman, personal communication, 1997).

The **Missourian Stage** was derived from the Missouri 'terrane' or formation named by Keyes (1893) for exposures along the Missouri River in Iowa and Missouri. It also covers the Northern Midcontinent Shelf (Fig. 2) and comprises about 650 ft (~200 m) of mainly limestone and shale with some sandstone in eastern Kansas, thinning northward to about 500 ft (150 m) in Iowa. It thickens southward into the basinal region of central Oklahoma, where it extends westward into the subsurface of the Anadarko Basin. On the northern shelf, the Missourian Stage contains well developed classic limestone-dominated cyclothems with distinctive dark phosphatic shale members that can be traced southward into the basinal region of central Oklahoma where the limestones disappear.

The Missourian was regarded variously as a stage or series by earlier authors, and was considered the lower stage of the upper Pennsylvanian Kawvian Series by Moore and Thompson (1949), a designation that (like the other series names of that publication) received little common usage. It has been considered the lower part of the fusulinid zone of *Triticites* (even though that genus does not occur in its lower three major marine units, and no large fusulinids occur in the lower two: Thompson, 1957). It is more generally characterized by the loss of the distinctive Desmoinesian taxa mentioned above (arborescent lycopods, chaetetids, *Mesolobus*, and *Neognathodus*), as well as by the appearance of evolving ammonoid (*Pennoceras*) and conodont (*Streptognathodus s.s.*) lineages. The Desmoinesian-Missourian boundary marks a distinctive biostratigraphic extinction event across much of North America, and the base of the Missourian was originally defined at a disconformity in the type area in the Missouri River valley (Moore, 1936), reflecting the much different chronostratigraphic procedure in those days. Our group recognizes the Desmoinesian-Missourian boundary at the first appearance of eccentrically grooved *Idiognathodus eccentricus* (Heckel, Boardman and Barrick, this guidebook). The boundary stratotype in northern Oklahoma (Stop B8) is placed at the base of a black shale that is the basinal equivalent of the Exline Limestone (Fig. 3), which lies in the Pleasanton Group on the northern shelf. This position is in the lower part of the Tacket Formation (the basinal equivalent of part of the Pleasanton and Kansas City Groups) some distance in a continuous marine succession above the appearance of partially grooved morphotypes of its ancestor, *I. sulciferus* in the base of the South Mound Shale (which is a member of the Checkerboard Limestone in Oklahoma).

The **Virgilian Stage** was established as a series by Moore (1932, named after a town in east-central Kansas) to encompass the upper part of the original Missourian unit above what was considered to be a major disconformity. The Virgilian is best developed on the northern shelf where it is about 1400 ft (420 m) of shale and limestone with subordinate sandstone, and well organized into limestone-dominated cyclothems like those of the Missourian in the lower part. It changes little in thickness into Oklahoma where it becomes dominated on outcrop by sandstone and conglomerate representing late stages of basin filling from the uplifts to the south.

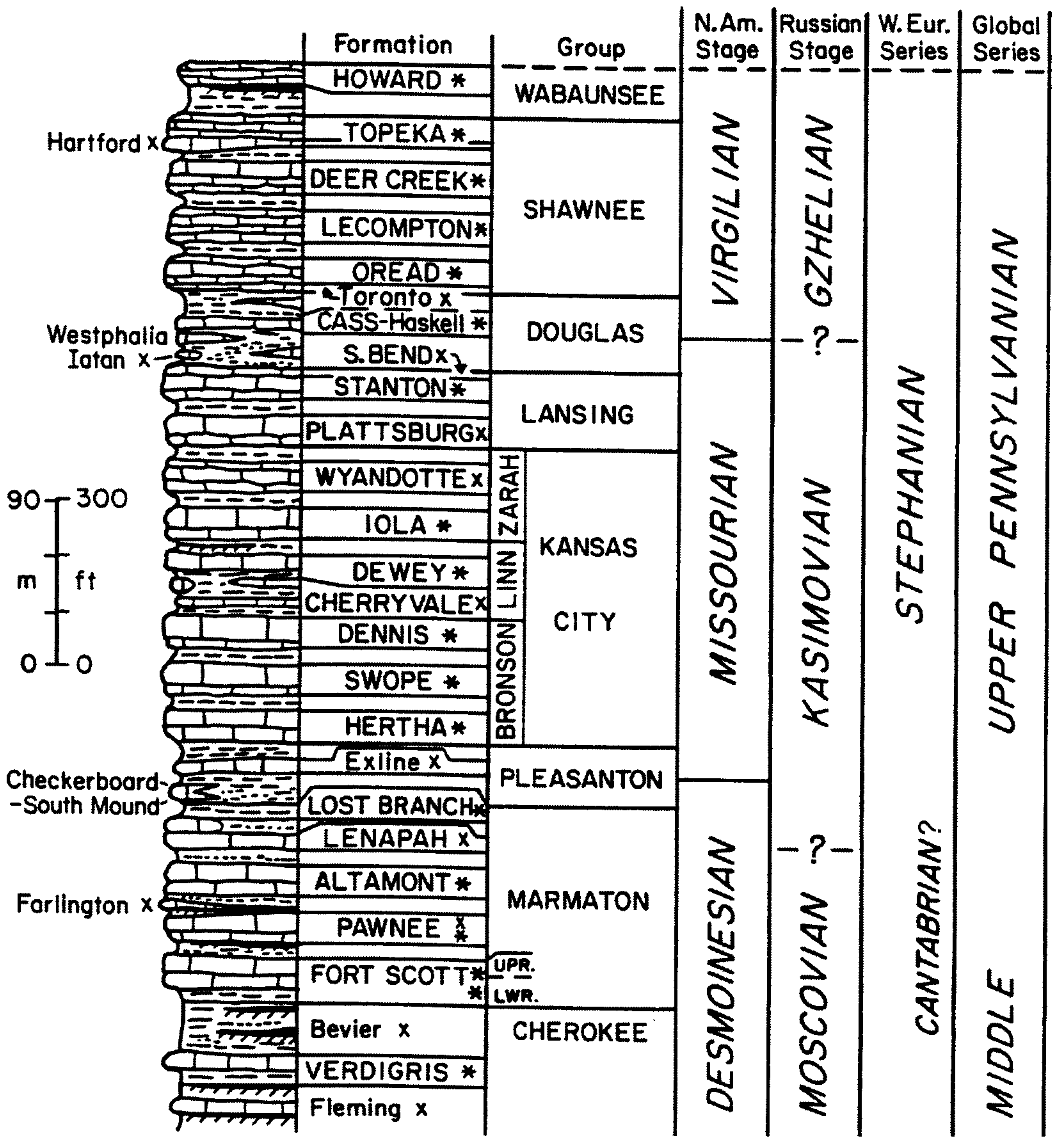


Fig. 3: Late Middle through mid-Upper Pennsylvanian lithostratigraphic succession on Northern Midcontinent Shelf, with groups and cyclothem-dominated formations in capital letters, and cyclothem-defining members in lower case, modified from Heckel (1990). * marks major cyclothems; x marks cyclothems of intermediate scale; intervening shale formations generally left blank. Names of chronostratigraphic units are slanted, and their inferred correlation is based on Heckel et al. (1998) supplemented by further interpretations in 1999. Approximate scale is for eastern Kansas, with limestones expanded at expense of shales.

The Virgilian was regarded as the upper stage of the little used upper Pennsylvanian Kawvian Series by Moore and Thompson (1949), and it forms the top of the Pennsylvanian Subsystem in the United States. It has been considered as the upper part of the fusulinid zone of *Triticites*, and its biotas of most fossil groups are only slightly changed from those of the Missourian. Its base was originally defined at a disconformity (Moore, 1936), which later was not able to be traced laterally (O'Connor, 1963). Our group currently recognizes the Missourian-Virgilian boundary in the lower part of the Cass -Haskell cyclothem (Fig. 3) in the middle of the Douglas Group, at the first appearance of a distinctive lobed morphotype of *Streptognathodus, S. zethus*, above units containing morphotypes of *S. pawhuskaensis* that may be ancestral to *S. zethus*. This boundary has a provisional stratotype at the spillway to Woodson County State Lake (Stop D1), pending discovery of a more continuous marine section from the unit with ancestral forms below.

It is apparent that the upper three regional stages of the North American Pennsylvanian (Desmoinesian, Missourian, and Virgilian) are well developed across the Northern Midcontinent Shelf from Iowa to northern Oklahoma. Although their surface exposure is generally covered by Pleistocene glacial deposits north of the latitude of Kansas City, their rocks are well exposed in numerous large quarries in that area, and long cores in southwestern Iowa and northwestern Missouri (Fig. 2) have allowed accurate correlation throughout this region. South of the limit of Pleistocene cover, the resistant limestone units form east-facing escarpments across eastern Kansas and adjacent Missouri into northern Oklahoma, which provide for numerous streamcuts, long roadcuts and many quarries. These exposures have allowed the tracing of major units into the basinal region. More recent recognition and repeated checking of the distinctive conodont faunas of the thin dark phosphatic shales has allowed the tracing of these thin widespread units, which has resulted in rectification of some earlier miscorrelations across this area of both subtle and abrupt facies changes on the lower shelf and the margin of the basinal region.

Paleosols and their attendant disconformities disappear southward at various distances into the Midcontinent Basin. This is in contrast to the Illinois Basin where paleosols, usually with coals, tend to persist into the deeper parts of the basin. It stands in particular contrast to the Appalachian Basin at this time, where this part of the succession is much thinner (Heckel, 1994), has fewer marine units and more well-developed paleosols that appear to extend across the entire basin. The Appalachian Basin at this time was apparently an apron of deposition (and erosion) on a relatively high shelf at the foot of Appalachian highlands that were less active than earlier. Therefore the only appropriate place to select regional stage boundaries of this part of the Pennsylvanian is in the basinal to basin marginal lower shelf region of the Midcontinent Basin, where exposures of continuously deposited marine successions up through several cycles of sea-level fluctuation are available.

TYPES OF STRATIGRAPHIC UNITS

The North American Stratigraphic Code of 1983 recognizes several types of stratigraphic classification and nomenclature, each oriented toward a particular set of purposes. The basic type is **lithostratigraphic** in which units of similar lithology are recognized as groups, formations, and members for purposes of geologic mapping, economic resource evaluation, and environmental management. Familiar to all geologists are **chronostratigraphic** units in which units of similar age are recognized as systems, series, and stages, and the parallel **geochronologic** units of geologic time recognized as periods, epochs, and ages.

Less well known are **allostratigraphic** units, which are defined and identified on the basis of their bounding discontinuities. These are units that may contain a variety of lithologies and fossils, but are unified by the inference that they resulted from a single episode of deposition that was separate from episodes of deposition represented by the allostratigraphic units above and below them. In the marine realm, these units are the 'stratigraphic sequences' of the more recently developed concepts of sequence stratigraphy, which are bounded by subaerial disconformities or their correlative basinward conformities that are often marked by stratigraphic discontinuities. In the context of glacial-eustatically controlled Pennsylvanian stratigraphy, cyclothems are allostratigraphic units that are transgressive-regressive 'stratigraphic sequences' resulting from a glacial-eustatic rise and fall of sea level. The classic cyclothems of the Illinois Basin and the northern shelf of the Midcontinent Basin are essentially the shelf manifestation of a 'stratigraphic sequence'. It is well worth noting that Wanless and Weller (1932) who coined the term 'cyclothem' for a "series of beds deposited during a single sedimentary cycle...", and Wanless and Shepard (1936) who recognized the cyclothem as the product of a glacially controlled rise and fall of sea level, introduced these 'modern' concepts more than 60 years ago.

Much of the Pennsylvanian succession in the Illinois Basin was classified into cyclothems before the lithostratigraphic classification of Kosanke at al. (1960) was introduced to facilitate geologic mapping because the lithically heterogeneous and often shale-dominated cyclothems there were difficult to map individually. The cyclothemic classification is still officially recognized there as a parallel classification with its own set of cyclothem names that often are different from the lithostratigraphic names, but which facilitate the interpretation of depositional history. Certainly cyclothems that are biostratigraphically distinct from one another provide a powerful tool for correlation and ultimately accurate interpretation of geologic history.

In the northern Midcontinent states of Kansas, Missouri, Iowa, and Nebraska, the limestone-dominated cyclothems are mostly lithically distinct enough that the lithostratigraphic classification that was developed there recognized most of them as individual limestone formations (see Fig. 3). This classification was largely formulated by Moore, 1936, with an apparent intent of defining genetically useful units (and quite successfully, in my opinion). In some places the cyclothem boundary is coincident with the formation boundary, though more often the cyclothem boundary lies somewhere within the intervening shale formations. Most cyclothems there are named after the limestone formation that encompasses the bulk of its deposits, but some cyclothems there are named after members or positional parts of formations that encompass more than one cyclothemic unit, as will be seen on the diagrams for the field trip stops.

MAJOR LITHOSTRATIGRAPHIC UNITS ON THE NORTHEN MIDCONTINENT SHELF

The entire Desmoinesian, Missourian and Virgilian succession on the Northern Midcontinent Shelf is subdivided lithostratigraphically into about 60 formally defined formations, most of which are subdivided into members that reach a total of about 150. These are combined into ten groups (of which the lower eight are shown on Fig. 3), for which the distinguishing lithic features are summarized below, in ascending order. The formations and members that will be visited will be described in the context of the cyclothem descriptions further below and in the descriptive text for the field trip stops.

The **Cherokee Group** is the basal major Pennsylvanian unit across the northern Midcontinent shelf, lying with erosional contact above various Mississippian and locally older formations. It encompasses the strata of the lower part of the Desmoinesian Stage and apparently includes Atokan strata at the base in many places. It comprises a succession of shale-dominated, coal-bearing cyclothems, probably mostly ranging from minor to intermediate in scale, with locally prominent sandstones. Several contain thin limestones, of which only one (Verdigris/Ardmore, associated with the only known major cyclothem in this group) has been traced throughout the region. Although subdivided into a succession of cyclothemic formations in Missouri, the Cherokee is divided into only a few lithostratigraphic formations and members in Kansas, Iowa and Oklahoma. It averages about 400 ft (120 m) thick in its type region in southeastern Kansas, thickening northward to perhaps twice that in the Forest City Basin of the Iowa-Missouri-Nebraska border region (Fig. 2), a thickening that essentially defines that basin north of the Bourbon Arch and east of the Nemaha Uplift. It thickens southward to at least 2500 ft (750 m) in northeastern Oklahoma approaching the Arkoma basin. The Cherokee contains most of the coal resources of the Midcontinent region.

The **Marmaton Group** overlies the Cherokee Group with a slight disconformity and encompasses nearly all of the upper part of the Desmoinesian Stage. It comprises a succession of limestone-dominated major cyclothems separated by locally thick shale formations with local sandstones and some widespread coals. It is classified into 9 formations that are traceable throughout the region, and these are subdivided into 15 members that are traceable across most of the region, and 16 beds that are traceable across various parts of the region. The Marmaton is about 250 ft (75 m) thick in its type area of east-central Kansas, thinning northward to about 140 ft (42 m) in Iowa, where it reflects the end of differential subsidence in the Forest City Basin by this time. It thickens southward to more than 500 ft (150 m) at the latitude of Tulsa in northeastern Oklahoma, approaching the Arkoma Basin. The Marmaton contains most of the remainder of the coal resources of the Midcontinent region.

The **Pleasanton Group** overlies the Marmaton Group with disconformity in most places and contains the newly proposed Desmoinesian-Missourian Stage boundary near the middle. It is a shale-dominated succession with local sandstone of various origins in the lower part and deltaic sandstone in the upper part northward. It is divided into two formations and several members based mostly on two thin limestones, one of which (Exline) is widely traceable as part of an intermediate-scale cyclothem in the middle of the group. The Pleasanton ranges from 100 to 150 ft (30-45 m) thick from its type region of east-central Kansas into northwestern Missouri, from which it thins northward into a few feet of paleosol mudstone on either side of the Exline Limestone in Iowa. Southward, the lower sandier part thickens into Oklahoma, whereas the upper part thins nearly to disappearance in a more basinal facies and is included with the lower part of the overlying Kansas City Group in the **Coffeyville Group** of the Kansas-Oklahoma border area.

The **Kansas City Group** overlies the Pleasanton Group, conformably south of Kansas City and with slight disconformity north of Kansas City. It forms most of the lower two-thirds of the Missourian Stage and comprises 15 formations, some subdivided into a total of 24 members, most of which are traceable across most of the region. It includes 6 limestone-dominated cyclothems that are traceable across the entire shelf and separated by shale formations that are locally thick where prodeltaic sedimentation prevailed, and one of which (Cherryvale) contains a cyclothem of intermediate scale. The Kansas City is about 300 ft (90 m) thick in its type region, and thins northward to about 150 ft (45 m) in Iowa where the intervening shales become paleosol mudstones. Southward, the Kansas City thickens as both limestones (often as phylloid algal buildups) and shales thicken toward the margin of the basin. From a depositional point of view, this basin extended farther northward in the lower part of the group, and strata of this shale-dominated lower part of the Kansas City are included in the Coffeyville Group in the Kansas-Oklahoma border region. In its type area, the Kansas City is subdivided into 3 subgroups (Fig. 3), in ascending order: Bronson Subgroup, a limestone-dominated succession (which mostly is replaced by Coffeyville shale in southern Kansas), Linn Subgroup, a shale-dominated succession, and Zarah Subgroup, a subequally limestone- and shale-dominated succession.

The **Lansing Group** overlies the Kansas City Group, conformably south of Kansas City and disconformably northward, and forms the lower part of the upper third of the Missourian Stage. It comprises 5 formations, including 3 limestone-dominated cyclothems (with 8 members that are traceable across the entire shelf) separated by shale formations that are largely paleosol mudstones from central and southern Kansas northward. The Lansing is about 80 ft (24 m) thick in its type area in northeastern Kansas, thinning northward to about 50 ft (15 m) in Iowa. It thickens southward to about 200 ft (60 m) in southern Kansas where parts of all three cyclothems are developed as phylloid algal mound facies before being replaced southward by basin-filling shale and sandstone.

The **Douglas Group** overlies the Lansing Group conformably across most of the region, and it contains the provisional Missourian-Virgilian Stage boundary. It is a shale-dominated group that comprises two thick shale formations separated by a thin limestone formation that is a major cyclothem. The Douglas is about 240 ft (72 m) thick in its type area in northeastern Kansas, thinning northward to about 60 ft (18 m) in Iowa and Nebraska where paleosol mudstones dominate the shale formations, and thickening southward to 500 ft (150 m) of more sandstone-dominated strata in southern Kansas.

The **Shawnee Group** overlies the Douglas Group disconformably and forms most of the lower one third of the Virgilian Stage. It comprises 4 relatively thick limestone formations that contain both classic major cyclothems and smaller scale cyclothems and are separated by 3 shale formations. It is subdivided into a total of 31 members, most of which are traceable across most of the shelf region. Paleosol mudstones are common in most of the shale units (both between and within the limestone formations) across much of the shelf. The Shawnee is about 330 ft (~100 m) thick in its type area in northeastern Kansas, thinning northward to about 200 ft (60 m) in Nebraska, and thickening somewhat southward in southern Kansas.

The **Wabaunsee Group** overlies the Shawnee Group with slight disconformity over much of the shelf and forms most of the upper two thirds of the Virgilian Stage. It is a shale-dominated group comprising 15 formations and 30 members. It is dominated by thick shale formations, often with thin limestone members and separated by thinner limestone formations that typically contain relatively thick shale members. Except for the lowest limestone formation (Howard), all of the cyclothems associated with the thin limestone members are of minor to intermediate scale. The Wabaunsee is about 500 ft (150 m) thick in its type area of northeastern Kansas, thinning northward to 340 ft (102 m) in Nebraska, and thickening somewhat southward in southern Kansas.

The **Admire Group** overlies the Wabaunsee Group disconformably and forms most of the remaining upper part of the Virgilian Stage. Like the Wabaunsee, it is a shale-dominated group with only thin limestones, but was regarded as the base of the Permian System in the Midcontinent before the Carboniferous-Permian boundary was selected in the Ural region of Eurasia and correlated into higher strata in the overlying Council Grove Group. The Admire averages about 130 ft (39 m) thick along outcrop.

The **Council Grove Group** overlies the Admire Group with disconformity and comprises several relatively thick limestone formations separated by shale formations that are dominantly paleosol mudstones. It contains the correlated Carboniferous-Permian boundary at the base of the second limestone formation (Red Eagle) above the base. Therefore about the lower 80 ft (24 m) form the top of the Virgilian Stage.

CYCLOTHEMS

It is now generally recognized that nearly all Pennsylvanian cyclothems are transgressive-regressive allostratigraphic units, which are 'stratigraphic sequences' that resulted from glacial-eustatic rise and fall of sea-level (e.g., Heckel, 1994; Soreghan and Giles, 1999). On the Northern Midcontinent Shelf, cyclothems of three informal orders of magnitude can be delineated: **Major cyclothems** are characterized by a widespread, conodont-rich, gray to black shale unit that extends across the entire shelf and into the basin, generally sandwiched between transgressive and regressive limestone units on the shelf. These cyclothems generally correspond to the limestone formations in the Marmaton, Kansas City, Lansing, and Shawnee Groups, and include one limestone formation each in the upper Cherokee, Douglas, and lower Wabaunsee Groups (* on Fig. 3). Names of each of these cyclothems are the same as that of the limestone formation that constitutes most of it, although the cyclothem boundaries are commonly within the intervening shale formations. **Intermediate cyclothems** are characterized by a conodont-rich gray shale or limestone across much of the shelf, but either with somewhat limited extent on the exposed part of the shelf, or with only shallow-water facies at the northern limit of outcrop in Iowa and Nebraska, on the higher end of the shelf. These cyclothems generally correspond to limestone units of lesser rank, but include a few of the limestone formations (x on Fig. 3.). **Minor cyclothems** (often referred to more simply as 'cycles') typically extend as marine units only a short distance into Kansas or Missouri from the Oklahoma basinal region, or represent minor reversals of sea-level change within the more major cyclothems. Some of these correspond to named members or beds, but some have not been named as separate units, and more are being discovered as detailed stratigraphic work continues. Many of these are 'parasequences' in typical sequence-stratigraphic terminology.

The **major cyclothems** and several **intermediate cyclothems** are characterized throughout all or most of their outcrop extent on the shelf by a distinctive vertical sequence of lithic members (Fig. 4A), variously termed a 'Kansas' or 'Kansas-Iowa' or 'Northern Midcontinent' cyclothem. Several of the remaining intermediate cyclothems display this sequence on a smaller part of the shelf. Each lithic member represents a particular phase of deposition within the transgressive-regressive sequence, and thus corresponds to much of each individual phase of glacial-eustatic sea-level fluctuation (transgression, highstand, regression, and lowstand). Most are sufficiently widespread to have been recognized and named as lithostratigraphic members of the limestone formation (the former three) or as the intervening shale formations (lowstand).

The **transgressive limestone** is typically a thin (1 to 3-ft / 0.3-0.9 m) marine limestone that overlies a variety of detrital rock types ranging from mudstone paleosols to terrestrial, deltaic, or nearshore shallow marine sandstone or shale that represent sea-level lowstand at or near the top of the underlying ('outside') shale formation (Fig. 4A). Although locally containing shallow-water packstones or grainstones at the base, most of it is skeletal wackestone with a diverse biota deposited below effective wave base. It represents a deepening-upward sequence that forms much of the 'transgressive systems tract' of the stratigraphic sequence. Transgressive limestones are typically dark, nonpelleted calcilutites with neomorphosed aragonite grains and overpacked calcarenites that generally lack evidence of early marine cementation or meteoric leaching or cementation. They apparently remained in the marine phreatic environment of deposition until buried by overlying marine strata, and became chemically stabilized in rock-dominated diagenetic environments. They underwent slow compaction before cementation, under decreasingly oxygenated conditions (Heckel, 1983) such that much fine-grained organic matter was preserved. Transgressive limestones that directly overlie coals (as is common in Middle Pennsylvanian strata) are generally little more that a thin layer of shells that often are pyritized, probably because the calcareous algae that were the probable source for most of the carbonate mud in these limestones were inhibited by unfavorable ecologic conditions of the underlying peat.

The **offshore ('core') shale** is typically a thin (0.3 to 3-ft / 0.1-0.9 m) nonsandy, marine, gray to black, phosphatic shale deposited as a condensed section under conditions of near sediment starvation in water deep enough to inhibit algal production and/or preservation of carbonate mud. Those shales that are gray generally carry a diverse benthic fauna of many invertebrate phyla attesting to open marine conditions. Carbonate mud that may have formed from disintegration of invertebrate material apparently was largely dissolved, as is suggested by corrosion of coarse skeletal debris in places in the shale and in overlying invertebrate skeletal calcarenites at the base of the regressive limestone member (Malinky and Heckel, 1998). Most offshore shales include a distinctive black, commonly fissile, facies typically underlain and overlain by the gray facies (Fig. 4A). The black facies contains from 3 to 30% organic matter, peloids, laminae, and nodules of nonskeletal phosphorite, and a fauna consisting mainly of conodonts and fish debris (both phosphatic), and in places, ammonoids and radiolarians preserved in early diagenetic calcitic nodules ('bullions') and in phosphorite nodules (Kidder, 1985). The black shale facies was deposited in water deep enough to develop a pycnocline that inhibited vertical circulation and prevented bottom oxygenation long enough to eliminate benthic organisms and preserve large amounts of organic matter that accumulated on the bottom over a long period of time. Where its distribution is patchy within the gray facies, the black facies occurs in topographic lows. That this pycnocline was a thermocline is strongly suggested by the preservation of ammonoids only in early diagenetic calcitic nodules in the black facies, and by the preservation of other originally aragonitic molluscs (along with ammonoids) only in thicker portions of laterally equivalent and overlying offshore, probably distal prodeltaic, gray shales in southern Kansas and Oklahoma. Apparently, the less stable aragonitic shells were dissolved in the colder water below the thermocline, unless they were preserved by early matrix mineralization in the bullion nodules or by rapid burial and replacement by siderite, phosphorite, or pyrite in the distal extents of prodeltaic sediments at the periphery of the black facies. Perturbation of the thermocline by wind stress in the tropical trade wind belt led to quasi-estuarine circulation and episodic upwelling, which eventually resulted in deposition of nonskeletal phosphorite. The offshore shale is also called the 'core' shale because of its position at the 'turnaround point' in the cyclothem between the transgressive and regressive limestone members, which are essentially mirror images of one another in general facies development. The core shale is not only the condensed section in sequence-stratigraphic terminology, but also represents the highstand deposits of the cyclothem on the presently preserved middle to lower part of the northern shelf.

The **regressive limestone** is typically a thick (5 to 30 ft / 1.5-9 m) classic shallowing-upward carbonate sequence, consisting of skeletal calcilutite (wackestone) at the base grading upward to skeletal calcarenite (packstone and grainstone) with abraded grains, algae, and local oolite beds. The grainstone is often cross-bedded and commonly capped with laminated, peritidal calcilutite (particularly northward) and/or an exposure surface. Subaerial exposure resulted in the infiltration of oxidizing undersaturated meteoric water into the regressive limestone before much compaction took place. This water oxidized most of the original organic matter in the sediment, leached aragonite grains and eventually became saturated enough to precipitate blocky calcite in both intergranular and moldic voids. This preserved the original peloidal fabric, the depositional looser packing of grains, and also the porosity where cementation was incomplete. Thus the lighter-colored, more porous and more conspicuously sparry upper part of the regressive limestone stands in contrast with the darker, denser (overcompacted) transgressive limestone and also with the lower, more offshore facies of the regressive limestone (Heckel, 1983). Because the regressive limestone on the presently preserved mid to low shelf region of the Midcontinent outcrop belt was deposited entirely during a fall in sea level, I prefer the term 'regressive' (or 'forced-regressive') rather than 'highstand' for the systems tract it represents (French and Heckel, 1994), because only the 'core' shale represents truly highstand deposits across this region. Only in a more shoreward position above a shallow-water facies of the 'core' shale would the lower part of the regressive limestone be part of the highstand systems tract (see Heckel et al., 1998, fig. 8). This modification of sequence-stratigraphic terminology is particularly pertinent for Pennsylvanian cyclothems in view of the glacial-eustatic control of regression and the recognition that the regressive phase, that is, glacial buildup of ice on the land, appears to occupy most of the time during Pleistocene glaciations, as shown on all Pleistocene sea-level curves.

The **nearshore/terrestrial ('outside') shale** is an extremely variable shale- (and locally sandstone-) dominated unit, which overlies the regressive limestone, underlies the next higher transgressive limestone, and forms the shale formations that separate the limestone formations (Fig. 3). This unit consists largely of fluvial, paralic and deltaic clastics in northeastern Kansas and Missouri, often grading southward to thick prodeltaic shales. Generally at the top of this unit, and often forming the entire unit northward, are gray to mottled reddish blocky mudstones (up to 5 ft / 1.5 m thick), which have been identified as paleosols, some extending for hundreds of miles along outcrop (e.g., Schutter and Heckel, 1984; Joeckel, 1994, 1999). The blocky mudstones are often overlain by a thin shale with marine fossils (Fig. 4A), which represents the base of the transgressive systems tract resting upon the sequence boundary at the top of the paleosol mudstone. In several cyclothems coal beds overlie the paleosols, particularly in the Desmoinesian succession when the climate was more humid (Schutter and Heckel, 1984; Cecil, 1990). These coal beds apparently formed in response to the early stages of sea-level rise of the succeeding transgression, which ponded fresh water runoff to form broad peat swamps in slight depressions on the surface of low relief. These swamps then migrated up-shelf just ahead of the marine transgression and became preserved as coal beds (Heckel, 1995). Thus the nearshore/terrestrial shale unit includes the upper part of the regressive systems tract when deltaic influx penetrated the region, the shelf facies of the lowstand systems tract when the sea had withdrawn from most or all of the shelf for a substantial period of time, and the lower part of the transgressive systems tract before carbonate production became established.

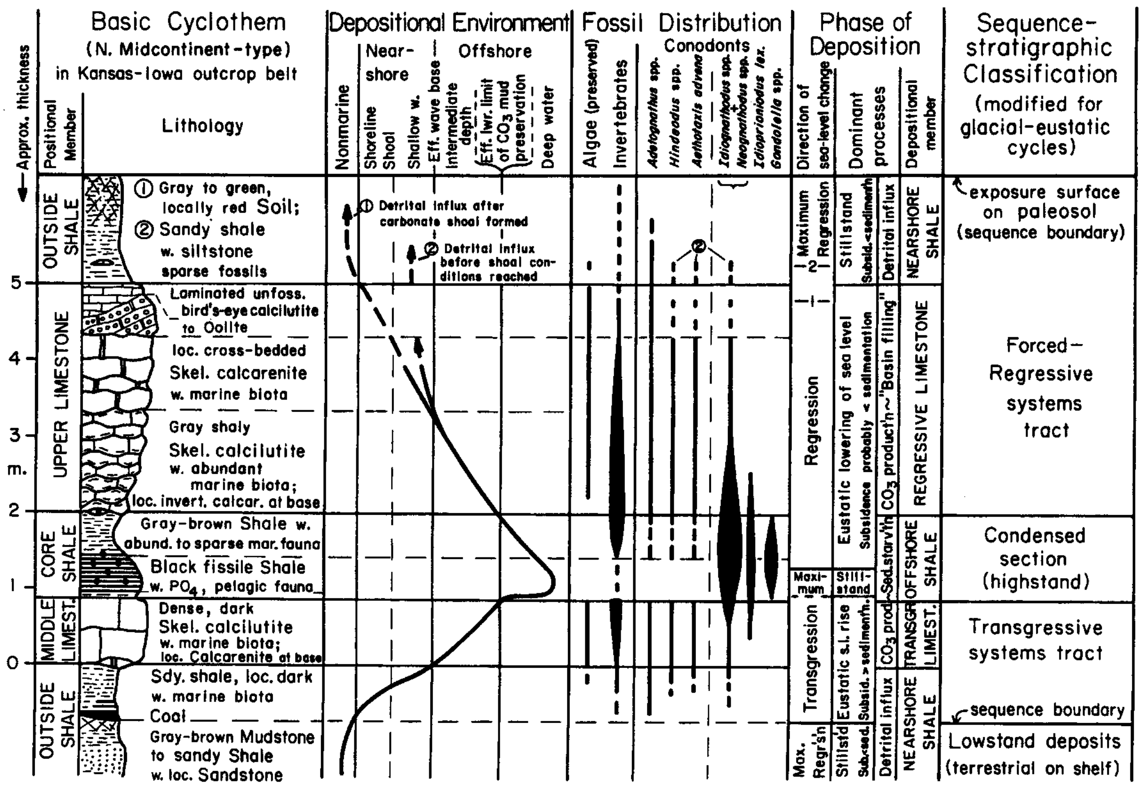


Fig. 4A: Basic northern Midcontinent major cyclothem on mid to low shelf, representing one complete marine inundation and withdrawal across the shelf (modified from Heckel, 1994).

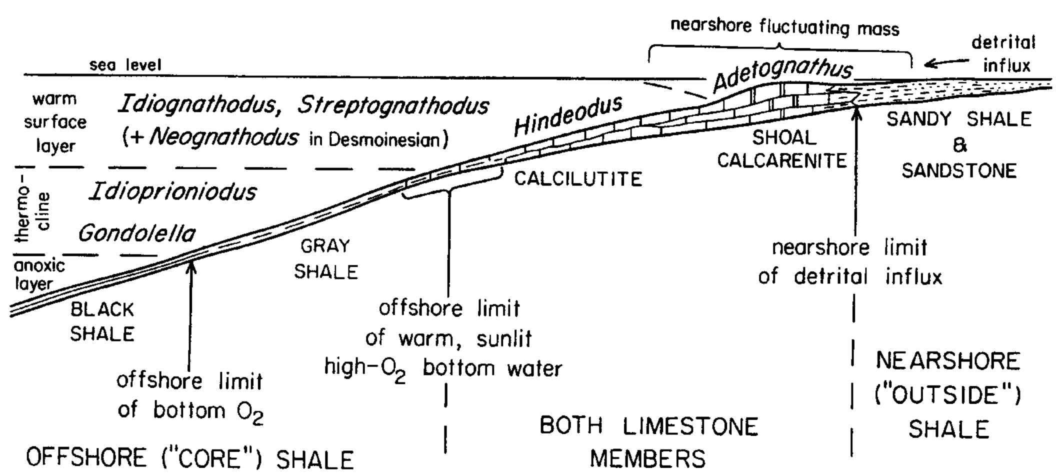


Fig. 4B: Depositional model for cyclic rock types that developed on shelf in relation to shoreline and water depth, showing inferred living positions of major conodont genera in water masses developed at sea-level highstand, derived from generic distribution pattern shown in Figure 4A (from Heckel, 1994)

CONODONT DISTRIBUTION

Detailed work on both outcrop and core successions by Heckel and Baesemann (1975), Swade (1985), and in various theses and unpublished data, has established that a distinctive vertical succession of common conodont genera characterizes all the major cyclothems on the Northern Midcontinent Shelf (Fig. 4A). The greatest contrast in this distribution lies between the two shale members of the cyclic sequence.

Both the gray and black facies of the **offshore 'core' shales**, which were slowly deposited at sea-level highstand, are characterized by great abundance of conodonts, hundreds to thousands per kilogram because of the lack of sediment dilution. These faunas are strongly dominated by *Idiognathodus* and/or closely related *Streptognathodus*, with common *Neognathodus* (in the Desmoinesian Stage), *Idioprioniodus*, and *Gondolella* (which is generally confined to the middle of the shale).

In contrast, the marine parts of the **nearshore/ terrestrial 'outside' shales**, which were more rapidly deposited in sediment-rich nearshore environments, generally contain sparse conodonts, up to only 20 or so per kilogram. These faunas are typically dominated by *Adetognathus*, locally subequally with *Idiognathodus* or *Streptognathodus* and, less commonly *Hindeodus*, but with *Idioprioniodus* and *Gondolella* conspicuously absent, and *Neognathodus* (Desmoinesian only) generally rare.

The two **limestone members** typically contain faunas that are gradational and intermediate between those of the adjacent shale members. Specifically, the basal bed of the regressive limestone, where sediment dilution was minimal, generally contains the greatest abundance of conodonts in that member (but only up to 100 or 200 per kilogram), and carries the genera of the underlying 'core' shale (except for *Gondolella*). The tops of the regressive limestones, where carbonate production predominated, contain few conodonts (1 to 5 per kilogram), mainly *Adetognathus*. The main part of these limestones tends to carry up to 10 or so conodonts per kilogram, subequally dominated by *Hindeodus* and *Idiognathodus* or *Streptognathodus*, with occasional *Adetognathus*. Although relatively more rare, the genera *Diplognathodus, Aethotaxis* and *Ellisonia* are found most often in this part of the cyclothem. The faunas of the transgressive limestones tend to be the mirror image of that of the regressive limestone, and both are thus symmetrical about the 'core' shale that separates them.

The distinctive differences in conodont faunas between the offshore and nearshore parts of the cyclothem appear related to the nature of the different water masses that covered the shelf at different sea-level stands (Heckel and Baesemann, 1975; Klapper and Barrick, 1978; Swade, 1985). *Idiognathodus* and *Streptognathodus* (with *Neognathodus* during Desmoinesian time) apparently dominated the normal open-marine, warm surface water mass (Fig. 4B) that covered most of the sea (away from strong fresh-water influx) during all sea-level stands, which explains their dominance throughout most of the cyclothem. *Idioprioniodus* probably occupied the deeper, slightly cooler water mass in the top of the thermocline, which explains its occurrence mainly in the offshore shale and adjacent deeper-water parts of the two limestone members. *Gondolella* apparently lived in deeper, even cooler and possibly slightly dysoxic water, lower in the thermocline, which explains its even greater confinement within the most offshore facies, primarily the middle of the black shale. These five genera most likely were pelagic, as all are generally abundant in the anoxic black shale facies, which lacks any definite benthic fossils, even in the early diagenetic nodules. At the other extreme, *Adetognathus* apparently inhabited and dominated the variable nearshore shallow water mass, where it tolerated fluctuations in salinity and other conditions that inhibited the other genera. *Hindeodus* and the rarer genera *Diplognathodus, Aethotaxis* and *Ellisonia* probably occupied a more stable environment associated with carbonate sediment, as they are most commonly found in the limestone members. All these latter five genera were more likely benthic, as they are absent in the anoxic black offshore shale facies, but are occasionally found in the gray offshore shale facies.

Because these distinctive patterns in abundance and dominance of conodont genera are reasonably related to the water mass, and hence to the depositional environment and phase of deposition within the cyclothem, they can be used to identify the phase of deposition within the overall transgressive-regressive sequence where the lithic composition is less distinctive or ambiguous. In this way, several of the intermediate cyclothems have been identified in the vertical succession (Fig. 3, 7), and distinguished from the minor cycles, which are generally characterized by lower abundance of conodonts, commonly with a dominance of nearshore genera.

Sizes of individual specimens among the different environments show an interesting pattern that is worthy of mention, although not yet well understood. In the offshore 'core' shales, size of individuals among all genera is generally the largest in the cyclothem, although medium-sized and small individuals are present. In the basal beds of the regressive limestones, size of individuals is more in the medium range for the various genera. In the main parts and tops of regressive limestones, most of the transgressive limestones, and the nearshore shales, size of individuals is generally small to medium, although some moderately large specimens of *Adetognathus, Ellisonia, Aethotaxis* and *Hindeodus* are found. In these shallower-water parts of the cyclothem, size of individuals among the idiognathodids is typically small, and it is not yet determined whether they are dominantly juvenile to adolescent forms of the large-sized species found in the 'core' shale, or adult forms of small-sized species. In several thin conodont-rich limestones and gray shales that are the 'cores' of intermediate cyclothems, especially northward on the shelf, the abundant faunas are strongly dominated by apparently juvenile to adolescent forms. It appears that the large individuals of particularly the idiognathodids that inhabited the surface water mass above the black 'core' shale environment had a sufficiently stable environment with a steady food supply to enable most of them to grow easily to maturity and old age. This is consistent with long-term development of a stable thermocline beneath a well-circulated surface water mass at sea-level highstand. The shallower-water, probably benthic genera with the size mode more toward the medium-small range may reflect the generally somewhat lesser stability of shallow-water environments. The rather consistently smaller sizes of the sparse idiognathodids in these shallower environments may also relate to this lesser stability. The abundant juvenile-dominated faunas of the deeper-water environments of the intermediate cyclothems that did not establish permanent thermoclines and black shale facies on the shelf may well be related to the great instability that might be expected in a deeper-water environment very close to the upper edge of a thermocline (that existed farther into the basin), which would be the focal point of upwelling where dysoxic to anoxic water episodically entered the living zone of the idiognathodids and caused mass mortalities of immature populations. This speculation is supported by the observations that several of these units grade basinward to black shales recording the more permanent thermocline in that direction (and containing larger morphotypes), and that their shelf facies often contain small phosphatized molluscs that may reflect another of the effects of upwelling.

The upward changes in species composition, particularly of the dominant genera *Idiognathodus* and its descendant *Streptognathodus*, in the offshore shales and limestones of successive cyclothems allow biostratigraphic discrimination of these cyclothems (Swade, 1985; Heckel, 1989; Barrick and Boardman, 1989; Boardman et al., 1990; Heckel, 1991; Barrick et al., 1996). This is leading to cyclothem-by-cyclothem correlation of the Midcontinent succession with those in other basins in North America, such as the eastern shelf of the Midland Basin in north-central Texas (Boardman and Heckel, 1989), the Illinois Basin (Heckel and Weibel, 1991), the Appalachian Basin (preliminary work with J.E. Barrick, summarized by Heckel, 1994 and in Fig. 6B herein), and the Paradox Basin of southwestern U.S. (Ritter et al., this guidebook). This potentially could lead to worldwide correlation of glacial-eustatic cyclothems once the taxonomic problems at the species level are resolved among workers in different parts of the world (see Barrick and Walsh; Barrick and Lambert; and Nemyrovska and Kozitska, in this guidebook), and enough agreed-upon short-ranging species are recognized in different parts of the world.

LATERAL VARIATION IN CYCLOTHEMS

Northward along the Midcontinent outcrop, the classic major cyclothems (Fig. 4A) change very little into northern Missouri and Iowa (Fig. 5), where large quarries and long cores (Fig. 2) provide a good data base in this area of Pleistocene cover. The transgressive limestones change very little. A few of the 'core' shales lose their black facies, and those that maintain the black color apparently lose a fair amount of the organic content as indicated by the greater ease of disaggregation of this facies without the use of bleach in this region. This trend would be expected in this higher shelf area where the permanent thermocline that protected the organic matter from oxidation on the sea floor was established for less time than southward. The lower part of the regressive limestone changes very little, but the top becomes dominated by laminated, muddy peritidal facies (Fig. 5A), most of which show more evidence of subaerial leaching, including karstification and clay infiltration than southward. Nearly all the 'outside' shales become mainly mudstone paleosols in this direction of the cratonic shoreline (Fig. 5B), which was farther into the drier climatic belt where less coarse water-borne detrital sediment was available during sea-level lowstands.

Southward along the Midcontinent outcrop, the major cyclothems retain their classic features as far as the two limestone members can be traced, which typically ranges from southern Kansas into northern Oklahoma. The regressive limestone tends to disappear first, as it was overwhelmed by prograding detrital influx from the southern orogenic detrital source as sea level dropped and reduced accommodation space. The transgressive limestone tends to extend farther, as it was protected from detrital dilution by sea level rise, which trapped detrital influx in estuaries that encroached on the detrital source. The conodont-rich 'core' shales can be traced far beyond the two limestone members (Fig. 5A) into the foreland basinal region of central Oklahoma. Here the gray 'core' shales of the intermediate cyclothems tend to become darker where they developed below a thermocline of less

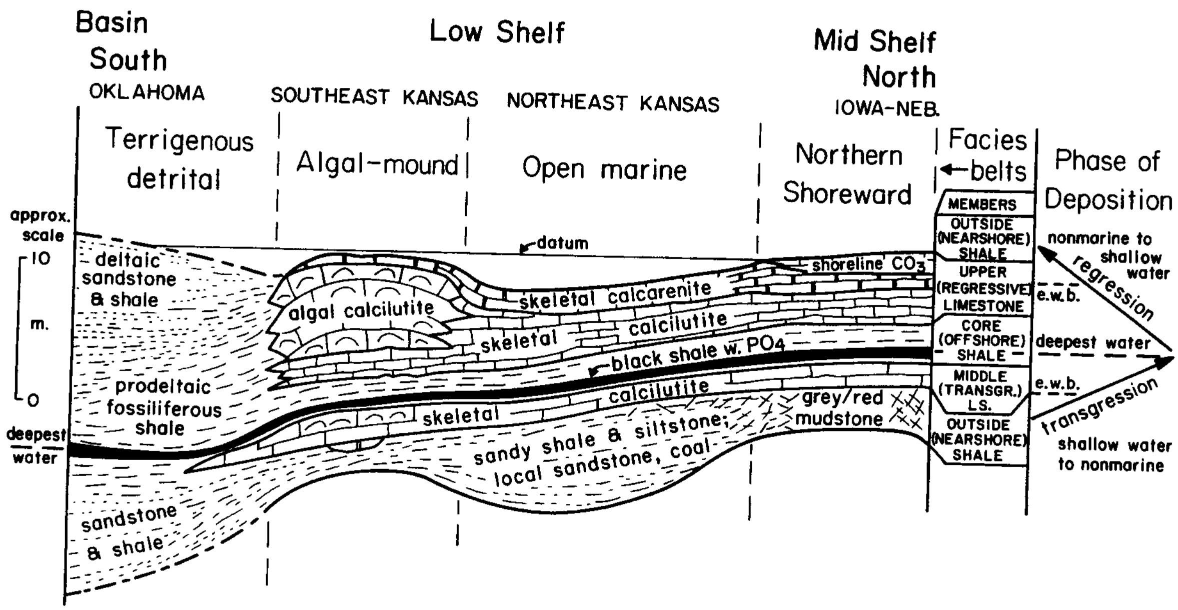


Fig. 5A: Lateral facies developed in members of basic major cyclothem (Fig. 4A) along Midcontinent outcrop belt where only low to mid-shelf portion is presently preserved; e.w.b. = effective wave base (from Heckel, 1994).

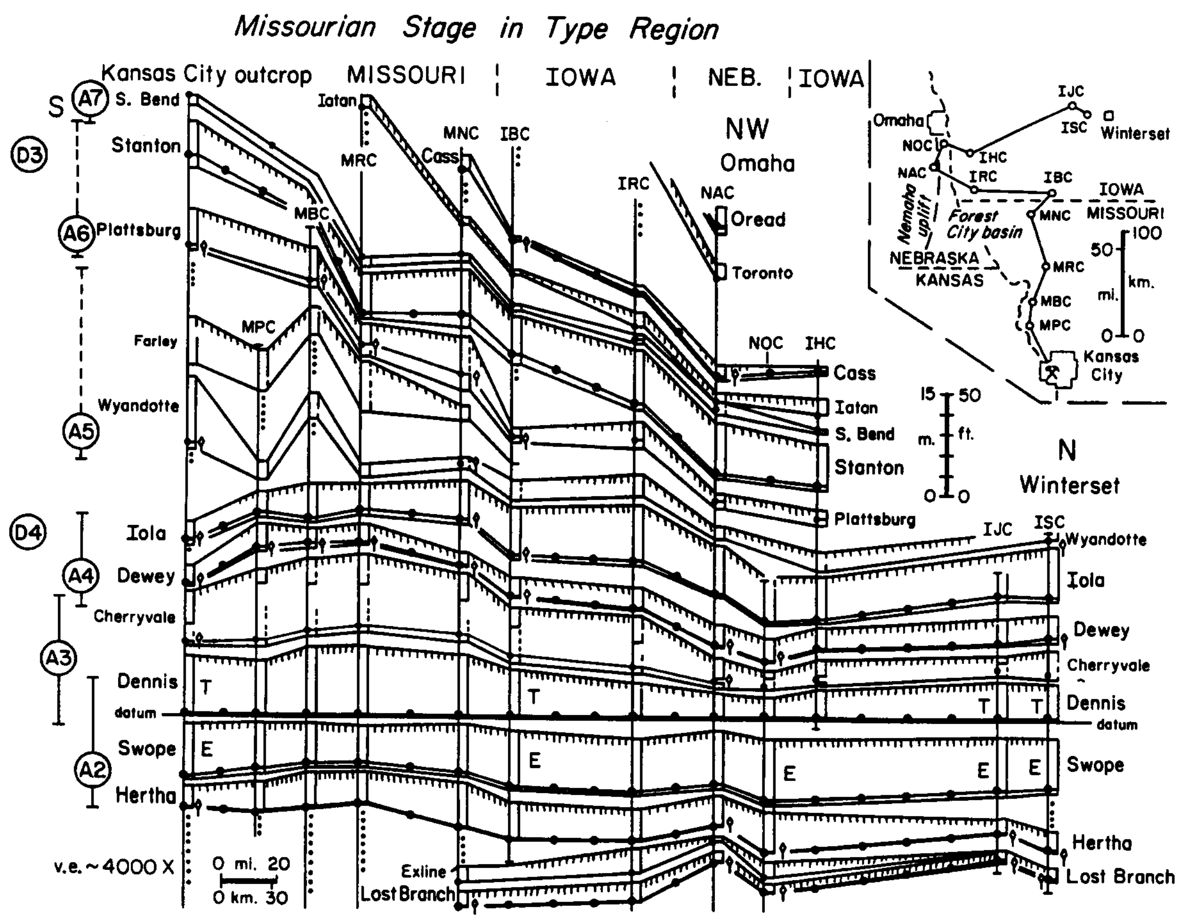


Fig. 5B: Correlation cross-section of Missourian Stage (= base of Exline to base of Cass) in type region from Kansas City to Iowa, a mid-shelf position on northern shelf (modified from Heckel, 1994). Lines with spots show condensed intervals; hachured lines show exposure surfaces. Stop numbers for various units shown on left.

lateral extent and more confined to the basin during lesser highstands of sea level. The black shales of the major cyclothems tend to thicken farther into the basin where they underwent an increase in silty detrital influx from the closer detrital source even at highstand. This dilution caused them ultimately to become somewhat lighter than northward on the shelf, but they are still darker and finer-grained than underlying and overlying detrital rocks. The 'outside' shales thicken southward across eastern Kansas where they became subject to deltaic and prodeltaic detrital influx during late regression and lowstand. Paleosols disappear southward beyond the position of the lowstand shoreline. The coals in this region formed during lowstand and the earliest phase of transgression. The thick coarser detrital units between the core shales in southern Kansas and Oklahoma are generally very complex successions that resulted from a variety of basin filling processes that operated during transgression (dominantly estuary-filling), regression (dominantly deltaic) and lowstand (perhaps deltaic to fan-deltaic), and which as yet have received little detailed study outside of paleovalley fillings in the Douglas Group in eastern Kansas (Archer et al., 1994; Feldman et al., 1995). An important point to make is that the conodont generic succession and abundance pattern of the classic cyclothem (Fig. 4A) stays the same above and below the 'core' shale southward as well as northward. That is, they maintains their lateral integrity regardless of the type of marine facies developed above or below the 'core' shale, although the actual abundance becomes significantly less southward due to detrital dilution from the orogenic sediment source in southern Oklahoma.

In the **Illinois Basin** most cyclothems contain phosphatic gray to black shales that carry abundant conodont faunas of the same genera and species as their counterparts in the Midcontinent. These similarly represent offshore sediment-starved units that were deposited at sea-level highstand when the Midcontinent Sea was connected across all the basins of central North America. They are generally overlain by regressive limestones that are thinner than in the Midcontinent (Fig. 6A) and these generally represent only the subtidal carbonate facies characteristic of the lower part of the Midcontinent sequence in this unit. Apparently they became overwhelmed by prodeltaic detrital clastics at an earlier phase of regression in this region, which was closer both to the Appalachian orogenic detrital source and to the paleoequator (Fig.1A) where more humid climates would have been established. Transgressive limestones are rare, perhaps because coal beds are more common above paleosols at the tops of the underlying lowstand deposits than in the Midcontinent. The peat swamps that the coal beds represent probably inhibited algal carbonate production and preservation of other fine carbonate during the ensuing transgression. Their greater abundance in the Illinois Basin is consistent with the more humid climate suggested above for this region by its closer proximity to the paleoequator. In the main central to southern part of the basin, the lowstand deposits intervening between open marine units are dominated by greater proportions of deltaic to terrestrial shales and sandstones, reflecting both greater proximity to the Appalachian detrital source and greater amount of tectonic-subsidence-induced accommodation space at times in that part of the basin (Pope and Heckel, 1998; Pope, 1999). The latter effect is illustrated by the presence of a much thinner coeval Missourian succession of several cyclothems in northern Illinois where the marine units are separated only by paleosols, much like the Midcontinent succession in Iowa on the northern shelf. Nevertheless, in spite of the greater tectonic subsidence in the southern part of the Illinois Basin, paleosols (often overlain by coals) formed at the tops of all (or nearly all) cyclothems there, indicating that the sea withdrew from the entire part of the basin that is still preserved at each lowstand. This places the entire preserved part of the Illinois Basin at an average shelf elevation equivalent to the northern outcrop extent of the Midcontinent Basin in Iowa. Because some of the more minor marine units recognized in Iowa are not yet identified in Illinois, the Illinois Basin in general is considered to represent an upper mid-shelf position (Fig. 6).

In the **Appalachian Basin** the entire Pennsylvanian succession is strongly dominated by detrital clastics (Fig. 6A), in which Ferm (1970) and coworkers described deltaic deposits. Nearly all these detrital intervals are capped by paleosols (Busch and Rollins, 1984; Cecil, 1990), many of which are well developed (e.g., Joeckel, 1995), and most of which are overlain by coal beds that tend to be thicker here than in the other basins. The marine units in the succession generally overlie the coal beds or paleosols, reflecting the same genetic sequence discussed by Heckel (1995) and seen elsewhere. Here, however, the marine units are typically thin and lithically heterogeneous, ranging from argillaceous/silty/sandy/ skeletal limestones (wackestones to packstones) to fossiliferous light to dark gray shales and calcareous siltstones to sandstones, all showing various degrees of lateral facies gradation. This is not surprising in a region so close to such a major detrital source as the Appalachian highlands where deltas could penetrate marine intervals even during sea-level highstands. There is no definite development of transgressive or regressive limestones or 'core' shales, but neither is this surprising at a time when the earlier Pennsylvanian foredeep was filled with sediment so that water depths were never great enough to form an offshore shale to separate the transgressive from regressive limestones. Rather, the skeletal-dominated limestones commonly contain abundant conodonts, glaucony and nonskeletal phosphorite, and thus appear to represent the condensed sections formed away from or between detrital influxes at sea-level highstand (Fig 6A) that elsewhere are represented by the 'core' shales (Fahrer and Heckel, 1992). The shallower water facies of the highstand condensed interval is consistent with the appearance of many fewer marine units in the Appalachian succession through the same time interval than in either the Illinois or Midcontinent Basins (Fig. 6B). The Appalachian Basin at this time was in a sufficiently high position on the shelf that only the greatest marine transgressions that produced the major cyclothems in the Midcontinent reached its presently preserved area. This interpretation is further supported by the fact that the thickness range of the Midcontinent succession from the Altamont to Oread Limestone interval in Iowa (130-150 m) is significantly greater than the 60-100 m thickness of the time-equivalent Upper Freeport Coal to Ames Limestone interval in the Appalachian succession, indicating less net accommodation space from tectonic subsidence there at that time. The lack of lateral continuity of many of the marine units in the Appalachian succession is readily explained by both valley incision of laterally continuous major units during the longer-term lower stands of sea level, and transgression only into the paleovalleys on the incised surface during lesser marine transgressions (Heckel et al., 1998).

In the deeper parts of the **Midland Basin** of west Texas, the entire later Pennsylvanian succession is basinal sediment-starved black shale (Fig. 6A). On the eastern shelf of this basin in north-central Texas (Fig. 1B, 2), however, the outcropping equivalent Pennsylvanian succession is similar to that in the Illinois Basin and to a lesser degree the Appalachian Basin. On this shelf, conspicuous deltaic/terrestrial shales and sandstones, typically with well-developed paleosols at the top, alternate with widespread marine intervals. Within these intervals, transgressive limestones, offshore shales, and regressive limestones are locally recognizable and laterally persistent for short to moderate distances along outcrop in areas away from strong detrital influx (Boardman and Heckel, 1989).

SUMMARY OF MID-DESMOINESIAN—MISSOURIAN CYCLOTHEMS IN MIDCONTINENT

It is appropriate to summarize briefly here the current state of knowledge concerning the lithic units and features that define the cyclothems recognized in the Midcontinent succession from Iowa to northern Oklahoma (Fig. 7), and their biostratigraphically significant conodonts that allow correlation within the Midcontinent and with other basins. Lateral variation is shown for upper Desmoinesian and lower Missourian units (Fig. 8, 9, 10). Information is derived from personal experience, many student theses, and general stratigraphic publications cited in Heckel (1989), with only minimal reference here. This summary covers the part of the succession from the upper middle Cherokee Group to the middle Douglas Group (to be visited on the field trip), in ascending order. Boardman (this guidebook) presents similar information for the upper Virgilian and lowermost Permian succession, and updates where possible the lower Virgilian (Shawnee Group) summary in Heckel (1989).

The **Fleming cyclothem** (Fig. 7) is a genetic unit that extends into west-central Missouri and spans the interval from the sequence boundary at the top of the underclay paleosol at the base of the Fleming Coal, upward to the top of the next underclay paleosol below the Croweburg Coal. Its early transgressive deposits are the Fleming Coal. Highstand is represented in the base of the marine Fleming caprock limestone, which carries a moderately abundant conodont fauna of about 50 /kg at the one locality studied (Stop B6), marking it as a minor to possibly intermediate cyclothem, depending on lateral extent and nature of the fauna elsewhere. Regression is recorded in the top of the limestone and overlying shale with local sandstone capped by the underclay of the overlying coal. The conodont fauna is dominated by *Idiognathodus*, mainly the forms seen in the overlying Verdigris cyclothem, but includes a distinctive morphotype characterized by anterior longitudinal ridges on the platform slightly bent from the transversely ribbed posterior part, which is not seen above. (The main part of this cyclothem above the Fleming Coal bed has been classified lithostratigraphically with the overlying Croweburg Coal bed in the Croweburg Formation in Missouri, a classification scheme that groups the coal with its underclay as an economically useful unit.)

The major **Verdigris cyclothem** (Fig. 7) extends across the entire Midcontinent and spans the interval from the top of the paleosol underclay beneath the Croweburg Coal upward to the top of the paleosol beneath the overlying coal bed, which is the Bevier Coal in this region. It includes the early transgressive Croweburg Coal at the base, the Verdigris Limestone (a lithostratigraphic unit comprising the Oakley Shale Member overlain by the Ardmore Limestone Member) in the middle, and overlying shale and local sandstone at the top. Late transgressive and highstand deposits are represented by the widespread black phosphatic Oakley Shale, which is conodont-rich above the base. Regressive deposits include the Ardmore Limestone and overlying shale and sandstone up to the next underclay. Locally the black facies of the Oakley Shale is separated from the Croweburg Coal by several feet of gray shale that may represent a slight regression (shown on Fig. 7), but only a thin conodont-poor shale with small molluscan fossils is present at Stop B6. The thin limestone bed within the Oakley here has only moderate conodont abundance, and may be the basinward

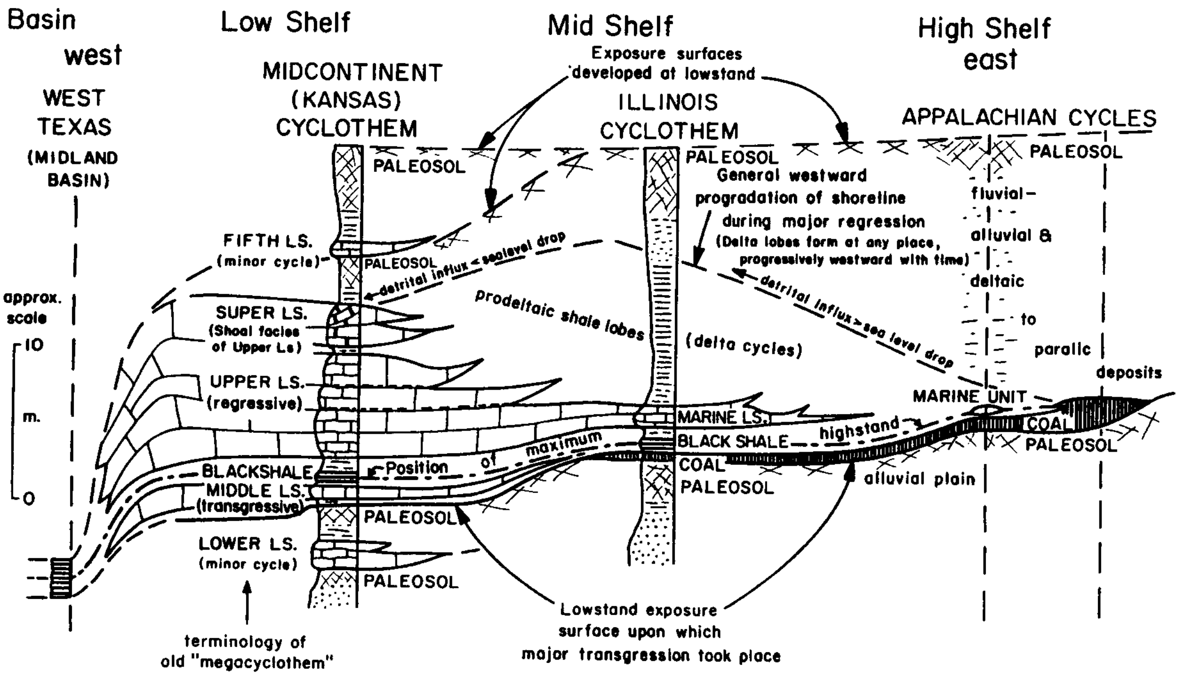


Fig. 6A: Inferred lateral facies developed in basic major cyclothem from Midland Basin of west Texas (where deep marine deposition was continuous) through Midcontinent and Illinois to Appalachian Basin, where all cyclothems ultimately become bounded by exposure surfaces, typically with paleosols (from Heckel, 1994).

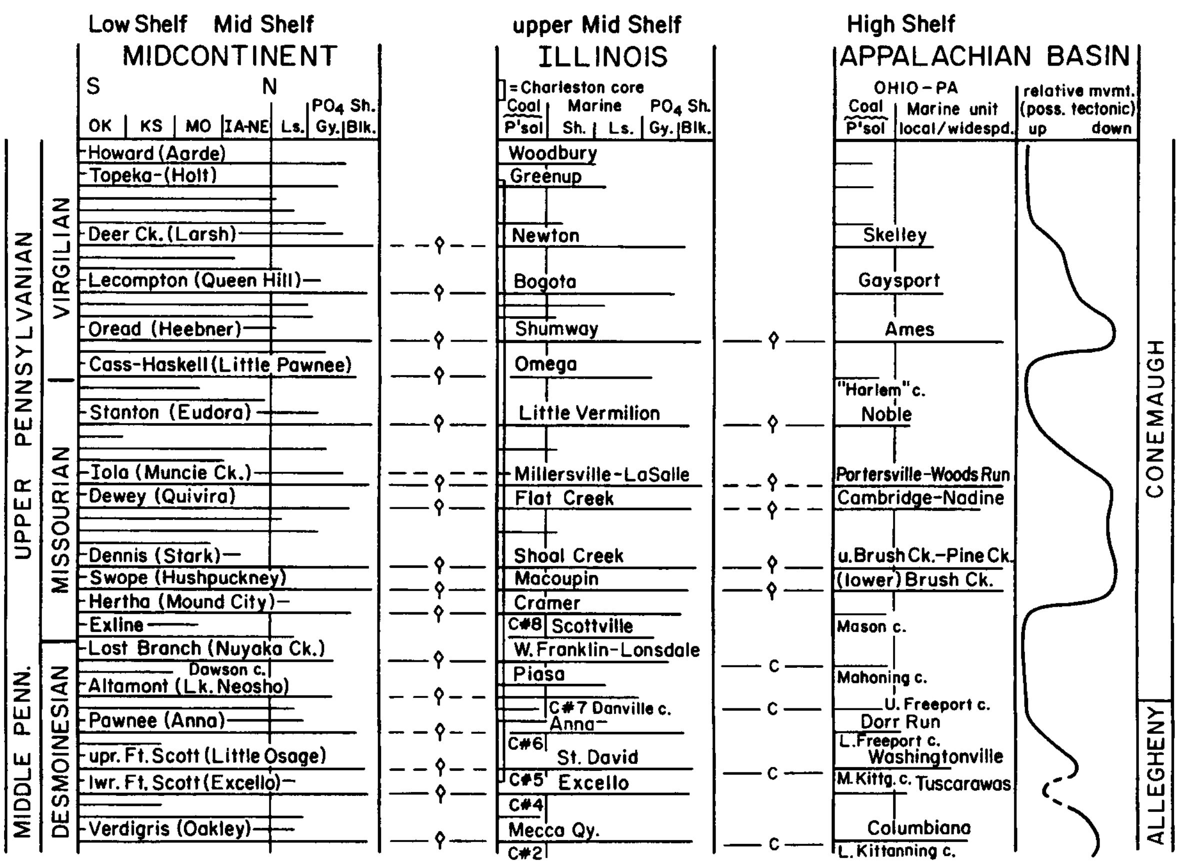


Fig. 6B: Preliminary correlation of major Midcontinent cyclothems (longest horizontal lines with name above) with those in Illinois (Heckel and Weibel, 1991) and Appalachian Basin (unpublished data), based on conodont faunas (tailed diamond symbols) and coal correlations (c) of Peppers (1996), (updated from Heckel, 1994).

equivalent of the conodont-poor lower part of the Ardmore Limestone in Iowa, which is overlain by a conodont-rich limestone that provided evidence for the second transgression (termed upper Ardmore on Fig. 7) within this cyclothem and is recorded here in the apparently equivalent upper Oakley dark shale bed. Northward in Missouri, the Wheeler Coal bed and its underclay lie below the Bevier Coal bed (and its underclay) directly upon the Ardmore Limestone, suggesting that another reversal of sea-level drop not readily detectable in Kansas (and not shown on Fig. 7) took place before final regression. The abundant conodont fauna in the Oakley Shale is dominated by morphotypes of *Idiognathodus*, including *I. delicatus*, *I.* sp. 2 of Swade 1985 (which is probably *I. acutus* Ellison 1941, named from the higher Excello Shale), and a pointed, large-lobed, elongate form that resembles *I. amplificus* Lambert 1992 (named from lower Cherokee beds in Iowa). It also contains *Neognathodus, Idioprioniodus*, and the highest occurrence of narrow and smooth-platformed *Gondolella* sp. 1 of Swade 1985 (probably the same as *G.* sp. 1 of Merrill and King 1971 from equivalent strata in Illinois). This species of *Gondolella* helps to confirm the longstanding correlation of the Verdigris cyclothem with the Liverpool Cyclothem in Illinois (which includes the black Mecca Quarry Shale and overlying Oak Grove Limestone).

The intermediate **Bevier cyclothem** (Fig. 7) extends across much of the Midcontinent. It spans the interval from the top of the paleosol beneath the Bevier Coal to the top of the paleosol beneath the Iron Post Coal in southern Kansas and Oklahoma, and to the top of the paleosol beneath the younger Mulky Coal northward. Its transgressive and highstand deposits include the Bevier Coal at the base, fossiliferous limestone and dark shale above the Bevier Coal in Kansas and Missouri, dark fossiliferous shale in Oklahoma, and fossiliferous shale above the paleosol in cores in Iowa and Nebraska. Its regressive deposits are the thick widespread Lagonda deltaic clastics from Iowa to southern Kansas, capped by the paleosol of the Iron Post Coal toward the south and by the paleosol to the Mulky Coal to the north. The dark shales carry an abundant conodont fauna dominated by *Idiognathodus delicatus*, and including *I.* sp. 2 of Swade 1985, *Neognathodus* and *Idioprioniodus*, but so far no *Gondolella* has been found in the few samples studied.

The minor **Breezy Hill cyclothem** (Fig. 7, 8) is a marine incursion that extends only into southeastern Kansas. It spans the interval from the top of the paleosol beneath the Iron Post Coal upward to the top of the paleosol beneath the Mulky Coal in southern Kansas and adjacent Oklahoma. Its transgressive and highstand deposits include the Iron Post Coal at the base, the overlying Kinnison Shale and Breezy Hill Limestone in Oklahoma, and just the Breezy Hill Limestone in Kansas. Its regressive deposits include plant-bearing sandstone in southern Kansas (seen at Stop B7) and the heavily pedogenized upper part of the Breezy Hill Limestone northward where ultimately the bounding paleosols merge. Southward in Oklahoma, the Mulky Coal and its paleosol disappear, and the top of the Breezy Hill Limestone appears to become the transgressive limestone to the overlying Lower Fort Scott cyclothem (Knight, 1985). The Breezy Hill Limestone contains a sparse conodont fauna dominated by *Idiognathodus*, and the Kinnison Shale has not yet been studied.

The major **Lower Fort Scott cyclothem** (Fig. 7, 8) extends across the entire Midcontinent and includes the lower part of the Fort Scott Limestone. It spans the interval from the top of the paleosol beneath the Mulky Coal upward to the top of the paleosol beneath the Summit Coal, which lies in the middle of the Fort Scott Limestone. This cyclothem includes the early transgressive Mulky Coal at the base from southern Kansas northward. Its late transgressive and highstand condensed interval is the widespread black phosphatic conodont-rich Excello Shale, a classic 'core' shale that extends from Iowa into the basinal region of Oklahoma. Its early regressive deposits include the lower part of the Blackjack Creek Limestone and the lower part of the deltaic Morgan School Shale northward in Iowa and Missouri. The upper part of the Blackjack Creek Limestone extends as a bed into the upper part of the Morgan School Shale in Iowa where it contains moderately abundant conodonts (Swade, 1985), thus apparently represents a minor transgression (which is not yet identified in the southern region). Final regression is recorded in the calcarenitic top of the Blackjack Creek Limestone and the overlying underclay of the Summit Coal. Southward in Oklahoma, the bounding paleosols and coals disappear, and the cyclothem comprises just the regressive Blackjack Creek Limestone, the highstand Excello Shale, and apparently the transgressive top of the underlying Breezy Hill Limestone in this region basinward of the lowstand shorelines. The Excello Shale contains an abundant conodont fauna dominated by *Idiognathodus*, mostly *I. delicatus*, but including *I. acutus* Ellison 1941 (named from this unit), another slightly grooved form, and the first appearance of *I.* sp. 3 of Swade 1985, which is probably *I. fustiformis* Gunnell 1933, rather than *I. claviformis* Gunnell 1931, as previously thought (Heckel, 1989). It also includes *Neognathodus* and *Idioprioniodus*, and the lowest occurrence of *Gondolella* sp. 2 of Swade (1985), a form with a broad platform bearing transverse ridges. The same conodont fauna in a similar shale unit called Excello near Peoria helps to confirm that longstanding correlation with the Illinois Basin.

The major **Upper Fort Scott cyclothem** (Fig. 7, 8) also extends across the entire Midcontinent. It spans the interval from the top of the paleosol beneath the Summit Coal upward to the top of the paleosol beneath the Alvis Coal in the lower Labette Shale above the Higginsville

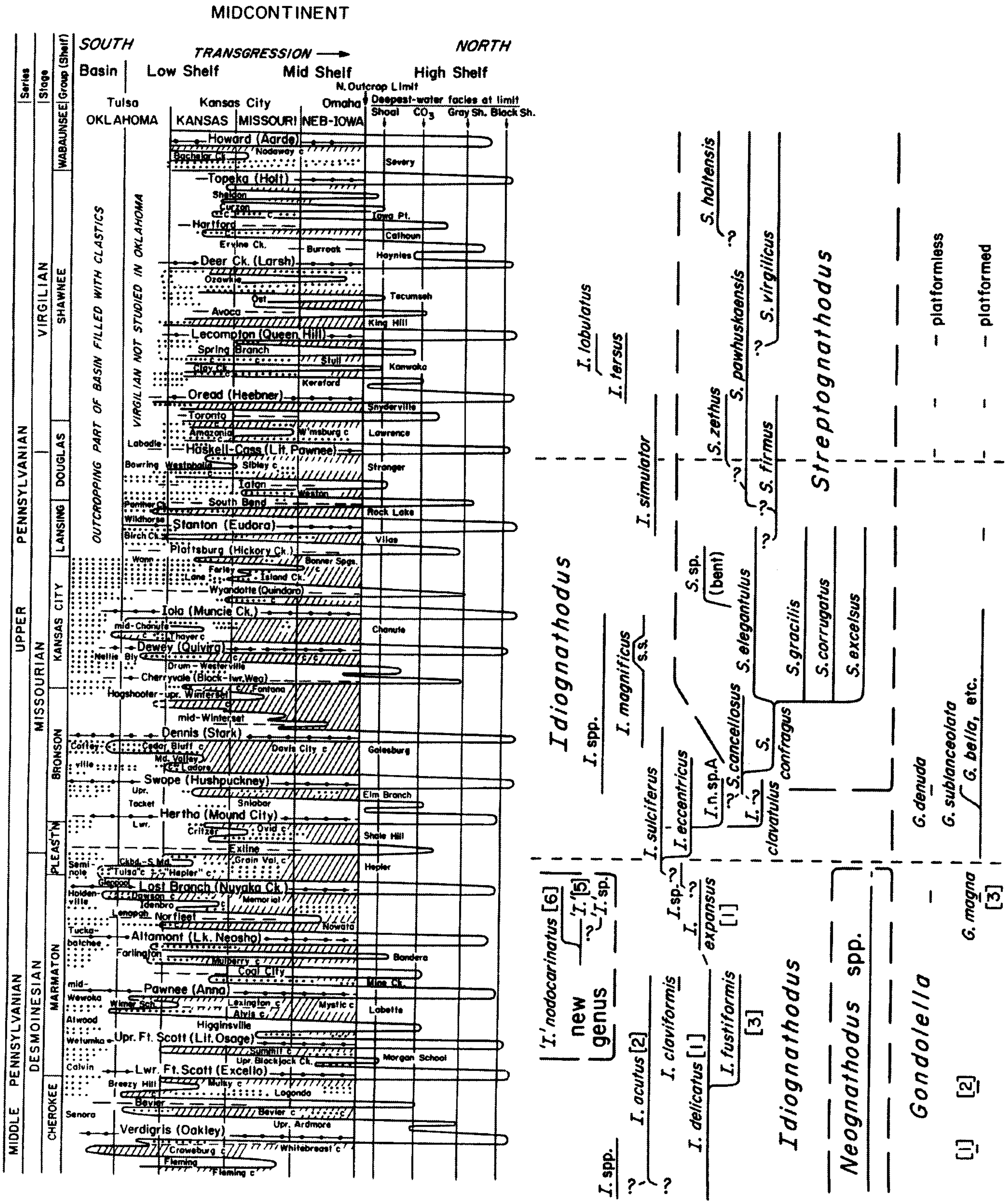


Fig. 7: Updated sea-level curve with current best estimate of ranges of selected, mainly idiognathodid conodont species (updated from Heckel, 1989, 1994). Numbers in brackets refer to species recognized by Swade (1985). Data from observations by P. H. Heckel, J. E. Barrick, and D. R. Boardman. For more detail in Virgilian, see Ritter (1995). On sea-level curve, lines with spots show condensed intervals in black (solid) and gray (dashed) shales; dots show coarse clastics; oblique lines on right show subaerial exposure.

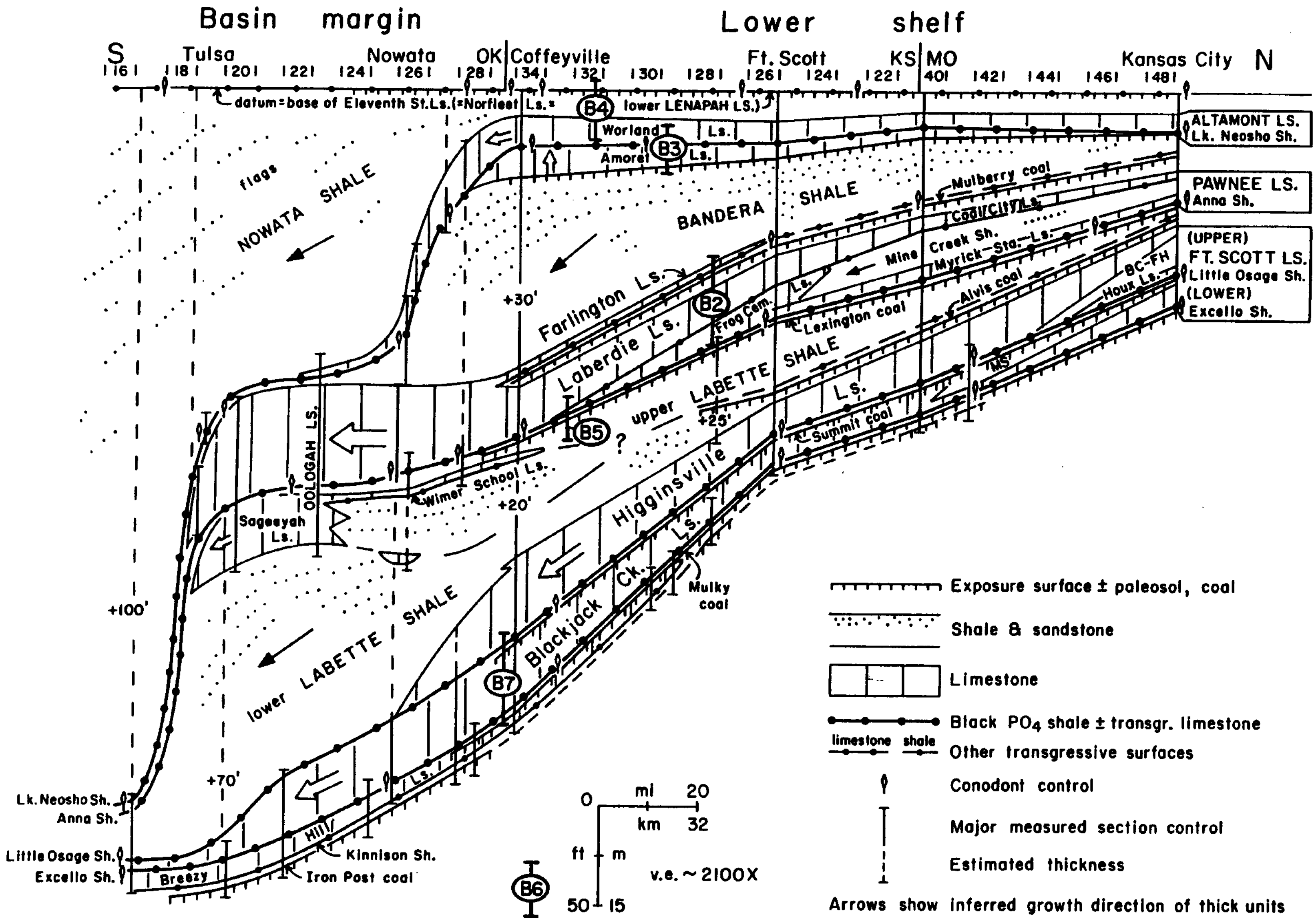


Fig. 8: Correlation cross-section of lower and middle Marmaton (upper Desmoinesian) cyclothems from Kansas City (at roughly middle to lower shelf boundary) across lower shelf to basin margin in Tulsa area of Oklahoma. Circled numbers show intervals covered by various field trip stops.

Limestone in Missouri. It includes the early transgressive Summit Coal at its base from southern Kansas northward, and the transgressive Clanton Creek Limestone in Iowa (Heckel and Pope, 1992). Its late transgressive and highstand condensed interval is the black phosphatic conodont-rich Little Osage Shale, another classic 'core' shale that also extends from Iowa to central Oklahoma, where it is the Wetumka Shale. Its early regressive deposits include the Houx Limestone in Missouri and Iowa and overlying deltaic Blackwater Creek Shale and Flint Hill Sandstone in Missouri and equivalent paleosol in Iowa. Above this, the Higginsville Limestone represents a transgression of intermediate scale that extends into Iowa where its lower part contains a conodont fauna of moderate abundance. Southward in Kansas, the Higginsville appears to represent the entire regressive phase of the Upper Fort Scott cyclothem, as the Houx Limestone is suspected to disappear into the Little Osage Shale in western Missouri. Late regression and lowstand is represented by the pedogenized top of the Higginsville Limestone and overlying paleosol in the north and by the thick detrital clastics of the lower part of the Labette Shale southward in southern Kansas and northern Oklahoma. The Little Osage Shale carries an abundant conodont fauna dominated by *Idiognathodus delicatus* and including *I. fustiformis*, *I. acutus, Neognathodus* and *Idioprioniodus*, but so far as known among samples collected at several places along outcrop and in the subsurface, no *Gondolella*. The lower Higginsville Limestone in Iowa and the apparently equivalent Atwood Shale in central Oklahoma carry a conodont fauna that is similar to that of the Little Osage Shale.

The minor **Wimer School cyclothem** (Fig. 7, 8) is definitely delineated so far only in northern Oklahoma and southernmost Kansas. It spans the interval from the marine transgressive contact at or below the base of the Wimer School Limestone upon coarse middle Labette detrital clastics upward to the top of the paleosol beneath the Lexington Coal. The lower boundary may be equivalent to the top of the paleosol beneath the Alvis Coal in Missouri and eastern Kansas, but this is not yet definite. The transgressive and highstand deposits are the Wimer School Limestone, and the regressive deposits are represented by shale and paleosol in the upper part of the Labette Shale. Southward in the Tulsa area, the Wimer School merges with the thicker Sageeyah Limestone, which may include at least one other minor cycle of transgression extending northward toward Kansas. The Wimer School contains so far as known, only a sparse conodont fauna dominated by *Idiognathodus delicatus*.

The major **Lower Pawnee cyclothem** (Fig 7, 8, termed simply Pawnee south of southern Kansas where it merges with the overlying Coal City cyclothem) includes the lower part of the Pawnee Limestone and extends across the entire Midcontinent. It spans the interval from the top of the paleosol beneath the Lexington Coal upward to the top of the paleosol beneath the coal smut near the top of the Mine Creek Shale in Iowa, to the top of unfossiliferous deltaic sandstone in Missouri, and to the base of the overlying transgressive deposits at the top of the Mine Creek Shale and the base of its southward extension, the Joe Shale bed elsewhere. The transgressive deposits of this cyclothem include the widespread Lexington Coal and the overlying Childers School Limestone bed of southern Kansas and Oklahoma. Its late transgressive and highstand condensed interval is the black phosphatic conodont-rich Anna Shale, a classic 'core' shale that extends from Iowa to central Oklahoma, where it lies in the middle of the Wewoka Formation. Early regression is represented by the Myrick Station Limestone from Iowa to eastern Kansas, and later regression is represented by the deltaic main part of the Mine Creek Shale in Iowa and Missouri and by the laterally equivalent Frog Cemetery Limestone in Kansas (Price, 1981, 1985). Like the older Little Osage Shale, the Anna Shale carries an abundant conodont fauna dominated by *Idiognathodus delicatus* and including *I. fustiformis, I. acutus, Neognathodus*, and *Idioprioniodus*, but no *Gondolella*.

The intermediate **Coal City cyclothem** (Fig. 7, 8) includes the upper part of the Pawnee Limestone and extends northward from the Kansas-Oklahoma border. It spans the interval from the base of the marine transgressive deposits in the top of the Mine Creek Shale and the base of its southward equivalent Joe Shale upward to the top of the paleosol beneath the Mulberry Coal in the base of the overlying Bandera Shale. Its transgressive and highstand condensed interval is represented by the conodont-rich zone that includes the Coal City Limestone in Iowa, the lower Coal City Limestone and upper Mine Creek Shale in Missouri, and the equivalent Joe Shale in Kansas, which merges southward with the top of the Anna Shale in southernmost Kansas and Oklahoma (Price, 1981, 1985) as seen at Stop B5. (South of here the two converged cyclothems are termed simply Pawnee). Regressive deposits of the upper or Coal City cyclothem include the upper part of the Coal City Limestone in Missouri, the entire equivalent Laberdie Limestone in Kansas and Oklahoma, capped by the underclay to the Mulberry Coal in the base of the overlying Bandera Shale. The conodont-rich zone, like the older Anna and Little Osage Shales below, carries an abundant fauna dominated by *Idiognathodus delicatus*, and including *I. fustiformis, I. acutus, Neognathodus* and *Idioprioniodus*. It is now known that this conodont-rich interval in the Mine Creek Shale near Lexington, Missouri, is the unit that yielded the conodonts that Gunnell (1931) first described as *Idiognathodus*, including *I. delicatus* and *I. claviformis*. [Gunnell (1931) denoted his original collecting locality as 'the shaly middle portion of the Fort Scott limestone....near the river bluff at Lexington, Missouri'. Later, Gunnell (1933) described *I fustiformis* from his

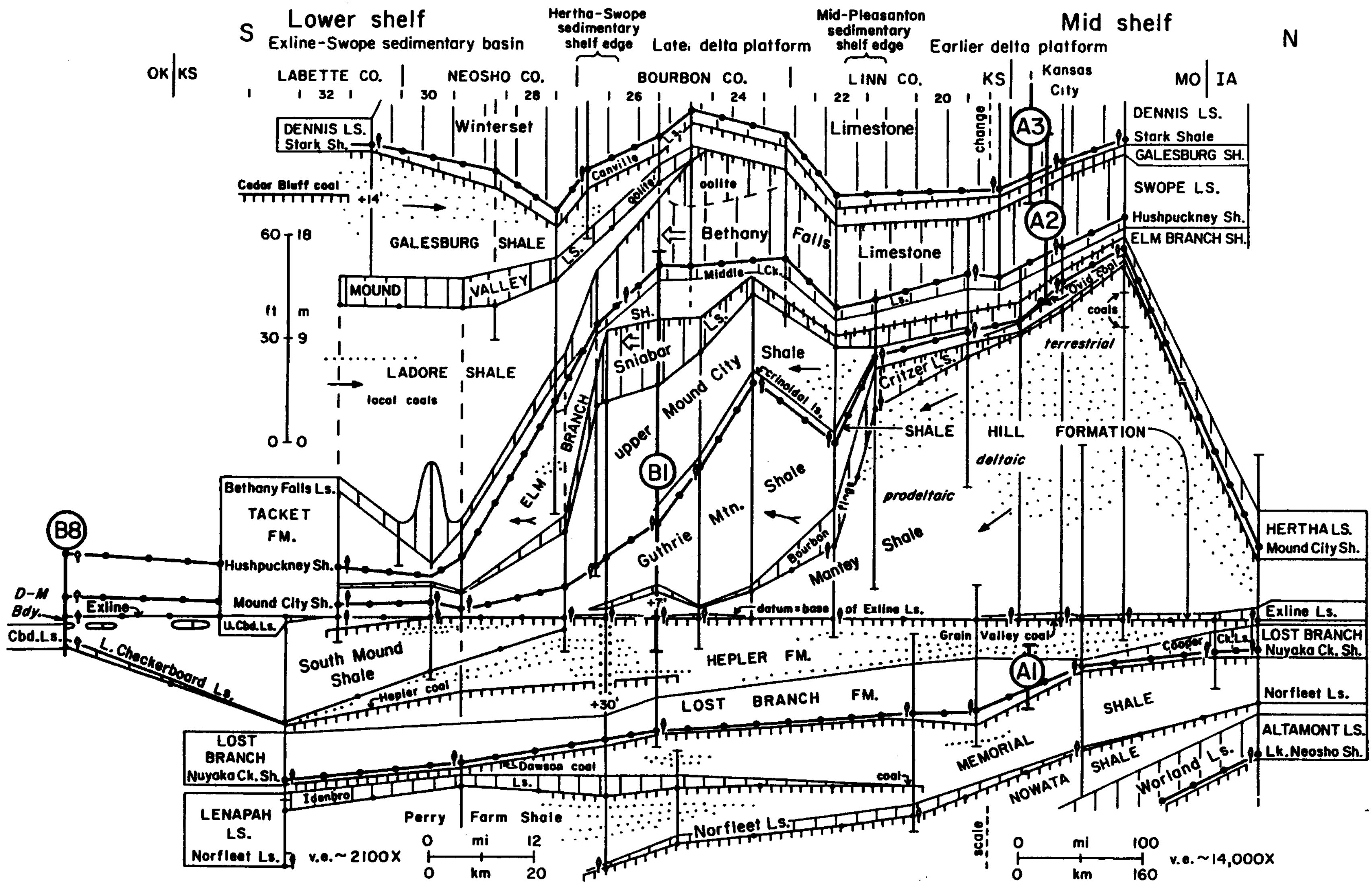


Fig. 9: Correlation cross-section of upper Marmaton, Pleasanton, and lower Kansas City (uppermost Desmoinesian to lower Missourian) cyclothems from Iowa (on mid shelf) to Kansas-Oklahoma border region (on lower shelf). Circled numbers show intervals covered by various field trip stops.

locality 1, which he denoted as 'Cherokee shale overlying Lexington coal, Lexington, Missouri', but this bed is now known to be the Anna Shale Member at the base of the Pawnee Limestone in the Marmaton Group. This latter misidentification was corrected by Ellison (1941, p. 140, locality 1266) as 'Lexington coal zone (not Cherokee)', but he did not mention the significance of this to the previous misidentification by Gunnell (1931). The Fort Scott Limestone has long been known to overlie the Cherokee shale (now Group) everywhere. Therefore, if Gunnell thought that the Lexington coal was 'Cherokee' in 1933, then he must have thought that the overlying limestone-rich section (where he most likely collected his original sample in the 'shaly middle') was 'Fort Scott' in 1931. The Pawnee limestone with the Mine Creek Shale Member in the middle not only forms the most conspicuous unit exposed in this area around Lexington, but in fact, it also closely resembles the Fort Scott Limestone at Fort Scott, Kansas, 100 miles (160 km) to the south, which would have been used as the standard for comparison.]

The intermediate **Farlington cyclothem** (Fig. 7, 8; formerly called post-Mulberry) extends at least into the subsurface of western Iowa and southeastern Nebraska. It spans the interval from the top of the paleosol beneath the Mulberry Coal upward to the top of the paleosol at or near the top of the Bandera Shale in Iowa and Missouri and to the top of the deltaic and related sandstones in the Bandera southward to northern Oklahoma. It includes the early transgressive Mulberry coal and the later transgressive Farlington Limestone (new name, Watney and Heckel, ms. in review) of southeastern Kansas. Its highstand condensed interval comprises the moderately conodont-rich top of the Farlington Limestone (seen at Stop B2, its type section) and northward equivalent fossiliferous shale and shaly lenticular limestones in Missouri and recovered in cores in Iowa and Nebraska. Its regressive deposits include thick Bandera paleosols in the north, marine sandstones in eastern Kansas (Brownfield et al., 1998), and the coarsening-upward thick Bandera deltaic sequence in northernmost Oklahoma. In sharp contrast to the older cyclothems, the Farlington conodont fauna is strongly dominated by the first appearance of *Idiognathodus* sp. 5 of Swade 1985, the first member of a strongly troughed clade of idiognathodids that he recognized as distinct from *Streptognathodus*, which evolved later during the early Missourian (Barrick et al., 1996; this guidebook). This new clade will be named as a separate genus in honor of Swade (see Lambert and Heckel, this guidebook). Its abrupt appearance here with no known ancestor in older rocks of this region suggest that it is an immigrant, and it marks the most abrupt break in idiognathodid conodont faunas in the Desmoinesian-lower Missourian part of the Midcontinent succession. The Farlington fauna also contains small numbers of *Adetognathus* (in increasing proportion downward toward earlier transgressive deposits), *Neognathodus, Hindeodus,* and rare *I. delicatus* and *Idioprioniodus*.

The major **Altamont cyclothem** (Fig. 7, 8) extends across the entire Midcontinent. It includes the Altamont Limestone and spans the interval from the top of the paleosol or other exposure surface at or near the top of the Bandera Shale upward to the top of the paleosol at the top of the Nowata Shale. Recent work in eastern Kansas for this field trip (Stop B3) has shown that the Amoret Limestone (once thought to be the simple transgressive limestone of the cyclothem) actually represents a minor cycle in its own right in this area, extending upward into the lower part of the lower gray facies of the overlying Lake Neosho Shale, which is a mudstone that contains corroded limestone nodules suggesting subaerial exposure. The Amoret and immediately overlying mudstone contain a sparse conodont fauna dominated by *Adetognathus* and including *Hindeodus* and *Idiognathodus* sp. 5 of Swade 1985. It is not known how far north this Amoret cycle extends (and it is not shown on Fig. 7 or 8). The main part of the Altamont cyclothem includes a transgressive limestone called Amoret in the Iowa cores that Swade (1985) studied, but it is not yet known how far south this unit is present. The late transgressive and highstand condensed interval of the Altamont cyclothem is represented by the conodont-rich top of the lower gray facies and the overlying phosphatic black and upper gray facies of the widespread Lake Neosho Shale, which extends from Iowa to Oklahoma. Its regressive deposits are the Worland Limestone capped by the paleosol-dominated overlying Nowata Shale from Iowa to Kansas, and by the immensely southward-thickening, basin-filling, lowstand shale and sandstone of the Nowata in Oklahoma. The 'core' portion of the Lake Neosho Shale carries an abundant conodont fauna, which unlike those of the lower shales, is dominated by *Neognathodus*. It contains *Idioprioniodus* throughout, and troughed *Idiognathodus* sp. 5 of Swade 1985 in the lower part, but flat morphotypes of *Idiognathodus* from the upper part of the black facies upward, with some overlap in the black facies. Although included in *I.* sp. 1 by Swade 1985, these flat morphotypes have more elongate platforms with more prominent noded lobes than typical *I. delicatus* below and more closely resemble *I. expansus* Stauffer and Plummer 1932 of the younger Lost Branch cyclothem. This species is similar enough to *I. delicatus*, however, that it may have descended from it during the time that flat morphotypes were essentially absent from the marine incursions in this region. This fauna has been identified above the Danville Coal in Illinois, and in the Honaker Trail section in Utah (Ritter et al., this guidebook).

The intermediate **Norfleet cyclothem** (Fig. 7, 8, 9) includes the lower part of the Lenapah Limestone and extends northward to the Missouri-Iowa border. It spans the interval from the top of the paleosol at or near the top of the Nowata Shale (or the transgressive surface in the upper Nowata southward) upward to the top of the paleosol at the top of the Perry Farm Shale in eastern Kansas (or equivalent sandstones southward). Transgressive deposits include a thin lenticular coal in southeastern Kansas and locally thin upper Nowata marine beds and lower parts of the Norfleet Limestone Member of the Lenapah Limestone. The highstand conodont-rich condensed interval includes in places the base, the top, or the entire Norfleet Limestone and its southern equivalent Eleventh Street Limestone in Oklahoma, and locally the base of the overlying Perry Farm Shale (which is partly a facies of the upper Norfleet). Its regressive deposits include in places the top of the Norfleet and everywhere the locally coarsening-upward deltaic to prodeltaic Perry Farm Shale, capped northward by a paleosol that is included in the overlying Memorial Shale toward the north. The condensed interval carries a moderately to locally very abundant conodont fauna in Oklahoma, Kansas and west-central Missouri that is in most places even more strongly dominated by *Neognathodus* than the Altamont cyclothem below, and contains in most places low numbers of *Hindeodus* and idiognathodids, but no *Idioprioniodus* or *Gondolella*. It also contains larger numbers of *Adetognathus*, which increase in proportion as total abundance diminishes northward in northern Missouri toward the highstand shoreline somewhere in Iowa. At one locality so far known (Stop B4) it contains an abundant fauna of idiognathodids, including flat *I. expansus*, morphotypes of the troughed clade, *I.* sp. 5 and *I.* sp. 6 of Swade 1985, and a less deeply troughed morphotype that resembles a form referred to as '*S. subexcelsus*' by A.S. Alekseev from the lower Krevyakinian Substage at the base of the Kasimovian Stage in the Moscow region of Russia (Heckel et al., 1998).

The minor **Idenbro cyclothem** (Fig. 7, 9) includes the upper part of the Lenapah Limestone and extends northward into west-central Missouri. It spans the interval from the paleosol or equivalent sandstone at the top of the Perry Farm Shale upward to the widespread paleosol beneath the Dawson Coal at the top of the Memorial Shale. The transgressive and highstand deposits of this cyclothem are represented mainly by the Idenbro Limestone Member of the Lenapah northward, which is replaced by an unnamed coal in east-central Kansas near the Missouri border. Its regressive deposits include local coarsening-upward detrital clastics in the Upper Member of the Memorial Shale and are capped everywhere by a paleosol. This unit carries only a sparse conodont fauna dominated by *Adetognathus* and containing rare *Hindeodus, Neognathodus* and *Idiognathodus*.

The major **Lost Branch cyclothem** (Fig. 7, 9) includes the Lost Branch Formation and extends across the entire Midcontinent. It spans the interval from the top of the widespread paleosol beneath the Dawson Coal upward to the top of the paleosol beneath the 'Hepler' and 'Tulsa' coals south of east-central Kansas. Northward where the upper paleosol and coal are absent, it may extend upward to the top of the paleosol beneath the Grain Valley Coal, but this interval is complicated with terrestrial sandstones and possible paleovalley fillings in places. This cyclothem includes the early transgressive Dawson Coal in Oklahoma and at places northward, and the later transgressive Sni Mills Limestone in Missouri and Homer School Limestone in central Oklahoma. Its highstand condensed interval is the conodont-rich black phosphatic Nuyaka Creek Shale, which extends from central Iowa to central Oklahoma. Its regressive deposits include the Cooper Creek Limestone in Iowa, coarsening-upward detrital clastics in parts of the states to the south, and the later regressive Glenpool Limestone locally in southern Kansas and Oklahoma (which may possibly represent a minor transgression into this region not delineated on Fig. 7). The Nuyaka Creek Shale carries an extremely abundant and diverse conodont fauna dominated by the troughed clade of idiognathodids, mainly *I.* sp. 6 of Swade 1985 [= '*I*'. *nodocarinatus* (Jones 1941)], and including flat morphotypes, mainly *I. expansus* Stauffer and Plummer 1932, and also *Neognathodus, Idioprioniodus*, and *Gondolella* (in its first appearance above the Excello Shale). The latter genus is represented by the only known Midcontinent occurrence of *G. magna* Stauffer and Plummer 1932, and one of the few occurrences of a platformless morphotype (*G.* cf. *gymna* / *G. denuda*) in the entire succession. The Glenpool Limestone and its equivalent fossiliferous shale in Oklahoma contains the highest occurrences of '*I*'. *nodocarinatus, I. expansus* and *Neognathodus* known in the Midcontinent. The fauna of the Nuyaka Creek Shale allows correlation of the Lost Branch cyclothem with the Lonsdale Limestone in northern Illinois, the upper part of the West Franklin Limestone in southeastern Illinois (Fig. 6B), and with the upper part of the East Mountain Shale in Texas (Boardman and Heckel, 1989), from which Stauffer and Plummer (1932) described *I. expansus*. '*I*'. *nodocarinatus* and *I. expansus* occur together at one level in the Honaker Trail section in Utah (Ritter et al., this guidebook), and the former also occurs in the upper Krevyakinian Substage of the lower Kasimovian Stage in the Moscow region of Russia (Heckel et al., 1998).

The minor **Checkerboard-South Mound cyclothem** (Fig. 7, 9) includes the Checkerboard Limestone of Oklahoma and the southern part of the top of the Hepler Formation in Kansas. It extends from Oklahoma into southern Kansas and spans the interval from the top of the paleosol beneath the 'Hepler' Coal upward to the top of the paleosol beneath the Grain Valley Coal and the overlying Exline Limestone in Kansas. Here this cyclothem includes the early transgressive 'Hepler' Coal at the base overlain by the marine South Mound Shale, which contains a moderately abundant conodont fauna marking highstand in a thin shaly limestone at its base toward the south. Its regressive deposits are the sparsely fossiliferous, locally coarsening-upward deltaic to prodeltaic main body of the South Mound Shale locally capped by sandstone and ultimately by paleosol to the north. Southward the upper paleosol disappears, and the South Mound Shale becomes overlain by a shallow-water limestone that extends southward into Oklahoma (in places as lenses) and ultimately merges with the thickening limestone at the base of the South Mound north of Tulsa to form the Checkerboard Limestone. In this region, this cyclothem apparently spans the interval from the top of the paleosol beneath the Tulsa Coal (as the local thin overlying coals do not appear to have paleosols) upward to the transgressive surface below the Exline equivalent shale above the Checkerboard Limestone. Farther southward, a paleosol overlain by a coal again appears below the Exline equivalent in east-central Oklahoma. The condensed interval occurs also in the base of the South Mound Shale above the lower Checkerboard Limestone as well as within the Checkerboard Limestone where it is a single bed. It contains a conodont fauna of moderate abundance that is dominated by *Idiognathodus* and contains *Adetognathus* (which dominates the sparser faunas northward in Kansas), with small numbers of *Hindeodus* and *Ellisonia* throughout and *Idioprioniodus* toward the south. The *Idiognathodus* is entirely *I. sulciferus* Gunnell 1933, a flat form that may possibly have descended from *I. expansus*.

The intermediate **Exline cyclothem** (Fig. 7, 9) includes the lower part of the Shale Hill Formation and extends across the Midcontinent. It spans the interval from the top of the paleosol beneath the Grain Valley Coal upward to the transgressive surface above sandstones below the Critzer Limestone in northeastern Kansas and upward to the top of the paleosol below the Ovid Coal in west-central Missouri. Transgressive deposits include the Grain Valley Coal and fossiliferous shale above the coal or paleosol. The highstand condensed interval is the argillaceous conodont-rich Exline Limestone, which contains phosphatized molluscs in places and grades southward into dark shale. Regressive deposits are represented by the Mantey Shale, which is mainly prodeltaic in northeastern Kansas, but coarsens upward into sandstone in a large deltaic complex in northwestern Missouri, and essentially disappears southward in southeastern Kansas as the overlying Critzer Limestone merges with the Exline. The Exline carries an abundant conodont fauna that is dominated by *Idiognathodus sulciferus*, and contains the first appearance of its descendant *I. eccentricus* (Ellison 1941) and also smaller numbers of *Adetognathus, Hindeodus* and *Idioprioniodus*. This fauna allows its correlation with the Scottville Limestone of southern Illinois (Fig. 6B).

The minor **Critzer cyclothem** (Fig. 7, 9) extends across most of eastern Kansas into Missouri and spans the interval from the base of the transgressive surface at or below the Critzer Limestone upward to the transgressive surface at the base of the Mound City Shale or to the paleosol beneath the Ovid Coal northward. The late transgressive and highstand condensed interval is in thin shale just below the base of the typical shelf facies of the Critzer Limestone and 'Bourbon flags' slope facies of the Critzer, and it occupies the entire thickness of its basinal facies in Bourbon County. Its regressive deposits include the shelf Critzer facies and the 'Bourbon flags' followed by the prodeltaic Guthrie Mountain Shale in the central area and capped by an exposure surface on the shelf facies of the Critzer to the north. The condensed interval in the southern facies and below the 'Bourbon flags' carries an abundant *Idiognathodus*- dominated conodont fauna that is essentially the same as that of the underlying Exline cyclothem, but this fauna becomes diminished in abundance and dominated by *Adetognathus* northward beneath the shelf facies of the Critzer Limestone.

The major **Hertha cyclothem** (Fig. 7, 9) includes the Hertha Limestone and extends across the entire Midcontinent. It spans the interval from the top of the paleosol beneath the Ovid Coal upward to the exposure surface on top of the Sniabar Limestone or at the top of the paleosol in the lower part of the overlying Elm Branch Shale in the northern region. Its transgressive and highstand condensed interval is the widespread conodont-rich phosphatic dark gray to black shale facies at the base of the Mound City Shale. Early regressive deposits comprise argillaceous limestone overlain by thick gray prodeltaic upper Mound City Shale in east-central Kansas (centered in Bourbon County). The base of the overlying Sniabar Limestone probably represents a minor transgression (shown on Fig. 7) that terminated detrital influx in this area. Late regression is recorded by the main part of the Sniabar and subaerial exposure in its locally pedogenized top and in the local basal paleosol of the overlying Elm Branch Shale. South of the basinward extent of these two exposure surfaces, the Hertha cyclothem spans the interval from the transgressive base of the Mound City Shale upward to the transgressive base of the younger Hushpuckney Shale. The condensed interval in the Mound City Shale carries an abundant conodont fauna dominated by *Idiognathodus* and containing *Idioprioniodus* and *Gondolella*. The idiognathodids include *I. sulciferus, I eccentricus*, and the first appearance of more nodose descendants, *I. clavatulus* (Gunnell 1933), and *I.* n. sp. A of Barrick et al. 1996. This fauna allows correlation with the black shale between the Chapel (#8) Coal and the Cramer Limestone (Trivoli Cyclothem) in the Illinois Basin (Fig. 6B), the Dog Bend Limestone of Texas, and a level in the Honaker Trail section in Utah (Ritter et al., this guidebook).

The major **Swope cyclothem** (Fig. 7, 9) includes the Swope Limestone and extends across the entire

Midcontinent. It spans the interval from the exposure surface on the Sniabar Limestone or on the paleosol in the lower Elm Branch Shale upward to the exposure surface represented by the Galesburg Shale in the northern region. Here its transgressive deposits are represented by the marine upper Elm Branch Shale overlain by the classic transgressive Middle Creek Limestone. Its highstand condensed interval is the widespread conodont-rich black phosphatic Hushpuckney Shale, and its regressive deposits are the shoaling-upward Bethany Falls Limestone capped by the Galesburg paleosol (see Joeckel, 1999). South of the basinward extent of these exposure surfaces, the Swope cyclothem spans the interval from the transgressive base of the Hushpuckney Shale upward to the top of the lowstand basin-filling Ladore Shale, which contains local coals. The Hushpuckney condensed interval carries an abundant conodont fauna dominated by *Idiognathodus* and containing good numbers of *Idioprioniodus* and *Gondolella*, including the first appearance of *G. sublanceolata*, and the next appearance of platformless *G. denuda* above the Lost Branch cyclothem. The idiognathodids include the species present below (*I. sulciferus, I. eccentricus, I. clavatulus*, and *I.* n. sp. A), and these are joined by the first appearance of the descendant genus *Streptognathodus*, *S. cancellosus* (Gunnell 1933), which apparently was derived from *I.* n. sp. A. This fauna allows correlation of the Swope cyclothem with the Macoupin Cyclothem in Illinois, the (Lower) Brush Creek Limestone in the Appalachian Basin (Fig. 6B), the upper Salesville Shale in Texas (Boardman and Heckel, 1989), and a level in the Honaker Trail section in Utah (Ritter et al., this guidebook).

The minor **Mound Valley cyclothem** (Fig. 7, 9) includes the Mound Valley Limestone and extends only from Oklahoma into east-central Kansas (Bourbon County). It spans the interval from the top of the lowstand Ladore Shale upward to the exposure surface at the top of the Galesburg Shale, or within its upper part at the paleosol beneath the Cedar Bluff Coal southward. Its transgressive deposits are the Mound Valley Limestone in the northern area, where the condensed interval is in the overlying base of the thick Galesburg Shale. Southward, the condensed interval is represented by the moderately conodont-rich shaly facies of the Mound Valley Limestone in Oklahoma. Its regressive deposits are the lower thick coarsening-upward detrital clastics of the Galesburg culminating in the paleosol beneath the Cedar Bluff Coal. The condensed interval carries a moderately abundant conodont fauna dominated by idiognathodids and containing *Adetognathus* (which increases in proportion as abundance decreases northward), small numbers of *Hindeodus*, and rare *Idioprioniodus* and *Gondolella* southward. The idiognathodids are dominated by *Streptognathodus cancellosus* and the first appearance of its descendant *S. confragus* (Gunnell 1933).

The major **Dennis cyclothem** (Fig. 7, 9) includes the lower part of the Dennis Limestone and extends across the entire Midcontinent. It spans the interval from the top of the paleosol in the Galesburg Shale upward to the top of the paleosol in the middle of the Winterset Limestone from Kansas to northern Missouri, which merges with the base of the overlying Fontana Shale in Iowa (Felton and Heckel, 1996). Its transgressive deposits include the local Davis City Coal in Iowa, and the Canville Limestone in southeastern Kansas (and locally northward) and Lost City Limestone in northeastern Oklahoma. Its highstand condensed interval is the widespread conodont-rich black phosphatic Stark Shale, and its regressive deposits are represented by the lower part of the Winterset Limestone, which displays a complex set of minor cycles (Fig 10) termed 'parasequences' in the Exxon terminology and representing 'phased regression' (Felton and Heckel, 1996). Early regression is recorded in the KC-1 cycle, which shoals upward to a paleosol in central Iowa but thins southward to 1 ft (0.3 m) of skeletal wackestone in the Kansas City area (well exposed at Stop A3). This is overlain by a conodont-rich dark shale traced from south of Kansas City into Iowa, which is a transgressive to minor highstand condensed interval that initiates the next phase of regression, the KC-2 cycle. Its regressive limestone shoals upward to a paleosol in southern Iowa and northern Missouri, and also thins southward, to about 4 ft (1.2 m) in the Kansas City area. This is overlain by another dark conodont-rich transgressive-minor highstand shale that initiates the next phase of regression, the K-3 cycle. This cycle thickens southward and comprises three more minor shallowing-upward carbonate cycles (A-C) in eastern Kansas (Fig. 10) before culminating in the paleosol in the thicker shale in the middle of the Winterset Limestone there. The two conodont-rich shales at the base of cycles KC-2 and KC-3 merge southward with the top of the Stark Shale in east-central Kansas, just as the Joe Shale merges southward with the top of the Anna Shale in the Desmoinesian Pawnee Limestone. It is probable that this is a common pattern in regressive limestones on the basinward-sloping shelf, and it has more recently been detected in the older Bethany Falls Limestone in the Iowa-Missouri border region by Pope (1996). The Stark Shale condensed interval carries an abundant conodont fauna dominated by idiognathodids and containing *Idioprioniodus* and *Gondolella*. The idiognathodids have not yet been well studied, but contain several flat morphotypes (one of which seems to lead to *I. magnificus* Stauffer and Plummer 1932) along with *Streptognathodus cancellosus* and *S. confragus*. This fauna allows correlation of this major cyclothem with the Shoal Creek Cyclothem in Illinois, the Palo Pinto Limestone in Texas, and with a level in the Honaker Trail section in Utah (Ritter et al., this guidebook). The two slightly younger transgressive shales carry similar faunas, but lack *Gondolella* and contain *Idioprioniodus* only into north-central Missouri. A third, higher thinner shale within cycle

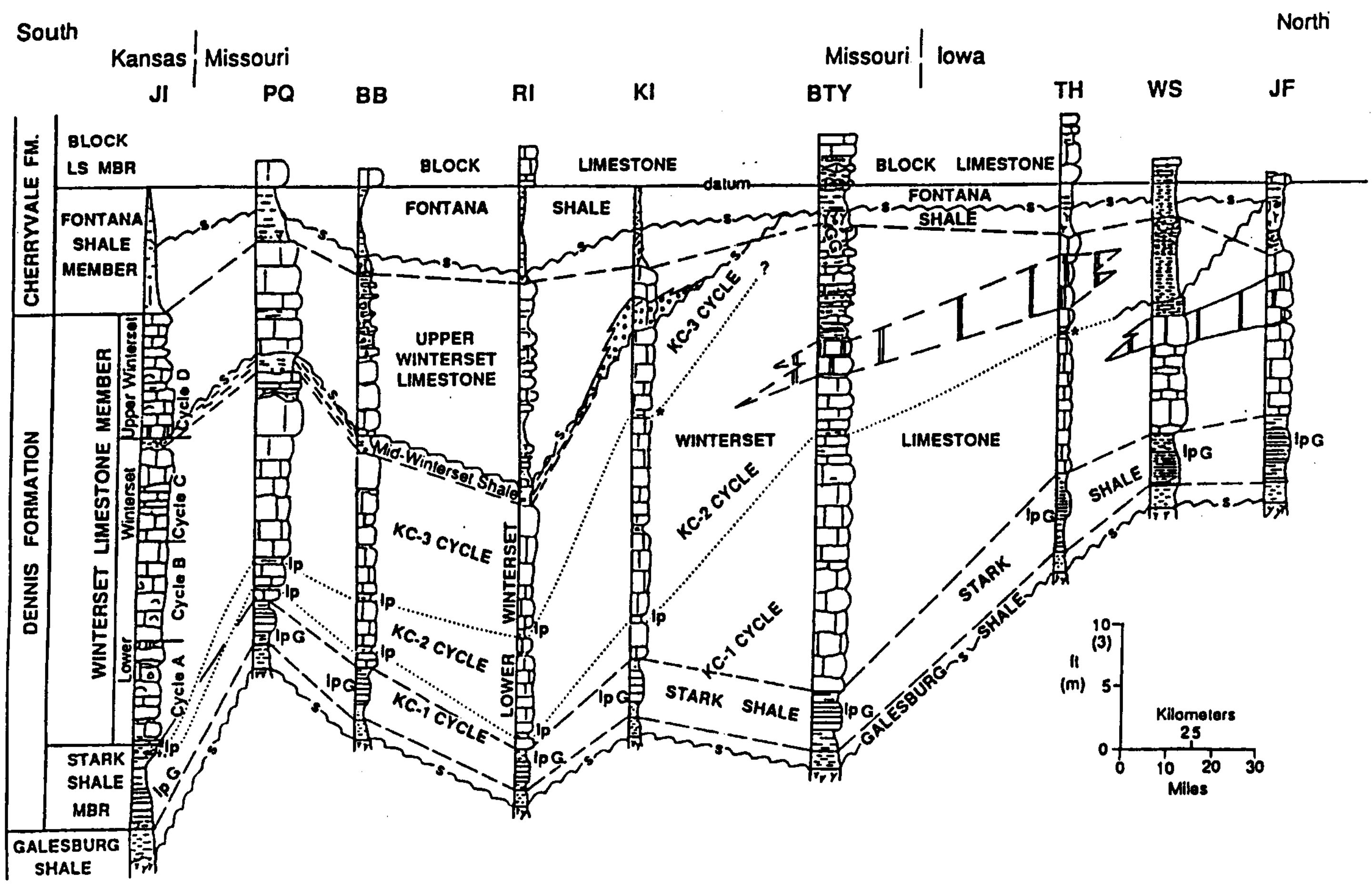


Fig. 10: Correlation cross-section of Dennis cyclothem complex (late early Missourian) from Iowa to eastern Kansas) showing regressive cycles in Winterset Limestone. Three northern cycles are marked by conodont-rich shales (mainly idiognathodids, but in which Ip = *Idioprioniodus* and G = *Gondolella* when present). Southern cycles (A, B, C) are minor shallowing-upward sequences in cycle KC-3. Cycle D is Hogshooter-upper Winterset cyclothem. Wavy lines marked by 's' are exposure surfaces that are also sequence boundaries. Section BB is close to field trip Stops A2 and A3 (from Felton and Heckel, 1996)

KC-3 (discovered at Stop A2 in preparation for this field trip and probably not a transgressive shale) contains a sparse fauna of *Streptognathodus* that includes slightly more deeply troughed specimens that resemble younger species of that genus.

The intermediate **Hogshooter-upper Winterset cyclothem** (Fig. 7, 10) includes the top of the Winterset Limestone Member of the Dennis Limestone and extends from Oklahoma into north-central Missouri. It spans the interval from the exposure surface in the middle of the Winterset Limestone upward to the top of the paleosol in the overlying Fontana Shale. Its transgressive deposits include a local coal bed in the Kansas City area and shoal-water and deepening-upward carbonates at the base of the upper unit of the Winterset Limestone in eastern Kansas. Its condensed interval consists of conodont-rich gray shale in southern Kansas and adjacent Oklahoma, where the exposure surface appears much lower in the Dennis succession in places, although the detailed stratigraphy there is uncertain. Regressive deposits include shoaling-upward limestone at the top of the upper Winterset capped by lower Fontana mudstone paleosol in eastern Kansas, which grades southward to generally thinner shaly limestone (termed Hogshooter) beneath the younger transgressive Cherryvale unit in northern Oklahoma. The condensed interval carries a moderately abundant idiognathodid-dominated conodont fauna with *Hindeodus* and *Idioprioniodus* in the southern region, but becomes dominated by *Adetognathus* where seen in eastern Kansas. The idiognathodids include a flat *Idiognathodus* morphotype with greatly reduced lobes, *Streptognathodus confragus*, possible *S. cancellosus*, and some more deeply troughed morphotypes approaching those common in the next overlying cyclothem.

The intermediate **Cherryvale cyclothem** (Fig. 7) includes much of the Cherryvale Formation and extends across the entire Midcontinent. It spans the interval from the top of the paleosol (or prodeltaic sequence southward) in the upper Fontana Shale upward to the exposure surface on the Westerville Limestone or above the paleosol in the overlying Nellie Bly Formation. Its transgressive deposits include the upper marine shale of the Fontana (with a local coal at the base) and the thicker skeletal wackestone facies of the overlying Block Limestone in eastern Kansas. Its highstand condensed interval is represented by thinner conodont-rich skeletal packstone facies of the Block Limestone in the Kansas City area and at other places northward and southward, and also by the base of the overlying Wea Shale where it is conodont-rich at a number of places along outcrop. Early regression is recorded in the generally relatively thick and locally coarsening-upward detrital clastic facies of the main part of the Wea Shale. Following a minor transgression recorded in the open marine base of the overlying Westerville Limestone (north) and Drum Limestone (south), final regression is recorded in their shallowing-upward carbonate facies, which culminates in most places in an exposure surface in the overlying Nellie Bly Formation, on a paleosol in the north and above a thick coarsening-upward detrital clastic sequence southward. The condensed interval in the Cherryvale cyclothem carries an abundant, idiognathodid-dominated conodont fauna with small numbers of *Hindeodus* and *Adetognathus*, and rare *Idioprioniodus* and *Gondolella* in the Kansas-Oklahoma border area. The idiognathodids include several flat *Idiognathodus* morphotypes, particularly in southern localities, but the fauna is characterized by the first abundant appearance of the classic more deeply troughed morphotypes of *Streptognathodus, S. gracilis, S. elegantulus, S. excelsus* [all Stauffer and Plummer 1932] and *S. corrugatus* Gunnell 1933. This fauna allows correlation with the Sorento cyclothem in Illinois and with a cycle in the lower Posideon Shale in Texas.

The major **Dewey cyclothem** (Fig. 7) includes the Dewey Limestone and extends across the entire Midcontinent. It spans the interval from the exposure surface in the Nellie Bly Formation (or on the Westerville Limestone) upward to the top of the underclay beneath the Thayer Coal in the Chanute Shale in Kansas or the exposure surface at or near the top of the Chanute northward. Its transgressive deposits include thin local coal beds from Kansas City northward, and the Pammel Park Limestone in Iowa (Heckel and Pope, 1992). The highstand condensed interval is the widespread conodont-rich dark phosphatic Quivira Shale, and the regressive limestone is the Cement City Limestone. There is increasing evidence for a second transgression near the top of the Cement City (Pope, 1999), but its lateral extent is not known, and it is not shown on Fig. 7. Later regression is recorded by paleosol forming most of the Chanute Shale northward, and by coarsening-upward detrital clastics culminating in paleosol in the middle Chanute southward. The highstand Quivira Shale carries an abundant idiognathodid-dominated conodont fauna that contains nearly equally large numbers of *Gondolella* (including the type species of the genus from the equivalent bed in Texas) in the middle, and lower numbers of *Idioprioniodus*. The idiognathodids include the several deeply troughed species of *Streptognathodus* that appeared below, but are dominated by the first abundant appearance of prominently lobed and delicately ribbed *Idiognathodus magnificus* Stauffer and Plummer 1932 (named from the equivalent bed in Texas). This fauna allows correlation of the Dewey cyclothem with the Flat Creek Cyclothem (and its equivalents) in Illinois (Pope, 1999), and with the mid-Posideon Shale in Texas (Boardman and Heckel, 1989). The Quivira Shale is the unit from which the holotype of *Streptognathodus oppletus* Ellison 1941 was collected.

The minor **mid-Chanute** cycle (Fig. 7) extends only into east-central Kansas and spans the interval from the top of the paleosol beneath the Thayer Coal upward to the exposure surface or top of the coarsening-upward detrital sequence at or near the top of the Chanute Shale. The transgressive to highstand deposits are the Thayer Coal and overlying limy, ostracode-bearing, possibly lagoonal shale in east-central Kansas, and rarely exposed more open marine shale southward. Regressive deposits are the coarsening-upward detrital clastics culminating in paleosol of the upper Chanute. Conodonts have not been recovered from this poorly studied unit.

The major **Iola cyclothem** (Fig. 7) includes the Iola Limestone and extends across the entire Midcontinent. It spans the interval from the exposure surface at near the top of the Chanute Shale upward to the exposure surface at the top of the Liberty Memorial Shale north of Kansas City, and to the base of the next higher transgressive unit southward. Its transgressive limestone is the Paola Limestone, and its highstand condensed interval is the conodont-rich phosphatic black Muncie Creek Shale, which is gray over thicker underlying Chanute Shale in east-central Kansas. Its regressive limestone is the Raytown Limestone, which shoals upward to an exposure surface in the north. The upper part of the Raytown is replaced southward by the prodeltaic Liberty Memorial Shale, which thins southward through the Kansas City region to disappearance in southern Kansas. The Muncie Creek Shale carries an abundant conodont fauna dominated by idiognathodids and containing low numbers of *Idioprioniodus* and *Gondolella*. The idiognathodids include several morphotypes of *Streptognathodus* including the species recognized in the two more widespread cyclothems below, and a delicately ribbed morphotype of *Idiognathodus* with a less prominent lobe that descended from *I. magnificus* and which we informally call 'postmagnificus'. This fauna allows correlation of the Iola cyclothem with the La Salle/Lower Millersville cyclothem in Illinois (Fig. 6B) and with the lower Wolf Mountain Shale in Texas (Boardman and Heckel, 1989), from which the holotypes of *Streptognathodus elegantulus* and *S. excelsus* (also the genotype) [both Stauffer and Plummer 1932] were collected.

The intermediate **Wyandotte cyclothem** (Fig. 7) includes the Wyandotte Limestone (as recently redefined and limited) and extends across the entire Midcontinent. It spans the interval from the exposure surface above the deltaic complex in the Liberty Memorial Shale upward to the exposure surface near the top of the Island Creek Shale in the Kansas City region and northwestern Missouri. The transgressive Limestone is the Frisbie Limestone in the Kansas City region, and the condensed interval is the widespread conodont-rich, locally dark gray Quindaro Shale. Regression is represented by shoaling-upward carbonate of the Argentine Limestone capped by the coarsening-upward deltaic clastics of the Island Creek Shale from Kansas City northward. Southward the Argentine thins and loses its shoal-water facies as it descends over the southward-thinning Liberty Memorial Shale (Arvidson, 1990) and ultimately rests directly on top of the Iola cyclothem (Raytown Limestone) from east-central Kansas into northern Oklahoma. Here late regression is recorded in the thick basin-filling coarsening-upward lower part of the Lane Shale. The Quindaro Shale carries an abundant *Streptognathodus*-dominated conodont fauna (including all three species recognized below, plus a morphotype in which the trough axis is bent laterally from the line of the carina), and carries low numbers of *Hindeodus, Adetognathus* and *Idioprioniodus*, but no *Gondolella*.

The minor **Farley cycles** (Fig. 7) include the Farley Limestone and are known only in northeastern Kansas and northwestern Missouri. They span the interval from the exposure surface near the top of the Island Creek Shale upward to the top of the well-developed paleosol near the top of the Bonner Springs Shale. The lower Farley cycle comprises shallow-water carbonates capped by the minor deltaic middle Farley shale, and the upper Farley cycle comprises shallow-water carbonates capped by Bonner Springs detrital clastics culminating in paleosol. The Farley cycles carry a sparse conodont fauna dominated by *Adetognathus* and *Hindeodus*.

The intermediate **Plattsburg cyclothem** (Fig. 7) includes the Plattsburg Limestone and extends across the Midcontinent. It spans the interval from the top of the paleosol in the Bonner Springs Shale upward to the top of the paleosol or of the coarsening-upward deltaic to prodeltaic clastics in the Vilas Shale. Its transgressive deposits include the marine top of the Bonner Springs Shale and the overlying deepening-upward Merriam Limestone. Its highstand condensed interval is the conodont-rich, locally dark gray Hickory Creek Shale, which is traced southward beyond the two limestone members into the thick detrital sequence of the Wann Formation of Oklahoma. Regression is recorded by the shoaling-upward Spring Hill Limestone capped by terrestrial clastics, paleosols, and (southward) a thick prodeltaic sequence in the Vilas Shale. The Hickory Creek Shale carries an abundant *Streptognathodus*-dominated conodont fauna like that of the Quindaro Shale in the Wyandotte cyclothem below (but with *S. elegantulus* and the morphotype with the bent trough axis more common), and also containing *Hindeodus* and small numbers of *Adetognathus* and *Idioprioniodus*, but no *Gondolella*.

The minor **Birch Creek cycle** (Fig. 7) is known only in northern Oklahoma where the shallow marine Birch Creek Limestone lies above the Plattsburg cyclothem and below the next higher (Stanton) cyclothem, separated from them by coarse detrital clastics. Its sparse conodont fauna is unstudied.

The major **Stanton cyclothem** (Fig. 7) includes the Stanton Limestone (as recently revised and limited) and extends across the entire Midcontinent. It spans the interval from the top of the paleosol in the Vilas Shale upward to the top of the paleosol in the Rock Lake Shale. In southern Kansas and Oklahoma, these two bounding units are thick coarsening-upward detrital units. The transgressive deposits include the marine top of the Vilas Shale and the transgressive Captain Creek Limestone. The highstand condensed interval is the widespread conodont-rich black phosphatic Eudora Shale, which is thin and gray in east-central Kansas above thick algal facies of the Captain Creek. Regression is recorded by the shoaling-upward Stoner Limestone capped by Rock Lake paleosol. The Eudora Shale carries an abundant idiognathodid-dominated conodont fauna that also contains *Idioprioniodus* and *Gondolella*. The idiognathodids are strongly dominated by the first appearance of *Idiognathodus simulator* (Ellison 1941), a finely ribbed form with an incipient to shallow trough for which the antecedent is uncertain. It also contains in its lower part the last appearance of the *S. elegantulus-gracilis-excelsus-corrugatus* group of species so dominant below, and in its upper part the first appearance of a morphotype resembling *Streptognathodus firmus* Kozitskaya 1978 (named from the Donets Basin of eastern Ukraine), which may have descended from *S. elegantulus*. This fauna allows correlation with the Little Vermillion Cyclothem in Illinois, the Noble Limestone (by means of *S. firmus*) of eastern Ohio, and the upper Winchell/Merriman Limestone of Texas.

The intermediate **South Bend cyclothem** (Fig. 7) includes the South Bend Limestone and extends across the Midcontinent. It spans the interval from the top of the paleosol in the Rock Lake Shale upward to the top of the coarsening-upward detrital sequence in the Weston Shale in Missouri and its equivalent paleosol in Nebraska. The transgressive deposits include the shallow marine top of the Rock Lake Shale in places and the deepening-upward Little Kaw Limestone. Its highstand condensed interval is the conodont-rich Gretna Shale, which can now be traced from Nebraska to northern Oklahoma. Its regressive deposits include the shoaling-upward Kitaki Limestone and capping paleosol in Nebraska, the coarsening-upward deltaic Weston Shale in northwestern Missouri, and equivalent more complex clastics in southern Kansas. The Gretna Shale carries an abundant conodont fauna that contains small numbers of *Idioprioniodus* and rare *Idiognathodus simulator*, but is strongly dominated by *Streptognathodus firmus* and the first appearance of its descendant *S. pawhuskaensis* (Harris and Hollingsworth 1932).

The intermediate **Iatan cyclothem** (Fig. 7) includes the Iatan Limestone, and is known in northwestern Missouri, Iowa and Nebraska, and has recently been discovered in southernmost Kansas. It spans the interval from the top of the coarsening-upward deltaic sequence of the Weston Shale upward to the top of the paleosol at the top of the Stranger Formation (Plattford in Nebraska), and to the base of later-formed paleovalleys in northeastern and southern Kansas. The type Iatan of northwestern Missouri contains a thin transgressive limestone at its base, overlain by a thin conodont-rich shale that represents the highstand condensed interval, which is overlain by a shoaling-upward limestone capped by a paleosol northward (Goebel et al., 1989). Its southern Kansas equivalent is thin argillaceous skeletal limestone with conodont-rich fossiliferous shale in the middle (seen at Stop C1) with a thick local lens of algal limestone nearby. The conodont-rich shales in both Missouri and southern Kansas carry a strongly *Streptognathodus*-dominated fauna that contains *Hindeodus* and *Adetognathus* and also *Idioprioniodus* in the south. Among the species of *Streptognathodus*, *S. pawhuskaensis* dominates *S. firmus*, and some of the larger specimens of the former display a tiny incipient node along the anterior margin of the platform.

The minor **Westphalia cyclothem** (Fig. 7) Includes the Westphalia Limestone and equivalent Bowring Limestone of Oklahoma and extends into eastern Kansas. In its type area of east-central Kansas, it spans the interval from the top of the coarse detrital clastics in the upper Stranger Formation upward to the top of a paleosol or coarsening-upward deltaic sequences in the Vinland shale. It appears in a small paleovalley in southern Kansas (Stops C2, C3), and its transgressive phase may have been involved in the tidal-dominated filling of the large Tonganoxie paleovalley in northeastern Kansas. This cyclothem is represented mainly by the shallow-marine skeletal calcarenitic Westphalia Limestone in southern Kansas, and appears to be represented by the Upper Sibley Coal overlain by a coaly ostracode-bearing, possible lagoonal calcilutite in northeastern Kansas. Both facies are overlain by either paleosol or coarsening-upward deltaic sequences in the Vinland Shale. The Westphalia Limestone carries a sparse *Adetognathus*-dominated conodont fauna with *Hindeodus* and locally *Streptognathodus pawhuskaensis*, a few of which also contain incipient nodes along the side of the platform.

The major **Cass cyclothem** (denoted as Haskell-Cass cyclothem on Fig. 7) includes the Cass Limestone (as recently revised) and extends across the entire Midcontinent. It spans the interval from the top of the paleosol or deltaic sequences in the Vinland Shale upward to paleosols, other exposure surfaces, or the tops of coarsening-upward detrital sequences in the middle of the Lawrence Formation. Its transgressive deposits include the shallow marine top of the Vinland Shale and the overlying widespread Haskell Limestone. Its highstand condensed interval is the equally widespread, conodont-rich, phosphatic, dark gray to locally black Little Pawnee Shale.

Regression is represented by the shoaling-upward Shoemaker Limestone (as newly revised) from Nebraska (where it is capped by a paleosol) to northeastern Kansas, by the Labadie Limestone in northern Oklahoma, and by various coarsening-upward deposits in between, including the Robbins Shale in east-central Kansas. The Little Pawnee Shale carries an abundant *Streptognathodus*-dominated conodont fauna, which also contains some *Idioprioniodus*, and rare *Adetognathus* and *Hindeodus*. Among *Streptognathodus*, *S. pawhuskaensis* strongly dominates *S. firmus*, and they are joined by the first appearance of a deeply troughed morphotype with a small inner accessory lobe, which resembles *S. zethus* Chernykh 1987 named from the southern Urals, and which may have descended from the form with incipient nodes seen in the underlying Westphalia and Iatan cycles. This appearance is currently used to define the Missourian-Virgilian Stage boundary in the base of the Cass cyclothem, but only provisional stratotypes are so far identified.

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VIRGILIAN AND LOWERMOST PERMIAN SEA-LEVEL CURVE AND CYCLOTHEMS

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INTRODUCTION

The cyclothemic nature of Pennsylvanian and Permian strata of the North American Midcontinent has been well established for many years (see Heckel 1984, 1985, 1994 for summary). Certainly one of the most significant contributions that should aid in the interbasinal and intercontinental correlation of Pennsylvanian and Permian strata is that these cyclothems were most likely controlled by glacial-eustasy (Wanless and Shepard, 1936; Heckel 1980, 1986, 1994; Boardman and Heckel 1989). The use of the locally derived sea-level fluctuation patterns established from the detailed stratigraphic and paleontological analysis of cyclothems has been recently established as a highly effective predictive model for interbasinal correlation (Boardman and Heckel 1989; Heckel and Weibel 1991; Boardman and Nestell 1993). A sea-level curve for the Virgilian to basal Artinskian (Lower Permian) is presented herein (Figure 1) and is modified from Heckel (1986) and Boardman and Heckel (1989) for the lower Virgilian part of the section. Much of the data are derived from Boardman and Nestell (1993), Boardman and others (1998), Boardman and Nestell (in press), and from Boardman and others (in review). Critical conodonts from the Carboniferous-Permian boundary strata from the Midcontinent are presented in Figure 2. These are based on identifications and stratigraphic information presented in Boardman and others (1998) and Boardman and others (in review).

The scope of the early interbasinal correlation efforts have been focused on the stratigraphic interval from the Marmaton to basal Wabaunsee Groups (upper Desmoinesian to middle Virgilian). Although considerable published as well as unpublished stratigraphic data are available for the Wabaunsee, Admire, and Council Grove groups, much of this data does not include regional stratigraphic analysis or paleontological analysis utilizing water depth identification trends as well as significant event surface identifications such as exposure surfaces and identification of paleosols. The biofacies model utilized for vertical depth trends in this paper is based on Heckel and Baesemann (1975), Boardman and others (1984), and Boardman and others (1995). The sequence stratigraphic terminology is modified from Watney and others (1989). This report is a status report of ongoing research efforts that focus on the uppermost Wabaunsee Group, Admire Group, and Council Grove Group, which includes data from Boardman and Nestell (1993), Boardman, Nestell, and Wardlaw (1998); Boardman, and Nestell (in press), and Boardman, Nestell, and Wardlaw (in review). Data for the upper Shawnee Group and the majority of the Wabaunsee Group is new unpublished data. Data for the Douglas and Shawnee groups are based in large part from previous work from Von Bitter (1972), Heckel (1989), and Ritter (1995) and some new material collected for this field conference.

Cyclothem definitions utilized in this paper are similar to those of Moore (1936). The megacyclothem concept is particularly close to that used by Moore (1936, 1964) for Shawnee cyclothems. However, the Hartford and Curzon cyclothems of the lower Topeka Limestone are included within the Deer Creek megacyclothem as representing the 'upper' and 'super' limestones respectively. Also, a megacyclothem is identified in the Douglas Group for the first time. Additionally, although Moore grouped two carbonate-dominated cyclothems separated by thin shales into formational units in the Wabaunsee Group, he made no attempt to add the concept of 'Wabaunsee megacyclothems'. New data show a distinct pattern of natural cyclothem bundles that are separated by major unconformities. The thick siliciclastic shale formations that separate the carbonate-dominated formations contain widespread major unconformities as evidenced by significant paleosol development along with incised valley fill deposits, whereas siliciclastics that separate the two limestone members within the limestone formation contain only locally developed minor exposure surfaces and no incised valley fill deposits. This paper recognizes Wabaunsee megacyclothems for the first time and identifies the megacyclothem boundaries as major unconformities that are located within the thick shale formations. No megacyclothems are defined herein in the upper Wabaunsee or Admire groups because no major paleosols or incised valleys have been identified in shales separating those cyclothems.

DOUGLAS GROUP CYCLOTHEMS

[HASKELL-CASS MEGACYCLOTHEM]

The Haskell-Cass megacyclothem comprises the Westphalia cyclothem, Haskell-Cass cyclothem, and the Amazonia cyclothem. Maximum marine flooding occurs in the black, locally fissile, and phosphatic Little Pawnee Shale that typically lies above the Haskell Limestone everywhere, which is at the base of the Robbins Shale in

Boardman, D. R., II, 1999, Virgilian and lowermost Permian sea-level curve and cyclothems; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99-27, p. 103–118.

areas with highstand deltas and beneath the Shoemaker Limestone in areas away from detrital influx. The Little Pawnee Shale is the regionally correlatiable marine condensed section.

Haskell-Cass Cyclothem

The major Cass cyclothem comprises the upper Vinland Shale, the Haskell Limestone, Little Pawnee Shale and Shoemaker Limestone Members of the Cass Limestone (newly recognized), and the Robbins Shale and Ireland Sandstone Members of the Lawrence Formation. Early transgressive deposits include sparsely fossiliferous siltstone that is overlain by sandy *Myalina*-bearing shale that is in turn overlain by a diverse fauna of bryozoans, brachiopods in the uppermost Vinland Shale. The Haskell is the transgressive limestone. Maximum marine flooding occurs in the black, locally fissile and phosphatic Little Pawnee Shale, which carries an abundant *Streptognathodus-Idioprioniodus-Gondolella* conodont fauna as well as abundant ammonoids, including the appearance of *Vidrioceras (V. conlini), Pseudaktubites stainbrooki,* as well as two new undescribed genera. Regressive deposits of this cyclothem include the Shoemaker Limestone (where developed) and the prodeltaic Robbins Shale and fluvial-deltaic Ireland Sandstone.

Amazonia Cyclothem

The minor Amazonia cyclothem comprises the Amazonia Limestone and the vast majority of the unnamed upper shale member of the Lawrence Formation. The Amazonia Limestone marks the transgressive surface of the cyclothem. Maximum marine flooding of the cyclothem occurs within the Amazonia Limestone and is characterized by fusulinaceans, bryozoans, brachiopods, and crinoids in addition to a sparse *Streptognathodus* conodont fauna. Regressive deposits of this cyclothem include well-developed red and green blocky mudstone paleosols at the top of the Lawrence Formation.

SHAWNEE GROUP CYCLOTHEMS

[OREAD MEGACYCLOTHEM]

The Oread megacyclothem comprises the Toronto cyclothem, Oread cyclothem, Kereford cyclothem, and the Clay Creek cyclothem. Maximum transgressive deposits occur in the black, fissile, and phosphatic Heebner Shale, which is a regionally correlatible marine condensed section.

Toronto Cyclothem

The intermediate Toronto cyclothem comprises the upper Lawrence Shale, Toronto Limestone, and the lower part of the Snyderville Shale. The early transgressive deposits include poorly fossiliferous upper Lawrence Shale with a sparse ***Adetognathus*** conodont fauna. The maximum marine flooding horizon occurs in a medial gray shale parting within the Toronto Limestone that contains a moderately abundant ***Streptognathodus*** conodont fauna (100-200 Pa elements per kilogram). The Toronto contains an abundant fauna of fusulinids, bryozoans, brachiopods, and crinoids. Regressive deposits include the upper Toronto with maximum lowstand deposits occurring in the well developed blocky-mudstone paleosols within the lower Snyderville Shale.

Oread Cyclothem

The major Oread cyclothem comprises the upper Snyderville Shale, Leavenworth Limestone, Heebner Shale, Plattsmouth Limestone, and the lower Heumader Shale. The transgressive upper Snyderville Shale as shown at Stop C4 of the fieldtrip is abundantly fossiliferous above the thin transgressive sandy carbonate lag. It contains abundant chonetid brachiopods, bivalves, and locally *Adetognathus* conodonts. The Leavenworth is the transgressive limestone. Maximum transgressive deposits occur in the black, fissile, and phosphatic Heebner Shale, which contains an abundant *Idiognathodus-Streptognathodus-Idioprioniodus* conodont fauna (100-1000 Pa elements per kilogram). In Oklahoma, the Heebner loses the fissile lithology and becomes a dark gray to black phosphatic clay shale that contains an abundant molluscan fauna including ammonoids. Regressive deposits of the Oread cyclothem include the Plattsmouth Limestone and lower Heumader Shale. The Plattsmouth contains a diverse fauna of phylloid algae, fusulinids, corals, bryozoans, brachiopods, and crinoids. Locally, especially in northern Kansas there is a shale parting near the middle of the Plattsmouth that carries a moderately abundant *Streptognathodus* conodont fauna that may indicate a flooding surface within the overall regressive limestone. This flooding interval has not been yet identified in southern Kansas. Maximum lowstand deposits of the Oread cyclothem occur in the lower Heumader Shale, which is marginal marine with sparse marine fossils.

Kereford Cyclothem

The intermediate Kereford cyclothem comprises the top of the Heumader Shale, Kereford Limestone, and Jackson Park Shale Member of the Kanwaka Shale. The top of the Heumader Shale contains brachiopods, bivalves, and a moderately abundant *Streptognathodus*-assemblage of conodonts. In northern Kansas the maximum transgressive deposits occur in the top of the Heumader Shale. The Kereford Limestone contains a relatively open marine assemblage of fusulinids, bryozoans, and brachiopods along with a reduced abundance of a mixed *Streptognathodus-Adetognathus* conodont fauna and represents the initial stage of regression. The Jackson Park Shale represents continued regression of the cyclothem and is generally marginal marine at the base becoming terrestrial at the top as evidenced by red and green blocky mudstones and fluvial channel deposits.

Clay Creek Cyclothem

The intermediate Clay Creek cyclothem comprises the Clay Creek Limestone and the lower part of the Stull Shale Member of the Kanwaka Shale. A gray shale parting within the Clay Creek Limestone represents maximum marine flooding and contains a moderate abundance of *Streptognathodus* conodonts (100-200 Pa elements per kilogram). This interval is abundantly fossiliferous and contains bryozoans, brachiopods, and crinoids. Regressive deposits within the cyclothem include the lower Stull Shale, which locally contains blocky mudstone paleosols.

[LECOMPTON MEGACYCLOTHEM]

The Lecompton megacyclothem comprises the Spring Branch cyclothem, Lecompton cyclothem, Avoca cyclothem, and Ost cyclothem. Maximum transgression of this megacyclothem occurs in the black, fissile, and phosphatic Queen Hill Shale which is a regionally correlatible marine condensed section.

Spring Branch Cyclothem

The intermediate Spring Branch cyclothem comprises the upper Kanwaka Shale, Spring Branch Limestone and lower Doniphan Shale. The early transgressive Kanwaka Shale contains brachiopods and bivalves along with sparse *Adetognathus* conodonts. Maximum transgressive deposits occur in the lower Spring Branch Limestone which contains a moderate abundance of *Streptognathodus* conodonts along with fusulinids, brachiopods, and crinoids. Regressive deposits include the upper Spring Branch Limestone and locally the lower Doniphan Shale. Commonly the top of the Spring Branch Limestone shows evidence of subaerial exposure such as brecciation.

Lecompton Cyclothem

The major Lecompton cyclothem comprises the upper Doniphan Shale, Big Springs Limestone, Queen Hill Shale, Beil Limestone, and King Hill Shale. The upper Doniphan Shale represents the earliest phase of transgression and has a sparse mixed *Adetognathus-Streptognathodus* assemblage with an invertebrate fauna of bivalves and brachiopods. The Big Springs is the transgressive limestone. Maximum marine flooding occurs in the black, fissile and phosphatic Queen Hill Shale that contains an abundant *Streptognathodus* fauna (200-1000 Pa elements per kilogram) and also includes *Gondolella*. In Oklahoma, the Queen Hill loses the fissile lithology and becomes a dark gray to black phosphatic clay shale that contains an abundant molluscan fauna, including ammonoids. Regressive deposits include the Beil Limestone and King Hill Shale. The Beil Limestone has an assemblage of *Caninia* corals that can be traced from northern Osage County, Oklahoma into Nebraska. The King Hill Shale locally contains green blocky mudstone paleosols and represents maximum lowstand.

Avoca Cyclothem

The intermediate Avoca Cyclothem comprises the Avoca Limestone and the lower Tecumseh Shale. The lowermost part of the Avoca Limestone that represents early transgression is poorly fossiliferous and contains sparse *Streptognathodus* and *Adetognathus*. The middle part of the Avoca Limestone is abundantly fossiliferous with fusulinids, sponges, and brachiopods and contains a moderate abundance of *Streptognathodus*. A thin gray shale parting near the top of the Avoca contains an abundant conodont fauna (100-1000 Pa elements per kilogram). The regressive part of the cyclothem is represented by the top of the Avoca Limestone and the lower Tecumseh Shale. The lower Tecumseh is silty marginal marine, whereas the majority of the overlying Tecumseh is blocky mudstone paleosol or fluvial channel deposits.

Ost Cyclothem

The minor Ost Cyclothem comprises the Ost Limestone and the upper Tecumseh Shale. This cyclothem is poorly developed and only locally present. Maximum marine flooding occurs in the Ost Limestone, which is a sparse molluscan carbonate with no conodonts. The top of the Tecumseh Shale represents the regressive part of the cyclothem and is typically a well-developed blocky mudstone paleosol.

[DEER CREEK MEGACYCLOTHEM]

The Deer Creek Megacyclothem comprises the Ozwakie cyclothem, Deer Creek cyclothem, Hartford cyclothem, and Curzon cyclothem. Maximum marine flooding of this cyclothem occurs in the black, fissile and phosphatic Larsh-Burroak Shale, which is a regionally correlatible marine condensed section.

Ozawkie Cyclothem

The minor Ozawkie Cyclothem comprises the Ozawkie Limestone and the majority of the Oskaloosa Shale. The Ozawkie Limestone, which represents maximum marine flooding, is an oolitic grainstone throughout much of the outcrop belt and contains abundant gastropods as well as algae. Only very rare *Adetognathus* is reported from this cyclothem. The majority of the overlying Oskaloosa Shale is composed of green or red blocky paleosol mudstones, which represent the regressive part of the cyclothem.

Deer Creek Cyclothem

The Deer Creek major cyclothem includes the top of the Oskaloosa Shale, Rock Bluff Limestone, Larsh-Burroak Shale, Ervine Creek Limestone, and Calhoun Shale. Early transgressive deposits within the top of the Oskaloosa Shale locally contain chonetid brachiopods and sparse fauna of *Adetognathus*. The Rock Bluff is the transgressive limestone. Maximum marine flooding occurs within the black, fissile and phosphatic Larsh Burroak Shale. This interval contains an abundant *Streptognathodus* fauna (1000 Pa elements per kilogram). *Streptognathodus pawhuskaensis* (Harris and Hollingsworth, 1933), was described from the Larsh-Burroak Shale in Osage County of northern Oklahoma. In Oklahoma the Larsh-Burroak Shale loses the fissile lithology and becomes a dark gray to black phosphatic clay shale that contains an abundant molluscan fauna, including ammonoids. Regressive deposits include the Ervine Creek Limestone and Calhoun Shale. The Calhoun Shale commonly contains coal beds. In southernmost Kansas the Calhoun Shale may be only a few centimeters in thickness and represents a significant exposure surface developed on top of the Ervine Creek Limestone.

Hartford Cyclothem

The intermediate Hartford cyclothem comprises the Hartford Limestone and the basal Iowa Point Shale. Early transgressive deposits include the lower bed of the Hartford Limestone which is typically a highly fossiliferous skeletal limestone. In northern and southern Kansas a highly fossiliferous gray shale with abundant *Streptognathodus* (200 Pa elements per kilogram) is present and represents maximum marine flooding at a marine condensed section. In northern Kansas the upper thicker Hartford Limestone, which is a highly fossiliferous skeletal wackestone, overlies the lower gray shale. This bed contains moderate numbers of *Streptognathodus*. In southern Kansas the upper bed of Hartford is similar but considerably thinner. However, in southern Kansas the basal Iowa Point Shale is highly fossiliferous with *Crurithyris* brachiopods and an abundant *Streptognathodus* fauna (100-200 Pa elements per kilogram) thus representing an additional core shale or another major flooding surface. In northern Kansas this interval may be equivalent to the uppermost Hartford, which contains abundant *Streptognathodus*. Regressive deposits of the Hartford cyclothem include the lower part of the Iowa Point Shale, which is silty and poorly fossiliferous. In northern Kansas this interval contains sparse *Adetognathus* and is apparently entirely shallow marine. In southern Kansas the basal Iowa Point Shale apparently is the upper condensed section, but this interval is followed by an upward increase in grain size becoming silty and poorly fossiliferous. This interval is overlain by thin coal beds with terrestrial vertebrates and thus represents non-marine conditions.

Curzon Cyclothem

The intermediate Curzon cyclothem comprises the top of the Iowa Point Shale, the Curzon Limestone and the Jones Point Shale. Early transgressive deposits include highly fossiliferous shales and thin lenticular skeletal wackestone beds that contain fusulinids, corals, bryozoans, brachiopods, bivalves, gastropods, nautiloids, trilobites, and crinoids with sparse numbers of *Streptognathodus*, along with some *Adetognathus*. Maximum marine flooding occurs within the lower part of the Curzon Limestone and is characterized by moderate numbers of *Streptognathodus* along with a profusion of fusulinids.

[UPPER TOPEKA MEGACYCLOTHEM]

The upper Topeka megacyclothem comprises the Sheldon cyclothem, upper Topeka cyclothem and the Bachelor Creek cyclothem. Maximum marine flooding of this cyclothem occurs in the black, fissile, and phosphatic Holt Shale, which is regionally correlatible.

Sheldon Cyclothem

The minor Sheldon cyclothem comprises the Sheldon Limestone and the lower part of the Turner Creek Shale. Early transgressive deposits include skeletal wackestone with brachiopods in the lower part of the Sheldon Limestone. This also corresponds to maximum marine flooding. This interval contains sparse numbers of *Adetognathus* conodonts. The upper Sheldon contains gastropods and algae. The lower Turner Creek Shale represents the late regressive part of the cyclothem and includes siltstones and silty shales with sparse fossils, including bivalves.

Upper Topeka Cyclothem

The upper Topeka major cyclothem comprises the upper part of the Turner Creek Shale, Dubois Limestone, Holt Shale, Coal Creek Limestone, and the Severy Shale of the Wabaunsee Group. Early transgressive deposits within the Turner Creek Shale include fossiliferous shale with thin molluscan carbonate lenses with rare to no conodonts. The Dubois is the transgressive limestone. The maximum marine flooding surface corresponds to the Holt Shale, which is now identified from Nebraska to Oklahoma (previously, it had not been recognized in southern Kansas). The black fissile Holt Shale contains sparse phosphate nodules, orbiculoid brachiopods and an abundant *Streptognathodus* conodont fauna (200-300 Pa elements per kilogram) including the type specimens of *Streptognathodus holtensis* Ritter (1994). The upper gray Holt Shale contains abundant brachiopods especially *Wellerella* and a moderate abundance of *Streptognathodus* conodonts. The regressive part of the cyclothem includes the Coal Creek Limestone and Severy Shale. The great thickness of the Severy Shale is due to the progradation of a major deltaic complex during early regression over most of the outcrop belt.

WABAUNSEE GROUP CYCLOTHEMS

Bachelor Creek Cyclothem

The minor Bachelor Creek cyclothem is included at the top of the Upper Topeka megacyclothem. It comprises the Bachelor Creek Limestone and basal traditional Aarde Shale, including underclay to the Nodaway coal bed. The transgressive surface of the Bachelor Creek cyclothem occurs at the base of the Bachelor Creek Limestone, which also corresponds to maximum marine flooding. Locally, the Bachelor Creek cyclothem contains brachiopods, bryozoans, and molluscs. No conodonts have been recovered from the Bachelor Creek cyclothem. The entire cyclothem is lenticular due to both non-deposition and erosion. For example, the Bachelor Creek Limestone is exposed at the west end of Stop C8 of this field trip but is only a sandy carbonate rubble on the east end of the locality. This is due to the extensive paleosol developed immediately above the carbonate. The regressive part of the cyclothem consists of green blocky mudstone paleosols that immediately overlay the Bachelor Creek Limestone, which is turn overlain by the Nodaway coal bed.

[HOWARD MEGACYCLOTHEM]

The Howard megacyclothem comprises the Howard cyclothem and the Winzler cyclothem. Maximum marine flooding coincides with the black, fissile, and phosphatic Shanghai Creek/ upper Aarde Shale, which is a regionally correlatable marine condensed section.

Howard Cyclothem

The major Howard cyclothem comprises the Nodaway Coal, Wauneta Limestone, Shanghai Creek Shale, and the Church Limestone. The Nodaway Coal (where present) or the base of the Wauneta Limestone (Chautauqua County, Elk County, and Greenwood County) and the equivalent Bird Creek Limestone of northern Oklahoma marks the trangressive surface of the cyclothem. In areas north of Greenwood County Kansas where the Wauneta Limestone is not developed, the Nodaway Coal and overlying gray fossiliferous shale (traditional upper Aarde) marks the base of the cyclothem. The transgressive Wauneta Limestone or Bird Creek Limestone is typically a dense sparsely fossiliferous wackestone. The maximum marine flooding surface corresponds to black, fissile, slightly phosphatic shale within the Shanghai Creek Shale or the top of the Aarde Shale to the north. This interval contains abundant *Streptognathodus* conodonts (100-200 Pa elements per kilogram), and orbiculoid brachiopods. The upper gray Shanghai Creek Shale that represents initial regression contains sparse *Streptognathodus* conodonts, brachiopods, bryozoans, gastropods, and ammonoids. In southern Kansas, the early regressive Church Limestone is typically a dense skeletal wackestone with a moderately diverse fauna including fusulinids, sponges, corals, bryozoans, brachiopods, and crinoids with a sparse mixed conodont assemblage of *Streptognathodus* and *Adetognathus*. In northern Kansas and Nebraska, the lower Church is typically a skeletal wackestone but the upper Church is locally a molluscan packstone/grainstone.

Winzeler Cyclothem

The Winzeler cyclothem comprises the Winzeler Shale, Utopia Limestone, and the basal White Cloud Shale Member of the Scranton Shale. The Winzeler Shale in all outcrop areas is a highly fossiliferous shale with brachiopods, bryozoans, corals, and a moderately abundant conodont fauna dominated by *Streptognathodus* (50-100 Pa elements per kilogram). The Winzeler Shale represents a marine flooding surface within the upper part of the Howard megacyclothem. The Utopia Limestone is a fossiliferous wackestone dominated by *Adetognathus*, which represents continued regression within the cyclothem. In southern Kansas (Chautauqua County) the Utopia pinches out into silty poorly fossiliferous shale and sandstone that represents deltaic progradation from northern Oklahoma above the marine flooding surface in the Winzeler Shale. Maximum regressive deposits of the Winzeler cyclothem are represented by red blocky mudstone within the lower part of the White Cloud Shale.

[SCRANTON MEGACYCLOTHEM]

The Scranton Megacyclothem comprises the White Cloud cyclothem, Happy Hollow cyclothem, and Rulo cyclothem. Maximum marine flooding coincides with the maximum marine flooding interval within the Rulo cyclothem.

White Cloud Cyclothem

The minor White Cloud cyclothem comprises an unnamed limestone within the upper part of the White Cloud Shale. The base of the White Cloud limestone corresponds to the transgressive surface of this cyclothem and is characterized by a poorly fossiliferous conglomeratic packstone that represents ravinement. Only agglutinated forams have been recovered from this limestone. Maximum marine flooding of this cyclothem corresponds to a gray slightly silty shale that overlies the limestone. This interval includes only a sparse assemblage of microfossils (foraminifers and ostracodes). Maximum regressive deposits include red and green blocky mudstones in the uppermost White Cloud Shale. This cyclothem has been thus far identified only in southern Kansas (Chautauqua and Elk counties). The regional extent of this cyclothem is unknown and is hampered by poor outcrops of the lower Scranton Shale.

Happy Hollow Cyclothem

The minor Happy Hollow cyclothem comprises the Happy Hollow Limestone and all but the top of the Cedar Vale Shale. The base of the Happy Hollow limestone is the transgressive surface of the cyclothem and is characterized by a fusulinid-rich skeletal wackestone. Maximum marine flooding at most localities in Kansas occurs near the base of the Happy Hollow Limestone and is denoted by fusulinids, brachiopods, and rare to moderate *Streptognathodus*-dominated conodont fauna (10-50 Pa elements per kilogram). In southern Nebraska the Happy Hollow Limestone is exceptionally thin and maximum marine flooding occurs at the top of the limestone in that area. The regressive part of the cyclothem includes gray silty shales forming most of the Cedar Vale Shale with maximum lowstand at the underclay to the Elmo coal bed near the top of the Cedar Vale Shale.

Rulo Cyclothem

The intermediate Rulo cyclothem comprises the Rulo Limestone and the lower half of the Silver Lake Shale. The base of the Rulo cyclothem corresponds to the transgressive surface that usually lies 0.15-0.13 meters below the base of the Rulo Limestone within the upper part of the Cedar Vale Shale. In northern Kansas and Nebraska this interval contains a molluscan assemblage of bivalves, gastropods, and an abundance of ostracodes. In southern Kansas this interval contains an abundant fauna of crinoids, brachiopods, and bryozoans with moderately abundant *Streptognathodus* (100 Pa elements per kilogram). Maximum marine flooding occurs at the base of the Rulo Limestone in southern Kansas and at its top in northern Kansas and Nebraska. Maximum marine flooding is denoted by a moderate number of *Streptognathodus*, and rare fusulinids. Regressive sediments of this cyclothem comprise a coarsening-upward sequence of siliciclastic sediments from gray silty sparsely fossiliferous shales to siltstones and finally sandstone. Maximum lowstand deposits include probable deltaic sands in the middle of the Silver Lake Shale.

[BERN MEGACYCLOTHEM]

The Bern megacyclothem comprises the Silver Lake cyclothem, Burlingame cyclothem, and the Wakarusa cyclothem. Maximum marine flooding of this cyclothem coincides with the gray marine shale condensed section in the Wakarusa cyclothem.

Silver Lake Cyclothem

The minor Silver Lake cyclothem comprises and unnamed limestone and locally fossiliferous interbedded shale, which is in turn overlain by silty shale and thin sandstones of the upper Silver Lake Shale. The transgressive surface of this cyclothem coincides with the base of the unnamed limestone. The regional limits of this minor cyclothem are undetermined, as it has only been positively identified in southern Kansas. Maximum marine flooding in this cyclothem occurs near the base of the unnamed limestone and is marked by a mixed assemblage of molluscans and brachiopods with sparse numbers of *Adetognathus* conodonts (5 Pa elements per kilogram). The top of the unnamed limestone is devoid of conodonts but contains an abundance of gastropods, especially bellerophontids. This cyclothem is terminated by a thin local green and red blocky mudstone paleosols with root mottling and red internal sediment in the top of the underlying unnamed limestone.

Burlingame Cyclothem

The intermediate Burlingame cyclothem comprises the Burlingame Limestone and Soldier Creek Shale Member of the Bern Limestone. The transgressive surface of this cyclothem in central and northern Kansas as well as Nebraska corresponds to the base of the Burlingame Limestone. In southern Kansas the transgressive part of the cyclothem consists of interbedded calcareous sandstone, siltstone, shale, and thin lenticular carbonates, all of which are highly fossiliferous and contain brachiopods, bryozoans, crinoids, bivalves and gastropods and is mapped as the upper part of the Silver Lake Shale. Maximum marine flooding occurs at the top of the lower Burlingame ledge in southeastern Nebraska, 0.3 meters above the base in northern Kansas and near the base of the massive ledge in southern Kansas. In all regions maximum marine flooding is associated with a diverse fauna of fusulinids, bryozoans, corals, brachiopods, crinoids, and a moderate abundance of *Streptognathodus* conodonts (50-100 Pa elements per kilogram). Regressive deposits include the upper Burlingame, which ranges from a coated grainstone to packstone followed by the Soldier Creek Shale. The base of the Soldier Creek Shale is locally marine but in other places is entirely blocky mudstone paleosols. Typically a thin coal is present in the upper part of the member underlying the Wakarusa Limestone.

Wakarusa Cyclothem

The intermediate Wakarusa cyclothem comprises the Wakarusa Limestone and the lower two thirds of the Auburn shale. The transgressive surface of the Wakarusa cyclothem typically coincides with the base of the Wakarusa Limestone, but includes the thin underlying coal, where present. Maximum marine flooding occurs in a highly fossiliferous gray to grayish-black shale parting near the middle to top of the Wakarusa Limestone. This interval is a marine condensed section typically having between 300-500 *Streptognathodus* Pa conodont elements per kilogram. This condensed shaly parting is traceable from northern Oklahoma throughout Kansas and into Nebraska. The Wakarusa is highly fossiliferous with fusulinids, corals, bryozoans, brachiopods, trilobites, and crinoids as well as the abundant conodonts. The type species of *Streptognathodus virgilicus* Ritter 1995 is from the Wakarusa Limestone. The regressive part of the cyclothem includes the Wakarusa Limestone above the condensed section and the lower two-thirds of the Auburn Shale. Within the lower Auburn Shale at least two flooding surfaces with a moderate abundance of *Streptognathodus* conodonts are recognized. The flooding surfaces separate sparsely fossiliferous silty shales from highly fossiliferous shales and thin carbonates. Maximum lowstand deposits occur in the middle of the Auburn Shale and typically consist of red to green blocky shale paleosols.

[EMPORIA MEGACYCLOTHEM]

The Emporia megacyclothem comprises the Reading cyclothem and Elmont cyclothem. Maximum marine flooding coincides with the maximum marine flooding horizon within the Reading cyclothem.

Reading Cyclothem

The intermediate Reading cyclothem comprises the upper Auburn Shale, Reading Limestone, Harveyville Shale and the lower Elmont Limestone. The transgressive surface is typically recognized within the upper Auburn Shale as highly fossiliferous shales and thin-bedded fossiliferous wackestones. Maximum marine flooding corresponds to either the top of the Reading Limestone or the base of the Harveyville Shale. Where the top of the Reading Limestone represents maximum marine flooding, there is a marine condensed section with glauconite, phosphatized molluscs, and an abundant conodont fauna with 100-300 conodont Pa elements per kilogram. The base of the Harveyville Shale (which is normally a dark gray to grayish-black clay shale) locally contains moderate to abundant conodonts (50-300 Pa elements per kilogram) and also locally contains pyritized molluscs including ammonoids, gastropods, bactritoids, and bivalves. The lower Elmont Limestone is genetically related to the Reading cyclothem and is poorly fossiliferous wackestone with local evidence of subaerial exposure.

Elmont Cyclothem

The intermediate Elmont cyclothem comprises the upper Elmont Limestone and the Willard Shale. The transgressive surface for the Elmont Cyclothem occurs at the base of the upper Elmont Limestone and is marked by a highly fossiliferous wackestone with fusulinids, brachiopods, bryozoans, and crinoids. Maximum marine flooding occurs at the top of the Elmont Limestone, which is usually a thinly bedded fossiliferous wackestone with an abundant *Streptognathodus* conodont fauna (200 Pa elements per kilogram). The regressive part of the cyclothem is represented by the Willard Shale. Locally in northern Kansas and Nebraska the basal Willard Shale is highly fossiliferous with moderately abundant *Streptognathodus* conodonts along with pyritized molluscs including gastropods, bivalves, and ammonoids. The upper Willard Shale represents maximum lowstand within the cyclothem and includes fluvial channels, incised valley fill deposits, and red and green blocky mudstone paleosols.

[ZEANDALE MEGACYCLOTHEM]

The Zeandale Megacyclothem comprises the Tarkio cyclothem, Wamego cyclothem and Maple Hill cyclothem. Maximum marine flooding coincides with the maximum marine flooding horizon within the Maple Hill cyclothem.

Tarkio Cyclothem

The minor Tarkio cyclothem comprises the Tarkio Limestone, and basal Wamego Shale. The transgressive surface of the Tarkio cyclothem occurs at the base of the Tarkio Limestone. Maximum marine flooding of the Tarkio cyclothem occurs usually between .3 to .6 meters above the base of the Tarkio Limestone and is characterized by a low to moderate number of *Streptognathodus* conodonts (10-20) per kilogram along with an abundance of fusulinids, corals, and brachiopods in a skeletal wackestone. The regressive part of the Tarkio cyclothem includes the Tarkio Limestone above the maximum flooding surface and the basal Wamego Shale. The upper Tarkio is typically a fusulinid packstone with little other macrofauna present. The very top of the Tarkio locally includes include echinoids and bryozoans in addition to the fusulinids. The basal Wamego Shale is unfossiliferous and silty. The Tarkio cyclothem has previously not been reported south of Lyon County Kansas due in part to the change of facies from a bench-forming solid limestone to a fossiliferous interbedded shale and thin shaly wackestone south of Lyon County, Kansas. The Tarkio cyclothem is present throughout Kansas but is difficult to identify except in fresh road cuts and stream cuts.

Wamego Cyclothem

The minor Wamego cyclothem comprises the middle and upper part of the Wamego Shale. The transgressive surface of the Wamego cyclothem occurs about 0.6 meters above the base of the Wamego Shale and is a highly fossiliferous shale with thin interbedded fossiliferous skeletal wackestones with bryozoans, brachiopods, and molluscs. Locally the Stormont Limestone bed is developed in this stratigraphic position and is also highly fossiliferous skeletal wackestone. No conodonts have been recovered from this cyclothem. The regressive part of this cyclothem corresponds with the progressively coarsening-upward upper Wamego Shale.

Maple Hill Cyclothem

The minor Maple Hill cyclothem comprises the Maple Hill Limestone and Pillsbury Shale. The transgressive surface of the Maple Hill cyclothem occurs at the base of the Maple Hill Limestone. Maximum marine flooding of the Maple Hill cyclothem occurs at the top of the Maple Hill Limestone and is denoted by a moderate number of *Streptognathodus* conodonts (40-60 Pa elements per kilogram). Also this interval is marked by a skeletal wackestone with fusulinids, brachiopods, bryozoans, and crinoids. The regressive part of the cyclothem corresponds to the base of the Pillsbury Shale, which is sparsely fossiliferous and coarsens upwards into silty shale, siltstone and to sandstone. locally, incised valley fills are prominent in the upper part of the Pillsbury Shale. The Maple Hill Limestone is not mapped by the Kansas Geological Survey south of Lyon County, Kansas, but the cyclothem has positively been identified throughout Kansas. In southern Kansas, the Maple Hill Limestone is no longer a ridge former but is a shaly thin-bedded limestone with associated fossiliferous shale.

[STOTLER MEGACYCLOTHEM]

The Stotler megacyclothem comprises the Dover cyclothem and the Grandhaven cyclothem. Maximum marine flooding coincides with the maximum marine flooding horizon within the Dover cyclothem.

Dover Cyclothem

The intermediate Dover cyclothem comprises the Dover Limestone and the Dry Shale. The transgressive surface of the Dover cyclothem occurs at the base of the Dover Limestone. The lower part of the Dover Limestone is commonly stromatolitic and carries few conodonts. Maximum marine flooding of the Dover cyclothem occurs as a marine condensed section either a shale parting near the top of the Dover Limestone, a shaly fossiliferous wackestone near the top of the Dover or as a highly fossiliferous shale overlying the lower bed of the Dover. In all cases 200-400 *Streptognathodus* Pa elements per kilogram are denoted. Where the marine condensed section is carbonate, it contains an abundant fauna of fusulinids, brachiopods, bryozoans, corals, and trilobites. In Lyon County, Kansas, as well as in southeastern Nebraska the top of the lower Dover Limestone and the base of the overlying shale are highly fossiliferous and have a high abundance of *Streptognathodus* conodonts (200-400 Pa elements per kilogram), and also have pyritized molluscs, including ammonoids in addition to brachiopods, bryozoans, corals, and trilobites.

Grandhaven Cyclothem

The intermediate Grandhaven cyclothem comprises the Grandhaven Limestone and all but locally the top 0.5 meter of the Friedrich Shale. The transgressive surface of the Grandhaven cyclothem occurs at the base of the Grandhaven Limestone or locally in the upper 0.3 meters of the Dry Shale. Maximum marine flooding of the Grandhaven cyclothem occurs near the top of the Grandhaven Limestone in highly fossiliferous wackestones with fusulinids, bryozoans, and brachiopods along with a moderate abundance of *Streptognathodus* conodonts (100 Pa elements per kilogram). Commonly shale partings are abundant within the upper Grandhaven Limestone, and at least one major flooding surface is present that carries a similar diversity of organisms and abundance of *Streptognathodus* conodonts per kilogram. Mudge and Yochelson (1962) noted ammonoids in the shale partings in the upper Grandhaven Limestone. The regressive part of the cyclothem corresponds to the Friedrich Shale. The base of the Friedrich Shale is silty and sparsely fossiliferous. The Friedrich Shale coarsens upwards and has red blocky mudstone paleosols developed near the top of the member.

[UNCLASSIFIED AS MEGACYCLOTHEMS]

Jim Creek Cyclothem

The minor Jim Creek cyclothem comprises the top meter of the Friedrich Shale, the Jim Creek Limestone, and the majority of the French Creek Shale. The transgressive surface of the Jim Creek cyclothem occurs at the base a coal or coaly shale in the upper 0.5 meters of the Friedrich Shale. Maximum marine flooding of the Jim Creek cyclothem occurs at the top of the Jim Creek Limestone in a highly fossiliferous wackestone with fusulinids, bryozoans, brachiopods, bivalves, with a moderate abundance of mixed *Streptognathodus-Adetognathus* conodont assemblage (40-50 elements per kilogram). The regressive part of the cyclothem corresponds to the majority of the French Creek Shale. The basal French Creek Shale is sparsely fossiliferous and coarsens upward into sandstone. Red and green blocky mudstone paleosols are developed above the coarse siliciclastics within the mid-to upper French Creek Shale.

French Creek Cyclothem

The minor French Creek cyclothem comprises a narrow stratigraphic interval bounded by coals in the upper part of the French Creek Shale. This cyclothem is thin (usually around one meter), locally developed and contains a sparse assemblage of forams and ostracodes and locally contains bivalves, bryozoans, and brachiopods at the maximum flooding surface. No conodonts have been recovered from this cyclothem. This cyclothem was first noted by Mudge and Yochelson (1962). The regressive part of the cyclothem corresponds to the base of the upper French Creek coal bed.

Nebraska City Cyclothem

The minor Nebraska City cyclothem comprises the upper 0.5 meters of the French Creek Shale, the Nebraska City Limestone, and the Plumb Shale. The transgressive surface of this cyclothem occurs at the base of the upper coal in the French Creek Shale and is marked by a fossiliferous shale with bivalves, gastropods, brachiopods and rare *Adetognathus* conodonts. Maximum marine flooding occurs at the top of the Nebraska City Limestone where rare fusulinids, bryozoans, brachiopods, bivalves and a sparse mixed assemblage of *Adetognathus-Streptognathodus* conodonts are found (30-40 Pa elements per kilogram). The regressive part of the cyclothem includes the Plumb Shale. The basal Plumb Shale is sparsely fossiliferous and coarsens upwards with local red and green blocky mudstone paleosols.

Grayhorse Cyclothem

The minor Grayhorse cyclothem comprises the Grayhorse Limestone and the majority of the Pony Creek Shale. The transgressive surface of this cyclothem occurs at the base of the Grayhorse Limestone and is marked by a fossiliferous molluscan packstone/grainstone dominated by bivalves with some gastropods, which also corresponds to maximum marine flooding. No conodonts have been recovered from the Grayhorse Limestone. Identification of this cyclothem is severely limited due to non-deposition and post-Grayhorse erosion. Incised valley fills are well developed in the overlying Pony Creek Shale and commonly have removed the Grayhorse Limestone. It is best developed in southern Kansas and northern Oklahoma. The regressive part of this cyclothem includes all but the top meter of the Pony Creek Shale. The Pony Creek also contains well developed green and red blocky mudstone paleosols.

Brownville Cyclothem

The Brownville intermediate cyclothem includes approximately the top of the Pony Creek Shale, the Brownville Limestone, and most of the Towle Shale. Typically, the transgressive surface of the Brownville Sequence is located within a meter below the top of the Pony Creek Shale. Above the transgressive surface, thin discontinuous limestones and fossiliferous gray shales contain abundant *Myalina* clams, bryozoans, ostracodes, and rare *Adetognathus* conodonts. Throughout the study area, the lower Brownville Limestone is represented by highly fossiliferous wackestones to packstones with an offshore open marine fauna of brachiopods, crinoids, fusulinids, and *Streptognathodus* conodonts. Maximum marine flooding of the Brownville cyclothem occurs at or near the top of the Brownville Limestone in the outcrop region from northern Oklahoma through central Kansas. Maximum flooding is characterized by marine cements, glauconite, phosphatized mollusks, abundant *Streptognathodus* conodonts as well as a diverse open marine fauna of brachiopods, corals, bryozoans, crinoids, and fusulinids. In northern Kansas the top of the Brownville Limestone is a highly fossiliferous wackestone but with only minor evidence of condensation. In that region, a green highly fossiliferous shale at the base of the Towle Shale is interpreted to represent the maximum flooding marine condensed section. This shale contains phosphatized mollusks, along with crinoids, brachiopods, fusulinids, and abundant *Streptognathodus.*

The regressive part of the Brownville cyclothem includes the lower two-thirds of the Towle Shale throughout the outcrop belt (except for the basal 0.3 meter, which represents the maximum flooding marine condensed section in northern Kansas). Throughout outcrops in Kansas, caliche-bearing red mudstones with local fluvial channels are present in the middle of the Towle Shale (Mudge and Yochelson, 1963). In northernmost Oklahoma, the basal Towle is a black mudstone with abundant *Crurithyris* and *Neochonetes* brachiopods along with sparse *Adetognathus,* whereas the middle Towle Shale is extremely silty with slightly fossiliferous carbonate concretions but no conodonts. At the top of the Towle (0.61 meters below Aspinwall) in northern Oklahoma, there is a reddish oxidized zone that may indicate subaerial exposure above gray highly fossiliferous mudstone with moderate numbers of *Adetognathus*. The cyclothem boundary is placed at the contact of the red mudstone and thin limestone in the upper Towle Shale throughout Kansas, and at the contact between the red-stained silty mudstone and fossiliferous non-silty shale in northernmost Oklahoma.

The Brownville cyclothem contains a unique assemblage of *Streptognathodus* including *S. brownvillensis* Ritter 1994 and *S. bellus* Chernykh and Ritter, 1997 and *S.* n.sp.. Additionally, the Brownville Limestone marks the appearance of the fusulinid *Leptotriticites* in the Midcontinent.

ADMIRE GROUP CYCLOTHEMS

Upper Towle Cyclothem

The minor upper Towle cyclothem is wholly contained in the upper part of the Towle Shale. Initial marine flooding of this cyclothem is marked by a thin carbonate (usually wackestone/packstone) in the upper Towle Shale throughout the study area and coincides with an abundant low-diversity ostracode and bivalve fauna in northern and central Kansas and by a low diversity brachiopod (*Neochonetes*) assemblage in northern Oklahoma. This level also corresponds to maximum marine flooding. Conodonts from this cyclothem include only *Adetognathus*, which has been recovered only from northern Oklahoma. The regressive deposits of this cyclothem consists of poorly fossiliferous silty nearshore shales in northern Oklahoma and southern Kansas and red blocky mudstones (paleosols) in central and northern Kansas. No significant faunal changes are noted in this unit.

Aspinwall Cyclothem

The minor Aspinwall cyclothem consists of the Aspinwall Limestone and basal Hawxby Shale. Initial marine flooding of the Aspinwall cyclothem occurs at the base of the Aspinwall Limestone throughout the Midcontinent Region. Maximum flooding occurs in a thin crinoidal packstone in the upper part of the Aspinwall Limestone in northern Kansas and in the basal Aspinwall Limestone in southern Kansas and northern Oklahoma. In northern Kansas maximum flooding is marked by moderate numbers of *Adetognathus* along with crinoids, whereas maximum flooding in southern Kansas and northern Oklahoma is marked by a more open marine assemblage of bryozoans, crinoids, and brachiopods along with increased numbers of *Adetognathus* and rare *Streptognathodus*. In northern Kansas, the lower Aspinwall Limestone is represented by a relatively thick bed of poorly fossiliferous hematitic sand-infilled mudcracked limestone in the lower part, followed by a crinoidal packstone and a poorly fossiliferous carbonate in the upper part. In central Kansas the Aspinwall interval contains numerous thin fossiliferous limestones interbedded with fossiliferous silty shales, whereas in northern Oklahoma and southern Kansas, the Aspinwall consists of two highly fossiliferous limestones separated by a thin highly fossiliferous shale with an open marine fauna. The Hawxby Shale in all regions contains red to green to gray silty blocky mudstones at or near the base that are interpreted as paleosols. The interval from the top of the Aspinwall Limestone through the lower part of the Hawxby Shale represents the regressive part of the cyclothem. No significant faunal changes are noted in this unit.

Falls City Cyclothem

The intermediate Falls City cyclothem comprises the upper Hawxby Shale, Falls City Limestone, and the lower West Branch Shale. The transgressive surface of the Falls City cyclothem occurs in the upper Hawxby Shale. The uppermost part of the Hawxby Shale is a gray highly fossiliferous shale that contains bryozoans, crinoids, brachiopods and *Adetognathus* conodonts. This unit is interpreted as representing the initial stages of marine flooding of the Falls City Sequence. In northern Kansas, maximum flooding in the Falls City cyclothem corresponds with a thin *Crurithyris*-bearing wackestone mapped as a limestone lens in the uppermost part of the Hawxby Shale. In central and southern Kansas, maximum flooding corresponds to a highly fossiliferous wackestone near the middle of the Falls City Limestone. In northern Oklahoma, maximum flooding occurs in the basal member of the Falls City Limestone. Highly fossiliferous wackestone with a mixed megafauna of bryozoans, brachiopods, crinoids, and clams along with a mixed *Adetognathus-Streptognathodus* conodont assemblage characterizes maximum marine flooding in all regions. The regressive part of the cyclothem includes the uppermost Falls City Limestone and the lower West Branch Shale. The Falls City cyclothem contains *Streptognathodus alius* Aktmetshina, 1990, and *S. bellus*.

West Branch Cyclothem

The minor West Branch cyclothem occurs in all outcrop regions in the upper West Branch Shale. In northern Kansas, this cyclothem is represented by a highly fossiliferous wackestone that carries a low diversity mixed brachiopod, bryozoan and molluscan assemblage that overlies a well developed rooted green blocky mudstone. In northern Kansas, either a coaly mudstone or caliche-bearing green blocky mudstone overlies the carbonate. In central Kansas, this cyclothem is manifested by a fossiliferous limestone that overlies a blocky mudstone and boxwork limestone and is in turn overlain by a coal bed. In southern Kansas and in northernmost Oklahoma this cyclothem is manifest by fossiliferous thin bedded foraminiferal packstones and wackestones and interbedded shales containing a low diversity of productid brachiopods and bryozoans at the maximum flooding surface and by abundant *Myalina* clams in the initial transgressive deposits. This sequence is underlain by a well developed coal bed and underclay and overlain by a coaly shale and underclay. No conodonts have been recovered from this cyclothem in the outcrop belt.

Five Point Cyclothem

The intermediate Five Point cyclothem comprises the Five Point Limestone and basal Hamlin Shale members of the Janesville Shale. The transgressive surface of the Five Point cyclothem is also equivalent to the maximum flooding surface and is recognized by a highly fossiliferous glauconitic wackestone that contains a fully open marine fauna including brachiopods, bryozoans, corals, crinoids and fusulinids, as well as a *Streptognathodus*-dominated conodont assemblage. This cyclothem contains the greatest diversity of marine fossils of any cyclothem in the Admire Group. Because maximum flooding occurs at the base of the cyclothem, virtually the entire Five Point Limestone and overlying Hamlin form the regressive deposits. The top of the Five Point Limestone in most regions of Kansas and Oklahoma consists of highly fossiliferous packstones and wackestones that were subaerially exposed as evidenced by red clay-internal sediment infillings of vugs along with regolith development on top of the limestone. This indicates rapid sea-level lowering and is prima-facie evidence for forced regression. The base of the Hamlin Shale (where exposed) consists of red blocky caliche-bearing mudstone paleosols. The Five Point cyclothem contains *Streptognathodus flexuosus* Chernykh and Ritter, 1997 along with *S. brownvillensis*. The Five Point Limestone also contains the first appearance of the fusulinid *Pseudofusulina* in the Midcontinent.

Lower Hamlin Cyclothem

The minor lower Hamlin cyclothem is represented by a foraminiferal-crinoidal packstone in the lower part of the Hamlin Shale in northern Kansas, a moderately fossiliferous shale in southern Kansas, and a *Myalina*-bearing packstone/grainstone in northern Oklahoma. In all regions of the Midcontinent the transgressive surface also corresponds to maximum marine flooding. The regressive deposits consists of silty shales overlain by red to green blocky mudstones. No conodonts or other significant faunal occurrences are denoted in this cyclothem.

Upper Hamlin Cyclothem

The minor upper Hamlin cyclothem is manifest by a stromatolitic carbonate mapped as the Houchen Creek Limestone in the upper Hamlin Shale in Nebraska and northern Kansas, and by an unnamed fossiliferous limestone in central and southern Kansas. This limestone is underlain and overlain by red and green blocky mudstones.

COUNCIL GROVE GROUP CYCLOTHEMS

Foraker Megacyclothem Complex

The Foraker megacyclothem complex comprises the Americus Limestone, Hughes Creek Shale, Long Creek Limestone, and the lower two-thirds of the Johnson Shale. The Foraker megacyclothem complex comprises eight cyclothems that are correlatable across the entire outcrop area. The lower six cyclothems are capped by nearshore marine to marginal marine deposits consisting of poorly fossiliferous silty shales, whereas the upper two are capped by green to red blocky caliche-bearing mudstones that are paleosols. The cyclothems that are capped by marginal marine deposits are analogous to the 'subtidal fifth-order cycles' of Goldhammer and others (1991) for the Desmoinesian of the Paradox Basin, whereas those capped by subaerially exposure surfaces are similar to his 'exposure fifth-order cycles'. The exposure cycles occur at the top of the Foraker fourth-order sequence in a similar fashion to those of the Paradox Basin. The base of each cyclothem within the complex is defined by a major flooding surface characterized by a highly fossiliferous wackestone with ubiquitous horizontal boxworks of the trace fossil *Thalassinoides* and an abundant open marine fauna including bryozoans, brachiopods and fusulinids. Chaplin (1996) interpreted the occurrences of horizontal boxworks of *Thalassinoides* to represent transgressive surfaces in analogous Lower Permian Chase Group strata of the Midcontinent. Maximum marine flooding surfaces are represented by highly fossiliferous wackestones without evidence of condensed sedimentation in cases of minor to intermediate sea-level rises. In contrast, highly fossiliferous glauconitic and phosphatic wackestones or dark gray to black shales with evidence of condensed sedimentation characterize more major sea-level rises. Three of the Foraker cyclothems contain marine condensed sections, including the upper Americus, middle Hughes Creek, and upper Hughes Creek. These maximum marine flooding surface condensed sections contain major evidence of condensed sedimentation including abundant glauconite and phosphatized mollusks, along with an abundant *Streptognathodus*-dominated conodont fauna that range from 100 to 1,000 platforms/kilogram. In northern

Kansas and Nebraska these marine condensed sections have well developed black shales, whereas in central and southern Kansas they occur as shaly, glauconitic and phosphatic wackestones. In contrast, maximum marine flooding surfaces of the lower Americus, lowermost Hughes Creek, top Hughes Creek-Long Creek, and Long Creek contain a mixed *Adetognathus-Streptognathodus* biofacies with no evidence of condensed sedimentation. Maximum marine flooding in the lower Johnson Shale contains only a sparse assemblage of ostracodes and encrusting foraminifers without conodonts.

The transgressive surface of the Foraker megacyclothem complex occurs at the base of the Americus Limestone and consists of a regionally extensive, transgressive lag and ravinement surface characterized by an ostracode-rich conglomeratic shale or carbonate. Maximum marine flooding for the Foraker megacyclothem complex is placed at the condensed section of the upper Hughes Creek cyclothem because it corresponds to the most widespread black shale bed northward, which is the greatest condensed interval in the sequence. Cyclothems above this level demonstrate progressively shallower water facies developed at maximum marine flooding, coupled with the cycles becoming terminated by subaerial exposure. The transgressive systems tract of the Foraker megacyclothem complex encompasses the Americus Limestone, and lower two-thirds of the Hughes Creek Shale, whereas the forced regressive deposits encompass the top of the Hughes Creek Shale, Long Creek Limestone and the lower two-thirds of the Johnson Shale.

The Foraker Megacyclothem complex contains three distinctive conodont faunas that can be correlated across the entire outcrop area. The upper Americus cyclothem contains *Streptognathodus wabaunsensis* Gunnell, 1933, *S. elongatus* Gunnell 1933, *S. farmeri* Gunnell 1933, and *S. flexuosus*. The lower Hughes Creek cyclothem contains *Streptognathodus flexuosus, S. conjunctus* Barskov, Isakova and Shchastlivseva 1981, *S. wabaunsensis*, *S. farmeri*, and *S. elongatus*. This conodont fauna can be distinguished from the upper Americus fauna by the addition of *S. conjunctus* in the Hughes Creek assemblage. The upper Hughes Creek cyclothem contains *Streptognathodus conjunctus, S.* n.sp. and *S. elongatus* Gunnell. This conodont assemblage is distinguished from the underlying upper Americus and lower Hughes Creek fauna in that *S.* n.sp. is present and *S. wabaunsensis*, and *S. farmeri* are absent due to apparent extinction.

Red Eagle Cyclothem

The Red Eagle Cyclothem comprises the upper Johnson Shale, Glenrock Limestone, Bennett Shale, Howe Limestone and the Roca Shale. Maximum marine flooding of this sequence corresponds to the provisional correlated position of the base of the Permian System in North America, based on the first appearance of *Streptognathodus isolatus* (Chernykh and others, 1997). The transgressive surface of the Red Eagle cyclothem occurs in the upper part of the Johnson Shale and is represented typically by a thin intraclastic packstone developed as a transgressive lag and ravinement surface. The lower part of the Red Eagle cyclothem is developed entirely within the top of the Johnson Shale and contains abundant ostracodes, rare conodonts of a mixed *Streptognathodus-Adetognathus* assemblage, along with locally abundant molluscs and brachiopods including *Juresania, Linoproductus,* and *Derbyia*. Maximum marine flooding of Red Eagle cyclothem occurs as two marine condensed sections in two stratigraphic positions, the lower one at the base of the Bennett Shale and the upper one about 0.3 meter above. The marine condensed sections are represented by abundant *Streptognathodus* conodonts, orbiculoid brachiopods, ammonoids, and fish debris. In northern Kansas through Nebraska these condensed sections occur as black fissile shale facies in contrast to central Kansas to Oklahoma, where they occur as highly fossiliferous shaly, glauconitic, phosphatic wackestones. In all regions they are characterized by abundant *Streptognathodus* conodonts from 500 to 1000 platforms/kilogram. Regressive deposits within the Red Eagle cyclothem consist of fossiliferous wackestones to packstones (locally phylloid-algal) of the upper Bennett, followed by foraminiferal grainstones of the Howe Limestone, and finally by well developed green to red blocky mudstone paleosols of the Roca Shale.

The Red Eagle Sequence is characterized by *Streptognathodus isolatus* Chernykh Ritter, and Wardlaw 1997, *S. minacutus* Barskov and Reimers 1996, and *S. invaginatus* Reshetkova and Chernykh 1986, *S. fuchengensis* Zhao 1982, *S. nodulinearis* Reshetkova and Chernykh 1986, *S.* n.sp. and *S. elongatus,* along with the appearance of *Sweetognathus expansus* (Perlmutter, 1975). This occurrence is based on as single specimen from southern Kansas.

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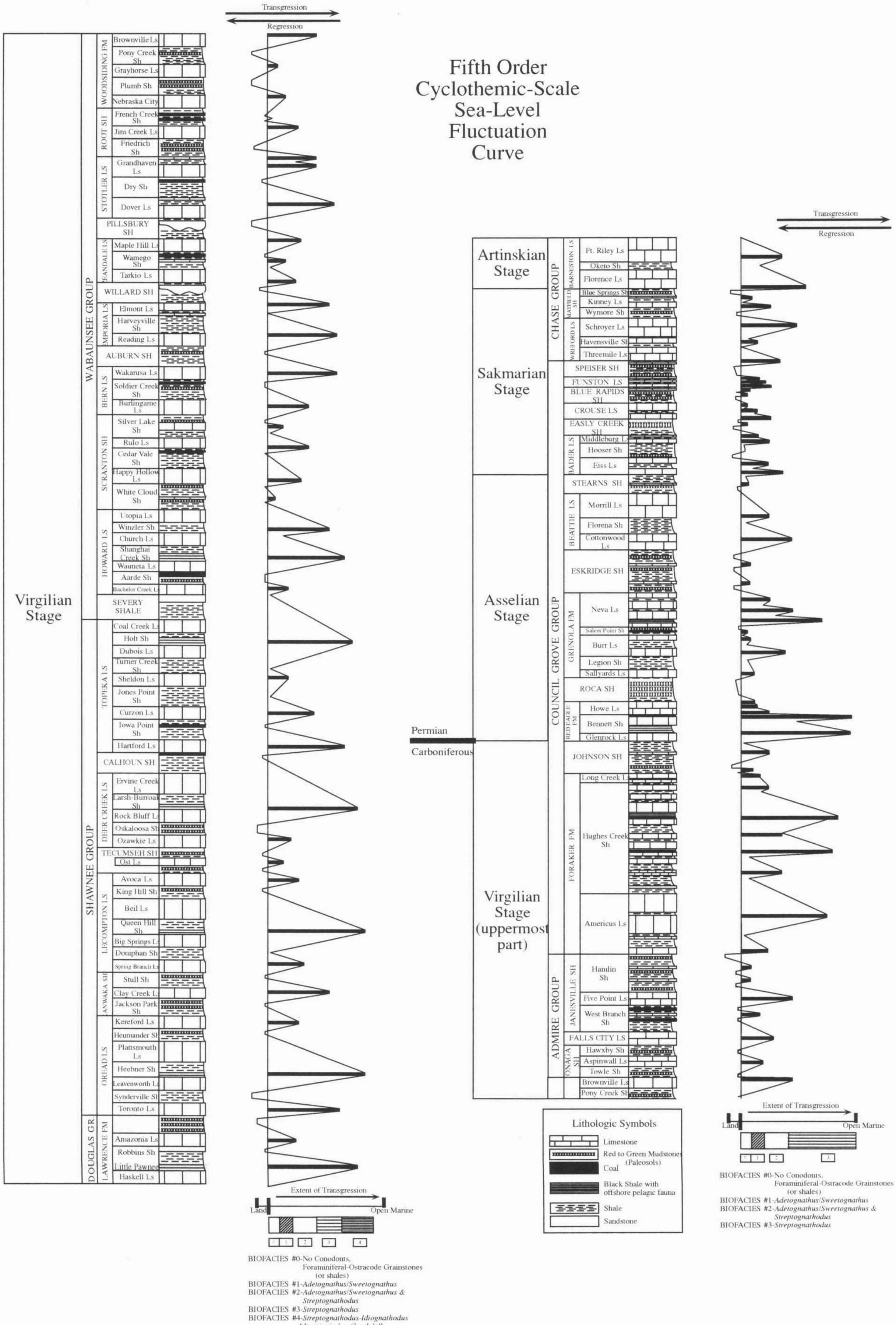

Fig. 1: Sea level curve for upper Pennsylvanian (Virgilian) and Lower Permian in midcontinent North America with superimposed sequence stratigraphy (modified from Boardman and Nestell, 1993, Boardman and others, 1995).

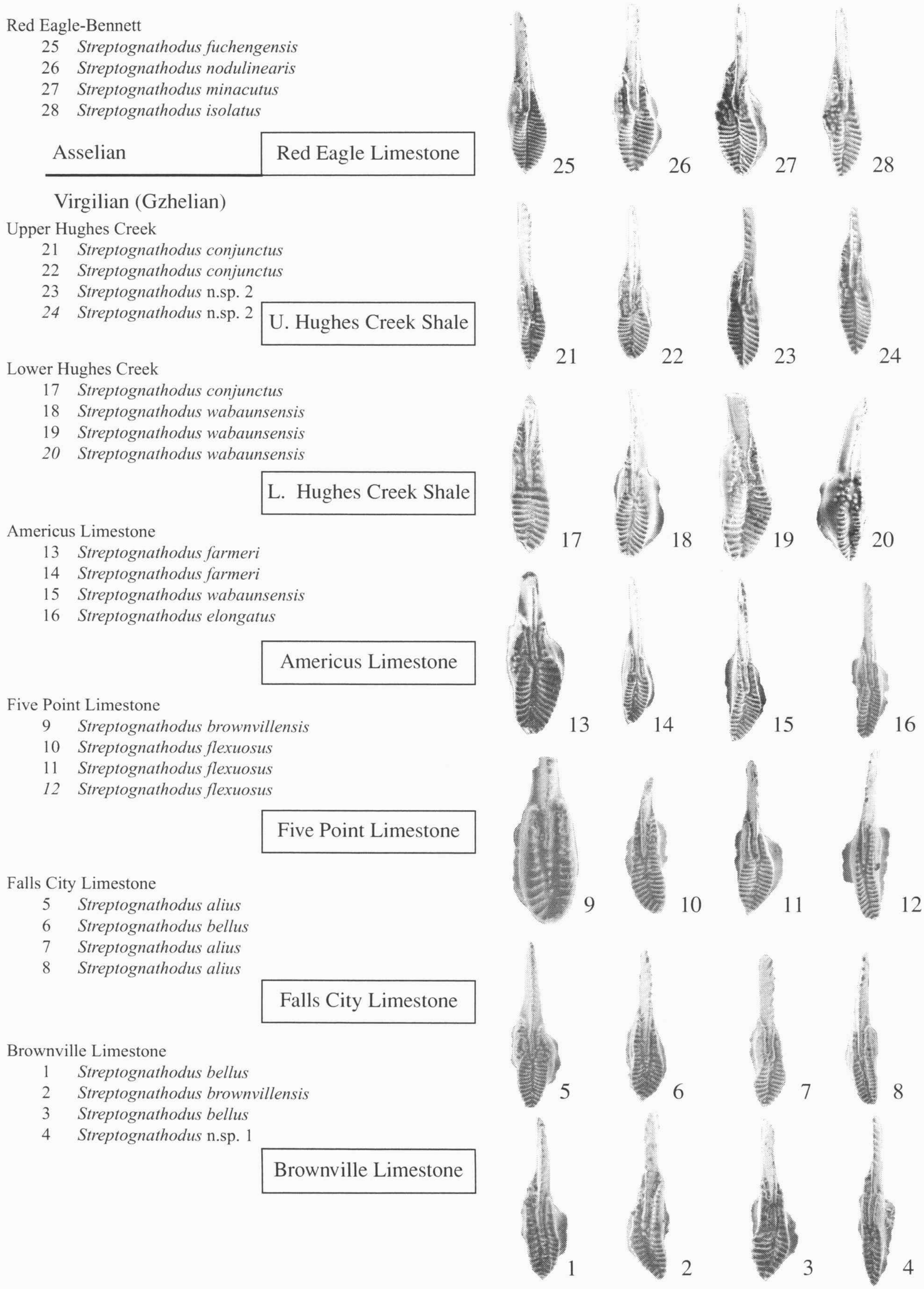

Fig. 2: Conodonts from upper Virgilian and lowermost Permian strata in midcontinent North America.

STRATIGRAPHIC ANALYSIS OF PENNSYLVANIAN IN THE SUBSUFACE OF KANSAS

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INTRODUCTION

This paper describes: 1) the geologic setting of the Kansas shelf during a portion of the Upper Pennsylvanian (late Carboniferous) and 2) reviews some of the methodology and results of current subsurface investigations. The stratigraphic interval examined is focused on the Missourian Stage, an important stratigraphic interval that harbors significant amounts of oil and gas in the Midcontinent U.S. and Kansas. The Kansas shelf, a division of the Midcontinent Basin (Heckel, 1999) covers the state of Kansas extending west of the surface exposures seen on this field trip. The subsurface study extends westward from the outcrops in eastern Kansas to the Colorado State line nearly 400 mi (644 km) to the west. Data resources of the subsurface study include several hundred cores and nearly 4000 wireline logs.

Cyclothem, genetic unit, and sequence stratigraphic concepts have been applied to the Pennsylvanian strata in the subsurface to improve understanding of oil and gas resources and improve efficiency and decrease risks in search and development of remaining petroleum. Cumulative petroleum recovered from Pennsylvanian reservoirs in Kansas is substantial, an estimated at 32 trillion cubic feet of natural gas and 9 billion barrels of crude oil. Oil and gas are recovered from carbonate sands and phylloid algal banks (Watney, 1980, Ebanks and Watney, 1985), incised valley fill, estuarine and fluvial dominated sandstone reservoirs (Archer, 1974; Dolson, et al., 1994), and fluvial point bars and distributary channels (Walton, 1996; Brenner, 1989).

Kansas and he greater Midcontinent U.S. are mature oil and gas producing provinces with a long history of development beginning in Kansas in 1860. Annual oil production in Kansas peaked in 1956 while natural gas production peaked in 1972. Stratigraphic and depositional anomalies are now more heavily sought in addition to the well-established methods of searching for structural highs and closure and drilling in proximity to shows of oil and gas. Remaining petroleum accumulations are decidedly more stratigraphic-dominated, smaller and more subtle and will require application of latest concepts and technologies to locate and develop them. Other petroleum-producing provinces will eventually reach this mature stage of development and will require similar procedures to maintain economic extraction.

Subsurface data, while lacking in abundant rock data except for limited cores, includes a wealth of wireline log data, sample cuttings, and well completion and production history. The wireline log data today is increasingly available in digital form sampled continuously through the stratigraphic section providing many properties of the rock suited to characterize cyclothems. In particular, mapping three-dimensional distribution of cyclothems helps to recognize anomalies important to petroleum accumulation and refine interpretation of cyclothem development. Initially, studies focused on thickness variation, but increasingly the emphasis has been on characterizing interval petrophysical attributes with the advent of significant new computer software.

GEOLOGIC SETTING

The Upper Pennsylvanian (upper Upper Carboniferous) outcrop belt in the upper Midcontinent USA extends from Iowa to Oklahoma, crossing the eastern one-third of Kansas (Figure 1). This area is part of the region often referred to as the Midcontinent Basin, which is subdivided into the Northern Midcontinent Shelf located adjacent to the Anadarko and Arkoma Basins (Heckel, 1999). The outcrop belt is oriented northeast to southwest with exposures that span upper reaches of the Northern Midcontinent Shelf on the north to the Arkoma Basin on the south (Figure 2). Kansas lies at a transition between the craton and basin during the Pennsylvanian with the northern 2/3rd of Kansas always located on the shelf while southern Kansas episodically fluctuated between shelf and basin. Upper Pennsylvanian strata in northeast Kansas consist of interbedded clastics and carbonates while the western Kansas shelf is dominated by carbonates. Heckel (1999) describes the cyclothems and nomenclature that are applied to these predominately marine deposits.

Outcropping Pennsylvanian strata dip westerly at about 25 ft/mi (4.7 m/km) immediately west of the outcrops in eastern Kansas, but dip reverses in western Kansas off Tertiary uplift associated with the Cordilleran orogeny (Figure 3). Central and western Kansas are sites

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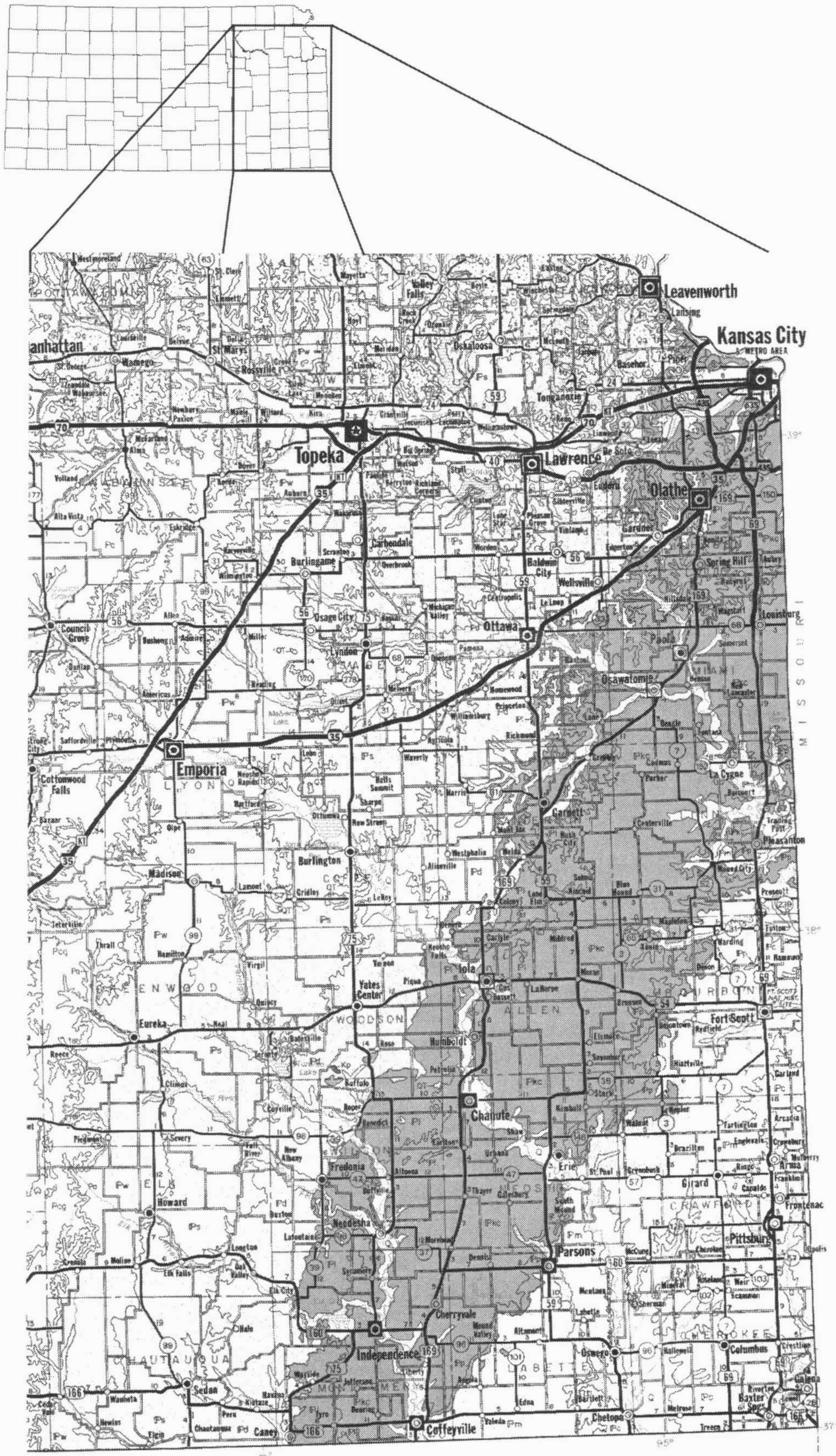


Fig. 1: Outcrop of upper Pennsylvanian in eastern Kansas.

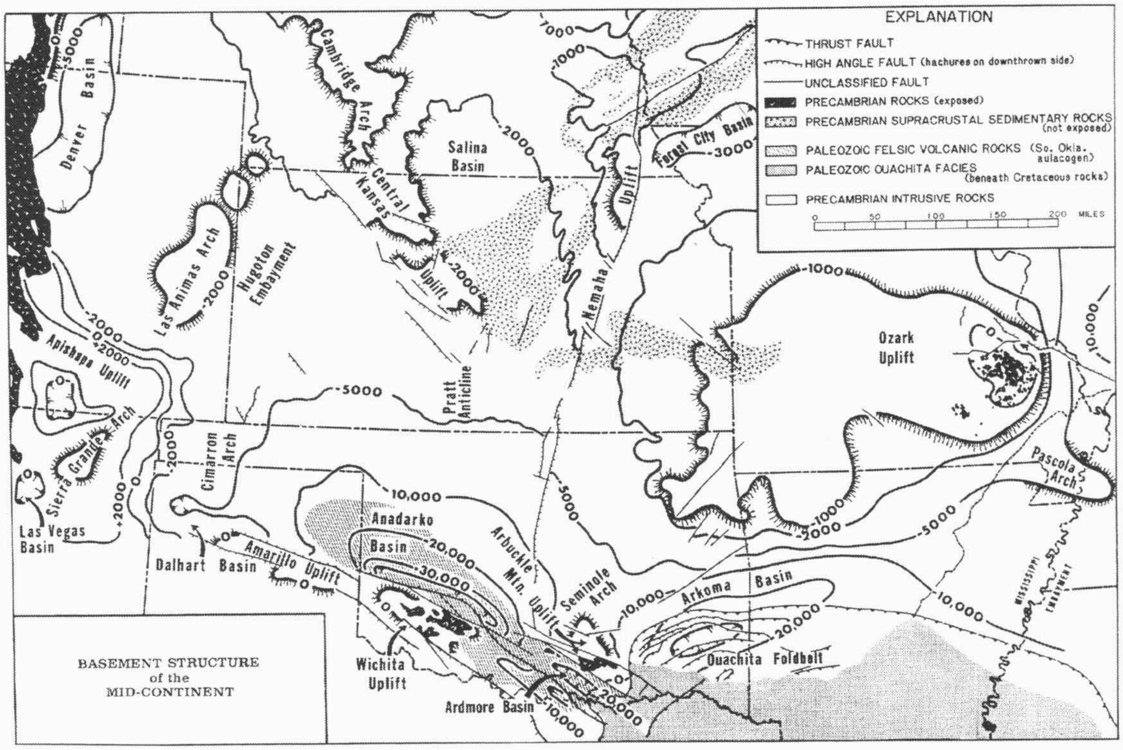


Fig. 2: Configuration of the Precambrian basement in the southern Midcontinent (from Rascoe and Adler, 1983). Kansas resides on shelf adjoining Arkoma and Anadarko Basins. While deeper portions of basins are several hundred km from Kansas, active tectonic activity during the Pennsylvanian impacted the Kansas Shelf.

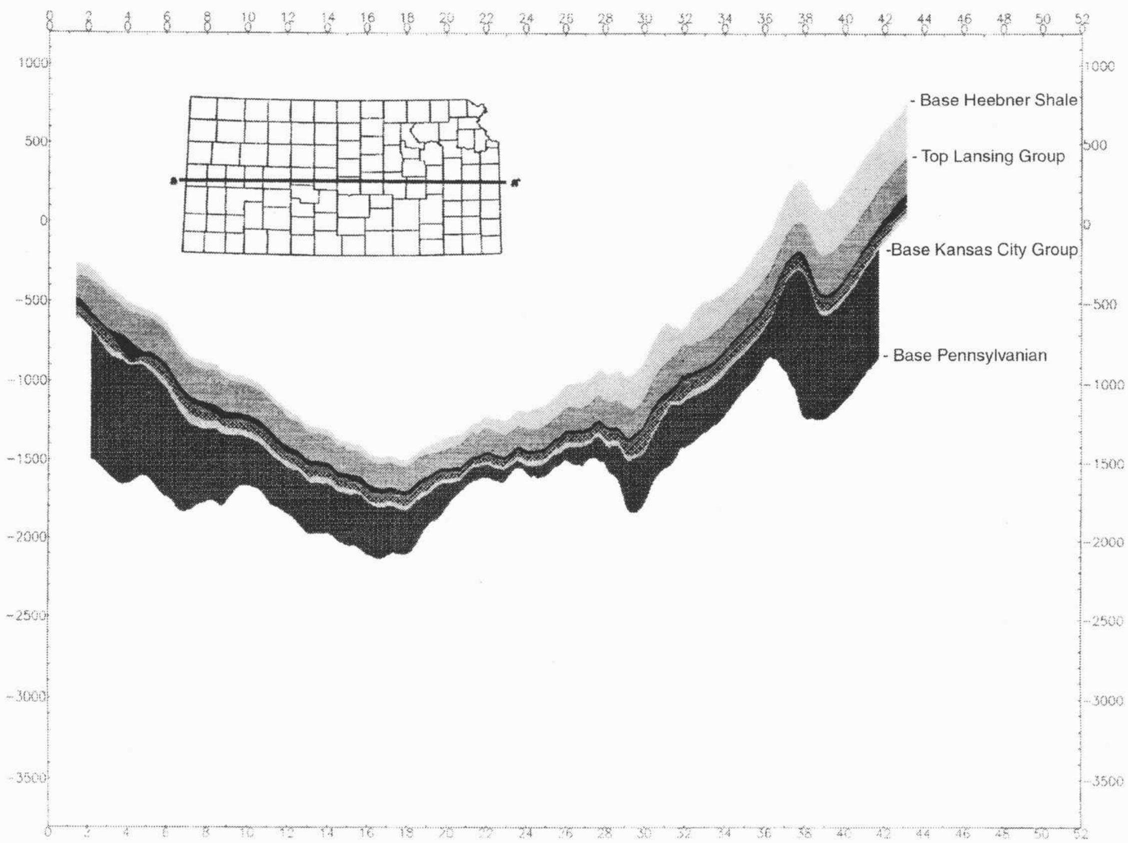


Fig. 3: West-to-east structural cross section of the Pennsylvanian across Kansas covering 350 mi (563 km). Current day structure is not closely related to the configuration of Kansas Shelf during the Pennsylvanian, but structure is related to petroleum accumulation.

of several thousand oil and gas fields, many which produce from Pennsylvanian reservoirs (Figure 4). Understanding the Pennsylvanian cyclothems that contain petroleum reservoirs is economically important to Kansas. Moreover, tens of thousands of boreholes are accessible to develop a three-dimensional database from which to refine our understanding on controls of cyclothem development. The Anadarko and Arkoma Basins were major tectonic basins that were active during Late Pennsylvanian time (Figure 2). These basins lie south of Kansas in Oklahoma and Arkansas with sediment thicknesses exceeding 30,000 ft (9.1 km). The Arkoma Basin was a foreland basin that developed through the Pennsylvanian in response to collision of Gondwana and Laurussia (Figure 5). South of the Arkoma Basin, the Ouachita Mountains, a prominent mountain chain during the Pennsylvanian, extended eastward to the Appalachians and eventually southward to the Glass Mountains of west Texas by the early Permian. Thrust plates moved northward from the Ouachita Mountain front, which led to basin loading and subsidence of the foreland basins and adjacent shelves (Quinlan and Beaumont, 1984). As the Pennsylvanian progressed, clastics shed from the Ouachitas episodically filled the adjoining Arkoma Basin and reached the Kansas shelf (Figure 6, Moore, 1979). Clastics deposited in northeastern Kansas were derived from northeastern, landward sources on the continent. Locally, valleys were incised across the Kansas shelf and led to intermittent sediment bypassing and deposition in the basin when it was underfilled (Archer, et al., 1994).

The Anadarko Basin located west of the Arkoma Basin and south of the western Kansas shelf is a hybrid foreland basin that underwent considerable subsidence during the Pennsylvanian (Figure 2). The Anadarko Basin was sediment-starved through most of the late Pennsylvanian and early Permian. Consequently, with limited clastic influx from the craton in western Kansas, that shelf area was dominated by carbonate accumulation (Figure 6).

Prolonged sediment starvation in the Anadarko Basin during the Missourian Age led to water depths estimated in excess of 1200 ft (366 m) before clastics and carbonates filled this space when subsidence decreased (Kumar and Slatt, 1984). Sediment starvation episodically reached the southern edges of the Kansas shelf, especially in south-central Kansas, leading to prominent carbonate shelf margins and distinct shelf-to-basin boundaries. Examination of burial history on the shelf and basin in this area indicate that subsidence rates at the stratigraphic stages scale varies from 0.2 m/ky to 2 m/ky from shelf to basin. The latter rates are sufficient to easily drown a location (Watney et al., 1991). Alternately, episodic declines in the rates of subsidence allowed sedimentation to catch up, and sometimes to fill the structural basin. Thus, differences between the depositional basin and structural basin could be considerable. Subsidence during initial thrust loading was markedly higher based on modeling studies (Quinlan and Beaumont, 1984) and probably played a prominent role in the shifting patterns of the depositional basin.

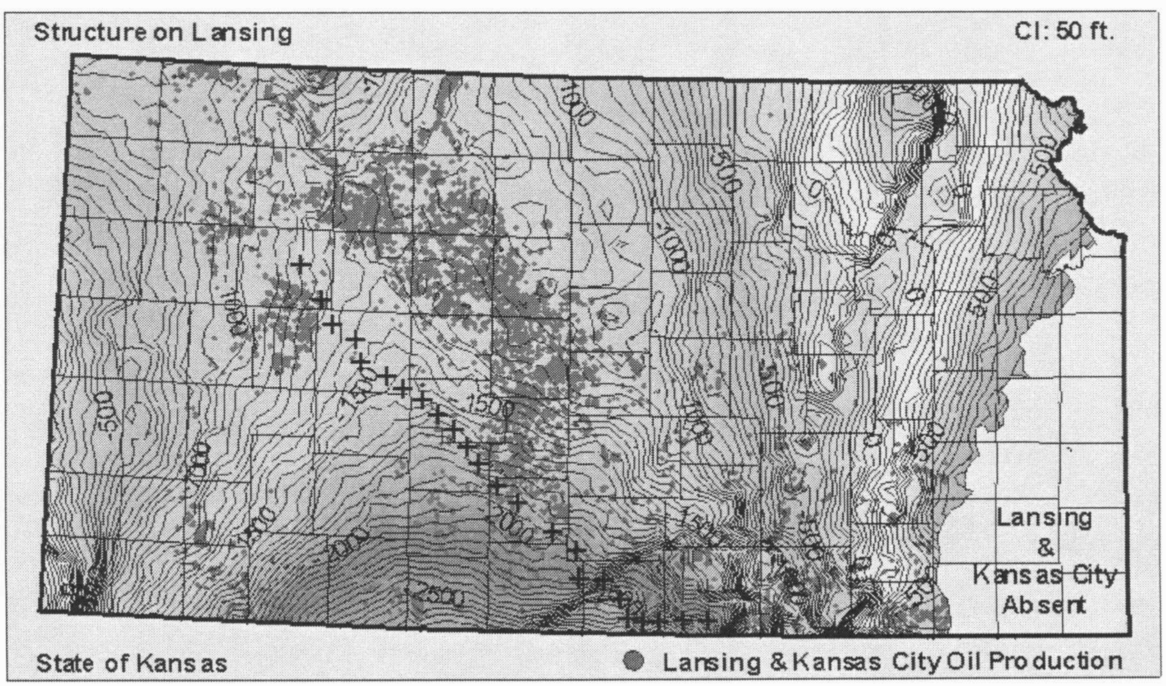


Fig. 4: Structural configuration of the top of Lansing Group in Kansas including location of oil fields. Map was prepared by P. Gerlach as part of the Digital Petroleum Atlas, located in Internet website: http://crude2.kgs.ukans.edu/DPA/Plays/ProdMaps/lgkc_oil.html. Map also serves as an index map for cross section shown in Figure 17.

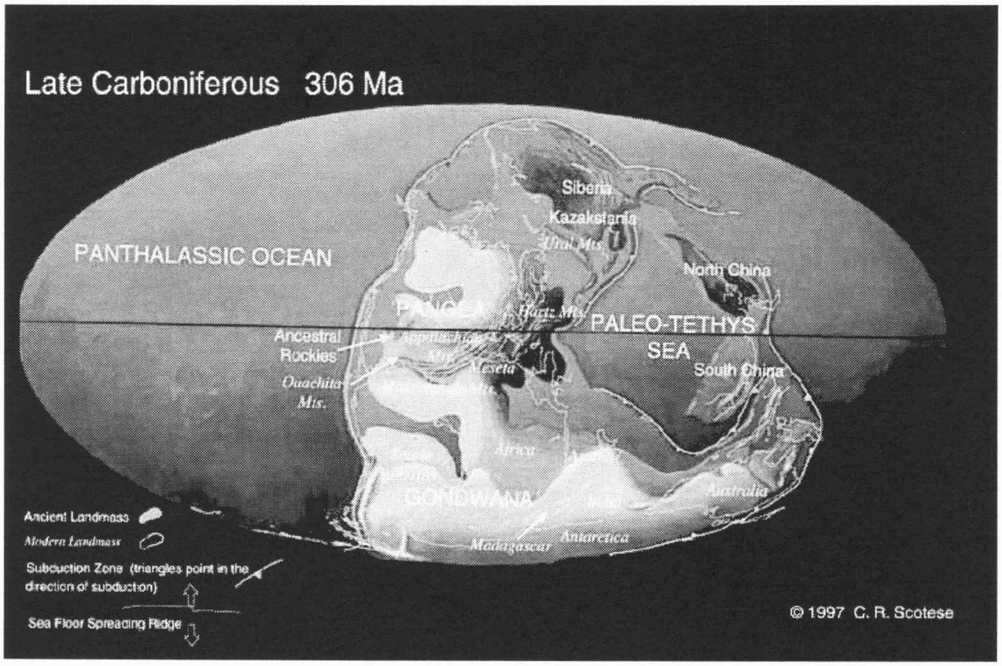


Fig. 5: Late Carboniferous paleogeogeography from Internet website of Scotese (1999): http://www.scotese.com/late.htm.

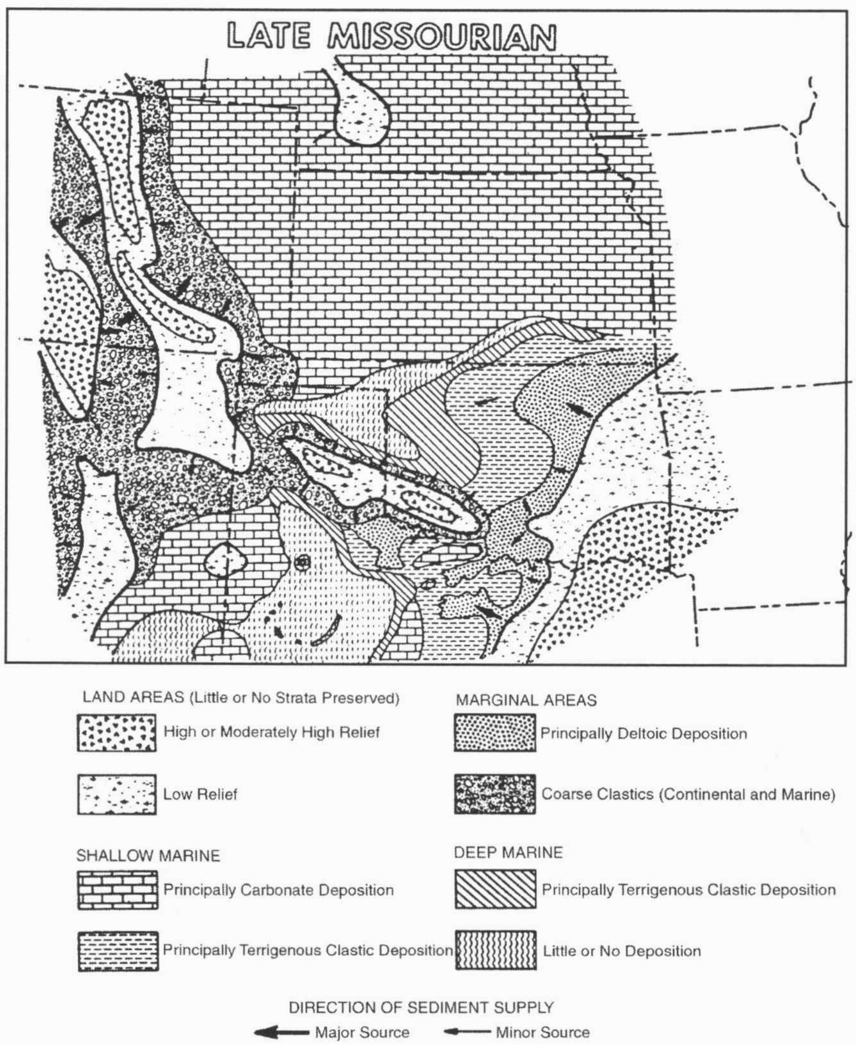


Fig. 6: Generalize paleogeography and paleoenvironments during Late Missourian of the southern Midcontinent after Moore (1979).

Change in shelf elevation due to accelerated rates of subsidence toward the basin along with varied sedimentation rates led to varied preservation and composition of the cyclothems. Clastic wedges flanked the uplifted Ouachita Mountains in Arkansas and eastern Oklahoma and created topographically high areas adjacent to the mountain front. Elevation of the clastic wedges declined northward across the basin. Recurring episodes of clastic accretionary wedges were developed, which closely correspond with equivalent cyclothems deposited on the Kansas shelf. The thin, distinctive offshore shales delimit these accretionary wedges much like these shales delineate cycles through the subsurface of western Kansas even though the gross lithic character of the cyclothems has changed considerably. The accumulation of these clastic wedges often kept up with and exceeded subsidence reaching the southern shelf margin of Kansas (Figure 6, Moore, 1979; Bennison, 1984; Figure 7 after Bennison, Fig. 16, p. 22, in Watney et al., 1989).

Sedimentation on the Kansas shelf was generally in closer balance with subsidence, but overall southward thickening of cyclothems along with addition of more stratal units and episodic sediment starvation suggest that shelf elevation decreased southward toward the basin. As elevation changed across the shelf, relative sea level experienced at any one site also varied. High shelf positions had more prolonged episodes of subaerial exposure during lower sea level while the lower shelf would be in deeper water over a longer duration during highstands (Watney, 1980; Watney et al., 1991).

Most Upper Pennsylvanian cyclothems continue northward beyond upper reaches of the Kansas shelf with a few exceptions, e.g., Cherryvale Formation. In contrast, lower shelf areas could be more easily drowned, but deposits could be thicker if sedimentation was able to keep up, e.g., formation of carbonate banks. The fidelity of the stratigraphic record, i.e., fraction of time preserved by the stratigraphic record, would be higher on the lower shelf, and this record would be more marine, if sufficient sedimentation occurred so as to prevent sediment starvation (Watney et al., 1991). Thus, sites of possible international stratigraphic reference should be located on the lower shelf where sedimentation was most continuous. The range in elevation of the Kansas Shelf was apparently less than the magnitude of the eustatic range (that is, under ~100 m) encountered during the Pennsylvanian cyclothems because exposure surfaces separate most of the cyclothems across most of the shelf (Boardman and Heckel, 1989; Heckel, 1994; Watney, et al., 1991). The active thrust belt and foreland basin migrated southwestward from the Ouachita Mountain and Arkoma Basin during the latest Pennsylvanian as the continents joined to form the supercontinent Pangaea. Pennsylvanian depocenters, e.g., the broader Midcontinent Basin, closely followed this active tectonic suture zone.

METHODOLOGY AND RESULTS FROM CURRENT RESEARCH ON THE KANSAS SHELF

Cyclothems

The methodology and concepts used to interpret Pennsylvanian cyclothems were developed and substantiated through study of surface exposures. Classification and nomenclature of these strata were also defined from the outcrop. The "Kansas cyclothem" was named for cyclothems that typify the mixed carbonate-clastic shelf in northeastern Kansas. Component strata include the transgressive limestone, offshore "core" shale, regressive limestone, and nearshore/terrestrial "outside" shale (Heckel, 1999).

The Kansas cyclothem is widely correlatable across the Kansas shelf west of the outcrop belt (Watney, 1980; 1995), as depositional strike essentially runs west-to-east. The proportion of carbonate strata increases westward as sources of clastics diminish. Physical correlations are based primarily on properties of the offshore shales. These shales are thin, phosphatic, often black or dark gray, associated with elevated gamma radiation, and vary little over 100's of kilometers. Wireline logs that measure natural gamma radiation are ideally suited to recognize and correlate these shales and, in turn, the related cyclothems. Conodonts and fusulinids are used to substantiate physical correlations of the offshore shales in the subsurface of Kansas (Lambert et al., 1991; Heckel et al., 1991).

Modern well logs also provide the means to distinguish porosity, lithology, and other properties of the cyclothem. Wireline logs calibrated to core and outcrop provide the ideal means to correlate and map cyclothems (Figure 8). During the past 15 years the Kansas Geological Survey has used a wireline core drilling rig to acquire cores up to 1500 ft (457 m) in length. Cores have been acquired immediately behind the outcrop to improve the linkage between surface and subsurface studies and to calibrate the wireline logs (Figure 9).

Genetic Stratigraphic Units (GSUs)

Genetic stratigraphic units, defined as correlatable stratal intervals between offshore shales, is a useful and practical stratigraphic division for subsurface mapping and is analogous to genetic stratigraphic sequences defined by Galloway (1989; Figures 8 and 9). Such a GSU is thus very similar to a cyclothem in thickness, and the more uniform character of offshore shales and their distinctive character on wireline logs provide relatively easy correlation of GSUs. In contrast, other cyclothem components can be difficult to trace. The same is true of depositional sequences (Watney et al., 1989). As deviations from the typical Kansas cyclothem occur, particularly along the southern margins of the Kansas shelf, the GSU provides a consistent and reliable stratigraphic subdivision in the subsurface. Once GSUs are correlated to an area with core control, the core can be used to establish the cyclothem or depositional sequence (Watney et al., 1995).

GSUs provide relatively high resolution, temporally distinct stratal divisions suited to regional mapping. Maps of GSUs have been used to characterize incremental paleogeographic changes on the Kansas shelf. A succession of six GSUs representing the Missourian Stage were mapped across the Kansas shelf, covering over 80,000 mi2 (207,000 km2) (Figures 10-15). The isopachous maps reveal an evolving pattern of shelf-to-basin sedimentation through successive GSUs (Watney et al., 1995). The Nuyaka Creek Shale is an offshore shale found near the base of the subsurface Pleasanton Group clastics. The lowermost GSU examined here is named after this shale (Figure 10). A predominately deltaic platform occupied much of northeastern Kansas during deposition of the Pleasanton Group including the upper reaches of the outcrop belt in eastern Kansas and western Missouri. However, southeastern Kansas was the site of greatly reduced sedimentation at this time.

The succeeding isopachous map includes the genetic unit containing the Sniabar Limestone, part of the Hertha cyclothem (Figure 11). This carbonate-dominated interval noticeably thickens along the south side of the thick, underlying deltaic platform. The regressive Sniabar Limestone forms thick (up to 30 m) phylloid algal-rich carbonate banks. The area south of the bank margin remained sediment starved. The overlying isopachous map is called the Hushpuckney GSU and corresponds to the Swope cyclothem (Figure 12). The map shows continued lateral accretion of the southern shelf to the point that the lower shelf became filled with sediment. The sediment filling the shelf margin consisted of both carbonate banks and flanking oolitic grainstones as well as lowstand clastic sediments probably derived from the Ouachita Mountain front (Figure 7). Western Kansas was occupied by a broad carbonate ramp characterized by oolitic grainstones, often serving as petroleum reservoirs.

The overlying isopachous map called the Stark GSU corresponds to the Dennis cyclothem (Figure 13). A carbonate bank margin again developed landward from the area of sediment infilling of the underlying cycle, indicating minor backstepping of the shelf margin at this location. A ramp development and grainstone accumulation during late regression in the Dennis cyclothem continued to dominate the western Kansas Shelf much like the underlying cycle.

The Cherryvale cyclothem is represented by the Wea GSU, named after the offshore shale forming the base of this interval (Figure 14). This marine event reached only the upper Kansas Shelf before it lapped out into a paleosol documented in cores from taken from northwestern Kansas (Watney et al., 1995). The uppermost map of this series is the Quivira GSU corresponding to the Dewey cyclothem (Figure 15). Note that the thickness variation is minimal and interval is thin overall. The Kansas shelf appears to have been relatively flat. Also the reduced thickness of the cyclothem suggests either reduced time for carbonate accumulation or reduced sediment accommodation space.

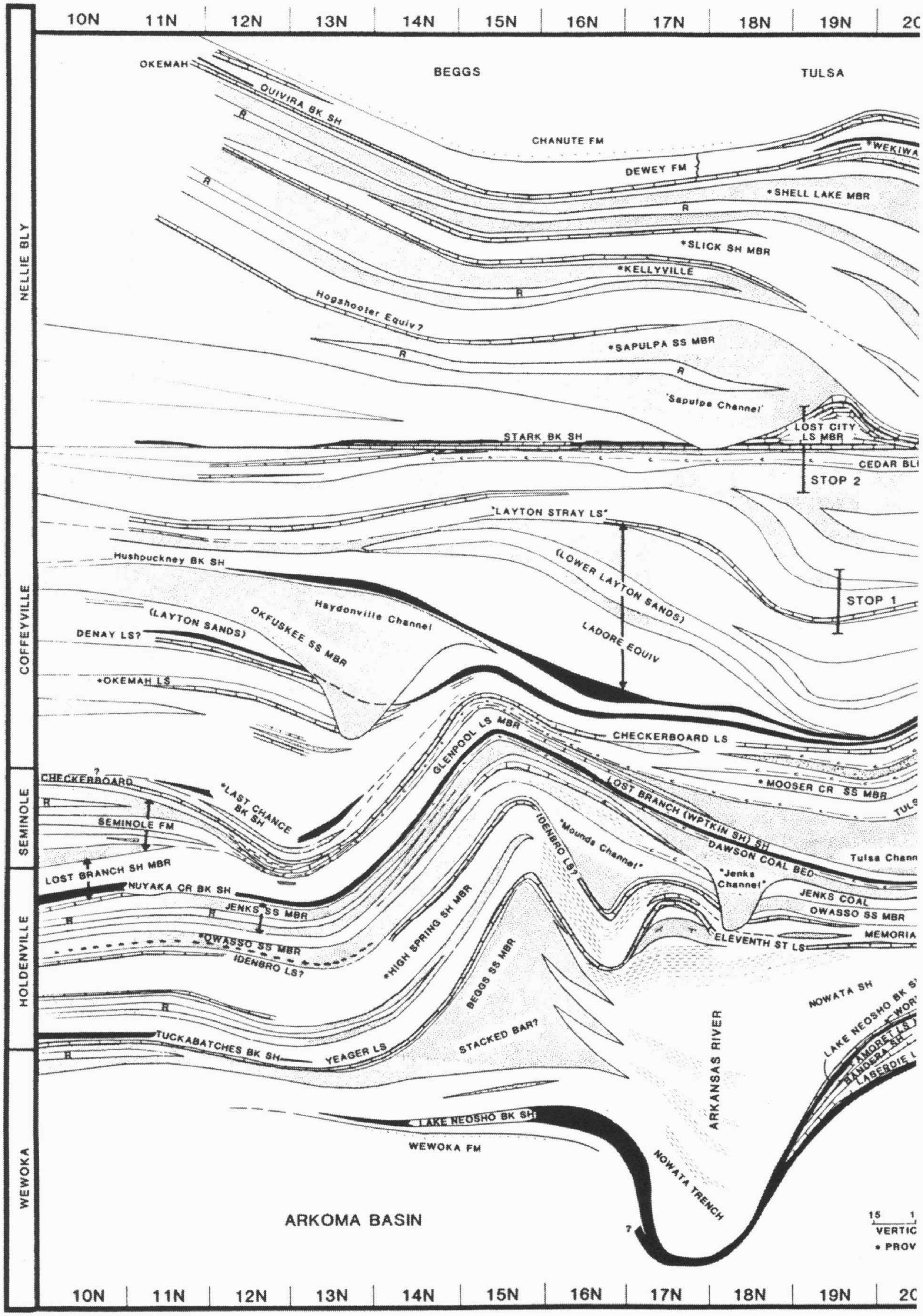
The Dewey cyclothem brings to close a longer-term episode of transgression and regression of a set of cyclothems that began with the latest Desmoinesian base of the mainly Missourian Pleasanton Group. While the carbonate shelf margin of the underlying Marmaton Group resides in central Oklahoma, the shelf margin associated with the Pleasanton Group and overlying carbonate-dominated cyclothems abruptly shifted landward some 100 mi (160 km), a prominent backstepping event. Similarly, the cyclothems overlying the Dewey Limestone indicate another abrupt backstepping event where the carbonate shelf margin of the Iola and later cyclothems shifted landward (Figures 16 and 17)

Cycle Sets (CSs) and Changing Configuration of the Kansas Shelf

As suggested in the preceding discussion, regional studies of the Kansas shelf indicate that cyclothems are organized into cycle sets that closely correspond to the formal stratigraphic groups as described in the previous section. Five to seven successive cyclothems or GSUs form each of these cycle sets that are each distinguished by progressive changes in stratal stacking patterns and lithofacies distribution. Examining the changing position of the southern carbonate margin of the Kansas shelf that borders the Arkoma and Anadarko Basins most easily recognizes the stratal-stacking pattern. Within an individual cycle set, the shelf margin abruptly shifts landward (backstep) at the base, followed by progressive basinward stepping or lateral accretion of the carbonate margin (Figures 16 and 17).

Initial backstepping associated with the lower boundary of a cycle set is best recognized during deposition of an offshore shale. The offshore shale of the boundary of a cycle set is often thicker, more phosphatic, and more radioactive, thus forming excellent subsurface markers. The Excello, Nuyaka Creek, Muncie Creek, and

Fig. 7 (over): Regional north-south stratigraphic cross section of the uppermost Des Moinesian and lower Missourian clastic-dominated strata along the traverse in eastern Oklahoma (prepared by A. Bennison, also Figure 16, p. 22 in Watney et al., 1989).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*SLICK SH MBR
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Hushpuckney BK SH
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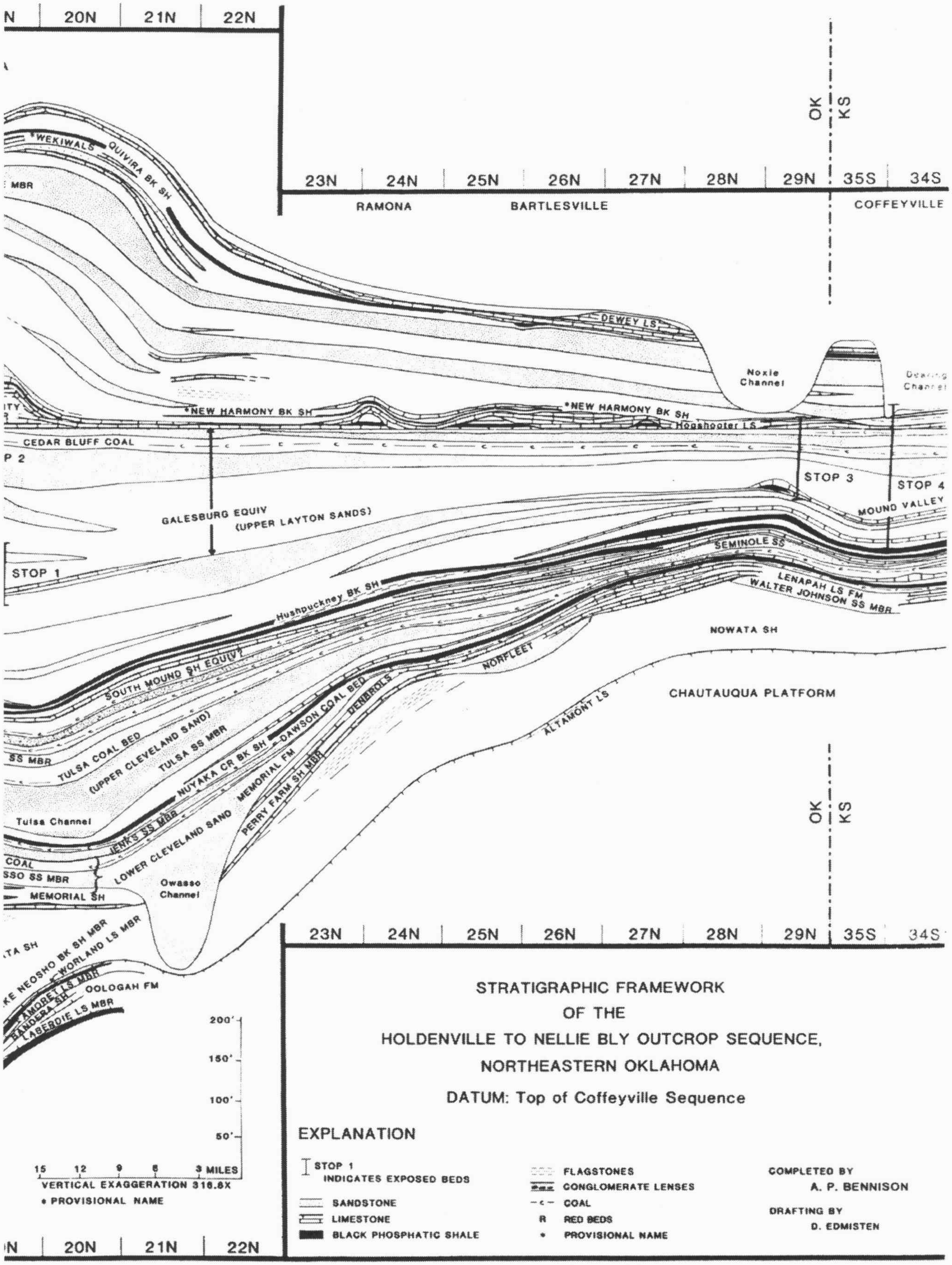

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LENAPAH LS FM
WALTER JOHNSON SS MBR
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OF THE
HOLDENVILLE TO NELLIE BLY OUTCROP SEQUENCE,
NORTHEASTERN OKLAHOMA
DATUM: Top of Coffeyville Sequence
EXPLANATION
STOP 1
INDICATES EXPOSED BEDS
SANDSTONE
LIMESTONE
BLACK PHOSPHATIC SHALE
FLAGSTONES
CONGLOMERATE LENSES
COAL
R RED BEDS
* PROVISIONAL NAME
COMPLETED BY
A. P. BENNISON
DRAFTING BY
D. EDMISTEN

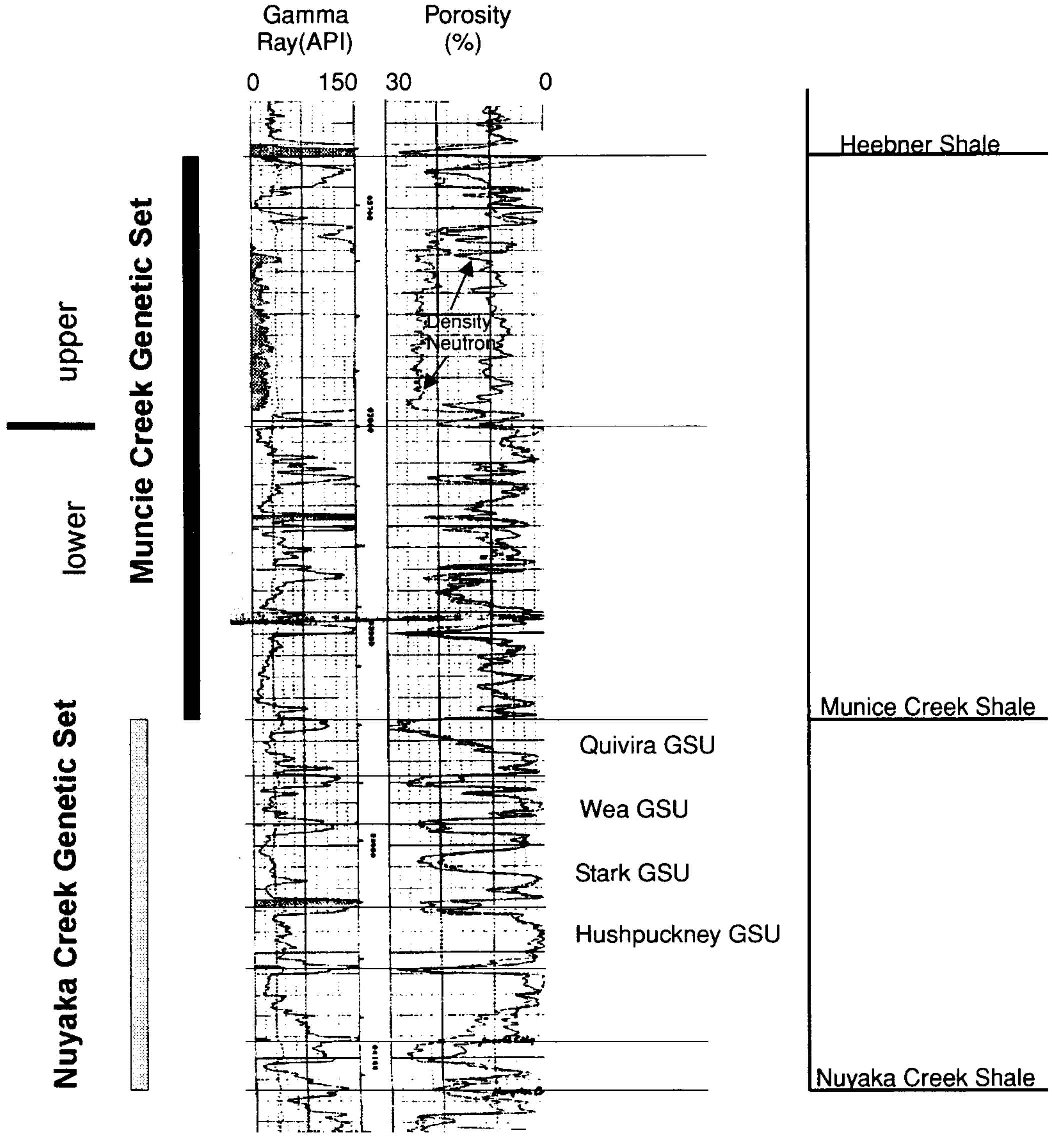

Fig. 8: Wireline log (gamma ray, neutron and density porosity) showing correlation of genetic stratigraphic units and genetic sets.

Heebner Shales delimit cycle sets in the Middle to Upper Pennsylvanian (Figures 16 and 17). Backstepping may continue through several of the lower GSUs/cyclothems and offshore shales, such as that exhibited by the Hushpuckney and Stark GSUs (Figures 16 and 17 and Figures 12 and 13). Overall thicknesses of cyclothems may be greater during backstepping, but this is a function of shelf position (elevation) and environmental conditions (slope, turbidity, clastic supply, climate) and depth and duration of the photic zone at a particular location on the shelf. In contrast, GSUs/cyclothems deposited late in the cycle set demonstrate marked lateral, basinward accretion, e.g., Cherryvale and Dewey cyclothems. Thicknesses of these forward stepping GSUs tend to be more uniform across the shelf with greatest thickness changes at the shelf margin as sediment accommodation space apparently increases. Incised valleys also appear to be more prominent at the close of the cycle set suggesting an overall fall in relative sea level. Sandstones in the Chanute Shale that overlie the Dewey cyclothem are often deposited in incised valleys suggesting prolonged lowstand conditions that brought to close a cycle set (Nuyaka Creek CS). Incised valleys and sandstones within the Douglas Group, are believed to herald the end of another cycle set (Muncie Creek CS).

The amount of backstepping and forward stepping associated with the cycle sets is related to the dynamics of subsidence rate and sediment supply under constant eustasy. Shifts in shelf position in western Kansas around the edge of the Anadarko Basin during the Upper

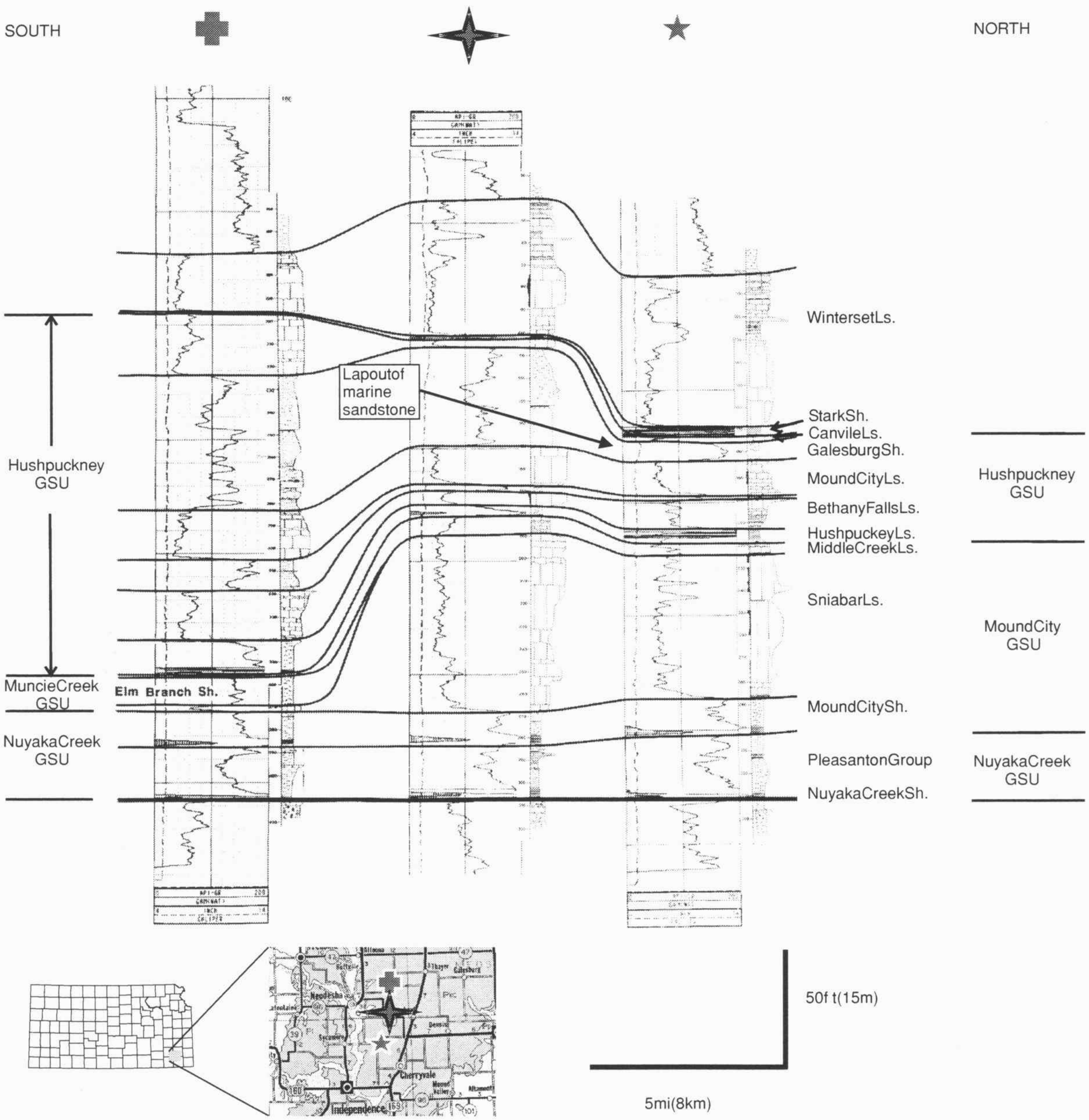

Fig. 9: A stratigraphic wireline log and core cross section of the lower Nuyaka Creek genetic set (GS) from southeastern Kansas adjacent to surface outcrops of the same strata. Datum of the cross section is the Nuyaka Creek Shale, the base of the genetic set of the same name. The Mound City genetic stratigraphic unit (GSU), bounded by the underlying Mound City Shale and overlying Huspuckney Shale, contains a carbonate bank in the Sniabar Limestone developed along the margin of a broad carbonate-dominated shelf. Eighty feet (24 m) of limestone thin down to less than a few ft over a distance of less than 5 mi (8 km). Thinning is assumed to occur by downlap of the carbonate unto its underlying condensed section. The overlying Hushpuckney GSU whose boundaries extend from the Hushpuckney Shale to the Stark Shale, thickens basinward (south) filling in accommodation space in front of the underlying carbonate bank. Index map for cross section is part of illustration. Modified from French, upublished.

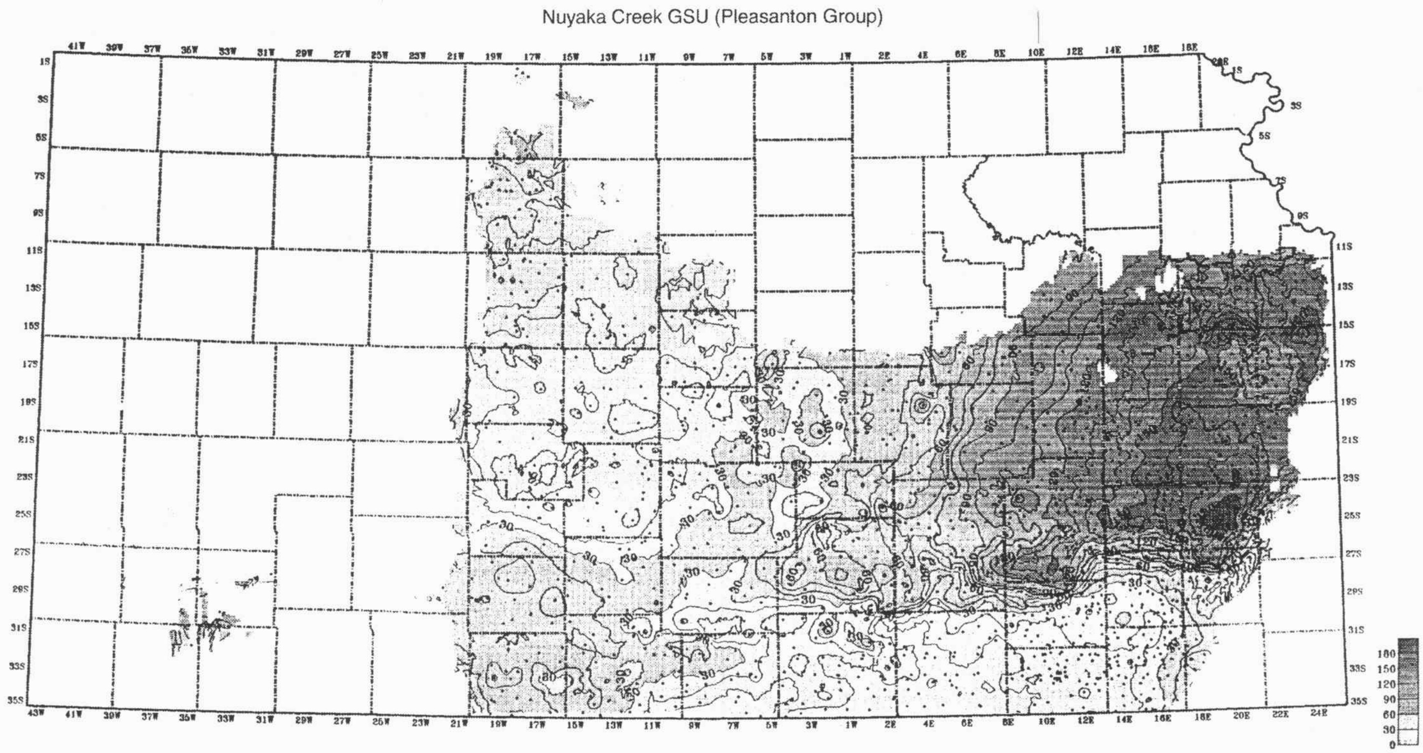

Fig. 10: Isopachous map of Nuyaka Creek GSU (containing Pleasanton Group) in Kansas.

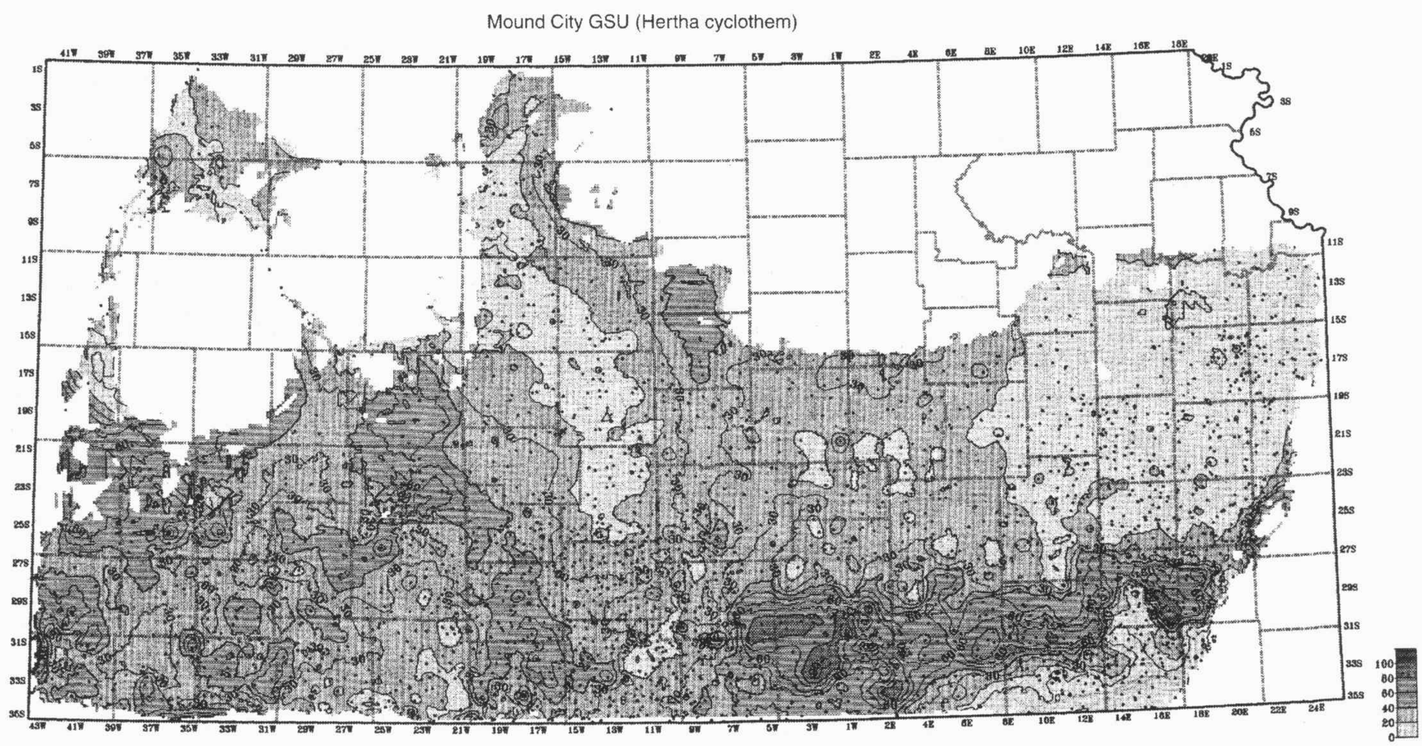

Fig. 11: Isopachous map of Mound City GSU (containing Hertha cyclothem) in Kansas.

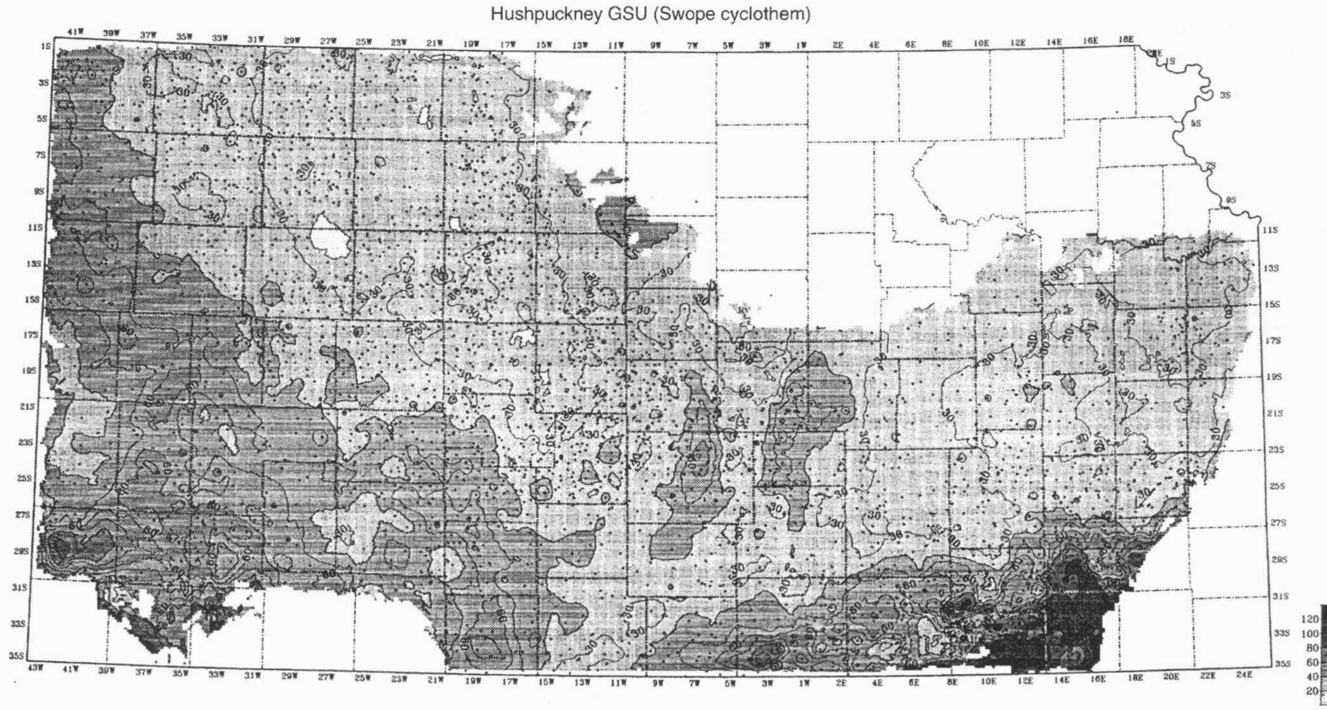

Fig. 12: Isopachous map of Hushpuckney GSU (containing Swope cyclothem) in Kansas.

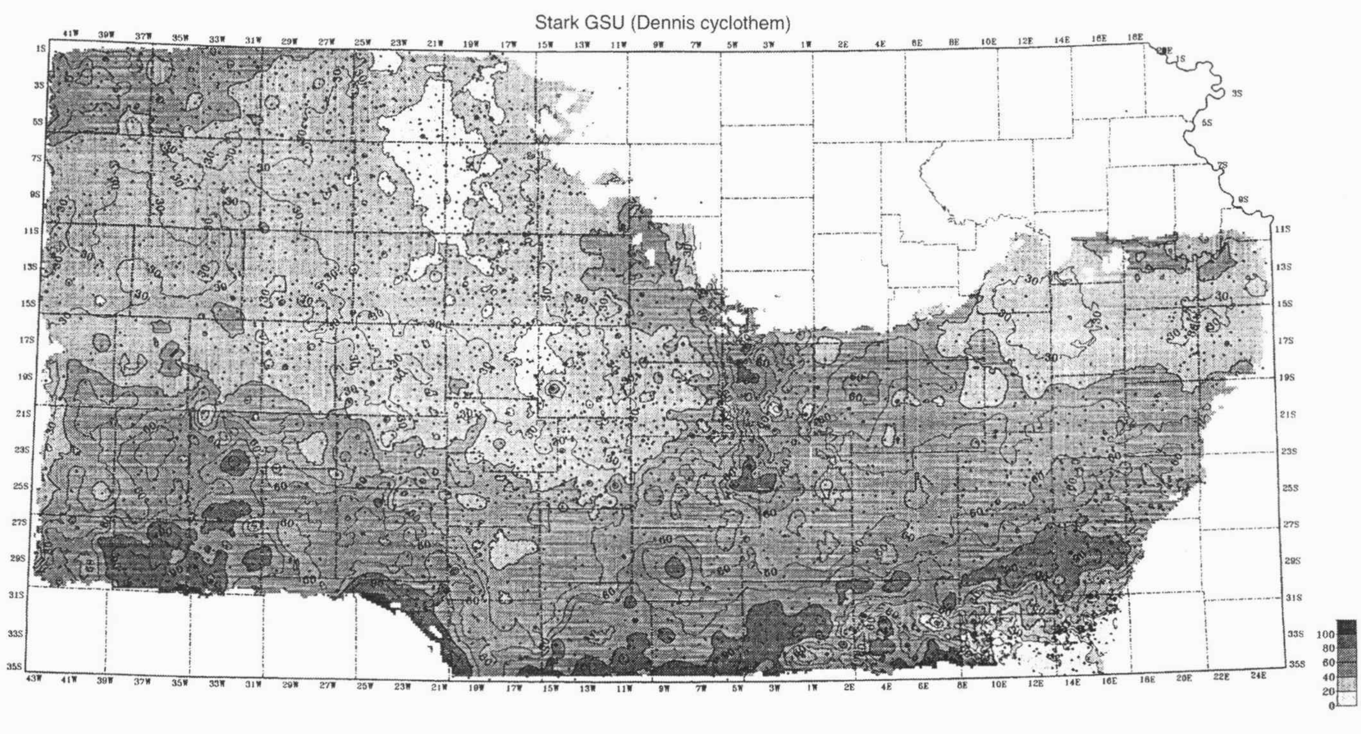

Fig. 13: Isopachous map of Stark GSU (containing Dennis cyclothem) in Kansas.

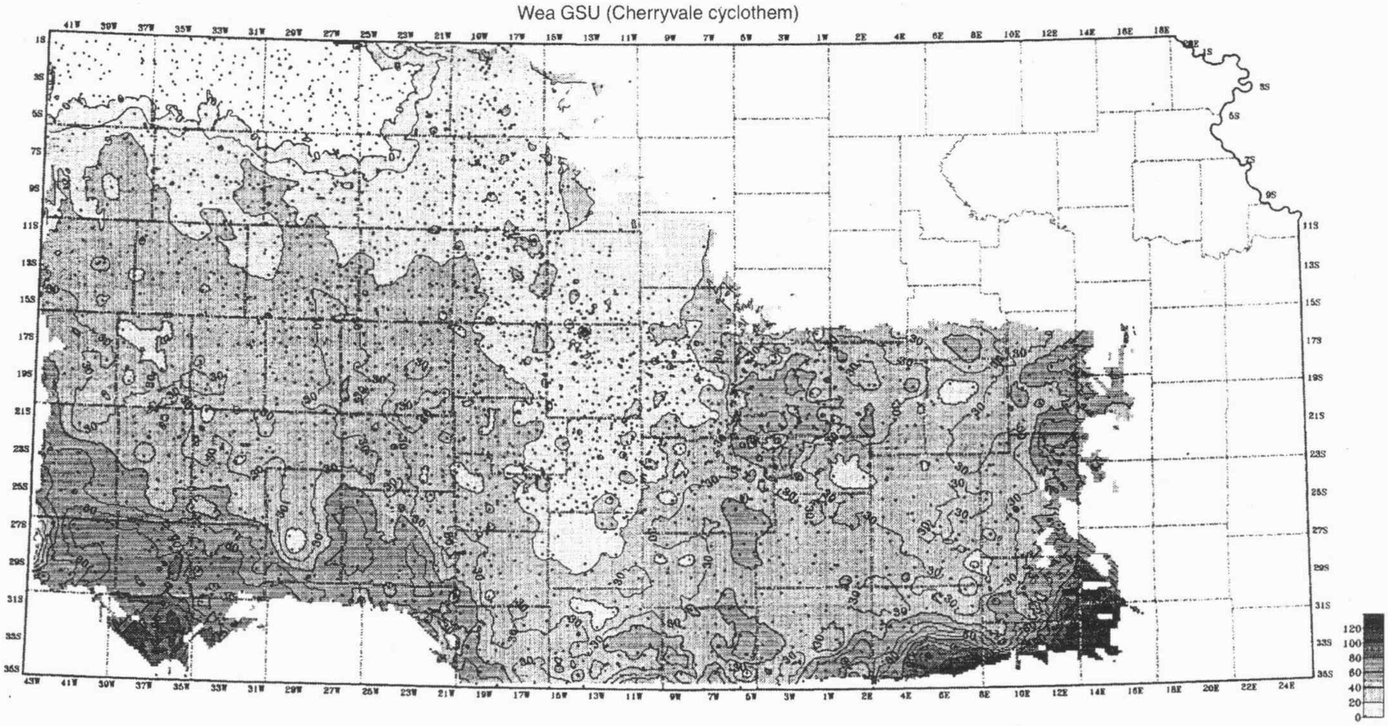

Fig. 14: Isopachous map of Wea GSU (containing Cherryvale cyclothem) in Kansas.

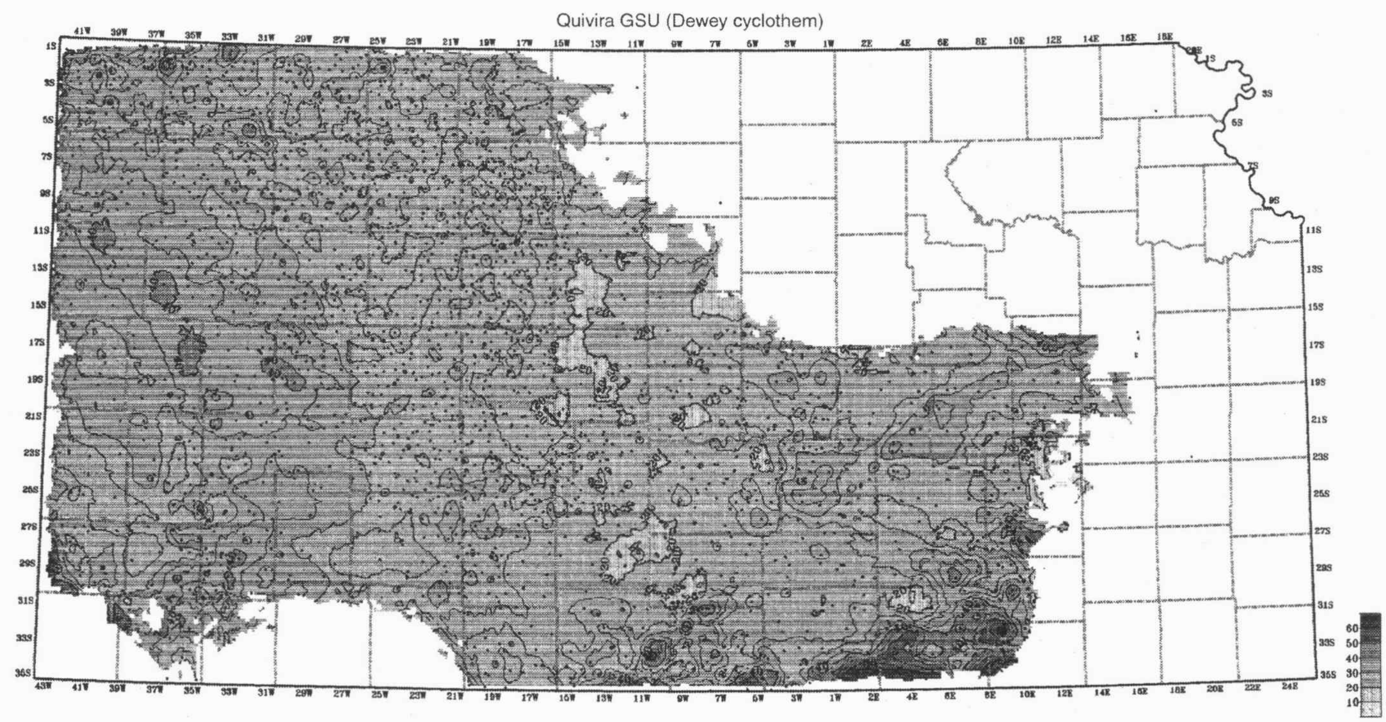

Fig. 15: Isopachous map of Quivira GSU (containing Dewey cyclothem) in Kansas.

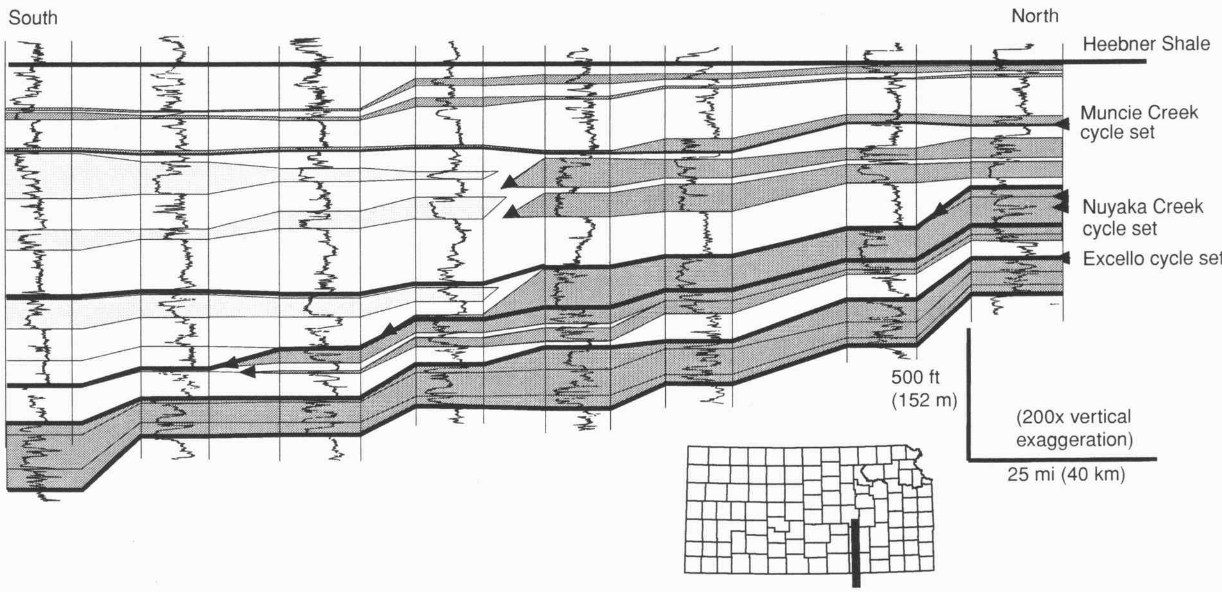

Fig. 16: Shelf-to-basin (south to north) stratigraphic cross section depicts carbonate margin for a portion of the Upper Pennsylvanian strata. Cross section contains conventional well logs located along a line of section extending from southeastern Kansas (Kansas Shelf) to northeastern Oklahoma (basin) as shown on the index map. Gray-toned filled strata are carbonate-dominated intervals closely corresponding with cycle sets as labeled. Section extends from Oread Limestone to the top of the Marmaton Group. Note intervenning clastic intervals typical of eastern Kansas. Length of cross section is 125 mi (201 km). Maximum thickness is 1200 ft (366 m).

Pennsylvanian were considerably less than in eastern Kansas. While 5 km was the maximum separation between the southern carbonate shelf edges at the base and top of the Muncie Creek cycle set in western Kansas, 160 km separated the equivalent shelf edges in eastern Kansas (Figures 16-18). Clastic sediment appears to have been supplied more frequently and was more widespread in eastern Kansas. In general, lower clastic sediment input produced a steeper shelf margin and decreased the lateral distance between backstepping and forward-stepping stratal packages.

Decreased clastic input and increased basinward subsidence led to ramp development of the western Kansas shelf and resulted in sites suited for generation and accumulation of high-energy oolitic grainstones, e.g., within the Swope and Dennis cyclothems. Oolites formed in regressive limestones of successive cyclothems that tracked up and down the shelf in western Kansas as an individual cycle set developed. Thicker trends of oolite accumulation progressively shifted landward and basinward during the cycle sets. In eastern Kansas the oolitic facies are more limited due, in part, to intermittent clastic input and probable reduction in slope of the shelf. The shelf margin lithofacies is typically oolitic grainstones and phylloid algal carbonate (Heckel and Cocke, 1969; Watney et al., 1995).

Role of Eustasy versus Tectonics

Successive cycle sets through the Pennsylvanian on the Kansas shelf show overall transgression (Youle et al., 1994; Watney et al., 1995). These long-term changes in shelf configuration closely follow the general trends in eustasy as defined by Vail et al. (1977), Ross and Ross (1987), Heckel (1994), suggesting that eustasy was a major influence on the shelf framework. These large-scale transgressive-regressive cycles are in excess of 1.5 m.y. in duration and correspond to 3rd-order cycles of Mitchell and Van Wagoner (1991). While eustatic change can explain general observations of this cyclicity, relative sea level changes influenced by subsidence and sediment supply locally impact the composition of cyclothems. The degree that subsidence and tectonics versus eustasy affect the development of cycle sets is still not totally clear, although similar 3rd order cycles have been recognized in the Permian Basin of the U.S. (e.g., 4 sequences of Canyon Group in the Horseshoe Atoll, Waite, 1993).

The locations of the shelf edges are one example of the control exerted by local variations in subsidence. Distinct linear trends of the shelf margin have been closely linked to reactivation and differential subsidence along basement structures (Watney et al., 1997; 1999a). Inferred sites of reactivation of basement weaknesses define sites on the shelf that underwent episodic flexure or fracture leading to differential subsidence. This produced changes in thickness and composition of cyclothems and cycle sets (Watney et al., 1999a). Statistical analysis of a succession of isopachous maps of GSUs and cycle sets, including the series of maps shown in Figures 10-15, reveal km-scale rectilinear divisions or blocks of the Kansas Shelf that correspond closely to lineaments on gravity and magnetic maps (Figure 19, Watney et al., 1999a). During

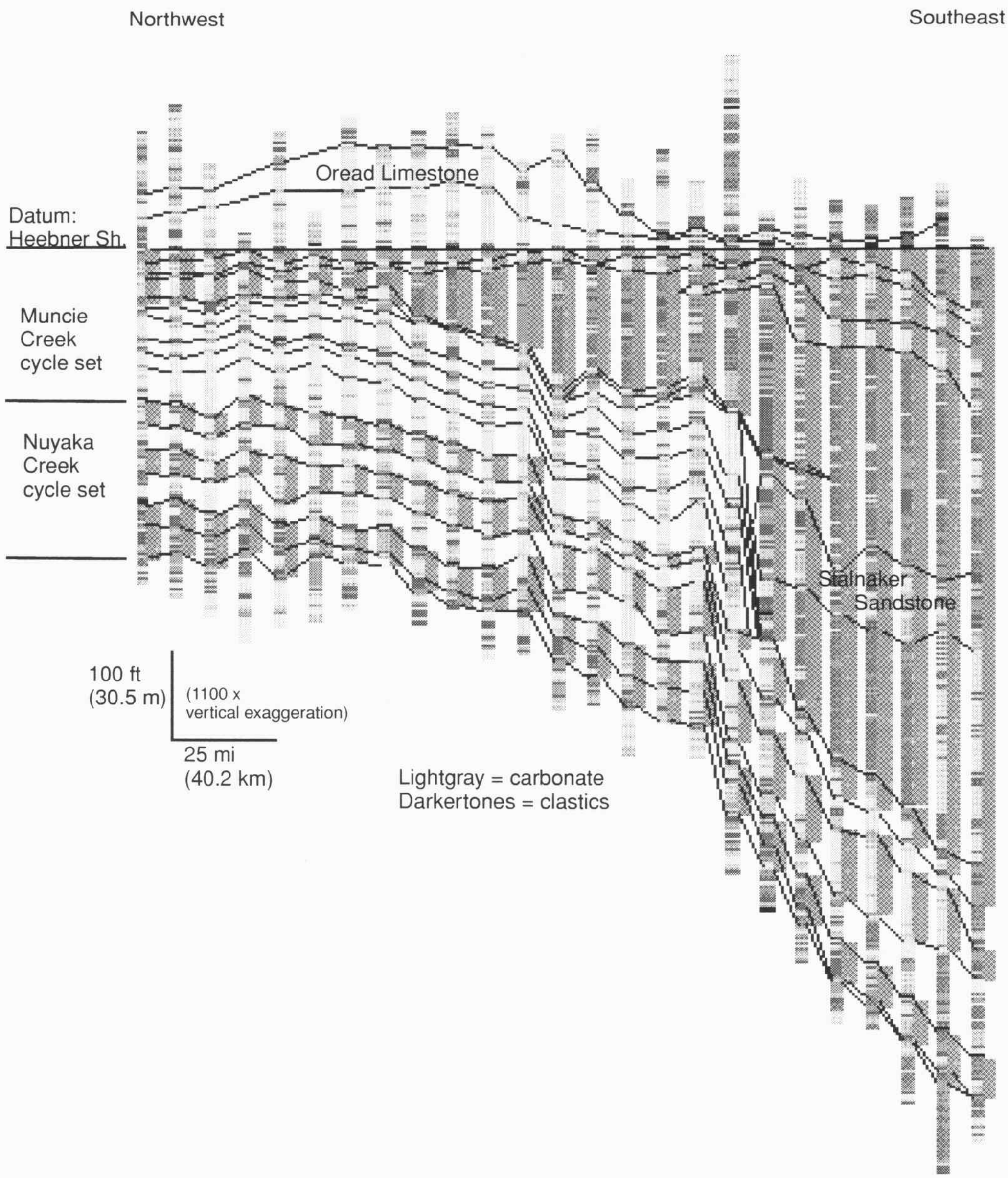

Fig. 17: Northwest to southeast stratigraphic cross section extending from central western Kansas to south central Kansas (west of the cross section in Figure 16). Index map shown in Figure 4). Vsh, shale fraction, derived from the natural gamma ray log is depicted in gray-toned image at each well location. Cross section includes stratigraphic interval from the Oread Limestone to the top of the Marmaton Group. Cross section was correlated manually, but wells are displayed as color images (gray level shown here). Datum is the Heebner Shale. Lighter colored intervals depict carbonates and sandstone and darker gray tones correspond to shales. Length of section is 200 mi (321 km). Maximum thickness of interval shown is 2400 ft (732 m). Section displayed using PfEFFER log analysis software (http://crude2.kgs.ukans.edu/PRS/software/pfeffer1.html). Correlations of genetic stratigraphic units in the carbonate-dominated shelf are delimited using alternating bars and correlation lines.

transgression associated with the beginning of a cycle set, differential subsidence across block boundaries led to local drowning of the lower carbonate shelf. Increased subsidence coupled with a eustatic rise probably led to drowning of the shelf.

The rectilinear structural blocks define areas with similar stratigraphy and lithofacies that suggest similar slope and elevation of the shelf. These blocks may prove important in predicting lithofacies trends and properties of petroleum reservoirs. Also, the configuration of the blocks appears to have influenced the location of fairways for

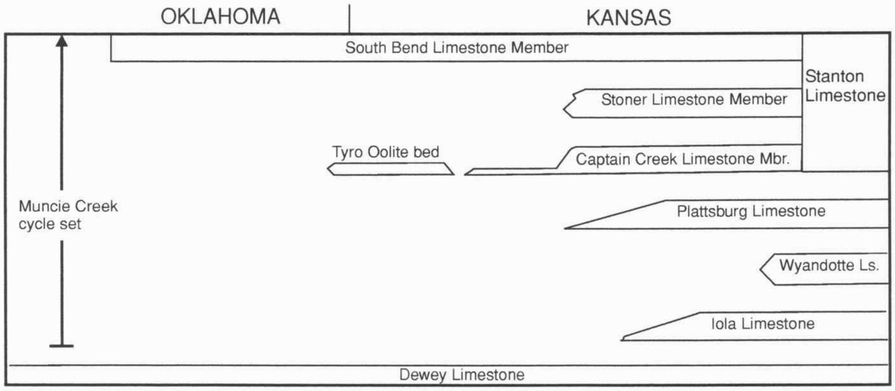

Fig. 18: Cross section of portion of Muncie Creek genetic set in eastern Kansas and Oklahoma (modified from Heckel, 1975).

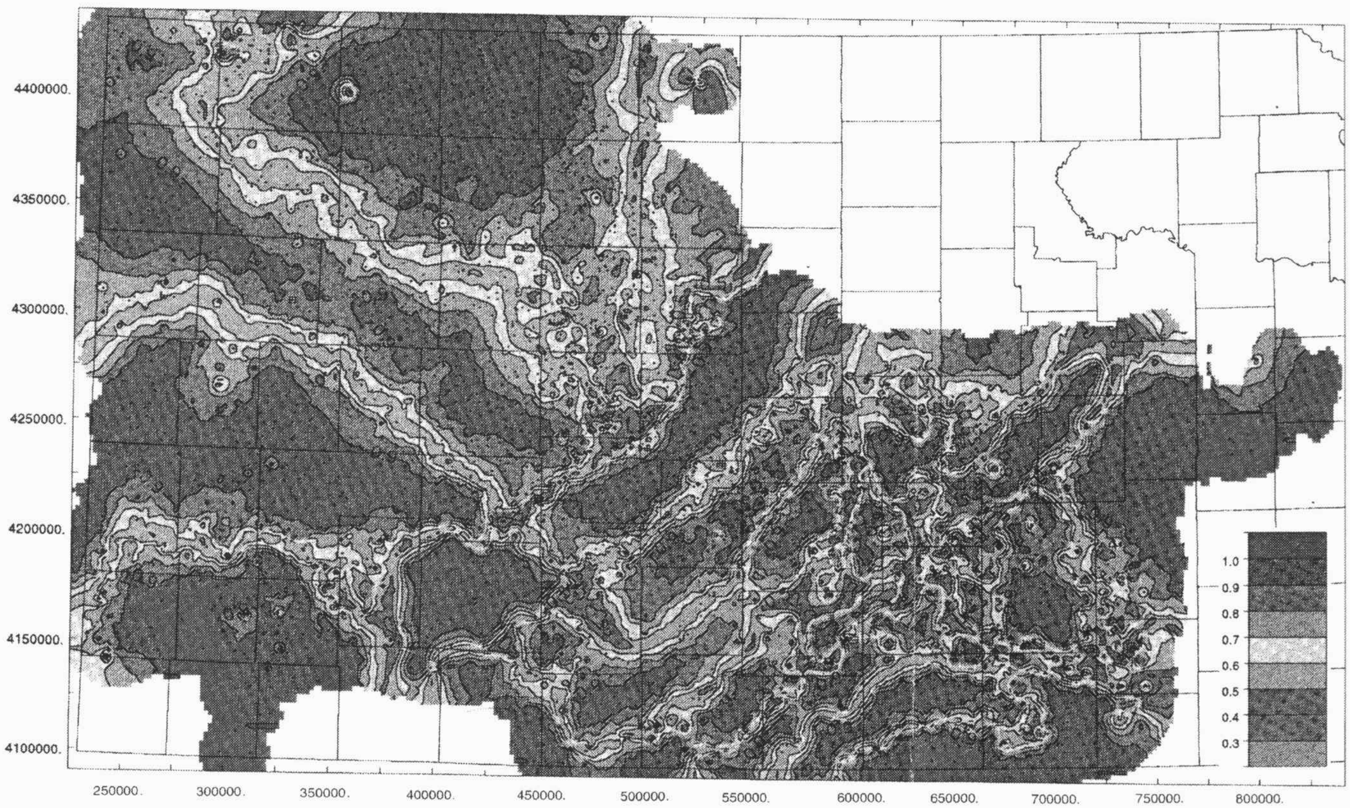

Fig. 19: Map of Kansas depicting 15 rectilinear, km-scale blocks derived from statistical analysis of thicknesses of six Upper Pennsylvanian GSUs and GSs (see stratigraphic intervals in Figure h). Analysis used to characterize the Kansas Shelf and to define areas that apparently underwent more homogeneous subsidence. Block boundaries are sharp and closely correspond to basement heterogeneities seen on potential fields maps (Watney et al., 1999a). Apparently, basement reactivation occurred during nearby foreland basin development leading to fragmentation of the shelf, locally important in loci for shelf margins, carbonate buildups, fairways (lower elevations) for clastic input.

clastic sediment transport across the shelf, e.g., thick clastics of the Pleasanton and Douglas Group in eastern Kansas (Watney, 1993).

Episodic reoccupation of lineaments as sites of shelf flexure strongly suggests recurrent basement reactivation and fragmentation of the shelf. This has been previously described for many years as plain folding among other terms (Merriam and Foerster, 1996). The deformation on the Kansas Shelf was apparently in response to forces transmitted from the subsiding foreland basins to the south. This deformation was coupled with eustasy and sediment supply to produce the observed character of these cyclothems.

Minor Cycles

Minor cycles (Heckel, 1999) are often recognized in regressive limestones. Conodont-bearing marine shales locally underlain by paleosols (Heckel and Watney, 1985) are frequently associated with these minor cycles and help substantiate correlations of the minor cycles (Felton and Heckel, 1996). Subaerial exposure of subtidal deposits associated with these minor cycles indicates forced regression and marked basinward shifts in baselevel. Minor cycles are important elements of petroleum reservoirs as they lead to layering of reservoir and non-reservoir-quality rock. A notable example of the importance of minor cycles is an oolitic grainstone reservoir of the Bethany Falls Limestone (Missourian Stage) in Victory Field in southwestern Kansas. The oolite contains layers that exhibit variations in overall thickness and dominant type of pores. Differences in grain size and extent of dissolution of ooids affect formation of molds and vugs. Cores suggest that the layers are minor cycles. These layers vary in spatial distribution over a prominent structure with some layers lapping out onto the flanks of the structure (Figure 20, 3-D, Watney et al., 1996). Contrasts in pore types in these ooid layers appears to be related to variations between minor cycles including ooid composition (either calcite or aragonite) and diagenetic overprint related to several episodes of subaerial exposure associated with successive minor cycles (French and Watney, 1993a, b; Watney et al., 1996; Watson and Algeo, 1994).

Minor cycles provide an important component in reservoir characterization and help resolve problems in establishing models for lateral reservoir continuity and conformance (vertical connectivity of pore space). Over 3 million barrels of oil is believed to be bypassed in Victory Field due to stratigraphic traps associated with these Upper Pennsylvanian cyclothems (Watney et al., 1996). Regional correlation of minor cycles using wireline logs using standard manual procedures is not reliable, but latest biostratigraphic information and new computer-assisted correlation techniques offer the potential to resolve these stratal elements (Felton and Heckel, 1996; Olea, 1994; Watney et al., 1999a).

Summary

The utilization of subsurface data describing the cyclothems, GSUs, and cycle sets provide a high-resolution record of the changing configuration of the Kansas shelf and has proven useful in resolving detailed paleogeography and predicting changes in stratal architecture that are useful in defining stratigraphic traps for petroleum.

High rates of tectonic subsidence coupled with abrupt eustatic rise apparently drowned the lower shelf. Sediment starvation would result and a new margin would develop as the elevation of the shelf increased with sedimentation, while the basin side continued to subside. Basin filling would occur episodically from as often as individual cyclothems, e.g., Swope cyclothem in eastern Kansas, when low stand clastic deposition would fill the basin alternating with carbonate shelf development. This is analogous to reciprocal sedimentation where a lower relief (<30 m high) shelf margin is developed. Alternatively, basin filling may be postponed for nearly an entire cycle set to create a steep, high relief (100+ m high) margin, e.g., Muncie Creek GS on the western Kansas Shelf (Figures 16 and 17). Such contrasting shelf margins are developed at equivalent times in western and eastern Kansas.

OTHER SUPPORTING SUBSURFACE STUDIES

Studies of Thorium:Uranium (Th:U) Ratio

Outside of the stratal stacking patterns along the basinward margin of the shelf, transgression and regressive patterns and relative sea level changes have also been indicated by the distribution and characteristics of cyclothems, particularly offshore and outside shales (Heckel, 1994). Paleosols in outside shales vary in intensity and duration and suggest possible changes in base level and associated duration of subaerial exposure in addition to climate and local drainage conditions. Widespread, dark, phosphatic radioactive offshore shales are more typical of major transgressive episodes on the shelf (Heckel, 1994; Watney et al., 1995), particularly at the boundaries of the cycle sets (Figure 21). As previously described, cycle sets show both pronounced landward (transgressive) and basinward (regressive) stepping geometries.

A possible independent indicator of relative sea level changes in through the study of the thorium:uranium

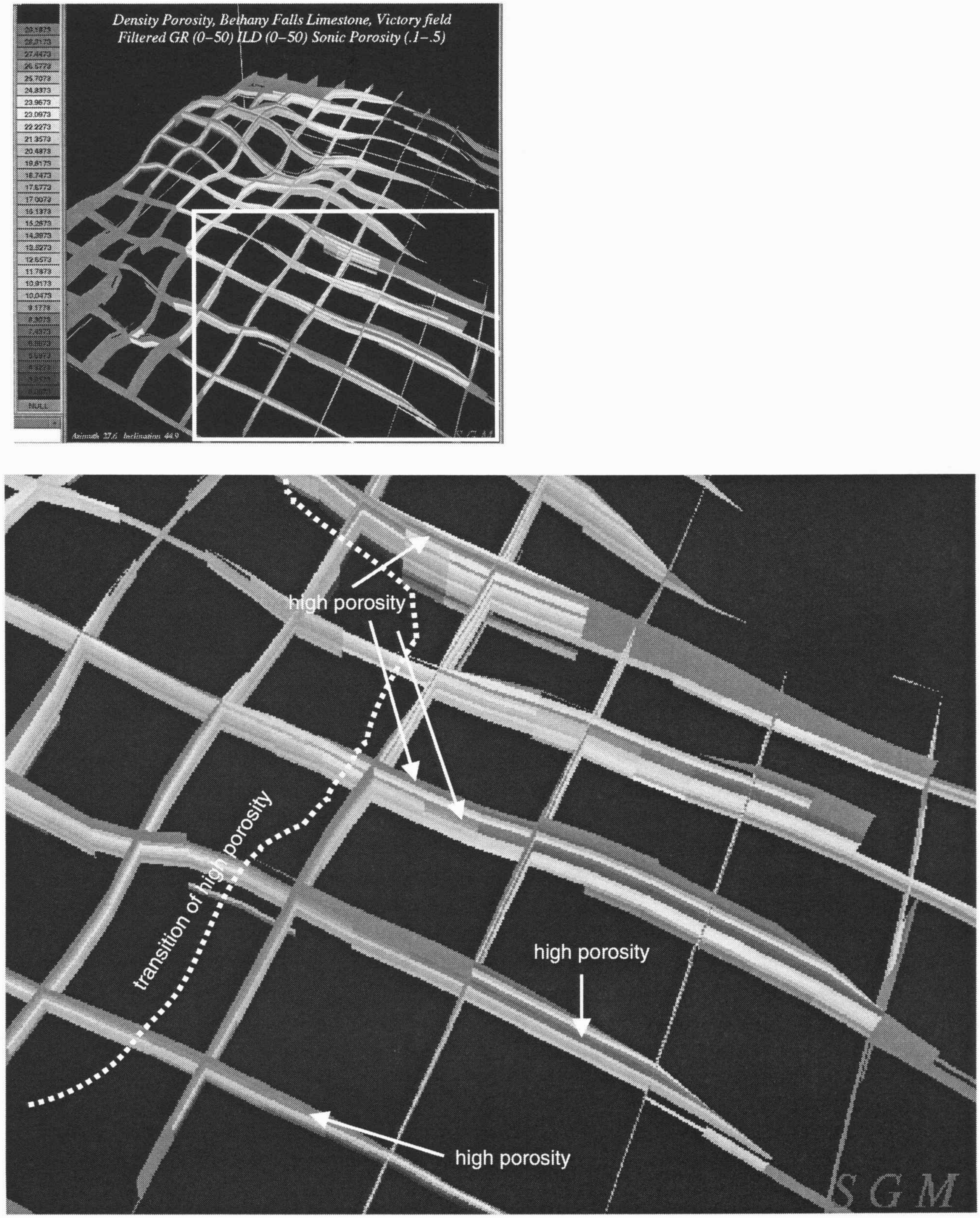

Fig. 20: 3-D geocellular model of density porosity in Bethany Falls Limestone in Victory Field using Stratamodel ™ software showing layering and updip onlap of high porosity associated with combination structural-stratigraphic traps.

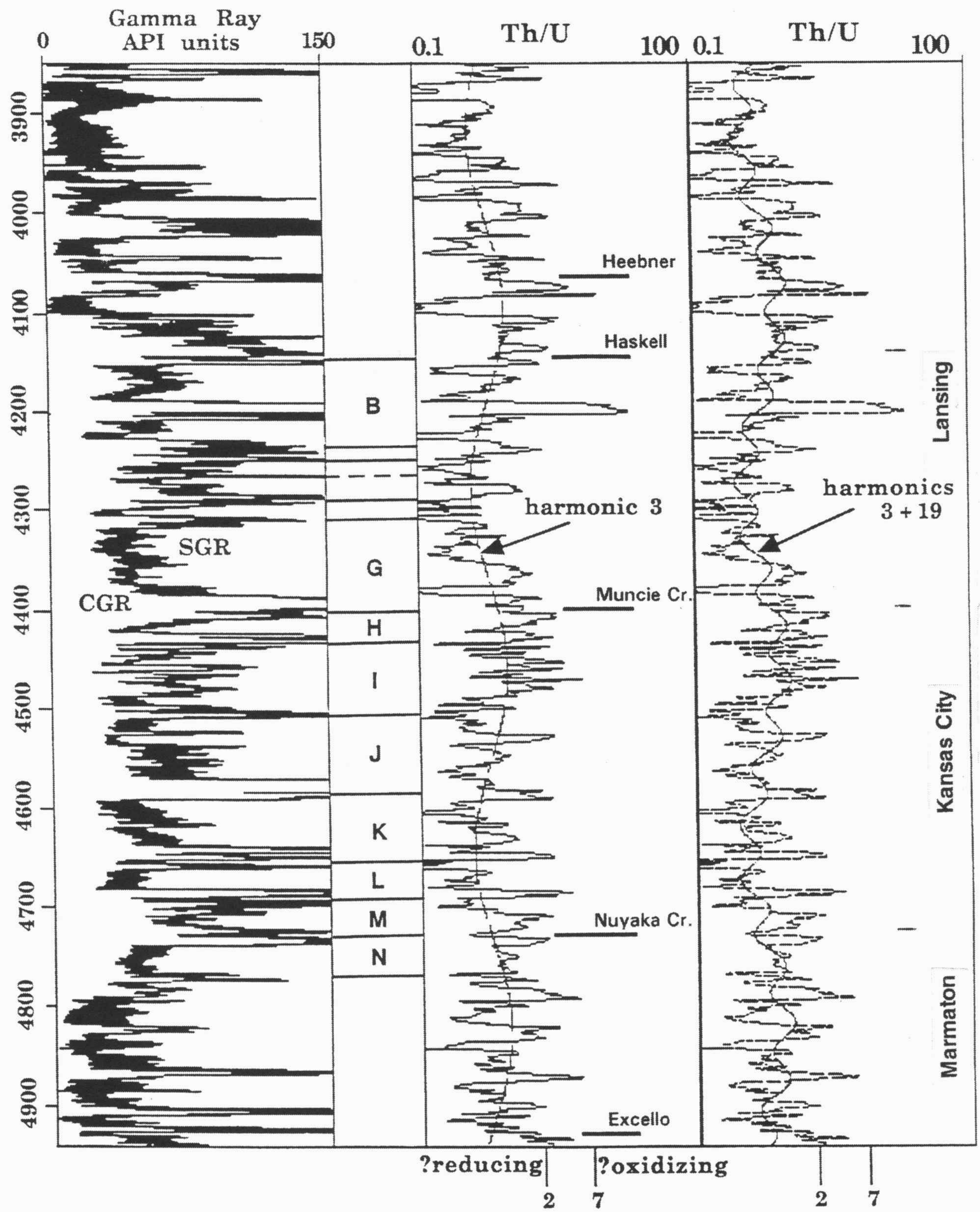

Fig. 21: Wireline log profile of Missourian and lower Virgilian strata in the Amoco Cox A-4 core in Victory Field, Haskell County, Kansas. Illustration includes two traces, the natural gamma ray curve and the Th:U ratio. Reducing (lower ratio) and oxidizing trends (higher ratio) delimit high frequency GSUs and longer GSs, including Nuyaka Creek, Muncie Creek, and Heebner GSs.

ratio. This ratio can now be measured continuously in gamma ray spectral wireline logs to provide a measure of oxidizing and reducing (redox) conditions of the sediment. Offshore shales and lowermost portions of the overlying regressive carbonate show the lowest Th:U ratio of the cyclothem indicating most reducing conditions. Consistent association of reducing conditions with dark, organic rich sediment suggests that this ratio, in this case, is a reasonable index of the level of anoxia associated with deposition. Variations in the redox conditions may well be linked to variations in the intensity of anoxia. Prolonged and more intense anoxia has been related to water depth and isolation of the bottom from surface circulation and oxidation. Alternatively, the reducing conditions may be linked to the level of organic productivity and depletion of oxygen or secondary enrichment of uranium, also through biologic processes (Coveney et al., 1991; Gerhard, 1991). However, the great lateral extent of the offshore shales, its fauna and geochemistry suggest water depth is a dominant variable in creating the anoxia.

In contrast, paleosols reveal varying levels of increased oxidation expressed as high Th:U ratios. Oxidation may be related to climate (latitude and atmospheric/oceanic circulation patterns) and local conditions of drainage, slope, parent material and duration of the paleosol, varying also with proximity to water and orographic features. The most consistently oxidized strata of the cyclothem are the paleosols. The spectral gamma ray log shows recognizable patterns of changing redox conditions of successive paleosols.

A study of a 1100 ft (335 m) long core and accompanying wireline log suite including the gamma ray spectral log show distinct trends of fluctuating Th:U ratio, and, in turn, oxidation and reduction. Fifty-foot (15 m) thick cycles of low (reducing) to high (oxidizing) Th:U ratios delineate the individual cyclothems (Figure 21, Watney et al., 1995). Longer 350-ft (107 m) long cycles of abruptly more reducing to more gradual oxidizing trends identify the cycle sets defined earlier and independently using regional strata stacking patterns. Boundaries of these cycle sets are the Nuyaka Creek, Muncie Creek, and Heebner Shale. The Th:U curve for the DesMoinesian through early Virgilian Stages resemble the relative sea level curves derived from previous studies (Heckel, 1994). Additional wells were analyzed across the Kansas Shelf resulting in additional Th:U curves. These wells reveal similar trends in different parts of the Kansas shelf. Changes in thickness and lithofacies have some effect on the curve, but the redox patterns are still evident suggesting that the Th: U curve may indeed be an independent proxy for relative sea level.

More work is needed to confirm this methodology and make it more generally applicable. As climate and paleogeography change through time and space, paleosols do change character. Offshore shales also probably change. Thus, the Th:U ratio probably needs to be calibrated to specific basin setting and stratal interval (Watney et al., 1995). What is indicated from current results is confirmation of a dominant, regional sea level control coupled with local tectonics and sediment supply to produce the observed cyclothems. The dynamic changes among these regional processes result in predictable trends. The question is whether the variables can be quantified and modeled to make quantitative reconstructions that are useful to resource evaluation.

PfEFFER Software

New tools to analyze subsurface data provide further insight and perspectives in the recognition, distribution, and origin of cyclothems and associated petroleum reservoirs on the Kansas Shelf. A PC-based software package called PfEFFER has been developed by the Kansas Geological Survey to analyze petroleum reservoirs using digital wireline logs (http://crude2.kgs.ukans.edu/PRS/software/pfeffer1.html). The software is modular in form, written in Visual Basic and operating under an Excel spreadsheet. The software reads and analyzes large sets of data for use in deciphering pore types and capillarity, fluid types, continuity and conformance of flow units (connected reservoir quality rock). Software such as this is used to flesh out reservoir properties for fluid flow reservoir simulators and to examine potential sites of bypassed or underproduced oil and gas reservoirs. Similar software is also being used to correlate cores and logs with seismic, particularly 3-D seismic information, to aid in reservoir attribute analysis and seismic sequence stratigraphic interpretation.

Software automatically assembles logs and can generate color-image cross sections (such as in Figure 17) and maps creating displays such as porosity log cross sections and sections of calculated pay. This is useful in the re-exploration that evaluates other petrophysical and analyzed results with respect to the cyclothems.

KIPLING Software

KIPLING is another software package developed at the Kansas Geological Survey that uses a robotics approach to decision making in classifying wireline log data. The software is part of the PfEFFER wireline log analysis family, written in Visual Basic code that runs in a Microsoft Excel spreadsheet (Bohling,). KIPLING was used to assign sequence stratigraphic components and facies to the same 1100 ft (335 m) long cored cyclothemic succession used in the Th:U analysis (Bohling, Doveton, and Watney, 1996). Physical and chemical properties were used successfully to classify facies in a consistent manner using a computer. Reliability is expressed in probability. This suggested that modern wireline suites and logical consistent analysis could provide reliable results in differentiating facies. The results also indicate that genetic units often have distinctive properties that can be differentiated using wireline logs.

KIPLING is now being used to classify hydrocarbon pays and shows (minor, nonproductive hydrocarbon accumulations) to aid the explorationist in examining large amounts of data (Watney et al., 1999b).

CORRELATOR Software

Computer-assisted correlation of digital wireline log data is able to provide reliable correlations that go considerably beyond routine lithologic tops. This is critical to isolating stratigraphic anomalies important in exploration. It may be these subtle, normally uncorrelated stratal elements that permit new insights and unlock opportunities and about potential stratigraphic traps.

The same wells used to construct the gamma ray cross section shown in Figure 17 was correlated using CORRELATOR software (Figure 22). Digitized gamma ray data sampled at 0.5 ft (15 cm) was normalized to a shale baseline set to 1 and a clean, shale-free lithology was set to 0. Normalizing resulted in a consistent log response between wells, but eliminated high gamma ray spikes associated with condensed sections (black marine shales) of the GSUs. The methodology is described in Olea (1994).

CORRELATOR cross-sections are coded so that the lighter the gray tone, the lower the rock shale content. Intervals that remain white represent no correlation between wells for that segment (Figure 22). These gaps serve to outline correlations between wells. Original illustrations are in color and are available on the Internet website of the Kansas Geological Survey.

Results as reported in Watney et al. (1999 in press) include:

1. Correlations within individual GSUs, thick shales, and transitions between successions of carbonates to shales suggest temporal correlations and stratal patterns of backstepping, forward stepping, onlap and downlap;
2. Stratal geometries within GSUs are recognized using CORRELATOR, including high frequency cycles (minor cycles) of onlap, downlap and laterally accreting carbonate strata onto a maximum flooding surface/condensed section, e.g., Oread cyclothem;
3. Isolated stratigraphic intervals between wells that could not be correlated provide precise sites of probable onlap and downlap;
4. Longer-term genetic sets were confirmed utilizing a combination of detailed correlations and gamma ray variation.
5. High-resolution stratigraphy conducted using software to automate the process results in consistent and unbiased correlations at a regional scale, which are not possible or practical using manual means alone. This technique offers the potential to better target subtle stratigraphic traps in a mature basin.

Simulation

Simulation or stratigraphic modeling provides a computer-driven tool to go beyond the conceptual and qualitative model to evaluate the relative roles and contributions of the processes controlling the development of cyclothems (Figure 23 d, Watney, et al., 1991; Watney, et al., 1999 at press). The integrated role of eustacy, subsidence (driven, differential subsidence via basement reactivation and directed stresses), and sediment supply provided a result using a simple two-dimensional model that closely resembles the regional stratal stacking pattern (Figures 16 and 17 repositioned in Figure 23). While suited for conceptual analysis and experimentation of general processes, the model is not predictive. Much work lies ahead for simulations that could meet the needs of the explorationists, e.g., predicting stratigraphic traps.

Predictions may one day originate from a simulation as new parameters describing processes are assembled and experiments run. Integration of processes can not be accomplished qualitatively, and we can not run experiments without a simulator. Studies of modern analogs provide many new parameters. As correlations, dating, and understanding of the relationships between processes and response increase, so will simulations improve. Computing power is ever increasing as is our understanding of the deposits and processes.

Expectations of model results necessarily begin small and simple, much as all of our ideas begin. The limits of deterministic models of cause and effect are unknown, but there is considerable promise. Representation of processes in current models involved in deposition and erosion of sediment range from first principles to the use of proxies. The model "engine" is dependent on the scale of application and the intended results. Algorithms are increasingly more sophisticated, as new ones are developed from study of modern and Holocene deposits (Watney et al., 1999 at press).

Dating and correlation are fundamental components to simulation, relying on new techniques in stratigraphy, biostratigraphy, geochemistry, and mathematical geology. An ideal scenario would be to have cycles correlated globally, and an age model defined, where tectonic, climate and sedimentation parameters are delimited by area and time. Prediction of resources in developing areas and reexploration and development in mature areas may one day be driven by simulation results, cycle by cycle.

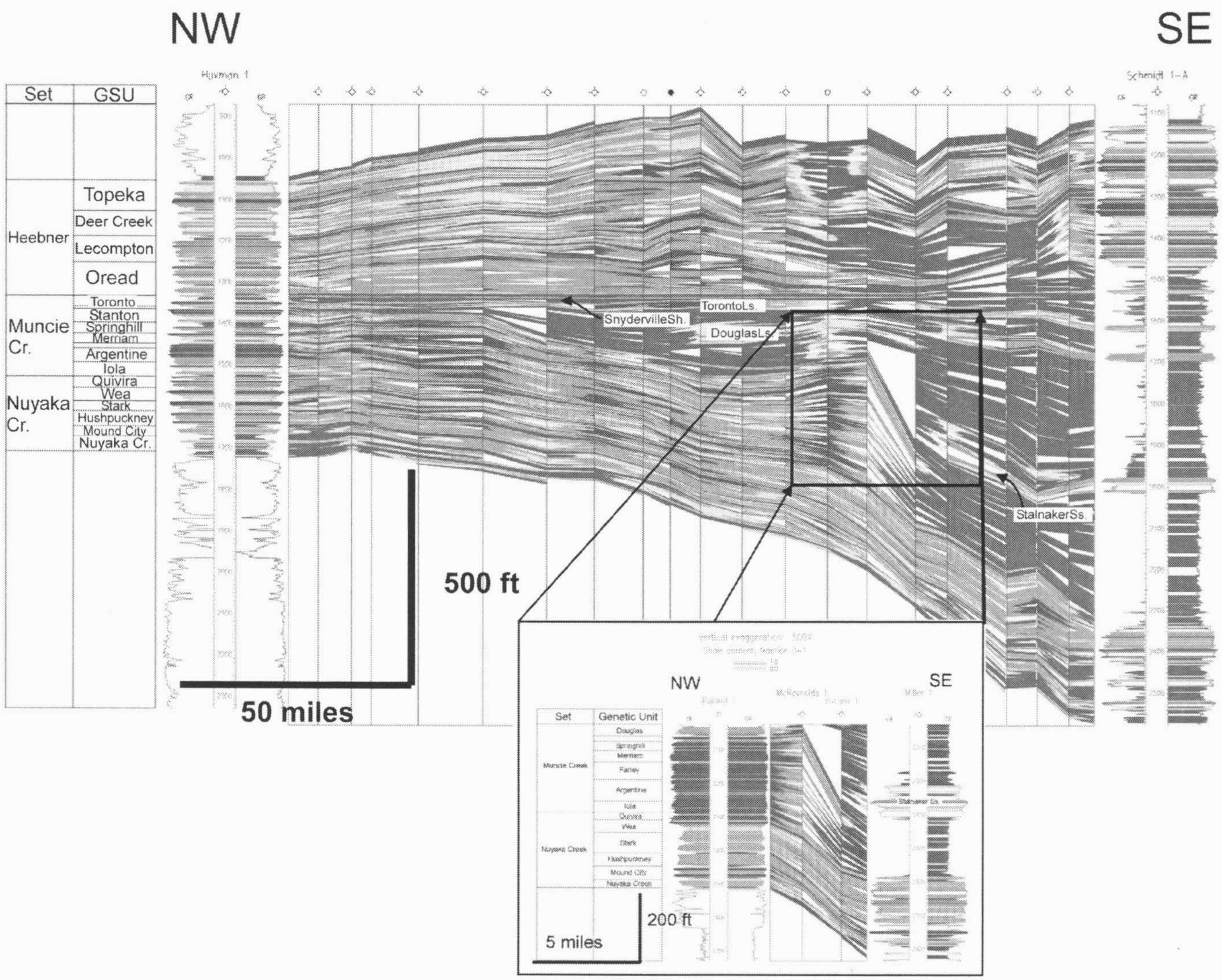

Fig. 22: Stratigraphic cross section depicting shale fraction (Vsh) derived from gamma ray logs. Cross section includes same wells shown in lower portion of Figure l. Cross section was correlated using software, CORRELATOR developed at the Kansas Geological Survey (Olea, 1994). Section shows considerable detail within GSUs including suggestions for onlapping and offlapping minor cycles. Some minor cycles have been substantiated (Watney et al., 1999 in press). White triangle indicate no correlation that are related to onlap or offlap geometries. Typically, carbonates show downlap basinward (white triangles point basinward) and shales onlap landward (white triangles point landward. Automated correlations are consistent and can assess reliability, but correlations need to be verified.

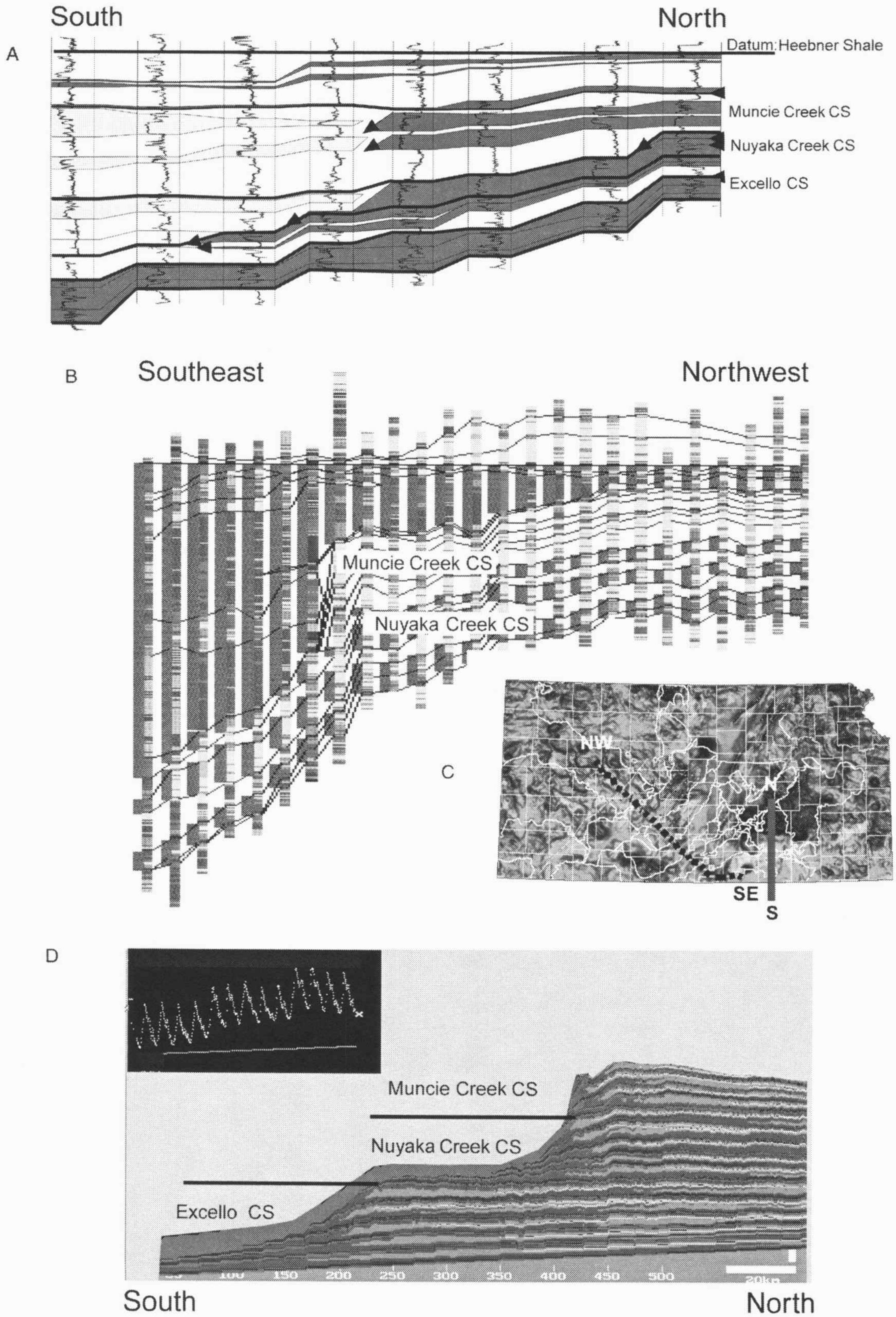
A
South
North
Datum: Heebner Shale
Muncie Creek CS
Nuyaka Creek CS
Excello CS
B
Southeast
Northwest
Muncie Creek CS
Nuyaka Creek CS
C
NW
SE
S
D
Muncie Creek CS
Nuyaka Creek CS
Excello CS
150
200
250
300
350
400
450
500
South
North

Fig. 23 (left): Two-dimensional simulation model (KanMod, French and Watney, 1996) shown in part d) preceded by previously presented cross section including Figure 16 in a) and Figure 17 included here in reoriented form as b). Total magnetic field intensity map is included in c). Differences in the magnetic values are caused by magnetic susceptibility changes (variations in magnetic mineral content such as magnetite) below the surface and reflect changes in rock type and/or structure. Steeper gradients in the magnetic map correlate with faults, shear zones, or other lithologic boundaries within the upper part of the Precambrian basement. Boundaries between blocks defined in Figure 19 are overlain in magnetic map (white outlines). There is good correlation with magnetic anomalies, particularly the higher magnetic gradients. The map was made using ER Mapper software from Earth Resource Mapping. Original magnetic map from Xia et al. (1995; KGS Map M-41D. Simulation focused on Missourian strata extending from shelf to basin. Simulator is carbonate model with basinal area shown as sediment-starved. Individual cycles and cycle sets driven by sawtooth eustatic curve with 115 m amplitude and 350 ky duration, analogous to Pleistocene glacio-eustasy. Cycle sets generated by abruptly increasing sea level of 15 m after each five high frequency cycles. Subsidence increases across the shelf into the basin. Carbonate shelf margins are generated on their own. Extent of backstepping is related to the subsidence and the 15 m rise. Insertion of clastics into the carbonate package would modify the location of the shelf margin.

CONCLUSIONS

Cycle components range from small scale minor cycles, to cyclothems and genetic stratigraphic units, to cycle sets. Genetic stratigraphic units (GSUs) can be easily correlated and mapped in the subsurface using wireline logs. Database of wireline logs is very large and has been integrated with outcrop information to create a three dimensional perspective of the Kansas Shelf. Cycle sets are recognized by stacking patterns along shelf margins using regional cross sections. Regional mapped geometries of GSUs, profiles of Th:U ratios also suggest the presence of cycle sets. Reactivated basement blocks that were active during Pennsylvanian sedimentation are strongly suggested by the subsurface data. The km-scale, rectilinear-shaped blocks indicate that tectonism, namely foreland basin subsidence, strongly affected shelf configuration and development of cyclothems. Tectonics and sediment supply are coupled with eustasy to form distinctive regional patterns of sedimentation.

Future resource extraction will depend on resolution of detailed stratal architecture obtained by continued integrated surface and subsurface projects. Quantification of processes and making predictions of stratigraphy and sedimentation may eventually aid in the search for remaining resources, particularly stratigraphic traps. Interest exists in transferring technology applied to Midcontinent U.S. to other areas with similar stratigraphy and resource issues.

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SOME OLDER NORTH AMERICAN TYPES OF *IDIOGNATHODUS* AND *STREPTOGNATHODUS*

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INTRODUCTION

After more than thirty years of relative inactivity, dating back to the major synthesis by Ellison (1941), detailed biostratigraphic and taxonomic studies of Middle and Upper Pennsylvanian conodonts were revived during the 1970s. Eastern European workers in the former Soviet Union found that the species concepts of Ellison (1941) were inadequate to accommodate the morphologic variety present in samples from different stratigraphic levels. Thus they proposed a number of new species to represent these morphotypes, especially in the two most common genera, *Idiognathodus* and *Streptognathodus* (Kossenko, 1975; Barskov and Alekseev, 1976; Kozitskaya et al., 1978; Barskov, Isakova and Shchastlivtseva, 1981; Barskov et al., 1987; Chernykh and Reshetkova, 1987; Nemirovskaya and Alekseev, 1994). Following work initiated by Merrill (1972, 1975) and Swade (1985), a comparable revision of Middle and Upper Pennsylvanian conodont faunas for use in detailed biostratigraphy is also underway in North America (e.g., Barrick and Boardman, 1989; Lambert, 1992; Ritter, 1994; Barrick, Boardman, and Heckel, 1996). As was true with the work in eastern Europe, the taxonomic and nomenclatural system created by Ellison (1941) has been found to be inadequate to express the variety of species-level morphotypes that these authors recognize.

Because of this renewed interest, the original species concepts and holotypes of all North American Middle and Upper Pennsylvanian conodont taxa are in the process of being reviewed. In addition to the problem of resolving species taxonomy, there remains the additional burden of clarifying the species nomenclature, even if one emphasizes Pa elements, and ignores the myriad of names applied to other elements in the multielement apparatus. As might be expected, some of the new species for Pa elements and additional morphotypes that have been recognized in North America were previously named in the North American literature (e.g., Gunnell, 1933). The majority of Gunnell's names were effectively removed from the active literature by being placed in synonymy with a small number of species names following the model of Ellison (1941). In some cases where taxonomic revision was conducted, older available names were not used because the original material was judged to be unrecognizable in the context of the new species being proposed (e.g., Merrill, 1972), or apparently just ignored.

Here we illustrate the holotypes of some of the older species of *Idiognathodus* and *Streptognathodus* based on North American material and briefly discuss their significance. This summary is not comprehensive, but is restricted to Desmoinesian through Virgilian names that have been used recently in the literature, either correctly or incorrectly. For many of the other species, especially those of Gunnell (1933), additional work on the systematics of *Idiognathodus* and *Streptognathodus* will be required before the species level nomenclature can be resolved. The publication of Jones (1941) represents a special case, and is discussed in a separate paper (Barrick and Lambert) in this guidebook.

GUNNELL (1931)

Idiognathodus n. gen.
I. claviformis n. sp. (Figure 1:2)
I. delicatus n. sp. (Figure 1:1)
I. arcuatus n. sp. (holotype lost)

Gunnell (1931) erected the genus ***Idiognathodus*** based on Pa elements obtained from the Mine Creek Shale Member of the Pawnee Limestone in the late Desmoinesian Marmaton Group near Lexington, Missouri (originally misidentified as shales in the Fort Scott Limestone: see discussion of Coal City cyclothem by Heckel in 'Overview' article in this guidebook). The type species of the genus was designated as ***Idiognathodus claviformis***, which is a short, wide form characterized by an upper surface with irregular nodes and ridges on the anterior part of the platform, transverse ridges on the posterior part, and a blunt posterior tip. Ellison (1941, p. 137) stated that two specimens were designated as syntypes (C487-5 and C487-4) and he reillustrated both (Ellison, 1941, Pl. 23, fig 12 [C487-4] and fig, 13 [C487-5]). Because Ellison believed that one of the syntypes (C487-5) should be referred to another species, *I. lobatus* Gunnell 1933, he selected the remaining cotype (C487-4) as the lectotype of *I. claviformis*. Ellison (1941) considered the lectotype to be "highly modified by senility" and "misleading in the characteristics of the species". There-

Barrick, J. E., and Walsh, T. R., 1999, Some older North American types of *Idiognathodus* and *Streptognathodus*; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 147–161.

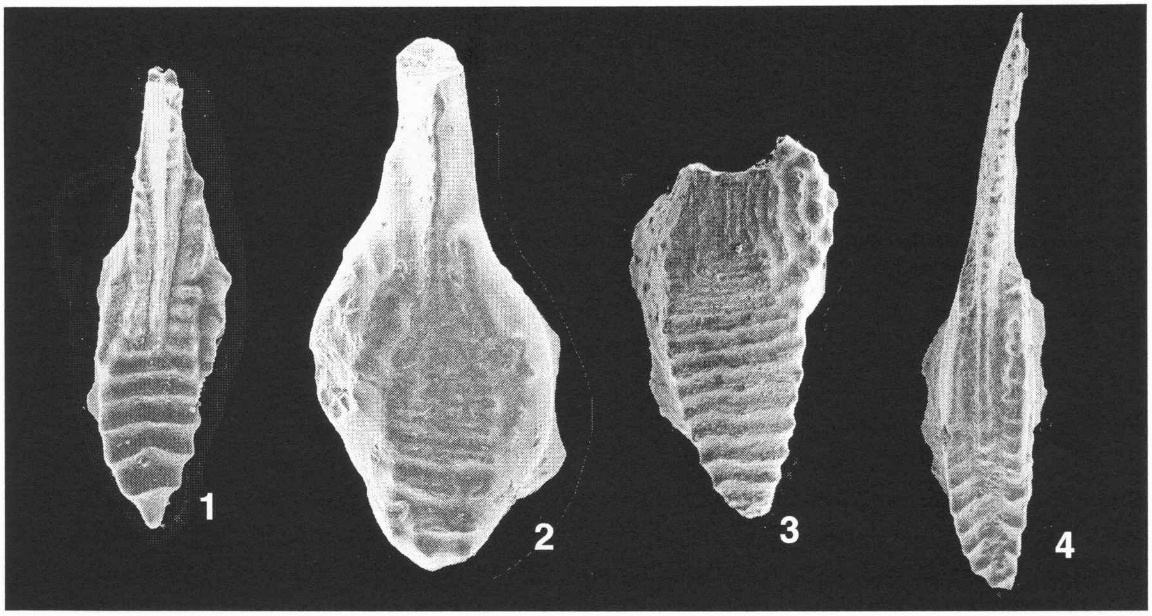

Fig. 1: Types of Gunnell (1931) and Harris and Hollingsworth (1933). 1 - *Idiognathodus delicatus* Gunnell, 1931, lectotype?, UM 488-1, 85X (Gunnell, 1931, p. 250, pl. 29, fig. 25). 2 - *Idiognathodus claviformis* Gunnell, 1931, lectotype, UM 487-4, 60X (Gunnell, 1931, p. 249-250, pl. 29, fig. 21). 3 - *Idiognathodus pustulata* Harris and Hollingsworth, 1933, holotype, USNM 114716, 56X (Harris and Hollingsworth, 1933, p. 204, pl. 1, fig. 11). 4 - *Polygnathus pawhuskaensis* Harris and Hollingsworth, 1933, holotype, USNM 114723, 80X (Harris and Hollingsworth, 1933, p. 199-200, pl. 1, fig. 12a,b).

fore, he modified Gunnell's diagnosis of the species, emphasizing the "rotund, stout appearance" of the species, the rounded posterior margin, and the discontinuous nature of the transverse ridges on the upper surface of the platform.

A second species, ***I. delicatus***, was erected by Gunnell (1931) to include longer, more slender platforms with a flat upper surface bearing several continuous transverse ridges, an inner lobe with rows of nodes, and a sharp posterior tip. Gunnell (1931, pl. 29, fig. 23-25) apparently illustrated two specimens, but did not designate a holotype. The reposited material consists of one specimen, and original writing on the slide labels it as a "cotype", but with reference made to all three illustrations. The one specimen in the slide is certainly that shown in figure 25, the lower view. This specimen does not match the upper view of figure 23, nor the lateral view of figure 24. Both figures show an element with a nearly complete blade; the one remaining cotype has a broken blade. Figure 23 is a dextral form; the existing cotype is sinistral and differs in some minor features. Figure 24 also differs in some minor aspects from the lateral view of the cotype. Ellison (1941) indicated that a "holotype" exists with the UM 488-1 number, and the word "holotype" was added to the slide by a later worker. Although it is possible that a single specimen was illustrated by Gunnell (1931), we think that this is unlikely. By our interpretation, the specimen in the slide is best considered to be a lectotype, rather than a holotype. Here, we illustrate its upper surface for the first time. Fortunately, its morphology is similar to that shown on the missing? specimen Gunnell illustrated in figures 23 and 25, so this minor discrepancy should not effect how the species is characterized. The lectoype is a small, presumably juvenile specimen in which only the most generalized *Idiognathodus* features are present. Ellison (1941) redefined the species to include all forms with continuous transverse ridges and an accessory lobe on one or both sides, except for those assigned to *I. magnificus* Stauffer and Plummer 1932 (outer accessory lobe is distinctly set off from platform), and *I. lobatus* Gunnell 1933 ("stubbiness" and greater width of platform). Because of this broad definition, the name *I. delicatus* has been applied to a wide range of lobed morphotypes ranging in age from Morrowan to Virgilian. The *Idiognathodus* fauna of the type level, the Mine Creek Shale and its equivalents (Joe Shale and basal Coal City Limestone), has not been described in detail, and for now it is not possible to give a good diagnosis for *I. delicatus* or *I. claviformis*. Swade (1985) illustrated some specimens from the immediately underlying Anna Shale in Iowa, and his specimens of *Idiognathodus* sp. 1 from this level (fig. 18:19-20) appear to be reasonable examples of *I. delicatus*. Our working group has seen few specimens that appear to be close to the lectotype of *I. claviformis*.

A third species of *Idiognathodus*, ***I. arcuatus***, was erected by Gunnell (1931) for a large broken specimen, which although lanceolate in shape, is relatively wide compared to the platform length. The sole illustrated specimen of *I. arcuatus* (Gunnell, 1931, pl. 29, fig. 26) is the holotype, but it has been lost (Ellison, 1962, personal communication to Merrill, cited in Merrill, 1964). Ellison (1941) did not mention this species in his revision of Gunnell's work. Fay (1952, p. 112) suggested a comparison with *I. claviformis*; Merrill (1964) compared it favorably with his concept of *I. magnificus*, but was reluctant to use the name without further study of the type level. Other workers have either not used the name *I. arcuatus* or included it in synonymies. We believe that it may an example of *I. delicatus*, if not a distinct third species occurring in this fauna.

Some conodont workers have chosen to view evolution within *Idiognathodus* as occurring at a slow rate, resulting in only a few species per age or epoch. Baesemann (1973) reduced the myriad of species names of *Idiognathodus* and the related genus *Streptognathodus* to two names: *I delicatus* Gunnell 1931 (forms with a flat upper surface and transverse ridges) and *I. elegantulus* (Stauffer and Plummer 1932) (forms with a distinct medial trough). In using *I. delicatus*, Baesemann (1973, p. 699) listed *I. claviformis* as a synonym of *I. delicatus*. Consequently, if these two morphotypes are considered by later workers to be the same species, then *I. delicatus* is the correct name (First Reviser Principle). Grayson and others (1990, p. 373) thus incorrectly used the name *I. claviformis*, with *I. delicatus* as a synonym, when they grouped Desmoinesian examples of *Idiognathodus* into a single species. (For a comparable example where the name of a type species is different from the species name of the species originally chosen as the type species, see the case of *Ozarkodina confluens* (Branson and Mehl), as discussed by Klapper and Philip, 1971).

STAUFFER AND PLUMMER (1932)

Idiognathodus antiquus n. sp. (Figure 2:4)
I. expansus n. sp. (Figure 2:2,3)
I. magnificus n. sp. (Figure 3:2-4)
Streptognathodus n. gen.
S. excelsus n. sp. (type species) (Figure 3:1)
S. elegantulus n. sp. (Figure 4:3,4)
S. gracilis n. sp. (Figure 2:1)
S. increbescens n. sp. (Figure 4:1,2)

Stauffer and Plummer (1932) named several new species and genera based on material from four localities that represent at least three different stratigraphic levels in the upper Desmoinesian to Missourian succession of north-central Texas. Merrill, Grayson and Mosley (1987) gave a thorough discussion of the localities, the stratigraphic levels of the collections, and their interpretation of the conodont fauna.

Stauffer and Plummer (1932) erected ***Idiognathodus antiquus*** based on material from the latest Desmoinesian East Mountain Formation at Mineral Wells, Texas (Merrill, Grayson, and Mosley, 1987; Barrick and Boardman, 1989). The sole illustrated specimen (pl. 4, fig. 17) was designated as the holotype (Fig. 2:4). The original major diagnostic feature of *I. antiquus* was the presence of an accessory lobe on only one side of the platform. Ellison (1941) retained this species, again emphasizing the presence of only a single lobe as the diagnostic character, and many subsequent authors have used the name in the same sense. Merrill, Grayson, and Mosley (1987) noted that the holotype of *I. antiquus* is badly corroded, and suggested that the holotype may represent the same biological species as *I. expansus*, the holotype of which occurs in the same bed. Our examination of the holotype of *I. antiquus* indicates that it possesses a nodose outer anterior margin that may be interpreted as a weakly developed lobe, identical with that found in *I. expansus*. Therefore, we consider *I. antiquus* to be a synonym of *I. expansus*, and choose to use the name *I. expansus* to designate the species. In removing the name *I. antiquus* from use, we also remove the incorrect morphological interpretation of the holotype (presence of only a single lobe). Other names will need to be provided to designate species of *Idiognathodus* in which the Pa element only possesses a single lobe (e.g., *I. antiquus* as used by von Bitter, 1972).

Stauffer and Plummer (1932) erected the species ***Idiognathodus expansus*** based on material also from the latest Desmoinesian East Mountain Formation at Mineral Wells, Texas. The authors designated the two illustrated specimens (pl. 4, fig. 1, 3) from the level as co-types. It is not clear how the authors considered *I. expansus* to differ from the similar species, *I. delicatus* Gunnell 1931, which they list as occurring at the same level. Ellison (1941) did not include *I. expansus* in his revision of Pennsylvanian conodonts, and the name has been used rarely. Merrill, Grayson, and Mosley (1987) suggested that *I. expansus* may be a synonym of *I. delicatus*, from which *I. expansus* appears to differ little in age and morphology. Barrick, Boardman, and Heckel (1996) began using the name to designate latest Desmoinesian *Idiognathodus* Pa elements that are characterized mainly by continuous transverse

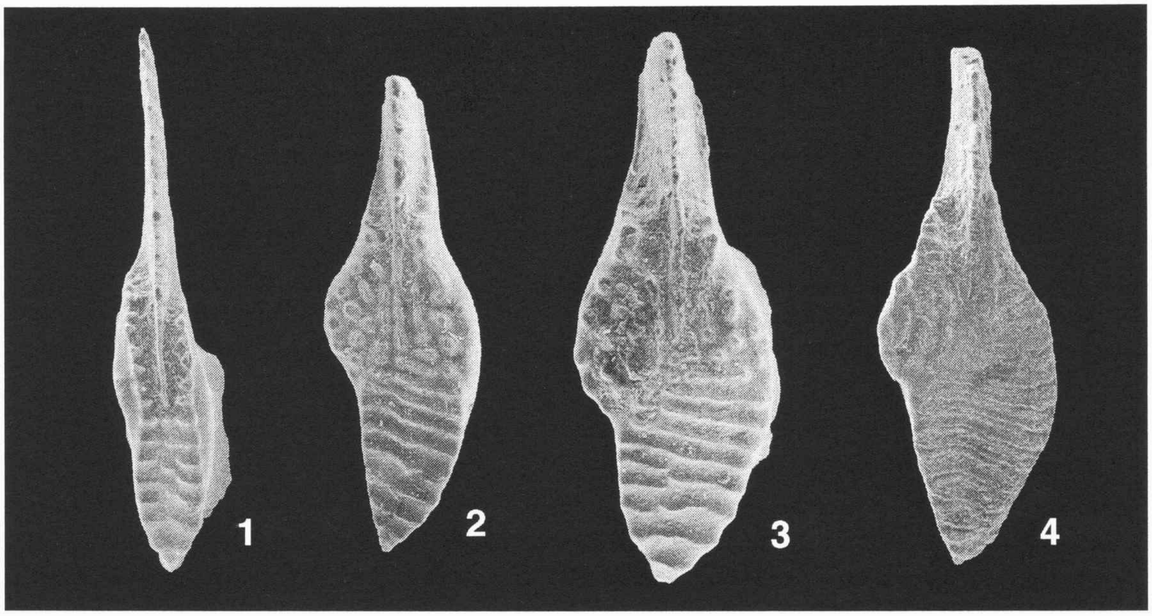

Fig. 2: Types of Stauffer and Plummer (1932). 1 - *Streptognathodus gracilis,* holotype, BEG 19169, 68X (Stauffer and Plummer, 1932, p. 48-49, pl. 4, fig. 12). 2, 3 - *Idiognathodus expansus,* cotypes, BEG 19163, 58X; BEG 20928, designated here as the lectotype, 60X (Stauffer and Plummer, 1932, p. 46, pl. 4, fig. 1, 3). 4 - *Idiognathodus antiquus,* holotype, BEG 19160, 50X (Stauffer and Plummer, 1932, p. 44-45, pl. 4, fig. 17).

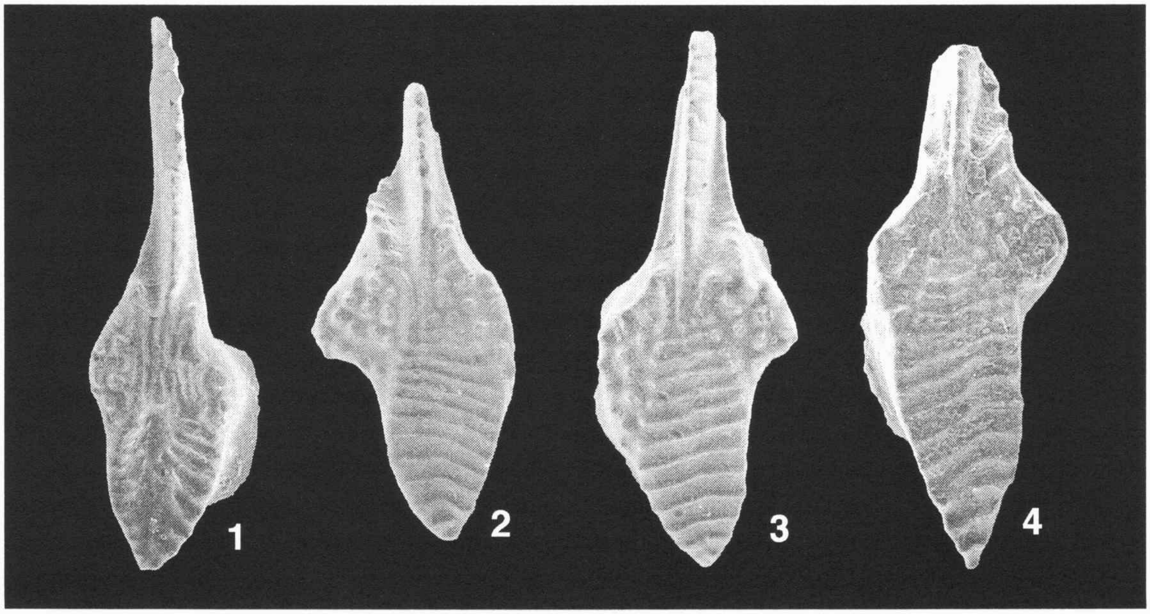

Fig. 3: Types of Stauffer and Plummer (1932). 1 - *Streptognathodus excelsus,* holotype, BEG 19168, 38X (Stauffer and Plummer, 1932, p. 48, pl. 4, fig. 2, 5). 2, 3, 4 - *Idiognathodus magnificus*, cotypes, BEG 19164, here designated as the lectotype, 48X; BEG 20926, 52X; BEG 20927, 52X (Stauffer and Plummer, 1932, p. 46-47, pl. 4, fig. 18-20).

ridges on the upper surface, and a reduced to shoulder-like outer lobe. However, they could not provide a clear distinction between this species and *I. delicatus*, because *I. delicatus* had not been fully characterized. This situation is still true, and we continue to use *I. expansus* in the same manner. Here, we choose one of the two cotypes to be the lectotype, BEG 20928 (Fig. 2:3; Stauffer and Plummer, 1932, pl. 4, fig. 3). This is the larger of the two cotypes, and the photograph shown here is the first published illustration of the upper surface of this specimen.

Stauffer and Plummer (1932) erected the species ***Idiognathodus magnificus*** to include large platforms with a prominent accessory lobe that they obtained from the shale member PP3 of the Posideon Formation, mid-Missourian in age, near the abandoned railroad stop of Wiles, in Stephens County, Texas (Merrill, Grayson, and Mosley, 1987). Three cotypes were originally designated. Ellison (1941, p. 135) did not include one of the cotypes in his synonymy for the species (BEG 20926; Stauffer and Plummer, 1932, pl. 4, fig 19), which he transferred to *I. delicatus.* Apparently no lectotype was designated, so here we choose BEG 19164 (Fig. 3:2; Stauffer and Plummer, 1932, pl. 4, fig. 18; Figure 1) to be the lectotype. Stauffer and Plummer (1932) were able to distinguish I. *magnificus* from the co-occurring *I. delicatus* and *I. expansus* by its larger size and more prominent lobes. Ellison (1941) indicated that *I. magnificus* differs from *I. delicatus* because the latter species is smaller, more slender, and bears lobes that are more clearly set off from the main part of the platform. Subsequent workers have struggled with the distinction between these two, with the result that generally larger forms with large accessory lobes have been assigned to *I. magnificus*, regardless of their age. Barrick and Boardman (1989) attempted to restrict *I. magnificus* to slender morphotypes with a large protruding lobe that characterize the PP3 shale member. Heckel (1989) used a similar concept of the species with identical forms from the mid-Missourian Quivira Shale in Kansas. Additional study of mid-Missourian forms of *Idiognathodus* will be required to prepare a more clear and useful diagnosis. Grayson and others (1990) combined all Missourian examples of *Idiognathodus* and *Streptognathodus* into a single species, to which they applied the name of *I. magnificus*.

The genus ***Streptognathodus*** was erected by Stauffer and Plummer (1932) for those Pa elements similar to *Idiognathodus*, but possessing a deep medial furrow on the upper surface. Most workers have followed this usage, but have uncritically included many species that we believe are unrelated to the type material (see Barrick, Boardman, and Heckel, this guidebook). The type species was designated as *S. excelsus*, which was obtained from shales at the now abandoned pit at a brick plant in Bridgeport, Wise County, Texas, that are assigned to the mid-Missourian Wolf Mountain Shale at the base of the Graford Formation (Merrill, Grayson, and Mosley, 1987). ***Streptognathodus excelsus*** was distinguished from other species of *Streptognathodus* by the "shelf-like extensions" bearing nodes on both sides of the platform. Ellison (1941) more clearly stated that the presence of accessory lobes on both sides and a "true medial trough" distinguished *S. excelsus* from other species. He also noted that the holotype of *S. excelsus* was a "senile specimen" in which the trough had shallowed.

It is not clear how Stauffer and Plummer (1932) distinguished their new species ***S. increbescens***, which is also based on specimens from the Bridgeport brick plant, from *S. excelsus.* Comparison of the original descriptions of these species suggest that *S. increbescens* possesses a more slender outline and less-well developed accessory lobes than *S. excelsus*. Two cotypes were originally selected. Here, we choose BEG 20949 (Fig. 4:1; Stauffer and Plummer, 1932, pl. 4, fig. 16), the larger of the two cotypes, to be the lectotype. Ellison (1941) synonymized *S. increbescens* under *S. excelsus*, as have all subsequent workers.

Stauffer and Plummer (1932) erected the species ***Streptognathodus elegantulus*** for deeply troughed Pa elements from the Bridgeport brick pit that lacked accessory lobes, a diagnosis that Ellison (1941) retained and subsequent workers have followed. The holotype is relatively small. When Baesemann (1973) combined all representatives of *Streptognathodus* into a single species of *Idiognathodus*, he chose e*legantulus* as the trivial name. Because of his action, *S. elegantulus* becomes the appropriate name whenever Stauffer and Plummer's *Streptognathodus* species are placed in a single species.

Streptognathodus gracilis was erected to include troughed Pa elements that possess only a single node on one or both sides of the platform (Stauffer and Plummer, 1932). In contrast to the other *Streptognathodus* species, the holotype was collected from the shale member PP3 of the Posideon Formation near the abandoned railroad stop of Wiles, in Stephens County, Texas. The PP3 shale member lies one major eustatic cycle lower than the Wolf Mountain Shale (Boardman and Heckel, 1989). The holotype is a small specimen (Fig. 2:1). Ellison (1941) modified the concept of the species to include platforms that possess a variable number of nodes on one accessory lobe. Barrick and Boardman (1989) restricted the definition of *S. gracilis* to comprise only those forms that possess a single node on the inner side, and assigned elements with a few nodes on one side *to S. corrugatus* Gunnell 1933 (see below).

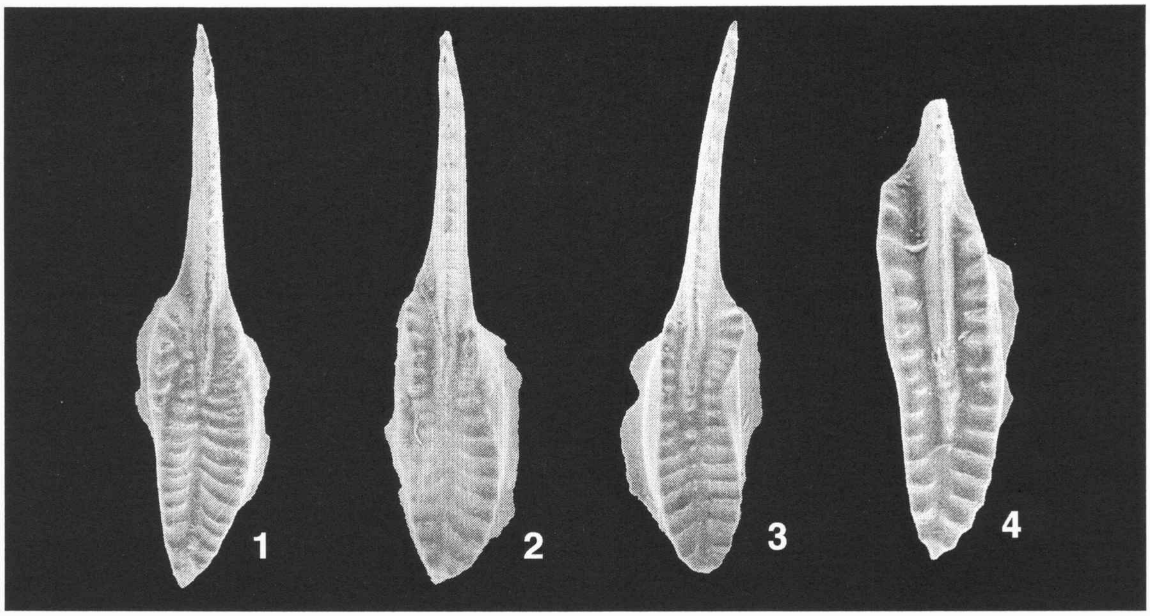

Fig. 4: Types of Stauffer and Plummer (1932). 1, 2 - *Streptognathodus increbescens,* cotypes, BEG 20949, here designated as the lectotype, 45X; BEG 19171, 55X (Stauffer and Plummer, 1932, p. 49, pl. 4, fig. 9, 16). 3, 4 - *Streptognathodus elegantulus*, holotype, BEG 19166, 52X; paratype, BEG 20938, 100X (Stauffer and Plummer, 1932, p. 47-48, pl. 4, fig. 6, 7, 22).

HARRIS AND HOLLINGSWORTH (1933, MARCH)

Idiognathodus pustulata n. sp. (Figure 1:3)
Polygnathus pawhuskaensis n. sp. (Figure 1:4)

Harris and Hollingsworth (1933) erected the species ***Idiognathodus pustulata*** based on material from the Boggy Formation, in Coal County, Oklahoma. We do not know the precise location of the type locality nor its stratigraphic position within the Boggy Formation. The Boggy Formation lies in the middle of the Cherokee Group, and is early Desmoinesian in age according to Boardman and others (1994, fig. 2), who recognize at least three major marine intervals in the Boggy Formation. It would be useful if the collection of Harris and Hollingsworth could be assigned to one of these levels, but regardless of its exact position, the level from which *I. pustulata* was obtained appears to be older by at least five major eustatic cycles than the level of the type of *I. delicatus*. The holotype of *I. pustulata* is the sole illustrated specimen (fig. 1:11). Note that the anterior part of the platform, the adcarinal groove, and the blade are missing (Fig. 1:3). Harris and Hollingsworth (1933) stated that this species differed from previously described ones in its greater number of transverse and longitudinal ridges, as well as its bulging accessory lobe with nodes arranged in curved rows. This comparison appears appropriate if the type of *I. delicatus* is considered, for the holotype of *I. delicatus* is a small specimen with weakly developed lobes. Harris and Hollingsworth (1933) may not have been aware of the work of Stauffer and Plummer (1932) when they prepared their paper, for it is not cited. Ellison (1941) placed *I. pustulata* in synonymy with the Missourian species *I. magnificus*, probably on the basis of the large lobe. We doubt that *I. pustulata* is conspecific with *I. magnificus* because of the long interval of time that separates the two species. It is more likely conspecific with *I. delicatus* or *I. amplificus* Lambert 1992, if it is not a distinct species.

Harris and Hollingsworth (1933) erected the species ***Polygnathus pawhuskaensis*** based on material from the Virgilian Larsh-Burroak Shale of the Deer Creek Formation of the Shawnee Group, west of Pawhuska, Osage County, Oklahoma (Ritter, 1994). The holotype was the only specimen illustrated (pl. 1, fig. 12a,b. Ellison (1941) considered the species to be a junior synonym of *Streptognathodus elegantulus* (Stauffer and Plummer, 1932). Ritter (1994) has recently reinstated ***S. pawhuskaensis*** as a valid species and discussed how it differs from *S. elegantulus*; he also illustrated a topotype (fig. 5:1) and gave an exact location for the type locality.

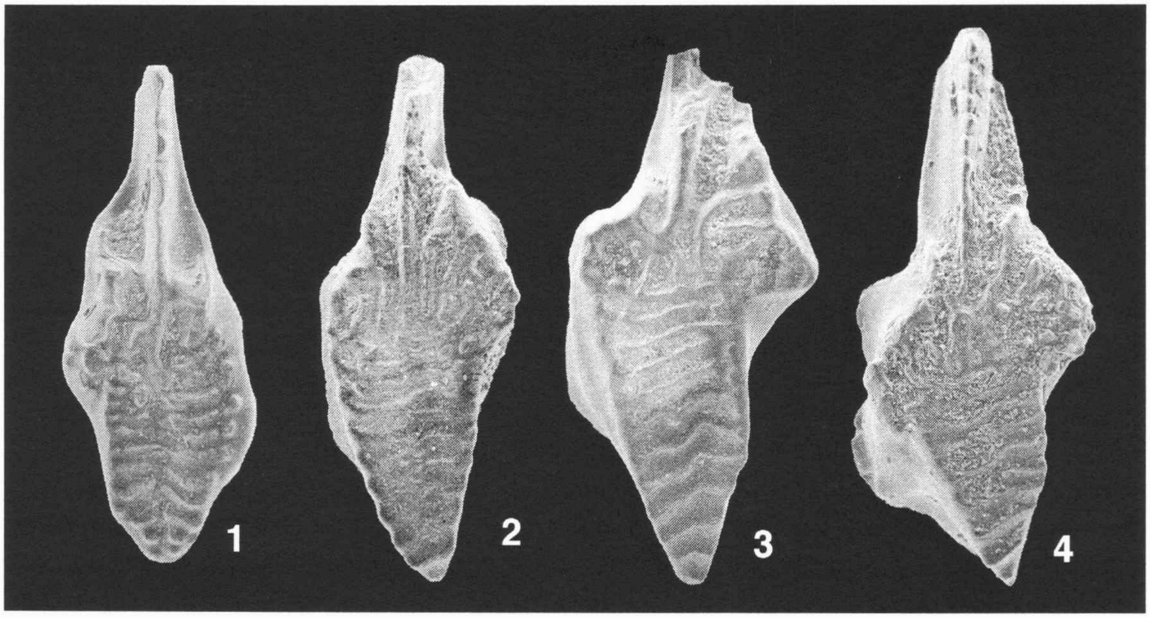

Fig. 5: Holotypes of Gunnell (1933). 1 - *Streptognathodus clavatulus,* UM 491-1, 53X (Gunnell, 1933, p. 280, pl. 31, fig. 9). 2 - *Idiognathodus cuneiformis*, UM 490-5, 48X (Gunnel, 1933, p. 270, pl. 31, fig. 8). 3 - *Idiognathodus harkeyi,* UM 491-3, 50X (Gunnell, 1933, p. 270, pl. 31, fig. 11). 4 - *Idiognathodus clavatus,* UM 493-2, 48X (Gunnell, 1933, p. 271-272, pl. 31, fig. 19).

GUNNELL (1933, SEPTEMBER)

Gunnell (1933) named 80 new species in his paper on Pennsylvanian conodonts, of which 44 were assigned to *Idiognathodus* and 22 to *Streptognathodus*. In revising these genera, Ellison (1941) reduced the number of species to 7 in *Idiognathodus* and 10 in *Streptognathodus*, including the five new species that he erected. In so doing, most of Gunnell's names became synonyms of older taxa. Because recent revisions of *Idiognathodus* and *Streptognathodus* are again increasing the number of species by splitting Ellison's groups, Gunnell's names must be considered before new names are erected. Here we discuss the one Desmoinesian species, forms that have been included in the recent revision of early Missourian conodonts by Barrick, Boardman, and Heckel (1996; this volume), and a Missourian name that Ellison (1941) retained. We should note that several of Gunnell's types are now either missing or destroyed, which will make redescription of some species difficult to impossible.

Desmoinesian

Idiognathodus fustiformis n. sp. (holotype lost)

Gunnell (1933) erected ***Idiognathodus fustiformis*** from the Anna Shale Member of the Pawnee Limestone near Lexington, Missouri, just below the level from which species described in Gunnell (1931) were obtained (see Heckel, 'Overview' article in this guidebook). Gunnell (1933) placed this locality in the lower Desmoinesian Cherokee Group, but Ellison (1941, p. 140, Loc. 1266) correctly reassigned it to the upper Desmoinesian Marmaton Group. Although Ellison (1941), Youngquist and Heezen (1948), and subsequent authors have considered *I. fustiformis* to be a junior synonym of *I. claviformis*, the illustration of the sole specimen (pl. 31, fig. 7), the holotype of *I. fustiformis* (now lost), resembles that of *I.* sp. 3 of Swade (1985, fig 18-22, 18-29) more than either resembles the holotype of *I. claviformis* Gunnell 1931 (Fig. 1-2). Therefore it is possible that *I. fustiformis* is a valid species awaiting restudy of the Anna and Mine Creek Shales at Lexington, Missouri.

Missourian: Hushpuckney Shale (Swope Formation):

Idiognathodus sulciferus n. sp. (Figure 6:1)
I. siculus n. sp. (Figure 6:2)
I. harkeyi n. sp. (Figure 5:3)
I. cuneiformis n. sp. (Figure 5:2)
I. porcatus n. sp. (Figure 6:3)
I. clavatus n. sp. (Figure 5:4)

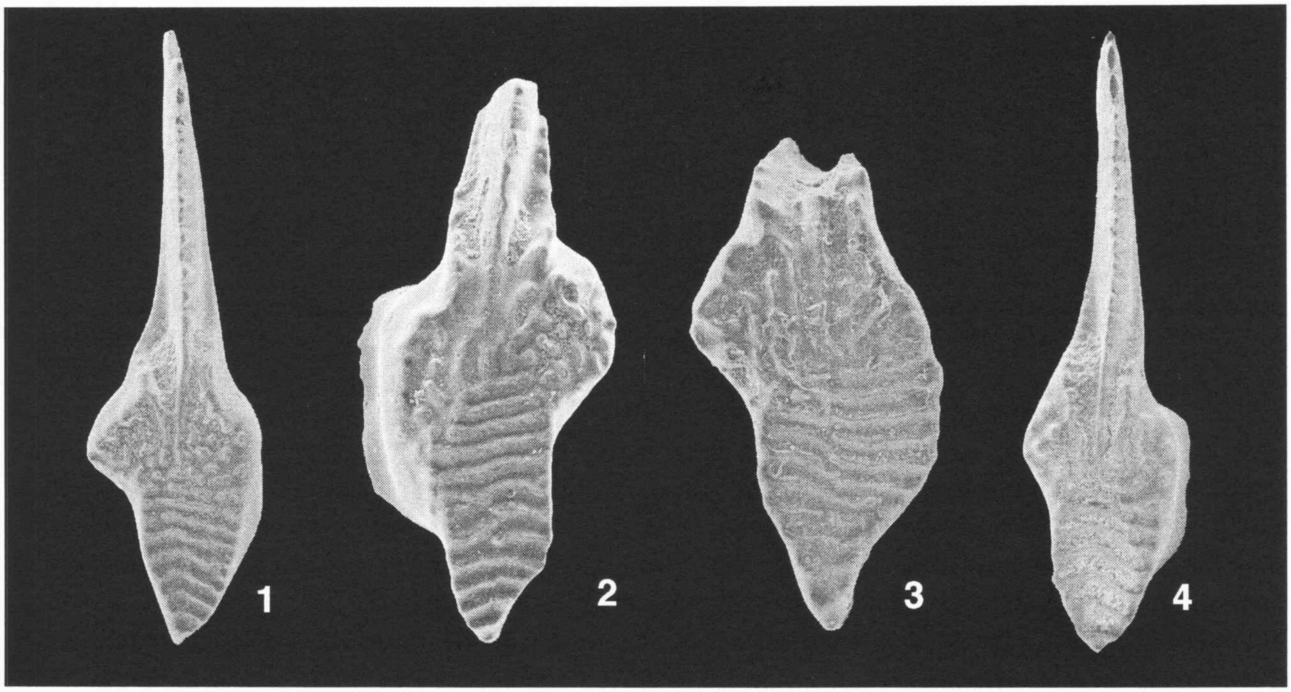

Fig. 6: Holotypes of Gunnell (1933). 1 - *Idiognathodus sulciferus,* UM 492-4, 40X (Gunnell, 1933, p. 271, pl. 31, fig. 16). 2 - *Idiognathodus siculus,* UM 492-2, 52X (Gunnell, 1933, p. 271, pl. 31, fig. 14). 3 - *Idiognathodus porcatus,* UM 493-4, 52X (Gunnell, 1933, p. 272, pl. 31, fig. 21). 4 - *Idiognathodus lobatus,* UM 492-5, 48X (Gunnell, 1933, p. 271, pl. 31, fig. 17).

I. lobatus n. sp. (Figure 6:4)
I. modulatus n. sp. (holotype lost)
I. chiriformis n. sp. (holotype lost)
I. ruidus n. sp. (holotype lost)
I. biconvexus n. sp. (holotype lost)
I. liratus n. sp. (holotype lost)
I. cancellosus n. sp. (Figure 7:3)
I. jugosus n. sp. (Figure 7:2)
I. nodostriatus n. sp. (Figure 7:1)
I. rugulatus n. sp. (holotype lost)
Streptognathodus clavatulus n. sp. (Figure 5:1)

The lowest Missourian level from which Gunnell (1933) selected types is the Hushpuckney Shale Member of the Swope Formation in the Kansas City Group from outcrops in the Kansas City area; (this level was denoted by him as 'basal Galesburg shale' or 'below Stark shale' before the nomenclature of these units was stabilized by Moore, 1936). Seventeen species came from this level, each illustrated by a single specimen, the holotype. The specimens of *Idiognathodus sulciferus* (pl. 31, fig. 16), *I. siculus* (pl. 31, 14), *I. harkeyi* (pl. 31, fig. 11), *I. cuneiformis* (pl. 31, fig. 8), *I. porcatus* (pl. 31, fig. 21), *I. clavatus* (pl. 31, fig. 9) are all illustrated on Figures 5 and 6. These [and *I. modulatus* (pl. 31, fig. 15), *I. chiriformis* (pl. 31, fig. 23), *I. ruidus*, (pl. 31, fig. 25), *I. biconvexus* (pl. 31, fig. 26); and *I. liratus* (pl. 31, fig. 27), for which the types are lost] are all forms that display the generalized *Idiognathodus* Pa morphology, in which the flat upper surface bears continuous transverse ridges and a pair of accessory lobes with numerous nodes to short ridges. Ellison (1941) combined all of these species with either *I. delicatus* or *I. magnificus.* Barrick and Boardman (1989) and Boardman, et al. (1990) originally used the name *I. lobatus* Gunnell, 1933, to designate the generalized *Idiognathodus* morphotype of Heckel's (1989) "nodose *Idiognathodus*" group that characterizes lower Missourian marine beds in the Midcontinent region, but did not construct a synonymy. Later, Barrick, Boardman and Heckel (1996) began using an alternative name, ***I. sulciferus*** to designate this morphology, because the type of *I. sulciferus* fit most closely their concept of the species (see below). Here we formally choose *I. sulciferus* as the name that we apply to early Missourian Pa elements of the "nodose *Idiognathodus*" group that lack the additional features found in other coeval species of the group (see below). We place the other names given in the list above in synonymy, but recognize that further studies of these

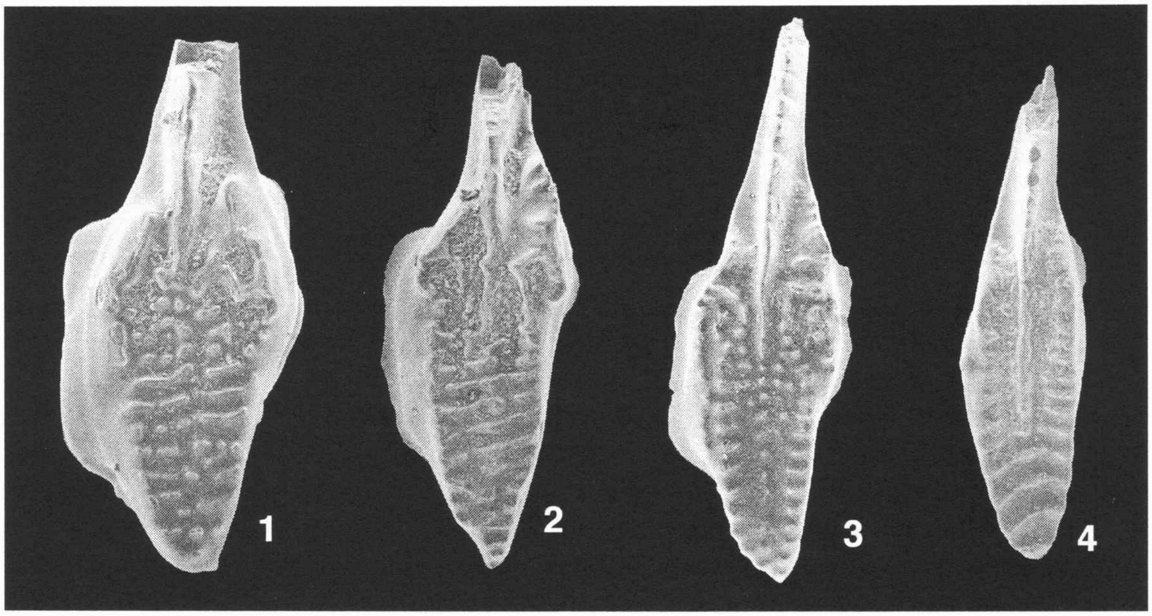

Fig. 7: Holotypes of Gunnell (1933). 1 - *Idiognathodus nodostriatus,* UM 493-3, 52X (Gunnell, 1933, p. 272, pl. 31, fig. 20). 2 - *Idiognathodus jugosus,* UM 491-5, 52X (Gunnell, 1933, p. 270-271, pl. 31, fig. 13). 3 - *Idiognathodus cancellosus,* UM 491-2, 52X (Gunnell, 1933, p. 270, pl. 31, fig. 10). 4 - *Idiognathodus confragus,* UM 498-1, 67X (Gunnell, 1933, p. 275, pl. 31, fig. 43).

forms may show that more than one species have been included. The species *Idiognathodus nodostriatus* Gunnell, 1933 (pl. 31, fig. 20; Fig. 7:1) does not easily fit into *I. sulciferus*, and we retain it as a separate species for now.

Gunnell (1933) distinguished *Streptognathodus clavatulus* from other taxa from lower Missourian strata by the presence of a longitudinal trough on the upper surface of the platform (pl. 31, fig. 9; Fig. 5:1). Ellison (1941) listed *S. clavatulus* as a synonym of *S. excelsus,* probably because it was a troughed form with two accessory lobes. Barrick and Boardman (1989), Boardman et al. (1990 [misspelled as *I. clavulatus*]), and Barrick, Boardman and Heckel (1996) used ***I. clavatulus*** to designate the troughed morphotype of the "nodose *Idiognathodus* " group. However, because their evolutionary model has the clade that represents *Streptognathodus* arising from other species later in time, they transferred the species to *Idiognathodus*. Gunnell (1933, pl. 31, fig. 17, 18) based the species *I. lobatus* on a pair of specimens, which could be distinguished from *I. sulciferus* by the lenticular outline around the transverse ridges. No holotype was designated by Gunnell, but Ellison (1941) indicates that UM 492-5 (Gunnell, 1933, pl. 31, fig. 17) is the holotype (Fig. 6:4). Ellison (1941) retained the species *Idiognathodus lobatus* and characterized it as having a short platform and blunt posterior end, noting that the ornamentation on the upper surface could be variable, but that transverse ridges are typically complete from one margin to the other. Inspection of the holotype indicates that *I. lobatus* possesses a distinct trough, identical with that of *I. clavatulus,* and we consider it to be a synonym of *I. clavatulus*.

Gunnell's (1933) species name *Idiognathodus cancellosus* has received widespread use as ***Streptognathodus cancellosus*** since the revision of Ellison (1941). The original description by Gunnell (1933, p. 270) emphasized that an important feature of the species is the medial longitudinal row of nodes on the upper surface that extends to near the end of the platform (pl. 31, fig. 10; Fig. 7:3). Ellison (1941, p. 131-132, and especially by his illustrated specimens, pl. 22, fig. 23, 26) modified the range of morphology of the species to include forms with two accessory lobes, with six to 18 transverse ridges cut only by a narrow medial trough. The presence of a narrow trough cutting the posterior transverse ridges was the primary way by which *S. cancellosus* could be distinguished from *I. delicatus* and *I. magnificus*, according to Ellison. The name *S. cancellosus* has been used by many workers since Ellison in this manner (e.g., Brown et al., 1991). Unfortunately, the new diagnosis of Ellison and subsequent workers effectively excludes the morphology of the holotype of Gunnell (1933). A possible source of this problem is the misleading illustration of Gunnell. His illustration minimizes the size of the medial trough and exaggerates the length of the transverse ridges, as well as the number of nodes appearing to form lobes on the upper surface. However, it does clearly show that the carina extends to near the end of the platform as a series of nodes. Barrick and Boardman (1989, p. 174, pl. 1, figs. 11, 12, 18), Boardman et al. (1990), and Barrick, Boardman, and Heckel (1996, p. 169) have restricted the use of the name *Streptognathodus cancellosus* to forms that more closely resemble the holotype. We do not consider the specimens that Ellison (1941) illustrated to be examples *of S. cancellosus*. Instead, we consider one of the specimens illustrated by Ellison (1941, pl. 22, fig. 14) as an example of *S. oppletus* from the Hushpuckney Shale (Swope Formation) to be a typical example of *S. cancellosus*. The Gunnell (1933) species *I. rugulatus* (pl. 31, fig. 24; type lost) also appears to be an example of *S. cancellosus*, and is here considered to be a synonym of that species.

The species ***Idiognathodus jugosus*** (Gunnell, 1933, pl. 31, fig. 13; Fig. 7:2) differs from the other *Idiognathodus* species by possessing a carina, a narrow outline, reduced lobes, and high margins around the platform. It resembles to some degree *S. cancellosus*, but lacks the long carina. *Idiognathodus jugosus* looks more like *Streptognathodus confragus* from the overlying cycle (see below), but retains more of the typical *Idiognathodus* morphology than does *S. confragus*. For now, we retain *I. jugosus* as a separate species.

Missourian: Stark Shale and Winterset Limestone (Dennis Formation):

Idiognathodus confragus n. sp. (Figure 7:4)

Gunnell (1933) named sixteen new species of *Idiognathodus* based on material from members of the lower Missourian Dennis Formation of the Kansas City Group in the Kansas City area. The *Idiognathodus/ Streptognathodus* fauna of the Dennis is complicated because it represents the level at which major transformations in these genera occur. During this time, species of *Idiognathodus* lost many of the features characteristic of the older "nodose *Idiognathodus*" group, and forms that resemble middle to late Missourian species like *I. magnificus* appear. The distinct troughed morphology of typical *Streptognathodus* is not yet fully developed, but transitional forms are present. Until detailed study is made of the Dennis *Idiognathodus/Streptognathodus* fauna, it will not be possible to resolve the taxonomic position of many of the species named by Gunnell from this interval.

In their model of the early Missourian evolution of *Streptognathodus* from an ancestor in the "nodose *Idiognathodus*" group, Barrick and Boardman (1989) and Barrick, Boardman and Heckel (1996) used the Gunnell species *I. confragus* (as ***Streptognathodus confragus***) to designate a form transitional to typical species of *Streptognathodus*. Gunnell (1933) indicated that the presence of continuous transverse ridges posterior of the carina and a lobe reduced to a single denticle are the distinguishing features of this species (Fig. 7:4). These are also the features that Barrick and Boardman (1989, 174-176) consider to be diagnostic of the species. Ellison (1941) did not include *I. confragus* in his revision of Pennsylvanian conodonts, nor have subsequent workers used this name.

Missourian: Cherryvale Formation:

Streptognathodus sulcatus n. sp. (Fig. 8:2)
S. corrugatus n. sp. (Fig. 8:1)

Gunnell (1933) named 16 species *of Idiognathodus* and *Streptognathodus* from the middle Missourian Cherryvale Formation of the Kansas City Group in the Kansas City area. In his original description of ***S. sulcatus***, it is not clear what the diagnostic features of the species are (Fig. 8:2). In comparison with another new species from this level, *S. multinodosus*, Gunnell (p. 280-281) indicated that *S. sulcatus* differs by lacking the nodose, well-developed lobe of *S. multinodosus*. Ellison (1941) retained the name *S. sulcatus*, and gave the species a modified diagnosis, in which he emphasized that the short platform and rounded posterior margin distinguished this species from other species of *Streptognathodus*. Subsequent workers have not used the name *S. sulcatus*, and evaluation of the species awaits a modern revision of Missourian species of *Streptognathodus*.

Gunnell (1933) erected the species ***Streptognathodus corrugatus*** for a slightly curved *Streptognathodus* Pa element with two or three nodes on the inner side (Fig. 8:1). Ellison (1941) included this species under the name *S. gracilis*, which he restricted to include elements that possess only a single lobe, but expanded to include elements with more than one node on the single lobe. Barrick and Boardman (1989) restricted the definition of *S. gracilis* to only those forms with a single node, and applied the name *S. corrugatus* to elements with a single lobe bearing a small number of nodes. Ritter (1995) has used *S. corrugatus* in the same way.

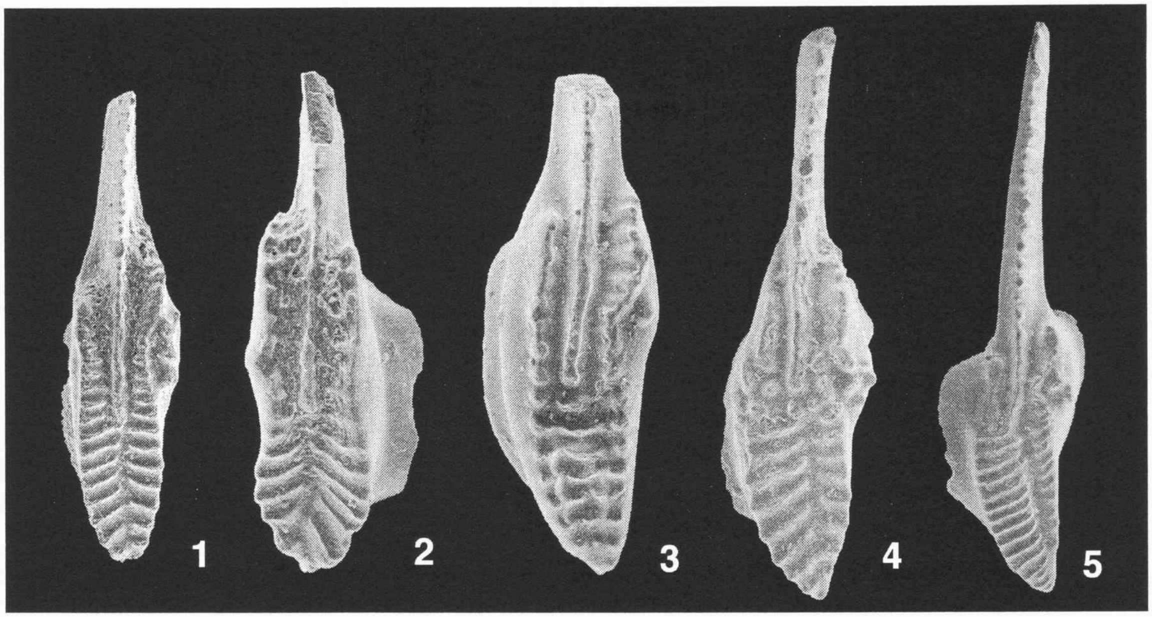

Fig. 8: Holotypes of Gunnell (1933) and Ellison (1941). 1 - *Streptognathodus corrugatus* Gunnell, 1933, UM 506-1, 70X (Gunnell, 1933, p. 281, pl. 32, fig. 13). 2 - *Streptognathodus sulcatus* Gunnell, 1933, UM 505-3, 80X (Gunnell, 1933, p. 280, pl. 32, fig. 10). 3 - *Streptognathodus oppletus* Ellison, 1941, UM 515-3, 80X (Ellison, 1941, p. 132, pl. 22, fig. 13). 4 - *Streptognathodus eccentricus* Ellison, 1941, UM 560-1, 52X (Ellison, 1941, p. 132-133, pl. 22, fig. 24). 5 - *Streptognathodus simulator* Ellison, 1941, UM 257-5, 38X (Ellison, 1941, p. 133, pl. 22, fig. 25).

ELLISON (1941)

Idiognathodus acutus n. sp. (no photo)
I. tersus n. sp. (holotype lost)
Streptognathodus oppletus n. sp. (Figure 8.3)
S. simulator n. sp. (Figure 8.5)
S. eccentricus n. sp. (Figure 8.4)

Ellison's (1941) revision of the Pennsylvanian conodonts grouped many of Gunnell's (1933) species into a much smaller number of species, as explained in the discussion above. In addition, he named five new species of *Idiognathodus* from collections ranging in age from Desmoinesian to Virgilian.

Ellison (1941) erected the species ***Idiognathodus acutus*** based on material from the top of the lower Desmoinesian Cherokee Group (Excello Shale, now basal Marmaton), near Harrisburg, Missouri. This is three cycles below the level from which Gunnell (1931) described the first species of *Idiognathodus.* Ellison (1941) indicated that the elongate platform with an acutely pointed posterior end was diagnostic of the species (pl. 23, fig. 21, 24). The name *I. acutus* has rarely, if ever, been used in the literature, but it resembles *I.* sp. 2 of Swade (1985, fig. 18-21, 18-28) illustrated from the slightly younger Little Osage and Anna Shales. The *species I. amplificus* Lambert, 1992, based on material from the lower Cherokee Group in Iowa, shares many features in common with *I. acutus*, and if not conspecific, it may be closely related.

Ellison (1941) erected the species ***Idiognathodus tersus***, based on material from the lower Virgilian Heebner Shale Member of the Oread Limestone in the Shawnee Group, but for which the holotype is now lost. The primary diagnostic feature of the species is the complete lack of lobes on the platform (pl. 23, fig. 5). In his study of the conodonts of the Shawnee Group, von Bitter (1972) discussed the morphology of *I. tersus* in more detail. He noted that it is transitional with *Idiognathodus* Pa elements bearing a single lobe, which he assigned to *I. antiquus,* but he concluded that *I. tersus* and the single-lobed form were most likely separate species.

Ellison (1941) proposed the new species name ***Streptognathodus oppletus*** to replace the name *Idiognathodus multinodosus* Gunnell, 1933. Gunnell (1933) erected *I. multinodosus* based on material from the middle Missourian Quivira Shale Member of the Dewey Limestone in the Kansas City Group (pl. 33, fig. 5; Fig. 8.3). The original description of Gunnell (1933) indicated that the long carina (5/9 of platform length), the presence of four transverse ridges posterior to the carina, a small lobe bearing a single node, and a nodose upper surface were significant features of the species. Ellison (1941) emphasized that the long carina, the posterior area of transverse ridges, and the small lobe consisting of a single node were the diagnostic features of the species. However, he believed that the species best fit into the genus *Streptognathodus*, but did not justify this assignment. Because Gunnell (1933) had previously named a *Streptognathodus multinodosus*, the trivial name *multinodosus* could not be used, and so Ellison proposed the new name *oppletus*. The holotype of *S. oppletus* is the same specimen as the holotype of *I. multinodosus*. It is not clear whether this species should be best assigned to *Idiognathodus* or to *Streptognathodus* (note that if the species is returned to *Idiognathodus*, the name reverts to *multinodosus*). Only revision of the Quivira fauna, which contains a wide variety of *Idiognathodus* and *Streptognathodus* Pa morphotypes, will be able to resolve this. The name *S. oppletus* has been applied to a variety of Late Desmoinesian and Missourian Pa elements, all of which possess a relatively long carina that extends well onto the platform surface, posterior of which are transverse ridges. Smaller specimens of *Idiognathodus* and *Streptognathodus* Pa elements often possess a relatively long carina, which appears to be a juvenile character. Assignment of these smaller specimens to *S. oppletus* (e.g., Brown, et al., 1991) is probably unwarranted. Because the long carina seems to be a juvenile character, it is not surprising that this character may appear repeatedly through time, whenever paedomorphosis drives change in the morphology of the Pa element. This is probably the case with the small, long carinate forms that occur in the "nodose *Idiognathodus*" group in the early Missourian, species that we believe are distinct from the taxa that occur at the Quivira level (Barrick and Boardman, 1989).

Ellison (1941) erected the species ***Streptognathodus simulator*** for Pa elements that possess a small eccentric trough (offset to the inside of the medial line of the element) and a single lobe. These distinctive Pa elements are important and diagnostic constituents of late Missourian to early Virgilian conodont faunas (e.g., Heckel, 1989). The holotype (pl. 22, fig. 25; Fig. 8.5) comes from the Heebner Shale of the Oread Limestone of the middle Virgilian Shawnee Group. Von Bitter (1972) provided additional information about this species in the Virgilian. Barrick and Boardman (1989) indicated that the species does not belong in the genus *Streptognathodus,* because morphological features suggested that it had been derived from a Missourian species of *Idiognathodus*. Late Missourian to middle Virgilian Pa elements with an eccentric trough and a pair of lobes were also assigned to *I. simulator*, because the name *S. eccentricus* Ellison was not appropriate (see below).

Ellison (1941) erected the new species ***Streptognathodus eccentricus*** to include Pa elements that possess a small eccentric trough and lobes on both sides of the platform. From his description and remarks, it appears that Ellison proposed the species primarily for Pa elements that occur with *I. simulator* in the upper Missourian Eudora Shale and lower Virgilian Heebner Shale. However, the holotype he chose and the only illustrated specimen (pl. 22, fig. 24; Fig. 8:4) comes from the Hushpuckney Shale Member of the Swope Limestone, which is early Missourian in age. Barrick and Boardman (1989) and Barrick, Boardman, and Heckel (1996) have shown that the eccentric grooved Pa element of the Hushpuckney Shale (including the holotype of *S. eccentricus*) is a member of the early Missourian "nodose *Idiognathodus*" group, and is distinct from the late Missourian to early Virgilian eccentric Pa elements. For these reasons, they restrict the name *Idiognathodus eccentricus* (Ellison) to these early Missourian forms, and decline to use the name *S. eccentricus* for the two-lobed eccentric Pa elements that occur with *I. simulator*.

OLDER TYPES THAT HAVE NOT BEEN CONSIDERED HERE

As can be seen from the brief discussion of names and types above, considerable work remains to be done on North American conodont faunas before issues of taxonomy and nomenclature can be resolved. Here we have examined only a portion of the North American type material of species of *Idiognathodus* and *Streptognathodus*. Species proposed in several other publications still require study before all the older species names are covered.

Ellison and Graves (1941) named eight new conodont species from the upper Morrowan Dimple Limestone of west Texas, including one of *Idiognathodus* and two assigned to *Streptognathodus*, which have not been used subsequently. Youngquist and Heezen (1948) and Youngquist and Downs (1949) described 21 new species from Desmoinesian strata in Iowa, seven of *Idiognathodus* and five assigned to *Streptognathodus*. These names have not been used since their publication, other than in an abstract that summarizes their probable affinities (Lambert, 1993). Sturgeon and Youngquist (1949) named two more species of conodonts from Desmoinesian strata in Ohio, one of which is a species of *Idiognathodus*. More recently, Murray and Chronic

(1965) proposed ten new species from the Desmoinesian of Colorado, one of which is a new species of *Idiognathodus*.

The vast majority of Gunnell's (1933) species of *Idiognathodus* and *Streptognathodus* are Missourian in age, and extensive study of the morphologically diverse and complex Missourian conodont faunas in Midcontinent cyclothems will be needed to decide the disposition of his names. Few names have been proposed for species from Virgilian strata, and most are considered here. Ritter (1995) discussed the modern application of Gunnell's (1933) names to species of *Streptognathodus* that occur in the Pennsylvanian-Permian boundary interval.

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CONODONT TAXA PROPOSED BY JONES (1941) ARE VALID

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INTRODUCTION

In the process of attempting to unravel the morass of nomenclature surrounding older species names and holotypes of North American Pennsylvanian conodonts, we encountered one case where a publication that should be considered valid for nomenclatural purposes had been incorrectly excluded from the literature and subsequently ignored. Because the names proposed by Jones (1941) include some common and biostratigraphically significant latest Desmoinesian taxa, we here give the history of this work, justify its validity, and review the most important of the taxa named in it.

In 1941, the University of Chicago Libraries issued the publication "The Conodont Fauna of the Seminole Formation" by Daniel John Jones. The 1941 publication is a lithographic copy of Jones's 1938 dissertation (Jones, 1938). In the 1941 publication Jones formally named four new genera of conodonts, and 49 new species, most from bedding plane surfaces of a black shale interval in the Collinsville area of Oklahoma. In addition, he described 15 partial bedding plane assemblages. Although the bedding plane assemblages have attracted considerable interest and restudy (e.g., Merrill and von Bitter, 1977; Rhodes and Austin, 1981), Jones's new taxa have not been used since their publication.

Fay (1952, p. 33) included Jones (1941) in the *Catalogue of Conodonts*. He clearly distinguished the 1941 publication from the 1938 dissertation, and noted that the 1941 publication had been distributed to leading institutions in the United States. However, because it did not have a copyright in the front, Fay did not consider it to be published. Even though the 1938 dissertation was occasionally cited in reference to the bedding plane assemblages (DuBois, 1943; Rhodes, 1952), there was little mention of Jones's 1941 publication until the 1960s. Nitecki and Richardson (1967, p. 3) discussed the validity of Jones's names in their catalogue of conodont types in the Field Museum. They correctly noted that copyright is not a requisite of publication, and concluded that because copies of the paper had been circulated, it seemed best to consider it published, in accordance with Article 8 of the International Code of Zoological Nomenclature as adopted by the 15th International Congress of Zoology (1964).

Lane and Straka (1974) appear to have come to the same conclusion in their discussion of *Neognathodus,* for which Jones's *Bicarniodus* could be considered a senior synonym. They did not dispute whether the name *Bicarniodus* had been correctly published, but for reasons discussed below considered it to be a *nomen dubium*. In contrast, Merrill and von Bitter (1977) argued that Jones (1941) could not be considered a valid publication because "Jones had distributed only a few copies to libraries and other institutions and that the document was never available for sale or free distribution" (1977, p. 10).

The main question regarding the validity of Jones's (1941) names is whether the edition prepared by the University of Chicago Libraries is considered "published" according to the guidelines set forth in the Code of Zoological Nomenclature. The essential part of the argument is not the type of publication, but whether the document had been distributed in a sufficiently wide manner. One must note that the phrase that Merrill and von Bitter (1977) quote is from the 1964 edition of the International Code of Zoological Nomenclature, and a comparable phrase does not occur in earlier versions of the Code and Opinions rendered up through the 1940s (Schenk and McMasters, 1948), which would apply to Jones (1941).

The Jones (1941) paper was part of series of publications of dissertations prepared at the University of Chicago. One requirement for obtaining the Ph.D. degree at the University of Chicago in the Division of the Physical Sciences at this time was the "Publication, or provision for publication, of the dissertation, or the essential part thereof" (University of Chicago, General Regulations, 1937-1938, p. 22). It was common practice for the University of Chicago Libraries to publish and distribute the dissertations to a number of institutions in the United States and several foreign countries.

The number of copies of Jones (1941) printed and distributed is not available, but library documents covering previous years give some idea of the magnitude of the University of Chicago Libraries dissertation publication series. A 1922 rule stipulated that at least 100 copies had to be deposited in various libraries. A distribution list dating from 1929 includes 30 U.S. and Canadian universities, 40 foreign universities and museums (to be sent by way of the Smithsonian Institution), and 14 societies to which the publications of the series were to be sent (S. Taraba, 1994, written communication). Because of the interruption of regular delivery of all materials by the Second World War, it is unlikely that a 1941 publication received a wide foreign distribution. Jones's publication was probably sent out at least to domestic institutions on the list. Lane (1968, unpublished letter), determined that

Barrick, J. E., and Lambert, L. L., 1999, Condodont taxa proposed by Jones (1941) are valid; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 162–169.

copies of Jones's publication had reached the University of Iowa, Ohio State University, and the University of Illinois in May, 1941, and the University of Wisconsin in July, 1941. The number of copies of the Jones (1941) publication that now exist is unknown. A search of on-line library databases indicates that at least 19 U.S. libraries possess copies, in addition to two European libraries.

From this information we conclude that the paper of Jones (1941) did receive as wide a distribution as was possible at the time. Its presence in several libraries, easy accessibility today (it can be obtained from at least 13 of the U.S. libraries by interlibrary loan), and continuing citation argue for the fact that is has become a permanent part of the scientific literature. Even under the more restrictive conditions of the 1964 Code, we would consider it to be properly published. A general interpretation of the criterion of publication that we find appropriate is that given by Jeffrey (1989, p. 19): "Essentially the Codes require publication in works that are printed, reasonably permanent, and made generally available to the interested public." Jones's work certainly satisfies these conditions, as well as the other requirements of the Zoological Code and, therefore, his names are valid. The only paper proposing new taxa of Pennsylvanian conodonts near the time of publication of Jones's work is that of Ellison (1941). Lane (1968, unpublished letter), in consultation with W. C. Sweet, determined that Jones's work (1941, May) postdated that of Ellison (1941, March), giving Ellison (1941) priority.

Independent support for the validity of Jones's names comes from the case of another taxonomic paper published in the same series by the University of Chicago Libraries. In this instance, Smith (1938) named new taxa of ammonoids from the Pennsylvanian Buckhorn Asphalt Quarry. The authors of the Paleozoic portion of the Treatise volume on cephalopods (Miller, Furnish, and Schindewolf, 1957, p. L66), included Smith's generic name *Walkerites* as a junior synonym of *Wellerites* Plummer and Scott, 1937. This indicates that they, as well as other workers (e.g., Boardman et al., 1994) considered Smith (1938) to be a valid publication. As Smith (1938) has been accepted as a valid publication, there seems to be no reason to exclude another work published in the same series, that of Jones (1941).

THE COLLINSVILLE CONODONT FAUNA

The conodonts described by Jones (1941) all came from the same stratigraphic interval of black fissile shale that was exposed in a series of open pit coal mines around Collinsville, Oklahoma. Ammonoids from this stratigraphic interval in the Collinsville area had been described by Miller and Owen (1937) and were interpreted by these authors to be earliest Missourian in age. Subsequent work, incorporating both lithostratigraphic studies and biostratigraphic information, established that the Collinsville fissile black shale belongs to the uppermost Desmoinesian Nuyaka Creek black shale bed of the Lost Branch Formation (Heckel, 1991; see Boardman, Mapes, and Work,1989, for a summary).

In addition to describing 15 bedding plane assemblages, Jones (1941) named 4 new genera and 49 new species of conodonts from three localities in the Nuyaka Creek shale, most of which are probably junior synonyms of taxa named by Stauffer and Plummer (1932) and Gunnell (1933). Although a few of the types and illustrated species are isolated from the black shale matrix, most are still embedded in the shale.

Many of these new species are ramiform elements that most likely belong to apparatuses of *Idiognathodus, Neognathodus*, *Gondolella*, and *Idioprioniodus*. We believe that all of these names will prove to be junior synonyms of multielement taxa, but considerable work will be required to assign each to a species. The numerous typographic errors in the publication will also create some uncertainty in the revision of the fauna.

Three of the new genera are included here:

Bicornognathus n. gen.

B. freemani n. sp. (type species, Figure 1:3)

This appears to be the element of an *Idioprioniodus* species.

Euprioniodella n. genus

E. delicatissima n. sp. (type species, Figure1:2)

E.? robusta n. sp.

The holotype appears to be an element in a *Gondolella* species.

Oxygonus n. genus

O. multidentatus n. sp. (type species, Figure 1:1)

O. grossus n. sp.

The holotype appears to be the N element of a *Neognathodus* or *Idiognathodus* species.

Other new ramiform species are:

Euprioniodina lacticompressa n. sp.

E. recta n. sp.

E. acuta n. sp.

E. fragilis n. sp.

E. croneisi n. sp.

E. equilateralis n. sp.

E. subequalis n. sp.

E. collinsvilleensis n. sp.

E. longicuspata n. sp.

E. scotti n. sp.

E. scotti acutus n. var.

E. minuta n. sp.

Hamulosodina regularis n. sp.

H. spinosa n. sp.

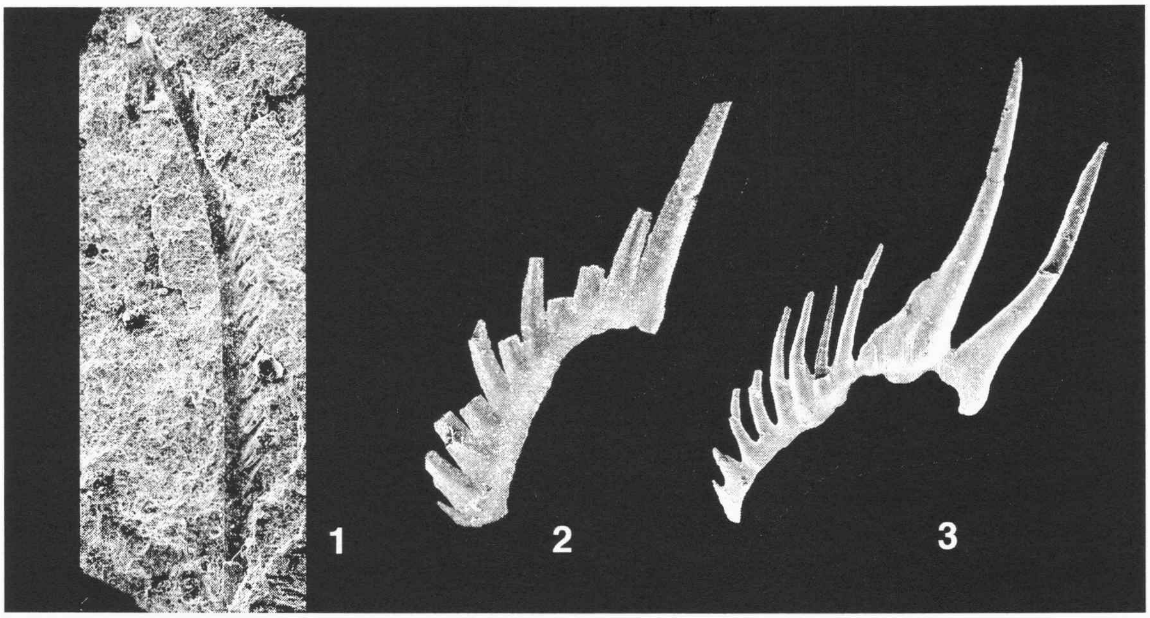

Fig. 1: Holotypes of type species of ramiform genera erected by Jones (1941). 1 - *Oxygonus multidentatus,* UC 44651, specimen is lost, only this mold in black shale remains, 56X (Jones, 1941, p. 31-32, pl. 3, fig. 14). 2 - *Euprioniodella delicatissima*, UC 44648, specimen is embedded in black shale that covers portions of the base of the element, 90X (Jones, 1941, p. 30, pl. 3, fig. 21). 3 - *Bicornognathus freemani,* specimen is embedded in black shale that covers portions of the base of the element, UC 44616, 32X (Jones, (1941, p. 17, pl. 1, fig. 2).

H. delicatissima n. sp.
H. delicatissima elongata n. var.
Hindeodella latidentata n. sp.
H. sinuata n. sp.
H. sinuata pigma n. var.
Lonchodina ligonodinoides n. sp.
L. equilatera n. sp.
L. gracilis n. sp.
L.? tridentata n. sp.
L.? horrida
L.? horrida rectus n. var.
Lonchodus multidens n. sp.
L. deckeri n. sp.
L. inclinatus n. sp.
L.? diversus n. sp.

Several new taxa are Pb elements of *Idiognathodus* and *Neognathodus* species:
Bryantodus seminolensis n. sp.
B. magnus n. sp.
B. pseudoalternata n. sp.
B. inclinatus n. sp.
B. curvata n. sp.
B. angularis n. sp.
B. multidentata n. sp.
B. pseudoregularis n. sp.
B. symmetricus n. sp.
B. alternatus n. sp.
B. parva n. sp.
B. altax n. sp.

Of greatest importance are the new names applied to Pa elements, including a new genus, *Bicarniodus*:
Gondolella cuneiformis n. sp. (Figure 2:4)
G. *ovata* n. sp. (Figure 2:5)
G. quadrata n. sp. (holotype is lost)

If one adopts a conservative approach to the species level taxonomy of *Gondolella* and believes that few species of *Gondolella* existed at any one time, then these three species are probably junior synonyms *of G. magna* Stauffer and Plummer, 1932 or *G. bella* Stauffer and Plummer, 1932. Both of these Stauffer and Plummer species were obtained from the latest Desmoinesian upper East Mountain Shale in north-central Texas, which has been correlated with the Lost Branch Formation (Boardman and Heckel, 1989). See Merrill, Grayson, and Mosley (1987) for a discussion of Stauffer and Plummer's localities and collections.

Streptognathodus nodocarinatus n. sp. (Figure 2:2)
S. excelsus rectus n. var. (Figure 2:3)
S. obliquisulcatus n. sp. (Figure 2:1)
S. equalis n. sp. (holotype is lost)

The holotypes of these four species are distinctive *Idiognathodus* Pa elements that possess a deep medial groove. Swade (1985, p. 62, Fig. 18:6, 7), who was the first to distinguish this grooved morphotype from other

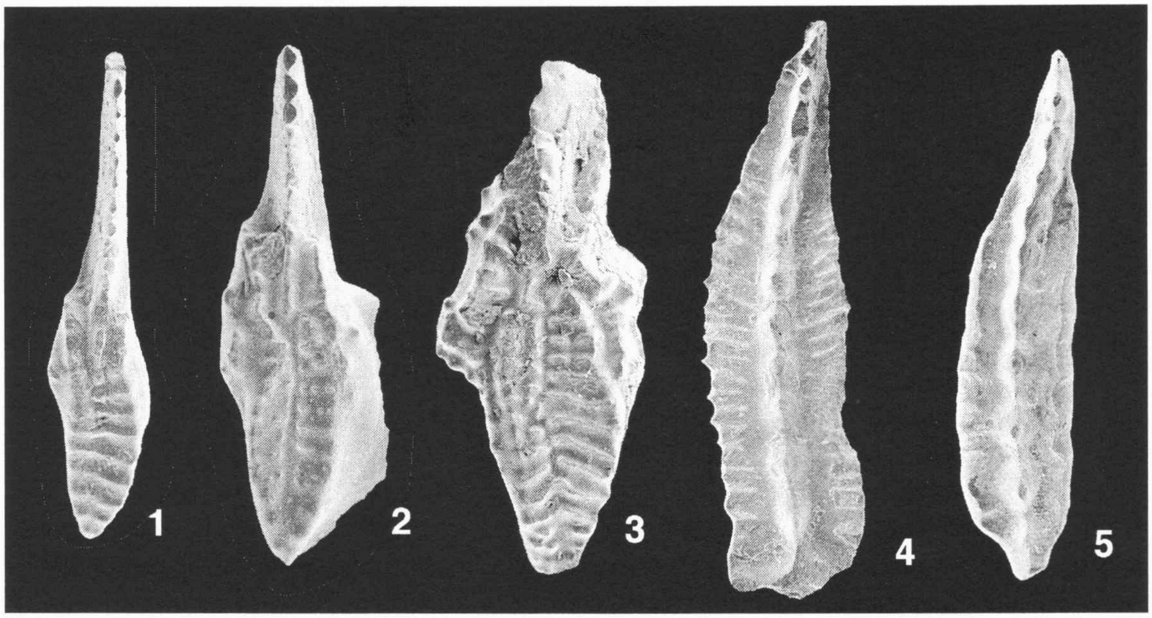

Fig. 2: Holotypes of Jones (1941). 1 - *Streptognathodus obliquisulcatus,* UC 44671, 63X (Jones, 1941, p. 39, pl. 3, fig. 7). 2 - *Streptognathodus nodocarinatus,* UC 44667, 63X (Jones, 1941, p. 38, pl. 3, fig. 2). 3 - *Streptognathodus excelsus rectus,* UC 44670, 48X (Jones, 1941, p. 39, pl. 3, fig. 3). 4 - *Gondolella cuneiformis*, UC 44644, 56X (Jones, 1941, p. 36-37, pl. 3, fig. 25). 5 - *Gondolella ovata,* UC 44665, 56X (Jones, 1941, p. 37, pl. 3, fig. 36).

late Desmoinesian species of *Idiognathodus*, informally designated it as *Idiognathodus* sp. 6. In contrast, Merrill, Grayson and Mosley (1987) considered the same forms from the East Mountain Shale of north-central Texas to be part of the morphological variation of *I. delicatus*. Barrick and Boardman (1989) incorrectly referred these morphotypes to *Idiognathodus concinnus* (Kossenko, 1975), and Boardman et al. (1990) modified the assignment to *I.* cf. *concinnus*. Since that time, the name *Idiognathodus nodocarinatus* Jones, 1941, has been used (Barrick, Boardman, and Heckel, 1996). At our current level of understanding of grooved *Idiognathodus* Pa elements in the latest Desmoinesian, all of the four holotypes of Jones (1941) fall within the definition of Swade (1985) for his n. sp. 6. For this reason we have chosen "*nodocarinatus*" to be the name applied to concept of n. sp. 6, and consider the other names to be synonyms of it. See also commentary by Lambert and Heckel in this guidebook.

Polygnathus? latus n. sp. (holotype lost?)

This form is a species of *Neognathodus*. Because the species level taxonomy of *Neognathodus* is in a state of flux, we do not attempt to assign it to any existing species.

Bicarniodus n. genus

B. oherni n. sp. (type species; holotype is lost)
B. bifurcatus n. sp. (Figure 3:3)
B. expansus n. sp. (Figure 3.1)

Jones (1941) erected a new form genus of conodonts, *Bicarniodus,* that included carminate Pa elements with a main carina that is flanked on one side by a ridge or a series of nodes. From his diagnosis, as well as from the holotypes of the type species, *B. oherni*, and two other species, *B. bifurcatus and B. expansus*, it is clear that *Bicarniodus* encompasses the series of late Desmoinesian species of *Neognathodus* that have been informally called the "terminal neognathodids." Thus, it would appear that *Bicarniodus* Jones, 1941, has priority over *Neognathodus* Dunn, 1970.

Lane and Straka (1974, p. 94) recognized the possibility that *Neognathodus* and *Bicarniodus* might refer to the same genus. They argued that because the holotype of the type species was lost and because they believed the illustrations and descriptions were inadequate for identification, *Bicarniodus* Jones should be considered to be a *nomen dubium*. In their paper, Lane and Straka (1974) were concerned primarily with collections of Early Pennsylvanian (Morrowan and Atokan) conodonts, in which *N. bassleri* (Harris and Hollingsworth, 1933), the type species of *Neognathodus*, and *N. symmetricus* (Lane, 1967) occur, which differ from the "terminal neognathodids" by possessing complete ridges on both sides of the carina on the platform.

From the description of Jones (1941, p. 40), *Bicarniodus oherni* resembles most closely *Neognathodus dilatus* (Stauffer and Plummer, 1932), and may be conspecific with that species. Although there may be some question about the species assignment of the lost holotype

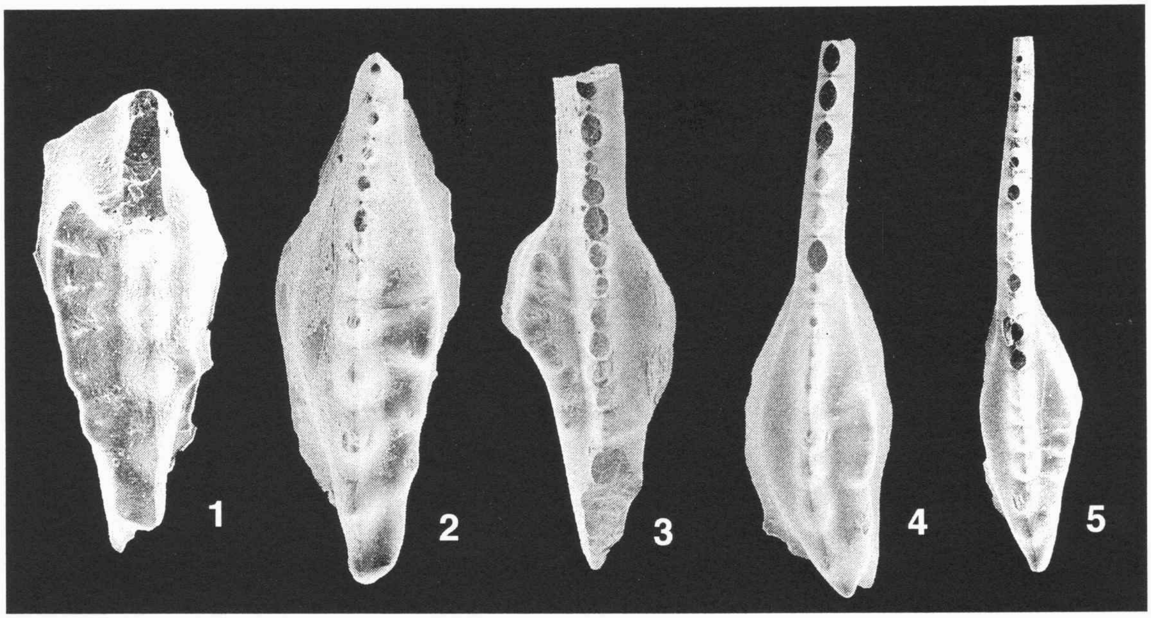

Fig. 3: Specimens of *Bicarniodus* Jones, 1941. 1 - *Bicarniodus expansus*, holotype, UC 44673, 95X (Jones, 1941, p. 41, pl. 3, fig. 9). 2, 4, 5 - Pa elements fitting the description of *Bicarniodus oherni*, type species of *Bicarniodus* (2 - TTU 99-1, 150X; 4 – TTU 99-2, 73X; 5 - TTU 99-3, 78X; all from locality described in text). 3 - *Bicarniodus bifurcatus*, UC 44672, 56X (Jones, 1941, p. 40, pl. 3, fig. 10).

of *B. oherni*, in our opinion there is no question that the species morphologies illustrated by Jones (1941) for *Bicarniodus* are now routinely included in *Neognathodus*. Due to reclamation efforts, most of the open pit coal mines in the Collinsville area have been filled, and it is difficult to reconstruct the exact localities that Jones visited in the 1930s. We have recollected the Nuyaka Creek Shale in the Collinsville area, near Locality No. 2 of Jones (1941). Our collection comes from the southeast one-quarter of section 20, T. 22 N., R. 14 E. Conodonts are extremely abundant on the bedding planes of the fissile black shale, and we have obtained a large fauna by splitting of the shales and from slow disaggregation of the black shale using bleach. Pa elements of the "terminal neognathodids" are common and conform to the morphologies described by Jones (1941) for *Bicarniodus* (Fig. 3:2,4,5).

Despite the fact that *Bicarniodus* is a valid older name for the "terminal neognathodids", we (and we suspect the vast majority of conodont workers) would prefer to retain the generic designation *Neognathodus*. The concept of *Neognathodus* is well established in the literature, and the generic name has been used in a clear and consistent manner by workers around the globe for nearly thirty years. We see two contrasting approaches to resolving the validity of *Bicarniodus* without disrupting the literature.

The conservative approach would be to submit a petition to the Commission on Zoological Nomenclature to formally suppress the name *Bicarniodus* in favor of *Neognathodus*. We had hoped that with the appearance of the Fourth Edition of the International Code of Zoological Nomenclature (effective January 1, 2000), *Bicarniodus* could be automatically suppressed as a "forgotten name." However, this argument apparently can be applied only to names proposed before 1899 (ICZN, http://www.iczn.org/code.htm/, 4/12/99). In either case, we will wait until seeing the complete version of the new Code before proceeding.

Note that the suppression of *Bicarniodus* as a valid generic designation would not remove the species names of Jones (1941) from consideration as valid names. A careful revision of the "terminal neognathodids" is needed before the species names of Jones (1941) for *Bicarniodus* can be evaluated. Lambert and Grayson (1993) pointed out that the proposed paedomorphocline (Merrill, 1972; 1975) that comprises the "terminal neognathodid" taxa does not exist in large populations, but that the observed range of morphology represents a continuum of intrapopulation variation (see also Swade, 1985). Based on relict distribution of white matter and a lack of paleoecological segregation for components of the morphological continuum, Lambert and Grayson (1993) interpreted the variable platform simplification of Desmoinesian species of *Neognathodus* to be a result of a loss of developmental canalization or selection pressure. For example, when he erected an earliest Desmoinesian species, *N. caudatus*, Lambert (1992) described and illustrated two morphotypes: 1) a completely developed, stable morphotype from which the holotype was selected, and 2) a variable, incompletely developed morphotype with the same stratigraphic range and general ontogenetic pattern.

A more radical approach would be to recognize the validity of *Bicarniodus* by contrasting the more constrained morphologies of pre-Desmoinesian species assigned to *Neognathodus* with the variably developed morphologies of Desmoinesian species assigned to *Bicarniodus*. This is a possible resolution if only the Pa element is considered. It may not be satisfactory with regard to the rest of the apparatus, which appears to change gradually from Morrowan through Desmoinesian time. It has yet to be demonstrated that the variable Desmoinesian species represent a distinct clade that developed from some Atokan *Neognathodus* species, as should be the case if *Bicarniodus* is to be retained as a generic designation for these species.

SUMMARY

As far as we can ascertain, there is no instance in which a younger species name is in widespread use for any of Jones's (1941) taxa. For this reason, we will continue to use Jones's species names where appropriate. *Bicarniodus* poses a somewhat thornier problem, but it can be resolved with additional effort following one of the approaches discussed above. Most of the types of Jones (1941) are available for study in the Field Museum of Natural History in Chicago (Nitecki and Richardson, 1967). New conodont faunas can be collected from the same stratigraphic level, the Nuyaka Creek shale, in the Collinsville, Oklahoma area. Hence, the potential exists for a complete restudy of the latest Desmoinesian conodont fauna originally described by Jones (1941), and for its integration into a modern understanding of conodont faunas across the Desmoinesian-Missourian boundary.

ACKNOWLEDGMENTS

The authors gratefully thank Suzy Taraba of the University of Chicago Library for searching through the library archives to find information pertinent to the publication of Jones (1941). Gregory A. Buckley (Field Museum of Natural History) and Julia Golden (University of Iowa Department of Geology Paleontology Repository) arranged for the loan of the type material. Darwin R. Boardman (Oklahoma State University) and Philip H. Heckel (University of Iowa) assisted by sharing their knowledge of the stratigraphy of upper Desmoinesian strata in the Collinsville area and discussing the implications of the Jones (1941) paper.

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SPECIES OF *IDIOGNATHODUS* AND *STREPTOGNATHODUS* FROM LATE CARBONIFEROUS STRATA OF THE DONETS BASIN, UKRAINE

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INTRODUCTION

Several new species of *Idiognathodus* and *Streptognathodus* from Late Carboniferous deposits in the Donets Basin were erected in the publication by Kozitskaya and others (1978). Because this publication did not receive wide circulation and is no longer available, incorporation of these species into more recent revisions of *Idiognathodus* and *Streptognathodus* has been difficult. In order to facilitate a better understanding of the Donets Basin conodonts, the types and some representative specimens of these species are illustrated here. Illustrations were prepared with the aid of Dr. Cor F. Winkler Prins of the National Museum of Natural History, Leiden, The Netherlands. A synonymy and summary of the stratigraphic distribution of each species are given. The Moscovian species of the Donets Basin are discussed more thoroughly in Nemyrovska, Perret, and Alekseev (1999, in press). Specimens are reposited in the collections of the Institute of Geological Sciences, Ukrainian National Academy of Sciences (NANU), Kiev, Ukraine.

DONETS BASIN SPECIES

***Idiognathodus bachmuticus* Kozitskaya, 1978** (Figure 2:1)

Idiognathodus bachmuticus Kozitskaya; Kozitskaya et al., 1978, p. 47-48, pl. 23, fig. 9-11.

Holotype Specimen 68/3048, IGS NANU, limestone O_4^1, C_3^2(O) Suite, borehole A-527, Debaltsevo area, Donets Basin, Ukraine.

Occurrence Donets Basin: Upper Kasimovian to base of Gzhelian; C_3^2 (O) Suite and base of the C_3^3 (P) Suite (formation), limestones O_4^1-P_1

***Idiognathodus lobulatus* Kozitskaya, 1978 (Figure 2:3)**

Idiognathodus lobulatus Kozitskaya; Kozitskaya, et al., 1978, p. 50-51, pl. 24, figs. 6-10.
Idiognathodus lobulatus Kozitskaya; Barskov, Alekseev, and Goreva, 1981, pl. 2, fig. 2.
Idiognathodus lobulatus Kozitskaya; Barskov, Isakova, and Shchastlivtseva, 1981, pl. 1, fig. 3.
Idiognathodus lobulatus Kozitskaya; Kozitskaya, 1983, pl. 1, figs. 5, 6.
Idiognathodus lobulatus Kozitskaya; Barskov et al., 1987, p. 78, pl. 19, figs.12-16.
Idiognathodus lobulatus Kozitskaya; Goreva and Kossovaya, 1997, pl. 3, fig. 26.

Holotype Specimen 68/3055, IGS NANU, limestone P_2, C_3^3(P) Suite, west of town of Dzerzhynsk, Donets Basin, Ukraine.

Occurrence Donets Basin and Dnieper-Donets Depression: Upper Kasimovian to Lower Gzhelian, upper part of the C_3^2 (O) Suite and lower part of the C_3^3(P) Suite, limestones O_6-P_2. Moscow Basin: Upper part of the Kasimovian to lower part of the Gzhelian. Timan: Upper Kasimovian.

***Idiognathodus obliquus* Kossenko and Kozitskaya, 1978 (Figure 1:1)**

Idiognathodus sp. B, Gabert, Stoppel and Vinken, 1965, p. 405, pl. 47, fig. 6.
Idiognathodus obliquus Kossenko and Kozitskaya; Kozitskaya et al., 1978, p. 51-53, pl. 22, fig. 6-9.
Idiognathodus obliquus Kossenko and Kozitskaya; Goreva, 1984, pl. 2, figs. 7-11.
Idiognathodus obliquus Kossenko and Kozitskaya; Barskov et al., 1987, p. 78, pl. 18, figs. 14-15.
Idiognathodus obliquus Kossenko and Kozitskaya; Goreva and Kossovaya, 1997, pl. 3, fig. 28.

Holotype Specimen 68/1024, IGS NANU, limestones M_{10}^1, C_2^7 (M) Suite, borehole 11382, Dobropolsky Kapitalny area, Donets Basin, Ukraine. Specimen illustrated here is from limestone N_1 in the area of the "Albert" mine.

Occurrence Donets Basin: Upper Moscovian, upper part of the C_2^7 (M) Suite and lower part of the C_3^1(N) Suite, limestones M_5-N_2. Moscow Basin and Timan: Kashirian and Myachkovian. South Korea: Upper Carboniferous.

Nemyrovska, T. I., and Kozitska, R. I., 1999, Species of *Idiognathodus* and *Streptognathodus* from Late Carboniferous strata of the Donets Basin, Ukraine; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous-Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 170–173.

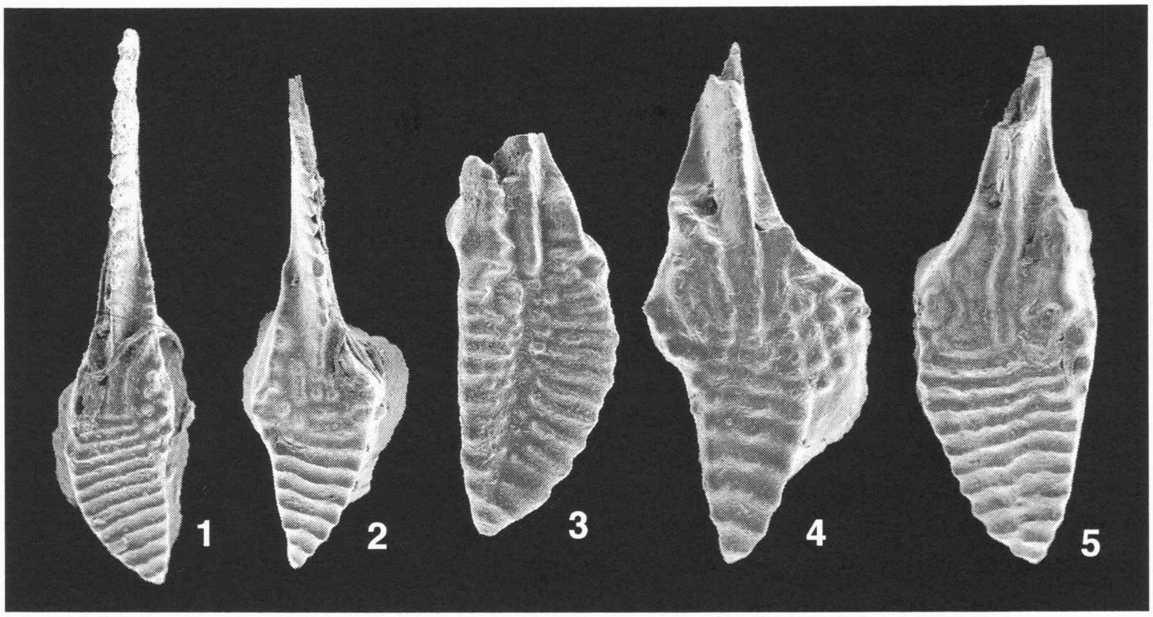

Fig. 1: Conodonts from the Donets Basin. 1 - *Idiognathodus obliquus*, Kozitskaya and Kossenko, 1978, specimen from limestone N_1, 64X. 2 - *Idiognathodus robustus*, Kozitskaya and Kossenko, 1978, specimen from limestone N_2^2, 48X. 3 - *Streptognathodus kalitvensis* Kozitskaya, 1978, holotype, 68/3087, 55X. 4 – *Idiognathodus sagittalis* Kozitskaya, 1978, holotype, 68/3039, 60X. 5 - *Idiognathodus toretzianus* Kozitskaya, 1978, holotype, 68/3050, 60X.

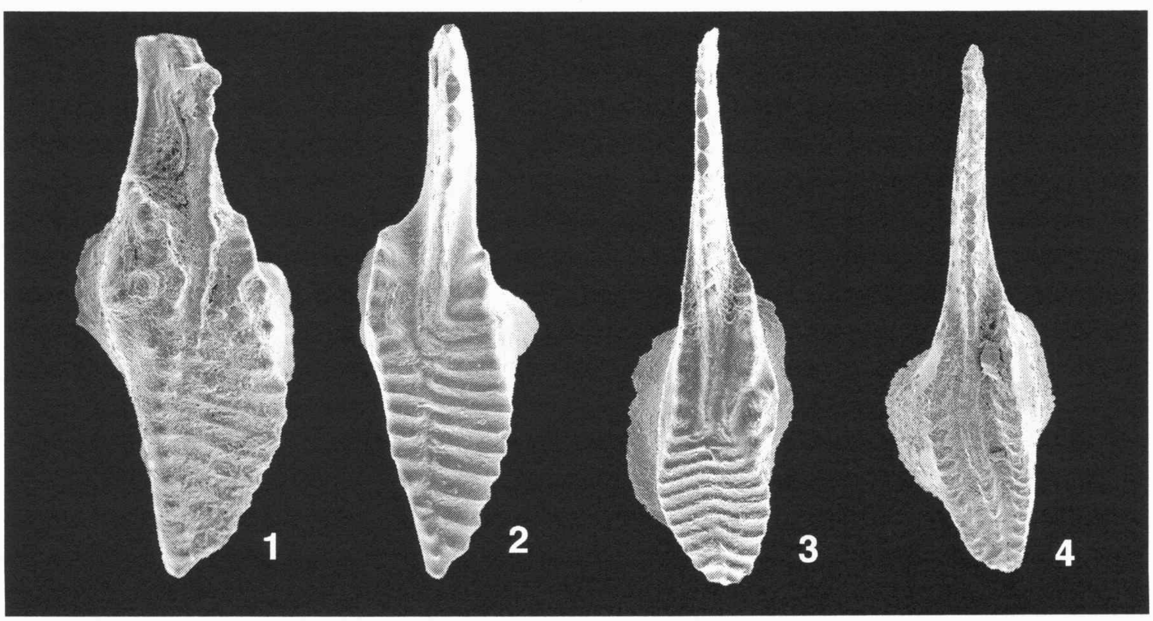

Fig. 2: Holotypes from the Donets Basin. 1 - *Idiognathodus bachmuticus* Kozitskaya, 1978, 68/3048, 66X. 2 - *Streptognathodus luganicus* Kozitskaya, 1978, 68/3116, 64X. 3 - *Idiognathodus lobulatus* Kozitskaya, 1978, 68/3055, 78X. 4 - *Streptognathodus firmus* Kozitskaya, 1978, 68/3103, 47X.

Streptognathodus luganicus Kozitskaya; Barskov et al., 1987, p. 89., pl. 22, fig. 1.

Holotype Specimen 68/3116, IGS NANU, limestone O_7, C_2^3 (O) Suite, Lugan' River, Kalinovskoe village, eastern side of the Bachmutka Depression, Donets Basin, Ukraine.

Occurrence Donets Basin and Dnieper-Donets Depression: Kasimovian/Gzhelian boundary deposits, uppermost part of the C_2^3 (O) Suite to the lowermost part of the C_3^3(P) Suite, limestones O_7 to P_1. Moscow Basin: Lower Gzhelian.

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A DISTINCT CLADE OF TROUGHED IDIOGNATHODID CONODONTS THAT PRECEDES THE APPEARANCE OF *STREPTOGNATHODUS*

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CONODONTS AND CLADISTICS

Conodonts are excellent subjects for illustrating the basic tenets of phylogenetic taxonomy because of the mosaic manner in which the multi-element skeletal apparatus evolved. Phylogenetic taxonomy (commonly referred to as cladistics) is a methodological approach to clustering taxa within a hierarchy of genealogical sets and subsets. When first introduced to cladistics, students tend to become bogged down with the clerical procedures of coding characters into the computer programs that are commonly used to cluster taxonomic entities from a complex of numerous characters. Furthermore, students frequently have trouble evaluating derived versus ancestral character-states for parsimony analysis. Conodont evolution, in a multi-element context, alleviates these problems by intuitively conveying the basic concepts of character-states, clades, and convergence, without relying on computer clustering programs.

Differential morphogenesis is inherent in multi-element taxonomy, because skeletal elements that occupied different locations within an individual conodont apparatus typically evolved at different rates in relation to elements in other positions through successive populations. More conservative elemental components thus exemplify plesiomorphic character-states in the vernacular of cladistics, whereas those elements that changed frequently exemplify apomorphic characters. The goal of cladistics is to group taxa by their degree of inferred relatedness, which is recognized most consistently by shared novel characters, called synapomorphies. The process of evaluating whether characters are apomorphic or result from convergence in different lineages forces the taxonomist to concentrate on ancestor-descendant relationships, rather than overemphasize the most conspicuous morphologic characters. Analogous to synapomorphies are symplesiomorphies, shared ancestral characters that, in somewhat of an incomplete reverse procedure, can be analyzed to approximate the relative clustering relationships among more distantly related predecessor groups (but not as part of formal systematics; see below).

The general pattern for Late Paleozoic conodonts was for those elements at the posterior end of the apparatus to be the most apomorphic, whereas those in anterior positions were the most plesiomorphic (likelihood of apomorphies: Pa>Pb>M>S transition series; see Merrill et al., 1990). The Pa elements thus illustrate the most apomorphic element position, and its morphogenesis indicates species level evolution. Elements that constitute the remainder of the apparatus evolved more slowly, such that several Pa morphotypes shared essentially identical Pb, M, and S elements with the clade's ancestor, indicating a genealogical group at the genus level. Consequently, significant changes in the Pb (and sometimes M) elements can be taken to indicate genus-level evolution, whereas significant changes among the S transition elements commonly indicate evolution at the family level (Merrill et al., 1990). The relatively simple concept of multi-element taxonomy for conodonts thus provides an intuitive understanding of cladistic methodology through incorporating differential changes in the elements of the integrated apparatus.

Systematists who practice cladistic methodology recognize three clustering types (taxonomic groupings) on the basis of ancestor-descendant relationships. Monophyletic groups are those comprising an ancestral taxon and all of its descendants. This natural genealogical grouping is formalized in phylogenetic taxonomy as a clade, and is the only type to merit Linnaean names. Paraphyletic groups are incomplete groups that lack some descendants, and are thus recognized by their symplesiomorphies. Considerable debate surrounds the proper taxonomic disposition of paraphyletic groups, although they can often be useful in paleontological analyses. Polyphyletic groups are based not on synapomorphies, but on convergence, homoplasy, or some other misleading indicator of relationship. Polyphyletic groups include more than one ancestor, and are considered invalid taxonomic entities in cladistics. A clearer picture of evolutionary history thus emerges when systematists adhere strictly to monophyletic taxa (de Queiroz and Gauthier, 1990; Kitching et al., 1998).

Lambert, L. L., and Heckel, P. H., 1999, A distinct clade of troughed Idiognathodid conodonts that precedes the appearance of *Streptognathodus*; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 174–177.

THE EXAMPLE OF '*STREPTOGNATHODUS*' AS A FORM GENUS

An excellent illustration of the foregoing discussion is provided by the genus *Streptognathodus* as it has traditionally been used. Originally erected on the character of a pronounced axial trough along the posterior platform (Stauffer and Plummer, 1932), specimens from throughout the Pennsylvanian that exhibit any degree of medial division across the transverse ridges have come to be assigned to it. As noted repeatedly by previous workers (e.g., Merrill and von Bitter, 1976, 1984; Sweet, 1988), *Streptognathodus* as so defined appears and disappears iteratively throughout the Pennsylvanian. Previous workers have also repeatedly pointed out that troughed Pa elements are a common juvenile character in idiognathodid conodonts. Because paedomorphosis appears to have been a major evolutionary driver in conodonts, such juvenile features were repeatedly carried over into adult morphologies in lineages that were only distantly related. As a consequence, *Streptognathodus (sensu lato)* could be considered an example of extreme form-taxonomy in conodonts. The generic concept as now commonly applied is polyphyletic, thus obscuring significant and otherwise discernable evolutionary relationships.

How should *Streptognathodus* be treated taxonomically? It certainly should not be directly equated with any iteratively evolving character. The genotype (and thus the appellation "*Streptognathodus*") belongs to a lineage that evolved from a single ancestor, representing a genus-level clade. Other troughed idiognathodid conodonts have to be evaluated separately as to whether or not they also represent a distinct lineage. Because a posterior axial trough appeared in adult idiognathodid conodonts several times through the Pennsylvanian, criteria must be selected to differentiate significant cladogenesis from spatially or temporally limited appearances of populations with the troughed platform character. It would be counterproductive to elevate the occasional lone troughed species to formal recognition as representing a monospecific genus. The purpose of the criteria is to avoid an unnecessary proliferation of generic names that could consequently obscure the evolutionary relationships being sought. Criteria to evaluate should include: 1) Do the specimens under consideration indicate an evolutionary trend comprising several descendant morphologies that exhibit synapomorphies? 2) Do the specimens under consideration possess a distinctive set of symplesiomorhpic ramiform elements? 3) Do the specimens under consideration represent a coherent set of paleoecological preferences?

One example that meets the above criteria is *Streptognathodus (sensu stricto)*. True *Streptognathodus* was named from the mid-Missourian of Texas. It evolved paedomorphically from an as yet unnamed antecedent (*Idiognathodus* n. sp. A of Barrick et al., 1996), with which it co-occurs in the early Missourian Swope cyclothem. This first species of *Streptognathodus* is *S. cancellosus*, which subsequently diversified into numerous species that together dominated the later Pennsylvanian and Early Permian. Diversification may have been concentrated in several evolutionary bursts (Barrick et al., this volume), and numerous species are discussed and illustrated throughout this volume (e.g., Barrick and Walsh; Barrick et al.; Heckel). The apparatus of *Streptognathodus* has been reconstructed by several workers, including von Bitter (1972), Baesemann (1973), and others. Although usually interpreted to be indistinguishable from the apparatus of *Idiognathodus*, there may be subtle differences. Merrill and von Bitter (1976, 1984; see also Barrick et al., this guidebook) have studied the paleoecological preferences shown by species of *Streptognathodus* through much of its range, and have concluded that by and large those preferences differed from the paleoecological preferences of most contemporaneous *Idiognathodus* species.

A DIFFERENT CLADE

Another example that meets the foregoing criteria for a distinct genus is the clade of troughed idiognathodid conodonts that characterize the Late Desmoinesian, prior to the evolution of *Streptognathodus (sensu stricto)*. These species have commonly been assigned to *Streptognathodus* because they bear a pronounced axial trough. However, J. W. Swade (personal communication to PHH, 1983) recognized that these specimens were distinct from true *Streptognathodus*. For his early contribution, we plan to name the new genus in honor of Swade, who unfortunately died before he could study the lineage more thoroughly. Here and throughout this guidebook, we refer to this troughed lineage as *'Idiognathodus'* or *'I'*. Like *Streptognathodus*, *'Idiognathodus'* appears to have evolved from a single (but as yet unknown) ancestor, then diversified rapidly into several species by the end of its range. Morphologic characters of the Pb element in the associated apparatus differ subtly from those of both *Idiognathodus* and *Streptognathodus*. Minor differences also exist between the troughed Pa elements of *Streptognathodus (sensu stricto)* and the troughed Pa elements of *'Idiognathodus'*. *Streptognathodus* has been characterized by Barrick and Boardman (1989) as having a relatively long carina, a high parapet fused with the outer platform margins, and posteriorly shifted, at best poorly developed accessory lobes. In contrast, the *'Idiognathodus'* clade sports a shorter carina (more reminiscent of most *Idiognathodus*), more variable platform height and its relationship to platform margins, and well developed nodes, ridges, and accessory lobes, most of which are located anterior of the troughed transverse ridge complex. Following their initial appearance in the Farlington and Amoret Limestones (where these forms dominate shallow water biofacies to the exclusion of *Idiognathodus*), these species developed and maintained a distinct paleoecological preference for offshore water masses. *Idiognathodus* species dominate the contemporaneous nearer-shore biofacies, underscoring the paleoecological segregation and phylogenetic independence of '*Idiognathodus*'.

In the North American Midcontinent, representatives of '*Idiognathodus*' first appear in the Farlington Limestone bed of the Bandera Shale (Stop B2). Two morphotypes with relatively simple characters are found at this stratigraphic level in several localities. As these faunas commonly lack co-occurring species of *Idiognathodus*, we are confident of our proposed multi-element reconstruction for '*Idiognathodus*'. Additionally, this pair of initial morphotypes is well represented by both juvenile and adult specimens. Characters considered transitional with any particular species of *Idiognathodus* have not been observed, and it is most likely that '*Idiognathodus*' immigrated to the Midcontinent from elsewhere. Both early morphotypes then underwent minor modifications, becoming somewhat more nodose by the stratigraphic level of the Lake Neosho Shale Member (above the Amoret Limestone Member in the overlying Altamont Limestone), where they are joined by a different morphotype that may merit a separate species designation. One of these species was referred to as "*Idiognathodus* sp. 5" by Swade (1985). Only one locality in the next higher Lenapah Limestone (Stop B4) has produced a significant number of specimens, but this single locality is important for two reasons. First, it produces both the oldest known occurrence of the common, distinctive latest Desmoinesian species, '*I.*' *nodocarinatus* Jones 1941 (referred to "*I.* sp. 6" by Swade, 1985; also see Barrick and Lambert, this guidebook). Second, it produces specimens resembling a morphotype from the Moscow region of Russia named "*S. subexcelsus*" by Alekseev and Goreva (in a manuscript that, unfortunately, has not yet been published). The latest Desmoinesian Nuyaka Creek Shale bed, of the next higher Lost Branch Formation, produces the most diverse assemblage of the clade, including '*I.*' *nodocarinatus*, "*S. subexcelsus*", and two additional species, one of which is a carryover from the Lake Neosho Shale. The clade then appears to have suffered total extinction following the sea-level lowstand that marks the traditional Desmoinesian-Missourian boundary in North America.

SIGNIFICANCE

Multi-element taxonomy can lead to an intuitive understanding of cladistic methodology. Within a monophyletic framework, both lead to better analyses of ancestor-descendant relationships and provide a clearer picture of evolutionary history. Careful genealogical studies can suggest better characters than gross morphology to evaluate for synapomorphies, such as those that reveal a previously obscured late Desmoinesian genus of troughed idiognathodid conodonts. Furthermore, the resolution of '*Idiognathodus*' will lead to improved biostratigraphy, because its component species should no longer be confused (and synonymized) with those of the later genus *Streptognathodus*. The rapid diversification of '*Idiognathodus*' in offshore biofacies of the latest Desmoinesian could possibly provide the speciation event for formal definition of the global Middle-Upper Pennsylvanian Series boundary (see Barrick et al., this volume).

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EVOLUTIONARY PATTERNS IN LATE PENNSYLVANIAN *IDIOGNATHODUS* AND *STREPTOGNATHODUS* AND IMPLICATIONS FOR CHRONOSTRATIGRAPHIC BOUNDARY CHARACTERIZATION AND RECOGNITION

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INTRODUCTION

Species of *Idiognathodus* and *Streptognathodus* are among the most common and widely distributed taxa of conodonts in Upper Pennsylvanian strata. In spite of this, they have only recently begun to be incorporated into detailed biostratigraphic zonations that will potentially permit the identification and correlation of small increments of Late Pennsylvanian time. Most previous work on the taxonomy and evolution of species in these genera has followed along two lines after the extraordinary oversplitting of these genera by Gunnell (1933). Many workers have followed the lead of Ellison (1941) in recognizing species that are based on relatively few simple morphological criteria, an approach that generally results in a small number of long-ranging species (Grayson et al., 1989; Brown et al., 1991). Eurasian workers have generally followed Ellison (1941), but have also recognized a number of new distinct species with short stratigraphic ranges (Kossenko, 1975; Barskov and Alekseev, 1976; Kozitskaya et al., 1978; Barskov, Isakova and Shchastlivtseva, 1981; Chernykh and Reshetkova, 1987; Nemirovskaya and Alekseev, 1994). In contrast, Merrill and co-workers (Merrill and von Bitter, 1976; Merrill and Martin, 1976; Grayson et al., 1990) have retreated from Ellison's species-level taxonomy in *Idiognathodus* and *Streptognathodus* by rarely identifying species. Reference is made to the *Idiognathodus/ Streptognathodus* plexus, a construct that compresses a broad range of morphological variability that is considered to be ecologically determined into a small number of taxa. In its more recent formulation, these authors indicate that only one species, restricted in time to a stage or part of a stage, lived at any one time during the Pennsylvanian (Grayson et al., 1989; 1990).

Beginning with Swade (1985), a number of authors working in the cyclothemic strata of the North American Midcontinent region have approached the taxonomy of *Idiognathodus* and *Streptognathodus* by identifying distinct morphotypes of Pa elements that are limited to short stratigraphic intervals, often to a single major cyclothemic unit. Because there is great ecologic variability in the Pa elements, resolution of time-significant morphotypes, usually given separate species names, has been a slow and difficult process. In spite of this, several papers have described morphotypes and species on a cyclothem-by-cyclothem basis (Barrick and Boardman, 1989; Heckel, 1989; Lambert, 1992), and have proposed new zonations for the Late Pennsylvanian to Early Permian interval (Ritter, 1994, 1995; Barrick, Boardman, and Heckel, 1996).

In conducting our research on the biostratigraphy of species of *Idiognathodus* and *Streptognathodus*, we have developed a general model for the pattern of morphological change in these genera. Barrick and Boardman (1989) presented an early version of the model, and Barrick, Heckel, and Boardman (1992), and Barrick, Boardman, and Heckel (1996) have discussed different aspects of the model. Here, we would like to explain more completely our ideas on the morphological evolution of the Pa element of these two genera and show the consequences of our model in using species of *Idiognathodus* and *Streptognathodus* for characterization and correlation of Pennsylvanian chronostratigraphic boundaries.

We interpret the Late Pennsylvanian history of *Idiognathodus* and *Streptognathodus* to be represented by a series of evolutionary bursts of species radiating from an ancestral form and replacing the older fauna. The reasons for the appearance of an evolutionary burst are not clear. We have seen cases where a burst follows a sharp reduction in conodont diversity (base of the Missourian) and also where a burst occurs in the midst of apparent high diversity, followed by rapid replacement of the fauna (early middle Missourian). Some component of ecological fitness appears to be involved, as was recognized many years ago by Merrill and von Bitter (1976, fig. 6), but not integrated into species-level evolution. This pattern of evolutionary radiations and turnovers is not unique to Late Pennsylvanian conodonts, for it has been well documented in the Devonian and Mississippian (Ziegler and Lane, 1987). We suspect that a similar pattern of radiations and diversifications may have characterized Early and Middle Pennsylvanian species of *Idiognathodus,* but do not have sufficient information to determine if this was the case.

For the Late Pennsylvanian, we recognize four major cycles of evolution in *Idiognathodus* and *Streptognathodus*, the last of which continued into the Early Permian:

Barrick, J. E., Heckel, P. H., and Boardman, D. R., 1999, Evolutionary patterns in Late Pennsylvanian *Idiognathodus* and *Streptognathodus* and implications for chronostratigraphic boundary characterization and recognition; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 178–185.

1. Early Missourian 'nodose *Idiognathodus*' group
2. Middle Missourian appearance of deeply troughed *Streptognathodus*
3. Late Missourian *Streptognathodus* turnover
4. Latest Virgilian- Early Permian *Streptognathodus* radiation

EARLY MISSOURIAN 'NODOSE *IDIOGNATHODUS*' GROUP

In Midcontinent North America, late Desmoinesian conodont faunas are abundant and diverse, especially in the dark phosphatic core shales of cyclothems, which we interpret to represent offshore, deeper water environments. The latest Desmoinesian Lost Branch fauna includes several morphotypes (species?) of *Neognathodus*, and at least two major groups of *Idiognathodus*, typical forms like *I. expansus* Stauffer and Plummer, and distinctly troughed forms assigned to *'I'. nodocarinatus* Jones (Barrick, Boardman, and Heckel, 1996), in addition to examples of *Idioprioniodus, Ellisonia, Diplognathodus*, and *Adetognathus*. As Merrill and von Bitter (1976) have illustrated, morphotypes of *Idiognathodus* like *I. expansus* occurred in a wide variety of environments, including shallow-water settings, whereas troughed forms ("*Streptognathodus*" of these authors) like *'I'. nodocarinatus*, were more characteristic of the offshore deeper environments of core shales.

In contrast, lowest Missourian marine units contain a much reduced conodont fauna. *Neognathodus* had disappeared, and only relatively generalized *Idiognathodus* Pa elements, assigned to *I. sulciferus* by Barrick, Boardman, and Heckel (1996) remain. One distinctive morphologic attribute of the earliest Missourian *Idiognathodus* Pa elements is the presence of a long carina persisting from juvenile forms into specimens of moderate size and the more obvious to flaring adcarinal ridges than in similarly sized Desmoinesian elements. These features are typically found in juvenile examples of Desmoinesian *Idiognathodus* species like *I. expansus*, and they suggest that the early Missourian forms may have been derived from a latest Desmoinesian ancestor through paedomorphosis. Grayson and others (1989; 1990) also stated that the anterior platform margin of these Missourian taxa has a more precipitous anterior termination than that seen in Desmoinesian forms. Less is known about changes in the other continuing conodont genera. Grayson and others (1989) indicated that the loss of the bidentatiform element in the apparatus of *Idioprioniodus* had occurred by this time. Merrill and others (1987) suggested that transitions between species of *Gondolella* may also have occurred across the boundary interval. It is not clear what is responsible for the extinction of conodont taxa at the end of the Desmoinesian, as well as other extinction events in the marine facies (e.g., the fusulinid *Beedeina*) and the abrupt transition in the terrestrial flora (Boardman et al., 1991). Schutter and Heckel (1985) reasoned that the large drop in sea level at the end of the Lost Branch marine cycle may have reduced living space in the marine shelf environment and ushered in significant climate changes that ultimately led to the biotic events that characterize the end of the Desmoinesian.

In succeeding Missourian cyclothems in the Midcontinent region, *Idiognathodus* Pa elements of greater morphological variety appear progressively (Barrick, Boardman, and Heckel, 1996). Forms with a moderately deep eccentric groove [*I. eccentricus* (Ellison, 1941)] are followed by forms with a medial row of nodes on the platform [*I.* n. sp. A], and a shallow medial trough (*I. clavatulus* [Gunnell, 1933)]. By the level of the Hushpuckney Shale, the third major cycle above the base of the Missourian, a diverse array of *Idiognathodus* Pa elements is present within the same cyclothem. As in the latest Desmoinesian, shallower water facies are dominated by Pa elements with flat upper surfaces, whereas the newer grooved to troughed forms characterize deeper water facies. The term 'nodose *Idiognathodus*' has been applied to these forms because of the tendency of the platform surface to break up into a complex series of nodes and short ridges in larger platforms. With the increase in diversity, distinctive narrow Pa elements appear, in which a reduction in lobe size, persistence of a long carina into full-sized forms, and high outer margins are characteristic features. These features are those that usually characterize very small, juvenile specimens of *Idiognathodus*. These morphotypes are the ancestral forms of *Streptognathodus, S. cancellosus* Gunnell and perhaps some similar forms like *I. jugosus* Gunnell.

MID-MISSOURIAN BURST OF DEEPLY TROUGHED *STREPTOGNATHODUS*

Barrick and Boardman (1989) restricted the use of the genus *Streptognathodus* to species that belong to a Missourian to Early Permian clade of species, which include the genotype and arise from a common ancestor in the transition to the mid-Missourian fauna. Pa elements with a longitudinal trough similar to typical species of *Streptognathodus* (e.g., *S. excelsus*) range from near the base of the Pennsylvanian into the Permian. However, the Morrowan through latest Desmoinesian examples represent separate derivations of a troughed morphology from typical *Idiognathodus* Pa elements that are unrelated to the Late Pennsylvanian clade of type *Streptognathodus*. As Merrill and von Bitter (1976) have shown, for the Morrowan through latest Desmoinesian forms, the trough is the morphology most characteristic of the offshore, deeper water core shales. Why this is the case is unclear, but recent investigations into the functional morphology of the *Idiognathodus* Pa element suggest that some aspect of food type and its processing by the apparatus may be involved (Donoghue and Purnell, 1999). However, with the radiation of true *Streptognathodus*, a new ecological pattern relative to Pa morphology arises.

The supposed ancestral forms of *Streptognathodus, S. cancellosus* (or possibly *I. jugosus*) arose late in the diversification of the early Missourian 'nodose *Idiognathodus*' group. In the slightly younger late early Missourian Mound Valley Limestone and overlying Dennis Formation, *S. confragus* appears, which possesses most of the typical features of *Streptognathodus*: high outer margins that arise as high anterior parapets separated from the carina by a deep adcarinal groove and merge with the platform near mid-length; a flaring outer parapet (frill); and an inner margin that is deflected around a lateral node, or small group of nodes. However, the medial trough is not as fully developed as in later, more typical examples of the genus. Within this basic morphology, *S. confragus* is a variable taxon, with some features exaggerated and others reduced in different collections. Compared with *S. cancellosus, S. confragus* represents another step in a paedomorphic retreat of adult morphology toward the juvenile features of *Idiognathodus*, a retreat not fully attained until the appearance of true, deeply troughed forms of *Streptognathodus* in the upper (Hogshooter) part of the Winterset Limestone and their dominance in the next younger cyclothem (Cherryvale). Many workers have commented on the ontogenetic transformation of "*Streptognathodus*-like" juvenile forms to *Idiognathodus* adult forms (e.g., Merrill and von Bitter, 1976; van der Boogaard and Bless, 1985; Merrill, Grayson and Mosley, 1987), but a few (e.g., Sweet, 1988) clearly recognized that Missourian (true) *Streptognathodus* could have arisen by paedomorphosis.

The number of species of *Streptognathodus* rapidly increased in the Cherryvale cyclothem, where a full array of Pa elements bearing different combinations of lobes appear: *S. elegantulus* Stauffer and Plummer with no nodes; *S. gracilis* Stauffer and Plummer with one node; *S. corrugatus* Gunnell, with a single complex lobe; *S. excelsus* Stauffer and Plummer with two nodose lobes; and the problematic form *S. oppletus* (see Barrick and Walsh, this guidebook). With this diversification of *Streptognathodus*, a major shift in ecological preferences occurred, as was shown by Merrill and von Bitter (1976). The most widely distributed of the forms, those with no nodes or only one node (*S. elegantulus* and *S. gracilis*) occur in most environmental settings and dominate in shallower water facies. Broader, slightly flatter forms with large well-developed lobes (*S. excelsus*) are common in the more offshore facies. The radiation of species of *Streptognathodus* radically modified the ecological distribution of *Idiognathodus*. From the mid-Missourian until its extinction in the Virgilian, *Idiognathodus* is nearly restricted to the phosphatic core shale facies, which represents the most offshore, deeper water facies within cyclothems. Not only does *Idiognathodus* become ecologically restricted, but it also adheres more closely to a generalized *Idiognathodus* morphology, as best shown by *I. magnificus* Stauffer and Plummer.

Unlike the case with the radiation of the early Missourian 'nodose *Idiognathodus*' group, which occurred after an apparent extinction event, *Streptognathodus* developed within a diverse *Idiognathodus* fauna, and then rather quickly displaced it as the most important genus. As far as our time resolution permits, the major changes occurred within the time span represented by an average major to intermediate cyclothem (~400,000 years). Some hints of the forthcoming changes are evident in the *Idiognathodus*-dominated fauna of the preceding Hogshooter-upper Winterset cyclothem and in the top of the underlying Dennis cyclothem at Kansas City. Additional work on the fauna of the entire Winterset Limestone should help document the initial radiation events in *Streptognathodus* and their impact on *Idiognathodus.*

Barrick and Boardman (1989) called this fauna the *Streptognathodus gracilis* interval, which ranged from the *S. confragus* fauna of the basal Palo Pinto Limestone (the Texas equivalent of the Dennis cyclothem) through the equivalent of the Stanton Limestone. Ritter (1995) erected a similar *Streptognathodus gracilis* Zone, but chose to place the lower boundary at the first abundant occurrence of *S. gracilis* in the younger Cherryvale Formation.

LATE MISSOURIAN TURNOVER IN *STREPTOGNATHODUS*

A major reorganization and turnover of species in *Streptognathodus* occurred in the latter part of the Missourian. Within one cyclothem, specifically in the Eudora phosphatic shale of the Stanton cyclothem, the diverse array of mid-Missourian *Streptognathodus* species is essentially replaced by a single morphotype called *S. firmus*. *Streptognathodus firmus* Kozitskaya and its immediate descendent *S. pawhuskaensis* (Harris and Hollingsworth), which appears in the next youngest South Bend cyclothem, are characterized by a simplified *Streptognathodus* morphology: a nearly straight platform with high margins, a deeply excavated trough, and lack of lobes (although an isolated one or two nodes may occur in the latter species). In *S. firmus*, the carina extends nearly to the posterior margin, making the platform appear superficially like some early species of *Neognathodus* (e.g., *N. bassleri*). Through a rapid decrease in carina length, *S. firmus* grades into *S. pawhuskaensis*, a form that persists through most all of the Virgilian (Ritter, 1995) and which is surely the most common species present during this time. It occurs in nearly all lithofacies from which conodonts can be extracted. This new group may have developed paedomorphically from an older species of *Streptognathodus* (Barrick and Boardman, 1989), but no definitely transitional forms have been recovered. Barrick and Boardman (1989) called this group the *Streptognathodus firmus - S. alekseevi (= pawhuskaensis)* fauna. During the Virgilian additional species of *Streptognathodus* diverged from *S. pawhuskaensis* (Ritter, 1994), including one species with moderately well developed lobes on both sides of the platform, *S. zethus* Chernykh and Reshetkova 1987, which occurs only in core shales in the Midcontinent region (Barrick, Boardman, and Heckel, 1995). Ritter (1995) has used some of these species to zone the Virgilian in the Midcontinent region.

Coincident with the appearance of *S. firmus* in the Eudora Shale, a species of *Idiognathodus* with an eccentric groove on the platform appears, *I. simulator* (Ellison). Although this species is usually placed in *Streptognathodus*, the narrow groove is the only feature that it shares in common with members of that genus. In all other aspects of platform shape, transverse ridges, and lobe morphology, it is much closer to Missourian species of *Idiognathodus*. Despite its distinctive morphology, *I. simulator* is largely restricted to the core shales of the best developed cyclothems in the Midcontinent region (Eudora; Heebner). Other species of *Idiognathodus* are uncommon and are found mainly in well-developed core shale intervals. Before the extinction of the genus in the middle Virgilian, mainly forms with strongly reduced to absent lobes occur (e.g., *I. tersus* Ellison 1941).

Even though the species composing *Streptognathodus* and *Idiognathodus* are different from those in the middle Missourian, a similar ecological distribution of morphotypes remains (Merrill and von Bitter, 1976). The narrow, unornamented species of *Streptognathodus* occur across a broad spectrum of facies, including the more shallow-water facies. Lobed forms occur most often in the more offshore, deeper water core shales, and the few remaining species of *Idiognathodus* are generally restricted to the core shale facies.

LATEST VIRGILIAN - EARLY PERMIAN *STREPTOGNATHODUS* RADIATION

Near the end of the Pennsylvanian a major morphological radiation in *Streptognathodus* occurred. In contrast to the relatively narrow, deeply troughed species that characterize most of the Virgilian, *Streptognathodus* diversified into a complex group of species that possess broad upper surfaces bearing transverse ridges that are interrupted by only a narrow trough (if any at all), in addition to deeply troughed species. Lobes became a widespread feature of the platform with some forms developing nodes on them. The Pa sinistral and dextral elements became significantly more asymmetrical with this radiation. Ritter (1995), Chernykh and Ritter (1997), and Boardman, Nestell and Wardlaw (1998) documented the radiation of species during this time and illustrate several of the species. Boardman, Nestell, and Wardlaw (1998) described the distribution of *Streptognathodus* in the northern Midcontinent, presented phylogenies of the latest Virgilian to Early Permian species, and recognized four groups among them: (1) a Pennsylvanian holdover lineage, (2) an elongate lineage, (3) a robust lineage, and (4) a nodose lineage.

The Pennsylvanian holdover lineage includes *S. brownvillensis* Ritter 1994, *S.* n. sp., and *S. bellus* Chernykh and Ritter 1997. This group appears in the Brownville Limestone and ranges upward through the Five Point Limestone. *Streptognathodus bellus* is thought to be the ancestral species for the other three lineages.

The elongate lineage appears in the Americus Limestone and is first marked by the appearance of *S. elongatus* Gunnell 1933. Other species belonging to this group include *S. longissimus* Chernykh and Reshetkova 1988, *S. constrictus* Reshetkova and Chernykh 1986, and three other undescribed species. This species group ranges upward through the upper Sakmarian Wreford Limestone.

The robust lineage appears in the Falls City Limestone with *Streptognathodus alius* Akhmetshina 1990. This species group is characterized by wide robust platforms that generally lack nodes. This lineage *includes S. flexuosus* Chernykh and Ritter 1997, *S. conjunctus* Barskov, Isakova and Shchastlivtseva 1981, *S. fuchengensis* Zhao 1982, *S. fusus* Chernykh and Reshetkova 1988, *S. barskovi* (Kozur 1976) and several new species. This species ranges upward through the upper Sakmarian Wreford Limestone.

The nodose lineage appears in the Americus Limestone *with S. wabaunsensis* Gunnell 1933 and *S. farmeri* Gunnell 1933. This species group includes forms with wide platforms and nodes, and includes *S. wabaunsensis, S. farmeri, S. invaginatus* Reshetkova and Chernykh 1986, *S. isolatus* Chernykh Ritter and Wardlaw 1997, *S. nodulinearis* Reshetkova and Chernykh 1986, *S. minacutus* Barskov and Reimers 1996, and several new species. The nodose lineage ranges upward through the lower Artinskian Barneston Limestone.

Two things are noteworthy about the latest Virgilian-Early Permian radiation of *Streptognathodus.* Firstly, it followed a long interval of time, most of the Virgilian, during which little morphological change in the genus occurred, according to Ritter (1995). Secondly, many of the new species developed many of the morphologic features that were characteristic of the now extinct genus *Idiognathodus*, especially the broad flat platform with well-developed transverse ridges. Intensive work on *Streptognathodus* species across the Pennsylvanian-Permian boundary are in progress, and should elucidate the details of this radiation and the ecological distribution of morphotypes.

IMPLICATIONS FOR BOUNDARY CHARACTERIZATION AND CORRELATION

Conodonts have become perhaps the most commonly used group in characterizing and correlating Middle and Late Paleozoic chronostratigraphic boundaries. For Devonian, Mississippian, and Permian chronostratigraphic units, boundaries have been placed in stratotype sections to coincide with the first occurrence of a distinctive conodont species in a rapidly evolving lineage. Because there appear to be fewer problems with conodonts with regard to provinciality (unlike fusulinids) and ecological restriction (unlike ammonoids) in the Pennsylvanian, it is likely that conodonts will figure prominently in the selection of boundary levels within this time interval as well. For this reason, it is important to consider how the evolutionary patterns detected in *Idiognathodus* and *Streptognathodus* may impact the use of species in these genera to characterize chronostratigraphic boundaries in North America for the later part of the Pennsylvanian: the Desmoinesian-Missourian Stage boundary and the Missourian-Virgilian Stage boundary, and ultimately the Middle-Late Pennsylvanian Series boundary. The basic pattern of evolution of *Idiognathodus* and *Streptognathodus* during the later part of the Pennsylvanian, as described above, consists of a series of four distinctive faunas, bounded by relatively abrupt faunal transitions.

The North American Desmoinesian-Missourian boundary lies at the level at which a major extinction in conodonts is followed by the radiation of the 'nodose *Idiognathodus*' group. The contrast between the late Desmoinesian faunas characterized by *Neognathodus* and distinctive toughed morphotypes of *Idiognathodus* and the early Missourian flat species of *Idiognathodus* is easy to see. However, as sharp as this contrast is, the conodonts do not provide a good index by which to recognize the exact position of this current boundary in time. The origin of *I. sulciferus* is not clear, for although transitional forms between it and an ancestral form may exist in the latest Desmoinesian beds, this transition has not been fully described. Documenting this transition will be difficult in the Midcontinent due to the paucity of marine units at the traditional base of the Missourian. For this reason, Barrick, Boardman, and Heckel (1996) recommended that one of the descendants of *I. sulciferus,* either *I. eccentricus*, or even its descendent *I.* n. sp. A, be used instead, because they form part of a rapidly evolving lineage in which the relationship between ancestor and descendent has been demonstrated. Thus, the boundary would lie, not at the base of the major conodont faunal unit, but within the interval of time during which the early species were radiating from the original ancestor of the group.

This argument follows precedents set for incorporating conodonts into decisions on where to place chronostratigraphic boundaries for other intervals of geological time. The base of the Carboniferous (base of the Mississippian) has been placed at a level that corresponds with the appearance of *Siphonodella sulcata*, the second species of a rapidly evolving genus of conodonts, not at the occurrence of *S. praesulcata*, an older species whose early history is less well known (Paproth and Streel, 1984; Sandberg, Leuteritz, and Brill, 1978). The base of the Permian has been placed at a level to coincide with the appearance of *Streptognathodus isolatus*, a species that appears early in the radiation of the late Pennsylvanian-Permian *Streptognathodus* group, but not at the start of the radiation (Chernykh, Ritter, and Wardlaw, 1997; Chernykh and Ritter, 1997). Although not all species of the defining group occur in the younger stage, most of the species do, making rapid reliable age assignments at the stage level possible. In contrast, some of the controversy (e.g., Riley, 1998) surrounding the choice of *Declinognathodus noduliferus* to characterize the Mid-Carboniferous boundary (base of the Pennsylvanian/ Upper Carbonifreous) may be due to placing the boundary to coincide with the start of a poorly understood radiation of conodonts, rather than at a point slightly later during the radiation where the evolutionary history is better understood.

Because the base of the Kasimovian Stage is significantly stratigraphically lower than the base of the Missourian (Heckel, Alekseev, and Nemyrovska, 1998; Ritter et al., this guidebook), it is possible that neither level may become the base of a global Middle-Late Pennsylvanian Series boundary. A boundary at the current base of the Kasimovian might be characterized by the appearance of "*Streptognathodus subexcelsus*" (a *nomen nudum*), but the evolutionary origin of this form has yet to be documented (Heckel, Alekseev, and Nemyrovska, 1998). As discussed above, the traditional base of the Missourian in North America cannot be used, and the newly proposed base of the Missourian lies slightly higher (Heckel, Boardman and Barrick, this guidebook). The most likely possibility of a compromise, intermediate boundary level between the base of the Kasimovian and the base of the Missourian, may lie in the interpretation of the evolution of the clade of troughed *'Idiognathodus'* that includes: "*S. subexcelsus*", and *Idiognathodus* sp. 5 and 6 of Swade (1985) [6 = *'I'. nodocarinatus* (Jones, 1941)] (see Lambert and Heckel, this guidebook). Although these forms occur both in North American cyclothems and on the Russian platform, they are at this point too poorly known to evaluate their applicability for boundary characterization and definition.

Incorporating conodonts into the boundary level for two late Pennsylvanian stages (Missourian/Virgilian or Kasimovian/Gzhelian) is hampered by the sudden turnover of species of *Streptognathodus* that occurs near the traditional boundaries of these units. The disappearance of many species of *Streptognathodus* and the sudden appearance of *S. firmus* and *Idiognathodus simulator* in the

Eudora Shale (although lower than the traditional Midcontinent stage boundary) are obvious biostratigraphic changes that should allow for easy recognition of two stages. However, the lack of a demonstrated ancestor-descendent transition for either *S. firmus* or *I. simulator* makes selection of a boundary here difficult. Unlike the examples discussed above, neither *S. firmus* nor *I. simulator* appear to be followed by a series of rapidly changing species from which an ancestor-descendent link might be chosen to characterize the boundary. Boardman, Barrick, and Heckel (1989) suggested that the distinctive lobed species *S. zethus,* which appears only a little higher than one of the traditional Missourian-Virgilian boundaries (in Missouri) in Midcontinent North America might be used to characterize the boundary (see discussion by Heckel, Alekseev, and Nemyrovska, 1998). However, transitional forms have yet to be described. Another possibility is that the extremely rapid reduction in carinal length that occurs in the transition from *S. firmus* to *S. pawhuskaensis* might be broken down into steps, one of could be used to characterize the boundary. Preliminary work in the Midcontinent region, north-central Texas, and New Mexico, suggests that biostratigraphic differentiation based on carina length in successive cycles is possible and correlatable over a large area (Keairns, 1999). As we understand the transition now, it may be possible to distinguish the South Bend cycle, which lies near the traditional base of the Virgilian in Kansas and Nebraska, from the underlying Eudora and overlying Iatan cycles. We do not know exactly where the *S. firmus-S. pawhuskaensis* transition lies in the Russian sequence.

SUMMARY

We believe that the major outline of evolution of species in *Idiognathodus* and *Streptognathodus* during Late Pennsylvanian time is fairly well understood as described above. The four distinct faunal intervals easily subdivide the succession into four major blocks of time. However, even though two of these breaks lie near traditional Midcontinent chronostratigraphic boundaries, the base of the Missourian and the base of the Virgilian, the most obvious stratigraphic breaks in the faunal succession do not provide the biostratigraphic resolution required for precise characterization and correlation of a chronostratigraphic boundary. Following the precedents set using conodonts to characterize boundaries at other times in the Paleozoic, we conclude that a boundary level that corresponds with the appearance of a species above its immediate ancestor within the well-documented early radiation of a group will best serve for boundary characterization and correlation. This approach is best shown by the proposed new level for the base of the Missourian Stage. Choice of a level early in the formation of a species group additionally allows for easy and reliable assignment of most conodont samples, including sparse or poorly preserved faunas, into the appropriate stage.

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PROPOSED DESMOINESIAN-MISSOURIAN STAGE BOUNDARY STRATOTYPE

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INTRODUCTION

Although initially recognizing the Pennsylvanian and Mississippian as the upper and lower series of the Carboniferous System, the U.S. Geological Survey in mid-century raised each in rank to system and regarded them collectively as the 'Carboniferous systems' (Bradley, 1953). Shortly thereafter, the U.S.G.S. adopted as official series designations the geographical terms Morrow, Atoka, Des Moines, Missouri, and Virgil for the Midcontinent region, and the positional terms Lower, Middle, and Upper for the Appalachian region and elsewhere (Bradley, 1956). Although the positional terms were considered approximately equivalent in the different regions, and the Lower was considered equivalent to the Morrow, the Middle to the Atoka and Des Moines, and the Upper to the Missouri and Virgil, no official biostratigraphic definition was given for any of these series subdivisions at that time. Prior to this, several workers had proposed similar groupings, but regarded the Midcontinent names as stages of the tripartite positional series names (Cheney et al., 1945) or of new geographic series names that received little further use (Moore and Thompson, 1949). Along with Moore and others (1944), these authors did provide general biostratigraphic characterization of these major subdivisions, but sought out disconformities for their boundaries in accordance with the traditional practice of that time. Workers since then have generally not provided careful biostratigraphic definitions for any of the boundaries, certainly not the rigorous requirements for selecting global boundaries outlined by Hedberg (1976), Cowie (1986) and Remane and others (1996). Since the 1960s the Kansas Geological Survey (where the senior author began his research program) has essentially followed Cheney and others (1945) in recognizing the Middle Pennsylvanian Series as comprising the Atokan and Desmoinesian Stages, and the Upper Pennsylvanian Series as comprising the Missourian and Virgilian Stages (Zeller, ed., 1968). All three of us have generally followed this practice in our recent work and have regarded the Desmoinesian-Missourian Stage boundary as the Middle-Upper Pennsylvanian Series boundary (e.g., Boardman et al., 1990; Barrick et al., 1996).

Several proposals recently have been made to the SCCS (Heckel and Villa, 1999a) to facilitate agreement on long-debated aspects of Carboniferous nomenclature. One set (Heckel and Villa, 1999b) calls for recognizing the Mississippian and Pennsylvanian as Subsystems of the Carboniferous System on a global scale (with Lower and Upper Carboniferous considered acceptable subequal terms, if defined by the former terms). Another (Heckel and Villa, 1999c) calls for global Lower, Middle, and Upper Series boundaries of the two subsystems to be selected according to the rigorous guidelines of the IUGS (recognizing that regional names could be used subequally if their boundaries are coincident), and for regional stage boundaries to be selected now to stabilize terminology in those areas (recognizing that these boundaries can be candidates for global series boundaries if they are determined to be globally correlatable). Part of the rationale for these proposals stems from two confounding factors in Carboniferous stratigraphy: 1) the long-standing recognition that the regional endemism of biotas, particularly in the Pennsylvanian, make it very difficult to correlate between the various regions, and 2) the increasing realization that the significant glacial-eustatic sea-level fluctuation that controlled so much of Pennsylvanian stratigraphy makes it very difficult to find acceptable boundary stratotypes in localities of continuous marine deposition in the shelf areas where the regional names have originated. As a result, it will take some more time to adequately search for globally correlatable series boundaries, but in some cases regional stage boundaries can be chosen now or in the near future, so that they can stabilize regional usage and correlation, and become possible candidates for the global series boundaries once the further extensive work needed to establish correlatability is completed. In the context and spirit of these proposals, we no longer regard the Desmoinesian-Missourian Stage boundary as necessarily coincident with the Middle-Upper Pennsylvanian Series boundary, but merely a candidate for this global boundary.

Because we now believe that we have enough knowledge of the lithostratigraphy, genetic stratigraphy, and biostratigraphy of the rocks below, across, and above the traditional Desmoinesian-Missourian boundary in Midcontinent North America, we are proposing a stratotype for this boundary that is consistent with the IUGS guidelines. This boundary stratotype is in a basin-marginal position in the southern Midcontinent region where many of the disconformities that separate all of the cyclothemic marine transgressive-regressive units north-

Heckel, P. H., Boardman, D. R., and Barrick, J. E., 1999, Proposed Desmoinesian–Missourian Stage boundary stratotype; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 186–198.

ward (thus higher) on the shelf disappear southward toward the basin. This boundary can be traced throughout the Midcontinent Basin, recognized in the Illinois Basin, the eastern shelf (in north-central Texas) of the west Texas Midland Basin, the Honaker Trail section in southeastern Utah, and with increasing hiatus, its position can be determined in the Appalachian Basin. Therefore it is a useful chronostratigraphic boundary in the region that was covered episodically during that time by the North American Midcontinent Sea. Further work in other parts of the world will be needed to determine whether or not it is a useful boundary globally.

TRADITIONAL DEFINITION OF THE TWO STAGES

The **Desmoinesian Stage** is derived from the Des Moines formation named by Keyes (1893) from exposures in the valley of the Des Moines River in south-central Iowa, and was soon termed a series (see Moore, 1936, p. 51). Its base was defined by the major disconformity above the Mississippian. Its top, which was originally placed at the base of the lower Missourian Bethany [Falls] Limestone (and later the slightly older Hertha Limestone), was stabilized by Moore (1932, 1936) at the major disconformity associated with the base of the even slightly older Pleasanton Group. This series was designated as the zone of *Fusulina* (Moore, 1949; Moore and Thompson, 1949), now *Beedeina* (Stewart, 1968). It had previously been noted as the brachiopod zone of *Mesolobus mesolobus* and *Marginifera muricatina*, and the ammonoid zone of *Owenoceras* and *Wellerites*, and the lower part (the Cherokee Group) was considered the fusulinid Subzone of *Wedekindellina* (Moore et al., 1944). More recent work summarized by Boardman and others (1990) show the Desmoinesian to be characterized also by the problematical coral-like sponge *Chaetetes*, the conodont *Neognathodus*, and the ammonoids *Gonioglyphioceras* and *Eothalassoceras* in addition to *Wellerites*. More recently Boardman and others (1994) recognized the Desmoinesian as comprising the ammonoid zone of *Wellerites* followed upward by the zone of *Eothalassoceras*. The terrestrial biota of the Desmoinesian is included in floral zones 9 (*Neuropteris rarinervis*) and 10 (*Neuropteris flexuosa* and *Pecopteris* spp.) of Read and Mamay (1964). It is characterized by abundant lycopods (Phillips et al., 1985), and by a diverse palynomorph flora dominated by *Lycospora* (Peppers, 1996). Not surprisingly Desmoinesian rocks contain the most abundant coal resources of the Midcontinent and Illinois Basins. Desmoinesian conodont faunas are characterized by the genus *Neognathodus*, but are largely dominated by flat-platformed *Idiognathodus delicatus* Gunnell 1931 and its relatives. In addition, the upper part of the Marmaton Group at the top is further characterized by the abrupt appearance of a troughed clade of idiognathodids that was recognized by J. W. Swade (personal communication to PHH, 1983) as distinct from *Streptognathodus*, which evolved later in the overlying Missourian Stage. This troughed clade will be named as a separate genus in honor of Swade (see Lambert and Heckel, this guidebook).

The **Missourian Stage** is derived from the 'Missouri terrane' named by Keyes (1893) for exposures along the Missouri River in Iowa and northwestern Missouri, and soon thereafter was referred to variously as a formation, stage, series, and group (see Moore, 1936, p. 68). Its base was originally placed at the base of the Bethany [Falls] Limestone, then the underlying Hertha Limestone, then firmly established by Moore (1936) at the disconformity recognized in the sandstone-dominated lower part of the underlying Pleasanton Group and equivalent Seminole Formation in Oklahoma, based on the stratigraphic practice of that time. Its upper part originally included the Virgilian, which was separated from it by Moore (1932; see Moore, 1936), based on another disconformity recognized at that time in the sandstone-dominated lower middle part of the Douglas Group. The Missourian was designated as the lower part of the zone of *Triticites* (Moore, 1949; Moore and Thompson, 1949), and it previously had been noted as the brachiopod zone of *Chonetina* and the ammonoid zone of *Eothalassoceras* (erroneously, based on a miscorrelation) and *Prouddenites* (Moore et al, 1944). More recent work shows that *Triticites* does not appear until the fourth major marine unit (Dennis) above the base (but these are considered advanced forms of this genus) and that *Eowaeringella* and a species of *Fusulina* occur in the third major marine unit (Swope) above the base (Thompson, 1957). Boardman and others (1994) updated the ammonoid information and recognized the Missourian Stage as comprising the zones of *Pennoceras*, *Preshumardites*, and the lower part of the zone of *Pseudaktubites*. The terrestrial biota of the Missourian Stage is included in combined floral zones 11 and 12 (*Odontopteris* sp.) of Read and Mamay (1964). The palynomorph flora is reduced in diversity from that of the Desmoinesian and strongly dominated by spores of ferns, especially certain species of *Punctatisporites* and *Cyclogranisporites* (Peppers, 1996). The conodont faunas of the Missourian are strongly dominated by idiognathodids throughout, by species of *Idiognathodus* that probably descended from the *I. delicatus* group in the lower part (and in one marine unit [Stanton] toward the top), and by the newly evolving descendant genus *Streptognathodus*, which appears in the third major marine unit (Swope) above the base, and dominates most of the upper part of the stage.

As mentioned previously, the traditional **Desmoinesian-Missourian boundary** was placed at the disconformity recognized to be associated with the sandstones that dominate the lower part of the Pleasanton Group (Moore, 1936), as this disconformity appeared to mark an abrupt faunal turnover in the Midcontinent succession. Recent summaries (e.g., Boardman et al., 1990) show the extinction of the following typically Desmoinesian genera: the brachiopod *Mesolobus*, the fusulinid *Beedeina*, the problematical sponge *Chaetetes*, the ammonoids *Gonioglyphioceras*, *Wewokites*, and *Eothalassoceras* (updated by Boardman et al., 1994), the palynomorphs *Granasporites*, *Thymospora*, and *Lycospora* (the latter, a great reduction, updated by Peppers, 1996), and the conodonts *Neognathodus* and the pre-*Streptognathodus* troughed idiognathodid clade. Schutter and Heckel (1984) and Heckel (1991) suggested that this extinction event may have resulted from a greater withdrawal of the glacial-eustatically fluctuating sea down to somewhat steeper, more basinal slopes than usual, which would have both crowded the living space of the marine forms and reduced the fresh-water swamp area needed for lycopod reproduction, as well as explain the previously recognized disconformity on the shelf. As a result, the earliest Missourian biotas are quite reduced in diversity, with few new generic appearances near the base, other than the ammonoid *Pennoceras* (Boardman et al., 1994). The great increase in fern spores is among taxa that were present in small numbers in the Desmoinesian (Peppers, 1996). Among conodonts, the lowest traditional Missourian beds contain a single lineage of idiognathodids represented by *I. sulciferus* Gunnell 1933, which probably descended from the *I. delicatus* group, but as yet without a specific documented ancestor. This species gave rise to a radiation of new species up through the lower part of the Missourian Stage (Barrick et al., 1996; this guidebook).

STRATIGRAPHY OF THE BOUNDARY STRATA

In its type region, the strata of the Desmoinesian Stage comprise the shale, coal and sandstone-dominated Cherokee Group overlain by the limestone-dominated **Marmaton Group**. Forming the top of the Marmaton Group are the largely terrestrial Memorial Shale overlain by the marine Lost Branch Formation (Fig. 1), which can be traced from Iowa across the entire Northern Midcontinent Shelf into the basinal region of central Oklahoma (Heckel, 1991). In Oklahoma and southern Kansas and locally northward, the Dawson Coal bed forms the top of the **Memorial Shale**, lying upon a paleosol that extends from Iowa at least to Okfuskee County in east-central Oklahoma. The Dawson Coal contains the highest widespread occurrence of the diverse, 'typically Desmoinesian' lycospore-dominated palynoflora (Peppers, 1996).

The **Lost Branch Formation** overlies the Dawson Coal or its paleosol at the top of the Memorial Shale (Fig. 1) and is a classic northern Midcontinent major cyclothem, but with limited development of the two limestone members. Its transgressive limestone consists of the thin Sni Mills Limestone Member, which extends from Iowa to the Missouri-Kansas border in the north, and the Homer School Limestone bed, which is present only in east-central Oklahoma in the south. The Homer School carries the highest reported occurrence of *Chaetetes* in the Midcontinent. The offshore 'core' shale of the Lost Branch cyclothem is the conodont-rich Nuyaka Creek Black Shale bed (with conodont-rich gray shale facies to the north), which extends from Iowa to east-central Oklahoma, overlying the Sni Mills Limestone, the Homer School Limestone, local transgressive shale facies, the Dawson Coal, or its paleosol. The Nuyaka Creek Shale carries an abundant conodont fauna dominated by troughed *'Idiognathodus' nodocarinatus* Jones 1941 [= sp. 6 of Swade, 1985] and flat-platformed *Idiognathodus expansus* Stauffer and Plummer 1932, and containing *Neognathodus, Idioprioniodus* and the only occurrence of *Gondolella magna* in the Midcontinent. It also carries the highest occurrences of the ammonoids *Gonioglyphioceras, Wewokites,* and *Eothalassoceras* (Boardman et al., 1994). Overlying the Nuyaka Creek Shale in Iowa is the regressive Cooper Creek Limestone Member, which carries the highest occurrence of the fusulinid *Beedeina* (*B. eximia*) in the Midcontinent (Thompson et al., 1956) and the highest occurrence of the conodont *Neognathodus* in this northern area. Elsewhere, the Nuyaka Creek black shale is overlain by a moderately to sparsely fossiliferous gray shale up to 14 ft (4.2 m) thick in Kansas and Missouri and up to 55 ft (17 m) thick in east-central Oklahoma. This gray shale carries the highest occurrence of the brachiopod *Mesolobus* in the Midcontinent and the highest occurrence of *Neognathodus* in Kansas. Capping this shale locally in northeastern Oklahoma and southeastern Kansas is the Glenpool Limestone bed, which represents a later phase of regression than the Cooper Creek Limestone owing to its more basinward position (or it is possibly a minor transgressive-regressive phase at the end of Lost Branch marine deposition). The Glenpool (and its southward equivalent fossiliferous shale in east-central Oklahoma) carries a sparse to moderate conodont fauna that is subequally dominated by *Adetognathus* and *Idiognathodus*, and includes the highest occurrences known of *Neognathodus, I. expansus*, and *'I.' nodocarinatus*. It also contains the first appearance of a new flat-platformed morphotype reported by Barrick and others (1996) as *I. arendti* Barskov & Alekseev 1976?, which is possibly transitional between *I. expansus* and younger *I. sulciferus*.

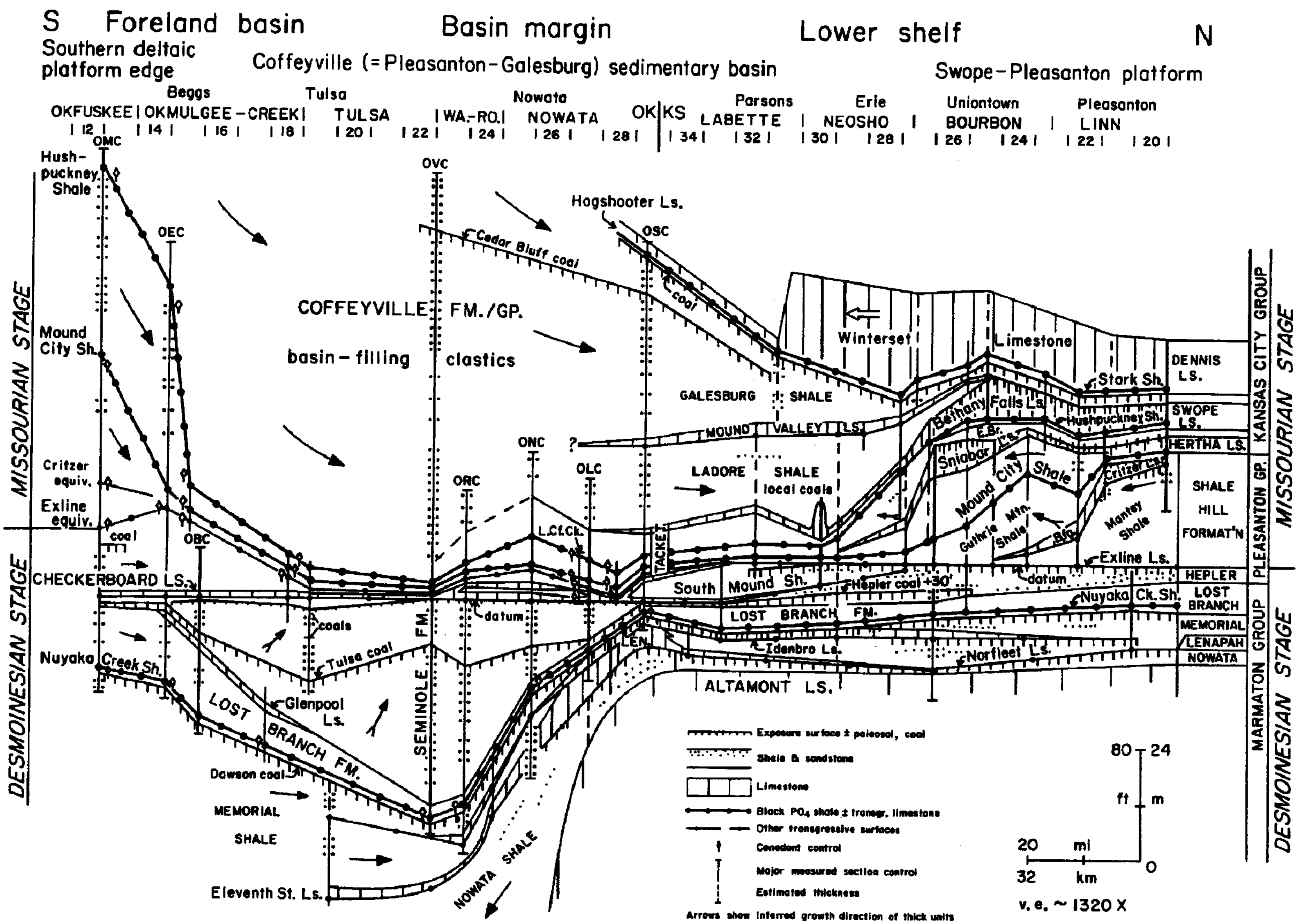

Fig. 1: Correlation cross-section of upper Marmaton, Pleasanton, and lower Kansas City succession from east-central Kansas (on lower shelf) to east-central Oklahoma (near southern basin margin), showing continuity of section across proposed Desmoinesian-Missourian boundary in basin margin region. L.Cf.Ck. = stratotype.

The Lost Branch Formation is overlain by the **Pleasanton Group** in Kansas and by the **Seminole Formation** in Oklahoma. The Seminole Formation is mainly sandstone and shale, with conglomerate southward, and contains up to three beds of coal in the Tulsa area (Fig. 1). The lower or Tulsa coal bed contains some *Lycospora*, but all three are dominated by the fern and other spores that are characteristic of younger Missourian coals (Peppers, 1996). The Pleasanton Group now comprises two formations in Kansas, the Hepler Formation overlain by the Shale Hill Formation (Heckel and Watney, in press), and the lower part of the Hepler Formation is equivalent to the Seminole Formation. The lithostratigraphic contact between the Lost Branch and overlying formations is either at the top of the regressive limestone (Cooper Creek, Glenpool) where present, or at the base of the lowest conspicuous, laterally persistent overlying sandstone bed where the upper Lost Branch is entirely shale (Heckel, 1991). Both limestones are generally overlain by mudstone paleosols, which have the subaerial sequence boundary at their top. In most places the basal Hepler and Seminole sandstones have abrupt bases and appear to be channel-filling, and therefore mark an erosional sequence boundary. In some places the basal sandstone of these formations is part of a coarsening-upward deltaic sequence, which would presumably have the sequence boundary at the top. In these places, the sequence boundary could be either submarine or subaerial depending on how far delta progradation extended before sea level started rising, but in any case, no marine fossils are yet known anywhere from the lower parts of either the Hepler or Seminole Formations, which thus appear to be terrestrial along outcrop.

The **Hepler Formation** is entirely mudstone paleosol in Iowa, and mainly sandstone overlain by terrestrial shale capped by mudstone paleosol in Missouri and Kansas, and it is overlain throughout this region by the Exline Limestone Member at the base of the Shale Hill Formation. In the top of the Hepler Formation in southeastern Kansas, the **South Mound Shale Member** appears above a coal bed ('Hepler') and paleosol in the middle of the Hepler (Fig. 1). The South Mound consists mainly of sparsely fossiliferous marine shale with a thin argillaceous skeletal limestone at the base, and a thin mudstone at the top that is locally overlain by a coal bed and locally underlain by a thin sandstone bed. South of the disappearance of the capping coal bed, the South Mound is overlain by a thin shallow-water limestone that is below the horizon of the Exline. The 'Hepler' coal contains a typical Missourian fern-dominated palynoflora (Peppers, 1996).

Farther southward across the Kansas-Oklahoma border, the **South Mound Shale Member** appears to grade into the **Checkerboard Limestone** (which overlies the Seminole Formation in Oklahoma) as the basal South Mound limestone bed and the overlying thin limestone bed merge in northern Oklahoma. Where the South Mound Shale Member is present within the Checkerboard Limestone, the two enclosing limestone beds are referred to as 'lower' and 'upper' Checkerboard. Because paleosols with local coal beds overlie both the north end of the South Mound Shale in Labette County, Kansas, and the shale above the south end of the Checkerboard Limestone in Okfuskee County, Oklahoma (Fig. 1), the South Mound-Checkerboard marine unit represents a minor transgressive-regressive unit (or cyclothem) above the marine Lost Branch Formation and below the Exline Limestone. Across northeastern Oklahoma into southernmost Kansas between the north end of the southern coal bed and the south end of the northern coal bed, the Checkerboard-South Mound cyclothem shallows upward but is overlain by the deepening deposits of the Exline cyclothem in a continuous marine sequence with no evidence of a subaerial disconformity. The condensed interval of this minor cyclothem consists of a zone of sparse to moderate conodont abundance in the lower limestone bed of the South Mound Shale in Kansas, in the lower part of the South Mound Shale facies within the Checkerboard Limestone in northern Oklahoma, and in the Checkerboard Limestone where it is a single bed in the Tulsa area. This fauna is dominated by *Adetognathus* in the north, by *Idiognathodus* toward the south, and contains sparse *Ellisonia* and *Hindeodus* throughout and sparse *Idioprioniodus* toward the south. The *Idiognathodus* are almost entirely *I. sulciferus* Gunnell 1933, but a few specimens of the possible transitional form that first appears in the Glenpool Limestone below are present in shale thought to be equivalent to the Checkerboard Limestone in east-central Oklahoma.

The **Shale Hill Formation** was established by Heckel and Watney (in press) to encompass the upper Pleasanton strata in Kansas and northward. It is subdivided into four members, in ascending order: Exline Limestone, Mantey Shale, Critzer Limestone, and Guthrie Mountain Shale (Fig. 1). Over 100 ft (30 m) thick in Missouri and northeastern Kansas, it thins southward in east central Kansas nearly to disappearance in southeastern Kansas. Here its thinned equivalent is included at the base of the dark shale succession of the Tacket Formation, which encompasses all the strata upward through the top of the Swope Limestone of the lower Kansas City Group of the northern shelf in this apparently basinal region of deposition developed at this time across southern Kansas and northeastern Oklahoma into Okmulgee County. Southward, the conodont-rich dark shales that serve as marker beds within the Tacket Formation become separated by thick sequences of upward-coarsening deltaic clastics derived from the southerly orogenic source. In the Morse core from Okfuskee County (OMC on Fig. 1), both the Exline and Critzer Limestones are again differentiated in this southward-thickening succession, and the Shale Hill Formation equivalent extends from the base of the Exline

Limestone upward to the base of the black Mound City Shale.

The **Exline Limestone Member** overlies the Hepler Formation at the base of the Shale Hill Formation. It is a dense, dark limestone in Iowa that becomes increasingly shaly southward in Missouri and Kansas, where in places it is an extremely fossiliferous calcareous shale. Southward it becomes a nearly black, but still fossiliferous shale that is softer than the overlying hard phosphatic Mound City and Hushpuckney black shales, but darker than the other dark gray shales that separate these marker beds in the Tacket Formation across northeastern Oklahoma. South of Tulsa, its fossil content increases to the point that it is again a shaly to more solid skeletal limestone that is traced southward into the cores in Okmulgee and Okfuskee Counties (Fig. 1). It is the condensed interval of the Exline cyclothem, a depositional unit that also encompasses the thin transgressive beds (including the Grain Valley Coal) above the paleosol near the top of the Hepler Formation and the regressive northward-thickening coarsening-upward prodeltaic to deltaic clastics of the Mantey Shale in Missouri and Kansas. Southward, this cyclothem includes the thin transgressive shale above the top of the Checkerboard Limestone and thin regressive shale below the base of the Mound City Shale and it also includes the Critzer cyclothem in the generally condensed succession of the Tacket Formation in northeastern Oklahoma. These two cyclothems again become separated as the Critzer Limestone equivalent reappears above the Exline in their southward thickening equivalents in core OMC in east-central Oklahoma. The Exline condensed interval in both argillaceous limestone and black shale facies contains an abundant conodont fauna dominated by *Idiognathodus*, including many juveniles in Missouri, and containing smaller numbers of *Hindeodus* (in the limestone facies), *Adetognathus* and *Idioprioniodus*, along with a scattering of *Ellisonia, Diplognathodus* and *Aethotaxis*. Most idiognathodids are *I. sulciferus*, but the remainder is the first appearance of its descendant *I. eccentricus* (Ellison 1941). Shale in the regressive phase of the Exline cyclothem carries the first appearance of the ammonoid genus *Pennoceras* (Boardman et al., 1994).

The **Critzer Limestone Member** overlies the Mantey Shale Member from the Kansas City area to east-central Kansas, where it descends southward over the thinning prodeltaic shale sequence and approaches the horizon of the Exline Limestone (Fig. 1). The Critzer is fine abraded skeletal calcarenite in its shelf facies to the north, grading to a distinctive alternation of sparsely skeletal calcilutite and shale ('Bourbon flags' [B.fg. on Fig. 1]) above the prodeltaic slope, and southward to argillaceous skeletal limestone beyond the toe of the slope, where it resembles the Exline Limestone just below. This southern facies contains relatively abundant conodonts marking it as a condensed interval of the Critzer cyclothem, but the condensed interval extends northward as the conodont-rich shale bed at the top of the Mantey Shale beneath the slope ('Bourbon flags') and shelf facies of the Critzer Limestone. Thus the Critzer cyclothem includes the transgressive and highstand very top of the thick Mantey Shale, the two regressive northern shelf and slope facies of the Critzer Limestone and the later regressive and lowstand Guthrie Mountain Shale (which is a paleosol in the Kansas City area). Southward, the Critzer Limestone (and cyclothem) apparently merges with the top of the Exline across southeastern Kansas and northeastern Oklahoma, and it is not recognized as a distinct unit again until it is separated by southerly derived clastics in the Morse core (OMC) in Okfuskee County (Fig. 1). The conodont fauna of the Critzer cyclothem is strongly dominated by *Adetognathus* below the shelf calcarenite facies in the north, but becomes dominated by *Idiognathodus* below the slope faces and southward, where it also contains smaller numbers of *Hindeodus* and *Idioprioniodus* as well as *Adetognathus*. Its idiognathodids are mainly *I. sulciferus* with subordinate *I. eccentricus*, just as in the Exline, which does not allow the two cyclothems to be differentiated where they are apparently physically merged across southeastern Kansas and northeastern Oklahoma.

The **Hertha Limestone** overlies the Shale Hill Formation from east-central Kansas northward and comprises two members, the Mound City Shale, overlain by the Sniabar Limestone (Fig. 1), which together form the main part of the Hertha cyclothem. The Mound City contains a dark phosphatic conodont-rich 'core' shale facies at the base, which is the condensed interval of the cyclothem from Iowa to east-central Oklahoma. From Kansas City northward it overlies a paleosol with the Ovid Coal bed locally at the base. Southward it overlies the exposure surface at the top of the shelf facies of the Critzer Limestone, then south of the Mantey Shale-'Bourbon flags' slope, it overlies the thickening Guthrie Mountain Shale with an abrupt but conformable contact, and in a few places with a thin unnamed transgressive limestone at the base of the black shale bed. In this same region, the upper part of the Mound City above the black phosphatic condensed interval thickens into a prodeltaic sequence of gray shale with skeletal limestone beds at the base, flaggy limestones locally in the middle, and local sandstone at the top. This is the initial regressive sequence of the Hertha cyclothem, and it is capped by the Sniabar Limestone, which in this region may represent a minor transgression that inhibited detrital influx before final regression and formation of the paleosol in the overlying thin Elm Branch Shale (E.Br. on Fig. 1) from Bourbon County northward. South of Bourbon County, both the upper gray Mound City and the Sniabar thin nearly to disappearance as the black phosphatic basal Mound City shale descends above the southward-thinning underlying Guthrie Mountain Shale, and approaches the Exline horizon in the middle of the Tacket Formation across southernmost Kansas and northeastern Oklahoma before becoming separated again by the thick coarsening-upward sequence of southerly derived clastics in east-central Oklahoma (Fig. 1). The overlying exposure surface disappears southward in Kansas where both the upper Mound City and Sniabar thin abruptly, and the overlying Elm Branch Shale thickens into lowstand but still marine clastics in Neosho County. The condensed interval in the black phosphatic facies of the Mound City Shale carries an abundant classic 'core'-shale conodont fauna dominated by *Idiognathodus*, and including good numbers of *Idioprioniodus* and *Gondolella* throughout the entire region. The idiognathodids include *I. sulciferus* (still dominant), *I. eccentricus*, and the first appearance of more nodose descendants, *I. clavatulus* (Gunnell 1933), and *I.* n. sp. A of Barrick and others (1996).

The **Swope Limestone** overlies the Elm Branch Shale from Neosho County in southeastern Kansas northward (Fig. 1). In this region it comprises three members that form the main part of a classic Midcontinent cyclothem: thin transgressive Middle Creek Limestone Member, thin black phosphatic Hushpuckney Shale Member, the 'core' shale condensed interval, and thick regressive Bethany Falls Limestone Member. The Swope cyclothem includes the early transgressive marine shale facies of the upper Elm Branch Shale at the base and the mudstone paleosol of the Galesburg Shale at the top. The Middle Creek Limestone disappears southward in Neosho County, the Bethany Falls Limestone thins southward there and disappears in northern Oklahoma, while the black phosphatic Hushpuckney Shale descends above the southward-thinning underlying units to approach the Mound City black shale horizon and extend southward just above it in the Tacket Formation across southernmost Kansas and northern Oklahoma until ascending again above the southerly derived deltaic clastic sequence in east-central Oklahoma (Fig. 1). The Hushpuckney Shale carries another abundant classic 'core'-shale conodont fauna dominated by *Idiognathodus* and containing good numbers of *Idioprioniodus* and *Gondolella*, including the first appearance of *G. sublanceolata* and one of the few appearances of platformless *G. denuda* in the Midcontinent. The Hushpuckney idiognathodid fauna displays a complex range of morphologic variation. It includes the species present below (*I. sulciferus, I. eccentricus, I. clavatulus,* and *I.* n. sp. A), as well as some forms that do not easily fit into those species designations. In this unit, *Idiognathodus* is joined by the earliest representative of its descendant genus *Streptognathodus, S. cancellosus* (Gunnell 1933), which apparently descended from *I.* n. sp. A, a descendant of *I. eccentricus* (Barrick et al., 1996).

In southeastern Kansas south of the disappearance or extreme thinning of the Sniabar, Middle Creek and Bethany Falls Limestones and their intervening and underlying shale units, the entire thinned succession from the top of the Checkerboard Limestone to the top of the thinned Bethany Falls Limestone is classified as the previously mentioned **Tacket Formation**. This unit is equivalent to the entire Shale Hill Formation, Hertha Limestone, Elm Branch Shale, and Swope Limestone (Fig. 1), that is, the upper part of the Pleasanton Group and the lower three formations of the Kansas City Group of the northern shelf. Its three marker beds are the three 'core' shales, the condensed intervals of the lowest three major marine units or cyclothems of the traditional Missourian Stage (Exline, Mound City/Hertha, and Hushpuckney/ Swope). It forms a continuous marine succession with the underlying Checkerboard-South Mound sequence from southern Kansas to east-central Oklahoma, a succession that extends upward into the overlying formations. The Tacket represents the dark dysoxic to periodically anoxic basinal facies of all the northern classic cyclothems (and southern coarsening-upward detrital equivalents) during a long period of time when sea level did not withdraw from this lower basin-marginal part of the shelf exposed along outcrop. The Tacket Formation (and northward the Swope Limestone) is overlain by the thick Ladore Shale, followed upward by the Mound Valley Limestone and the greatly thickened Galesburg Shale (Fig. 1), which are grouped in the Coffeyville Group in Kansas (Formation in Oklahoma). The Ladore represents a lowstand detrital influx, and the Mound Valley Limestone represents a minor transgression, and neither of them extended (or were preserved) north of the Swope shelf in Bourbon County, Kansas. The overlying thick detrital facies of the Galesburg Shale includes the core shale of the Mound Valley cyclothem at the base and largely represents its regressive facies. All three of these formations overlying the Tacket Formation in the Kansas-Oklahoma border region represent basin-filling facies without a definite surface of subaerial exposure upward until the paleosol of the Cedar Bluff Coal bed high in the Galesburg succession, and they serve to accentuate the starved-basin environment of the Tacket Formation in this region.

SUMMARY OF IDIOGNATHODID CONODONT SUCCESSION

The succession of species of idiognathodid conodonts mentioned in the previous discussion of stratigraphy is summarized here. This is the most abundant group of conodonts in middle to late Pennsylvanian strata in central and eastern North America. It strongly dominates the very abundant faunas of the offshore 'core' shales of the cyclothems and the less abundant faunas in the adjacent offshore carbonate facies, and it is at least subequally present in many of the even sparser nearer-shore carbonate faunas. Just as important, this group also displays a sequence of descendant species in the traditional early Missourian strata that allows the definition of a meaningful Desmoinesian-Missourian boundary for Midcontinent North America (see Barrick, Heckel, and Boardman, this guidebook). Because idiognathodids appear to be sufficiently abundant elsewhere in the world at this time, this boundary should be able to provide a viable candidate for a Global Stratigraphic Section and Point (GSSP).

Most upper Desmoinesian Marmaton Group faunas are strongly dominated by *Idiognathodus delicatus* Gunnell 1931 and other members of its group. In the highest Marmaton Lost Branch Formation, *I. expansus* Stauffer & Plummer 1932 of this group subequally dominates (along with '*I.*' *nodocarinatus* Jones 1941 of the separate troughed lineage) the abundant fauna of the Nuyaka Creek 'core' shale and is present in the higher late regressive Glenpool Limestone. Also in the Glenpool, a new more triangular morphotype appears that has a less prominent inner lobe and fewer and coarser transverse ridges than *I. expansus*; smaller specimens have a long carina, a feature that is more typical of Missourian species of *Idiognathodus*, but like only the smallest, juvenile specimens of *I. expansus*. This was called *I. arendti* Barskov & Alekseev 1976*?* by Barrick and others (1996).

The faunas of the lowest traditional Missourian marine unit, the South Mound Shale and equivalent Checkerboard Limestone (constituting the Checkerboard-South Mound cyclothem) are strongly dominated by *I. sulciferus* Gunnell 1933, which has a long triangular platform with coarse transverse ridges and well developed lobes, and longer, more flaring adcarinal ridges than Desmoinesian species. Small adolescent forms have a long carina that becomes progressively shorter in larger specimens (Barrick et al., 1996). Some mature specimens show a short anterior groove or other interruption in the transverse ribbing extending toward the posterior along the inner side of the platform. A few specimens of the morphotype that first appeared in the older Glenpool Limestone are found with *I. sulciferus* in beds of this or slightly younger age in central Oklahoma (off the left side of Fig, 1). This morphotype may be the ancestor of *I. sulciferus* (ibid.), but this has yet to be established.

The faunas of the next higher and much more widespread Missourian marine unit, the Exline cyclothem (and the overlying Critzer minor cyclothem) are again dominated by *I. sulciferus*, but it is joined by smaller numbers of *I. eccentricus* (Ellison 1941). This species is distinguished by a continuous groove along the inner side of the platform from the adcarinal groove to near the posterior end, and it descended from *I. sulciferus* by stabilization of the irregular breaks in the transverse ridges along the inner side of some specimens of that species (Barrick et al., 1996). The faunas of the widespread Mound City Shale in the next higher Hertha major cyclothem are also dominated by *I. sulciferus* and include *I. eccentricus*, but these are joined by two new species, *I.* n. sp. A of Barrick et al., 1996, and *I. clavatulus* (Gunnell 1933). The former has a medial row of carinal nodes that extend posteriorly and developed from *I. eccentricus* by posterior extension of the outer adcarinal groove (ibid.). The latter has a deep medial trough that developed from the shallow medial trough in some morphotypes of *I. sulciferus* (ms. in prep.). The faunas of the widespread Hushpuckney Shale in the next higher Swope major cyclothem are even more diverse, with all four species known in the Hertha recognized, but with the addition of a least one new species, *Streptognathodus cancellosus* (Gunnell 1933). This species is characterized by the dominance of flaring adcarinal ridges over lateral lobes on the anterior margin of the platform and by a long carina that extends toward the posterior end as a single to double row of nodes (Barrick et al., 1996). It apparently developed from *I.* n. sp. A by reduction of lobes and by strengthening and lengthening of the adcarinal grooves.

DESMOINESIAN-MISSOURIAN BOUNDARY POSITION

This radiation of idiognathodid conodonts upward through the lowest several glacial-eustatic cycles of the traditional Missourian Stage provides several levels of new appearances of species with known ancestor-descendant relationships, each of which could serve as a point where a boundary could be placed. The most conspicuous paleontological boundary is that where so many elements of the Desmoinesian biota became extinct, but not only are extinctions inappropriate horizons to define the base of the overlying chronostratigraphic unit, this particular level of extinction is marked (as far as can be determined) by a surface of subaerial exposure with local channeling along most of the present outcrop. The amount of time involved at this disconformity may not be great because the possible intermediate form of *Idiognathodus* between those dominant below and those dominant above is present both below and above it. Moreover, the amount of unrepresented time involved is the least in this region compared to anywhere else that has been studied so far in North America, because rocks equivalent to the immediately overlying Checkerboard-South Mound cyclothem are not known elsewhere at this time in the Illinois, Appalachian, or Texas regions. In order to achieve a boundary as close as possible to this important biotic break while adhering to the modern guidelines for selecting a chronostratigraphic boundary, we choose to place the Desmoinesian-Missourian Stage boundary at the first appearance of *Idiognathodus eccentricus* in the Exline Limestone and its equivalents near the base of the Exline cyclothem. This also keeps the Desmoinesian-Missourian boundary closer to the roughly corresponding Moscovian-Kasimovian boundary in Russia, which appears from present conodont data to lie at a position just one major depositional cycle below the Lost Branch Formation in the upper Desmoinesian (Heckel et al., 1998).

By necessity, this boundary places the South Mound Shale and Checkerboard Limestone into the top of the Desmoinesian Stage, but this is unavoidable. Ambiguity would result only if a thick succession of sparse faunas containing only *I. sulciferus* were found without appearances of the descendant species in higher beds. The fact that this lowest cyclothem of traditional Missourian affinities is the least widespread of lower Missourian cyclothems in the Midcontinent suggests that it may be missing in many other areas, which then makes the boundary easier to identify at a disconformity in locations higher on the shelf. Furthermore, the descendant species have already been identified above disconformities to mark the base of the Missourian at several localities elsewhere in the United States. The Exline correlative has been identified by the presence of *Idiognathodus sulciferus* and *I. eccentricus* without the younger descendants (and below the beds that contain them) in the Scottville Limestone in southwestern Illinois (see Heckel, this guidebook, fig. 6B). The Hertha (Mound City) correlative has been identified by the presence of these taxa along with *I.* n. sp. A in shale associated with the Cramer Limestone (Trivoli Cyclothem) in Illinois, in the Dog Bend Limestone of north Texas (Boardman and Heckel, 1989), and in the Honaker Trail section in southeastern Utah (Ritter et al., this guidebook). The Swope (Hushpuckney) correlative has been identified by the presence of all these along with *Streptognathodus cancellosus* in the Macoupin Cyclothem in the Illinois Basin, in the upper Salesville Shale of north Texas, in the Honaker Trail section in Utah, and also in the (lower) Brush Creek Limestone in the Appalachian Basin, where it is the lowest Missourian marine unit in that area. No separate marine unit possibly correlative with the South Mound-Checkerboard cyclothem is yet known in these other regions, which shows that the boundary probably is chosen in one of the most basinward positions available, and that this boundary will be relatively easy to identify at disconformities in most other places. Further work in areas outside the United States, such as Russia, Ukraine, northern Spain, China, etc. will be required to determine if this boundary can be identified elsewhere in the world and thus be a viable candidate for a GSSP.

PROPOSED DESMOINESIAN-MISSOURIAN BOUNDARY STRATOTYPE

Because all the traditional lower Missourian cyclothems are developed in a continuously deposited basin-marginal succession that lacks disconformities in the Kansas-Oklahoma border region, this is the area that should be able to provide a section at which a boundary stratotype can be placed. Good exposures of such a thin shale-dominated sequence as the South Mound Shale and Tacket Formation are not easy to find, however, in this succession where resistant sandstones in both the underlying Seminole Formation and in the upper part of the overlying upper Coffeyville Group/Formation provide most of the exposures. One excellent exposure was recently discovered by Allan P. Bennison, an independent consulting geologist of Tulsa, Oklahoma, in the bank of Little California Creek in northern Nowata County, Oklahoma.

In this exposure (Fig. 2), the fossiliferous lower limestone bed of the Checkerboard Limestone, lying upon sandstone at the top of the Seminole Formation, forms the bed of the creek for some distance. Above the lower Checkerboard in the bank of the creek is 4 ft (1.2 m) of dark gray shale, the South Mound Shale Member, which contains a diverse macrofauna dominated by brachiopods and including crinoid debris, bryozoans, and small snails and clams (mainly as internal molds) in the lower 1.5 ft (45 cm). This zone contains a conodont fauna of moderate abundance (~50 per kg) subequally dominated by *Adetognathus* and *Idiognathodus* at the base, becoming dominated by *Idiognathodus* upward and containing sparse *Ellisonia, Hindeodus*, and *Idioprioniodus*. All specimens of *Idiognathodus* are *I. sulciferus*, including a few forms that have a short anterior groove or other disruption of transverse ridges along the inner side, which are morphological features that suggest ancestry to *I. eccentricus*. The upper part of the South Mound Shale carries sparser macrofossils, and is overlain by the lenticular upper Checkerboard Limestone, which contains productid and other brachiopods. Both of these units carry only a sparse conodont fauna consisting so far only of *Adetognathus*. Above this, the lower 2 ft (0.6 m) of the Tacket Formation is dark gray shale that is very sparsely fossiliferous. Overlying this bed, 6.5 ft (2 m) above the lower Checkerboard Limestone (and 5 ft [1.5 m] above the top of the conodont-rich zone in the lower South Mound Shale), is a 0.7 ft (20 cm) bed of relatively soft black fossiliferous shale that carries brachiopods, crinoid and echinoid debris, and small molluscs, including snails, clams and cephalopods. This black shale bed also carries a conodont fauna of moderate abundance (~50 per kg) that is dominated by *Idiognathodus* and includes scattered *Adetognathus, Ellisonia, Hindeodus*, and slightly more common

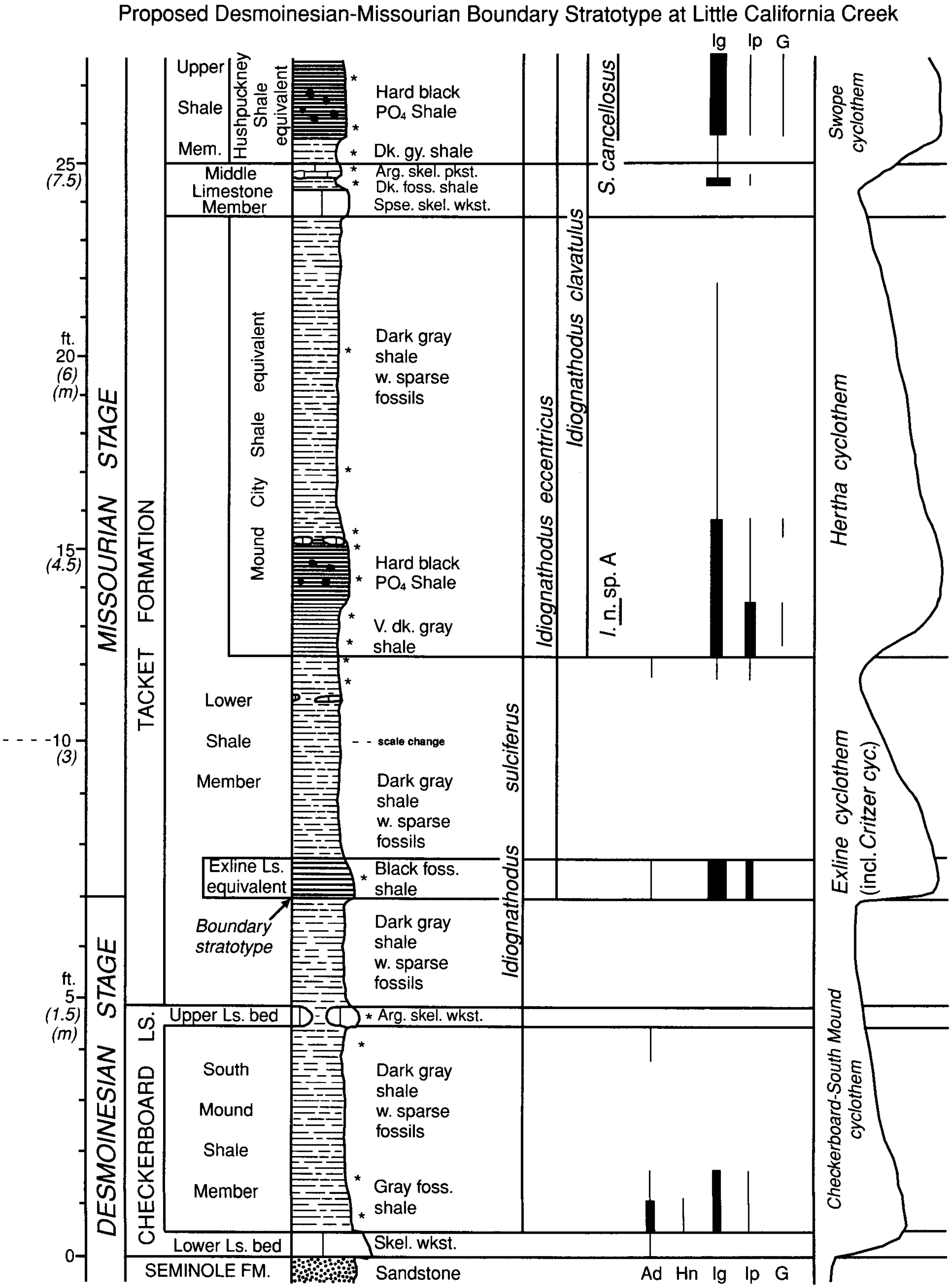

Fig. 2: Stratigraphic succession at Little California Creek showing distribution of conodont genera on right, and ranges of species of idiognathodid conodonts on left. Samples with identifiable conodonts shown by *. Some intervening samples contain unidentifiable conodont fragments and nearly all contain other sparse marine fossils.

Idioprioniodus. Most of the *Idiognathodus* are *I. sulciferus*, but some are *I. eccentricus*. This is the basinward equivalent of the Exline Limestone, and it may include the basinward facies of the overlying Critzer Limestone in its top. The Desmoinesian-Missourian Stage boundary is placed at the base of this black shale bed (Fig. 2) in the southwestern bank of the creek. This bed is overlain about 5 ft (1.5 m) higher by the very dark gray to hard black phosphatic Mound City Shale, which contains the first appearances of *I.* n. sp. A and *I. clavatulus*, in a moderately abundant *I. sulciferous*-dominated fauna. About 10 ft (3 m) higher (and above middle Tacket limestone beds) is the hard black phosphatic Hushpuckney Shale, which carries the first appearance of *Streptognathodus cancellosus*, and completes the exposure of the 4 (5, if the Critzer is counted) lowest cycles of the traditional Missourian Stage in a section of continuous marine deposition.

Among other fossil groups commonly used for long-distance correlation, fusulinids are not present at the proposed boundary stratotype. However, they are not known in the lower units of the traditional Missourian (up through the Critzer Limestone) anywhere in the Midcontinent, and they are represented by only small genera (*Schubertella* and *Oketaella*) in the Sniabar Limestone of the Hertha cyclothem elsewhere (Thompson et al., 1956; Thompson, 1957). Only in the Bethany Falls Limestone of the Swope cyclothem do large genera (*Eowaeringella ultimata, Fusulina fallsensis*) appear toward the north. Small ammonoids are known from the boundary stratotype, and they are currently under study by Boardman and his colleagues.

Although this property containing the boundary along Little California Creek is privately owned, it will be accessible to professional geologists and paleontologists through the Oklahoma Geological Survey, which is associated with the University of Oklahoma in Norman, Oklahoma. Interested persons who are not acquainted with the owners should contact the Oklahoma Survey by letter (100 East Boyd Street, Norman, OK 73019-0628), by telephone (405-325-3031), or by e-mail (jlcoleman@ou.edu). Contact should be made sufficiently ahead of time for Survey personnel to contact the owners in order to settle upon a mutually agreeable time to visit. The protocol for such a visit is outlined in the guidelines for visiting this locality (B8) on this field trip.

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STRATAL AND FAUNAL RELATIONSHIPS ACROSS THE DESMOINESIAN-MISSOURIAN BOUNDARY AT HONAKER TRAIL, PARADOX BASIN, UTAH: A SEQUENCE BIOSTRATIGRAPHIC APPROACH

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INTRODUCTION

The biostratigraphic definition of the Desmoinesian-Missourian (~ Middle-Upper Pennsylvanian) boundary in North America, and its correlation with the Eurasian Moscovian-Kasimovian boundary, have been under active study in recent years (e.g. Boardman et al., 1990; Barrick et al., 1996; Barrick et al., this guidebook; and Heckel et al., this guidebook). Definition of the boundary has been hampered by the cyclic nature of boundary strata in the Midcontinent stratotype areas and elsewhere, and by insufficient documentation of the biostratigraphic and biogeographic ranges of key index fossils.

The primary purpose of this paper is to present integrated conodont and fusulinid biostratigraphic data in a sequence-stratigraphic framework across the Desmoinesian-Missourian boundary at the Honaker Trail Formation stratotype in the San Juan River Canyon of southeastern Utah. The integrated biostratigraphy and sequence stratigraphy of this southern Rocky Mountain section is then compared to and correlated with the Midcontinent stratotype sections.

The Honaker Trail stratigraphic section is particularly important for two reasons. First, the sequence stratigraphy has been developed recently (Goldhammer et al., 1991), thereby providing a framework for comparison to the cyclothemic Midcontinent Desmoinesian-Missourian stratotypes. Secondly, both the conodonts and fusulinids from the Honaker Trail section have been studied, providing the opportunity to integrate biostratigraphic data on two of the primary index fossil groups through the boundary section. Of particular importance is the occurrence in the upper Desmoinesian part of the section of the fusulinid *Protriticites*, which is a key index fossil in Eurasian Moscovian-Kasimovian boundary sections (Wahlman et al., 1997).

GEOLOGICAL SETTING

The Honaker Trail section is located in the San Juan River Canyon of southeastern Utah (Fig. 1). Paleogeographically, it is located on the southwestern shelf of the Paradox Basin , which is a northwest-southeast trending intracratonic basin that formed during the Pennsylvanian Period. During formation of the ancestral Rocky Mountains, the Uncompahgre Uplift emerged to the northeast, and the rapidly subsiding basin was filled with over 2000 m of Permo-Carboniferous sediments. Stacked depositional sequences accumulated in three nearly parallel facies belts: a northeastern clastic wedge adjacent to the Uncompahgre Uplift, basin-center evaporites and black shales, and a southwestern carbonate shelf.

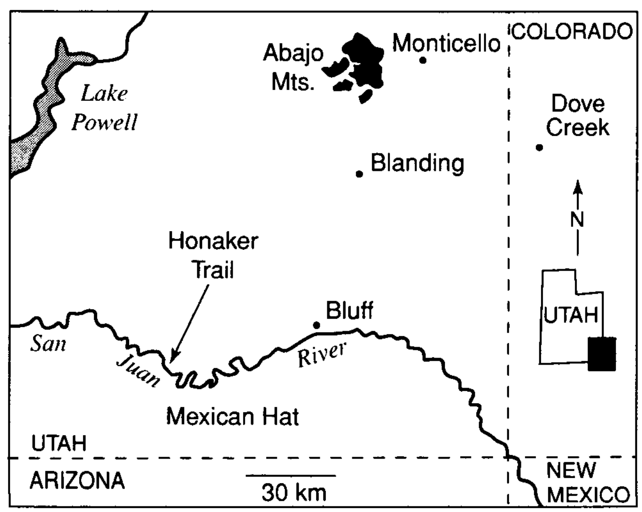

Fig. 1: Index map showing major depositional provinces of Paradox basin and location of Honaker Trail section.

Ritter, S. M., Barrick, J. E., Wahlman, G. P., and Skinner, M. R., 1999, Stratal and faunal relationships across the Desmoinesian–Missourian boundary at Honaker Trail, Baradox Basin, Utah: A sequence biostratigraphbic approach; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 199–207.

PREVIOUS CORRELATIONS OF PARADOX BASIN PENNSYLVANIAN STRATA

In the 1950s, the discovery of oil in Desmoinesian phylloid-algal buildups on the carbonate shelf engendered numerous studies of the Pennsylvanian System in the Paradox Basin, including attempts to correlate precisely between evaporite basin and shelf sections. Because of the lack of adequate fossil remains in the evaporite basin and clastic wedge sediments, correlation attempts were made primarily by geophysical and lithostratigraphic means. In particular, evaporite-black shale cycles in the basin were correlated with shelf sedimentary cycles (Hite and Buckner, 1981). Fusulinid correlations have been commonly applied to the carbonate shelf sediments, but very little has been published on the fusulinid biostratigraphy of the basin, and there has been no comprehensive studies based on systematic sampling. Welsh (1958) illustrated some fusulinids from the Honaker Trail section, but he did not assign most specimens to species, and did not attempt biostratigraphic correlations with other areas. Baars et al. (1967) proposed a fusulinid zonation for the Desmoinesian section of the Paradox Basin. The current study generally agrees with their zonation with some modifications that will be discussed below.

STRATIGRAPHY

The upper Desmoinesian-lower Missourian strata discussed herein comprise 120 m of interbedded siliciclastic and carbonate rocks assigned to the lower half of the Honaker Trail Formation (Figs. 2, 3). This interval includes strata between the top of the Horn Point Limestone and base of the Little Loop Limestone of Wengerd's (1963) measured section. The interval corresponds also to beds 83 through 121 of Weber et al.'s (1995: 'Mobil') measured section, which is used herein with one modification (elimination of beds 109 and 110 due to repeated section) as a framework for locating important stratigraphic horizons and paleontological collections.

The most striking feature of Pennsylvanian rocks at Honaker Trail is their cyclicity (Fig. 2). Laterally continuous, horizontal ledge-slope couplets ascend like an oversteepened staircase to a height of 500 m above the San Juan. The Lower Honaker Trail Formation (Mobil beds 83-121) contains 18 trangressive-regressive parasequences (stair-steps) that range in thickness from 2 to 7 m each (Goldhammer et al. 1991). [Editor's note: the term 'parasequence' as used herein is essentially equivalent to the term 'cyclothem' as used in the Midcontinent.] Individual parasequences are bounded by marine flooding surfaces and contain an asymmetrical succession of

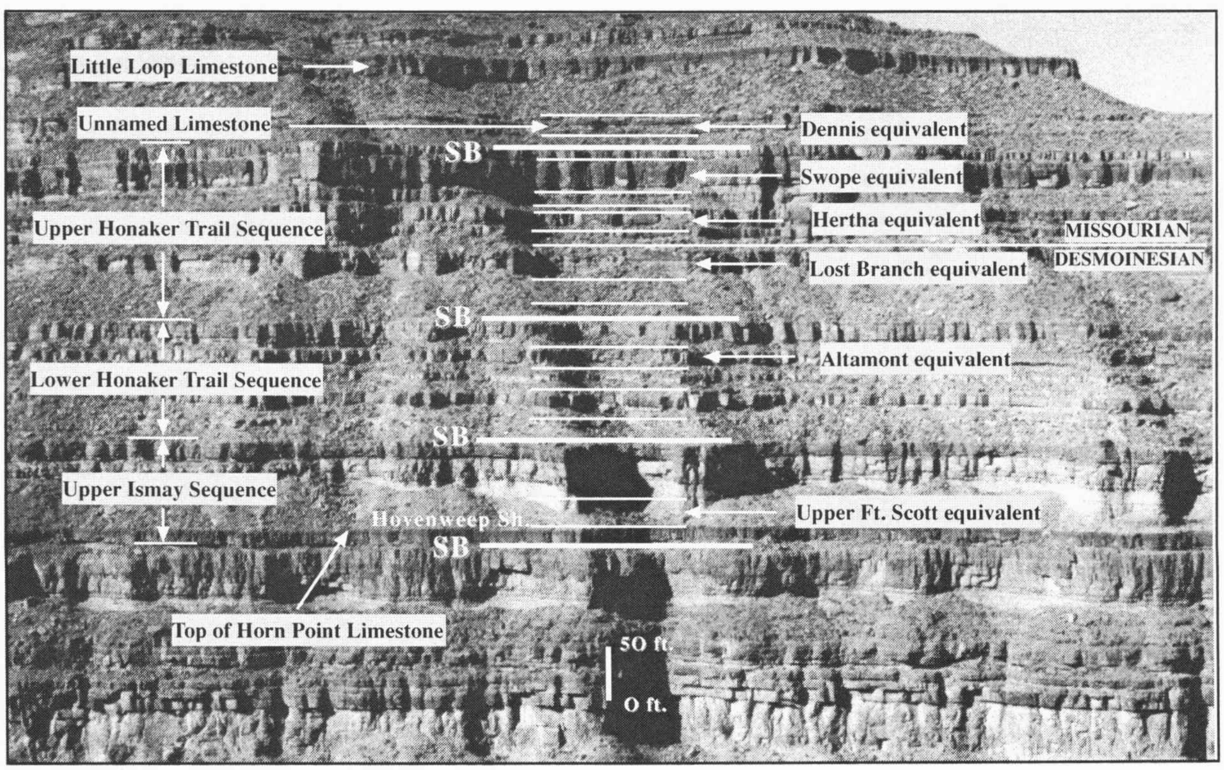

Fig. 2: Photograph of Desmoinesian-Missouran boundary strata showing parasequence and sequence boundaries.

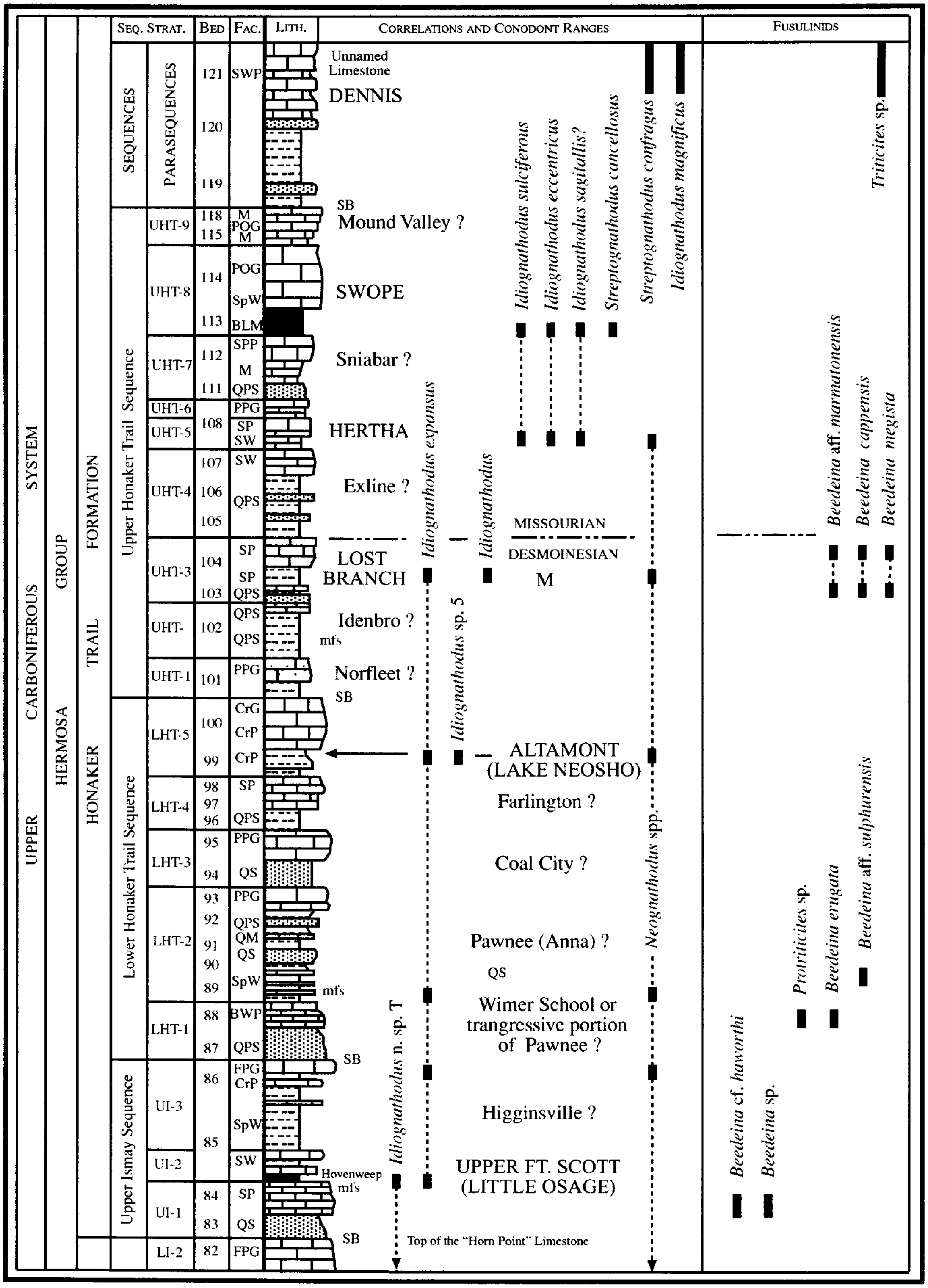

Fig. 3: Stratigraphic column showing lithostratigraphic and sequence stratigraphic subdivisions of Honaker Trail Formation at type locality along with occurrences of important conodont and fusulinid species. Correlations with Midcontinent cyclothems of Heckel (1989) are shown to right of graphic column. Capital letters designate cycles correlated on basis of distinctive conodont faunas. Remaining correlations (lower case) are interpolated from Heckel's Midcontinent sea-level curve. Lithofacies abbreviations: BLM=black laminated mudstone (black shale); BWP=fine bioclastic wackestone to packstone; CrG=crinoidal grainstone; CrP=crinoidal packstone; FPG=small foraminiferan-peloid grainstone; M=carbonate mudstone; POG=ooid-peloid grainstone; PPG=peloidal packstone to grainstone; QM=quartz-silty carbonate mudstone; QPS=quartz-peloid sandstone; QS=quartz sandstone; SP=skeletal packstone; SpW=spiculiferous wackestone; SW=skeletal wackestone, Also, mfs=maximum flooding surface; SB=sequence boundary.

upward shallowing microfacies. The typical facies suite grades from slope-forming, deeper-water siliciclastic-dominated sediments at the base to ledge-forming, subtidal to shoal-water carbonates at the top. Basal siliciclastics include fine sandstone, black shale, and shaly lime mudstone. Carbonate microfacies include cross-bedded superficial ooid grainstone, peloidal wackestone to packstone, and a wide range of skeletal carbonates. It is important to note that no cycle contains the whole range of lithologies cited above and that no two parasequences contain an identical succession of lithofacies.

Each parasequence is identified with a letter and number code reflecting its place in one of three depositional sequences (Fig. 3) defined previously by Goldhammer et al. (1991). For example, cycle UHT-2 is the second parasequence in the Upper Honaker Trail sequence. Although we adopt the sequence terminology of Goldhammer et al. (1991), we have re-positioned the lower boundaries of their Upper Ismay and Lower Honaker Trail sequences to correspond with demonstrable exposure surfaces (Fig. 3). Specifically, the bottom of the Upper Ismay sequence is shifted from the base of bed 85 to the base of bed 83, and the lower boundary of the Lower Honaker Trail sequence from the base of bed 89 to the bottom of bed 87. The transfer of beds 87 and 88 from the top of the Upper Ismay sequence to the base of the Lower Honaker Trail sequence could conceivably engender confusion regarding the stratigraphic occurrence of *Protriticites* at Honaker Trail. The latter bed (88) contains the sole documented occurrence of this important fusulinacean at Honaker Trail. From a lithostratigraphic point of view, this bed forms part of Wengerd's (1963) informal Ismay interval. Accordingly, Wahlman et al. (1997) and Wahlman (this volume) correctly state that *Protriticites* occurs in the Upper Ismay **interval**. From a sequence stratigraphic point of view (this paper), however, *Protriticites* occurs in the lower part of the Lower Honaker Trail **sequence**.

Goldhammer et al. (1991) demonstrated that early highstand parasequences are composed of relatively deep-water facies (black shales and spicule-rich wackestones) with a thin submarine cap (subtidal cycles) whereas late highstand parasequences are composed of intermediate facies shallowing to non-skeletal or skeletal-cap facies with subsequent formation of subaerial diagenetic features (exposure cycle). Eight of the 18 parasequences constituting the Lower Honaker Trail Formation (UI-3, LHT-2, LHT-5, UHT-1, UHT-2, UHT-3, UHT-6, and UHT-9) are exposure cycles (Fig. 3). The duration of individual hiatuses represented by these exposure surfaces is not known.

SEQUENCE BIOSTRATIGRAPHIC CONCEPTS

Efforts to subdivide Pennsylvanian and Lower Permian strata into a succession of widely recognized faunal zones have lagged behind those of other geological systems. The root cause is our inability to determine the "true" stratigraphic ranges and phylogenetic relationships of species in sections characterized by strong glacio-eustatic cyclicity. In such sections, fossiliferous marine units alternate with unfossiliferous marginal marine to non-marine strata. As a result, first and last occurrences (along with stratigraphic recurrences) are controlled by hiatuses at sequence boundaries and facies shifts within and between individual parasequences. Simply put, the eustatic signal obscures the evolutionary signal, making it impossible to subdivide the section into a continuous succession of rock packages whose boundaries are defined primarily on the basis of evolutionary (e.g., first true and last true occurrences) events.

The foregoing situation dictates that a modified biostratigraphic approach, called **sequence biostratigraphy**, be taken. The stratigraphic section is subdivided into genetic units using sequence-stratigraphic criteria. The parasequence, a natural package of rock and time, is the basic operational unit of the sequence biostratigraphic approach. It is this entity that we describe, characterize, and correlate. Fossil taxa are employed simply as a means of distinguishing an individual parasequence or set of parasequences from others in a vertical succession. The biotic signature can be a single, stratigraphically restricted species, or a species association unique to part or all of given cyclothem. Highest biostratigraphic resolution is attained when each successive cycle can be fingerprinted.

Although the term sequence biostratigraphy was coined later (Loutit et al., 1991; Posamentier and Goodman, 1992), the concept was discovered by Swade (1985) while studying conodonts from the subsurface Pennsylvanian of Iowa. Having documented subtle differences between conodont faunas in six successive cycles, he considered the "... possibility of correlating cycles throughout the Midcontinent by means of these distinctions in conodont faunas of the offshore shales...". Swade died before he could test this possibility, but subsequent workers have shown that the maximum transgressive deposits of many Desmoinesian through Wolfcampian cyclothems in both the Midcontinent (Von Bitter, 1972; Heckel, 1986, 1989; Ritter, 1994, 1995) and north-central Texas (Barrick and Boardman, 1989; Boardman and Heckel, 1989) do indeed contain cycle-specific conodont faunas. In this paper we apply Swade's elegant approach to Pennsylvanian rocks of the Paradox basin utilizing both conodonts and fusulinids.

SYSTEMATIC SEQUENCE BIOSTRATIGRAPHY

The 18 parasequences constituting the lower part of the Honaker Trail Formation were analyzed for conodonts and fusulinids. *Idiognathodus-*, *Streptognathodus-*, and *Neognathodus*-dominated conodont faunas were obtained from "deeper water" facies of seven cycles. Fusulinids were obtained from five (Table 1 and Fig. 3).

Upper Ismay Sequence.—Each parasequence contains a diagnostic fauna. UI-1 comprises the lowstand and transgressive systems tracts of the Upper Ismay sequence. The basal 1.5 m consists of fine-grained quartz sandstone. This is overlain by 3.1 m of skeletal wackestone and packstone with abundant brachiopods and fusulinids. The joint occurrence of *Beedeina* cf. *haworthi* and *Beedeina* sp. distinguishes the cycle from other Honaker Trail cycles.

UI-2 is a thin (1.5 m) parasequence composed of a basal fine-grained sandstone (0.25 m) that grades upwards into alternating thin beds of olive gray calcareous shale and dense lime mudstone (1.25 m). Goldhammer et al. (1991) correlated these alternating shales and mudstones with the Hovenweep horizon of the basin center. Abundant representatives of *Idiognathodus expansus* and *I.* n. sp. T were recovered from a brown, phosphate-rich shale (condensed, maximum flooding surface) directly overlying the basal (0.25 m) sandstone. The overlap of *I.* n. sp. T with its descendant *I. expansus* renders this parasequence faunally distinct.

Foraminiferal packstones and grainstones capping UI-3 yield a meager conodont fauna dominated by Pa elements of *Idiognathodus expansus* and species of *Neognathodus*. This fauna represents the second occurrence of *I. expansus* and the first without *I.* n. sp. T.

Lower Honaker Trail Sequence.—Three of five parasequences contain conodont elements and/or fusulinids. The lowstand and trangressive systems tracts, represented by LHT-1 consist of 1.5 m of fine peloidal-quartz sandstone capped by 3.3 m of limestone (bed 88), which grades laterally from sparse skeletal wackestone to phylloid algal packstone over a distance of 20 m. Fusulinids occur in both microfacies but are much more common in the skeletal wackestone lithology. The unique biotic signature of this cycle comprises the joint occurrence of *Protriticites* sp. and *Beedeina erugata* (see Walhman, this guidebook).

Sparse spiculiferous wackestones at the base of LHT-2 (bed 89) form the maximim flooding interval of the Lower Honaker Trail sequence. The remaining beds (90-93) comprise a shoaling package of skeletal to peloidal packstones and siltstones. The basal units (bed 89) yield a conodont fauna (*Idiognathodus expansus* and *Neognathodus* spp.) similar to that of UI-3. These parasequences are distinguished, however, by the occurrence of *Beedeina* aff. *sulphurensis* in the middle of LHT-2 (bed 91).

The third and fourth parasequences are devoid of conodont elements and fusulinids. Shaly crinoidal packstones at the base of LHT-5, however, contain conodont faunas dominated once again by *Idiognathodus expansus*. In addition, a new morphotype of *Idiognathodus, I.* sp. 5 of Swade, appears. This is the only cycle that contains both *I. expansus* and *I.* sp. 5 of Swade. This conodont fauna allows correlation with the Altamont cyclothem of the Midcontinent (Fig. 3).

Upper Honaker Trail sequence.—Three parasequences (UHT-3, UHT-5, UHT-8) contain biostratigraphically useful faunas. The lowest, UHT-3, is distinguished by the first occurrence of *Idiognathodus nodocarinatus, Beedeina* aff. *marmatonensis, B. cappensis,* and *B. megista* in association with the last occurrence of long-ranging *I. expansus*. Fusulinids are abundant in two horizons: a thin limestone ledge at the top of bed 103 and in skeletal packstones at the top of bed 104. This fauna contains the last occurrence of *Beedeina* in the Honaker Trail section, and is the local extinction of an important Desmoinesian index genus. Conodonts were obtained from fine-grained silty skeletal packstones at the base of bed 104. This conodont fauna allows correlation with the Lost Branch cyclothem of the Midcontinent (Fig. 3).

UHT-5 is a 4.3 m-thick parasequence that grades from shaly skeletal wackestone at the base to crinoidal packstone at the top. White chert blebs are common in the ledge-forming packstones and grainstones forming the upper 2 m. This cycle contains the first appearance of three new species: *Idiognathodus sulciferus* Gunnell, *I. eccentricus* (Ellison) and *I. sagittalis?* Kozitskaya. This idiognathodid fauna allows correlation with the Hertha cyclothem of Missourian age in the Midcontinent (Fig. 3). Significantly, these faunas also contain the last occurrence of *Neognathodus*, represented by a few juvenile specimens. The joint occurrence of *Neognathodus* with these idiognathodids poses somewhat of a stratigraphic problem because *Neognathodus* is generally restricted to the Desmoinesian stage. The association of *Neognathodus* with the above-cited species of *Idiognathodus* suggests that the former may have persisted into the early part of the Missourian Age in the North American southwest

Conodont faunas from black shales in the base of UHT-8 are identical to those of UHT-5 with one important addition, the appearance of the genus *Streptognathodus,* represented by *S. cancellosus.* This conodont fauna allows correlation with the Swope cyclothem of the Midcontinent (Fig. 3). *Streptognathodus* appears somewhat above the current base of the Missourian stage and continues as the dominant element of most Missourian through middle

TABLE 1. Sequence biostratigraphic data for the Honaker Trail Formation, Honaker Trail, Utah.

PARA.	BED	CONODONTS	FUSULINIDS	PRODUCTIVE FACIES
UNNAMED LIMESTONE				
UL	121	*Streptognath. confragus** *Idiognathodus magnificus**	*Triticites* spp.*	Skeletal wackestone to packstone. Whole jasperized spiriferid brachiopods, crinoid stem segments.
UPPER HONAKER TRAIL SEQUENCE				
UHT-8	113	*Streptognathodus cancellosus** *Idiognathodus sulciferous*** *Idiognathodus eccentricus*** *Idiognathodus sagittalis?***		Black laminated mudstone; thin crinoidal packstone interbed.
UHT-5	108	*Idiognathodus sulciferous** *Idiognathodus eccentricus** *Idiognathodus sagittalis?** juvenile *Neognathodus* sp.**		Skeletal wackestone to packstone; bioclasts in overpacked finer-grained matrix; brachiopods, crinoid ossicles, rare bryozoans.
UHT-3	104	*Idiognath. nodocarinatus** *Idiognathodus expansus*** *Neognathodus* spp.	*Beedeina* spp.	Skeletal wackestone to packstone; fusulinids; partially jasperized crinoid ossicles, rare snails.
	103		*Beede.* aff *marmatonensis** *Beedeina cappensis** *Beedeina megista**	Fusulinid-skeletal packstone; common brachiopod fragments and spines; crinoid ossicles, forams (*Bradyina, Climacammina*, paleotextulariids, encrusting forms); poorly preserved phylloids; larger bioclasts encrusted.
LOWER HONAKER TRAIL SEQUENCE				
LHT-5	99	*Idiognath*. Sp. 5 of Swade* *Idiognathodus expansus* *Neognathodus* spp.		Shaley crinoidal packstone. Abundant brachiopods and bryozoans.
LHT-2	91?		*Beedeina* aff. *sulphurensis**	Skeletal-peoidal packstone, sparse fusulinids and bioclasts in an overpacked finer-grained matrix; *Tetrataxis* and *Syzrania*.
	89	*Idiognathodus expansus* *Neognathodus* spp.		Spiculiferous wackestone with crinoid ossicles and whole brachiopods.
LHT-1	88		*Protriticites* sp.* *Beedeina erugata** *Eoschubertella* sp.	Phylloid algal-fusulinid wackestone to packstone, sparse tubular encrusting forams, *Globivalvulina*, peloids, quartz, silt.
UPPER ISMAY SEQUENCE				
UI-3	86	*Idiognathodus expansus* *Neognathodus* sp.		Small foram packstone to grainstone. Well-sorted, fine-grained, micritized grains, peloids, dasycladacean algae, quartz sand.
UI-2	85	*Idiognathodus* n. sp. T** *Idiognathodus expansus**		Condensed section. Brown calcareous shale with abundant phosphatic grains.
UI-1	84		*Beedeina* cf. *haworthi** *Beedeina* sp.*	Brachiopod/fusulinid packstone with abundant small forams and bioclastic debris.

* = lowest occurrence in section. ** = highest occurrence in section.

Wolfcampian (Kasimovian-Asselian) conodont faunas. The first occurrence in bed 113 represents a major development in the Late Carboniferous evolution of the phylum.

Unnamed Limestone.—Above bed 118, second-order restriction of the shelf is reflected by the upward increase in siliciclastic red beds. The unnamed limestone is the lowest of three marine limestones occurring in the lower part of the red bed succession. This 8 m carbonate is comprised of alternating beds of shaly, whole fossil wackestone and purplish-gray, ledge-forming bioclastic grainstone. Ooids are present is some of the grainstones. Red, jasperized spirifers are distinctive of this depositonal sequence as are the appearances of *Streptognathodus confragus, Idiognathodus magnificus* (s. l.), and *Triticites* spp. This fauna allows correlation with the Dennis cyclothem of the Midcontinent (Fig. 3)

CHRONOSTRATIGRAPHY

The traditional base of the Missourian Stage, essentially the Middle-Upper Pennsylvanian boundary in the Midcontinent region, corresponds to the unconformity at the base of the Pleasanton Group in Kansas and Missouri and is the level above which no definitively Desmoinesian forms such as the fusulinid *Beedeina* and the brachiopod *Mesolobus* occur (Moore, 1932). In the Midcontinent region, the uppermost beds of the Desmoinesian are indicated by the last occurrences of the genus *Neognathodus* and a group of troughed idiognathodids that includes *I. nodocarinatus*. Lowermost Missourian marine beds contain low-diversity conodont associations that are dominated by a generalized species of *Idiognathodus, I. sulciferus*. The appearance of *I. eccentricus* a short interval above the base of the Missourian serves as the first species event that can be used to reliably indicate the presence of Missourian strata (Barrick et al., 1996; see Heckel, Boardman and Barrick, this guidebook).

The position of the Desmoinesian-Missourian boundary in the Honaker Trail section can be approximated using conodonts in conjunction with fusulinids. The highest Desmoinesian conodont fauna, the *Idiognathodus nodocarinatus* fauna, occurs in cycle UHT-3 in the lower part of the Upper Honaker Trail sequence. The highest occurrence of *Beedeina* occurs in the same cycle. The lowest conodont fauna with the Missourian species *I. eccentricus* appears two cycles higher, in cycle UHT-5. Because in the Midcontintent region a small interval of strata separates the first appearance of *I. eccentricus* from the base of the Missourian (Barrick et al., 1996), we place the base of the Missourian at the base of cycle UHT-4 (bed 105) at Honaker Trail. It is important to note that juvenile specimens of *Neognathodus* sp. occur in these lowest Missourian strata. This is somewhat problematic in that *Neognathodus* did not survive beyond the end of the Desmoinesian in the Midcontinent. Neognathodid elements in UHT-4 may represent reworked material (although no evidence currently exists in support of this possibility) or may indicate the previously unrecognized persistence of *Neognathodus* into the Missourian Age.

Previously, the base of the Missourian at the Honaker Trail section was placed at the first appearance of the fusulinid *Triticites* (e.g. Wengerd, 1963, fig. 5) in the unnamed limestone approximately 50 m above our provisional placement. It is well established that *Triticites* does not appear at the base of the Missourian in the Midcontinent region, but at least three major cycles above the base of the stage in the Dennis cyclothem (Thompson, 1957; Boardman et al., 1990; Barrick et al., 1996). In the Dennis cyclothem, *Triticites* occurs with conodonts of the *Streptognathodus confragus* fauna, as it does at the Honaker Trail section, indicating that the appearance of *Triticites* at the Honaker Trail section is also well above the base of the Missourian.

The Moscovian-Kasimovian boundary of Eurasia appears to lie well below the base of the Missourian in the Honaker Trail section. Wahlman et al. (1997) recovered specimens of the fusulinid *Protriticites* from Mobil bed 88. This is consistent with the most recent information from eastern Europe (Villa et al., 1997), which shows that the first appearance of *Protriticites* is in the upper Peski Formation, just below the Moscovian-Kasimovian boundary in the Moscow region of Russia.

CORRELATION WITH THE MIDCONTINENT

Conodont sequence biostratigraphy provides a framework for correlating Paradox basin parasequences with the well-studied cyclothems of the American Midcontinent (Heckel, 1986). Correlations suggested below are necessarily tentative because of 1) the need for an up-to-date, cycle-by-cycle study of Midcontinent Desmoinesian conodonts, 2) the lack of conodonts in several of the Paradox parasequences, 3) the differences in facies architecture of Midcontinent-style and Paradox-style depositional cycles, and 4) the subjective nature of cycle ordination (3rd order, 4th order, etc.). In spite of these limitations, conodonts permit matching of several depositional entities between the two areas, and provide compelling evidence for the eustatic nature of Late Carboniferous cyclothems.

Figure 3 shows the biostratigraphic tie points between the Paradox basin and Midcontinent curve of

Heckel (1989). Conodont faunas from the Chimney Rock, Gothic (both lower units than those shown on Fig. 3), LHT-4, UHT-3, UHT-5, UHT-8, and the unnamed limestone (as indicated in the section on conodont sequence biostratigraphy above) can be matched with faunas from individual Midcontinent cycles as described by Barrick et al. (1996). All nine of Heckel's major cycles between the Verdigris and Dennis appear to have counterparts in the Paradox basin indicating that the same sea-level highstands that permitted widespread development of black shales over much of the Midcontinent resulted in sedimentation on the southwestern shelf of the Paradox basin, although only three were sufficiently deep to produce shelf-wide black shales (Chimney Rock shale, Gothic shale, and the black shale at base of parasequence UHT-8). Using these correlations as a template, Paradox cycles that have sparse conodonts, or no conodonts, can still be matched with the Midcontinent succession. These interpolations indicate correspondence of the Hovenweep with the Little Osage (Upper Fort Scott) as suggested previously by Weber et al. (1995) on the basis of fusulinids and cycle hierarchy. All minor cycles of the Marmaton, Pleasanton, and Bronson Groups (except for the Critzer) also appear to match with individual Paradox parasequences (Fig. 3).

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FUSULINID BIOSTRATIGRAPHY OF THE HONAKER TRAIL SECTION, SAN JUAN RIVER CANYON, SOUTHEASTERN UTAH

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NORTH AMERICAN DESMOINESIAN FUSULINID ZONATIONS

In order to better understand the correlations and significance of the Desmoinesian fusulinid faunas from Honaker Trail, it is necessary to briefly review North American Desmoinesian fusulinid zonations. The Desmoinesian Stage essentially corresponds to the range zone of the fusulinid genus *Beedeina* (= *Fusulina* in older literature). Traditionally, four Desmoinesian fusulinid subzones have been widely used, based primarily on studies in the Eastern and Midcontinent United States, (e.g., Dunbar and Henbest, 1942; Moore et al., 1944; Waddell, 1963; Douglass, 1987, Nestell, 1989) (see Table 1).

TABLE 1: Traditional Desmoinesian fusulinid subzones and equivalent lithostratigraphic equivalents in the Midcontinent USA region.

Midcontinent Units	Fusulinid Subzones
Upper Marmaton Group	*Beedeina eximia-B.acme*
Lower Marmaton Group	*Beedina girtyi-B. haworthi*
Upper Cherokee Group	*Beedeina novamexicana-Wedekindellina euthysepta*
Lower Cherokee Group	*Beedeina insolita-B. leei*

The Midcontinent region has long formed the standard for the biostratigraphic definition of subunits within the Desmoinesian Stage in the USA. Appendix 1 summarizes the published stratigraphic occurrences of fusulinids in several Midcontinent Desmoinesian sections. In the Midcontinent region, the two lower fusulinid subzones correspond to the Cherokee Group and the two upper subzones correspond to the Marmaton Group. This bipartite lithostratigraphic division, as represented by the four-part fusulinid zonation, has been widely used by many fusulinid biostratigraphers throughout the North America. As such, fusulinid assemblages have been commonly designated as being, for example, Upper Cherokee (*Beedeina novamexicana* subzone) or Lower Marmaton (*Beedeina girtyi* subzone) in age. Notably, Wengerd (1973, and other papers) used such fusulinid age designations on his measured sections of Honaker Trail and elsewhere in the Four Corners area. The four subzones are discussed briefly below, in ascending order.

Beedeina insolita-B. leei subzone: Basal Desmoinesian strata are characterized by fusulinids that are transitional between Late Atokan *Fusulinella* and *Beedeina*, such as *Fusulinella iowensis* and *F. famula*. These species are sometimes associated with primitive *Wedekindellina*?, such as *W. matura* and *W. gryphyae*, which Wilde (1990) referred to the genus *Nipperella*. This fauna is succeeded through the rest of the subzone by small, relatively primitive, inflated fusiform to fusiform species of *Beedeina (e.g., B. insolita, B. pumila, B. leei, B. hayensis,* etc.*)* and small to moderate sized, generally elongate species of *Wedekindellina* (e.g., *W. euthysepta*). In the Midcontinent region, the subzone of the fusulinid genus *Wedekindellina* nearly corresponds to the Lower Desmoinesian Cherokee Group, but the basal appearance of the genus is commonly just above the first primitive specimens of *Beedeina*, and the top occurrences of the genus appear to be quite variable, even being reported to extend up into the lowermost *Beedeina girtyi/haworthi* subzone occasionally.

Beedeina novamexicana-Wedekindellina euthysepta subzone: In the Upper Cherokee, species of *Beedeina* become somewhat larger than in the underlying subzone, and develop more complex, but still irregular, septal fluting (e.g., *B. novamexicana, B. euryteines, B. distenta, B. rockymontana*). Species such as *B. leei* and *B. pumila* continue from the underlying zone. *Beedeina*

Wahlman, G. P., 1999, Fusulinid biostratigraphy of the Honaker Trail section, San Juan River canyon, southeastern Utah; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 208–216.

bowiensis and related species characterize the upper part of the subzone and have been reported to continue upward into the lowermost part of the overlying subzone. Species of *Wedekindellina* are often common to abundant elements of the subzone fauna. They also tend to become relatively larger, and can vary from elongate (*W. euthysepta, W. excentrica, W. henbesti, W. rockymontana*) to inflated (*W. ellipsoides, W. magna*) shell forms, the latter becoming more common in the upper part of the subzone.

Beedeina girtyi-B. haworthi subzone: The base of the Lower Marmaton interval is defined by the appearance of moderate-sized species of *Beedeina* with more regular and intense septal fluting (e.g., *B. girtyi, B. haworthi, B. illinoisensis, B. knighti*). *Wedekindellina* spp. generally do not range up into this subzone, but have occasionally been reported in its lower part. In the western USA, *Beedeina retusa* is a common element of this subzone, and the fusulinid genera *Bartramella* and *Protriticites* appear in the upper part of the subzone, the former genus apparently continuing up through the overlying subzone.

Beedeina eximia-B. acme subzone: The Upper Marmaton interval is characterized by relatively large and elongate fusiform to cylindrical species of *Beedeina* with intense septal fluting and sometimes with minor secondary axial fillings (e.g., *B. eximia, B. megista, B. mysticensis, B. acme)*. At least some of these elongate uppermost Desmoinesian species should probably be returned to the genus *Fusulina*, as suggested by Wilde (1990), but the necessary taxonomic studies have not yet been done. *Beedeina haworthi* and related species sometimes range up into the lower part of this subzone to co-occur with *B. megista*. *Bartramella* has been reported in association with this assemblage of advanced *Beedeina*, and might range throughout the subzone.

Also, the fusulinid genus *Eowaeringella*, which is characteristic of the overlying basal Missourian Stage, has also been reported by Stewart (1968) to overlap with uppermost Desmoinesian species of *Beedeina* in the southern Rocky Mountains. Notably, Verville, Thompson and Lokke (1956) described two new species of *Fusulinella* in association with *Bartramella* in the Upper Desmoinesian of Nevada. But this occurrence of *Fusulinella* is anomalously high stratigraphically in the North American section, and perhaps those new species should be re-evaluated as possible primitive (or ancestral) species of *Eowaeringella*.

Some modified Desmoinesian fusulinid zonations have been proposed, particularly in association with studies in the western USA. Ross and Sabins (1965), Ross and Tyrrell (1965) and Ross (1969) defined the Desmoinesian fusulinid zones in the mountain ranges of southeastern Arizona. Although a number of new species were named, the succession of fusulinid assemblages described was very similar to that of the Midcontinent, and essentially the same zonation was employed, that being, in ascending order: *Beedeina hayensis* zone, *Wedekindellina euthysepta* zone, *Beedeina girtyi* zone, *Beedeina eximia* zone.

Ross and Ross (1988, Figure 6B), in their attempt to demonstrate the widespread correlation of Pennsylvanian depositional sequences, charted correlations of stratigraphic sections across North America and attempted to characterize each sequence with a fusulinid assemblage. They recognized five fusulinid subzones within the zone of *Beedeina*. Unfortunately, their fusulinid subzone assemblages sometimes do not appear to agree with the published occurrence data for some species. For example, Ross and Ross (1988) cited *Beedeina haworthi* as characteristic of the Altamont sequence in Kansas-Oklahoma, but that species was originally described by Beede (1916), Dunbar and Condra,(1927), and Dunbar and Henbest (1942) from the Lower Fort Scott limestone of Kansas, which is two cycles lower in the section. Alexander (1954) confirmed that *B. haworthi* is characteristic of the Lower Fort Scott limestone in northeastern Oklahoma. In Missouri, Bebout (1963) recognized the *B. haworthi* from the Lower Fort Scott limestone, but also cited it from the overlying Pawnee and Altamont limestones, with its peak of abundance in the Upper Fort Scott-Pawnee intervals. Therefore, the species can occur as high as the Altamont cycle in the Midcontinent section, but it is most characteristic of the Fort Scott, and possibly the Pawnee cycles. The closely related species *Beedeina girtyi* was also described by Dunbar and Condra (1927) and Dunbar and Henbest (1942) from the Fort Scott limestones in Kansas. Another example is the *Beedeina novamexicana* assemblage cited by Ross and Ross (1988, figure 6). All species in that assemblage (*B. novamexicana, B. euryteines, B. bowiensis, W. ellipsoides*) are characteristic of sub-Fort Scott stratigraphic units (i.e., upper Cherokee Group) in the Midcontinent (e.g., Dunbar and Henbest, 1942), yet Ross and Ross (1988, Figure 6) correlated that assemblage to the Pawnee depositional cycle. There appear to be problems with some correlations between Ross and Ross' (1988, figure 6) Desmoinesian depositional cycles and representative fusulinid assemblages, and additional evaluation and clarification are needed.

Wilde (1990) outlined a Desmoinesian fusulinid zonation based primarily on the subsurface and adjacent outcrop areas of the Permian Basin region in Texas and New Mexico (Table 2). Essentially, Wilde's zones DS-4 and DS-5 corresponds to the *Beedeina eximia-B. acme* zone of the Midcontinent, his zone DS-3 corresponds to the *Beedeina girtyi-B. haworthi* zone of the Midcontinent, his zone DS-2 and probably upper DS-1 correspond to the *Beedeina novamexicana-Wedekindellina euthysepta* zone of the Midcontinent, and his lower DS-1 corresponds to the *Beedeina insolita-B. leei* zone of the Midcontinent.

TABLE 2: Summary of Wilde's (1990) Desmoinesian fusulinid zones and assemblages of the Permian Basin and surrounding areas.

Wilde Zone	Assemblage Zone Name	Representative Fusulinids
DS-5	Upper Zone of *Fusulina*	*Fusulina cylindrica* group
DS-4	Lower Zone of *Fusulina*	*Fusulina megista/mysticensis* *Fusulina acme/eximia/lonsdalensis* *Fusulina bellatula* *Bartramella bartrami*
DS-3	Upper Zone of *Beedeina*	*Beedeina girtyi/illinoisensis* *Beedeina haworthi/similis* *Plectofusulina spp.* *Frumentella spp.* *Dutkevichella(?) rickerensis/arenaria*
DS-2	Middle Zone of *Beedeina*	*Beedeina novamexicana/distenta* *Beedeina levicula*
	Upper Zone *Wedekindellina*	*Wedekindellina euthysepta* *Wedekindellina henbesti* *Wedekindellina excentrica* *Wedekindellina ellipsoides* *Wedekindellina magna*
DS-1	Lower Zone of *Beedeina*	*Beedeina euryteines* *Beedeina novamexicana* *Beedeina leei* *Beedeina pumila*
	Lower Zone of *Wedekindellina*	*Wedekindellina euthysepta*, etc. *Fusulinella iowensis*

Finally, the Upper Desmoinesian occurrences in the Rocky Mountains of two additional significant fusulinid genera, *Bartramella* and *Protriticites*, need to be briefly discussed. Verville, Thompson and Lokke (1956) described the new genus and species *Bartamella bartrami* from the Upper Desmoinesian of Nevada, where it was associated with a *Beedeina weintzi* and two new species that they assigned to *Fusulinella* (which may be better assigned to *Eowaeringella*?). Cassity and Langenheim (1966) reported *Bartramella bartrami* at Arrow Canyon in Nevada, where it occurred in association with *Beedeina retusa*. The generic range zone of *Bartramella* has not yet been well established, but it is thought to appear in the upper *Beedeina girtyi-B. haworthi* subzone and extend up through the *B. eximia-B. acme* subzone.

Recently, Wahlman, Verville and Sanderson (1997) reported the first known USA occurrences of the fusulinid *Protriticites* , an important index fossil in Moscovian-Kasimovian boundary beds of Eurasia. *Protriticites* was reported in stratigraphic sections from Nevada, Idaho, and Utah. In Nevada, rare specimens were found in association with *Beedeina* cf. *retusa*, *B*. cf. *clarkensis*, and *Plectofusulina* sp., and within the range zone of *Bartramella bartrami*. In Idaho, *Protriticites* occurred well above the *Beedeina novamexicana-Wedekindellina* subzone, and in association with *Beedeina* cf. *haworthi* and *Bartramella bartrami*. In Utah, it was found in the Honaker Trail section in the Upper Ismay cycle, above the subzone of *B. novamexicana-Wedekindellina*, below the subzone of *Beedeina eximia-B. acme*, and in association with *B*. cf. *haworthi* and *B. erugata*. Therefore, from currently available data, *Protriticites* is thought to occur in the upper part of the *Beedeina girtyi-B.haworthi* subzone in the western USA.

SUMMARY OF DESMOINESIAN FUSULINID BIOSTRATIGRAPHY OF THE HONAKER TRAIL SECTION

The Honaker Trail Section was sampled for fusulinid biostratigraphy by the author on July 10-11, 1991. A total of 18 fusulinid samples were taken. The fusulinids identified from the Honaker Trail section are listed in descending sample order in Table 3 (following the Bibliography), and brief petrographic/microfacies descriptions of the samples are given in Appendix 2.

The lowermost part of the section, the Akah cycle (samples HT-2 to HT-8), is characterized by primitive species of *Beedeina* (*B. arizonensis*, *B.* cf. *leei*, *B.* aff. *pristina*) and species of *Wedekindellina* (*W. coloradoensis*, *W. excentrica*). These fusulinids indicate assignment to the upper *Beedeina insolita-B. leei* subzone. The interval is middle Early Desmoinesian in age, and correlates with the upper Lower Cherokee Group of the Midcontinent. It also correlates with Wilde's (1990) Permian Basin DS-1 zone, with Ross and Sabins' (1965) *Beedeina hayensis* and lower *Wedekindellina euthysepta* zones in southeastern Arizona.

The overlying Desert Creek cycle (samples HT-9 to HT-10) is characterized by *Beedeina euryteines*, *B. novamexicana*, *B. rockymontana*, and *B. curta*. Interestingly, in the Midcontinent and Permian Basin areas, this *Beedeina* assemblage is generally associated with common *Wedekindellina* (e.g., *W. ellipsoides*, *W. euthysepta*, etc.), but no associated specimens of *Wedekindellina* were found in this section. These samples are assigned to the *Beedeina novamexicana* subzone, and are late Early Desmoinesian in age. The interval correlates with the Upper Cherokee of the Midcontinent (probably Verdigris-Breezy Hill interval). It also correlates with Wilde's (1990) DS-2 middle zone of *Beedeina,* and with Ross and Sabins' (1965) *Wedekindellina euthysepta* subzone in southeastern Arizona.

The Lower Ismay cycle (samples HT-12 to HT-15) is characterized by *Beedeina bowiensis* in its lower part and by *B.* cf. *haworthi* in its upper part. The interval is assigned to the upper *Beedeina novamexicana* subzone, and may extend into the lower *Beedeina girtyi-B. haworthi* subzone, and is thus Middle Desmoinesian in age, probably correlating with the uppermost Cherokee and possibly the lowermost Marmaton Groups of the Midcontinent. It also correlates with Wilde's (1990) uppermost zone DS-2 and probably lower zone DS-3, and to Ross and Sabins' (1965) upper *Wedekindellina euthysepta* subzone and probably lower *Beedeina girtyi* subzone.

The Upper Ismay cycle (samples HT 11, 16, 17, 18, and 19) is characterized by *Protriticites* sp., *Beedeina erugata*, and *B.* aff. *sulphurensis*. As discussed above, occurrences of *Protriticites* in the Rocky Mountains have been assigned to the *Beedeina girtyi-B. haworthi* subzone (Wahlman, Verville and Sanderson, 1997). Also, *Beedeina erugata* is associated with *B. haworthi* in its type area (Waddell, 1963). Ross and Sabins (1965) described *B. sulphurensis* from the Upper Desmoinesian of Arizona, where it occurred above *B. haworthi*, but was not directly associated with any other age-diagnostic fusulinids. *B.* aff. *sulphurensis* is similar in test size and shape to the holotype of that species, but appears somewhat more primitive, with less intense septal fluting. This interval is assigned to the *Beedeina girtyi-B. haworthi* subzone (early Late Desmoinesian), and correlates with the lower Marmaton Group (Fort Scott-Pawnee) of the Midcontinent. It also correlates with Wilde's (1990) upper DS-3 zone (and possibly lower DS-4 zone), and to the upper part of Ross and Sabins' (1965) *Beedeina girtyi* subzone in Arizona.

The upper part of the Desmoinesian section (samples HT-20 and HT-21) in the Honaker Trail section contains the typical latest Desmoinesian fusulinids *Beedeina megista* and *B. cappensis*. Also identified was a single specimen of *B.* aff. *marmatonensis*, a species described by Bebout (1963) from the Fort Scott through Altamont interval in Missouri, but it is suspected here that this species is actually a microspheric form of one or more other species such as *B. haworthi* and/or *B. megista*. This interval is assigned to the *Beedeina eximia-B. acme* subzone and correlates with the Upper Marmaton of the Midcontinent (Altamont-Lenapah). This interval correlates with Wilde's (1990) DS-4 zone, and with Ross and Sabins' (1965) *Beedeina eximia* zone in Arizona.

It should be noted that Welsh (1958) has previously illustrated some fusulinids from the Honaker Trail section, but he did not assign most specimens to species, and did not attempt biostratigraphic correlations with other areas. Also, Baars, Parker and Chronic (1967) proposed a fusulinid zonation for the Paradox Basin Desmoinesian section. The current study generally agrees with their zonation, with some exceptions. The Barker Creek cycle is not exposed at Honaker Trail, contrary to Wengerd's (1973, and previously published) measured sections, but it is known from other areas to be in the *Beedeina insolita-B. leei* subzone (e.g., see Gianinny, 1995). Baars et al. (1967) labelled the Akah as the zone of *Beedeina rockymontana-Wedekindellina excentrica*, which would be assigned here to the upper part of the *Beedeina insolita-B. leei* subzone. Baars et al. (1967) matched the Desert Creek cycle to the *Beedeina novamexicana* subzone, as was done here. They assigned the Ismay to a *Beedeina haworthi-B. weintzi* zone. Here, the Lower Ismay cycle is assigned to the uppermost *B. novamexicana*-

Wedekindellina subzone and possibly lowermost *B. girtyi-B. haworthi* subzone, and the Upper Ismay cycle is correlated with the *B. girtyi-B. haworthi* subzone. And finally, they assigned the upper part of the Desmoinesian section to a *Beedeina knighti* zone, but here that section is correlated with the *Beedeina eximia-B. acme* subzone.

The Honaker Trail section fusulinid fauna provides data sufficient for a good approximate correlation with Desmoinesian sections in the Midcontinent and other regions. In order to get a more complete understanding of the Paradox Basin fusulinid faunas, and their zonation and correlation, several stratigraphic sections from the area need to be sampled, preferably for multidisciplinary biostratigraphic data (e.g., fusulinids and conodonts). A preliminary multidisciplinary study for the Honaker Trail section is presented by Ritter, Barrick, Wahlman and Skinner in this guidebook.

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TABLE 3: Fusulinid species identified from the Honaker Trail Section samples, and correlative bed numbers from Wengerd (1973) and Mobil Oil Company (see Ritter, Barrick, Wahlman, and Skinner, this guidebook) measured sections.

Sample No.	Wengerd Beds	Mobil Beds	Fusulinid Species
UPPER DESMOINESIAN			
HT-21	113	112	*Beedeina megista*
HT 20	107	104	*Beedeina megista* *Beedeina cappensis* *Beedeina aff. marmatonensis* (probably a microspheric form)
UPPER ISMAY CYCLE			
HT-19	just above 88	91?	*Beedeina* aff. *sulphurensis*
HT-18	88 (upper)	88	*Protriticites* sp. *Beedeina erugata*
HT-17	88 (middle)	88	*Protriticites* sp. *Beedeina erugata* *Eoschubertella* sp.
HT-16	88 (lower)	88	*Protriticites* sp. *Beedeina* aff. *erugata*
HT-11	88	88	*Protriticites* sp.
LOWER ISMAY CYCLE			
HT-15	82 (Horn Pt.)	84	*Beedeina* cf. *haworthi* *Beedeina* sp.
HT-14	82 (Horn Pt.)	84	*Beedeina* cf. *haworthi* *Beedeina* sp.
HT-13	79	80	*Beedeina bowiensis*
HT-12	79	80	*Beedeina bowiensis* *B.* cf. *rockymontana*
DESERT CREEK CYCLE			
HT-10	74	76?	*Beedeina euryteines* *Beedeina curta*
HT-9	72	74-75?	*Beedeina rockymontana* *Beedeina euryteines* *Beedeina* cf. *novamexicana*

continued next page

Table 3 continued

Sample No.	Wengerd Beds	Mobil Beds	Fusulinid Species
AKAH CYCLE			
HT-8	50	53	*Beedeina* cf. *pristina*
HT-7	30?	32-34	*Beedeina arizonensis* *B.* aff. *leei*
HT-5	17 (upper)	17-18	*Wedekindellina coloradoensis*
HT-3	17 (lower)	17-18	*Wedekindellina coloradoensis* *Wedekindellina excentrica* *Beedeina arizonensis*
HT-2	17 (lower)	17-18	*Wedekindellina coloradoensis*

APPENDIX 1: Some published stratigraphic occurrences of Midcontinent Desmoinesian fusulinid faunas.

Dunbar and Condra (1927) - Nebraska

Lenapah Ls.	*Beedeina haworthi*
Altamont Ls.	*B. haworthi*
Pawnee Ls.	*B. haworthi, B. illinoisensis (=F. meeki robusta)*
Upper Fort Scott Ls.	*B. girtyi* (sparse)
Lower Fort Scott Ls.	*B. girtyi* (abundant), *B. haworthi*
Cherokee undiff.	*B. euryteines (=F. meeki)*

Dunbar and Henbest (1942) - Kanasas-Oklahoma occurences

Upper Fort Scott Ls. (Marmaton)	*B. knighti, B. girtyi, B. illinoisensis*
Spaniard Creek Ls.(Cherokee)	*B. novamexicana, W. euthysepta*

Dunbar and Henbest (1942) - Illinois Basin

UPPER MARMATON	
Lonsdale Ls.	*B. lonsdalensis, B. acme, B. eximia, B. megista, B. mysticensis, B.* sp.
Cutler Ls.	*B. piasaensis, B. acme, B. eximia, B. megista, B.* cf. *haworthi,*
Piasa Ls.	*B. piasaensis, B. acme, B. eximia, B. megista, B. mysticensis, B.* cf. *Illinoisensis*
LOWER MARMATON	
Bankston Fork Ls.	*B. girtyi, B. illinoisensis, B. knighti*
Brereton-Herrin Ls.	*B. girtyi, B. illinoisensis, B. haworthi, B. cf. haworthi, B. lucasensis*
St. David Ls.	*B. girtyi, B. illinoisensis, B. haworthi*
UPPER CHEROKEE	
Absher ls.	*B. lucasensis, B. levicula, Fusulinella cadyi* (probably a microspheric form of *Beedeina levicula*)
Oak Grove Ls.	*B. spissiplicata, B.* sp., *W. euthysepta, W. excentrica, W. ellipsoides, W. sp.*
Sta. B3 (Wine Hill)	*B. pumila, B.* cf. *leei, W. euthysepta?*
Seahorne Ls.	*B. pumila, B.* cf. *leei, W. euthysepta*
Stonefort Ls.	*B. novamexicana, B. sp. A, W. euthysepta, W. minuta, W. excentrica?*
Sta. B1 (Murphysboro)	*B. novamexicana, W. euthysepta* ????????

LOWER CHEROKEE	
Curlew Ls.	*B. leei*
Seville Ls.	*Fusulinella iowensis, F. iowensis stouti, F. gephryea*

Bebout (1963) - Missouri

UPPER MARMATON	
Lenapah Fm. (Sni Mills mbr.)	*B. megista, B. acme*
Altamont Fm. (Worland mbr.)	*B. megista, B. acme, B. tumida, B. haworthi, B. marmatonensis*
LOWER MARMATON	
Pawnee Fm.	*B. tumida,* numerous *B. haworthi, B. girtyi, B. knighti, B. marmatonensis*
Fort Scott Gr. (Higginsville Fm.)	*B. haworthi, B. girtyi, B. lucasensis, B. marmatonensis, B. higginsvillensis*
Fort Scott Gr. (Little Osage Fm., Houx Mbr.)	*B. girtyi, B. marmatonesis, B. boonensis*
Fort Scott Gr. (Little Osage F., Blackjack Creek Mbr.)	*B. haworthi, B. occulifrons, B. lucasensis, B. boonensis*
CHEROKEE	
Cabaniss Gr.	*W. euthysepta, B. euryteines, B. leei, B. kayi, B. boonensis, B. cadyi, B.? problematica*

Waddell (1963) - Ardmore Basin, Oklahoma

LOWER MISSOURIAN	
ZONE VI	*Eowaeringella ardmorensis, Triticites tomlinsoni*
UPPER MARMATON	
ZONE V	*Beedeina acme, B.* aff. *whitakeri*, (*Bartramella* in subsurface)
LOWER MARMATON	
ZONE IV	*B. haworthi, B. erugata, Wedekindellina* spp.
UPPER CHEROKEE	
ZONE III	*B. novamexicana, B. euryteines, Wedekindellina* spp.
LOWER CHEROKEE	
ZONE II	*B. insolita, B. plattensis, B. pumila, B. mutabilis, Wedekindellina* spp.
UPPER ATOKAN	
ZONE I	*Fusulinella* spp.

Alexander (1954) - Oklahoma, McAlester Basin shelf

UPPER MARMATON	
Altamont Fm. (Worland mbr.)	*Beedeina mysticensis*
Pawnee Fm. (U. Pawnee)	*B. megista*
LOWER MARMATON	
Pawnee Fm. (Myrick Station mbr.)	*B. tumida*
Pawnee Fm. (Wimer School mbr.)	*B. megista*
Ft. Scott Fm. (Higginsville mbr.)	*B. girtyi, B. occulifrons*
Ft. Scott Fm. (Blackjack Creek mbr.)	*B. girtyi, B. haworthi*
UPPER CHEROKEE	
Breezy Hill Fm.	*B. expedita, B. plena*
Verdigris Fm.	*B. equilaqueata,*
Fleming Cap Fm.	*W. euthysepta, B. kayi*
Russell Creek Fm.	*B. equabilis*
Tiawah Fm.	*B. attenuata*
LOWER CHEROKEE	
Inola Fm.	*B. leei, W. henbesti, Fusulinella trisulcata, Eoschubertella gallowayi, Pseudostaffella hollingsworthi*
Sam Creek Fm.	*Fusulinella* sp.
Spaniard Fm.	*B. novamexicana*

APPENDIX 2: Brief petrographic/microfacies descriptions of the fusulinid samples from Honaker Trail section.

HT-2 Skeletal-peloidal packstone-wackestone; common brachiopod shell fragments and spines; sparse fusulinids, fenestrate bryozoan fragments, mollusc shell fragments, crinoid ossicles; and rare smaller forams (endothyrids, *Tuberitina*, paleotextulariids).

HT-3 Skeletal-peloidal packstone; common molluscs, crinoid ossicles; sparse fusulinids, ostracods, paleotextulariid and endothyrid forams, brachiopod fragments; rare *Komia*(?) and fish fragments.

HT-5 Same as HT-3.

HT-7 Skeletal wackestone, brownish; sparse donezellid algal fragments (*Donezella lutugini)*, crinoid ossicles, bryozoan fragments, small shell fragments, and *Tuberitina* smaller forams.

HT-8 Peloidal-skeletal packstone; very fine-grained peloidal matrix; common tubular smaller forams; sparse crinoid ossicles, fusulinids, ostracods, donezellid algal fragments, and smaller forams (*Tuberitina*, *Pseudobradyina*).

HT-9 Silty skeletal-peloidal packstone; quartz silt distributed throughout; poorly sorted; common crinoid ossicles, brachiopod shell fragments and spines, and fusulinids; sparse ostracods, bryozoans; rare smaller forams (endothyrids, tubular forams).

HT-10 Phylloid algal-skeletal wackestone; sparse phylloid algal fragments, tubular forams, and crinoid ossicles; very sparse brachiopods, fenestrate bryozoans, smaller forams (*Tetrataxis*, *Tuberitina*).

HT-11 Phylloid algal-skeletal wackestone; common phylloid algal fragments; sparse fusulinids, tubular forams, crinoid ossicles, gastropods; rare ostracods, smaller forams, donezellid algal fragments, brachiopods.

HT-12 Skeletal wackestone, mud matrix partially dolomitized, finely crystalline; sparse fusulinids, crinoid ossicles, fenstrate bryozoan fragments, and small shell fragments.

HT-13 Same as HT-12, but less dolomitization and fewer skeletal grains.

HT-14 Skeletal packstone-wackestone; common fusulinids, and brachiopod shell and spine fragments, and ostracods; sparse bryozoan fragments, crinoid ossicles, smaller forams, and possibly sponge spicules.

HT-15 Crinoidal-skeletal packstone-wackestone; common crinoid ossicles, brachiopod fragments; sparse fusulinids, bryozoan fragments; and a couple of apparently redeposited intraclasts.

HT-16 Phylloid algal-skeletal packstone-wackestone; common phylloid algal plate fragments and fusulinids; sparse tubular forams, ostracod and mollusc fragments and crinoid ossicles; rare smaller forams (*Globivalvulina*).

HT-17 Phylloid algal-skeletal-peloidal packstone-wackestone, similar to HT-16 but with a more peloidal matrix.

HT-18 Phylloid algal-fusulinid wackestone; common phylloid algal plates and fusulinids; sparse tubular encrusting forams and rare smaller forams (*Globivalvulina*).

HT-19 Skeletal-peloidal packstone, with sparse fusulinids and other larger bioclasts in an overpacked finer-grained skeletal-peloidal matrix; common fusulinids; sparse brachiopod spines, crinoid ossicles, ostracods, bryozoan fragments, and smaller forams (*Tetrataxis*, *Syzrania*).

HT-20 Fusulinid-skeletal packstone; abundant fusulinids; common brachiopod shell fragments and spines; moderately common bryozoans, crinoid ossicles, foraminifera (especially *Bradyina* and tubular encrusting forams, but also *Climacammina*, palaeotextulariids, and unidentified agglutinate forams); sparse poorly preserved phylloid algal plate fragments. Many larger bioclasts encrusted by tubular forams.

HT-21 Silty skeletal-pelletal wackestone to packstone; sparse quartz silt grains scattered through muddy matrix with mostly small bioclasts; moderately common fusulinids; sparse crinoid ossicles, brachiopod shell fragments and spines, and probable ostracods; rare bradyinid foraminifera.

LISTING OF FOSSILS RECOGNIZED AT FIELD TRIP STOPS

John P. Pope and **Philip H. Heckel**, University of Iowa, with information from
James E. Barrick, Texas Tech University, and Darwin R. Boardman, Oklahoma State University

In order to facilitate collecting by interested field trip participants, all fossils easily recognized on outcrop, in hand samples collected for later conodont analysis, or in washed shales or formic-acid residues of limestone samples processed for conodonts, are listed below in descending stratigraphic order for most field trip stops, in the order that they will be visited. Conodont taxa are listed in decreasing order of abundance, first by genus, then by species. Terms indicating estimated total abundance: Sparse = < 20 nearly whole elements / kg; Moderately sparse ~ 20-60 / kg; Moderate ~ 60-100 / kg; Moderately abundant ~ 100-200 / kg; Abundant ~ > 200 / kg.

Stop A1: Creek bank south of Sni Mills, Missouri

Lost Branch Formation (upper gray shale unit)

*0.5-1.0' (15-30 cm) above Sni Mills Limestone:

Forams: ammodiscoid, uniserial; Ostracodes
Conodonts: rare fragments

*0.1-0.5' (3-15 cm) above Sni Mills Limestone (faunally like Nuyaka Creek Shale bed):

Brachiopods incl. *Crurithyris*; Fish pieces; Ostracodes
Forams: ammodiscoid, uniserial, encrusting
Conodonts (abundant): *'I.'* spp., mostly *'I.' nodocarinatus* [= *'I.'* sp. 6 of Swade 1985], *Idiognathodus expansus, I.* sp., *Neognathodus, Idioprioniodus, Gondolella magna, G. denuda*

Nuyaka Black Shale bed (of Lost Branch Formation):

*0-0.1' (0-3 cm) above Sni Mills Limestone:

Brachiopods: *Crurithyris, Composita, Neochonetes, Orbiculoidea,* productids
Bryozoans: rhomboporids, fistuliporids
Coral: solitary rugose *Stereostylus?*
Conodonts: same as above

Sni Mills Limestone Member (of Lost Branch Formation):

Brachiopods incl. productids; Crinoid debris; Gastropods; Ostracodes; Phylloid algae
Conodonts (moderate): *'I.' nodocarinatus, Idiognathodus expansus, Hindeodus, Neognathodus, Diplognathodus, Idioprioniodus, Gondolella*

Memorial Shale: No fossils seen

Stop A2: Road/stream cut at 63rd St. west of I-435 and onramp to I-435, Kansas City, Missouri

Winterset Limestone Member (of Dennis Limestone) [along onramp to I-435]

*9.5' (2.9 m) above base:

Brachiopods: *Neospirifer, Teguliferina, Composita, Derbyia, Antiquatonia, Chonetinella, Hustedia, Juresania*
Crinoid debris; Echinoids; Bryozoans; Trilobites; Ostracodes; Fish pieces
Forams: uniserial; biserial/uniserial; encrusting
Conodonts (mod. sparse): *Streptognathodus confragus*, and deeper troughed forms; *Idiognathodus* sp.; *Adetognathus*

*0.5' (15 cm) dark shale 5.0' (1.5 m) above base:

Brachiopods: *Crurithyris, Dielasma, Orbiculoidea*, productids
Gastropods; Clams; Rhomboporid bryozoans; Crinoid debris; Fish pieces

Pope, J. P., and Heckel, P. H., 1999, Listing of fossils recognized at field trip stops; *in*, Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin, U.S.A., P. H. Heckel, ed.: XIV International Congress on the Carboniferous–Permian, Field Trip #8 Guidebook; Kansas Geological Survey, Open-file Report 99–27, p. 217–236.

Forams: encrusting, ammodiscoid, uniserial
Conodonts (abundant): *Idiognathodus cf. magnificus, I.* sp.; *Streptognathodus cancellosus, S. confragus*; *Idioprioniodus, Hindeodus*

0.3' (9.0 cm) dark shale 1.0' (30 cm) above base:
Brachiopods: *Crurithyris, Chonetinella, Dielasma, Antiquatonia, Kozlowskia, Derbyia, Neospirifer, Punctospirifer, Composita*
Rhomboporid bryozoans; Encrusting forams; Echinoids; Ostracodes; Crinoid debris; Fish pieces
Conodonts (abundant): *Idiognathodus cf. magnificus, Idioprioniodus, Hindeodus, Aethotaxis*

Bethany Falls Limestone Member (of Swope Limestone) [in stream cut]
*7' (2.1 m) above base:
Brachiopods: *Pulchratia, Composita, Phricodothyris*; Bryozoans: rhomboporids, fenestellids
Crinoid debris; Fish pieces; Echinoids; Biserial/uniserial forams
Conodonts (sparse): *Streptognathodus cf. cancellosus*

*4' (1.2 m) above base:
Brachiopods: *Composita*, productids; Bryozoans: rhomboporids, fenestellids
Fish pieces; Crinoid debris; Solitary rugose coral
Forams: biserial/uniserial forams; fusulinids
Conodonts (sparse): small *'Streptognathodus'*

*2' (0.6 m) above base:
Brachiopods; Crinoid debris; Fish pieces; Bryozoans; Fusulinids
Conodonts (sparse): small *'Streptognathodus', Aethotaxis?*

*1' (30 cm) above base:
Brachiopods: *Hustedia*, chonetids, productids; Crinoid debris; Fish pieces
Conodonts (sparse): small *'Streptognathodus'; Idiognathodus* sp.

*base: Crinoid pieces; Brachiopods, incl. orbiculoids; Bryozoans; Fish Pieces; Encrusting forams
Conodonts (moderate): *Idiognathodus* spp.; *Streptognathodus cancellosus, Idioprioniodus, Hindeodus*

Hushpuckney Shale Member (of Swope Limestone)
*Upr Gray, top 0.5' (15 cm):
Brachiopods: *Crurithyris, Orbiculoidea*, productids
Crinoid debris; Fish pieces; Solitary rugose coral; Ostracodes; Rhomboporid bryozoans
Conodonts (abundant): *Idiognathodus* spp., incl. *I. sulciferus, I. eccentricus, I.* n sp. A; *Streptognathodus cancellosus, Idioprioniodus, Hindeodus*

*Upr Gray 2.0-2.5' (0.6-0.8 m) above base (massive bed):
Brachiopods: *Crurithyris*, productids
Ostracodes; Gastropods; Clams; Encrusting forams; Fish pieces
Conodonts (mod. sparse): *Idiognathodus sulciferus, I. eccentricus, I.* n. sp. A, *Idioprioniodus*

*Upr Gray 1.0-2.0' (30-60 cm) above base:
Brachiopods incl. *Crurithyris*
Ammodiscoid and encrusting forams; Ostracodes; Gastropods; Clams; Fish pieces
Conodonts (moderate): *Idiognathodus* spp., incl. *sulciferus; Idioprioniodus, Gondolella*

*Upr Gray 0-1.0' (0-30 cm) above base:
Brachiopods incl. *Crurithyris*; Encrusting forams; Fish pieces
Conodonts (mod. abundant): *Gondolella* spp., incl. *G. sublanceolata, G. denuda; Idiognathodus* spp., incl. *I. sulciferus; Idioprioniodus*

*Upr Black 1.0' (30 cm):
Fish pieces

Conodonts (abundant): *Idiognathodus* spp., incl. *I. sulciferus, I. eccentricus, I. clavatulus, I.* n. sp. A; *Streptognathodus cancellosus, Idioprioniodus, Gondolella* spp., incl. *G. denuda*

*Lwr Black 0.1-0.5' (3.0-15 cm):
Fish pieces
Conodonts (abundant): *Idiognathodus* spp., incl. *I. sulciferus, I. eccentricus, I. clavatulus, I.* n. sp. A; *Streptognathodus cancellosus, Idioprioniodus, Gondolella* sp. [platformed only]

*Lwr Gray 0.1' (3.0 cm):
Brachiopods: *Composita, Derbyia, Crurithyri*s, chonetids
Bryozoans incl rhomboporids
Conodonts (mod. abundant): *Idiognathodus* spp., incl. *I. sulciferus, I. eccentricus, I. clavatulus, I.* n. sp. A; *Idioprioniodus*

Middle Creek Limestone Member (of Swope Limestone)
*Upr bed, top:
Forams: uniserial, encrusting

* Upr bed, base:
Brachiopods incl. *Orbiculoidea*; Gastropods; Encrusting forams; Fish pieces
Conodonts (mod. sparse): *Idiognathodus* sp. (juv.), *Hindeodus, Aethotaxis?*

*0.3' (9 cm) shale:
Brachiopods: *Neochonetes, Derbyia, Punctospirifer*
Crinoid debris; Clams; Ostracodes; Trilobites; Echinoids; Gastropods; Fish pieces; Encrusting forams
Bryozoans: rhomboporids, fistuloporids, fenestellids
Conodonts (mod. sparse): *Idiognathodus* sp. (juv.), *Adetognathus, Hindeodus, Aethotaxis?*

* Lwr bed top:
Forams: ammodiscoid, encrusting; Fish pieces
Conodonts (sparse): *Adetognathus*

*Lwr bed base:
Forams: ammodiscoid, encrusting; Fish pieces
Conodonts (sparse): *Adetognathus*

Elm Branch Shale
*Upr 0.7' (21 cm):
Brachiopods: *Derbyia*, productids; Bryozoans: rhomboporids, fenestellids
Ostracodes; Scolecodonts; Gastropods; Echinoids; Holothuroids; Crinoid debris; Fish pieces
Forams: ammodiscoid, encrusting, *Tetrataxis*

Sniabar Limestone Member (of Hertha Limestone)
* 6.0' (1.8 m) above base:
Forams: encrusting, fusulinids; Crinoid debris
Conodonts (sparse): *Adetognathus*

*4.5' (1.4 m) above base:
Brachiopods incl. *Lingula*; Gastropods; Clams; Crinoid debris; Fish Pieces
Conodonts (moderate): *Adetognathus, Idiognathodus* spp. (juv.), *Hindeodus, Aethotaxis*

*4.0' (1.2 m) above base:
Macrofossils, as above
Conodonts (sparse): *Idiognathodus sulciferus* + juv., *Hindeodus*

*3' (0.9 m) above base:
Crinoid debris; Encrusting forams

Conodonts (mod. sparse): *Idiognathodus sulciferus*, adol. n. sp. A

*1.5' (0.5 m) above base:

Brachiopods; Crinoid debris; Encrusting forams

Conodonts (mod. sparse): *Idiognathodus sulciferus, Hindeodus, Idioprioniodus*

*base: Productid brachiopods; Crinoid debris; Encrusting, uniserial forams

Conodonts (sparse): *Idiognathodus sulciferus* + juv., *Hindeodus, Aethotaxis?*

Mound City Shale Member (of Hertha Limestone)

*lr dark: Brachiopods

Conodonts (abundant): *Idiognathodus sulciferus, I. eccentricus, I.* n. sp. A, *Idioprioniodus, Gondolella*

More detailed collection from cut above U.S. 71 at Bannister Road, 4 miles to south:

Mound City Shale Member

*U. Gy: Brachiopods: *Crurithyris, Derbyia, Dielasma, Punctospirifer, Composita, Orbiculoidea*, productids

Forams: *Tetrataxis*

Rhomboporid bryozoans; Ostracodes; Crinoid debris; Trilobites; Fish pieces

Conodonts (abundant): *Idiognathodus sulciferus, I. eccentricus, I.* n. sp. A, *I. clavatulus?, Hindeodus, Idioprioniodus, Gondolella*

*mid black: Conodonts (abundant): *Idiognathodus* n. sp. A, *I. sulciferus, I. eccentricus, I. clavatulus, Idioprioniodus, Gondolella*

*Lr Gy: Brachiopods: *Crurithyris, Antiquatonia, Dielasma, Punctospirifer, Composita, Kozlowskia*, productids

Rhomboporid bryozoans; Ostracodes; Fish pieces

Conodonts (moderate): *Adetognathus, Idiognathodus sulciferus, I.* n. sp. A, *Idioprioniodus,* 1 *Gondolella*

Stop A3: I-435 Roadcut east of Blue River, Kansas City, Missouri

Wea Shale Member (of Cherryvale Formation)

*base: Brachiopods: *Crurithyris*, productids

Bryozoans: rhomboporids

Encrusting forams; Ostracodes; Crinoid debris

Block Limestone Member (of Cherryvale Formation)

*top, middle, and base:

Brachiopods incl. *Crurithyris*; Crinoid debris; Encrusting forams; Fish pieces

Conodonts (abundant): *Streptognathodus excelsus, S. corrugatus, S. gracilis, S. elegantulus, S. cf. kalitvensis, Idiognathodus* spp., incl. *I. cf. toretzianus; Adetognathus*

Fontana Shale Member (of Cherryvale Formation)

*top: Brachiopods: *Crurithyris, Composita, Derbyia, Hustedia, Lingula*, productids

Forams: encrusting, ammodiscoid, endothyrid

Ostracodes; Crinoid debris; Bryozoans; Fish pieces

Conodonts (abundant): *Streptognathodus gracilis, S. corrugatus, S. excelsus, S. elegantulus, Idiognathodus* spp., incl. *I. cf. toretzianus, I. cf. magnificus* (elongate form)

*middle: Clams, incl. pectenoid; Brachiopods, incl. *Juresania, Composita, Neospirifer, Derbyia*; Criniod ossicles, Bryozoans; all with thick encrustations of algae and forams.

[Not collected for conodonts]

Winterset Limestone Member (of Dennis Limestone) [Upper unit: 'Hogshooter']

*about 1' (30 cm) above base:

Brachiopods incl. *Linoproductus, Juresania, Composita, Chonetinella, Isogramma, Antiquatonia*; Bryozoans; Ostracodes; Crinoid debris; Fish pieces

[only sparse *Adetognathus*-dominated conodont faunas were reported from this unit by Baesemann, 1973]

[Lower unit]
* 16.0' (4.9 m) above base:
Brachiopods incl. *Composita, Antiquatonia*
Trilobites; Rhomboporid bryozoans; Pecten-like bivalves

*13.5' (4.1 m) above base:
Brachiopods: *Derbyia, Orbiculoidea*, productids
Crinoid debris; Encrusting forams; Fish pieces
Conodonts (mod. sparse): *Adetognathus*

*7.0-9.0' (2.1-2.7 m) above base:
Brachiopods: *Lingula, Punctospirifer, Hustedia, Composita, Kozlowskia*, productids
Bryozoans: rhomboporids, encrusting, fenistellid
Encrusting forams; Crinoid debris; Fish pieces; Echinoids
Conodonts (sparse): *Hindeodus* at 9'; *Idiognathodus* sp. [juv.] at 7'

*5.0' (1.5 m) above base:
Brachiopods: *Composita, Hustedia, Neochonetes, Puntospirifer*, productids
Bryozoans: rhomboporids, fenistellids
Encrusting and biserial/uniserial forams; Crinoid debris; Fish pieces; Echinoids

*4.0' (1.2 m) above base:
Brachiopods: *Composita, Hustedia, Kozlowskia, Crurithyris*
Forams: encrusting, ammodiscoid; Bryozoans; Gastropods; Crinoid debris; Fish pieces
Conodonts (sparse): *Idiognathodus cf. magnificus, Diplognathodus*

*2.5' (0.8 m) above base:
Brachiopods: *Composita, Hustedia, Kozlowskia*
Encrusting forams; Bryozoans; Crinoid debris; Sponge spicules

*2.0' (0.6 m) above base:
Brachiopods incl. *Lingula*; Ostracodes; Clams; Gastropods; Sponge spicules

*1.0' (0-30 cm) above base
Brachiopods incl. *Orbiculoidea* and productids; Encrusting forams; Fish pieces; Crinoid debris
Conodonts (abundant): *Idiognathodus* spp., incl. *I. cf. magnificus, Streptognathodus confragus, Idioprioniodus, Hindeodus*

*base: Macrofossils, same as above
Conodonts (abundant): *Idiognathodus cf. magnificus, Streptognathodus confragus, S. cancellosus?, Idioprioniodus*

Stark Shale Member (of Dennis Limestone)
*Upr gray shale, upr 0.4' (12.0 cm):
Brachiopods: *Crurithyris*, productids
Forams: ammodiscoid, encrusting
Bryozoans; Fish pieces; Scolecodonts
Conodonts (abundant): *Idiognathodus* spp., incl. *I. sulciferus, I. cf. magnificus, Streptognathodus* spp., incl. *cancellosus, S. confragus, Idioprioniodus*

*Upr gray shale, lower 0.3' (9.0 cm):
Brachiopods; Gastropods; Clams; Crinoid debris; Ostracodes; Ammodiscoid forams; Ammonoids?
Conodonts (mod. abundant): *Idiognathodus sulciferus, I. cf. magnificus, Streptognathodus cancellosus, S. confragus, Idioprioniodus, Gondolella*

*Black, upper 0.3' (9cm) [hard]:

Conodonts (mod. abundant): *Idiognathodus* spp., incl *I. sulciferus, I. cf. magnificus, Streptognathodus cancellosus, S. confragus, Idioprioniodus, Gondolella*

*Black, middle 0.5' (15.0 cm) [chippy]:
Productid brachiopods
Conodonts (abundant): *Gondolella, Idiognathodus* spp., incl. *I. Sulciferus, I. cf. magnificus, Streptognathodus cancellosus, S. confragus, Idioprioniodus*

*Black, lower 0.4' (12 cm) exposed [hard]:
Conodonts (abundant): *Idiognathodus cf. magnificus* + spp., *Streptognathodus cancellosus, S. confragus, Gondolella, Idioprioniodus*

Stop A4: Roadcut on Kaw Drive west of I-635, Kansas City, Kansas

Cement City Limestone Member (of Dewey Limestone)
*7' (2.1 m) above base:
Brachiopods incl. *Composita* and productids,
Forams: Encrusting, biserial/uniserial, and uniserial
Crinoid debris; Fish pieces; Sponge spicules; Rhomboporid bryozoans
Conodonts (sparse): *Streptognathodus gracilis, S. excelsus*

*4' (1.2 m) above base:
Brachiopods incl. *Composita* and productids,
Forams: Fusulinids, encrusting, biserial/uniserial, and uniserial
Crinoid debris; Fish pieces; Sponge spicules; Rhomboporid bryzoans
Conodonts (sparse): fragments

*shale 3.5' (1.0 m) above base:
Brachiopods: *Composita, Hustedia, Rhipidomella*, chonetids, productids
Forams: biserial/uniserial, encrusting
Rhomboporid bryozoans; Echinoids, Ostracodes; Crinoid debris; Fish pieces; Sponge spicules
Conodonts (sparse): juvenile *Streptognathodus, Idiognathodus; Hindeodus*

*1-2' (0-60 cm) above base:
Forams: encrusting, uniserial, *Tetrataxis*
Brachiopods incl. *Lingula*, *Orbiculoidea, Composita,* productids
Gastropods; Crinoid debris, Fish pieces; Sponge spicules; Rhomboporid bryozoans
Conodonts (sparse): *Hindeodus, Aethotaxis?*

*base: Macrofossils and forams, same as above
Conodonts (moderate): *Streptognathodus elegantulus, S. corrugatus, S. gracilis, Idiognathodus magnificus, Hindeodus, Aethotaxis*

Quivira Shale Member (of Dewey Limestone) [top 5 samples from roadcut along I-70, 2 miles to east]

*Upr 0.75' (23 cm) gray:
Brachiopods: *Lingula, Crurithyris, Derbyia*, chonetids, productids
Ostracodes; Crinoid debris; Fish pieces; Encrusting forams
Conodonts (abundant): *Idiognathodus magnificus, Streptognathodus excelsus, S. elegantulus, S. gracilis*

* mid upr 0.5' (15 cm) dark gray:
Brachiopods incl. *Lingula*, productids; Ostracodes; Fish pieces
Forams: Ammodiscoid, uniserial, encrusting
Conodonts (abundant): *Idiognathodus magnificus, Streptognathodus gracilis, S. excelsus, S. elegantulus, S. corrugatus*

*mid 1.25' (38 cm) gray:

Brachiopods: *Orbiculoidea, Crurithyris, Composita*, productids, chonetids
Ostracodes; Crinoid debris; Fish pieces; Forams: Ammodiscoid, encrusting
Conodonts (abundant): *Idiognathodus magnificus, Streptognathodus gracilis, S. elegantulus, S. excelsus, S. corrugatus, Idioprioniodus, Gondolella*

*lwr mid 1' (30 cm) black:
Conodonts (abundant): *Idiognathodus magnificus, Gondolella, Streptognathodus excelsus, S. gracilis, S. elegantulus, S. corrugatus, Idioprioniodus*

* lwr 1' (30 cm) gray:
Brachiopods: *Lingula, Composita, Crurithyris*, productids; Clams; Gastropods
Forams: Ammodiscoid, encrusting
Conodonts (mod. abundant): *Streptognathodus excelsus, S. gracilis, S. elegantulus, Idiognathodus* spp., incl. *I. magnificus, I. cf. toretzianus?*

* lwr gray 0.35-0.5' (10.0-15.0 cm) above Westerville Limestone:
Brachiopods: *Crurithyris, Composita*, productids Ostracodes; Gastropods; Echinoid, Crinoid debris; Fish pieces; Forams: Fusulinids incl. staffellids, ammodiscoid, encrusting
Conodonts (mod. abundant): *Streptognathodus excelsus, S. gracilis, S. corrugatus, S. elegantulus, Idiognathodus* spp., incl. *I. magnificus*

*lwr gray 0.1-0.35' (3.0-10.0 cm) above Westerville Limestone:
Brachiopods: *Crurithyris, Composita, Wellerella*, productids
Forams: Fusulinids, encrusting
Bryozoans; Echinoids; Gastropods; Ostracodes; Crinoid debris; Fish pieces
Conodonts (mod. abundant, most small): *Streptognathodus excelsus, S. corrugatus, S. gracilis, S. elegantulus, Idiognathodus* sp. [nonlobed]

*lwr gray basal 0.1' (3.0 cm) upon Westerville Limestone **[this is the position of the Nellie Bly Formation]**:
Brachiopods: *Crurithyris, Composita, Wellerella, Lingula*, productids
Bryozoans; Echinoids; Gastropods; Ostracodes; Crinoid debris; Fish pieces; Coaly fragments
Forams: Fusulinids, encrusting; No conodonts

Stop A5: Roadcut at I-435 southbound offramp to Holliday Drive, Kansas

Argentine Limestone Member (of Wyandotte Limestone)
*base: Brachiopods; Encrusting forams; Fish pieces
Conodonts (moderate): *Streptognathodus elegantulus, S. gracilis, S. excelsus, Idioprioniodus, Hindeodus*

Quindaro Shale Member (of Wyandotte Limestone)
Brachiopods: *Crurithyris, Hustedia, Chonetinella, Linoproductus, Punctospirifer, Composita*
Rugose coral; Bryozoans: sev. spp. Echinoid, Crinoid debris; Ostracodes; Fish pieces; Encrusting forams
Conodonts (abundant): *Streptognathodus elegantulus, S. gracilis, S. corrugatus, S. excelsus, S.* [bent morphotype], *Idioprioniodus, Hindeodus*

Frisbie Limestone Member (of Wyandotte Limestone)
*top: Brachiopods incl. productids; Uniserial and encrusting forams; Gastropods; Fish pieces
Conodonts (sparse): *Streptognathodus elegantulus, S. gracilis*

Stop A6: K-7 Roadcut north of Bonner Springs, Kansas

Spring Hill Limestone Member (of Plattsburg Limestone)
* base: Encrusting forams; Fish pieces
Conodonts (mod. abundant): *Streptognathodus elegantulus, S. gracilis, S.* [bent morphotype], *Hindeodus*

Hickory Creek Shale Member (of Plattsburg Limestone) [*from I-70, I-435 jct., 4 miles to northeast]
Brachiopods: *Crurithyris, Composita*; Ostracodes; Crinoid debris; Echinoids; Fish pieces

Forams: Ammodiscoid, encrusting
Conodonts (abundant): *Streptognathodus gracilis, S. elegantulus, S.* bent morphotype, *S. corrugatus, S. excelsus, Hindeodus, Diplognathodus, Ellisonia, Adetognathus*

Merriam Limestone Member (of Plattsburg Limestone)
*top: Productid brachiopods; Encrusting forams; Fish pieces
Conodonts (mod. sparse): *Streptognathodus elegantulus, S. gracilis, S* bent morphotype, *Hindeodus*

Stop A7: K-7 Roadcut south of U.S. 40, Wyandotte County, Kansas

Gretna Shale Member (of South Bend Limestone)
*upr 0.4' (12.0 cm):
Brachiopods: *Dielasma, Composita, Derbyia*, productids
Ostracodes; Encrusting forams; Rhomboporid bryozoan; clams; Holothuroids; Fish pieces; Crinoid debris
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. firmus, Idioprioniodus, Adetognathus*

*lwr 0.2' (6.0 cm):
Brachiopods: *Dielasma, Composita, Derbyia, Rhipidomella, Wellerella, Punctospirifer*, chonetids productids
Ostracodes; Encrusting forams; Rhomboporid bryozoan; clams; Holothuroids; Fish pieces; Crinoid debris
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. firmus, Idiognathodus simulator, Idioprioniodus, Adetognathus, Hindeodus*

Little Kaw Limestone Member (of South Bend Limestone)
*U, top: Brachiopods: *Neochonetes, Derbyia, Composita*
forams: Ammodiscoid, encrusting, fusulinids; Fish pieces; Crinoid debris
Conodonts (mod. sparse): *Streptognathodus firmus, S. pawhuskaensis*

*U, upr: Brachiopods: *Neochonetes, Derbyia, Composita, Linoproductus, Cancrinella*
Fish pieces; Encrusting and fusulinid forams; Crinoid debris
Conodonts (sparse): *Streptognathodus firmus, Hindeodus, Adetognathus*

*U, middle: Brachiopods: *Neochonetes, Derbyia, Composita, Linoproductus, Neospirifer*
Fish pieces; Encrusting and fusulinid forams; Crinoid debris
Conodonts (sparse): *Streptognathodus firmus, Adetognathus*

*U, lwr: Brachiopods incl. *Composita*; Fish pieces; Encrusting and fusulinid forams; Crinoid debris
Conodonts (sparse): *Adetognathus*

*U, base: Brachiopods incl. *Composita*
Fish pieces; Encrusting and fusulinid forams; Crinoid debris; Gastropods
Conodonts (sparse): *Streptognathodus firmus, Adetognathus, Aethotaxis*

*L, upr: Brachiopods incl. *Composita, Linoproductus*; Myalinid clams; Gastropods; Coaly fgs. & macrospores

Stop A8: K-32 Roadcut west of Linwood, Kansas

Shoemaker Limestone Member (of Cass Limestone)
*upr: Fish pieces; Encrusting forams; Crinoid debris
Conodonts (sparse): *Streptognathodus pawhuskaensis*, incl. lat. noded morph., *Hindeodus*

*lr mid: Fish pieces; Encrusting forams; Crinoid debris
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, S. zethus, S. firmus, Hindeodus*

*base: Fish pieces; Encrusting forams; Crinoid debris
Conodonts (sparse): *Streptognathodus pawhuskaensis, S. firmus. S. zethus, Hindeodus*

Little Pawnee Shale Member (of Cass Limestone)

* upr: Brachiopods incl. *Composita*, productids
Ammodiscoid and encrusting forams; Fenistellid bryozoans; Ostracodes; Fish pieces; Crinoid debris
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. zethus, S. firmus, Adetognathus, Ellisonia*

*lwr: Brachiopods: *Hustedia, Derbyia, Neospirifer, Composita*, chonetids, productids
Bryozoans: Rhomboporid, fenistellid; Ostracodes; Crinoid debris; Fish Pieces; Echinoids
Forams: Ammodiscoid, encrusting, fusulinid, *Tetrataxis*
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. zethus, S. firmus, Idioprioniodus, Adetognathus*

Haskell Limestone Member (of Cass Limestone)

*top: Brachiopods incl. *Lingula*, productids; Encrusting and uniserial forams; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis,* incl. lat. noded morph., *S. firmus, Aethotaxis*

*upr: Brachiopods incl. *Lingula*, productids; Encrusting and uniserial forams; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis, S. firmus, S. zethus?*

*middle: Brachiopods; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis,* incl. lat. noded morph.

*lwr: Fish pieces
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, S. firmus, Hindeodus*

*base: Fish pieces
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, Adetognathus*

Stop B1: K-3 Roadcut south of Uniontown, Kansas

Sniabar Limestone Member [#15] (of Hertha Formation)

* base: Encrusting forams; Fish pieces; Conodonts (sparse): *Adetognathus*

Mound City Shale Member [#5-14] (of Hertha Formation)

*#14-u: Ammodiscoid forams; Gastropods; Conodonts (sparse): *Adetognathus*

* #14-lr: Echinoids; Crinoid debris; Ammodiscoid forams; Gastropods; Fish pieces; Coaly fragments
Conodonts (sparse): *Adetognathus, Hindeodus, Idiognathodus* sp.

*#9 Ls-t: Productid brachiopods; Fish pieces
Conodonts (abundant): *Idiognathodus sulciferus, I. eccentricus, I.* n. sp. A, *Idioprioniodus*

*#9 Ls-b: Ammodiscoid and encrusting forams; Crinoid debris; Fish pieces
Conodonts (sparse): *Idiognathodus eccentricus,* juveniles

*#8 Dark shale btw. 2 limestones:
Ammodiscoid and encrusting forams; Brachiopods; Fish pieces
Conodonts (mod. abundant): *Idiognathodus* spp., incl. *I.* n. sp. A., very nodose morphotype, *I. sulciferus, I. eccentricus, Idioprioniodus*

*#6 base dark shale:
Brachiopods incl. *Composita*; Ammodiscoid and encrusting forams; Crinoid debris; Fish pieces
Conodonts (mod. abundant): *Idiognathodus eccentricus, I.* n. sp. A, very nodose morphotype, *I. sulciferus, Idioprioniodus, Gondolella*

*#5 Black shale:
Ammodiscoid forams; Fish pieces

Conodonts (abundant): *Idiognathodus eccentricus, I.* n. sp. A, *I. sulciferus, Idioprioniodus, Gondolella*

Guthrie Mountain Shale Member [#4] (of Shale Hill Formation)
* base dark shale:
Brachiopods; Ostracodes; Crinoid debris
Conodonts (moderate): *Idiognathodus sulciferus, I. eccentricus, Adetognathus, Hindeodus, Idioprioniodus, Ellisonia*

Critzer Limestone Member [#3] (of Shale Hill Formation)
*top, upr: Encrusting forams; Echinoderms; Fish pieces
Conodonts (mod. abundant): *Idiognathodus sulciferus, I. eccentricus,* more nodose adolescent, *Idioprioniodus, Ellisonia, Adetognathus*

*middle: Encrusting forams; Echinoderms; Fish pieces
Conodonts (mod. sparse): *Idiognathodus* juveniles, *Idioprioniodus, Aethotaxis, Hindeodus, Adetognathus*

*lr, base: Encrusting forams; Echinoderms; Fish pieces
Conodonts (mod. abundant): *Idiognathodus sulciferus, I. eccentricus* [mostly juveniles], *Idioprioniodus, Adetognathus, Ellisonia, Hindeodus*

Mantey Shale Member [#2] (of Shale Hill Formation)
*dark shale 2' (0.6 m) below Critzer Limestone: Conodonts (sparse fragments)

*dark shale 10' (3 m) below Critzer Limestone:
Ammodiscoid and encrusting forams; Brachiopods; Gastropods; Echinoids; Crinoid debris; Fish pieces
Conodonts (sparse): *Idiognathodus* juveniles

*dark shale 0.5' (15 cm) above Exline Limestone:
Forams: Ammodiscoid, endothyrid, encrusting
Gastropods; Clams; Cephalopods; Echinoids; Crinoid debris; Fish pieces; Brachiopods; Bryozoans
Conodonts (mod. sparse): *Idiognathodus sulciferus* and juveniles

Exline Limestone Member [#1] (of Shale Hill Formation)
Clams; Cephalopods; Echinoid 7 Crinoid debris; Brachiopods; Bryozoans; Gastropods incl. *Trepospira*
Forams: Ammodiscoid, endothyrid, encrusting; Fish pieces
Conodonts (abundant): *Idiognathodus sulciferus, I. eccentricus, Idioprioniodus, Adetognathus*

Hepler Formation [#0]
*shale 0.5-1.0' (15-30 cm) below Exline Limestone:
Clams; Ammodiscoid and encrusting forams; Gastropods; Cephalopods; Crinoid debris; No conodonts

*shale 14' (4.3 m) below Exline Limestone:
Ostracodes; Clams; Gastropods; Ammodiscoid forams; Crinoid debris; No conodonts

* shale 24' (7.3 m) below Exline Limestone:
Brachiopods; Crinoid debris; Fish pieces; No conodonts

Stop B2: Quarry north of Farlington

Farlington Limestone bed (of Bandera Shale)
*top: Brachiopods: *Mesolobus, Composita, Orbiculoidea,* productids
Gastropods; Solitary rugose coral; Crinoid debris; Echinoids; Rhomboporid bryozoans;
Encrusting forams; Carbonized fragments; Fish pieces
Conodonts (abundant): *'Idiognathodus'* sp. 5 of Swade 1985, *Neognathodus, Adetognathodus, Hindeodus*

*middle: Brachiopods; Echinoids; Crinoid debris; Rhomboporid bryozoans; Phylloid algae; Clams
Encrusting forams; Carbonized fragments

Conodonts (mod. sparse): *'Idiognathodus'* sp. 5 of Swade 1985, *Adetognathus, Neognathodus, Hindeodus*

*lower: Brachipoods; Crinoid debris; Phylloid algae
Conodonts (sparse): *Adetognathus, 'Idiognathodus'* sp. 5 of Swade 1985

*base: Brachiopods incl. *Composita*, productids; Gastropods incl. *Naticopsis*; Rhomboporid bryozoans
Fish pieces; Encrusting forams;; Carbonized fragments
Conodonts (mod. sparse): *Adetognathus, 'Idiognathodus'* sp. 5 of Swade 1985, *Neognathodus*

*very base (shaly limestone above Mulberry Coal bed):
Brachiopods; Encrusting forams; Rhomboporid bryozoans; Crinoid debris; Fish pieces; Echinoids
Conodonts (sparse): *Adetognathus, 'Idiognathodus'* sp. 5 of Swade 1985

Laberdie Limestone Member (of Pawnee Limestone)
*3' (0.9 m) above base:
Brachiopods: *Phricodothyris*, productids, *Orbiculoidea capiluformis*?
Encrusting forams; Echinoids; Crinoid debris; Phylloid algae
Conodonts (sparse): *Idiognathodus delicatus*

*1' (30 cm) above base
Brachiopods: *Composita; Antiquatonia; Dielasma; Phricodothyris*; Echinoids; Crinoid debris;
Gastropods; Solitary rugose coral; Phylloid algae; Encrusting, uniserial forams
Conodonts (sparse): *Idiognathodus delicatus, Neognathodus, Hindeodus*

Joe Shale bed (of Mine Creek Shale Member of Pawnee Limestone)
*1" (2.5 cm) shale in north main quarry wall:
Brachiopods incl. *Crurithyris*; Echinoids; Crinoid debris; Fish pieces; Rhomboporid bryozoans
Encrusting, ammodiscoid, fusulinid forams
Conodonts (abundant): *Idiognathodus delicatus, I. fustiformis, I. acutus, I. claviformis? Idioprioniodus, Neognathodus*

*limestone in Joe Shale to south:
Brachiopods; Gastropods; Fish pieces; Crinoid debris; Biserial/uniserial, fusulinid forams; Trilobites
Conodonts (mod. abundant): *Idiognathodus delicatus, I. fustiformis, I. claviformis? Idioprioniodus, Neognathodus, Hindeodus*

Frog Cemetery Limestone bed (of Myrick Station Limesone Member of Pawnee Limestone)
*top: Conodonts (sparse): *Hindeodus*

*9' (2.7 m) above base:
Brachiopods; Echinoids; Crinoid debris; Fish pieces; Phylloid algae
Encrusting, fusulinid forams; No conodonts

*4' (1.2 m) above base:
Brachiopods: *Composita, Phricodothyris*, productids; Trilobites; Fenestellid bryozoans; Crinoid debris;
Laminar chaetetids; Clams; Gastropods; Solitary rugose corals; Fish pieces; Phylloid algae
Forams: Fusulinids, encrusting
Conodonts (sparse): *Neognathodus, Idiognathodus delicatus*

*3' (0.9 m) above base:
Brachiopods: *Composita, Phricodothyris*, productids
Gastropods; Rhomboporid, fistuloporid bryozoans; Crinoid debris; Fish pieces; Encrusting forams
Conodonts (sparse): *Idiognathodus delicatus*

*2' (0.6 m) above base:
Brachiopods: *Composita, Derbyia*, productids
Laminar chaetetids; Fusulinid, encrusting forams; Clams; Gastropods; Bryozoans; Crinoid debris; Fish

Conodonts (sparse): *Idiognathodus delicatus, Hindeodus*

Myrick Station Limestone Member (of Pawnee Limestone) [basal bed]

*top: Brachiopods; Gastropods; Fenestellid bryozoans; Fish pieces; Encrusting forams; Crinoid debris
Conodonts (mod. sparse): *Idiognathodus delicatus, Hindeodus, Aethotaxis*

Stop B3: Roadcut south of St. Paul, Kansas

Worland Limestone Member (of Altamont Limestone)

*5' (1.5 m) above base:
Encrusting forams; Fish pieces; No conodonts

*3' (0.9 m) above base:
Encrusting forams; Fish pieces
Conodonts (sparse): *Idiognathodus* sp., *Aethotaxis*

* 1.5' (46 cm) above base:
Encrusting forams; Fish pieces; Brachiopods incl. *Composita, Phricodothyris*, productids
Conodonts (sparse): *Idiognathodus* sp., *Neognathodus, Hindeodus*

*base: Encrusting forams; Fish pieces; Brachiopods; Ostracodes; Clams; Gastropods; Crinoid debris
Conodonts (mod. abundant): *Neognathodus, Idiognathodus expansus, I.* sp. [grooved morphotype], *Idioprioniodus, Hindeodus*

Lake Neosho Shale Member (of Altamont Limestone)

*upr gray, top:
Brachiopods: *Crurithyris, Composita, Dielasma*, productids
Encrusting forams; Crinoid debris; Fish pieces; Bryozoans
Conodonts (mod. abundant): *Neognathodus, Idiognathodus expansus, I.* sp. [grooved morhotype], *Idioprioniodus, Ellisonia, Adetognathus*

*upr gray, upr middle:
Brachiopods incl. *Crurithyris*, productids; Ostracodes; Encrusting forams; Crinoid debris; Fish pieces
Conodonts (mod. abundant): *Neognathodus, Idiognathodus expansus, Idioprioniodus*

*upr gray, lwr middle:
Brachiopods incl. *Crurithyris*, productids; Ammodiscoid, encrusting forams; Ostracodes; Fish pieces
Conodonts (mod. abundant): *Neognathodus, Idiognathodus expansus, Idioprioniodus*

* upr gray, lwr:
Brachiopods incl. *Crurithyris*, productids; Ammodiscoid, encrusting forams; Ostracodes; Fish pieces
Conodonts (mod. sparse): *Neognathodus, Idioprioniodus, Idiognathodus expansus*

*black, top:
Brachiopods incl. *Crurithyris*; Encrusting, ammodiscoid forams; Fish pieces
Conodonts (abundant): *Neognathodus, Idiognathodus expansus* (some slightly grooved), *Idioprioniodus*

*black, upr middle:
Brachiopods incl. *Orbiculoidea*; Encrusting, ammodiscoid forams; Fish pieces
Conondonts (abundant): *Neognathodus, Idiognathodus expansus* (some slightly grooved), *Idioprioniodus*

black, middle:
Brachiopods incl. *Orbiculoidea*; Encrusting, ammodiscoid forams; Fish pieces
Conodonts (abundant): *Neognathodus, Idioprioniodus, 'Idiognathodus'* sp. 5 of Swade, 1985

black, base:
Brachiopods incl. *Orbiculoidea*; Encrusting, ammodiscoid forams; Fish pieces

Conodonts (mod. abundant): *'Idiognathodus'* spp., incl. sp. 5 of Swade 1985, *Idioprioniodus, Neognathodus*

*lwr gray, top 0.3' (9 cm):
Brachiopods: *Crurithyris, Punctospirifer, Derbyia, Composita*
Ammodiscoid, encrusting forams; Crinoid debris; Fish pieces; Scolecodonts
Conodonts (moderate): *'Idiognathodus'* spp., mostly sp. 5 of Swade 1985, some sp. 6? of Swade 1985, *Neognathodus, Idioprioniodus, Adetognathus*

*lwr gray, middle:
Brachiopds: *Crurithyris, Punctospirifer, Derbyia, Composita*
Endothyrid, fusulinid, encrusting forams; Crinoid debris; Echinoids; Gastropods
Conodonts (sparse): *Adetognathus, Ellisonia*

*lwr gray, lwr:
Brachiopods: *Crurithyris, Punctospirifer, Derbyia, Composita, Mesolobus*
Endothyrid, fusulinid, encrusting forams; Crinoid debris; Echinoids; Gastropods
Conodonts (sparse): *Adetognathus, 'Idiognathodus'* sp. 5 of Swade 1985

Amoret Limestone Member (of Altamont Limestone)
*top: Brachiopods incl productids; Gastropods; Crinoid debris; Fish pieces; Encrusting forams; Rhomboporids
Conodonts (sparse): *Adetognathus, Hindeodus, 'Idiognathodus'* sp. 5 of Swade 1985

*upr 1.3' (40 cm) below top:
Brachiopods incl. productids; Crinoid debris; Fish pieces; Encrusting forams
Conodonts (sparse): *Adetognathus*

Stop B4: Southwest quarry southwest of Parsons, Kansas

Perry Farm Shale Member (of Lenapah Limestone)
*0.5-1.0' (15-30 cm) above base (hard zone):
Brachiopods incl. *Crurithyris*, productids; Gastropods; Ostracodes; Fish pieces, Crinoid debris
Encrusting, ammodiscoid forams
Conodonts (sparse): *Neognathodus*

* base: Brachiopods: *Crurithyris, Mesolobus, Composita, Dielasma*, productids
Ammodiscoid, encrusting forams; Gastropods; Fish pieces; Crinoid debris; Ostracodes; Bryozoans
Conodonts (mod. abundant): *Neognathodus, 'Idiognathodus'* sp. 5 of Swade 1985, *'I.'* sp 6 of Swade 1985, *Adetognathus, Ellisonia*

Norfleet Limestone Member (of Lenapah Limestone)
*upr: Brachiopods incl. *Orbiculoidea, Mesolobus, Composita,* productids, chonetids; Clams incl. pectens
Echinoderms; Bryozoans incl. fenestellids, rhomboporids; Gastropods; *Platyceras*; Crinoid debris
Ostracodes; Fish pieces; Ammodiscoid, encrusting forams
Conodonts (abundant): *'Idiognathodus'* sp. 5 of Swade 1985, *'I.'* sp. 6 of Swade 1985, *'I.'* sp. resembling 'S. subexcelsus' of Alekseev and Goreva manuscript, *Neognathodus*

* base: Brachiopods incl. *Orbiculoidea, Lingula*; Echinoderms; Bryozoans; Gastropods; Fish pieces; Clams
Conodonts (sparse): *Adetognathus, Neognathodus*

Worland Limestone Member (of Altamont Limestone)
* top, about 10' (3 m) above base:
Encrusting forams; Fish pieces
Conodonts (sparse): *Hindeodus*

*9' (2.7 m) above base:
Brachiopods incl. *Composita, Derbyia*, productids; Encrusting forams; Echinoderms; Fish pieces
Conodonts (sparse): *Adetognathus, Aethotaxis, Idiognathodus* sp.

*7' (2.1 m) above base:

Brachiopods: *Composita, Dielasma, Antiquatonia*, productids; Solitary rugose coral; Echinoderms
Fenestellid bryozoans; Fusulinid, encrusting forams; Fish pieces
Conodonts (sparse): *Hindeodus*

Stop B5: Road ditch southwest of Labette, Kansas

Laberdie Limestone Member (of Pawnee Limestone)
Two samples from lower 3' (1 m):

Conodonts (sparse): *Diplognathodus, Aethotaxis, Hindeodus, Idiognathodus delicatus*

Joe Shale bed (of Anna Shale Member of Pawnee Limestone)
*upr gray (=RCP-12A):

Brachiopods: *Composita, Mesolobus, Punctospirifer, Rhipidomella, Crurithyris, Kozlowskia, Derbyia, Lingula, Orbiculoidea*, Chonetids
Rhomboporid bryozoans; Crinoid debris; Ostracodes; Fish pieces
Forams: Encrusting, endothyrid, ammodiscoid
Conodonts (moderate): *Idiognathodus* spp., mostly *I. delicatus; Idioprioniodus, Neognathodus*

*mid dark (RCP-12): Conodonts (mod. abundant): *Idiognathodus* spp., incl. *I delicatus,* grooved morphotype, *I. claviformis*; *Idiorpioniodus, Neognathodus*

* basal 0.5' (15 cm) dark (=RCP-11):

Brachiopods: *Composita, Mesolobus, Desmoinesia, Derbyia, Crurithyris, Neospirifer*, productids
Rhomboporid bryozoans; Crinoid debris; Ostracodes; Fish pieces; Echinoids; Clams incl. *Astartella*
Forams: Encrusting, endothyrid, ammodiscoid
Conodonts (abundant): *Idiognathodus delicatus, I. fustiformis, I. claviformis? Idioprioniodus, Neognathodus*

Frog Cemetery Limestone bed (of Anna Shale)
*RCP-10: Crinoid debris; Brachiopods; Fenestellid bryozoans; Trilobites

Conodonts (moderate): *Idiognathodus delicatus, Idioprioniodus, Neognathodus, Hindeodus*

Anna Shale Member [proper] (of Pawnee Limestone)
*upper gray shale (RCP-9):

Conodonts (abundant): *Idiognathodus* spp., incl. *I. delicatus, I. fustiformis, I. acutus,* grooved morphotype; *Idioprioniodus, Neognathodus*

Childers School Limestone bed (of Anna Shale)

Brachiopods: *Derbyia, Antiquatonia, Composita, Orbiculoidea*
Rhomboporid bryozoans; Clams; Crinoid debris; Echinoids; Fish pieces; Ostracodes; Macrospores
Forams: Encrusting, ammodiscoid, *Tetrataxis*
Conodonts (sparse): *Idiognathodus delicatus, Adetognathus, Hindeodus, Idioprioniodus*

Stop B6: Overman bridge south of Oswego, Kansas

Shale above Ardmore Limestone Member (of Verdigris Limestone)
*shale 3.5' (1 m) above yellow limestone:

Brachiopods: *Derbyia, Juresania, Mesolobus, Lingula*
Encrusting, uniserial forams; Echinoids; Gastropods; Ostracodes; Fish pieces; Crinoid debris; Bryozoans
Conodonts (sparse): *Idiognathodus delicatus, Adetognathus, Neognathodus*

Oakley Shale Member (of Verdigris Limestone)
*upr unit, top:

Brachiopods: *Mesolobus, Crurithyris, Derbyia, Desmoinesia, Hustedia, Wellerella, Antiquatonia, Cleiothyridina, Lingula, Orbiculoidea*; Gastropods; Bryozoans; Echinoid, Crinoid debris
Encrusting, ammodiscoid forams; Ostracodes; Fish pieces

Conodonts (moderate): *Idiognathodus* spp., incl. *I. delicatus, Neognathodus, Idioprioniodus*

*upr unit, lwr:
Brachiopods incl. *Mesolobus, Composita*, productids; Bryozoans; Crinoid debris; Fish pieces
Ammodiscoid, encrusting forams
Conodonts (abundant): *Idiognathodus* spp., incl. *I. delicatus, I. acutus; Idioprioniodus, Neognathodus*

*mid-Oakley limestone:
Brachiopods incl. productids; Clams; Echinoids; Gastropods; Gastropods
Ammodiscoid, encrusting forams; Fish pieces
Conodonts (mod. sparse): *Idiognathodus* spp., incl. *I. delicatus; Idioprioniodus*

*lwr dark shale, top:
Brachiopods incl. *Crurithyris*, productids; Gastropods; Clams; Ostracodes; Crinoid debris; Fish pieces
Conodonts (abundant): *Idiognathodus* spp., incl. *I. delicatus, I. acutus; Idioprioniodus, Neognathodus*

*lwr gray shale, top:
Brachiopods; Clams; Gastropods; Fish pieces
Conodonts (sparse): *Idiognathodus* spp., *Idioprioniodus, Ellisonia*

Fleming Caprock Limestone
*top: Brachiopods: *Composita, Mesolobus, Juresania, Antiquatonia*
Clams; Gastropods; Echinoids; Fish pieces; Crinoid debris; Encrusting forams; Coaly fragments
Conodonts (sparse): *Hindeodus, Idiognathodus* spp., incl. *I. delicatus*

*base: Brachiopods: *Composita, Mesolobus, Juresania, Desmoinesia, Neospirifer*
Encrusting forams; Bryozoans; Crinoid debris; Fish pieces; Coaly fragments
Conodonts (moderate): *Idiognathodus* spp., incl. *I. delicatus, I. acutus, I.* [longitudinally bent morphotype], *Hindeodus, Neognathodus, Idioprioniodus*

Stop B7: U.S. 166 Roadcuts east of Bartlett, Kansas

Little Osage Shale Member (of Fort Scott Limestone) [upper Fort Scott cyclothem]
*upr gray, top 0.4' (12.0 cm):
Clams; Gastropods; Fish pieces; Ammodiscoid forams
Conodonts (mod. abundant): *Idiognathodus* spp., mostly *I. delicatus, I. fustiformis; Idioprioniodus, Neognathodus*

*0.4-0.6' (12.0-18.0 cm) below top:
Clams; Gastropods; Fish pieces; Ammodiscoid forams
Conodonts (sparse): *Neognathodus*

*0.6-1.0' (18.0-30.0 cm) below top:
Uniserial forams; Fish pieces; No conodonts

Excello Shale Member (of Fort Scott Limestone) [lower Fort Scott cyclothem]
*upr gray, top 0.2' (6.0 cm):
Brachiopods incl. productids; Echinoids; Fish pieces
Conodonts (abundant): *Idiognathodus* spp., incl. *I. delicatus* (most), *I. acutus, I. fustiformis, I.* [posterior grooved morphotype]; *Neognathodus, Idioprioniodus*

Stop B8: Little California Creek

Hushpuckney Shale equivalent (in Tacket Formation)
*upr, 1.5-2.0' (45-60 cm) above base:
Conodonts (mod. abundant): *Idiognathodus sulciferus, I. clavatulus, I. eccentricus, Streptognathodus cancellosus, Idioprioniodus, Gondolella denuda*

*basal 0.5' (15 cm) of black facies:
Conodonts (mod. abundant): *Idiognathodus eccentricus, I. clavatulus, I. sulciferus, Streptognathodus cancellosus, Idioprioniodus, Gondolella* sp. [platformed], *G. denuda*

Mound City Shale equivalent (in Tacket Formation)
*4.5-5.0' (1.35-1.5 m) above top of black facies:
Conodonts (sparse): *Idiognathodus sulciferus, I. clavatulus*

*1.5-2.0' (45-60 cm) above top of black facies:
Conodonts (mod. sparse): *Idiognathodus sulciferus, I. eccentricus*

*basal 0.5' (15 cm) above top of black facies:
Conodonts (moderate): *Idiognathodus sulciferus, I. eccentricus, I. clavatulus, Idioprioniodus, Gondolella*

*top 0.5' (15 cm) below top of black facies:
Conodonts (mod. sparse): *Idiognathodus* juveniles

*1.0-1.5' (30-45 cm) below top of black facies:
Conodonts (mod. sparse): *Idiognathodus* sp., *Idioprioniodus*

*2.0-2.5' (60-75 cm) below top of black facies: *Idiognathodus sulciferus, I. eccentricus, I.* n. sp, A, *Idioprioniodus, Gondolella*

*2.5-3.0' (75-90 cm) below top of black facies:
Conodonts (mod. abundant): *Idiognathodus sulciferus, I. eccenticus, I. clavatulus, Idioprioniodus, Ellisonia, Gondolella*

*3.0-3.5' (90-105 cm) below top of black facies:
Conodonts (mod. sparse): *Idiognathodus sulciferus, I. eccentricus, Adetognathus, Idioprioniodus*

*3.5-4.0' (1.05-1.3 m) below top of black facies: No conodonts

Exline Limestone equivalent (in Tacket Formation)
*black soft shale 6.5-7.3' (~2 m) above Cbd Ls:
Brachiopods incl.. *Crurithyris*; Clams; Ostracodes; Cephalopods; Gastropods; Crinoid debris; Fish pieces
Encrusting, ammodiscoid forams
Conodonts (abundant): *Idiognathodus sulciferus, I. eccentricus, Idioprioniodus, Adetognathus*

Checkerboard Limestone, upper limestone bed [lenticular]
Brachiopods: *Composita, Punctospirifer, Derbyia, Antiquatonia*
Gastropods; Echinoids; Fish pieces; Encrusting forams
Conodonts (sparse ramiforms)

South Mound Shale Member (of Checkerboard Limestone)
*top: Brachiopods: *Composita, Punctospirifer, Derbyia,* productids, etc.; echinoid, crinoid, holothuroid debris; Gastropods; Fish pieces
Conodonts (sparse): *Adetognathus*

* lwr, 0.5-1.0' (15-30 cm) above lower Checkerboard Ls:
Brachiopods: *Composita, Punctospirifer, Derbyia, Dielasma, Desmoinesia, Neospirifer, Hustedia, Juresania,* chonetid; Bryozoans: Rhomboporids, fenestellids, fistuloporids; Clams; Echinoids; Ostracodes Trilobites; Holothuroids; Encrusting forams; Crinoid debris, Fish pieces
Forams: Encrusting, *Tetrataxis*
Conodonts (mod. sparse): *Idiognathodus sulciferus, Adetognathus, Idioprioniodus, Ellisonia*

*base, 0-0.5' (0-15 cm) above lower Checkerboard Ls:

Brachiopods: *Derbyia, Dielasma, Hustedia*, productids; Bryozoans: Rhomboporids, fenestellids
Echinoids; Ostracodes; Trilobites; Crinoid debris, Fish pieces; Forams: Encrusting, *Tetrataxis*
Conodonts (moderate): *Adetognathus, Idiognathodus sulciferus, Hindeodus, Ellisonia, Idioprioniodus*

Stop C1: US-166 Roadcut west of Niotaze, Kansas

Iatan Limestone Member (of Stranger Formation)
*foss. shale between two limestone beds:
Brachiopods, incl. *Chonetes, Punctospirifer*; Rhomboporid, fenestellid bryozoans; echinoid, crinoid debris
Encrusting forams
Conodonts (mod. abundant): *Streptognathodus pawhuskaensis* [a few with incipient lateral nodes], *S. firmus, Hindeodus, Adetognathus, Idioprioniodus*

Stop C3: US-166 Roadcut west of Peru, Kansas

Little Pawnee Shale Member (of Cass Limestone)
*Gray foss. shale 8-9' (2.4-2.7 m) above limestone:
Brachiopods; Crinoid and echinoid debris; Snails; Clams; Worm tubes
Ostracodes (abundant); Ammodiscoid forams
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, Hindeodus, Adetognathus*

*Gray foss. shale 6-7' (1.8-2.1 m) above limestone:
Brachiopods; Crinoid and echinoid debris; Snails; Ostracodes; Ammodiscoid forams
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, S. zethus, Idioprioniodus*

*Dark shale 5' (1.5 m) above limestone:
Brachiopods (*Crurithyris*); Snails; Ammodiscoid forams
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, S. zethus, Idioprioniodus, Hindeodus*

*Dark shale 2-3' (60-90 cm) above limestone:
Brachiopods (*Crurithyris*); Ammodiscoid forams
Conodonts (moderate): *Streptognathodus pawhuskaensis, S. zethus, Idioprioniodus, Hindeodus*

*Black shale 1-1.5' (30-45 cm) above limestone:
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, Idioprioniodus, Hindeodus, Adetognathus, Gondolella* (rare from this zone elsewhere)

*Dark gray foss. shale 0.1-0.5' (2-15 cm) above limestone:
Brachiopods; Crinoid and echinoid debris; Snails; Worm tubes: Ostracodes
Conodonts (abundant): *Streptognathodus pawhuskaensis, Hindeodus, Adetognathus, Idioprioniodus*

Haskell Limestone Member (of Cass Limestone):
Brachiopods (*Crurithyris*)
Conodonts (abundant): *Streptognathodus pawhuskaensis, Hindeodus, Adetognathus*

Vinland Shale Member (of Stranger Formation)
*Top 1.5' (45 cm) foss. shale:
Brachiopods; Crinoid debris, etc.
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, Adetognathus*

*Next 1.5' (45 cm) shale down:
Myalinid clams, ostracodes, etc.
Conodonts (mod. sparse): *Adetognathus, Streptognathodus pawhuskaensis*

Stop D1: Woodson County State Lake spillway

Little Pawnee Shale Member (of Cass Limestone)

*2.5-3.5' (0.7-1.0 m) above Haskell Limestone:
Brachiopods incl. *Crurithyris*; Gastropods; Cephalopods; Clams; Ostracodes; Fish pieces; Crinoid debris
Encrusting, ammodiscoid, uniserial forams
Conodonts (sparse): *Streptognathodus pawhuskaensis, S. firmus*

* 0.5-1.0' (15-30 cm) above Haskell Limestone:
Brachiopods incl. *Crurithyris*; Gastropods; Cephalopods; Clams; Ostracodes; Fish pieces; Crinoid debris
Encrusting, ammodiscoid, uniserial forams
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, S. zethus, S. firmus, Hindeodus, Adetognathus*

*basal 0.5' (15 cm):
Brachiopods: *Crurithyris, Hustedia, Wellerella, Composita, Neospirifer,* productids
Crinoid debris; Ostracodes; Bryozoans; Trilobites; Solitary rugose coral; Fish pieces
Forams: Ammodiscoid, encrusting, uniserial
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. zethus, S. firmus, Idioprioniodus, Adetognathus*

Haskell Limestone Member (of Cass Limestone)
*top: Ammodiscoid, encrusting forams; Fish pieces
Conodonts (moderate): *Streptognathodus pawhuskaensis,* incl. lat. noded morph., *S. firmus*

*upr: Brachiopods incl. *Neospirifer*; Crinoid debris; Encrusting forams; Fish pieces
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis*

*middle: Brachiopods: *Derbyia, Phricodothyris*, productids; Crinoid debris; Encrusting forams; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis, S. firmus*

*lwr: Brachiopods: *Linoproductus, Neochonetes, Composita*; Crinoid debris; Encrusting forams; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis*

*base: Brachiopods incl. productids; Crinoid debris; Encrusting, fusulinid forams; Fish pieces
Conodonts (mod. sparse): *Streptognathodus pawhuskaensis, Adetognathus*

Vinland Shale Member (of Stranger Formation)
*U, top: Brachiopods incl. productids; Crinoid debris; Fish pieces; Gastropods; Ostracodes; Scolecodonts
Encrusting, fusulinid forams;
Conodonts (sparse): *Adetognathus, Streptognathodus pawhuskaensis,* incl. lat. noded morph., *Hindeodus*

*Lr, upr: Crinoid debris; Encrusting, fusulinid forams; Fish pieces; Gastropods; Ostracodes; No conodonts

*Lr, lwr: Crinoid debris; Encrusting, fusulinid, *Tetrataxis* forams; Fish pieces; No conodonts

Westphalia Limestone Member (of Stranger Formation)
*top: Brachiopods incl. productids; encrusting, fusulinid forams; Crinoid debris; Fish pieces
Conodonts (sparse): *Adetognathus, Ellisonia*

*middle: Brachiopods incl. productids; encrusting, fusulinid forams; Crinoid debris; Fish pieces
Conodonts (sparse): *Streptognathodus pawhuskaensis* [with laterally noded morphotype reported from larger collections], *Adetognathus*

Stop D2: U.S. 54 Roadcut north of Toronto, Kansas

Toronto Limestone *mid shale:
Brachiopods: *Crurithyris, Composita*, productids
Solitary rugose coral; Crinoid debris; Fish pieces
Conodonts (abundant): *Streptognathodus pawhuskaensis, S. firmus, S. zethus*

Stop D3: Roadcut north of Pottawatomie Creek, Anderson County, Kansas

Stoner Limestone Member (of Stanton Limestone)

*shale 0.2' (6.0 cm) above Stoner base:

Brachiopods: *Punctospirifer, Composita, Hustedia*, productids; Crinoid, Echinoid debris; Bryozoans; Trilobites; Holothuroids; Ostracodes; Encrusting, uniserial forams

Conodonts (sparse): juvenile idiognathodids

*base: Brachiopods incl. productids; Encrusting forams; Fish pieces

Conodonts (sparse): *Idiognathodus simulator; Idioprioniodus, Gondolella*

Eudora Shale Member (of Stanton Limestone)

*upr gray, 0.3' (9.0 cm):

Brachiopods: *Punctospirifer, Composita, Hustedia, Crurithyris, Rhipidomella, Neochonetes,* productids

Bryozoans: Fenestellid, rhomboporid, fistuloporid

Echinoids; Crinoid debris; Holothuroids; Gastropods; Fish pieces

Conodonts (abundant): *Idiognathodus simulator, I.* sp., *Gondolella, Idioprioniodus, Streptognathodus firmus, S. excelsus?*

*middle black: Conodonts (abundant): *Idiognathodus simulator, Gondolella, Idioprioniodus, Strepto. gracilis*

*lwr gray 0.2' (6.0 cm):

Solitary rugose corals; Crinoid debris; Gastropods; Ostracodes; Fish pieces

Conodonts (mod. abundant):, *Streptognathodus elegantulus, S. gracilis, S. corrugatus, S. excelsus, Idiognathodus simulator* [and less grooved forms], *Gondolella, Idioprioniodus, Adetognathus*

Captain Creek Limestone Member (of Stanton Limestone)

*top: Brachiopods incl. productids; Echinoids, Crinoid debris

Conodonts (mod. sparse): *Streptognathodus elegantulus,* many juveniles, *Hindeodus*

Stop D4: Roadcut southeast of Paola, Kansas

Raytown Limestone Member (of Iola Limestone)

*top , 7' (2.1 m) above base:

Brachiopods incl. productids; Encrusting forams; Fish pieces; Crinoid debris

Conodonts (sparse): *Streptognathodus* (juv.), *Hindeodus, Ellisonia*

*5' (1.5 m) above base:

Brachiopods: *Derbyia, Neospirifer, Composita, Hustedia*, productids

Encrusting, uniserial forams; Fish pieces; Crinoid debris; Fenestellid bryozoans

Conodonts (sparse): *Streptognathodus* (juv.), *Adetognathus*

*3' (0.9 m) above base:

Encrusting, uniserial forams; Fish pieces; Crinoid debris; Brachiopods

Conodonts (sparse): *Streptognathodus gracilis, S. elegantulus, Hindeodus, Aethotaxis?*

*1.5' (0.5 m) above base:

Brachiopods incl. productids; Crinoid debris; Fenestellid, rhomboporid bryozoans; Encrusting, uniserial forams; Fish pieces; No conodonts

*base: Brachiopods incl. productids, *Neochonetes*; Crinoid debris; Fenestellid, rhomboporid bryozoans

Encrusting, uniserial forams; Fish pieces

Conodonts (moderate): *Streptognathodus gracilis, S. corrugatus, S. elegantulus, S. excelsus, Hindeodus, Adetognathus*

Muncie Creek Shale Member (of Iola Limestone)

Brachiopods: *Derbyia, Hustedia, Rhipidomella, Punctospirifer, Composita, Neochonetes, Wellerella, Dielasma,* productids

Bryozoans: Fenestellids, rhomboporids, fistuloporids; Crinoid debris

Encrusting, ammodiscoid, uniserial forams; Ostracodes; Fish pieces

Conodonts (abundant): *Streptognathodus excelsus, S. gracilis, S. elegantulus, S. corrugatus, Idiognathodus* spp., incl. *I. cf. magnificus* ('postmagnificus'), *I. cf. toretzianus, Idioprioniodus, Gondolella*

Paola Limestone Member (of Iola Limestone)

*top: Brachiopods incl. *Orbiculoidea*; Crinoid debris; Encrusting forams; Fish pieces
Conodonts (sparse): *Streptognathodus gracilis, S. excelsus, Hindeodus*

*lwr: Brachiopods incl. *Orbiculoidea*; Crinoid debris; Encrusting forams; Fish pieces
Conodonts (moderate): *Streptognathodus gracilis, S. elegantulus, S. excelsus, S. corrugatus, Hindeodus, Adetognathus*

*base: Brachiopods incl. *Orbiculoidea*; Crinoid debris; Bryozoans; Encrusting forams; Fish pieces
Conodonts (moderate): *Streptognathodus elegantulus, S. gracilis, S. corrugatus, Hindeodus*