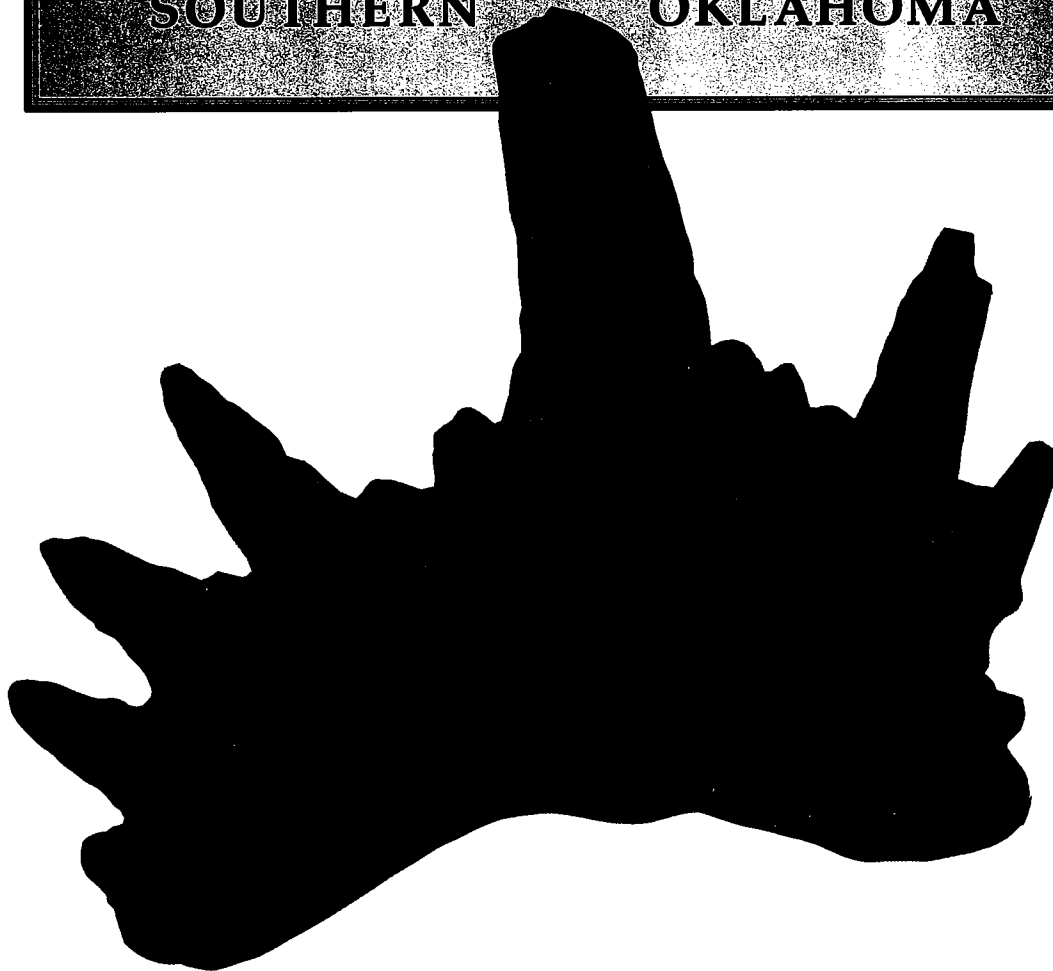


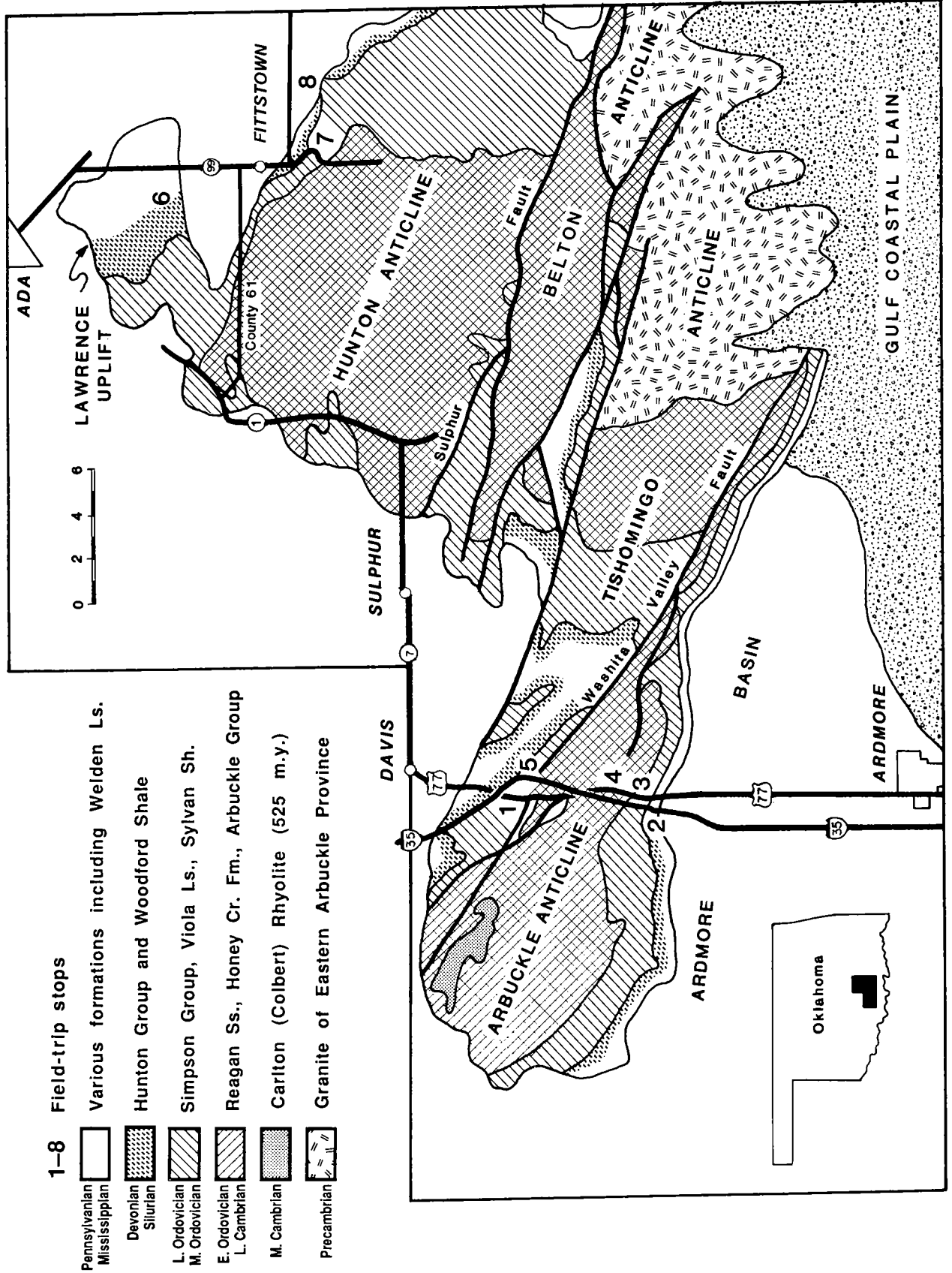
EARLY TO MIDDLE
PALEOZOIC
CONODONT
BIOSTRATIGRAPHY
OF THE ARBUCKLE MOUNTAINS
SOUTHERN OKLAHOMA



1990

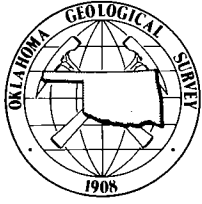
Oklahoma Geological Survey
Guidebook 27

GENERALIZED GEOLOGIC MAP OF THE ARBUCKLE MOUNTAINS, SHOWING FIELD-TRIP STOPS



1-8 Field-trip stops

- | | |
|--|---------------|
| | Pennsylvanian |
| | Mississippian |
| | Devonian |
| | Silurian |
| | L. Ordovician |
| | M. Ordovician |
| | E. Ordovician |
| | L. Cambrian |
| | M. Cambrian |
| | Precambrian |
-
- Various formations including Welden Ls.
 - Hunton Group and Woodford Shale
 - Simpson Group, Viola Ls., Sylvan Sh.
 - Reagan Ss., Honey Cr. Fm., Arbuckle Group
 - Carlton (Colbert) Rhyolite (525 m.y.)
 - Granite of Eastern Arbuckle Province



Oklahoma Geological Survey
Charles J. Mankin, *Director*

ISSN 0078-4400

Guidebook 27

Early to Middle Paleozoic Conodont Biostratigraphy of the Arbuckle Mountains, Southern Oklahoma

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Guidebook for field trip, March 3–4, 1990, preceding the 24th annual meeting of the South-Central Section of the Geological Society of America, March 4–6, 1990, Stillwater, Oklahoma.

The University of Oklahoma
Norman, Oklahoma
1990

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Front Cover

Chirognathus duodactylus from the Bromide Formation along Interstate 35,
north flank of the Arbuckle Mountains (Stop 5 of this guidebook).

This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1981, Section 3310, and Title 74, Oklahoma Statutes, 1981, Sections 231–238. 500 copies have been prepared for distribution at a cost of \$3,450 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

Preface

This guidebook was prepared for a Pander Society field trip held March 3–4, 1990, prior to the 1990 annual meeting of the South-Central Section of the Geological Society of America at Oklahoma State University, Stillwater, Oklahoma, March 4–6, 1990. The two-day trip examined the Early Ordovician through Middle Pennsylvanian stratigraphy and conodont biostratigraphy of the Arbuckle Mountains of southern Oklahoma. The stops were centered around excellent exposures along Interstate Highway 35 in the Arbuckle anticline (Stops 1–5) and in the Hunton anticline and Lawrence uplift (Stops 6–8). Revision and refinement of chronostratigraphic (both system and series) boundaries on the basis of new conodont data were emphasized.

I wish to thank Dr. Charles Mankin, director of the Oklahoma Geological Survey, for his willingness to publish this volume as part of the Oklahoma Survey's guidebook series. I also wish to thank Larry Stout of the Oklahoma Geological Survey, who served as technical editor for this guidebook and saw to its final production. Credit is due Christie Cooper and Diana Gilstrap of the Oklahoma Geological Survey, who overcame many difficulties in mastering a new desktop publishing system, making the timely publication of this guidebook possible. Charles A. Sandberg (U.S. Geological Survey, Denver), Rodney D. Norby (Illinois Geological Survey), Mark Kleffner (Ohio State University), John E. Repetski (U.S. Geological Survey, Reston), Glen K. Merrill (University of Houston–Downtown), and W. Britt Leatham (California State University–San Bernardino) willingly reviewed various manuscripts on short notice. Finally, I wish to thank the guidebook contributors for their patience and their timely delivery of manuscripts.

SCOTT M. RITTER
*Field-Trip Chairman
and Editor*

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PART I

Road Logs and Stop Descriptions

Road Log—First Day

Scott M. Ritter

The first day of the field trip will be spent studying excellent exposures of Lower Ordovician through Upper Devonian rocks along old Highway 77 and along Interstate 35 in the Arbuckle Mountains just north of Ardmore, Oklahoma. Five stops will afford participants an opportunity to study the stratigraphy of and collect microfossil samples from early to middle Paleozoic strata including the Arbuckle Group (Lower Ordovician), Simpson Group (Middle Ordovician), basal Viola Group (Middle Ordovician), Hunton Group (Upper Ordovician to Early Devonian), and Woodford Shale (Upper Devonian). Although many outcrops in addition to those which constitute the formal stops of this field trip are noted in the road log, this is not a comprehensive guide to outcrops along Interstate 35 through the Arbuckle Mountains; for comprehensive treatment of I-35 outcrops, the reader is referred to Fay (1989).

The formal trip commences in Stillwater, Oklahoma, and proceeds south to the Arbuckle Mountains along Interstate 35. Persons approaching the field-trip area from other directions (or using the guidebook at a later date) may wish to begin following the road log at Stop 1 (Segment 2).

SEGMENT 1—STILLWATER TO STOP 1

(North Limb of Arbuckle Anticline)

Mileage begins at the intersection of Western Avenue and U.S. 51 (6th Street) on the west side of Stillwater, Oklahoma.

<i>Cumulative Mileage</i>	<i>Interval</i>				
			77.6	13.2	Junction of Interstate 35 and U.S. 77 South. Continue south on Interstate 35.
0.0	0.0	Proceed west on U.S. 51.	83.8	6.2	Bridge over the Canadian River.
0.8	0.8	Bridge over Stillwater Creek.	112.7	28.9	Paoli exit. Continue on Interstate 35.
15.4	14.6	Junction of U.S. 51 and Interstate 35. Proceed south on Interstate 35.	119.4	6.7	Pauls Valley exit. Continue on Interstate 35.
24.9	9.5	Bridge over Cimarron River.	128.3	8.9	Wynnewood exit. Continue on Interstate 35.
40.1	15.2	Road cut in Permian Garber-Wellington sandstone.	134.3	6.0	Rest area.
41.5	1.4	Rest area.	136.7	2.4	Junction of Interstate 35 and Highway 7 to Davis and Sulphur. Continue south on Interstate 35.
52.6	11.1	Junction of Interstate 35 and Interstate 44 East. Continue south on Interstate 35.	137.1	0.4	Entering Murray County.
57.6	5.0	Junction of Interstate 35 and Interstate 44 West. Continue south on Interstate 35.	139.2	2.1	Weigh station.
58.6	1.0	Remington Park Race Track on the right.	141.4	2.2	Junction of Interstate 35 and U.S. Highway 77 (Exit 51). Exit and proceed south at stop sign on Highway 77 in the direction of Turner Falls.
62.9	4.3	Junction of Interstate 35 and Interstate 40 East. Continue on Interstate 35.			
64.4	1.5	Separation of Interstate 35 and 40 West. Stay in left lane and diverge to the south on Interstate 35.	142.0	0.6	Stop 1—Hunton Group. Road cut on west side of Highway 77 presents a nearly complete exposure of strata from

Upper Ordovician Sylvan Shale (southern end of outcrop) to Lower Devonian Haragan Formation (northern end of road cut). The upper Haragan Forma-

tion and Woodford Shale form the strike valley to the north. The Mississippian Sycamore Formation holds up the next resistant ridge to the north.

SEGMENT 2—STOP 1 TO ARDMORE, OKLAHOMA

<i>Cumulative Mileage</i>	<i>Interval</i>				
0.0	0.0	Proceed south on Highway 77 toward Turner Falls.	8.6	1.2	reached by first driving south (1.2 mi) to the underpass at the junction of Interstate 35 and Highway 53.
0.7	0.7	Bridge over Honey Creek.	8.7	0.1	Exit 42 at junction of Interstate 35 and Highway 53. Leave Interstate 35.
1.1	0.4	Entrance to Turner Falls on right. Continue south on Highway 77. Note exposures of carbonate-clast-rich Collings Ranch Conglomerate (middle Virgilian) along road for next few hundred yards.	9.7	0.1	Stop sign. Turn left, pass beneath bridge then turn left again and proceed north on Interstate 35.
1.5	0.4	Hairpin turn. Proceed up hill.	10.1	1.0	Honey Creek Pass sign.
1.8	0.3	Fault contact between Pennsylvanian Collings Ranch Conglomerate and Ordovician Cool Creek Formation on left.	10.5	0.4	Milepost 44. Road cut in Sycamore Limestone.
2.0	0.2	Turner Falls overlook and gift shop on right. Low outcrops of stromatolite-bearing Cool Creek Limestone exposed on left (north) side of road.	11.1	0.4	Road cuts in Viola Limestone.
4.0	2.0	Junction with Interstate 35. Leave Highway 77 and proceed south on Interstate 35.	11.9	0.6	Stop 3—Lower Simpson Group. Pull off on right side of road near signpost 45. The uppermost Joins and Oil Creek Formations are exposed in road cuts on the east side of the east lane. A less complete exposure of the Oil Creek is exposed in the median.
5.1	1.1	Scenic turnout.	12.1	0.8	Stop 4—Arbuckle Group. Park in the scenic turnout. Arbuckle Group continuously exposed in road cuts for ~0.8 mi.
5.5	0.4	Road cut through stromatolite-bearing Cool Creek Limestone.	12.1	0.2	Murray County line.
5.8	0.3	Carter County line.	13.3	1.2	Junction of Interstate 35 and Highway 77. Continue north on Interstate 35.
6.5	0.7	Road cut in Oil Creek Formation.	15.0	1.7	Scenic turnout. Continue north.
7.0	0.5	Road cut in Viola Formation.	15.6	0.6	Road cuts through Collings Ranch Conglomerate.
7.4	0.4	Stop 2—Henryhouse, Haragan, and Woodford Formations. S-dipping beds of the Henryhouse through Woodford Formations are exposed in road cuts on the west side of the southbound lane of Interstate 35.	16.2	0.6	Stop 5—Upper Simpson Group and basal Viola Limestone. Park on right shoulder of Interstate 35 at approximate position of milepost 50.
		Stop 3 is just to the north along the northbound lane of Interstate 35. Stop 3 is	17.1	0.9	Junction with U.S. 77 to Davis, Oklahoma. Exit and return south on Interstate 35 ~20 mi to Ardmore, Oklahoma. End of first day.

STOP 1 Hunton Group (Late Ordovician–Early Devonian)

NW¹/₄ sec. 30, T. 1 S., R. 2 E.
Murray County, Oklahoma

James E. Barrick, Gilbert Klapper, and Thomas W. Amsden

Strata of very late Ordovician, Silurian, and Early Devonian age make up an incomplete sequence of rocks referred to as the Hunton Group (Fig. 1). These strata are widely distributed and exposed in the Arbuckle Mountains and Criner Hills region. They are almost exclusively low-magnesium argillaceous and skeletal limestones, commonly with an oolite (Keel) at the base. The maximum thickness of the Hunton Group in the outcrop area is ~140 m, but in most places it is substantially thinner because of post-Hunton, pre-Woodford erosion. Most Hunton strata are richly fossiliferous, and numerous faunal groups are represented, including brachiopods, ostracodes, corals, trilobites, crinoids, graptolites, conodonts, and foraminifers. Little algal material is present, and no reefs or boundstones have been observed in Oklahoma. These strata appear to represent sheets of skeletal detritus spread out on the seafloor. Their lithostratigraphic and biostratigraphic character indicates that they are part of the series of shallow-water carbonates that were widespread over the continental interior during much of the middle Paleozoic.

The outcrop at Stop 1 is a road cut on the west side of the I-35 interchange; it presents a nearly complete exposure of strata from the Upper Ordovician Sylvan Shale through Silurian and Lower Devonian strata into the lower part of the Upper Devonian Woodford Shale (Fig. 2). The road cut is just a few tens of meters east of section M17 of Amsden (1960). The upper Sylvan, Chimneyhill Subgroup, Henryhouse, and lower Haragan Formation are completely exposed. However, the upper Haragan and lower Woodford are rather poorly exposed, and this part of the section can be observed to better advantage in a road cut on Highway 77A, a few hundred meters east of Stop 1. Approximately 60 m of Hunton section is present; only the Bois d'Arc and Frisco Formations are absent. The Bois d'Arc Formation is a cherty and calcarenitic facies of the Haragan argillaceous limestones, and its absence is due to the local merging of the facies. The Frisco Formation, a slightly younger skeletal limestone, has been removed by post-Hunton, pre-Woodford erosion.

The oldest Hunton formation is the Keel, a fossiliferous oolite, partly with a micrite matrix and partly cemented by calcite spar. At Stop 1 this unit is 1.10 m thick and exhibits well-defined upper and lower contacts. Brachiopods from the Keel are similar to those

from the lower Edgewood Group of eastern Missouri and western Illinois, and to the Hirnantian fauna of Europe, suggesting a very latest Ordovician (late Ashgillian) age (Amsden, 1974; Amsden in Amsden and Barrick, 1986). The hiatus between the Keel and the overlying Cochrane Formation represents a time interval spanning a considerable part of the Early Silurian (early and middle Llandoveryian), during which there was at least local erosion and truncation of the Keel.

The Keel Formation contains a sparse conodont fauna of low diversity, which was described by Barrick (in Amsden and Barrick, 1986). The fauna is characterized by elements of *Noixodontus girardeauensis* (Satterfield), *Istorinus erectus* Knüpfer, and a species of *Eocarniodus* Orchard, in addition to several types of coniform elements. The age of this conodont fauna is not well constrained, but its association in the Keel with a Hirnantian shelly fauna places it in the latest Ashgillian/Hirnantian Stage.

At this stop, the lower 0.6 m of the Keel bears a moderately abundant conodont fauna containing all the important taxa. The basal 0.3 m is best, yielding almost 100 elements per kilogram (Amsden and Barrick, 1986, table 3, section M17), but many of these elements were obtained from a 230-mesh sieve (65 μ m), having passed through a 120-mesh (125- μ m) sieve.

The Cochrane Formation is largely a skeletal limestone with a varied shelly fauna; at this stop it is ~2 m thick and strongly glauconitic. The Cochrane has yielded a brachiopod fauna that indicates a late Llandoveryian age (C₁₋₂) at some localities and in the subsurface (Amsden, 1971; in Amsden and Barrick, 1988). The sparse conodont fauna of the Cochrane is generally dominated by undiagnostic coniform elements (*Panderodus* and *Walliserodus*), as at this stop; at other localities and in the subsurface, a *celloni* Zone fauna (Llandoveryian C₂) has been recovered from the top of the Cochrane.

The Clarita Formation is ~4 m thick and is completely exposed at Stop 1. The formation is divided into a lower Prices Falls Member, a thin but persistent shaly or marly bed that occurs over most of the outcrop area, and the upper Fitzhugh Member, a thinly bedded, skeletal to slightly argillaceous limestone. At this stop, the lower 3 m consists of the arthropod micrite facies, and the upper 1.3 m consists of the ostracode silty marlstone facies of Amsden (in Amsden and others,

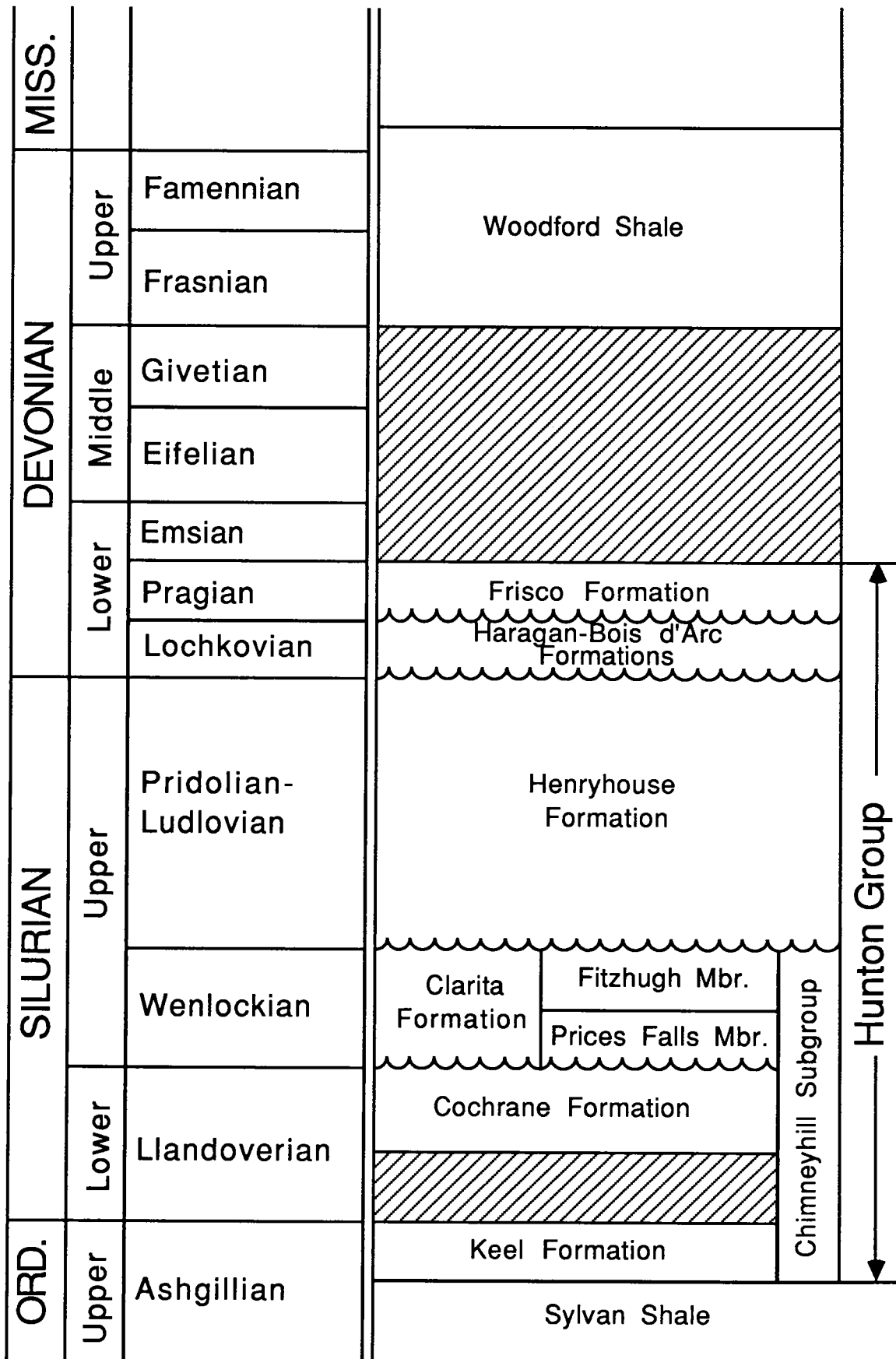


Figure 1. Stratigraphic subdivisions of uppermost Ordovician, Silurian, and Devonian Systems recognized on outcrop in the Arbuckle Mountains and Criner Hills of south-central Oklahoma. Scalloped lines indicate unconformable contacts that at least locally represent only minor hiatuses. Not to scale in terms of time or thickness.

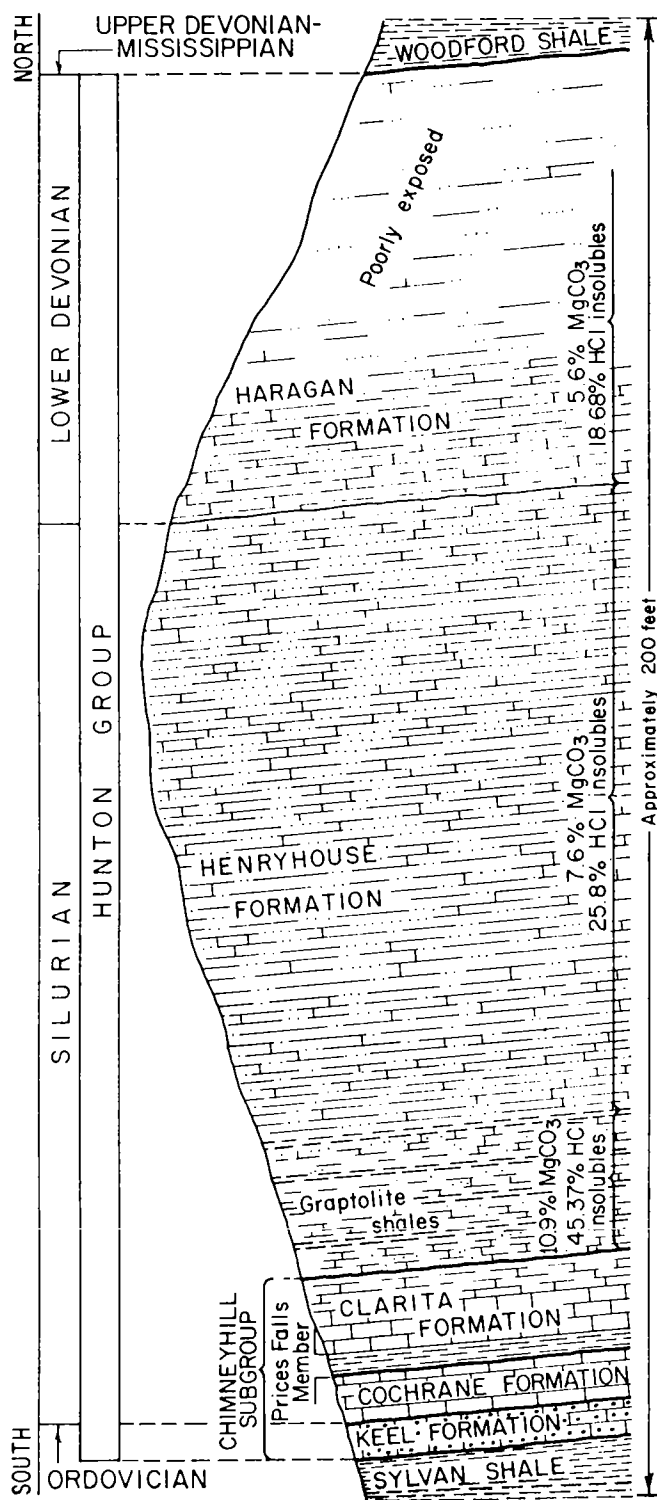


Figure 2. Outcrops of Sylvan Shale, Hunton Group, and Woodford Shale. West side of I-35 interchange, NW 1/4 sec. 30, T. 1 S., R. 2 E., Murray County, Oklahoma. (Cut is near stratigraphic section M17 of Amsden, 1960). Pre-Woodford erosion has removed all of the Frisco Formation and part of the Haragan-Bois d'Arc Formations.

1980). The third facies of the Fitzhugh, the crinoid sparite facies from which Wenlockian brachiopod (Amsden, 1968) and trilobite (Holloway, 1980) faunas have been obtained, is not present in this area; it occurs on the Lawrence uplift to the northeast.

Barrick and Klapper (1976) described the pectiniform conodont species from this Clarita outcrop (Highway 77 section, table 1; Table 1 herein). Note that the number of non-coniform elements per kilogram is rather low. The Prices Falls Member contains a relatively poor *amorphognathoides* Zone fauna at Stop 1, including an unusual number of Pa elements of *Pterospirifer celloni*. The Fitzhugh Member at this section illustrates the faunal distribution on which Barrick and Klapper (1976) based their local zonation using species of *Kockelella*. Except for the basal 0.09 m, which also contains *P. amorphognathoides* and *Distomodus stauropathoides*, the lower 1.65 m is characterized by elements of *Kockelella ranuliformis* and *Ozarkodina excavata excavata*. *Kockelella amsdeni* appears in moderate abundance at 1.65 m; sample 20A (1.90–1.95 m) is the type stratum for this species. *Ozarkodina bohémica* appears at 2.16 m, just below the first occurrence of *K. stauros* (2.59 m). *Kockelella variabilis* occurs only in the uppermost part of the Fitzhugh Member (3.7–4.03 m).

The coniform fauna of the Fitzhugh Member is significantly more abundant, but not much more diverse than the pectiniform fauna. Barrick (1977) described the coniform fauna of the Clarita, but did not include the Highway 77 section (Stop 1) in his faunal lists. The coniform fauna at Stop 1 appears to be identical with that of section Ca2 in the southern Arbuckles (Barrick, 1977, table 1). The fauna is strongly dominated by elements of *Dapsilodus obliquicostatus*, and elements of *Pseudooneotodus bicornis* and *Decoriconus fragilis* are abundant. *Panderodus uniconostatus* is relatively uncommon. *Walliserodus santclairi*, *Dapsilodus sparsus* and *D. praecipuus* occur in the lower part of the Fitzhugh, and *Belodella silurica* is present in the upper samples.

In addition to conodonts, insoluble residues from the Fitzhugh Member at Stop 1 yield abundant agglutinated foraminifers and acrotretid brachiopods (Toomey, in Amsden and others, 1980, text-figs. 12–20, section M17). The most diverse foraminiferal faunas and most abundant acrotretid brachiopods occur in the lower 1.5 m of the Fitzhugh Member. Chatterton and Whitehead (1987) reported the acrotretids *Artiotreta parva* Ireland, *Acrotretella silurica* Ireland, and *Opsiconidion* n. sp. from this locality, and described predatory borings in *A. parva*.

The Henryhouse Formation is ~30 m thick at Stop 1 and is mostly marlstone, with a few calcareous shale beds in the lower part. The contact between the top of the underlying Clarita and the base of the Henryhouse is marked by a sharp increase in insoluble residues, to over 40% in the basal beds of the Henryhouse, and a sharp reduction in the concentration of microfossils. The contact appears within a bed as a distinct line separating the relatively hard, brown micrite of the Clarita from the soft-weathering, gray-brown, argillaceous limestone of the Henryhouse.

TABLE 1.—DISTRIBUTION OF PECTINIFORM CONODONT SPECIES
IN THE CLARITA FORMATION AT THE HIGHWAY 77 SECTION (STOP 1)

SAMPLE NUMBER	HIGHWAY 77																							
	11	12	12A	13	14	17	18	19	20	20A	15	16	21	22	23	24								
STRATIGRAPHIC INTERVAL	0	0	.09	.37	.67	.82	1.13	1.40	1.65	1.90	1.95	2.16	2.59	2.89	3.05	3.70								
LITHOFACIES	sh	m	b	b	b	b	b	b	b	b	m	m	m	m	m	m								
SAMPLE WEIGHT (kg)	6.3	5.0	4.9	4.4	5.2	5.1	5.1	5.4	2.0	4.6	6.2	5.0	5.1	5.1	7.1									
<i>Pterospathodus celloni</i>	Pa	61																						
	Pb	63																						
<i>P. pennatus procerus</i>	Pa	1																						
<i>Carniodus carnulus</i>	Pa	1																						
<i>Delotaxis petila</i>		5																						
	Pa	2	2																					
	Pb	18																						
<i>Distomodus</i>	M	47	2																					
<i>staurogathoides</i>	Sc	41	2																					
	Sb	11	1																					
	Sa	22	2																					
<i>Pterospathodus amorphognathoides</i>	Pa	1	1																					
<i>Aulacognathus kuehni</i>	Pa	1																						
<i>A. ceratoides</i>	Pb	1																						
	Pa	10	14	17		2		19	13	1	43	34	31	6	4									
	Pb	13	11	15		2		13	5	1	26	21	28	6	5									
<i>Ozarkodina</i>	M	8	23	29		4		18	12		25	15	19	7										
<i>excavata excavata</i>	Sc	11	35	35		3		36	26	4	53	32	31	4	4									
	Sb	19	30	49	1	3	1	22	17	3	46	25	22	8	2									
	Sa	6	16	34		1	1	7	14		21	30	10	3	2									
	Pa	11	3	4		3	4	3	3															
<i>Kockelella</i>	Pb	4	4	4	1	2																		
<i>ranuliformis</i>	M	3	1			1	1																	
	Sc	3	3	6		1																		
	Sb	6	5	8		1	2																	
	Sa	2	2	3																				
	Pa							28	15		?1													
<i>Kockelella</i>	Pb							23	18		7													
<i>amsdeni</i>	M							15	11		4													
	Sc							26	26		11													
	Sb							23	24		3													
	Sa							12	8		3													
<i>Ozarkodina</i>	Pa							2																
<i>sagitta rhenana</i>	Pb								1															
<i>Kockelella walliseri</i>	Pa								2															
	Pa										21	7	4	2	3									
<i>Ozarkodina</i>	Pb										5		5											
<i>sagitta bohémica</i>	M																							
	Sc										1													
	Sb										2	1												
	Sa										1													
	Pb										5													
<i>Delotaxis</i> sp. A	M											1												
	Sc										2	1												
	Sb										2	3												
	Sa																							
	Pa											3												
<i>Kockelella</i>	Pb											4												
<i>stauros</i>	M											3												
	Sc											13												
	Sb											10												
	Sa											5												
	Pa												1	3	4									
<i>Kockelella</i>	Pb													3										
<i>absidata</i>	M													2	2									
	Sc													2	6									
	Sb													2	4									
	Sa													2	2									
	Pa														5									
<i>Kockelella</i>	Pb														3									
<i>variabilis</i>	M														4									
	Sc														7									
	Sb														5									
	Sa														2									

Source: Barrick and Klapper (1976, table 1).

The Henryhouse bears a large, well-preserved shelly fauna, and several faunal groups have been described: brachiopods (Amsden, 1951); corals (Sutherland, 1965); trilobites (Campbell, 1967); ostracodes (Lundin, 1965); crinoids (Strimple, 1963). These authors assigned the Henryhouse to the upper Silurian, although its exact position has generally not been specified. At Stop 1, shelly fossils are only poorly represented; the most diverse and abundant Henryhouse localities occur to the northeast on the Lawrence uplift.

The lower 6 m of the Henryhouse at Stop 1 is high in clay- and silt-sized terrigenous detritus, averaging 45%, and includes four thin, graptolite-bearing shale bands. This is one of the three localities from which Decker (1935) reported graptolites (Stop 1 is near Decker's Honey Creek locality). Graptolites collected by Amsden at 3.44 and 5.27 m above the base of the Henryhouse Formation at this locality were correlated by Jaeger (1967, personal communication; in Barrick and Klapper, 1976, p. 62) with the Ludlovian (eB1-Kopanina), as indicated by the presence of *Monograptus bohemicus*. Conodonts are sparse in this shaly interval, but an abundant, although somewhat fragmented fauna containing *Polygnathoides siluricus* has been obtained from a prominent bed 3.5 m above the base of the Henryhouse.

Above the basal shaly interval of the Henryhouse, the proportion of insoluble detritus falls to an average of 25%. In a thin interval 7–9 m above the base of the Henryhouse, a number of relatively clean carbonate beds are intercalated with more-argillaceous beds. In these cleaner carbonates, an abundant and diverse conodont fauna is present, characterized by the abundance of elements of *Dapsilodus obliquicostatus* and *Ozarkodina excavata excavata*, and less common *Decoriconus fragilis* and *Panderodus unicosatus*. A smaller number of elements of *O. snajdri* and *O. n. sp.* of Schönlaub (in Chlupác and others, 1980, p. 157, pl. 17, figs. 6–8) are present, and fragments possibly referable to *Pedavis latialata* have been recovered. This association corresponds to the late Ludlovian *snajdri* Zone as recognized by Schönlaub (in Chlupác and others, 1980, p.

175–177) in the Barrándian area of Czechoslovakia. The Henryhouse section at Stop 1 contains one of the best examples of this fauna in southern Oklahoma.

The upper part of the Henryhouse Formation at Stop 1 yields relatively few conodonts. *Oulodus elegans* appears at 18.5 m, and *Ozarkodina remscheidensis eosteinhornensis* first occurs at 22.2 m. Elements of *O. excavata excavata*, and *Belodella* spp. occur in most samples; other species are uncommon. This upper fauna of the Henryhouse can be assigned to the *eosteinhornensis* Zone in the expanded sense of Schönlaub (in Chlupác and others, 1980, p. 157, 175–177). The *eosteinhornensis* fauna is better represented in the upper part of the Henryhouse at other sections, in particular those on the Lawrence uplift.

The Haragan Formation is ~20 m thick at Stop 1, but due to slumping the lower contact is not well exposed. The exposed beds have a marlstone texture similar to that of the Henryhouse, but average somewhat less in insoluble terrigenous detritus (~19%). The Haragan contains a large, well-preserved shelly fauna, dominated by brachiopods (Amsden, 1958a), with many ostracodes (Lundin, 1968), trilobites (Campbell, 1977), corals, and bryozoans. Loeblich and Wicander (1976) described and illustrated 31 species of organic-walled microplankton from the Haragan and the related Bois d'Arc Formations of Oklahoma. The two units have been interpreted as Early Devonian in age (Helderbergian) by Amsden (1958a, 1975; Amsden, in Amsden and Barrick, 1988).

Because of the poor exposure of the contact at Stop 1, it is difficult to examine the lithologic and faunal relationships between the upper Henryhouse and lower Haragan. It is possible to approximate the base of the Haragan at this section by the appearance of a bed bearing numerous *Scyphocrinites* (*Camarocrinus*) holdfasts. Conodont samples taken above this level when the outcrop was in better condition were relatively poor, but did contain Early Devonian forms of *Icriodus*. At Stop 2, the Henryhouse/Haragan contact is well exposed, and the lithologic and faunal succession can be examined in greater detail.

STOP 2 Henryhouse and Haragan Formations (Late Silurian–Early Devonian) and Woodford Shale (Late Devonian–Early Mississippian)

NW¹/₄ SE¹/₄ sec. 25, T. 2 S., R. 1 E.
Carter County, Oklahoma

James E. Barrick and Gilbert Klapper

The Upper Silurian Henryhouse Formation is similar in lithofacies and biofacies to the overlying Lower Devonian Haragan Formation, and the boundary between these units is based almost entirely on differences between the shelly faunas. Both formations are argillaceous limestones (marlstones) that are so similar in texture and composition that it is difficult, if not impossible, to separate them lithologically in the Arbuckle Mountains region, even in areas of complete exposure. A notable exception is an exposure on Bois d'Arc Creek on the Lawrence uplift (Pontotoc County; Amsden, 1957, p. 30–31, 1960, p. 277, 1988, text-fig. 4), where there is a clearly marked discordance between upper Henryhouse and lower Haragan strata.

Amsden (in Amsden and Barrick, 1988, and earlier papers cited therein) interpreted the lithostratigraphic and biostratigraphic data to indicate that an unconformity separates the two formations. Maxwell (1931) and Amsden (1951, 1958a, b, 1960, 1975, 1980; Amsden, in Amsden and Barrick, 1988; Amsden and Ventress, 1963) described the detailed lithostratigraphic and biostratigraphic characteristics of the Henryhouse and Haragan Formations. They demonstrated that the Haragan locally truncated Henryhouse strata, bringing the Lower Devonian Haragan and related Bois d'Arc beds into direct contact with the Clarita (Wenlockian) and Cochrane (late Llandoveryan) over a large area in the southeastern part of the Arbuckle Mountains (Wapanucka area).

Detailed collections from measured sections crossing the Henryhouse/Haragan boundary show a well-defined taxonomic and phylogenetic separation of Henryhouse and Haragan brachiopods (Amsden, in Amsden and Barrick, 1988, pls. 2–4, text-fig. 6). Similarly detailed collections of ostracodes from the Henryhouse and Haragan Formations by Lundin (1965, 1968) demonstrate an identical separation. Lundin (1968, p. 11) also recognized abraded Henryhouse ostracodes mixed with the basal Haragan fauna at one locality on the Lawrence uplift. Studies of trilobites from the Henryhouse and Haragan by Campbell (1967, 1977), show a similar segregation of taxa. However, evaluation of the magnitude of the hiatus at the Henryhouse/Haragan contact has been

difficult. Amsden (in Amsden and Barrick, 1988, p. 13–14) discussed problems associated with the brachiopod faunas and interpreted that of the Keyser Limestone of Maryland and adjacent states (Bowen, 1967) to be transitional between the Henryhouse and Haragan faunas.

At Stop 2, ~20 m of argillaceous limestone of the upper Henryhouse and lower Haragan formations is exposed in a small road cut on the west side of Interstate 35. The Hunton marlstone interval is ~60 m thick here, and the more resistant beds of the middle part of the Henryhouse can be seen cropping out in the pasture north of the road cut. The small ridge ~50 m north of the road cut is the Chimneyhill Subgroup, including the Clarita, Cochrane, and Keel Formations. The Haragan is overlain by the basal shales of the Upper Devonian Woodford Shale, the upper part of which is well exposed in another road cut 50 m south of this one. The Hunton section exposed here is similar to section Ca2 of Amsden (1960), which lies in the pasture just east of the interstate. Using brachiopod faunas to recognize the Henryhouse/Haragan contact, Amsden (1960) identified ~7 m of Haragan–Bois d'Arc overlying ~46 m of Henryhouse. Although the section is lithologically rather homogeneous, five lithologic units can be distinguished in the road cut, starting at the top of the Hunton (Fig. 3):

- Unit E. 0.00–6.60 m; medium-bedded, argillaceous, grayish-brown carbonate mudstones and wackestones, with a variable amount and unequal distribution of marly intercalations.
- Unit D. 6.60–8.35 m; thin-bedded (5–10 cm), relatively clean, grayish-brown skeletal packstones and wackestones separated by marly intercalations.
- Unit C. 8.35–10.85 m; medium-bedded, argillaceous, grayish-brown carbonate mudstones and wackestones, with only a few marly intercalations.
- Unit B. 10.85–14.5 m; medium-bedded, highly argillaceous, brown carbonate mudstone and wackestone grading into marls.
- Unit A. 14.5 m to base of good exposure; medium-bedded, argillaceous, brown carbonate mudstones and wackestones with few marly intercalations.

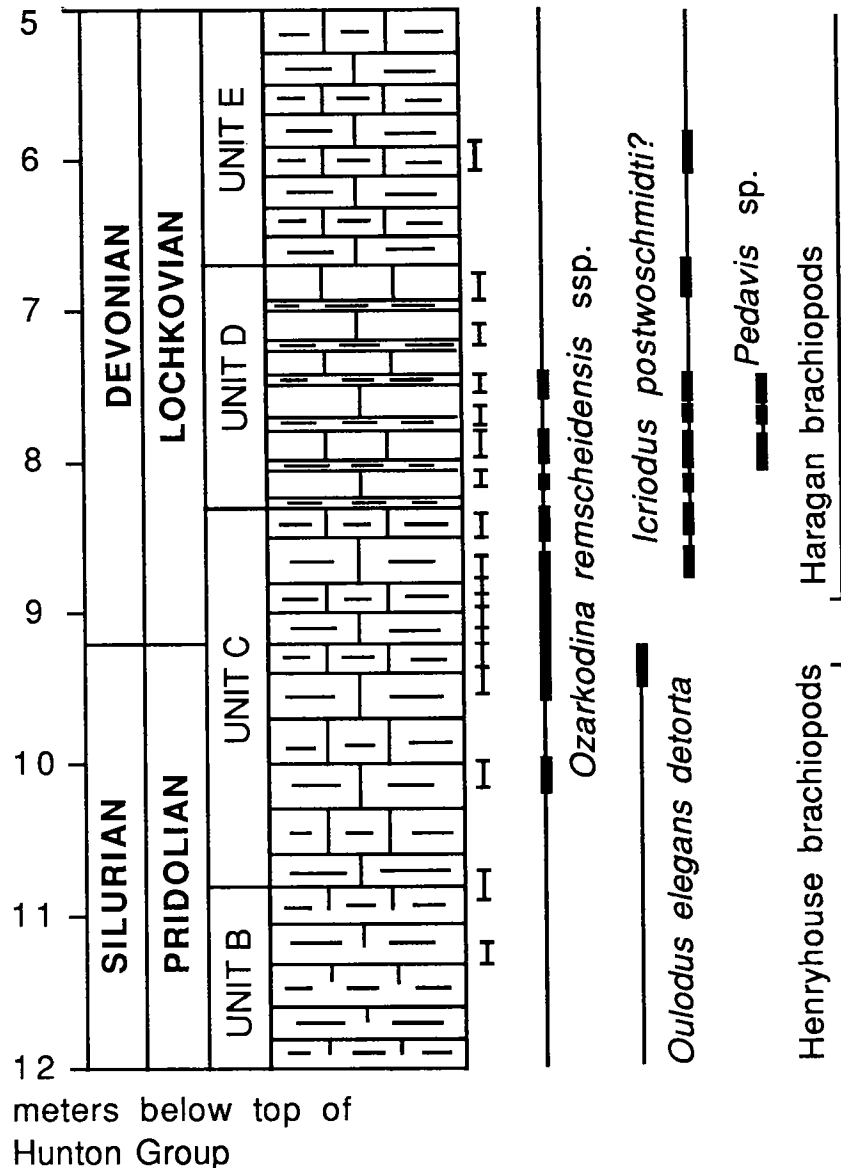


Figure 3. Stratigraphic column of the Silurian-Devonian boundary interval at Stop 2. Ranges of important conodonts and the highest occurrence of Henryhouse and lowest occurrence of Haragan brachiopods are shown. Descriptions of lithologic units are given in the text.

The most distinct lithologic break at this section lies at the base of Unit D; however, the change in the shelly fauna and the conodont fauna lies within Unit C. Henryhouse brachiopods can be collected from marly beds in Unit B, and a single specimen of "*Lissatrypa*" *henryhousesensis* was obtained from a conodont sample taken at 9.40–9.50 m, near the middle of Unit C. Units D and E bear the Haragan shelly fauna, and a single specimen of *Meristella atoka*, a Haragan species, was found in the conodont sample taken near the top of Unit C (8.75–8.90 m). (Brachiopods identified by T. W. Amsden.)

Samples from the upper part of the Henryhouse, Units A and B, are relatively poor, yielding at best only a few tens of conodonts per kilogram. *Ozarkodina*

remscheidensis eosteinhornensis, *O. excavata*, and *Oulodus elegans* (including *O. elegans detorta* of Jeppsson, 1989) are present, but faunas are dominated by elements of *Belodella*, with fewer elements of *Dvorakia*, *Panderodus*, *Decoriconus*, and *Dapsilodus*. The Henryhouse conodont fauna extends up to 9.25 m, within Unit C. The interval from 9.25 to 10.10 m contains moderately well-preserved, but sparse conodonts.

Above 9.25 m in Unit C, a different conodont association, the Haragan fauna, occurs. Elements of *Pseudooneotodus beckmanni* and *Decoriconus* become abundant, and those of *Belodella* become less common. *Oulodus elegans* disappears and Pa elements of *Ozarkodina remscheidensis* tend more toward the *O. r. remscheidensis* than the *O. r. eosteinhornensis* morphology. Insoluble

residues also contain significantly greater numbers of an acrotretid brachiopod, *Opsiconidion* sp. and diverse agglutinated foraminifers. Near the top of Unit C (8.65–8.75 m), *Icriodus* appears.

The thin-bedded wackestones and packstones of Unit D yield the most significant and best preserved Haragan conodonts, although 4–5 kg of sample are required to obtain a representative fauna. The morphotypes of *Icriodus* most closely resemble *I. postwoschmidti* Mashkova, and some of the other elements of the *Icriodus* apparatus are present. A few specimens of a *Pedavis* species that is similar to *P. biexoramus* Murphy and Matti have also been recovered from Unit B and relatively few elements of the *Ozarkodina remscheidensis* group are present. Coniform elements include species of *Belodella*, *Decoriconus*, *Dvorakia*, and *Pseudooneotodus beckmanni*.

In Unit E, the upper part of the Haragan exposed at this outcrop, *Icriodus* elements are uncommon, and the members of the *Ozarkodina remscheidensis* group are better represented. Overall conodont abundance remains low, a few tens of elements per kilogram. The relative proportions of species of the coniform fauna varies greatly, but near the top of the section some samples contain large *Belodella* faunas.

In this section, as well as on the Lawrence uplift, the change from the Henryhouse to the Haragan shelly fauna coincides with changes in the composition of the conodont faunas. The shift in conodont biofacies appears to be a response to a sudden ecologic change, one that dramatically affected the shelly fauna, but the shift could also be the result of a significant break in deposition, an unconformity. Evaluation of the magnitude of

the hiatus at this unconformity is not easily done using the conodont faunas. If *Oulodus elegans detorta* is restricted to the uppermost beds of the Silurian, as reported by Jeppsson (1988, 1989), then little of the uppermost Silurian may be absent. Most of our specimens of *Icriodus* appear to belong to *I. postwoschmidti*, which occurs slightly above the base of the Devonian, and it is possible that the lowermost Devonian is absent here. However, taxonomic studies of the important Henryhouse and Haragan conodonts are not complete, nor have the ranges of some taxa occurring near the Silurian/Devonian boundary been rigorously demonstrated.

The lowermost beds of the Upper Devonian–Lower Mississippian Woodford Shale are moderately well exposed at Stop 2. The brownish to greenish shales at the base of the formation here contain abundant Frasnian conodonts (unfortunately, most are badly broken) that were concentrated as lag deposits during the early transgressive phases of Woodford deposition. The middle part of the Woodford is covered south of this road cut, but the top of the formation, containing the Devonian/Mississippian boundary, is well exposed in the next road cut to the south. The upper Woodford in this area comprises interbedded black chert and hard, siliceous, black shale in which large phosphate nodules are common. Conodonts can be seen on bedding planes near the top of the Woodford, but systematic stratigraphic processing in this lithofacies has been extremely difficult. At Stop 6, the upper Woodford yields more abundant and readily obtained Late Devonian and Early Mississippian conodonts from a less siliceous lithofacies.

STOP 3

Joins and Oil Creek Formations (Pre-Chazyan Whiterockian, Middle Ordovician)

SE ¼ sec. 24, T. 2 S., R. 1 E.

Carter County, Oklahoma

Scott M. Ritter and Jeffrey A. Bauer

This stop will afford field-trip participants an opportunity to collect representative southern Midcontinent lower and middle (pre-Chazyan) Whiterockian conodont faunas, including topotype material, from the upper Joins and lower Oil Creek Formations. The Joins and Oil Creek Formations constitute the lower two units of the five-formation Simpson Group (Decker and Merritt, 1931) in the southern Arbuckle Mountains (stratigraphic columns, inside back cover). The Joins Formation is ~100 m thick at Stop 3, but is absent in the northeastern part of the Arbuckle Mountains (Hunton anticline). The overlying Oil Creek, which is nearly 260 m thick at this locality (Fay, 1969, 1989), is regionally more persistent. Both the Joins and Oil Creek comprise interbedded thin shales and fossiliferous, grain-rich limestones. Numerous invertebrate groups are represented, including bryozoans, brachiopods, gastropods, cephalopods, graptolites, ostracodes, trilobites, and conodonts.

The uppermost Joins and a nearly complete section of the Oil Creek are exposed in the road cut on the east side of the eastbound lane of Interstate 35 adjacent to milepost 45. A less complete section of the Oil Creek is exposed in road cuts along the median. The majority of the Joins Formation is poorly exposed on private property in a broad swale just north and east of the road cut; however, a part of the upper 19 m of the Joins can be sampled in low, discontinuous outcrops along the north-south fence line just north of the road cut. The Joins/Oil Creek contact is placed at the extreme north end of the east road cut, at the base of a zone of calcareous sandstone 16 m downsection from the position of Marker 7 of Fay (1969, 1989). Unfortunately, the plaque which constituted Marker 7 has been removed; however, the stratigraphic position of the marker is easily located at a 0.70-m-thick, ledge-forming lime grainstone with obvious crossbedding near the north end of the east road cut. Reconnaissance sampling suggests that conodonts are abundant in most limestone units within the Oil Creek Formation. However, to guarantee recovery, the occurrence and abundance of conodonts in five

samples from the upper Joins Formation (J1-J5) and five samples in the lowest Oil Creek (OC-1, -1A, -1B, -2, -2B) are shown in Table 2. Also shown is the occurrence of the problematical "fish-hook" fossil *Ptiloncodus simplex* Harris.

Conodont faunas from the Joins and lowermost Oil Creek have been described by Harris (1962), Mound (1965), and McHargue (1974, 1982). Harris (1962) established *Oistodus multicorugatus*, *Drepanoistodus angulensis*, and the genus *Histiodellella* (*H. altifrons* and *H. serrata*) on the basis of material collected from the Joins Formation along Highway 77 (0.5 km east of Stop 3). From these same collections Harris established *Ptiloncodus simplex*. A few years later Mound (1965) reported Joins conodonts from the southern Arbuckles and established *Paraprioniodus costatus* and *Scandodus sinuosus*. McHargue (1982) divided the Joins Formation and basal 30 m of the Oil Creek into 4 lineage zones based upon evolution within the *Histiodellella* lineage (Fig. 4). Although the *altifrons* and *minutiserrata* zones are covered at this locality, specimens of *Histiodellella minutiserrata*, *H. sinuosa*, and *H. serrata* can be collected from the upper Joins and basal Oil Creek.

In the Arbuckle Mountains, the pre-Chazyan part of the Whiterockian Series comprises the upper 30 m of the West Spring Creek Formation (upper Arbuckle Group) in addition to the overlying Joins and Oil Creek Formations. The position of the Lower/Middle Ordovician boundary within the upper West Spring Creek was documented on the basis of brachiopods, ostracodes, and conodonts by Derby (1969). The assignment of the Joins and Oil Creek to the Whiterockian on the basis of conodonts was reported by Sweet and Bergström (1973). Other faunal groups substantiating a Whiterockian age for the Joins and Oil Creek include graptolites (Bergström and Cooper, 1973), trilobites (Shaw, 1974), cephalopods (Flower, 1971), and brachiopods (Cooper, 1956; Derby, 1969). The locally unconformable boundary between the lower and middle (pre-Chazyan) and upper (Chazyan of classical reports) Whiterockian is located in the basal part of the McLish Formation.

TABLE 2.—DISTRIBUTION AND ABUNDANCE OF CONODONTS IN THE UPPERMOST JOINS AND LOWERMOST OIL CREEK FORMATIONS AT STOP 3

sample number and interval in meters species	upper Joins Formation					lower Oil Creek Formation				
	J1	J2	J3	J4	J5	OC1	OC1A	OC1B	OC2	OC2B
	-19	-12	-4.1	-3.3	-0.3	13	16	18.3	20.4	27
<i>Drepanoistodus angulensis</i> *	42	5	8	2	2	23	14	15	6	12
<i>Histiodela minutiserrata</i>	1		2							
<i>Histiodela serrata</i> *			3	4		8			7	
<i>Histiodela sinuosa</i>	12			7	7	3				
<i>Oistodus cristatus</i>								2		
<i>Oistodus multicorrugatus</i> *	9	9	16	10	1	15	10	9	4	48
<i>Microzark. ? marathonensis</i>	1		3	4	5	3				
<i>Multioistodus auritas</i>		36								
<i>Neomultioistodus compressus</i>		6	46	65	100+	100+	58	35	200+	42
<i>Paraprioniodus costatus</i> *			4	3	10	17		4	10	
<i>Pteracontiodus cryptodens</i>	28		9	3		15			4	
<i>Scandodus ? sinuosus</i> *	38	44	76	83	92	100+	100+	67	100+	200+
<i>Ptiloncodus simplex</i> *		1	4	2	8	18	7	15	26	6

Notes: Sample horizons are shown in meters above (positive numbers) and below (negative numbers) the base of the Oil Creek Formation. Conodont abundances are reported in specimens per 0.7 kg of sample. An asterisk indicates a species that has its type locality in the southern part of the Arbuckle anticline.

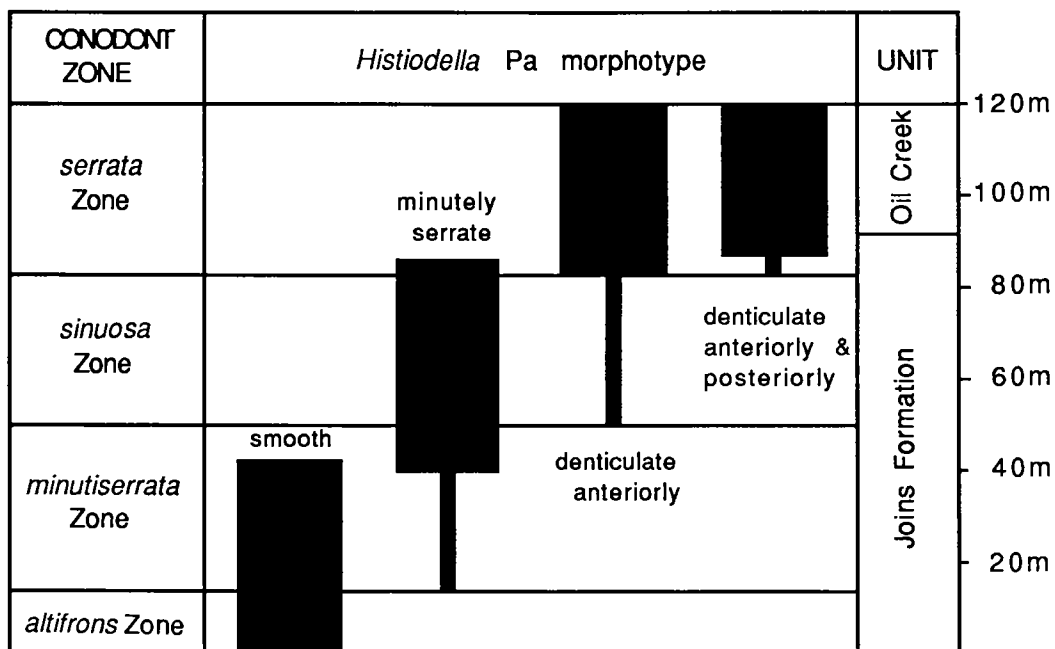


Figure 4. Stratigraphic ranges and relative abundances of Pa elements of *Histiodela* within the Joins and lower Oil Creek Formations (modified from McHargue, 1982). *Histiodela* lineage zones of McHargue (1982) are also shown. Faunas described in Table 2 are largely from the *serrata* Zone.

STOP 4 Upper Arbuckle Group (Lower Ordovician)

NE $\frac{1}{4}$ sec. 24, T. 2 S., R. 1 E.
Carter County, Oklahoma

Raymond L. Ethington and Russell I. Dresbach

The Arbuckle Group of southern Oklahoma consists of >6,000 ft of Cambrian to Early Ordovician shallow-water limestones and dolomites in eight formations (stratigraphic columns, inside back cover). A nearly complete sequence of the Cambrian to Early Ordovician Arbuckle Group is exposed in road cuts along Interstate 35 and on the adjacent Chapman Ranch in the southern Arbuckle Mountains (Figs. 5–10). Systematic sampling has demonstrated that conodonts are common throughout the Ordovician part of the Arbuckle Group and that the conodont succession can be used for comparison with other Lower Ordovician sequences in North America.

Owing to time constraints, and because the road leading to outcrops on the Chapman Ranch is not adequate for heavy traffic, we will not visit the lower part of the Arbuckle Group on this field trip. The upper three formations (Cool Creek, Kindblade, and West Spring Creek) are exposed along Interstate 35 adjacent to the scenic turnout.

Because traffic is heavy, caution must be exercised in crossing the highway!

The lower Cool Creek is exposed in the northernmost road cut along the west lane of the interstate north of the parking area. Samples collected in the northern half of the outcrop will yield *Oneotodus*, but little else. A somewhat more diverse fauna with rare specimens of *Macerodus diana* can be recovered in the southern part of the Cool Creek exposure. The upper part of the Cool Creek is not accessible along the interstate, but can be sampled in the adjacent ranch lands to either side. Permission from the land owners must be obtained before entering these private properties.

The remainder of the Arbuckle Group is continuously exposed, beginning with the Kindblade in the exposure on the east lane of the highway. The Cool Creek/Kindblade contact is 90 ft stratigraphically below the lowest exposure of the Kindblade in the road cut. Much of the upper Kindblade must be examined in the outcrop along the median, beginning just opposite the entrance to the parking area. The West Spring Creek is exposed on the east side of the east lane, beginning at the sign reading "No Stopping or Standing." Almost any sample collected from the Kindblade will yield conodonts; abundances on the order of 75 to 150 elements per kilogram are typical, and some samples yield 1,000 elements per kilogram. Recovery is much more variable in the West Spring Creek, but nonstromatolitic carbonate beds almost certainly will be productive.

The Lower Ordovician/Middle Ordovician boundary is ~80 ft below the top of the West Spring Creek as that formation was defined by Fay (1969, 1989; in unit 13 of Fay's measured section; note that Fay's Unit 1, 42 ft, is no longer exposed along the interstate). Samples collected in the top 30 ft of the exposures contain an admixture of forms typical of the Lower Ordovician part of the West Spring Creek, together with forms such as *Scandodus sinuosis* Mound, *Tricladiodus clypeus* Mound, *Pteracontiodus cryptodens* (Mound), and *Neomultioistodus compressus* Harris and Harris that are dominant elements in the overlying (but no longer exposed) Joins Formation. Commonly the elements in this interval have been so severely abraded, presumably by turbulence in shallow water, that they can be identified only in very general terms.

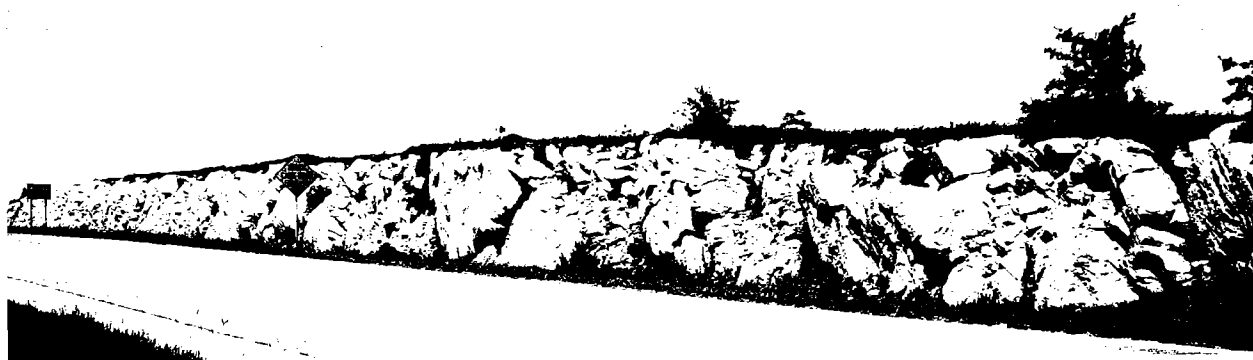


Figure 5. Road cut exposing the lower Kindblade Formation, east side of Interstate 35 (Stop 4).

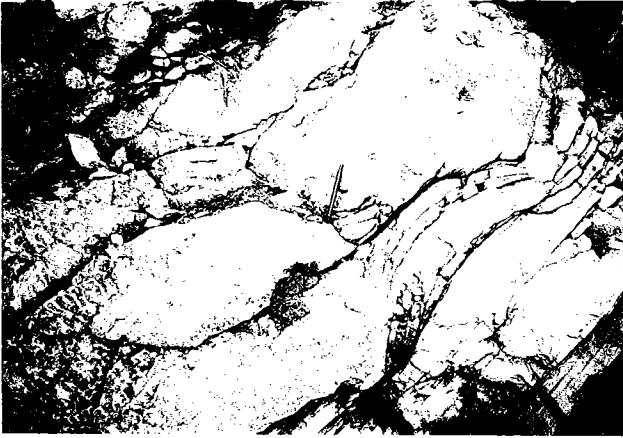


Figure 6. Ledge with digital stromatolites overlying laminated layers with planar and domal stromatolites, Cool Creek Formation, west side of Interstate 35 (Stop 4). Pen (center) is 5.25 in. long.



Figure 7. Alternating thin- and thick-bedded units in the lower Kindblade Formation, east side of Interstate 35 (Stop 4).



Figure 8. Syncline and anticline in the basal Kindblade, east side of Interstate Highway 35 (Stop 4).



Figure 9. Contact between the Kindblade and West Spring Creek Formations, east side of Interstate 35 near sign reading "No Stopping or Standing" (Stop 4).



Figure 10. Interval with red beds and shales ~1,000 ft above the base of the West Spring Creek, east side of Interstate 35 (Stop 4).

STOP 5 Upper Simpson Group (Western Arbuckle Facies, Middle Ordovician), Interstate 35 Section

SE¹/₄ sec. 30, T. 1 S., R. 2 E.
Murray County, Oklahoma

Jeffrey A. Bauer

The Interstate 35 section of the upper Simpson Group (McLish, Tulip Creek, Bromide Formations) is located on the north flank of the Arbuckle anticline. This section, which is representative of western Arbuckle facies development, is exceptional because of its thickness, continuity, and good exposure. Fay (1969,1989), Bauer (1987a,b), and Longman (1976) have described all or part of the upper Simpson section at this locality.

McLISH FORMATION

The McLish Formation forms a small ridge in a valley just east of the highway and near milepost 50 (Fig. 11). Beds are overturned and dip 65–70° S. The McLish is composed of a lower sandstone succeeded by interbedded limestone, mudstone, and shale.

Approximately 18 m of sandstone (quartz arenite) is exposed at this stop. The lower 6 m down to the contact between the McLish and subjacent Oil Creek Formation is covered at this stop. In general, the McLish sandstone has a significant amount of calcite cement and can be



Figure 11. Overturned McLish Formation exposed in valley just east of Interstate 35 (Stop 5). Base of section at far right is basal McLish sandstone. Upper part of section (to left) comprises limestones and shales.

disaggregated by standard processing with a weak acid. However, the conodonts recovered from sandstone samples are few and very poorly preserved.

Moving north along the outcrop, 46 m of alternating limestone and mudstone is exposed above the lower sandstone. The lower 15 m of this interval is of great interest because three distinctly different conodont faunas are represented. Species of *Neomultioistodus*, *Scandodus?*, and *Pteracontiodus* dominate the oldest fauna, followed in stratigraphically higher samples by faunas with abundant *Phragmodus polystrophos* and *Phragmodus* n. sp. 1, respectively. Middle McLish samples in the remaining 31 m of the outcrop generally yield large collections dominated by *Phragmodus* n. sp. 1, and also contain elements of *Ansella robusta* (Ethington and Clark), *Cahabagnathus* n. sp., *Drepanoistodus suberectus* (Branson and Mehl), *Panderodus gracilis* (Branson and Mehl), *Protopanderodus varicostatus* (Sweet and Bergström), and *Staufferella* n. sp.

The upper McLish is mostly covered. Samples from several isolated limestone and sandstone ledges in this interval have yielded large conodont collections containing *Phragmodus* n. sp. 2, *Thrincodus palaris* Bauer, *Phragmodus? arcus* Webers, *Ansella* n. sp., *Belodina monitorensis* Ethington and Schumacher, *Cahabagnathus directus* Bauer, *Erismodus arbucklensis* Bauer, and *Leptochnirognathus quadratus* Branson and Mehl.

TULIP CREEK FORMATION

The Tulip Creek Formation is recognizable as a distinct unit only in the western Arbuckle facies. Beds of the Tulip Creek are overturned like those of the underlying McLish. The lower beds of the Tulip Creek and the upper beds of the McLish are well exposed and form a prominent ridge to the east of the highway (Fig. 12).

Cross-bedded or bioturbated sandstones (quartz arenites) dominate the lithology of the lower 42 m of the Tulip Creek. These sandstones contain appreciable calcite cement and can be disaggregated by standard techniques. Samples generally yield large conodont collections which have nearly the same species composition as those from the upper McLish.



Figure 12. McLish/Tulip Creek contact (arrow) at Interstate 35 road cut (Stop 5). McLish exposed to right of arrow in this overturned section.

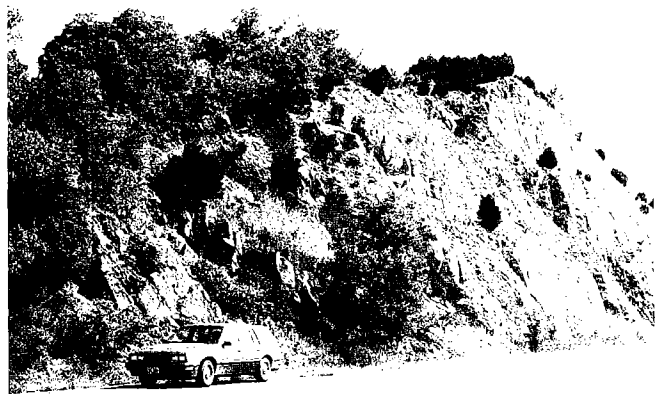


Figure 13. S-dipping beds of the Bromide Formation along the east side of Interstate 35 at milepost 50, northern Arbuckle anticline (Stop 5).

The upper 50+ m of the Tulip Creek (probably mudstone) is mostly covered, and is present beneath the south slope of the previously mentioned ridge. Samples of several thin limestone ledges within the upper Tulip Creek have produced key species of conodonts, such as *Cahabagnathus chazyensis* Bergström, *Plectodina* n. sp., and *Dapsilodus variabilis* (Webers).

BROMIDE FORMATION

Rather than continue upsection to the north from the Tulip Creek outcrop, a better exposure of the Bromide Formation and overlying Viola Springs Formation is located back near milepost 50. Moving upsection to the south, along the east side of the highway, a long road cut exposes a nearly complete section of the Mountain Lake and Pooleville Members of the Bromide. A fault juxtaposes the lower Bromide with the Oil Creek Formation. The beds of the Bromide and Viola Springs dip 30–40° S (Fig. 13).

Three major lithologic divisions of the Bromide can be recognized at the I-35 road cut. The lowest division is dominated by sandstone, the middle by alternating limestone and mudstone, and highest by calcilutite. The lower two divisions collectively constitute the Mountain Lake Member, and the upper division is the Pooleville Member.

The lower sandstone of the Mountain Lake has an exposed thickness of ~18 m. The base of the section is

~10 m above the base of the Bromide. Conodonts collected from samples of sandstone and interbedded mudstone layers include *Phragmodus inflexus* Stauffer, *Plectodina* n. sp., *Oneotodus? ovatus* (Stauffer), *Erismodus typus* Branson and Mehl, and *Cahabagnathus sweeti* (Bergström).

Alternating beds of limestone (calcarenite and calcilutite) and mudstone overlie the Mountain Lake sandstone and reach a thickness of 42 m. Conodonts represented in this interval most notably include *Eoplacognathus elongatus* (Bergström), *Prioniodus (Baltoniodus) gerdae* Bergström, *Bryantodina* n. sp., *Appalachignathus delicatulus* Bergström, Carnes, Ethington, Votaw, and Wigley, *Ansella nevadensis* (Ethington and Schumacher), *Plectodina flexa* (Rhodes), and *Staufferella falcata* (Stauffer). *P. (B.) gerdae* and *E. elongatus* first occur 52 m and 22 m, respectively, above the base of the section.

The upper calcilutite division (Pooleville member) is ~22 m thick. Pooleville beds are characterized by birdseyes, cryptalgal laminations, and oncolites. Macrofauna includes leperditid ostracodes and *Tetradium*. Only samples from the lower beds of the Pooleville have produced conodont collections of appreciable size. The Pooleville conodont fauna is dominated by *Plectodina* n. sp., *Walliserodus* sp., *Panderodus gracilis*, *Erismodus typus* Branson and Mehl, and *Curtognathus* spp. The lowest bed of the overlying Viola Springs Formation contains *Dapsilodus mutatus* (Branson and Mehl), and *Protopanderodus liripipus* Kennedy, Barnes, and Uyeno.

Road Log—Second Day

Scott M. Ritter

SEGMENT 3—ARDMORE TO FITTSTOWN, OKLAHOMA

Mileage begins at freeway entrance 31A to the northbound lane of Interstate 35 on the west side of Ardmore, Oklahoma.

<i>Cumulative Mileage</i>	<i>Interval</i>				
			29.2	2.7	Bridge.
			31.2	2.0	Entering Sulphur, Oklahoma.
0.0	0.0	Enter Interstate 35 at entrance 31A and proceed north.	32.2	1.0	Traffic light. Continue east.
5.7	5.7	Junction of Highway 77-53 and Interstate 35 (Exit 40). Continue north on Interstate 35.	32.7	0.5	Artesian well on right.
			33.0	0.3	Stop sign. Turn north (left) on Highway 7-177.
11.2	5.5	Junction of Interstate 35 and Highway 53.	33.3	0.3	Turn right and proceed eastward on State 7 East.
12.4	1.2	Honey Creek Pass.			
12.8	0.4	Milepost 44 and outcrop of Sycamore Limestone.	34.3	1.0	Oklahoma School for the Deaf on north side of road.
13.2	0.4	Road cuts in Viola Limestone.	37.4	3.1	Cross Mill Creek.
13.8	0.6	Road cuts in Bromide Formation.	39.7	2.3	Stop sign at junction of State 7 East and State 1 East. Turn left (north) on State 1 East. Entering Murray County.
14.5	0.7	Scenic turnout (Stop 4 of first day).			
14.7	0.2	Murray County line.	43.4	3.7	Hickory, Oklahoma.
16.0	1.3	Junction with Highway 77 to Turner Falls. Continue north on Interstate 35.	46.0	2.6	Pontotoc County line.
			47.8	1.8	Entering Roff, Oklahoma.
17.7	1.7	Scenic turnout.	48.4	0.6	Sharp eastward turn in highway.
19.9	2.2	Junction with U.S. 77 to Davis, Oklahoma. Exit Interstate 35. Turn right at stop sign and proceed north-northeast on U.S. 77.	49.4	1.0	Turn right on State 61 to Fittstown.
			49.7	0.3	East Hill Cemetery on left.
20.4	0.5	Bridge over Washita River.	52.9	3.2	Bridge.
23.0	2.6	Entering Davis, Oklahoma.	54.3	1.4	Bridge.
23.2	0.2	Dolese cement plant on right.	60.9	6.6	Junction State 99. Turn left onto State 99 and proceed north.
23.7	0.5	Junction of U.S. 77 and State Road 7. Yield and turn right onto State 7 East. Proceed east.	63.5	2.6	Cross Bois d'Arc Creek. Road cut on left just before bridge in crinoidal mounds of Devonian Frisco Formation.
24.0	0.3	Cross railroad tracks.			
24.2	0.2	Junction U.S. 77 North. Continue east on State 7 East.	65.0	1.5	Turn left on County Road 161. Proceed west along gravel road.
25.7	1.5	Divided highway begins.	65.6	0.6	Crest of low hill, proceed 0.1 mi down the hill to Stop 6.
25.9	0.2	Junction 110 South on right side of road. Continue on State 7 East.	65.7	0.1	Stop 6—Woodford to basal Caney Shale (Hass G section). The Woodford to Caney Shale outcrops are located ~25 yd north
26.5	0.6	Oil field.			

- of the road along the east-southeast bank of the creek. 79.3 3.3 Gate leading to private road on south side of highway. Turn right and proceed through gate. Permission to enter must be obtained from Max Skelton, who resides in Ada, Oklahoma. Proceed 0.4 mi, first south and southwest, then northwest along south bank of Canyon Creek for 0.6 mi to a flood-control levee in the W¹/₂NE¹/₄, sec. 8, T. 1 N., R. 7 E. Vehicles must be left at this point.
- Retrace route to Highway 99.
- 66.4 0.7 State 99. Turn south and proceed to Fittstown, retracing part of previous route.
- 70.7 4.3 Fittstown, Oklahoma.
- 71.4 0.7 Junction with Highway 99A East on left. Continue south on 99.
- 74.2 2.8 Road cut through resistant ridge of N-dipping Viola Limestone. 79.9 0.6 **Stop 8—Mississippian/Pennsylvanian Boundary at Canyon Creek.** The section is reached by crossing the levee and continuing south on foot down the main branch of Canyon Creek for ~0.7 mi.
- 74.8 0.6 **Stop 7—Upper Simpson Group (eastern Arbuckle facies).** Pull out on right at top of hill. The road cuts on the west side of the road to the north constitute Stop 7.
- Turn around and proceed north on State 99.
- 76.0 1.2 Turn right onto State Route 61 and proceed east.
- Return to vehicles and retrace route to Highway 99.
- End of road log.**
-

STOP 6

Woodford Shale (Late Devonian–Early Mississippian), Pre-Welden Shale, Welden Limestone, and Basal Caney Shale (Mississippian); Hass G Section

SE ¼ SE ¼ sec. 35, T. 3 N., R. 6 E.
Pontotoc County, Oklahoma

James E. Barrick, Jill N. Haywa-Branch, and D. Jeffrey Over

Stop 6 is a small ledge along the southeastern bank of the South Fork of Jackfork Creek. The Welden Limestone forms the ledge, and the pre-Welden shale of Cooper (1939) and the top of the Woodford Shale are exposed beneath the Welden. At the top of the ledge more than a meter of the basal shales of the Caney Shale overlies the Welden; up a small, shallow ravine to the northeast, a few more beds of the lower Caney can be found. The section was described by Hass and Huddle (1965) as their section G. It is designated the Hass G section in papers on the Woodford Shale (Over and Barrick) and the Welden Limestone (Haywa-Branch and Barrick) in this guidebook. Orth and others (1988) described the geochemistry of the Hass G section, and noted the presence of anomalous horizons where metals, including iridium, are concentrated.

Only the uppermost 4 m of the Woodford Shale can be observed at the base of the outcrop at Stop 6 (Fig. 14), but just to the southwest the entire thickness of the formation on the Lawrence uplift, ~80 m, is exposed in a series of shale pits and natural outcrops. The top 4 m of the Woodford on the Lawrence uplift comprises dominantly black fissile to blocky shales, and lacks the chert beds and abundant, large, spherical phosphate nodules characteristic of the top of the formation in the main part of the Arbuckle Mountains. The phosphate that is present occurs as thin, discontinuous layers of pelloidal grains that often possess a grapestone-like texture when observed in thin section. The discrete nature of the phosphate layers in the black shale suggests that deposition was probably intermittent and that numerous disconformities are present. The number and spacing of phosphate layers is variable, but the layers are more common and better developed in the top 1 m. The combination of black, organic-rich shale and phosphates suggests that the upper Woodford was deposited in relatively deep water near the oxygen-minimum zone (Heckel and Witzke, 1979). Orth and others (1988) reported that Ir (0.25 ppb), Pt, Au, V, Ni, U, and all measured chalcophiles (Cu, Zn, As, Se, Mo, Ag, Sb, and Hg) are highly enriched in the top 1 cm of the Woodford at Stop 6.

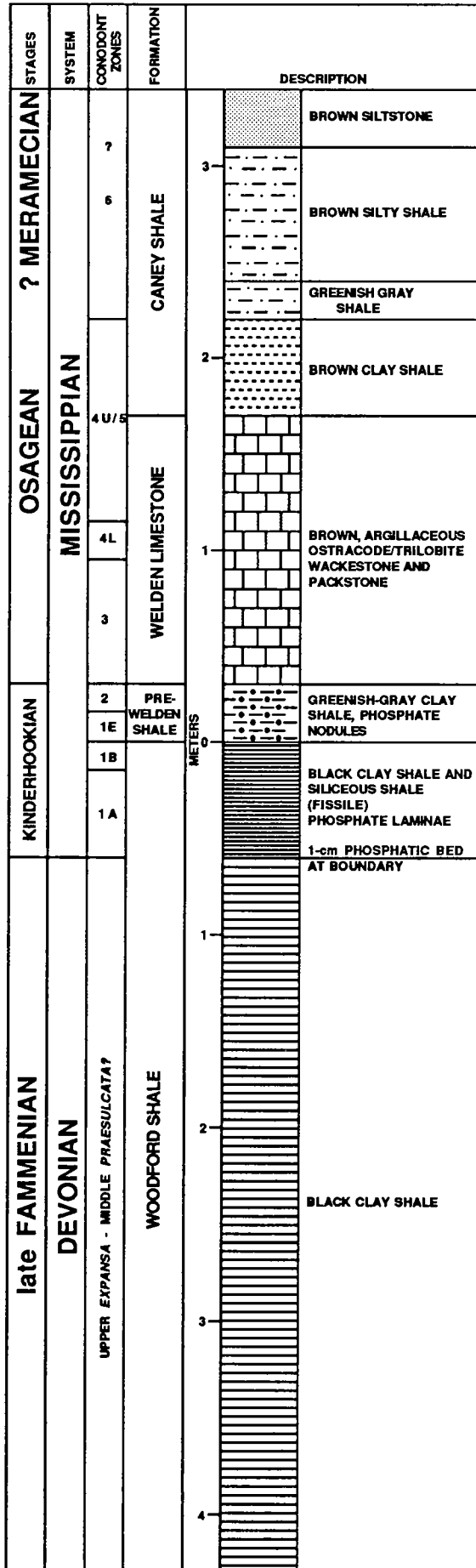
Conodonts are moderately abundant in the upper 2 m of the Woodford Shale, and excellent specimens can

be extracted from the black shale using bleach, with or without sodium hydroxide (Stone, 1987), and patience. Only a few elements are present below 2 m from the top, then abundance rises from ~50 Pa elements per kilogram at 1.6 m to >10,000 per kilogram in the top 1 cm. Samples taken 0.6 m below the top of the Woodford and lower yield a late Famennian fauna. The most diagnostic species are *Pseudopolygnathus marburgensis trigonicus* and *Palmatolepis gracilis gracilis*, but the fauna is dominated by apparatuses bearing carminate pectiniform elements, *Bispathodus stabilis*, *B. aculeatus aculeatus*, and species of *Branmehla* (Over and Barrick, this volume). Also present are *Pelekysgnathus guizhouensis?*, *Polygnathus "symmetricus,"* and a species of the unusual conodont *Fungulodus Gagiev* (Wang and Klapper, 1987). These species indicate an age for these beds that is no older than the Upper *expansa* Zone of Ziegler and Sandberg (1984a), but possibly as young as the Middle *praesulcata* Zone.

It is not possible to demonstrate the presence of the Lower through upper *praesulcata* zones at this section, because the diagnostic species *Siphonodella praesulcata*, and *Protognathodus kockeli* do not occur below the first occurrence of *S. sulcata*, which is used to characterize the base of the Mississippian.

Conodonts of the the basal Mississippian *sulcata* Zone appear abruptly in the section, 0.60 m below the top of the Woodford, at a more prominent phosphate layer. The fauna from the interval 0.60–0.25 m includes *Siphonodella sulcata*, *S. praesulcata*, *Protognathodus collinsoni*, *Pr. kockeli*, *Pr. meischneri*, and *Pseudopolygnathus dentilineatus/primus*. Elements of *Polygnathus communis communis* and *Ps. dentilineatus/primus* dominate the fauna. The appearance of *S. duplicata* M1 and M2 of Sandberg and others (1978) at 0.12 m places the topmost part of the Woodford in the Lower *duplicata* Zone. The fauna of the lower *duplicata* Zone is similar to that of the *sulcata* Zone, but it contains more abundant *Siphonodella* elements, and lacks *S. praesulcata*; *Protognathodus* elements are rare.

The greenish-brown pre-Welden shale of Cooper (1939) overlies the black shale of the Woodford with a sharp contact at Stop 6. At other localities a few kilometers to the north, the Woodford/pre-Welden contact



is more gradational, and a transitional interval of brownish shale occurs at the top of the Woodford. Cooper (1939) described the abundant conodont fauna of the pre-Welden shale from the Welden type section ~2.5 km to the northwest and proposed numerous new species and genera (see Lane and others, 1980, table 6, for a partial summary). The pre-Welden shale at Stop 6 yields a conodont fauna apparently identical with that of the type Welden section, but preservation is slightly better here. Abundance of elements is high, averaging ~8,000 Pa elements per kilogram of shale, most of which belong to species of *Siphonodella* and *Pseudopolygnathus*. Preliminary study of the pre-Welden faunas indicates that the shale contains an extremely condensed, but not strongly admixed conodont succession. Based on three successive 10-cm samples taken from the pre-Welden shale, the Lower *crenulata* and Upper *crenulata-isosticha* zones appear to be represented at this section. The older Upper *duplicata* and *sandbergi* zones can not be distinguished and may be missing at the base of the pre-Welden shale. Of particular interest is the presence of relatively common elements of *Protognathodus* and *Gnathodus* species in the top 10 cm, including *G. typicus* and *G. punctatus*, which were first described from the pre-Welden shale.

The Welden Limestone is a good example of the Lower Mississippian Starved Magnafacies of Lane and DeKeyser (1980), which formed in deeper-water areas basinward of prograding Osagean carbonate shelves. The Welden comprises a condensed sequence of 1.4 m of trilobite and ostracode wackestones that rest with sharp contact on the pre-Welden shale. Orth and others (1988) recognized two peaks in the concentration of Ir in the Welden. The Ir peak 0.10 m above the base is relatively weak, only three times background, and associated with a peak in the Ce/La ratio, which generally indicates oxidation. A stronger peak, 0.42 ppb (15 times limestone background), occurs 0.11 m below the top, and is associated with a high Ce/La ratio and enrichment of Co, As, Ni, and Pt.

Haywa-Branch and Barrick (this volume) recognize three faunal intervals in the Welden based on species abundance and composition. At the Hass G section, the basal interval of moderate conodont abundance (200 Pa elements/kg) extends from the base of the Welden to 0.30 m. The basal fauna is characterized by abundant

Figure 14 (left). Stratigraphic column of Late Devonian (late Famennian) through Early Mississippian (Meramecian?) units exposed at Stop 6. Mississippian conodont zones follow the numeric designations of Lane (1982) and correspond to the Kinderhookian *Siphonodella* zones of Sandberg and others (1978) and Osagean zones of Lane and others (1980): 1A—*sulcata* Zone; 1B—Lower *duplicata* Zone; 1E—Lower *crenulata* Zone; 2—*isosticha*—Upper *crenulata* Zone; 3—Lower *typicus* Zone; 4L—Upper *typicus* Zone; 4U/5—*anchoralis-latus* Zone; 6—*texanus* Zone.

Gnathodus punctatus, *Polygnathus communis communis*, and *P. c. carina*. Smaller numbers of other *Gnathodus* species—including *G. typicus* M1 and M2 of Lane and others (1980), *G. semiglaber*, *G. delicatus*, and *G. cuneiformis*, as well as a few *Siphonodella* elements—are present. This fauna can be assigned to the Osagean *typicus* Zone of Lane and others (1980) and to the partially equivalent *Polygnathus communis carina* Zone of Chauff (1981).

The second faunal interval (0.3–0.9 m) possesses low conodont abundance (50 Pa elements/kg), and a less diverse assemblage. *Polygnathus communis communis* and *Gnathodus* species (*G. semiglaber*, *G. typicus*, *G. delicatus*, and *G. cuneiformis*) are the most common forms. *Pseudopolygnathus multistriatus* first occurs in the second faunal interval; its appearance marks the base of the *Pseudopolygnathus multistriatus* Zone of Chauff (1981).

At 0.95 m above the base of the Welden, conodont abundance rises to over 500 Pa elements per kilogram, and diversity increases sharply, forming the third Welden faunal interval. In the lower beds of this interval, 0.95–1.15 m, *Gnathodus cuneiformis*, *G. semiglaber*, *G. typicus*, *Protognathodus praedelicatus*, *Polygnathus communis communis*, *Pseudopolygnathus multistriatus*, and *Bactrognathus* species are common. Rare *Ps. oxypageus* and *Pr. cordiformis* appear in the lower part, placing it in the Upper *typicus* Zone of Lane and others (1980). At 1.15 m, *Doliognathus latus* appears, and the upper part of the interval can be assigned to the *anchoralis-latus* Zone of Lane, and others (1980) and the *Doliognathus latus* Zone of Chauff (1981). The conodont association remains relatively unchanged from the lower part of the third interval, but *Pr. praedelicatus* and *Ps. multistriatus* are uncommon in the upper part.

The base of the overlying Caney Shale can be exposed with only a little excavation at Stop 6. The basal 0.25 m of glauconitic and sandy brown shale yields an

abundant fauna (1,000 Pa elements/kg) that includes an admixture of pre-Welden and Welden conodonts, in addition to younger species: *Bactrognathus distortus lanei*, *Scaliognathus anchoralis anchoralis*, *S. a. europensis*, and *G. subbilineatus*. This is the stratigraphic interval from which Branson and Mehl (1941a) described several Osagean conodont taxa at this locality: *Staurognathus cruciformis* (genotype), *Bactrognathus excavata*, *B. distorta*, *B. inornata*, *B. angularis*, and *Doliognathus dubia*. The overlying 0.30 m of brown silty shale contains equally abundant conodonts, but reworked elements are uncommon, and the fauna is dominated by *Gnathodus bilineatus* and *G. bulbosus*. The faunas of this lower Caney interval belong to the upper part of the *anchoralis-latus* Zone of Lane and others (1980), and may be equivalent to the *Bactrognathus distortus lanei* through *Gnathodus bulbosus* Zones of Chauff (1981) (middle to late Osagean).

In gray-green clay shale 0.60 m above the base of the Caney, *Gnathodus texanus* appears, marking the base of the late Osagean–early Meramecian? *texanus* Zone of Lane and others (1980). The *texanus* Zone beds are characterized by rapidly decreasing conodont abundance, falling from 500 Pa elements per kilogram at 0.60 m to 20 per kilogram at 0.80 m. The most common forms in addition to *G. texanus* are other species of *Gnathodus*, in particular the *G. bulbosus* morphotype. Conodonts are rare to absent in the brown silty shales that occur higher in the Caney at this section.

In the lower 0.50–0.70 m of the Caney Shale anomalously high concentrations of Ir (as much as 0.56 ppb) occur (Orth and others, 1988). Co, Ni, As, Pt, and Th display a similar enrichment. The concentration of Pt reaches 150 ppb, in the range of abundance observed in deep-sea manganese nodules. The dependence of metal concentrations on clay content suggests that the metals were carried in with detrital sediments that might have been eroded from ultramafic source rocks.

STOP 7 Upper Simpson Group (Eastern Arbuckle Facies), Highway 99 Section

SW¹/₄ sec. 12, T. 1 N., R. 6 E.
Pontotoc County, Oklahoma

Jeffrey A. Bauer

A section of the upper Simpson is exposed along the east and west side of Oklahoma Highway 99 ~5 km south of Fittstown, Oklahoma. Beds dip 10–25° N in the north flank of the Hunton anticline. Approximately 15 m of the upper McLish is exposed along with 60 m of the Bromide Formation. The Tulip Creek is not distinguishable at this location.

McLISH FORMATION

The lower sandstone of the McLish is not exposed at Stop 7, but can be traced in the subsurface throughout the Arbuckle Mountains region. The upper 15 m of McLish, which constitutes the outcrop along Highway 99 (Fig. 15), is a very distinctive birdseye calcilutite which has no similar counterpart in the McLish of the western Arbuckle Mountains. The lowermost 3 m is characterized by large, irregular, calcite-filled vugs. Small numbers of conodonts recovered from this interval include *Belodina monitorenensis*, *Drepanoistodus suberectus*, *Leptochirognathus quadratus*, *Plectodina joachimensis* (Andrews), and *Panderodus gracilis*.

The upper part of the McLish exposure is composed of thin to thick beds of calcilutite (some fossiliferous), nodular calcilutite, and a few thin beds of sandstone. A key bed ~5 m above the base of the section produced a diverse, well-preserved conodont fauna composed of *Plectodina* n. sp., *Phragmodus* n. sp. 2, *Erismodus typus*, *Bryantodina* n. sp., and species of *Walliserodus*, and *Pteracontiodus*.

BROMIDE FORMATION

The lower 5 m of the Mountain Lake member of the Bromide is covered. The lower 8 m of the exposed section is composed of cross-bedded sandstone and calcarenite (Fig. 16). The upper 32 m of the Mountain Lake is made up of alternating limestone and mudstone, but, unlike its counterpart in the western Arbuckles, this section shows a distinct imprint of current activity (e.g., cross-bedding and ripple marks), suggesting shallower-water conditions.

Conodonts are numerous in samples from the Mountain Lake and include many of the same species repre-



Figure 15. Upper McLish Formation exposed on west side of Oklahoma Highway 99 south of Fittstown, Oklahoma (Stop 7).

sented in the underlying McLish. Lower Mountain Lake collections also include *Staufferella* n. sp. and *Thrinacodus palaris*. *Phragmodus inflexus*, *Dapsilodus variabilis*, and a species of *Walliserodus* are represented in the middle and upper Mountain Lake.

Approximately 19 m of the Pooleville Member is exposed in a road cut through a low ridge just north of the McLish and Mountain Lake exposure (Fig. 17). The Pooleville is composed mostly of calcilitite beds which exhibit birdseyes, desiccation features, and cryptalgal laminations. Low-angle cross-bedding is developed in several calcarenite beds. The uppermost beds of the Pooleville (referred to as Corbin Ranch by Harris, 1957)

display a curious variegated coloration interpreted as oxidation marks by Longman (1976). The overlying Viola Springs Formation can be distinguished by abundant chert within the lower beds.

Samples from beds in the lower Pooleville Member contain *Appalachignathus delicatulus*, *Ansella nevadensis*, *Curtognathus* spp., *Phragmodus inflexus*, and *Plectodina aculeata* (Stauffer), among others. A sample from the lowermost bed of the Viola Springs produced *Amorphognathus tvaerensis* Bergström, *Icriodella superba* Rhodes, *Periodon grandis* (Ethington), *Plectodina aculeata*, and *Phragmodus undatus* Branson and Mehl.



Figure 16. Cross-bedded, fossiliferous sandstone and sandy biosparite of Bromide shoreface lithofacies, Highway 99 section (Stop 7). Lowermost bed (left) is ~5 m above the top of the McLish.

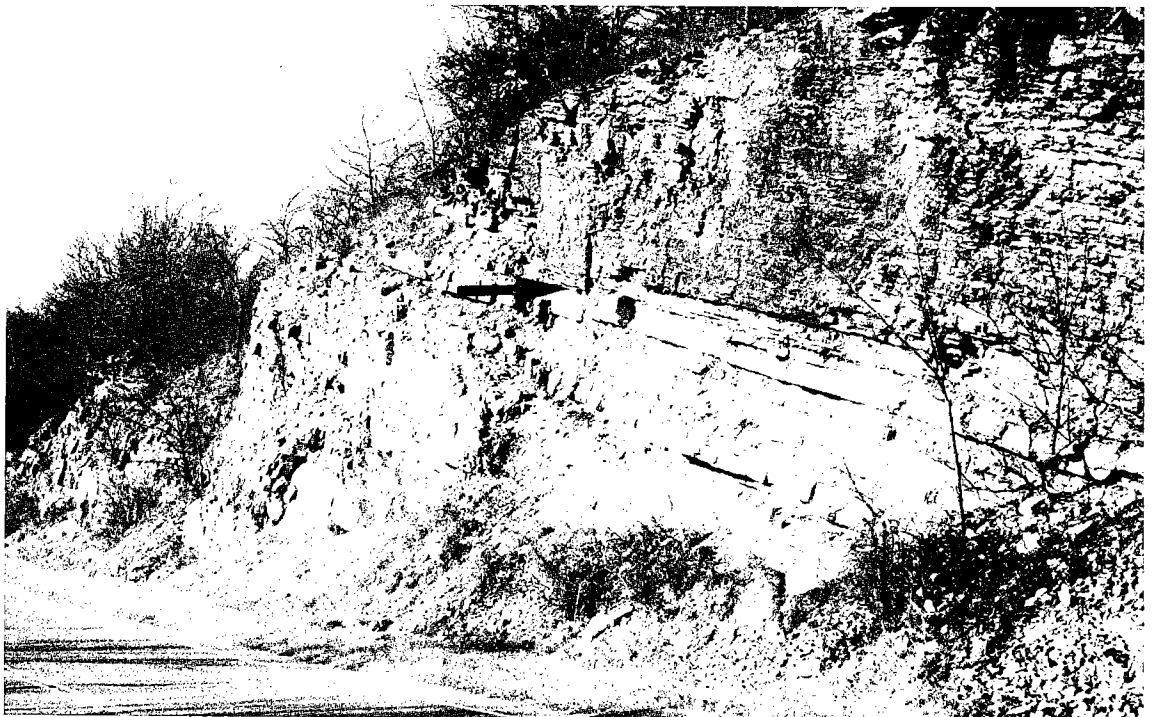


Figure 17. Upper Bromide Formation along the west side of Highway 99 (Stop 7). The contact with the overlying Viola Springs Formation is indicated by the arrow.

STOP 8 Canyon Creek: Mississippian/Pennsylvanian Boundary and Lower to Lower-Middle Pennsylvanian Conodont Succession

SE 1/4 sec. 8, T. 1 N., R. 7 E.
Pontotoc County, Oklahoma

Robert C. Grayson, Jr.

The Canyon Creek locality is the most continuously exposed section of a critical, predominantly mudrock succession available in southern Oklahoma. Canyon Creek has incised into a dipping sequence of stratigraphic units including the Rhoda Creek, "Union Valley," unnamed shale, Wapanucka, Atoka, and McAlester Formations. This succession contains four chronostratigraphic boundaries (Devonian/Mississippian, Mississippian/Pennsylvanian, Morrowan/Atokan, and Atokan/Desmoinesian). One of these, the Mississippian-Pennsylvanian boundary, will be examined in greatest detail. This boundary is located in the Rhoda Creek Formation at a change in lithology and geochemistry. Mississippian conodonts, below the boundary, are characteristic of the *Adetognathus unicornis* Zone. Pennsylvanian conodonts, above the boundary, do not represent any existing North American conodont zone. However, excluding differences resulting from taxonomic treatment, they are identical to forms recorded by Higgins (1975) from his *Idiognathoides noduliferus*-*Streptognathodus lateralis* Zone; in Europe this zone contains occurrences of the important mid-Carboniferous ammonoid cephalopod genus *Homoceras*. *Homoceras* has not yet been positively identified here, because the few specimens found so far do not reveal the nature of the sutures.

In addition to viewing and collecting from the Mississippian/Pennsylvanian boundary, field-trip participants may want to examine and collect from other parts of the succession for their taxonomic, biostratigraphic, and phylogenetic significance (Grayson, this volume). Markers have been placed to help locate some intervals of possible lithostratigraphic and conodont biostratigraphic interest. The following list provides information on intervals marked with wooden stakes:

- 1) Woodford/Caney formation boundary.
- 2) Caney/Rhoda Creek formation boundary.
- 3) Mississippian conodont assemblage containing

elements of *Gnathodus bilineatus*, *Lochriea commutata*, and *Kladognathus* sp.

4) Mississippian/Pennsylvanian boundary. Collections below the boundary yield an *Adetognathus unicornis* Zone conodont assemblage; those above produce the mid-Carboniferous index taxon *Declinognathodus noduliferus*.

5) Basal Pennsylvanian conodont assemblage containing elements of *Gnathodus* cf. *G. girtyi* and *G. higginsii*.

6) Base of "Union Valley" formation.

7) Lowest determinable occurrences of *Neognathodus symmetricus* and *Idiognathoides sinuatus*.

8) Lowest *Declinognathodus* sp. B.

9) Interval containing elements of *Neognathodus basleri* and *Declinognathodus* sp. C.

10) Oldest occurrence of *Idiognathodus sinuosus*.

11) Base of unnamed shale.

12) Base of Wapanucka Formation.

13) Interval containing elements of *Ellisonia latilaminata* and *Idiognathodus klapperi*.

14) Base of Atoka Formation.

15) Interval yielding specimens of *Declinognathodus marginodosus* and *Idiognathodus incurvus*.

16) Interval containing *Neognathodus atokaensis* and *N. "bothrops"*.

17) Interval producing elements of *Idiognathodus incurvus*, *Ellisonia conflexa*, and *Aethotaxis*.

At first glance one might assume that there is little in the way of exposure except for the intermittent outcrops along the banks of the creek. Upon closer inspection, one can observe that a relatively continuous section is exposed in the bed of the creek. In fact, examination of the Mississippian/Pennsylvanian boundary involves the rather unglamorous necessity of standing and collecting in knee-deep water. Although the prospect of creek-wading may not be appealing, the significance of the locality should make it worthwhile.

PART II

**Contributed
Papers**

Ordovician Conodonts in the Arbuckle Group, Southern Arbuckle Mountains, Oklahoma

Raymond L. Ethington and Russell I. Dresbach

ABSTRACT.—The Ordovician rocks of the Arbuckle Group are displayed essentially in entirety in roadside exposures along Interstate Highway 35 and on the adjacent Chapman Ranch. The sequence has been sampled in detail at an average stratigraphic spacing of 25 ft through this nearly 5,000 ft of section. Almost all of the samples have been productive of conodonts, and many of them have yielded large numbers of specimens. A succession of faunal associations has been recognized among these conodonts; they can be used to correlate with other sections in which the Arbuckle Group is represented, and for comparisons with other Lower Ordovician sequences in North America.

INTRODUCTION

J. A. Taff (1902) introduced the name Arbuckle to identify a sequence of carbonate strata in southern Oklahoma that occupies the interval between the Cambrian Reagan Sandstone and rocks that he assigned to the Simpson Formation. Although most of this sequence demonstrably is of Ordovician age, Taff reported that the Cambrian/Ordovician boundary fell within the Arbuckle succession as he defined it. Subsequently C. E. Decker (1933, 1939) elevated the Arbuckle rocks to group status, transferred the lowest 120 ft of the Arbuckle of Taff into an underlying Timbered Hills Group, and subdivided the remaining nearly 5,000 ft of Arbuckle rocks into nine formations. Miser and others (1954) did not recognize one of Decker's nine units within the Arbuckle Group, and stabilized the formational nomenclature at four units of presumed Cambrian age (Fort Sill, Royer, Signal Mountain, Butterly, in ascending order) and four Ordovician formations (McKenzie Hill, Cool Creek, Kindblade, West Spring Creek). Modern interpretations of Arbuckle stratigraphy were established by the late W. E. Ham of the Oklahoma Geological Survey, who (1950, 1955) studied these rocks in detail and mapped them using a combination of key beds and fossil occurrences to provide regional stratigraphic control.

The rocks of the Arbuckle Group consist primarily of carbonate strata, although sandstones and shales are minor components of some parts of the sequence. Sedimentary features such as oolites, desiccation cracks, and laminar and digitate stromatolites are distributed through the entire section and demonstrate that this succession of 5,000 ft of rock was deposited wholly in shallow water. Outcrops are distributed intermittently across the southern part of Oklahoma from the Arbuckle Mountains on the east to the Wichita Mountains on the west. These outcrops parallel the axis of the depositional basin in which the Arbuckle rocks were deposited. Following the interpretation of Hoffman

and others (1974), this basin has been reported as a failed continental rift, the southern Oklahoma aulacogen, that extended in a northwesterly direction from southeastern Oklahoma to the present location of the Rocky Mountains. Except for their great thickness, the rocks of the Arbuckle Group are very similar to the widespread Sauk carbonates that blanket much of the North American craton.

Arbuckle rocks have been penetrated by drilling for hydrocarbons both south and north of the outcrops. A thinned Arbuckle is the reservoir for petroleum production on the central Kansas uplift. Discovery of major natural-gas fields for which the Arbuckle rocks are the reservoirs (see, e.g., Shirley, 1988, 1989) has stimulated renewed interest in these units in the southern Mid-continent.

ARBUCKLE FOSSILS

The Ordovician rocks of the Arbuckle Group are rather sparingly fossiliferous. Ulrich (1911) reported fossils in the upper 2,300 ft of the sequence, which would correspond to the Kindblade and West Spring Creek Formations in modern terminology, but his study did not provide specific references to horizons at which many of the fossils were found. The fauna includes brachiopods, trilobites, cephalopods, ostracodes, graptolites, and especially gastropods, including *Ceratopea*, which he used to correlate the Arbuckle with sections in other parts of North America. Ulrich concluded that most of the Arbuckle probably belonged within his Canadian System.

Decker (1936) interpreted graptolites from high in the McKenzie Hill Formation as indicating Cambrian age, but Bridge (1936) demonstrated that the associated invertebrates dictated Early Ordovician assignment. Decker also noted the presence of *Didymograptus protobifidus* within an interval of ~30 ft beginning ~900 ft below the top of the West Spring Creek Formation.

Brachiopod collections reported by Ulrich and Cooper (1938) included *Diaphelasma* from the Cool Creek in the Wichita Mountains, *Tritroechia* and *Finkelburgia* from the Kindblade, and *Syntrophopsis*, *Pomatotrema*, and *Diparelasma* from the West Spring Creek. Ross (1966) described an ectoproct collected near the middle of the Kindblade Formation in the Wichita Mountains. The distribution of the species of *Ceratopea* reported from the Arbuckle Group was summarized by Yochelson (1973), who provided a detailed plot of their occurrences in the Kindblade and West Spring Creek Formations and compared their distributions with those of other invertebrate fossils. These gastropod opercula have been shown to occur in several discrete intervals within the upper Arbuckle, and therefore are widely used for stratigraphic interpretations across the outcrop belt.

Recent detailed biostratigraphic and taxonomic investigations of trilobites from the Arbuckle have been conducted by Stitt (1971, 1977, 1983), who concluded that the Cambrian/Ordovician boundary—however it eventually is defined in the course of current deliberations—will likely fall within the Signal Mountain Limestone, below where it has been placed by earlier workers. Trilobites are relatively uncommon above the McKenzie Hill Formation, as compared to their abundance in the Cambrian part of the Arbuckle Group. Kindblade trilobites currently are being investigated at the University of Missouri–Columbia by James Loch.

Toomey and Nitecki (1979) monographed the occurrence of algal–sponge associations that were responsible for trapping sediment and the construction of mounds in Lower Ordovician rocks of Oklahoma and Texas. Such an association is represented within the lower 100 ft of the Kindblade by abundant occurrences of the lithistid sponge *Archaeoscyphia annulata* Cullison and the alga *Calathium*, together with occasional specimens of the enigmatic fossil *Pulchrilamina spinosa* Toomey and Ham. A second but thinner interval with this same fossil association occurs ~450 ft above the base of the Kindblade.

Conodonts from the Arbuckle Group

Conodonts have been known from rocks in southern Oklahoma since the first proliferation of North American conodont studies in the 1930s, but these early efforts did not include Lower Ordovician faunas. The pioneering work on these fossils was based on collections made from clays and shales, so that the carbonate sequence of the Arbuckle Group did not attract the early workers. The first report of conodonts from Arbuckle rocks was made by K. J. Müller (1959), who described *Cordylodus proavus* from the upper part of the Signal Mountain Limestone in outcrops on the Chapman Ranch east of Highway 77 in the southern Arbuckle Mountains. His type collection was obtained from a single sample provided to him by A. R. Palmer; no other species were reported.

Harris and Harris (1965) named seven form-species of conodonts for specimens they recovered from outcrops of the West Spring Creek Formation along High-

way 77 in Carter County, Oklahoma. Five of these species now are known to be introduced in the Arbuckle Group in Whiterockian (Middle Ordovician) strata ~80 ft below the top of the West Spring Creek; these species range upward into the lower part of the overlying Simpson Group. The other two of their species are representative of a diverse population of conodonts distributed through all but the uppermost part of the West Spring Creek; the bulk of this fauna was not mentioned in their report.

The first attempt at a systematic study of Arbuckle conodonts was offered by Mound (1968), who described conodonts from the uppermost McKenzie Hill and Cool Creek Formations in samples collected along the east side of Highway 77 in the southern limb of the Arbuckle anticline. Mound's report is marred by inconsistency in the taxonomic treatment of the elements that he found and by illustrations that were done at such small magnifications that the nature of the coniform elements he studied cannot be discerned. Ethington and Clark (1971) illustrated, but did not describe, conodonts from the Cool Creek and Kindblade Formations in their synthesis of Lower Ordovician conodonts of North America as they were understood at that time. Faunal lists of conodonts from samples taken in and near the organic mounds in the Kindblade Formation were provided by Ethington (in Toomey and Nitecki, 1979), but this report did not give comprehensive coverage of the distribution of these fossils through the formation. Miller and others (1982) recorded the ranges of conodonts in a sequence of closely spaced samples through the Signal Mountain Formation in the Wichita Mountains in a discussion of potential stratotype sections for the Cambrian/Ordovician boundary. A detailed examination of conodont occurrences across the McKenzie Hill/Cool Creek boundary was presented by Ethington and others (1987). Unpublished accounts of conodonts in the Kindblade and West Spring Creek Formations in the Arbuckle Mountains are found in a series of theses at the University of Missouri–Columbia (Potter, 1975; Brand, 1976; Felton, 1979; Mills, 1980). Data from these theses and from the previous studies were used by Ethington and Repetski (1984) in their summary of the distribution of species of Lower Ordovician conodonts in the central and western United States.

These several sources include almost all of the conodonts known to occur in the Ordovician part of the Arbuckle Group and provide general biostratigraphic limits for the individual formations. They do not, however, present documentation of the ranges of all of the taxa within these units, and they do not collectively constitute a biostratigraphic analysis of the Arbuckle. These reports demonstrate that conodonts are present through the Lower Ordovician of southern Oklahoma and that their preservation generally is very good. The Arbuckle Group offers virtually continuous exposure through a stratigraphic interval that elsewhere on the North American craton is displayed only in geographically isolated and stratigraphically limited outcrops, despite wide geographic distribution. Conodonts like those in the Arbuckle are widely distributed in these

rocks, so that documentation of their ranges in the Arbuckle offers a standard for comparison and correlation that will be useful in stratigraphic studies of Lower Ordovician strata across all of the central United States. To this end we have systematically sampled the Ordovician part of the Arbuckle in road-cut exposures along Interstate Highway 35 north and west of Ardmore, Oklahoma, and on the Chapman Ranch to the west of the Interstate. A detailed, bed-by-bed description of the outcrops along the highway is given by Fay (1969, 1989). The section on the Chapman Ranch is described by Stitt (1983); permission to visit this locality must be secured from the owners of the ranch. Details of the distributions of the conodonts will be published elsewhere; following is a summary of the results.

Signal Mountain, Butterly, and McKenzie Hill Formations

The Signal Mountain, Butterly, and McKenzie Hill Formations do not crop out along the interstate highway, and the Cool Creek is incomplete at both top and bottom in the road-cut exposures. The entire sequence is available on the Chapman Ranch, and key beds at the Cool Creek/Kindblade boundary can be traced across a mile of rolling countryside to connect with the highway section.

The Signal Mountain Formation was reported by Ham (1950) to be 365 ft thick where we sampled it. Our collections came from the upper 150 ft of the formation. *Eoconodontus notchpeakensis* (Miller) is present in the lowest sample in our section. Faunas through the remainder of the Signal Mountain are dominated by *Cordylodus proavus*, in association with *Teridontus nakamurai* (Nogami) and *Hirsutodontus hirsutus* Miller. Less abundant and only locally represented in the upper Signal Mountain is *Lapetognathus preaengensis* Landing.

The base of the Butterly Formation was selected arbitrarily within a transitional interval between the thin- to medium-bedded, gray limestone ledges of the Signal Mountain and a succession of gray-brown, sugary dolostones. The dolostones of the Butterly are poorly exposed in a brushy area along our line of section, so that only occasional, irregularly spaced outcrops could be sampled. Our measured thickness of 329 ft of Butterly is ~30 ft greater than that reported by Ham (1950) for the same general locality. The difference may reflect different arbitrary placements of the base of the formation in the two studies.

The conodonts recovered from these samples are the first fossils reported from this unit, other than a few poorly preserved brachiopods found by Ham (1950). Elements of *Cordylodus* that are intermediate between those of *C. proavus* and those of *C. intermedius* Furnish are present in the lowest sample from the Butterly, but this genus is represented by only occasional elements in samples from higher in the formation. *Clavohamulus elongatus* Miller is the dominant component of the fauna in the middle of the formation, where its only common associate is *Teridontus nakamurai*. Samples taken in the top 50 ft of the Butterly have *Utahconus utahensis* (Miller)

and *Monocostodus sevierensis* (Miller) in a low-diversity fauna.

Because the outcrops are so sporadic, we are unable to provide more refined biostratigraphy for the Butterly. Comparison of the faunas with those reported by Miller from the stratigraphically equivalent upper Signal Mountain Formation in the Wichita Mountains indicates that the Butterly begins low in the *Cordylodus proavus* Zone, and its upper part is near the top of that zone.

The McKenzie Hill Formation was divided into two members by Stitt (1983), a lower lime-mudstone member that constitutes the lower 40% of the formation and an upper lime-grainstone unit. Chert is common to abundant in the upper two-thirds of the McKenzie Hill, but absent from the lower part. We measured 920 ft of McKenzie Hill, which is essentially identical to the thickness obtained in the same vicinity by Ham (1950), but slightly more than was recorded at this locality by Stitt (1983). Our collection consists of 35 samples, all of which produced conodonts. Recovery ranged from three elements from a kilogram of rock to as high as slightly more than 200 elements; average yield is 40–50 specimens. Preservation generally is rather good, with many nearly complete elements in each sample. Surfaces generally are somewhat frosted, probably reflecting diagenetic changes that have affected the rock; CAI is 1.5.

The lowest sample from the McKenzie Hill, collected just above the top of the Butterly Formation, contains a few specimens of *Cordylodus intermedius* Furnish. A sample taken at 100 ft in the formation contains *Cordylodus angulatus* Pander, *Variabiloconus bassleri* (Furnish), and "*Acontiodus*" *staufferi* Furnish. *Loxodus bransonii* Furnish and "*Acodus*" *oneotensis* Furnish are present at 125 ft, and *Clavohamulus densus* Furnish has its lowest occurrence at 150 ft. *Rossodus manitouensis* Repetski and Ethington and "*Acodus*" *triangularis* (Furnish) appear at 175 ft. *Acanthodus lineatus* (Furnish) and "*Scolopodus*" *sexplicatus* Druce and Jones are introduced at 350 ft, and *Chosonodina herfurthi* Müller at 675 ft.

All of these species except *C. intermedius* are major components of what Ethington and Clark (1971) termed Fauna C, the third-oldest of the conodont assemblages that they recognized in the Lower Ordovician of North America. Landing and others (1986) defined a *Rossodus manitouensis* Zone, whose base coincides with the lowest occurrence of the nominate species, and whose faunas includes the species listed above. Thus, at least the upper 750 ft of the McKenzie Hill is in the *R. manitouensis* Zone, and up to 175 ft at the bottom of the formation corresponds to the range of Fauna B of Ethington and Clark (1971; their Fauna A = *Cordylodus proavus* Zone of later authors). This faunal interval has been subdivided by Miller (1988) at the base of the range of a younger species of *Cordylodus*, *C. lindstromi* Druce and Jones. The lowest occurrence of the latter species defines one of the horizons under active consideration for stabilization of the base of the Ordovician System. *Cordylodus* is represented very sparingly in the lower McKenzie Hill, and we did not identify any elements of *C. lindstromi* among the few specimens avail-

able to us from this interval.

The boundary between the McKenzie Hill and Cool Creek Formations is a subtle one in the Arbuckle Mountains, marked by an influx of sand into the depositional basin at the beginning of deposition of the younger formation. Ham (1950) found this a useful criterion in his regional mapping, but the occurrence of abundant sand is not persistent even over short distances. We followed Stitt, who used a stromatolitic layer with abundant sand to identify the base of the Cool Creek. Although this is not a prominent lithologic boundary, it does coincide with a significant change in the conodonts. As noted by Ethington and others (1987), the conodonts of the *R. manitouensis* Zone persist to the top of the McKenzie Hill and are replaced essentially instantaneously by an impoverished fauna dominated by species of *Oneotodus* Lindström in the lowest Cool Creek. This abrupt replacement in the conodont succession of the Midcontinent Province occurs across the North American craton. In the exposures of the Arbuckle Group in the Wichita Mountains, this event is recorded in the basal part of the Cool Creek Formation, rather than at the formational boundary as it is here.

Cool Creek Formation

At the time Fay (1969) described the sequence along Interstate 35, then under construction, a complete succession of Cool Creek was available for examination. Subsequently, grading and vegetation have covered much of the formation, so that only less than half can now be examined along the west side of the highway. Our measured section on the Chapman Ranch is continuous with that in which the lower formations of the Arbuckle Group were sampled. We measured the Cool Creek at 1,307.5 ft, which is comparable to the 1,300 ft reported by Fay along the highway.

The Cool Creek consists of thin- to medium-bedded limestones. In the exposures along the interstate, Fay (1969) recognized 23 stratigraphic intervals containing noteworthy amounts of sand, and 14 oolitic intervals. Stromatolites are commonplace in the Cool Creek, including planar-laminated varieties, digitate forms, and massive, hemispherical types (see Fig. 6 of the Stop Descriptions, Part I). Much of the sequence is cherty; the cherts display a variety of colors, orange, gray, and black being most common. The cherts typically are isolated masses within the limestone layers; irregular outlines suggest replacement origin, perhaps along early fractures. In some instances chert masses are elongate and simulate interbedding with the enclosing limestone.

We collected 52 samples in our measured section of the Cool Creek on the Chapman Ranch; seven of these were barren, but the others produced conodonts in abundances ranging from a few elements to several hundred per kilogram. Diversity of conodonts within the samples commonly is rather low, particularly in those from the lower third of the formation. Preservation generally is very good. CAI values are comparable to those of conodonts in the McKenzie Hill, but the surface etching that is common in those older faunas

usually is not seen on the specimens from the Cool Creek.

The conodonts in the samples from the basal 450 ft of the Cool Creek are dominated by *Oneotodus simplex* (Furnish). Much of the rest of the fauna in this part of the formation consists of albid coniform specimens that either are previously unrecognized elements of *O. simplex* or are components of the apparatus of a new species of that genus. Also present in this part of the section are hyaline coniform elements that probably represent a species of *Drepanoistodus* Lindström. Although these simple, albid coniform species continue through the remainder of the formation, their dominance decreases upward as hyaline forms are introduced.

*Macerodus diana*e Fähræus and Nowlan is common in the interval 475–1,025 ft; it is associated with rare *Histiodella donna*e Repetski in the middle of this interval. This zone within the Cool Creek may be of significance for placement of the Arbuckle sequence in the Ordovician System, for *M. diana*e occurs in western Newfoundland in association with *Tetragraptus approximatus*, a graptolite that frequently is cited as evidence for the recognition of the base of the Arenigian Series of the British Ordovician succession (Fähræus and Nowlan, 1978). *Scolopodus floweri* Repetski is common at 1,025 ft, but was not found in any of the other samples from the Cool Creek. Typical components of what Ethington and Clark (1971) identified as Fauna D appear in the section at ~1,100 ft and continue to the top of the formation and into the overlying Kindblade. These include *Drepanodus curvatus* (Branson and Mehl), *Glyptoconus quadruplicatus* (Branson and Mehl), *Eucharodus parallelus* (Branson and Mehl), and form-species of *Ulrichodina* Furnish.

Kindblade Formation

All but the lower 90 ft of the Kindblade is exposed in the road cuts along either side of the eastern trafficway of Interstate 35. The missing basal beds are available just east of the highway on the Chapman Ranch (permission must be obtained from the owner of the ranch before examining this part of the section). The basal beds can be fit into the road-cut exposures with confidence by tracing any of several prominent ledges that outcrop essentially continuously in the intervening region.

The Kindblade consists of rhythmic alternations of very thin-bedded, argillaceous limestones and massive to thick-bedded limestones (see Fig. 7 of the Stop Descriptions, Part I). Oolitic intervals are common in the upper two-thirds of the formation, and sandy beds (either arenaceous limestones or thin sandstones) are present near the top. Laminated, stromatolitic intervals are common, but the digitate and hemispherical forms common in the underlying Cool Creek are infrequent. The lower mound interval of Toomey and Nitecki (1979) is represented by *Archaeoscyphia* in beds exposed just south of the anticline-syncline at the north end of the outcrop along the highway (see Fig. 8 of the Stop Descriptions, Part I). The higher mound horizon is indicated by a similar occurrence ~100 ft stratigraphically

below the termination of the Kindblade outcrop, just north of the entrance to the parking area on the east side of the right-of-way.

The detailed, bed-by-bed descriptions of Fay (1969, 1989) can be used as a guide to the succession of lithologies in the road cuts, although some of his divisions, which seem to have been defined from surface exposures, are difficult to differentiate in the somewhat monotonous fresh limestones of the cuts. We measured 1,405 ft of Kindblade along the interstate, which almost duplicates Fay's observation of the same sequence; addition of the 90 ft at the bottom results in nearly 1,500 ft of Kindblade in this section. We collected 60 samples from this section; all but one were productive of conodonts, with abundances ranging from a few specimens to over a thousand elements per kilogram. Average yield was slightly more than 100 elements per sample.

Hyaline species such as *E. parallelus*, *G. quadruplicatus*, and *Ulrichodina* spp. continue upward into the Kindblade and persist through the entire formation. They constitute virtually all of the specimens recovered from some samples, particularly low in the Kindblade. A species of *Drepanoistodus* that is close to, if not conspecific with, *D. inconstans* (Lindström) *sensu* van Wamel (1974) is present and frequently abundant throughout the Kindblade. *Oneotodus costatus* Ethington and Brand is present above 100 ft, and *Drepanodus arcuatus* Pander is present above 335 ft. *Cristodus loxoides* Repetski has its lowest occurrence at 385 ft and occurs sporadically through the rest of the Kindblade; only a few specimens were found in any of the samples that contained it. A lineage of prioniodont species—some of which are morphologically close to those traditionally assigned to *Acodus deltatus* Lindström, but others of which are more generalized in form—is present between 410 and 1,125 ft. Within this interval, these several forms appear and disappear in sequence several times. This lineage probably gave rise to *Diaphorodus delicatus* (Branson and Mehl), which has its lowest occurrence at 1,150 ft in the Kindblade and becomes a dominant part of the fauna in the overlying West Spring Creek. *Scolopodus rex* Lindström ranges from 435 to 735 ft. A species of *Paroistodus* resembling *P. proteus* (Lindström) occurs in the interval 650–1,000 ft above the base of the Kindblade. *Protoprioniodus russoi* (Serpagli) was found in a relatively thin interval between 700 and 885 ft, and *Protoprioniodus papillosus* (van Wamel) occurs as low as 1,455 ft.

West Spring Creek Formation

The West Spring Creek Formation is the most lithologically variable of the formations within the Arbuckle Group. Following Fay (1969, 1989), we took as the base of the formation a sandstone layer that weathers to a recess in the road cut (see Fig. 9 of the Stop Descriptions, Part I). Fay's section description can be followed in detail through the entire formation, and our collections are recorded in terms of the beds that he recognized. He reported 1,528 ft of strata along the right-of-way of I-35. The West Spring Creek consists primarily of medium- to thick-bedded, dolomitic limestones, many of the ledges displaying laminations of planar

stromatolites. The upper 1,200 ft contains numerous beds of sandstone and siltstone; red beds are common throughout this part of the section. The frequent occurrence of oolitic intervals, coupled with the high content of detrital materials and abundance of planar stromatolites, led Potter (1975) to interpret the environment of deposition of the upper West Spring Creek as peritidal. The uppermost 45 ft of the West Spring Creek cannot be examined along the highway. This interval, together with the lower part of the overlying Simpson Group, occupies a grassy swale in the countryside.

Most of the conodonts recovered from the West Spring Creek Formation also occur in the Kindblade. Both *Diaphorodus delicatus* and *Oepikodus communis* become more common upward in the West Spring Creek, and one or the other is the dominant faunal component in most of the samples we have studied; although not mutually exclusive in their occurrences, typically one is much more abundant than the other in those samples in which both occur. "*Microzarkodina*" *marathonensis* (Bradshaw) occurs sporadically above 285 ft. *Tropodus comptus* (Branson and Mehl) is introduced in the section at 319 ft, and "*Scolopodus*" *parabruptus* Repetski is found beginning at 340 ft; both are moderately common throughout the remainder of the unit. "*Scolopodus*" *carlae* Repetski is common in several samples in an interval beginning at 420 ft. *Parapanderodus asymmetricus* (Barnes and Poplawski) is present but not common above 647 ft. *Oistodus bransoni* Ethington and Clark, *Scolopodus rex*, and *Protoprioniodus papillosus* occur sporadically in the upper half of the formation. Specimens resembling *Jumudontus gananda* Cooper, but with considerable albid matter in their denticles, are introduced at 1,323 ft. A species of *Prioniodus* similar to *P. elegans* is found in a thin interval above 1,428 ft. Hyaline elements that are among the major components of the conodont faunas of the Joins Formation (basal Simpson Group) are introduced 80 ft below the top of the West Spring Creek, together with species typical of the lower part of the formation. Their presence reinforces the conclusion of Derby (1969) that the base of the lower Middle Ordovician Whiterockian Stage falls within the upper part of the formation. Shoaling of the sea in the basin must have occurred, for many samples from the uppermost part of the West Spring Creek contain conodonts that have been abraded severely enough to remove costae and other surface features, and in some situations they have been reduced to rounded and polished fragments that are not identifiable. McHargue (1981) made a detailed study of the rocks and conodonts of this interval and concluded that they demonstrate a regressive-transgressive couplet interrupted by an unconformity.

ACKNOWLEDGEMENTS

We are indebted to the owners of the Chapman Ranch for permission to collect on their property. This study was made possible by a grant from the National Science Foundation (EAR-8610418), for which our appreciation is hereby expressed.

Stratigraphy and Conodont Biostratigraphy of the Upper Simpson Group, Arbuckle Mountains, Oklahoma

Jeffrey A. Bauer

ABSTRACT.—The upper Simpson Group (McLish, Tulip Creek, and Bromide Formations) of the Arbuckle Mountains was generated by three transgressive–regressive cycles of a shallow Middle Ordovician sea. Each upper Simpson formation is composed of a shoreface sandstone facies succeeded upward by interbedded limestone and mudstone, which were produced in deeper-water, carbonate-ramp and shelf environments. The Tulip Creek T–R cycle is distinguishable only in western Arbuckle facies. In the eastern Arbuckles, upper McLish tidal-flat deposits are overlain by transgressive Bromide facies.

The upper Simpson conodont faunas are dominated by species of *Phragmodus* and *Plectodina*. In the western Arbuckle section along Interstate 35, species of *Eoplacognathus*, *Cahabagnathus*, and *Prioniodus* are sparsely represented, but are instrumental in correlating the McLish, Tulip Creek, and lower Bromide with the upper Whiterockian Series (Chazyan Stage). The Whiterockian/Mohawkian boundary is projected at a level high in the Mountain Lake Member of the Bromide.

In the eastern Arbuckle section along Highway 99, the McLish fauna includes *Plectodina* n. sp., *Bryantodina* n. sp., *Appalachignathus delicatulus*, and *Erismodus typus*, which indicate that the formation is younger in the east than in the west. *Cahabagnathus sweeti* is represented in the Mountain Lake Member and indicates that the lower Bromide is equivalent to the uppermost Whiterockian Series.

INTRODUCTION

The Arbuckle Mountains region of south-central Oklahoma offers some of the finest exposures of White-rockian and Mohawkian (Middle Ordovician) strata in the North American Midcontinent. The following report focuses on the stratigraphy and conodont biostratigraphy of a part of that interval comprising the upper Simpson Group.

The Simpson Group, comprising in ascending order the Joins, Oil Creek, McLish, Tulip Creek, and Bromide Formations, is unique in comparison to typical Midcontinent deposits because it is exceptionally thick and generally uninterrupted by major unconformity. Simpson formations consistently yield copious collections of well-preserved conodonts from nearly all levels of a wide array of different lithofacies. Consequently, the Simpson contains an extraordinary record of Middle Ordovician conodont development and represents a key to correlation of Midcontinent rocks.

STRATIGRAPHY

Previous Studies

The “Simpson formation” was first named and mapped by Joseph A. Taff (1902). Taff (p. 3) estimated 1,500 ft of “sandstones and fossiliferous limestone with interbedded greenish clay shales and marls” lying between the Arbuckle and Viola limestone. Further description of the Simpson was given by Taff (1903, 1904),

who included several faunal lists furnished by E. O. Ulrich.

Ulrich (1929) divided the Simpson into seven formations: in ascending order, the Joins, Oil Creek, McLish, Falls, Tulip Creek, Criner, and Bromide. Charles E. Decker (in Decker and Merritt, 1931) officially elevated the Simpson to group status and established the presently accepted five-fold division by eliminating Ulrich’s (1929) Falls and Criner Formations. Decker’s classic work contains measured sections at localities across the Arbuckle Mountains and remains the most useful guide to Simpson stratigraphy.

Cooper (1956) subdivided the Bromide Formation into Mountain Lake and Pooleville Members. The Mountain Lake is the siliciclastic-rich lower Bromide; the Pooleville is the “upper limy beds” (Cooper, 1956, p. 121).

Harris (1957) established the Corbin Ranch Formation for the uppermost part of the Bromide, which is composed of dense, lithographic limestone. Authors of recent reports consider the Corbin Ranch to be a member of the Bromide (Grahn and Miller, 1986), or have chosen to reincorporate the unit into the Pooleville Member (Longman, 1981, p. 3; Fay and Graffam, p. 16, in Sprinkle, 1982).

Upper Simpson Group

The McLish Formation is named for the McLish ranch near Bromide, Oklahoma, in the eastern Arbuckles. In the vicinity of its type locality, the lower beds of

the McLish are loosely indurated sandstone, which Decker (in Decker and Merritt, 1931) reported to be unconformable with the underlying Oil Creek. Sandstone is succeeded upward by birdseye limestone and thin interbeds of mudstone. In the western Arbuckle Mountains, the McLish consists of well-indurated sandstone succeeded upward by limestone and mudstone. Birdseye limestone is absent in the western Arbuckles.

Ulrich (1929) assigned the western McLish facies to the Falls Formation and maintained (Ulrich, 1933) that it was older than the McLish in the eastern Arbuckles. However, Decker (in Decker and Merritt, 1931) combined the Falls and the McLish, based on "interlocking faunas" (p. 28). Obviously, both Decker and Ulrich were using biostratigraphic rather than lithostratigraphic principles to support their contentions and, consequently, a reevaluation of stratigraphic nomenclature may be warranted. For simplicity, this report utilizes Decker's concept of the McLish. The thickness of the McLish ranges from >160 m along Sycamore Creek to a little more than 100 m along West Spring Creek (Decker and Merritt, 1931).

The Tulip Creek Formation is locally developed in the western Arbuckles and consists of a basal sandstone succeeded by mudstone with several thin beds of limestone. Decker (Decker and Merritt, 1931) reported a maximum thickness of 120 m at the type locality along Tulip Creek.

The Bromide is more lithologically consistent across the Arbuckle Mountains than either the McLish or Tulip Creek. The Mountain Lake and Pooleville Members are distinguishable in sections throughout the outcrop area. The Bromide varies in thickness from >130 m in the western Arbuckles to a little more than 50 m in the eastern Arbuckles.

DEPOSITIONAL MODELS AND REGIONAL FACIES PATTERNS

Depositional Models

The upper Simpson is made up of interbedded carbonate and siliciclastic rocks. Modern examples of shallow-water, marine environments characterized by adjacent and interfingering carbonate and siliciclastic facies are very uncommon (Ginsburg and James, 1974; Mount, 1984). Consequently, most Holocene sedimentation models are not directly applicable to interpretation of the Simpson. Instead, a combination of models that explain peritidal siliciclastic (summarized by Reineck and Singh, 1980) and carbonate-platform (summarized by Read, 1985) sedimentation is used in the following lithofacies interpretations.

Reineck and Singh (1980) defined major peritidal to deeper subtidal zones of sediment accumulation, which include the backshore, foreshore, shoreface, transitional zone, and shelf. The latter three zones are characterized by (1) cleanly washed sands; (2) storm-generated sand and silt, shell lags, and mud with high faunal diversity; and (3) pervasive mud with subordinate shell layers and storm-generated sand and silt layers, respectively.

Longman (1976, 1981, in Sprinkle, 1982) combined peritidal siliciclastic and carbonate-platform models to explain deposition of the Bromide Formation. The Mountain Lake Member was interpreted as a transgressive deposit reflecting an increased rate of subsidence with respect to sediment accumulation.

Pooleville lithofacies represent a shallowing-upward sequence of lagoonal to supratidal carbonate mud. Longman (1981, p. 2) suggested that a eustatic rise in sea level drowned the siliciclastic source and resulted in the pure carbonate sediments of the Pooleville. Maximum water depth was estimated at 32 m (Longman, in Sprinkle, 1982).

Depositional interpretations of lithofacies in the western Arbuckle (Stop 5 of this guidebook) and eastern Arbuckle (Highway 99, Stop 7) facies are presented in the following paragraphs. Each section is divided into units based on similarity of rock type, sedimentary structure, and/or fossil assemblage.

Western Arbuckle Facies

The composite section located near Interstate Highway 35, western Arbuckles, is divided into 18 units. Units 1A through 9A represent the McLish and Tulip Creek Formations (Text-fig. 1). Units 1B through 9B represent the Bromide Formation (Text-fig. 2).

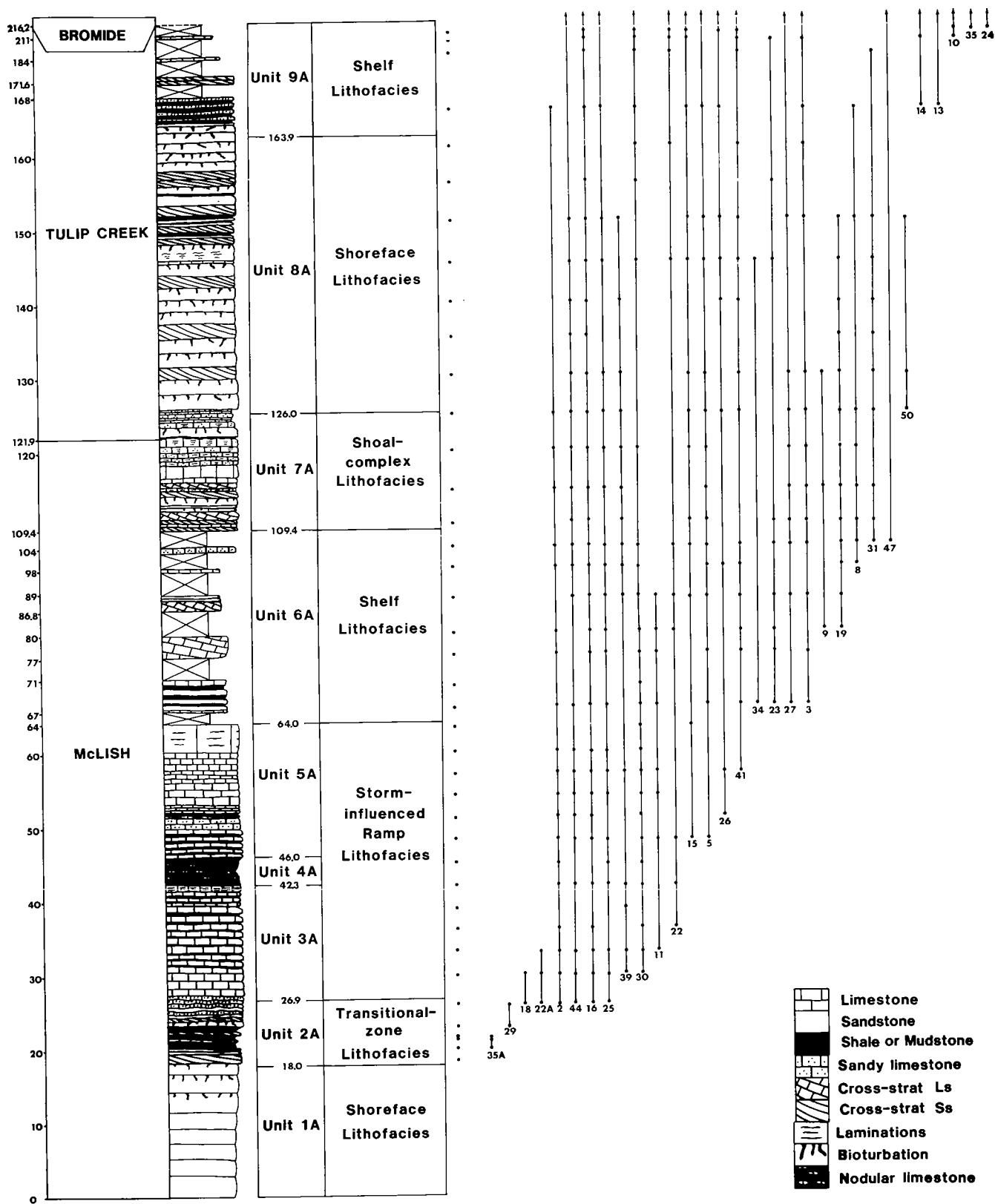
The lower McLish records a relative rise in sea level and includes transgressive shoreface, transitional-zone, and carbonate-ramp deposits. The McLish Shoreface Lithofacies (Unit 1A) is composed of fossil-poor quartz arenite which records shallow-water deposition above average maximum wave base.

The Transitional-Zone Lithofacies (Unit 2A) records deeper-water conditions influenced by both nearshore and distal marine sediment sources, resulting in intercalated, coarse siliciclastic and carbonate sediments, respectively. Continued sea-level rise or subsidence terminated quartz-sand deposition and produced a carbonate-ramp environment (Units 3A–5A). Storm-generated waves deeply reworked many proximal ramp deposits, whereas distal, deeper-water ramp deposits preserve in situ skeletal accumulations which were buried by muds deposited by storm-driven currents ("zone of deposition" of Brett, 1983). Deepest-water deposits (Unit 4A) show indications of reduced carbonate productivity and probably represent distal extremities of storm-generated deposition.

The upper Storm-Influenced Ramp Lithofacies (Unit 5A) represents a regressive phase of deposition during which deeper-water ramp deposits are overlain by winnowed, shallow-water carbonate sediments and are capped by prograding quartz sand and mud of the Shelf Lithofacies (Unit 6A).

The Shoal-Complex Lithofacies (Unit 7A) includes beds of probable tidal-flat origin and indicates continued regression.

The Tulip Creek Shoreface Lithofacies (Unit 8A) records renewed transgression. The shoreface buildup may represent a barrier-bar or island complex, as suggested by the sedimentary structures and geometry of the sand body. Thickness is consistent along deposi-

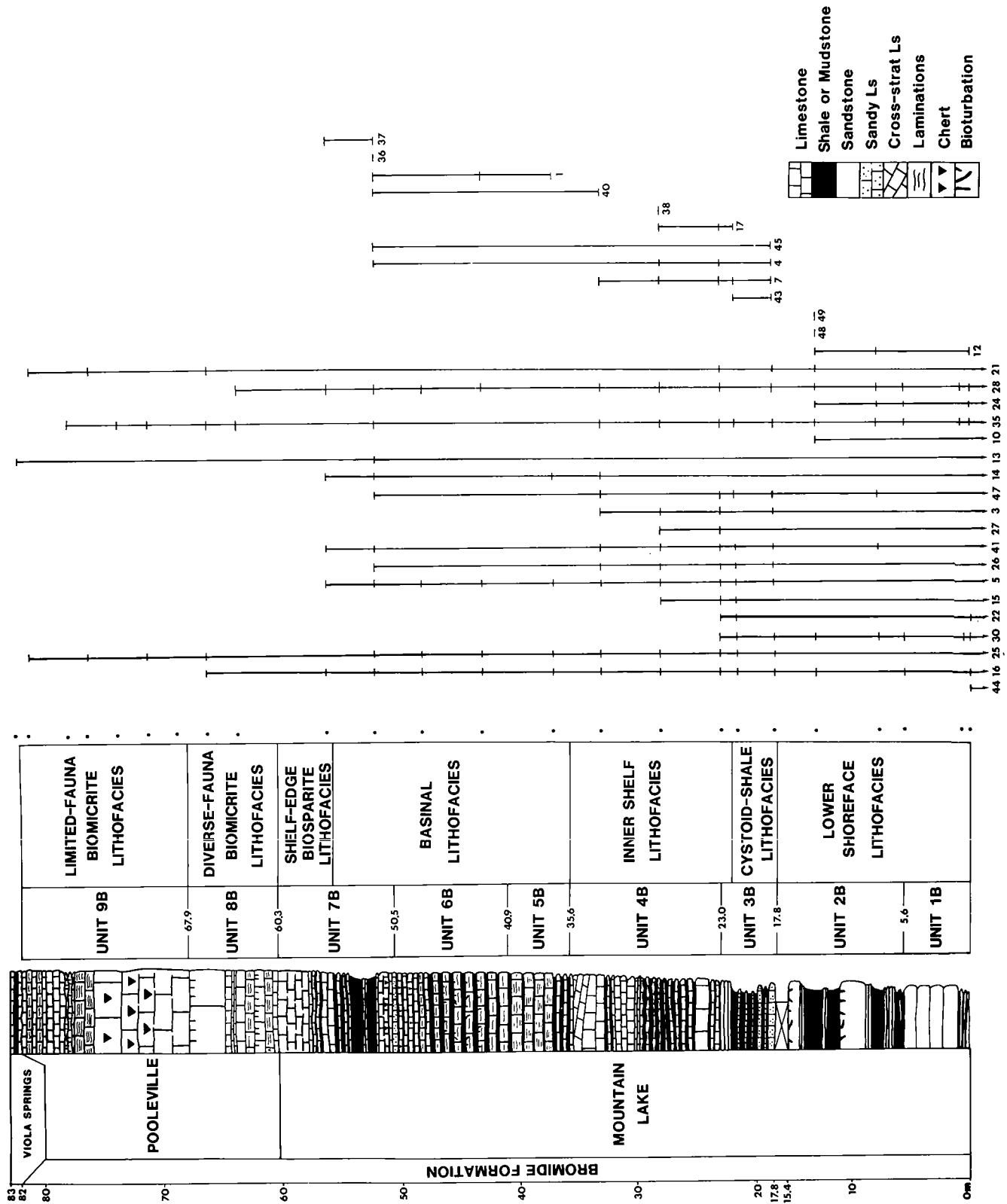


Text-figure 1. Stratigraphic section and conodont ranges, McLish and Tulip Creek Formations, I-35 section. Distribution of units and lithofacies is shown to the right of the stratigraphic column. Dots to the right of the lithofacies column represent sample levels. Species numbers correspond to those assigned in Table 1.

TABLE 1.—RANGES (IN METERS) OF CONODONT SPECIES REPRESENTED
IN THE I-35 AND HIGHWAY 99 SECTIONS

Species	I-35	Hwy. 99
1 <i>Ansella nevadensis</i>	264–279	59
2 <i>A. robusta</i>	23–166	
3 <i>A. n. sp.</i>	67–260	5–56
4 <i>Appalachignathus delicatulus</i>	245–279	5–59
5 <i>Belodina monitorenensis</i>	48–283	0–50
6 <i>Belodella?</i> sp.	27	
7 <i>Bryantodina n. sp.</i>	245–260	5–44
8 <i>Cahabagnathus directus</i>	98–166	
9 <i>C. friendsvillensis</i>	80–140	
10 <i>C. sweeti</i>	191–240	23–32
11 <i>C. n. sp.</i>	33–88	
12 <i>Chirognathus duodactylus</i>	227–240	
13 <i>Dapsilodus mutatus</i>	166–309	29–75
14 <i>D. variabilis</i>	163–283	27–75
15 <i>Drepanoistodus?</i> sp.	48–255	5–32
16 <i>Drepanoistodus suberectus</i>	23–293	0–75
17 <i>Eoplacognathus elongatus</i>	248–255	
18 <i>E. foliaceus</i> – <i>E. reclinator</i>	25–36	
19 <i>Erismodus arbucklensis</i>	37–151	23
20 <i>E. quadridactylus</i>	30–70	
21 <i>E. typus</i>	208–308	
22A <i>Erraticodon patu</i>	26–33	
22 <i>E. sp. cf. E. balticus</i>	25–250	
23 <i>Leptochirognathus quadratus</i>	64–191	0–6
24 <i>Oneotodus?</i> <i>ovatus</i>	208–240	23–25
25 <i>Panderodus gracilis</i>	26–308	0–75
26 <i>P. panderi</i>	51–279	5–41
27 <i>Phragmodus?</i> <i>arcus</i>	67–255	5
28 <i>Phragmodus inflexus</i>	208–290	29–70
29 <i>P. polystrophos</i>	23–26	
30 <i>P. n. sp. 1</i>	28–250	21–25
31 <i>P. n. sp. 2</i>	75–215	5–50
33 <i>Plectodina aculeata</i>	59–75	
34 <i>P. joachimensis</i>	67–145	0–25
35A <i>P. sp. cf. P. polonica</i>	20–21	
35 <i>P. n. sp.</i>	191–304	5–70
36 <i>Pravognathus idoneus</i>	279	75
37 <i>Prioniodus (B.) gerdae</i>	279–283	
38 <i>P. (B.) sp.</i>	255	
39 <i>Protopanderodus varicostatus</i>	25–151	
40 <i>Pseudobelodina?</i> sp.	260–279	
41 <i>Pterocontiodus alatus</i>	26–283	5–59
43 <i>Staufferella falcata</i>	245–248	
44 <i>Staufferella n. sp.</i>	25–227	23–25
45 <i>Staufferella sp.</i>	245–279	27–41
46 <i>Thrincodus palaris</i>	77–104	27
47 <i>Walliserodus n. sp.</i>	104–279	5–59
48 Genus indet., sp. 1	240	23
49 Genus indet., sp. 2	240	23
50 Genus indet., sp. 3	125–151	

Notes: In composite I-35 section, the top of the McLish is at 122 m, Tulip Creek at 216 m, and Bromide at 308 m (numbers rounded off). In the Highway 99 section, the top of the McLish is at 15 m and the Bromide at 74 m.



Text-figure 2. Stratigraphic section and conodont ranges, Bromide Formation, l-35 section. Distribution of units and lithofacies is shown to the right of the stratigraphic column. Dots to the right of the lithofacies column represent sample levels. Species numbers correspond to those assigned in Table 1.

tional strike (NW trend) but decreases abruptly to the northeast and southwest (Statler, 1965).

The Tulip Creek Shoreface Lithofacies is succeeded upward by the poorly exposed Shelf Lithofacies (Unit 9A), which, as indicated by the few exposed beds, may represent a vertical succession similar to the lower McLish shoreface to carbonate-ramp transgressive sequence. The uppermost Tulip Creek is reported to be gradational with the overlying Bromide shoreface deposits (Longman, 1976) and apparently represents a regressive phase.

The vertical succession of Bromide lithofacies is detailed by Longman (1976, 1981, in Sprinkle, 1982). Progressively deepening water produced transgressive Upper and Lower Shoreface, Cystoid-Shale, Inner Shelf, and Basinal Lithofacies, representing shoreface, transitional-zone, proximal-ramp, and distal-ramp facies, respectively.

The gradational unit of the Basinal Lithofacies and the Shelf-Edge Biosparite Lithofacies reflect conditions of higher turbulence and are comparable to the upper Storm-Influenced Ramp Lithofacies of the McLish. Longman (1976) suggested that winnowed skeletal banks developed at this stage and dissipated wave energy. The overlying, regressive lithofacies (Pooleville Member) represent a progradation of back-barrier, lagoonal, carbonate muds. The uppermost Pooleville is an intertidal deposit capped by an unconformity marking the Bromide/Viola contact.

Eastern Arbuckle Facies

The Highway 99 section is divided into 12 units representing 6 lithofacies (Text-fig. 3). Units 1C through 4C represent the upper McLish, and Units 5C through 12C represent the Bromide Formation. The Tulip Creek is not recognized in the eastern Arbuckles and is apparently a locally developed facies within the upper Simpson. Bromide lithofacies designations and interpretations are taken from Longman's reports (1976, 1981, in Sprinkle, 1982).

Units 1C through 4C represent supratidal, intertidal, and possibly shallow-subtidal sediment accumulation. Dismicrite or birdseye micrite of Units 1C and 3C features large, irregular, spar-filled voids recording high-intertidal to supratidal conditions. Birdseyes are also recognized in other units, but are generally much smaller and include many burrow-generated voids ("pseudo-birdseyes" of Shinn, in Scholle and others, 1983). Very thin-bedded quartz arenite in Units 2C and 3C contains micrite intraclasts and resulted from infrequent transport of offshore-bar or onshore-dune sands.

McLish tidal-flat deposits are overlain by the transgressive deposits of the lower Mountain Lake Member. Shoreface and Cystoid-Shale/Inner Shelf Lithofacies record a relative sea-level rise. In comparison to the Mountain Lake in the western Arbuckles, that of the Highway 99 section was developed under shallower-water conditions, as evidenced by numerous beds with textures (e.g., biosparite beds) and sedimentary structures (e.g., cross-stratification) representing conditions of high turbulence. Maximum depth was probably only

a few tens of meters below wave base, and carbonate sediments intermittently built up to wave base.

The Diverse- and Limited-Fauna Biomicrite, Burrowed Micrite, and Birdseye Micrite Lithofacies represent a shallowing-upward sequence of carbonate mud accumulating in a back-barrier environment. The uppermost unit of supratidal origin is capped by an unconformity and overlain by relatively deep-water deposits of the Viola Springs Formation.

CONODONT BIOSTRATIGRAPHY

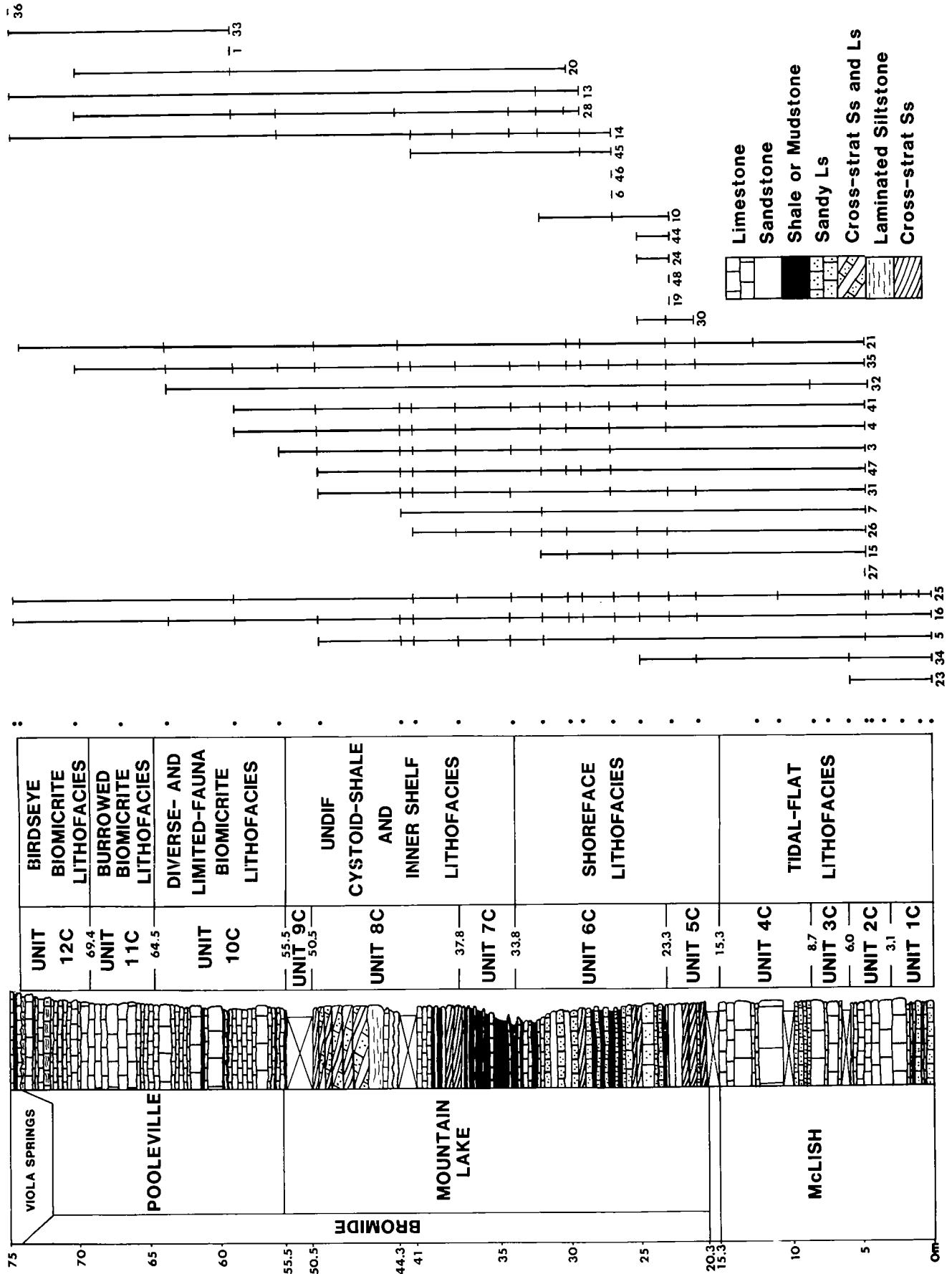
Branson and Mehl (1943), Bergström (1971), Sweet and others (1971, 1973), Sweet and Bergström (1973, 1976), Sweet (in Amsden and Sweet, 1983), Sweet (1984), and Bauer (1987a,b) described or commented on conodont faunas from the upper Simpson Group. Bergström (1971) referred the McLish to Cooper's (1956) Marmor Stage, based on its conodont fauna. Sweet and Bergström (1976) reported *Polyplacognathus friendsvillensis* Bergström-*P. sweeti* Bergström transition (= *Cahabagnathus chazyensis*) from the Tulip Creek, and *Phragmodus flexuosus* Moskalenko, *P. inflexus*, *Prioniodus* (*B. gerdae*), *Plectodina aculeata*, and "fibrous" conodonts from the Bromide. The McLish through lower Mountain Lake were interpreted to be Chazyan; the upper Mountain Lake and Pooleville, Blackriveran; and the Corbin Ranch, Rocklandian and Kirkfieldian.

Sweet (1984; in Amsden and Sweet, 1983) recorded occurrences of upper Simpson conodont species and used their ranges in graphic methods of correlation. Sections of the McLish through Bromide were referred to the upper Whiterockian (Chazyan) and lower Mohawkian (Blackriveran or Ashbyan) Series. Sweet (in Amsden and Sweet, 1983) reported *Phragmodus undatus*, *Plectodina aculeata*, *Periodon grandis*, *Belodina compressa* (Branson and Mehl), *Amorphognathus tvaerensis?*, *Icriodella superba*, and *Rhodesgnathus elegans* (Rhodes) from the Corbin Ranch and suggested a latest Blackriveran to earliest Kirkfieldian age.

Bauer (1987a) reported that the McLish and Tulip Creek (I-35 section) were assignable to the upper Whiterockian Series as defined by Ross and others (1982), and were representative of the Chazyan and Marmor Stages of Cooper (1956). Occurrences of *Eoplacognathus foliaceus* (Fåhraeus)-*E. reclinatus* Fåhraeus transition in the lower McLish and *Cahabagnathus sweeti* (reported in Bauer, 1987b) in the upper Tulip Creek indicate that the McLish/Tulip Creek section is referable to the *Pygodus serra* and *P. anserinus* Zones of Bergström (1971).

Western Arbuckle Faunas

Conodont collections from the I-35 section are stored at The Ohio State University, bear locality designations 82JA, 83JD, and 83JE, and are described in Bauer (1987a,b). Ranges of conodont species are shown in Text-figures 1 and 2. The lowermost productive samples of the McLish yielded a fauna composed of *Neomultioistodus compressus* Harris and Harris, *Drepanoistodus angulensis* (Harris), *Pteracontiodus* sp., and *Scandodus? sinuosus* Mound, all of which were presumed to be older,



Text-figure 3. Stratigraphic section and conodont ranges, McLish and Bromide Formations, Oklahoma Highway 99 section. Distribution of units and lithofacies is shown to the right of the stratigraphic column. Dots to the right of the lithofacies column represent sample levels. Species numbers correspond to those assigned in Table 1.

redeposited specimens. Those samples also contained specimens previously referred to *Bryantodina* sp. (Bauer, 1987a), but which are now considered to be a species of *Plectodina* assigned to *P.* sp. cf. *P. polonica* (Dzik).

The conodont fauna from the remainder of the upper Simpson is dominated by species of *Phragmodus* and *Plectodina*. *Phragmodus polystrophos* Watson occurs with the *Eoplacognathus foliaceus*–*E. reclinatus* transition in the lower McLish. *P.* n. sp. 1 and 2 (= morphotypes B and A, respectively, in Bauer, 1987a) are representatives of the *Phragmodus flexuosus* plexus and range from the middle McLish through the Mountain Lake Member of the Bromide. *P. inflexus* is represented in samples from the Bromide.

Plectodina n. sp. was described by Votaw (1971), Carnes (1975), and others, and is an important component of the fauna from the upper Tulip Creek through the Bromide Formation. *P. flexa* is represented in the uppermost Mountain Lake Member.

Species of *Cahabagnathus* are represented in small numbers at several levels in the upper Simpson section. *C. directus* and *C. friendsvillensis* (Bergström) occur in the upper McLish and lower Tulip Creek. *C. chazyensis* is represented in the upper Tulip Creek. *C. sweeti* ranges from the upper Tulip Creek to the lower Bromide.

Specimens of *Prioniodus* (*B.*) *gerdae* and *Eoplacognathus elongatus* are represented in the middle to upper Mountain Lake Member. *P.* (*B.*) *gerdae* ranges from 52 to 56 m and *E. elongatus* from ~22 to 28 m above the base of the Bromide section.

Hyaline conodont species belonging to *Chirognathus*, *Curtognathus*, *Erismodus*, and *Erraticodon* are sparsely represented in the upper Simpson section, but make up a significant component of the small collections from the Pooleville Member of the Bromide.

Eastern Arbuckle Faunas

Conodonts collected from the Highway 99 section are stored at The Ohio State University and bear locality designation 83JF. Species ranges are shown in Text-figure 3. The fauna is similar to that of the I-35 section in that it is dominated by specimens of *Phragmodus* and

Plectodina. Unlike the I-35 fauna, this conodont fauna generally lacks species that are key indices of Bergström's (1971) zonal and subzonal scheme.

The upper McLish fauna includes *Phragmodus* n. sp. 2, *Belodina montorensis*, *Ansella* n. sp., *Leptochirognathus quadratus*, *Plectodina joachimensis*, *P.* n. sp., *Bryantodina* n. sp., *Erismodus typus*, and *Appalachignathus delicatulus*. The latter four species are represented exclusively in the Tulip Creek and/or Bromide at Interstate Highway 35, which may indicate that the McLish is younger in the Highway 99 section than in the western Arbuckles. The ranges of those species are poorly known and, consequently, species occurrences may reflect differences in environmental parameters rather than time.

The conodont fauna of the Mountain Lake Member is similar to that of the upper McLish, but also includes *Phragmodus* n. sp. 1, *Staufferella* n. sp., *Oneotodus? ovatus*, *Erismodus arbucklensis*, and *Thrincodus palaris*. The middle and upper Mountain Lake fauna comprises *Phragmodus inflexus*, *Walliserodus* n. sp., and *Dapsilodus variabilis*.

Samples from the lower Pooleville Member contain a more varied fauna than do samples from the corresponding interval in the I-35 section. *Appalachignathus delicatulus*, *Ansella nevadensis*, *A.* n. sp., *Dapsilodus variabilis*, *Phragmodus inflexus*, *Plectodina aculeata*, *P.* n. sp., *Pteracontiodus alatus* (Dzik), and species of *Erismodus* and *Curtognathus* are represented in the Pooleville.

The uppermost occurrence of *Cahabagnathus sweeti* is approximately 17 m above the base of the Bromide and includes specimens with features somewhat like *C. carnesi* Bergström. Bergström (1983) showed the ranges of those two species to overlap in the *Amorphognathus inaequalis* Subzone of the *Pygodus anserinus* Zone, below the first occurrence of *Prioniodus* (*B.*) *gerdae*. Consequently, all the rocks at or below that level are referred to the upper Whiterockian (Chazyan Stage). However, the Whiterockian/Mohawkian boundary cannot be confidently projected into the Highway 99 section. The lowermost bed of Viola Springs contains *A. tvaerensis*, *Icriodella superba*, *Periodon grandis*, *Phragmodus undatus*, and *Plectodina aculeata*, indicating an age no older than Rocklandian.

Plates

PLATE 1

Representative conodonts from the upper Simpson Group. Specimens are in type collections of the Orton Geological Museum, The Ohio State University, Columbus, Ohio.

Figure 1.—*Ansella nevadensis* (Ethington and Schumacher), biconvex element, outer lateral view, 130×, OSU 41003, upper Mountain Lake Member.

Figures 2,7.—*Ansella robusta* (Ethington and Clark); 2, triangular element, 95×, OSU 41160; 7, planoconvex element, 70×, OSU 41161; lower McLish Formation.

Figures 3,4.—*Appalachignathus delicatulus* (Bergström and others); 3, bipennate Sc, 50×, OSU 41015; 4, angulate Pb, 50×, OSU 41014; Bromide Formation.

Figure 5.—*Belodina?* sp., 55×, OSU 41024, Mountain Lake Member.

Figures 6,11.—*Ansella* n. sp.; 6, triangular element, 60×, OSU 41009, Mountain Lake Member; 11, biconvex element, outer lateral view, 72×, OSU 41010, Tulip Creek Formation.

Figures 8,10,13,14.—*Bryantodina* n. sp.; 8, Sc element, 120×, OSU 41017; 10, Pa element, 70×, OSU 41020; 13, Pb element, 85×, OSU 41021; 14, Sb element, 85×, OSU 41016; Mountain Lake Member.

Figure 9.—*Belodina monitorenensis* Ethington and Schumacher, grandiform element, 65×, OSU 41026, Mountain Lake Member.

Figure 12.—*Belodella* sp., 75×, OSU 41002, Mountain Lake Member.

Figures 15,20.—*Cahabagnathus chazyensis* Bergström; 15, pastiniplanate element, 35×, OSU 41179; 20, stelliplanate element, 40×, OSU 41178; Tulip Creek Formation.

Figures 16,17.—*Cahabagnathus sweeti* (Bergström); 16, pastiniplanate element, 85×, OSU 41029; 17, stelliplanate element, 90×, OSU 41031; Mountain Lake Member.

Figures 18,19.—*Cahabagnathus* n. sp.; 18, pastiniplanate element, 50×, OSU 41163; 19, stelliplanate element, 95×, OSU 41164; McLish Formation.

Figures 21,22,29.—*Chirognathus duodactylus* Branson and Mehl; 21, Sb element, 110×, OSU 41032; 22, Pb element, 140×, OSU 41034; 29, M? element, 100×, OSU 41036; Mountain Lake Member.

Figure 23.—*Eoplacognathus* sp. (= *E. foliaceus*–*E. reclinatus* transition), sinistral pastiniplanate element, 65×, OSU 37215, McLish Formation.

Figures 24,25.—*Dapsilodus variabilis* (Webers); 24, acodontiform element, 80×, OSU 41052; 25, symmetrical distacodontiform element, 110×, OSU 41051; Mountain Lake Member.

Figures 26–28.—*Drepanoistodus suberectus* (Branson and Mehl); 26, suberectiform element, 100×, OSU 41045; 27, drepanodontiform element, 50×, OSU 41044; 28, oistodontiform element, 65×, OSU 41046; Mountain Lake Member.

Figures 30,31.—*Eoplacognathus elongatus* (Bergström); 30, pastiniplanate element, 43×, OSU 41048; 31, stelliplanate element, 43×, OSU 41047; Mountain Lake Member.



PLATE 2

Representative conodonts from the upper Simpson Group. Specimens are in type collections of the Orton Geological Museum, The Ohio State University, Columbus, Ohio.

Figures 1,2,7,13.—*Phragmodus? arcus* Webers; 1, tertiopedate Sb element, 80×, OSU 41080; 2, pastinate P element, 50×, OSU 41077; 7, dolabrate M element, 90×, OSU 41078; 13, dolabrate Sc element, 75×, OSU 41076.

Figures 3,4,8,9,15.—*Erismodus quadridactylus* (Stauffer); 3, Pb element, 60×, OSU 41057; 4, M element, 70×, OSU 41054; 8, Sa element, 50×, OSU 41059; 9, Sba element, 85×, OSU 41058; 15, Sc element, 85×, OSU 41055; Bromide Formation.

Figures 5,6,10,11.—*Erismodus typus* Branson and Mehl; 5, Sc element, 38×, OSU 41065; 6, Sba element, 110×, OSU 41067; 10, Pa element, 130×, OSU 41070; 11, Sa element, 80×, OSU 41068; Bromide Formation.

Figures 12,17.—*Erraticodon patu* Cooper; 12, Pa element, 43×, OSU 41182; 17, M element, 55×, OSU 41183; McLish Formation.

Figure 14.—*Panderodus panderi* (Stauffer), arcuatiform element, outer lateral view, 63×, OSU 41120, McLish Formation.

Figure 16.—*Leptochirognathus quadratus* Branson and Mehl, graciliform element, 70×, McLish Formation.

Figures 18,19,24.—*Plectodina flexa* (Rhodes); 18, pastinate Pa element, 110×, OSU 41092; 19, dolabrate M element, 80×, OSU 41095; 24, angulate Pb element, 85×, OSU 41097; Mountain Lake Member.

Figure 20.—*Pseudobelodina? sp.*, 145×, OSU 41042, Mountain Lake Member.

Figure 21.—*Panderodus gracilis* (Branson and Mehl), falciform element, 110×, OSU 41112, Mountain Lake Member.

Figures 22,27.—*Staufferella sp.*; 22, acontiodontiform Sa element, 120×, OSU 41150; 27, Sc element, 75×, OSU 41148; Mountain Lake Member.

Figures 23,28.—*Staufferella n. sp.*; 23, Sa element, 110×, OSU 41142; 28, scandodontiform Sc element, 120×, OSU 41143; Mountain Lake Member.

Figures 25,26,30,31.—*Walliserodus n. sp.*; 25, acontiodontiform element, 80×, OSU 41138; 26, scandodontiform element, 80×, OSU 41140; 30, multicostate acontodontiform element, 100×, OSU 41137; 31, drepanodontiform element, 70×, OSU 41139; Mountain Lake Member.

Figure 29.—*Staufferella falcata* (Stauffer), acontiodontiform Sa element, 90×, OSU 41153.

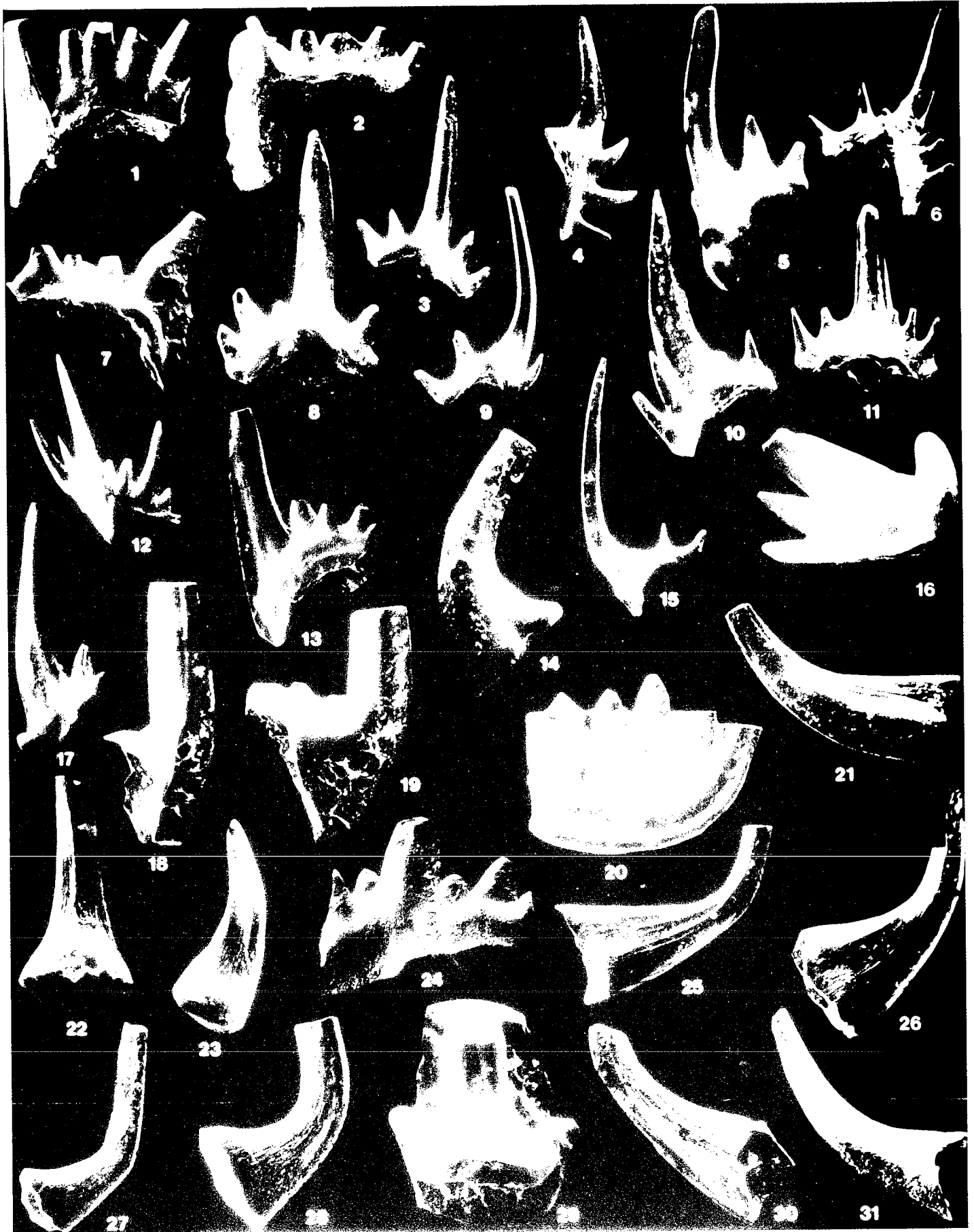


PLATE 3

Representative conodonts from the upper Simpson Group. Specimens are in type collections of the Orton Geological Museum, The Ohio State University, Columbus, Ohio.

Figures 1,2,6.—*Phragmodus polystrophos* Watson; 1, Sa element, 60×, OSU 41224; 2, P element, 80×, OSU 41225; 6, M element, 140×, OSU 41226; McLish Formation.

Figure 3.—*Phragmodus inflexus* Stauffer, Pa element, 75×, OSU 41216, Mountain Lake Member.

Figures 4,5.—*Phragmodus* n. sp. 1; 4, P element, 100×, OSU 41219; 5, M element, 75×, OSU 41217; McLish Formation.

Figure 7.—*Phragmodus* n. sp. 2, Pa element, 110×, OSU 41227.

Figures 8,12,17.—*Plectodina* n. sp.; 8, angulate Pb element, 70×, OSU 41091; 12, pastinate Pa element, 80×, OSU 41089; 17, bipennate M element, 60×, OSU 41088; Bromide Formation.

Figures 9,10,11,15,20.—*Plectodina* sp. cf. *P. polonica* (Dzik); 9, alate Sa element, 100×, OSU 41168; 10, bipennate M element, 140×, OSU 41165; 11, bipennate Sc element, 110×, OSU 41166; 15, angulate Pb element, 60×, OSU 41167; 20, pastinate Pa element, 100×, OSU 41169; McLish Formation.

Figures 13,16,18,21.—*Plectodina joachimensis* (Andrews); 13, alate Sa element, 75×, OSU 41212; 16, angulate Pb element, 55×, OSU 41209; 18, pastinate Pa element, 40×, OSU 41211; 21, digyrate Sb element, 45×, OSU 41208; McLish Formation.

Figures 14,19.—*Plectodina aculeata* (Stauffer); 14, bipennate Sc element, 60×, OSU 41082; angulate Pb element, 60×, OSU 41085; 19, bipennate M element, 65×, OSU 41081; Pooleville Member.

Figures 22,23,27,28.—*Pteracontiodus alatus* (Dzik); 22, oistodontiform element, 35×, OSU 41132; 23, acontiodontiform element, 50×, OSU 41131; 27, acodontiform element, 35×, OSU 41134; 28, drepanodontiform element, 45×, OSU 41135.

Figure 24.—Genus indeterminate, sp. 3, 65×, OSU 41181, McLish Formation.

Figure 25.—*Thrinodus parlaris* Bauer, 50×, OSU 41158, Mountain Lake Member.

Figures 26,31.—*Prioniodus (Baltoniodus) gerdae* Bergström; 26, pastinate element, 90×, OSU 41106; 31, pastiniscaphate element, 48×, OSU 41107; Mountain Lake Member.

Figure 29.—*Pravognathus idoneus* (Stauffer), 180×, OSU 41127, Mountain Lake Member.

Figure 30.—*Oneotodus? ovatus* (Stauffer), 140×, OSU 41053.

Figure 32.—Genus indeterminate, sp. 1, 140×, OSU 41156, Mountain Lake Member.

Figure 33.—Genus indeterminate, sp. 2, 150×, OSU 41157, Mountain Lake Member.



Late Ordovician–Early Devonian Conodont Succession in the Hunton Group, Arbuckle Mountains and Anadarko Basin, Oklahoma

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ABSTRACT.—Late Ordovician through Early Devonian conodont faunas occur in surface exposures of the Hunton Group in the Arbuckle Mountains and in the subsurface of the Anadarko basin of central and southern Oklahoma. The Keel Formation, the lowest unit of the Hunton Group, contains a sparse latest Ordovician fauna that is interpreted to be Hirnantian in age, based on associated brachiopods. No strata of Llandoveryian A or B age are known to be present in the Hunton Group; the presence of late Llandoveryian (C_{1-2}) age beds in the Cochrane Formation is suggested by brachiopod faunas. The lower part of the Cochrane Formation lacks diagnostic conodonts, but its upper part contains a *celloni* Zone conodont fauna (Llandoveryian C_2). The overlying Clarita Formation yields extremely abundant and diverse conodont faunas that range in age from the latest Llandoveryian (C_2) to earliest Wenlockian *amorphognathoides* Zone to near the end of the Wenlockian (*crassa* Zone). The Henryhouse Formation, which at least locally rests conformably on the Clarita, contains a succession of conodont faunas of variable abundance and diversity that span Ludlovian and Pridolian time. The Haragan–Bois d’Arc Formations yield sparse conodonts that are Lochkovian, earliest Devonian, in age. The earliest Devonian conodont Zone, the *woschmidtii* Zone, has not been recognized, and a minor hiatus may exist at the Silurian/Devonian boundary. The Frisco Formation is separated from the Haragan–Bois d’Arc by a distinct unconformity; its poorly preserved fauna suggests a Pragian age (Early Devonian). The Sallisaw Formation, which rests unconformably on the Frisco, yields a sparse fauna of late Emsian age (*serotinus* Zone?), and locally in the subsurface Eifelian (Middle Devonian) conodonts may be present.

INTRODUCTION

The Hunton Group comprises a series of distinctive carbonate units lying above the Upper Ordovician Sylvan Shale and below the Upper Devonian Woodford Shale in central and southern Oklahoma. The eight formations that constitute the Hunton Group range in age from latest Ordovician (Hirnantian) through the late Lower Devonian (Emsian; Fig. 1). In a number of papers, Amsden (e.g., 1957, 1960, 1967, 1975) summarized the stratigraphic relationships of the Hunton Group in the Arbuckle Mountains outcrop area and the subsurface of the Anadarko basin and described lithofacies, biofacies, and megafaunal biostratigraphy of the constituent formations. More recently, Amsden (in Amsden and Barrick, 1988) placed the stratigraphic succession of the Hunton Group in a regional perspective of Late Ordovician through Early Devonian depositional sequences in the south-central United States.

The pattern of conodont faunas obtained from the formations of the Hunton Group is a result of the interaction of a number of geologic and biologic factors. Although units of the Hunton are locally conformable,

most are separated by unconformities that represent significant breaks in deposition and interrupt the conodont succession. The differing representation of paleoenvironmental settings in the Hunton Group, both vertically and laterally, has resulted in biofacies shifts at some lithostratigraphic boundaries, often accentuating the faunal changes. However, the most profound changes in the stratigraphic sequence of conodont faunas do not generally correspond to the local stratigraphic succession, but are related to cycles of conodont evolutionary development as recognized by Ziegler and Lane (1987) and Sweet (1988).

The summary of conodont faunas presented here is derived from a large number of partially analyzed samples from the outcrop area of the Arbuckle Mountains collected by the authors over a number of years. Although descriptions of the fauna of some units have been published (e.g., the Clarita Formation), the taxonomic characterization of the conodonts of other units, such as the Henryhouse–Haragan marlstone interval, is still in progress. For this reason, the information presented here varies greatly in detail, depending on our understanding of the faunas and their significance. A

number of samples of the Hunton Group from the subsurface of the Anadarko basin have been processed for conodonts in conjunction with the subsurface lithofacies-biofacies research of T. W. Amsden. Information from the most significant of these samples has been included in order to show the nature of some conodont associations in the Anadarko basin. Locations of wells mentioned in the text are given in the Appendix.

HUNTON GROUP

Keel Formation

The Keel Formation consists chiefly of an oolite with a shelly fauna dominated by disarticulated pelmatozoan plates. The unit is irregularly distributed, occurring as a belt of oolitic strata at the base of the Hunton Group from the Arbuckle Mountains westward along

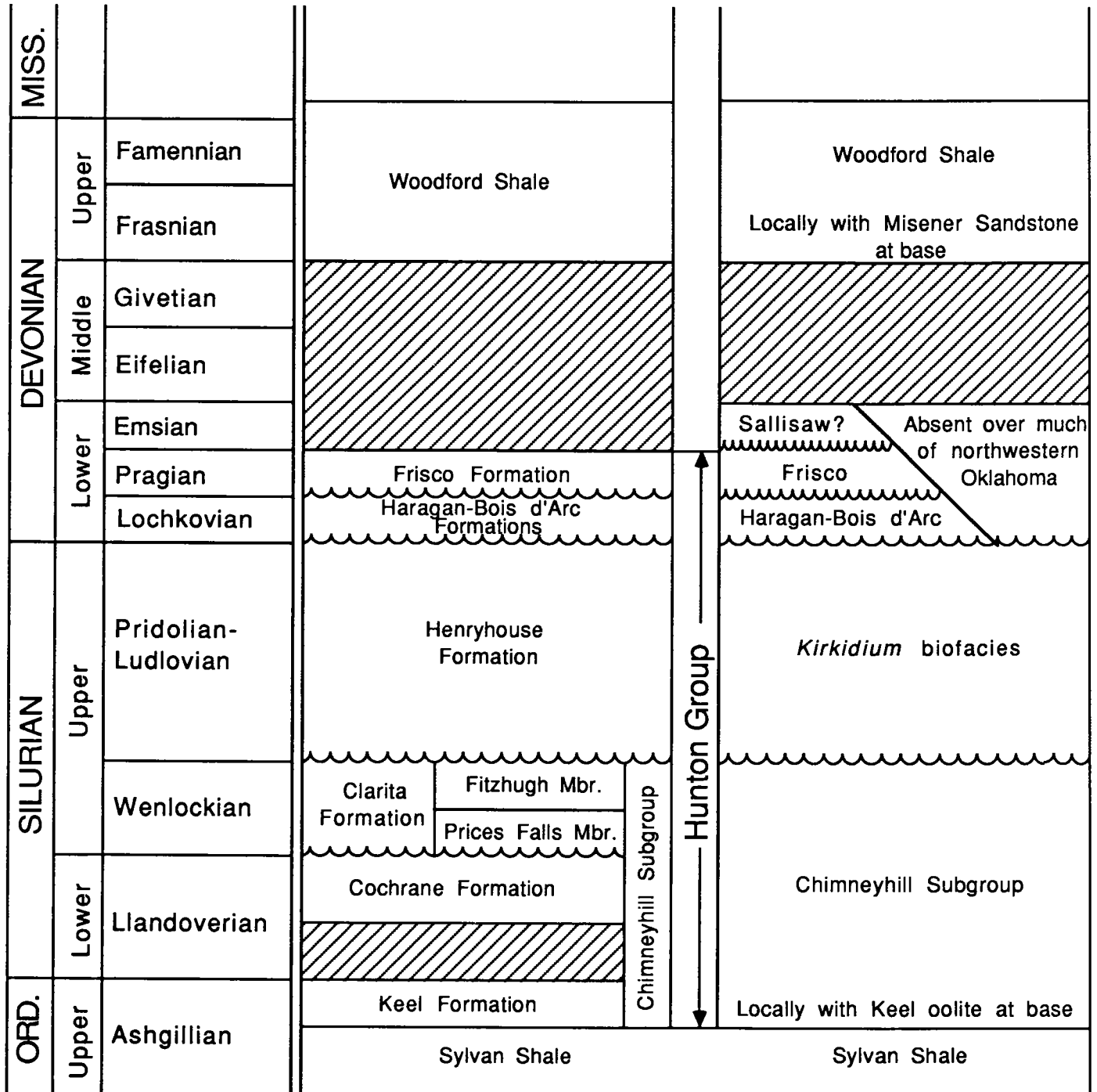


Figure 1. Chart showing stratigraphic divisions of uppermost Ordovician, Silurian, and Devonian strata recognized on outcrop in the Arbuckle Mountains and Criner Hills of south-central Oklahoma (left column) and in the subsurface of central and western Oklahoma (right column). Scalloped lines indicate unconformable contacts that at least locally represent only minor hiatuses. Not to scale in terms of time or thickness.

the structurally deep part of the Anadarko basin. In most places in the Arbuckle Mountains, the Keel is <3 m thick, but along the eastern margin it may be as thick as 4.5 m (Amsden, 1960). In the Anadarko basin the Keel probably does not exceed 7 m in thickness. Amsden (in Amsden and Barrick, 1986) recognized two well-marked facies in the Keel in the Arbuckle Mountains, an oolitic skeletal limestone and a laminated limestone. The oolitic skeletal limestone facies locally contains abundant brachiopods, which are interpreted by Amsden (1974; in Amsden and Barrick, 1986, 1988) to be Hirnantian, latest Ordovician, in age.

Conodont elements are sporadically distributed and relatively uncommon in the Keel Formation. Many beds lack conodonts, and the more abundant samples yield <20 elements per kilogram. A majority of elements are small and pass through a 120-mesh (125 µm) sieve. The Keel conodont fauna contains representatives of several Late Ordovician species of uncertain taxonomic position and biostratigraphic value, all of which deserve further study. Elements of *Noixodontus girardeauensis* (Satterfield) are most characteristic of the fauna. Sweet (1988) suggested that *Sagittodontina* Knüpfner may be a senior synonym of *Noixodontus*, but McCracken (1987) discussed the features that may be used to distinguish the two genera. Many of the larger ramiform elements of *N. girardeauensis* from the Keel possess one to two denticles on the posterior process (Barrick, in Amsden and Barrick, 1986, pl. 7, fig. 11), instead of being adenticulate as described by McCracken and Barnes (1982). Elements of *Istorinus erectus* Knüpfner (Barrick, in Amsden and Barrick, 1986, pl. 7, figs. 7, 8, 13; see Sweet and Bergström, 1984, appendix A, for a suggested reconstruction) and a species of *Eocarniodus* Orchard occur with those of *N. girardeauensis* in several samples. *Plectodina*, *Phragmodus*, and possibly elements of similar genera are present in low numbers. A variety of coniform elements, belonging to several different genera, occur in the Keel. *Decoriconus costulatus* (Branson and Mehl), *Panderodus gracilis* (Branson and Mehl), and a number of forms that may belong to species of *Besselodus*, *Dapsilodus*, *Scabbardella*, or *Walliserodus* (listed as *Dapsilodus? mutatus* in Amsden and Barrick, 1986) have been recovered.

Due to uncertainty in the knowledge of the stratigraphic ranges of the Late Ordovician conodont taxa occurring in the Keel, it is difficult to use them for biostratigraphy (Barnes and Bergström, 1988). However, the association of the Keel conodonts with the Hirnantian brachiopod fauna indicates a latest Ordovician age assignment.

Cochrane Formation

The Cochrane Formation is largely a skeletal limestone with a varied fauna that includes brachiopods, corals, bryozoans, trilobites, and mollusks (Amsden, 1960, 1971). In outcrop it varies from carbonate wackestones and packstones to relatively coarse-grained pelmatozoan grainstone. The unit contains variable amounts of glauconite, and in many parts of the Arbuckle Mountains chert is present as irregular nodules

and lenses. The Cochrane is widely variable in thickness, absent in a few localities, and ranging up to 16 m in the eastern outcrop area. In the subsurface of the Anadarko basin, the Cochrane may be much thicker, 60 m, but its contact with the overlying Clarita Formation is generally obscured by dolomitization, and the two units are grouped together as the Chimneyhill Subgroup (Fig. 1). In most instances, the Cochrane and Clarita Formations can be positively identified in the subsurface only by using paleontological information.

Despite the relatively fossiliferous nature of the Cochrane, few fossils have been extracted from the hard carbonate beds. The most diagnostic form recovered from the outcrop is the brachiopod *Triplexia alata* Ulrich and Bassler, described and illustrated by Amsden (1971, 1973). In the subsurface, another brachiopod, *Stricklandia protriplesiana* (Amsden) has been obtained (Amsden, 1975; in Amsden and Barrick, 1988). On this evidence, Amsden (in Amsden and Barrick, 1988) interpreted at least part of the Cochrane as late Llandoveryan in age (C₁₋₂).

Elements of two coniform groups, *Panderodus unicostatus* (Branson and Mehl) in the broad sense and *?Walliserodus sancticlairei* Cooper, dominate the conodont fauna of the Cochrane Formation in the Arbuckle Mountains. Abundance of elements is variable, ranging from samples with only a few elements per kilogram to those yielding >100 specimens per kilogram. Other coniform species are much less abundant: *?Decoriconus fragilis* (Branson and Mehl), *?Dapsilodus praecipuus* Barrick, *Panderodus* n. sp. aff. *P. recurvatus* (Rhodes), and *Pseudooneotodus tricornis* Drygant. Elements of *Distomodus* occur in many samples, and *Oulodus* elements appear sporadically. At a few localities, *D. staurognathoides* (Walliser), *Pterospathodus celloni* (Walliser), and *P. pennatus angulatus* (Walliser) are present in the upper beds of the Cochrane. The latter two species indicate that at least the upper part of the Cochrane is in the *celloni* Zone (late Llandoveryan, C₃).

Some samples of the Cochrane Formation from the Anadarko basin yield a similar, but slightly more diverse conodont fauna. In Woodward County, a *celloni* Zone fauna containing *Distomodus staurognathoides*, *Ozarkodina polinclinata* (Nicoll and Rexroad), *Aulacognathus kuehni* Mostler, *Astropentagnathus irregularis* Mostler, and *Oulodus* elements was obtained from the Cochrane (Texaco 1 Wheeler Unit; 7,765 ft). In the Texas Panhandle (Gray County), *D. staurognathoides*, *O. polinclinata*, and *Pterospathodus pennatus angulatus*, a *celloni* Zone fauna, occur in the upper part of the sampled Cochrane (Phillips 1-D Franklin; 11,802–11,773 ft), above the level (11,930–11,932 ft) from which *Stricklandia protriplesiana* was obtained by Amsden (1975).

Clarita Formation

The Clarita Formation is divided into a lower Prices Falls Member and an upper Fitzhugh Member. The former is a thin unit, probably nowhere >0.5 m in thickness, that is composed of argillaceous marlstone locally grading into calcareous shale (Amsden and others, 1980). The Fitzhugh Member is a distinctively thin-

bedded, skeletal limestone that is generally <6 m thick in the outcrop area of the Arbuckle Mountains, but may range up to 14 m. The Clarita is difficult to separate from the underlying Cochrane in the subsurface, but paleontological information suggests that it may be thicker in the Anadarko basin. Three major intergrading lithofacies–biofacies divisions are recognized in outcrop: (1) crinoid sparites, (2) arthropod micrites, and (3) ostracode silty marlstones (Amsden, in Amsden and others, 1980). There is some stratigraphic and geographic control to the distribution of the facies. Crinoid sparites locally dominate the upper part of the Fitzhugh Member in the northeastern part of the Arbuckle Mountains, whereas ostracode silty marlstones are best developed in the uppermost strata in the central part of the mountains. Arthropod micrites occur at the base of the Fitzhugh in both areas, and are in part intimately interbedded with the other facies higher in the member.

The Prices Falls Member has not yielded any megafossils, but the Fitzhugh Member contains a large megafauna of brachiopods (at least 23 species in the sparites; Amsden, 1968), trilobites (Holloway, 1980), bryozoans, ostracodes, and mollusks that have been interpreted to be Wenlockian in age (Amsden, in Amsden and Barrick, 1988). In contrast to many other Silurian carbonate units, no stromatoporoids have been observed, and corals, represented mostly by small rugosans, compose an insignificant part of the fauna. A diverse microfauna of foraminifers (Ireland, 1939; Toomey, in Amsden and others, 1980), acrotretid brachiopods (Ireland, 1961; Toomey, in Amsden and others, 1980), and conodonts occurs in acid-insoluble residues of the Fitzhugh Member.

Two major conodont faunas occur successively within the Clarita Formation (Barrick and Klapper, 1976; Barrick, 1977). The distinctive fauna of the *Pterospathodus amorphognathoides* Zone (late Llandoveryan, C₆, to early Wenlockian) characterizes the Prices Falls Member and the lowermost bed of the Fitzhugh at a few localities in the eastern Arbuckle Mountains. Elements of a few coniform species dominate the fauna: *Panderodus unicostatus* (broad sense, including *P. equicostatus* as used by Jeppsson), *Walliserodus sancticlairei*, *Dapsilodus praecipuus*, and *Decoriconus fragilis*. Specimens of *P. langkawiensis* (Igo and Koike), *P. sp. cf. P. recurvatus* (Barrick, 1983, p. 239), and *Pseudooneotodus tricornis* are less common.

Distomodus staurogathoides is the most abundant pectiniform–ramiform species occurring in the *amorphognathoides* Zone in the Clarita. Elements of *Pterospathodus amorphognathoides* (Walliser), *P. pennatus procerus* (Walliser), *Carniodus carnulus* Walliser, *Kockelella ranuliformis* (Walliser), *Ozarkodina hadra* (Nicoll and Rexroad), *O. polinclinata*, *Oulodus petila* (Nicoll and Rexroad), and *Johnognathus huddlei* Mashkova occur in varying proportions. *Pterospathodus celloni* is present in only a few samples from the Prices Falls shale at a couple of localities.

The top of the *amorphognathoides* Zone in the Clarita is marked by the extinction of two genera characteristic of the late Llandoveryan, *Carniodus* and *Pterospathodus*. *Distomodus* apparently persisted a short time after the

extinction of *P. amorphognathoides*. At the top of the zone at least six Llandoveryan species of longer-ranging genera also disappear (Barrick and Klapper, 1976, fig. 3; Barrick, 1977, fig. 1). The base of the overlying *ranuliformis* Zone is characterized by the appearance of three species absent in the *amorphognathoides* Zone in Oklahoma, but known to range down into that zone in other areas (e.g., Mabillard and Aldridge, 1985). *Dapsilodus obliquicostatus* (Branson and Mehl) is overwhelmingly dominant (often comprising >90% of the elements in a sample), *Pseudooneotodus bicornis* Drygant is common, and *Ozarkodina excavata excavata* (Branson and Mehl) is the most typical pectiniform–ramiform species. Elements of *Panderodus unicostatus*, *Walliserodus sancticlairei*, and *Decoriconus fragilis* remain relatively abundant, but no longer dominate the fauna as in the *amorphognathoides* Zone. The base of the *ranuliformis* Zone coincides with the base of the Fitzhugh Member at many sections, but in the Hunton Townsite area (sections C1 and C2 of Amsden, 1960), the turnover occurs within the arthropod micrites of the basal Fitzhugh.

The diversification of species of *Kockelella* during the Wenlockian is recorded within the Fitzhugh Member. At least six new species appear, three of which Barrick and Klapper (1976) used to erect a series of zones for the Wenlockian in Oklahoma. The *Ozarkodina sagitta* lineage appears, represented by *O. sagitta rhenana* Walliser in the lower Fitzhugh and *O. bohémica* Walliser in the upper Fitzhugh. Within the upper part of the Fitzhugh a species of the coniform genus *Belodella* first occurs, as does a form of *Oulodus*. "*Ozarkodina*" *crassa* Walliser, a Pb element that probably belongs to an early species of *Ancoradella*, and *K. variabilis* Walliser occur in the uppermost beds of the Fitzhugh. These species indicate that the top of the Clarita corresponds approximately to the Wenlockian/Ludlovian boundary, as far as it can be recognized using conodonts.

Barrick (in Amsden and others, 1980) discussed conodont biofacies in the Fitzhugh Member of the Clarita Formation. All three lithofacies–biofacies associations recognized by Amsden are strongly dominated by elements of *Dapsilodus obliquicostatus*. The major exception to the dominance of *D. obliquicostatus* is the brief acme of a closely related species, *D. praecipuus* Barrick, in the upper part of the *amsdeni* Zone. The acme of *D. praecipuus* occurs in all three facies, and appears to represent a biological event with possible local biostratigraphic significance. Elements of *Panderodus unicostatus*, *Decoriconus fragilis*, and *Walliserodus sancticlairei* are relatively more abundant in the crinoid sparite facies and the interbedded sparite/arthropod-micrite facies than in the arthropod-micrite facies. *Belodella silurica* Barrick is abundant in the ostracode silty marlstone at the top of the Fitzhugh, but its absence in underlying facies may be a function of its stratigraphic range.

Conodont faunas from the Clarita Formation in the Anadarko basin are similar to those of the outcrop, but differences in conodont biofacies are more pronounced. The *amorphognathoides* Zone has been recovered from shaly strata at the base of the Clarita in Kingfisher County (Pan American 1 Droke, 8,848–8,850 ft) and Oklahoma County (Gulf 1 Streeter; 7,291–7,292 ft).

Lower Clarita beds can be identified by the presence of *Kockelella ranuliformis* and the appearance of *Pseudooneotodus bicornis*, and are characterized by the high abundance of elements of *Dapsilodus obliquicostatus* (Gulf 1 Streeter, Oklahoma County; Pan American 1 Droke and Texaco 2C Foster, Kingfisher County; Woods 1-25 McDannald, Dewey County; Gulf 1-23 Shaffer, Blaine County). Faunas higher in the Clarita in the subsurface are more difficult to characterize because the conodont biofacies shift to the mixed and *Panderodus unicostatus* biofacies (Barrick, 1983), and diagnostic forms are generally absent. *Kockelella amsdeni* has been recovered only from Kingfisher County (Pan American 1 Droke, 8,827 ft). In a number of wells, the acme of *D. praecipuus*, typical of the upper *amsdeni* Zone in the outcrop, is present (Gulf 1-23 Shaffer, 10,692 ft; Texaco 2C Foster, 7,483–7,479 ft; and Gulf 1 Streeter, 7,270 ft). Similarly, *Belodella silurica* appears in the upper Clarita in Blaine County (Gulf 1 Shaffer, 10,626 ft). Whether the latter two events represent time-equivalent occurrences is uncertain, but their stratigraphic positions in the subsurface are compatible with those seen in outcrop.

Henryhouse Formation

Henryhouse strata constitute the lower portion of the Hunton marlstone interval, the upper part being the overlying Haragan Formation. In the Arbuckle Mountains outcrop region, the Henryhouse attains a maximum thickness of ~75 m, but it is absent in some areas where the Haragan–Bois d'Arc rests directly on the Clarita or Cochrane Formation. The Henryhouse is typically an evenly bedded, moderately fossiliferous marlstone having a mud-supported texture. The matrix is composed of finely divided lime mud mixed with clay- and silt-sized extrabasinal terrigenous detritus, averaging ~20% of the total rock volume (Amsden, 1981).

The Henryhouse contains a richly diverse invertebrate marine fauna, including graptolites (Decker, 1935), crinoids (Strimple, 1963), brachiopods (Amsden, 1951), corals (Sutherland, 1965), ostracodes (Lundin, 1965), trilobites (Campbell, 1967), bryozoans, mollusks, and conodonts. The assemblages of brachiopods, crinoids, corals, trilobites, and ostracodes make up compact associations that show no clear evidence of zonation within the Henryhouse, but are sharply differentiated from the faunas of the underlying Clarita and overlying Haragan–Bois d'Arc Formations. In studies of these groups, the Henryhouse has been interpreted as Ludlovian in age, but there is some indication that the formation may include some Pridolian equivalents.

In outcrop, Henryhouse strata show some well-developed lithofacies–biofacies changes (Amsden, 1981). As is the case with the Clarita, the most pronounced facies changes occur between the Arbuckle Mountains to the southwest and the Lawrence uplift to the northeast. The Henryhouse Formation in the Criner Hills and southern Arbuckle Mountains is almost exclusively a mud-supported marlstone, the matrix averaging ~87% and skeletal debris ~13% of total rock volume. Clay- and silt-sized insoluble residue averages 25% by

weight. The megafauna consists mostly of disarticulated pelmatozoan plates, ostracodes, trilobites, bryozoans, and brachiopods. Toward the northeast, on the Lawrence uplift, the proportions of skeletal debris and matrix are about equal in volume, and terrigenous detritus has decreased to ~17% by weight. Beds with a grain-supported texture (packstones) are moderately common, and some beds tend toward grainstone textures. The sessile filter-feeding pelmatozoans, bryozoans, and brachiopods increase substantially, and corals, which are rare in the southern facies, are common. Most of the more common Henryhouse brachiopod species are well-represented in both facies areas (17 species), but the rhynchonellids, rhynchospirinids, and meekellids, which are represented by seven species, are known only from the northeastern facies area (Amsden, 1981).

In contrast to other faunal elements, conodonts of the Henryhouse Formation make up three distinct successive faunas. In the southern and central part of the Arbuckle Mountains area, extremely marly beds locally bearing graptolites are present near the base of the Henryhouse. The conodont fauna of these basal beds is similar to that of the top of the underlying Clarita Formation, but is less abundant and diverse. *Kockelella variabilis* and *K. absidata* Barrick and Klapper and *Ozarkodina excavata excavata* are characteristic forms. *Dapsilodus obliquicostatus* is the most common species, and *Panderodus unicostatus* (broad sense), *Decoriconus fragilis*, *P. recurvatus*, and *Belodella* elements are commonly present. At only a few sections (e.g., M17; Amsden, 1960), do *Polygnathoides siluricus* Branson and Mehl and elements of *Ozarkodina confluens* (Branson and Mehl) join the *Kockelella* fauna a few meters above the base of the Henryhouse.

The *Kockelella* fauna disappears slightly higher in the Arbuckle Mountains region and is replaced by an *Ozarkodina–Dapsilodus* fauna, especially in a short interval of cleaner carbonates ~8 m above the base of the Henryhouse. In this second Henryhouse fauna, *Ozarkodina snajdri* (Walliser), *Ozarkodina* n. sp. of Schönlaub (in Chlupáč and others, 1980, p. 157, pl. 17, figs. 6–8), and extremely rare *Pedavis latialata* (Walliser) appear. Elements of *Dapsilodus obliquicostatus* and *Ozarkodina excavata excavata* strongly dominate the fauna, and elements of *Decoriconus fragilis*, *Panderodus unicostatus*, and *Belodella* spp. are less common. This conodont association corresponds to the late Ludlovian *snajdri* Zone as recognized by Schönlaub (in Chlupáč and others 1980, p. 175–177) in the Barrandian area of Czechoslovakia. The *Ozarkodina–Dapsilodus* fauna occurs near the base of the Henryhouse in sections on the Lawrence uplift, and the early Ludlovian *Kockelella* fauna appears to be absent. In this area a hiatus including the later part of the Wenlockian and early part of the Ludlovian may be developed, in contrast to the apparently continuous stratigraphic record that characterizes the Clarita/Henryhouse contact at sections Ca2 and M17 (Amsden, 1960) in the central Arbuckle Mountains.

In the upper part of the Henryhouse in both areas the *Ozarkodina–Dapsilodus* fauna disappears and is replaced by a different conodont association. The following

forms appear through a short stratigraphic interval: *Oulodus elegans* (Walliser), *Ozarkodina remscheidensis eosteinhornensis* (Walliser), the coniform genus *Dvorakia Klapper* and Barrick, and a multitude of morphotypes of *Belodella* with extremely broad bases, including *B. mira* Khodalevich and Tschernich (see Jeppsson, 1989, for a description). *Dapsilodus obliquicostatus*, *Decoriconus fragilis*, and *Panderodus unicostatus* persist from the older faunas, but are rarely abundant. The presence of *O. remscheidensis eosteinhornensis* allows assignment of this fauna to the *eosteinhornensis* Zone in the expanded sense of Schönlaub (in Chlupác and others, 1980, p. 157). The *eosteinhornensis* Zone ranges from the latest Ludlovian (Kopanina Formation) through the Pridolian (Pridoli Formation) in the Barrandian (Schönlaub, in Chlupác and others, 1980, p. 155, 157, 176–177).

There appears to be no major difference in conodont biofacies between coeval Henryhouse strata in the southern and central Arbuckles and strata on the Lawrence uplift. Nearly all species occur in both areas, but in general faunas are somewhat more abundant in strata on the Lawrence uplift.

Toward the northwest, in the subsurface of the Anadarko basin, the marlstones of the Henryhouse Formation grade into skeletal limestones of the *Kirkidium* biofacies (Amsden, 1981; in Amsden and Barrick, 1988). The *Kirkidium* biofacies is characterized by the presence of the large pentamerid *Kirkidium*, which may occur as scattered, isolated specimens in marlstones interbedded with grain-supported limestone, but are most commonly crowded into shell banks with small amounts (<10%) of insoluble detritus. In some beds, disarticulation of shells is complete, and the shelly debris has been subjected to much breakage. The higher energy level is also indicated by the presence of *Kirkidium*-bearing oolitic beds in the upper part of this biofacies. Due to problems in collecting from cores, a complete faunal analysis is not possible (Amsden, 1981), but rugose and tabulate corals are widely distributed, and in some areas they are the dominant element. Small heads of the alga *Girvanella* occur throughout the *Kirkidium* biofacies.

A number of samples of the *Kirkidium* biofacies have been processed for conodonts with little success. Many samples are barren of conodonts, and small faunas characterized by elements of *Panderodus unicostatus* are typical. In a few wells an association including *P. unicostatus*, *P. recurvatus*, *Belodella* spp., *Ozarkodina confluens*, and *O. excavata excavata* has been recovered (e.g., Gulf 1 Streeter, Oklahoma County, 7,083 ft). *Polygnathoides siluricus* occurs in beds with an uncertain relationship to the *Kirkidium* biofacies in the Pan American 1 Post Unit (8,325 ft) in Kingfisher County (Amsden, 1975, p. 38).

Similar undiagnostic faunas occur near the base of the more typical marlstone facies of the Henryhouse just north of the outcrop area (Anadarko Production 1-35A Harris, Garvin County, 9,150 ft). In the same area, an upper Henryhouse fauna containing *Ozarkodina remscheidensis eosteinhornensis* and *Oulodus elegans* was obtained from the subsurface (Anadarko Production 1-24-A Phoenix, Garvin County, 7,457 ft).

Haragan–Bois d'Arc Formations

The Haragan Formation is remarkably similar to the underlying Henryhouse Formation in lithofacies and biofacies characteristics. Both formations are marlstones so similar in composition and texture that even in areas of complete exposures it is difficult to separate them. However, the Haragan can be distinguished by its distinctive Early Devonian brachiopod fauna (Amsden, 1962; in Amsden and Barrick, 1988, text-fig. 6), and comparable differences exist among the ostracodes (Lundin, 1968) and trilobites (Campbell, 1977).

Conodont faunas show three changes in species composition at the same stratigraphic level as the shelly faunas: (1) *Oulodus elegans* disappears; (2) *Ozarkodina remscheidensis remscheidensis* morphotypes appear; and (3) species of *Icriodus* appear.

Jeppsson (1988, 1989) reported that at least one subspecies of *Oulodus elegans* ranges into the Devonian, on evidence of collections from the Klunk section and other samples from the Barrandian region of Czechoslovakia. He observed that a second subspecies, *O. elegans detorta*, is restricted to a small interval (1 m) just below Bed 20 at Klunk, the boundary stratotype for the base of the Devonian System. Elements like those of *O. elegans detorta* have been recovered at least 5 m below the top of the Henryhouse at some sections. The morphologic transition from *Ozarkodina remscheidensis eosteinhornensis* to *O. r. remscheidensis* appears to be controlled in part by ecologic factors (Denkler and others, 1983; Denkler and Harris, 1988, p. B6, who reported *remscheidensis* morphotypes as low as the late Ludlovian in the Appalachians). However, the transition occurs near the Silurian/Devonian boundary in a number of sections in the Barrandian (Schönlaub, in Chlupác and others, 1980; Jeppsson, 1988, 1989), the Carnic Alps (Walliser, 1964), and Nevada (Murphy and Edwards, 1977). The morphology of the specimens of *Icriodus* that appear near the base of the Haragan is variable, but most conform to the characteristics of *I. postwoschmidti* Mashkova, a species that occurs in lower, but not lowest Lochkovian strata in the Barrandian (Schönlaub, in Chlupác and others, 1980, p. 157–159). Associated with the lower Haragan *Icriodus* fauna are a few examples of a *Pedavis* species that resembles *P. biexoramus* Murphy and Matti.

Given the available conodont data, it is difficult to determine if a biostratigraphic hiatus exists between the Henryhouse and Haragan Formations, as has been proposed by Amsden (in Amsden and Barrick, 1988, and earlier papers). In addition to the species ranges listed above, the conodont biofacies change slightly at the boundary. Elements of *Pseudooneotodus beckmanni*, rare in the Henryhouse, are abundant in basal Haragan beds. Elements of *Belodella*—common and including a diverse range of morphotypes in the Henryhouse—are uncommon and nondiverse in the lower Haragan. Samples from beds higher in the Haragan are disappointingly poor in conodonts, especially at White Mound, a major megafossil locality. Only a few elements of *Belodella* and *Dvorakia* have been recovered from the richly fossiliferous beds of the Haragan.

The Haragan marlstones grade vertically and laterally into the cherty marlstones of the Cravatt Member of the Bois d'Arc Formation, which grade upward into the grain-supported skeletal limestones of the Fittstown Member (Amsden, in Amsden and Barrick, 1988, text-fig. 5). The brachiopod fauna of the Bois d'Arc differs from that of the Haragan mainly by changes in the relative proportions of species, and Amsden (in Amsden and Barrick, 1988, p. 9, text-fig. 6) indicated that there is no distinct zonation. Campbell (1977) in his study of the trilobites suggested that the upper Cravatt and Fittstown Members may be slightly younger than the Haragan, as did Boucot and Johnson (1967), based on the brachiopods.

Conodonts are relatively scarce in Bois d'Arc strata, making it difficult to determine biostratigraphic relationships. In the Cravatt Member conodonts are often concentrated in thin skeletal lag beds. Elements of *Belodella* and *Dvorakia* are the most common forms. *Ozarkodina excavata wurmi* (Bischoff and Sannemann) and *O. remscheidensis remscheidensis* occur in a few samples. In packstone beds near the top of the Cravatt Member, *Icriodus* elements that are questionably referred to *I. postwoschmidti*, a Haragan species, are present.

Even fewer conodont elements are present in the coarse skeletal grainstones of the Fittstown Member, the upper member of the Bois d'Arc. Most are elements of *Belodella* and *Dvorakia* species, and a few specimens of *Ozarkodina remscheidensis remscheidensis* are present. From a few samples in the middle of the Fittstown Member, elements of *Ancyrodelloides transitans* (Bischoff and Sannemann) have been recovered. This species is characteristic of the late Lochkovian in Europe (Schönlaub, in Chlupáč and others, 1980) and occurs in the *delta* Zone of the North American Cordilleran zonation (Klapper and Murphy, 1980).

Frisco Formation

The Frisco Formation crops out only in the northeastern part of the Arbuckle Mountains region, having been removed by pre-Woodford erosion elsewhere in the outcrop. The Frisco is composed of skeletal grainstones in which the fossil debris has been extensively fragmented. Oolitic beds occur at some levels, and glauconite may be present in some beds. In outcrop it is usually <7 m thick, attaining a maximum thickness of ~18 m (Amsden, 1975). The Frisco covers a relatively large area in the subsurface of central Oklahoma (Amsden, 1975), where it retains its typical lithologic character and ranges up to 30 m in thickness. The extensive megafauna is dominated by pelmatozoan plates and brachiopods, and includes gastropods, bryozoans, trilobites, and corals. The brachiopod fauna (Amsden and Ventress, 1963; Amsden, 1975) and trilobite fauna (Campbell, 1977) indicate an Early Devonian age (Deerparkian) for the Frisco, in outcrop and in the subsurface.

Conodont elements from the Frisco Formation are abundant, but badly fragmented. Pieces of elements of

Dvorakia and *Icriodus* are present in most samples. Klapper (in Amsden, 1985, p. 2) indicated a possible relationship of *Icriodus* elements with *I. claudiae* Klapper. *Icriodus claudiae* appears in the *sulcatus* Zone and ranges into the *kindlei* Zone in Nevada (Murphy and Cebecioglu, 1984). These zones are correlative with Pragian strata in the Barrandian area. Only a few samples of the Frisco from the subsurface have been processed for conodonts, and faunas identical in character and preservation with those from surface samples were obtained (Reserve 1-9 Osborn, Grady County, 12,194–12,134 ft).

Turkey Creek Limestone

The Turkey Creek limestone is an informally named Lower Devonian stratigraphic unit limited to a small inlier in Marshall County, Oklahoma. The Turkey Creek is dominantly a pelmatozoan grainstone with abundant trilobite and ostracode debris; bryozoans, brachiopods, and tabulate corals are less common. Earlier work on conodonts (Klapper and Ziegler, 1967) and trilobites (Ormiston, 1968) suggested that the Turkey Creek was intermediate in age between the Frisco and Sallisaw Formations (Emsian, late Early Devonian). Klapper (in Amsden, 1985, p. 2) reported that the *Icriodus* specimens from the Turkey Creek most closely resemble *I. claudiae*, a conodont species possibly present in the Frisco Formation.

Sallisaw Formation

The Sallisaw Formation is absent in the Arbuckle Mountains region, cropping out only in eastern Oklahoma. It strongly resembles the Frisco in lithology, differing by locally containing abundant quartz sand and bearing considerable quantities of chert. The Sallisaw megafauna consists predominantly of pelmatozoan plates and disarticulated to broken brachiopods (Amsden, 1963). The brachiopod fauna is considered to be correlative with the Sawkillian Stage of Rickard (1964), which is late Early Devonian in age (Amsden, in Amsden and Barrick, 1988) and correlative with some part of the standard Emsian Stage. The Sallisaw Formation, bearing its characteristic brachiopod fauna, is sporadically distributed in the subsurface of the Anadarko basin extending into the Texas Panhandle, probably as isolated erosional remnants.

Klapper (in Amsden, 1985, p. 2) reported *Icriodus latericrescens robustus* Orr from the Sallisaw Formation in outcrop in eastern Oklahoma. This form ranges from the *serotinus* Zone (late Emsian) into the early Middle Devonian, Eifelian (Klapper and Johnson, 1980), but presumably the Oklahoma occurrence is within the *serotinus* Zone. *Icriodus latericrescens robustus* was also recovered from the Phillips 1-D Franklin, Gray County, Texas (11,469–11,467 ft), and higher in the core *Icriodus angustus*, an Eifelian species (Middle Devonian, *costatus-kockelianus* Zone equivalent), occurs.

APPENDIX: LOCATIONS OF WELLS

PAN AMERICAN 1 DROKE UNIT—CNE¹/₄NE¹/₄ sec. 4, T. 18 N., R. 9 W., Kingfisher County, Oklahoma.

TEXACO 2-C FOSTER—sec. 13, T. 17 N., R. 6 W., Kingfisher County, Oklahoma.

PHILLIPS 1-D FRANKLIN—1,050 ft FSL, 1,000 ft FWL sec. 53, BLK. A-6, H&GN Survey, Gray County, Texas.

ANADARKO PRODUCTION 1-35A HARRIS—sec. 35, T. 3 N., R. 3 W., Garvin County, Oklahoma.

WOODS 1-25 McDANNALD—E¹/₂SW¹/₄NE¹/₄ sec. 25, T. 18 N., R. 18 W., Dewey County, Oklahoma.

RESERVE 1-9 OSBORN—sec. 9, T. 9 N., R. 7 W., Grady County, Oklahoma.

ANADARKO PRODUCTION 1-24-A PHOENIX—sec. 24, T. 3 N., R. 3 W., Garvin County, Oklahoma.

PAN AMERICAN 1 POST UNIT—CNW¹/₄SE¹/₄ sec. 34, T. 16 N., R. 7 W., Kingfisher County, Oklahoma.

GULF 1-23 SHAFFER—SE¹/₄SW¹/₄ sec. 23, T. 16 N., R. 10 W., Blaine County, Oklahoma.

GULF 1 STREETER—SE¹/₄SE¹/₄ sec. 20, T. 13 N., R. 4 W., Oklahoma County, Oklahoma.

TEXACO 1 WHEELER UNIT—sec. 25, T. 25 N., R. 18 W., Woodward County, Oklahoma.

The Devonian/Carboniferous Boundary in the Woodford Shale, Lawrence Uplift, South-Central Oklahoma

D. Jeffrey Over and James E. Barrick

ABSTRACT.—Black color, radiolarians, offshore conodont faunas, and lack of bioturbation indicate that the Woodford Shale on the Lawrence uplift of south-central Oklahoma was deposited in a predominantly deep-water anoxic setting. Nondepositional and erosional episodes are evidenced by laminae, beds, and nodules of pelloidal phosphate in strata transcending the Devonian/Carboniferous boundary. *Pseudopolygnathus marburgensis trigonicus*, which ranges through the Upper *expansa* Zone into the Middle *praesulcata* Zone (late Famennian), occurs in the highest Devonian beds. The absence of *Siphonodella praesulcata* and *Protognathodus kockeli* below the first occurrence of *Siphonodella sulcata* prohibits recognition of the Lower through Upper *praesulcata* zones. The three earliest Carboniferous (Kinderhookian) conodont Zones, the *sulcata*, Lower *duplicata*, and Upper *duplicata* Zones, occur successively in the upper 0.60 m of the Woodford.

INTRODUCTION

In 1979 the IUGS Working Group on the Devonian–Carboniferous Boundary defined the base of the Carboniferous (Mississippian) to correspond with the appearance of the conodont *Siphonodella sulcata* (Huddle), but did not designate a boundary stratotype. This decision has led to extensive study of Devonian/Carboniferous boundary strata throughout the world, and numerous sections have been proposed as possible stratotypes (Paproth and Streel, 1984; Flajs and others, 1988). The purpose of this report is to document the conodont distribution across the Devonian/Carboniferous boundary in three sections of the Woodford Shale on the Lawrence uplift, south-central Oklahoma. Although the paucity of macrofossils in the Woodford sections precludes them as potential boundary stratotypes, the well-preserved and diverse conodont fauna recommends the Lawrence uplift as an important reference area for the Devonian/Carboniferous boundary in North America.

The Woodford Shale is a part of the widespread Upper Devonian–Lower Mississippian black-shale facies that covers extensive areas of North America. In Oklahoma, the Woodford consists predominantly of black shale that is locally cherty, phosphatic, or pyritic. It lies unconformably on Ordovician to Lower Devonian strata, although throughout most of the Arbuckle Mountains region the Woodford rests on Lower Devonian units of the Hunton Group (Amsden, 1960). In the subsurface of central Oklahoma, the Misener Sandstone, which contains Middle to Late Devonian conodonts (Amsden and Klapper, 1972), locally lies at the base of the Woodford. The top of the Woodford is conformable with the “pre-Welden shale” (upper Kinderhookian, Mississippian) of Cooper (1939) on parts of

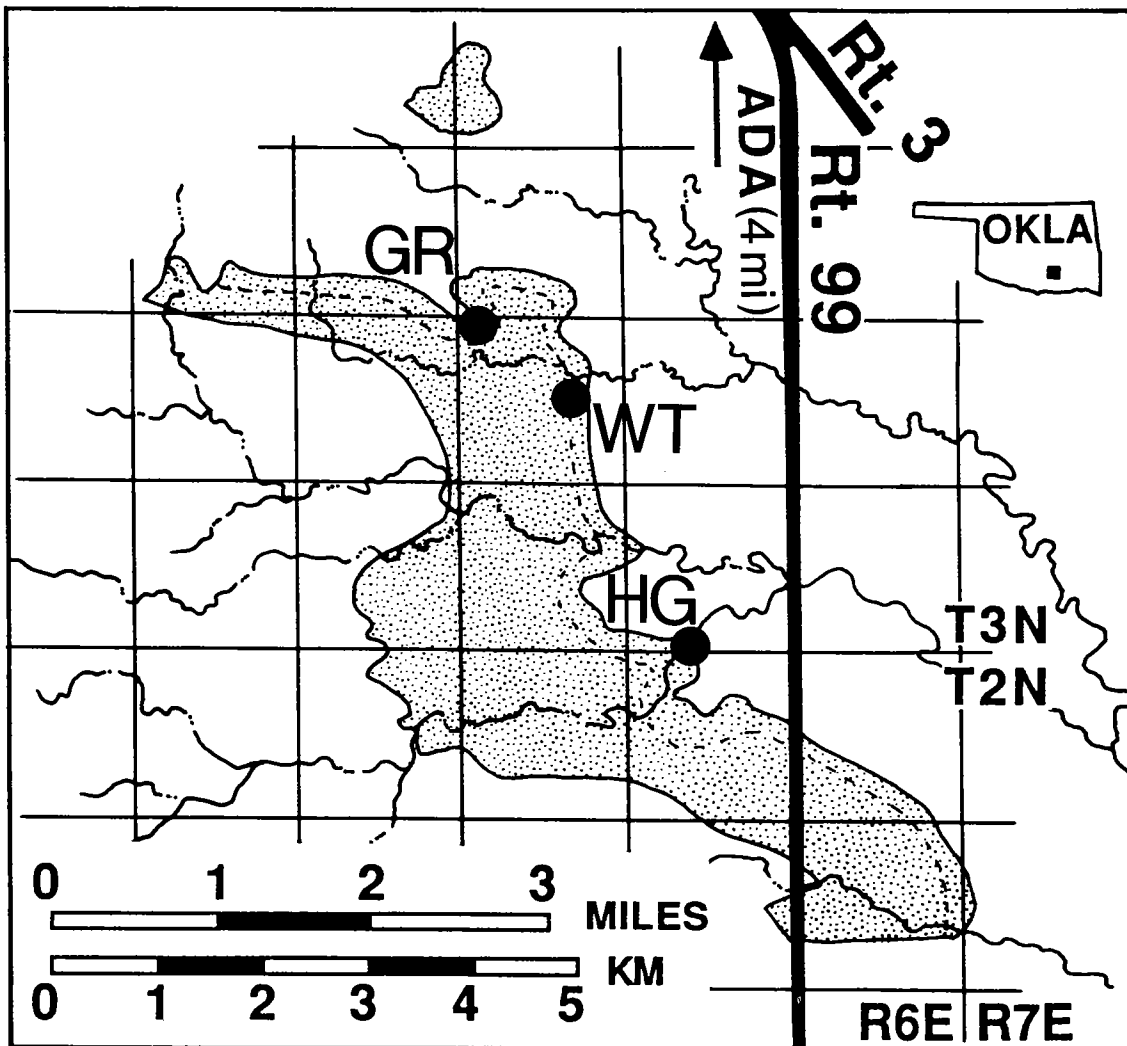
the Lawrence uplift, or is disconformably overlain by the Caney Shale or Sycamore Limestone, the basal beds of which are late Osagean to Meramecian in age (Haywa-Branch and Barrick, this volume).

LOCAL STRATIGRAPHY

On the Lawrence uplift (Text-fig. 1), the Woodford Shale is approximately 80 m thick. The lower Woodford consists of 30 m of black to dark-gray, platy to fissile shale, bearing little phosphate, that weathers light gray in color. The upper Woodford comprises 50 m of black to dark-brown shale characterized by horizons bearing irregular to spherical phosphate nodules. In the top meter of the Woodford, the interval containing the Devonian/Carboniferous boundary, laminae and beds of pelloidal phosphate are common. The upper Woodford on the Lawrence uplift differs from the upper Woodford in the main part of the Arbuckle Mountains, where bedded black cherts constitute more than a third of the unit.

Three measured sections from the Woodford outcrop belt on the Lawrence uplift were collected for conodonts. Each section includes a stratigraphic succession consisting of the uppermost Woodford Shale, the pre-Welden shale, the Welden Limestone, and the lowermost Caney Shale.

The Hass G section (Text-fig. 2), Locality G of Hass and Huddle (1965), is along the southeast bank of the South Fork of Jackfork Creek (SE¹/₄SW¹/₄ sec. 35, T. 3 N., R. 6 E.). The upper 4 m of the Woodford Shale is exposed, overlain by 0.30 m of pre-Welden shale. The Woodford consists of hard, black to dark-brown, thinly laminated shale that weathers into platy fragments. Thin, light-colored, discontinuous phosphatic laminae,



Text-figure 1. Woodford Shale outcrop belt and locations of sections studied on the Lawrence uplift, northeastern Arbuckle Mountains, south-central Oklahoma. GR = Guest Ranch section, WT = Welden type section, HG = Hass G section.

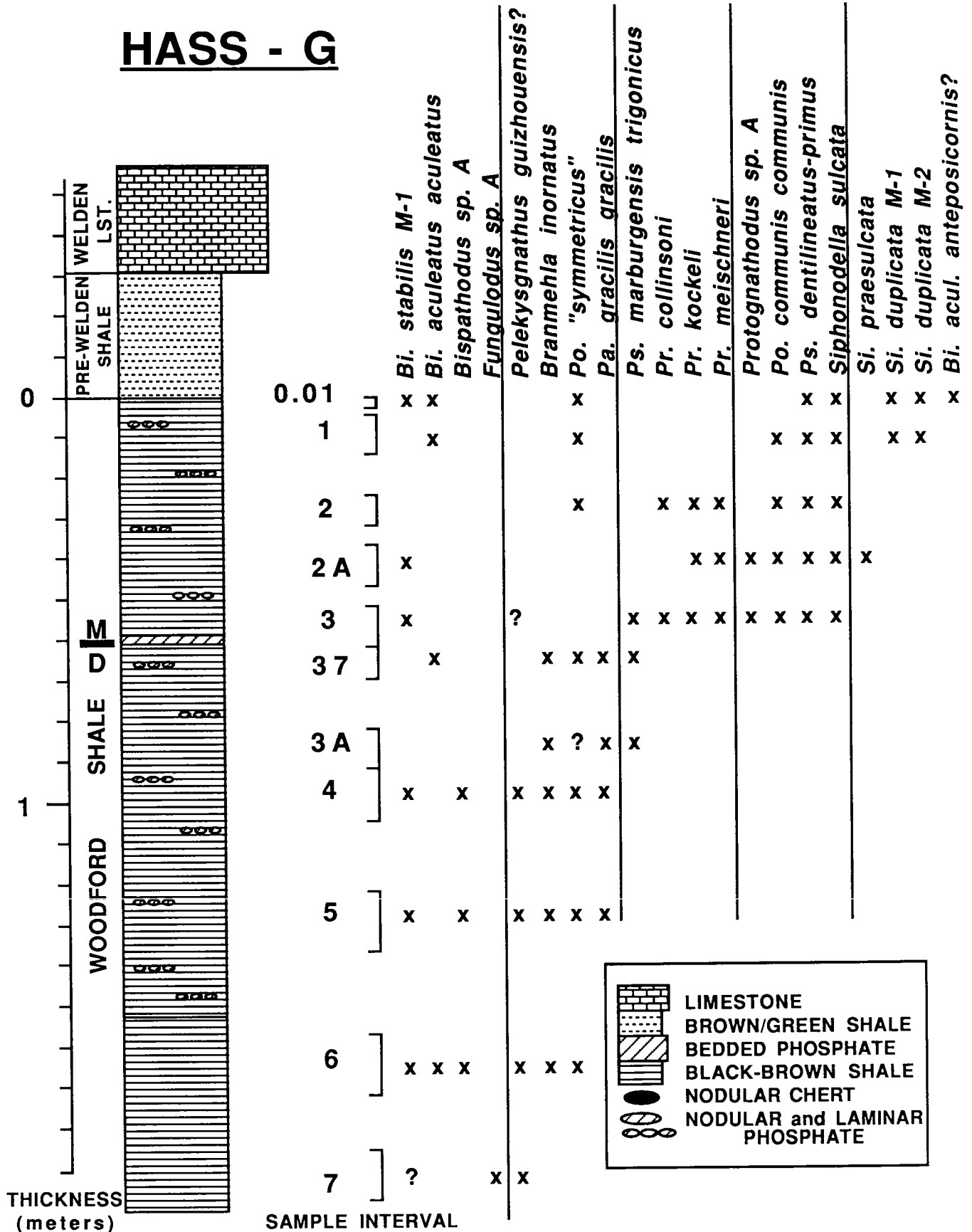
consisting of pelloidal phosphate with a grapestone texture, occur in the upper 1.5 m of the Woodford. These laminae are more common in the upper meter, where a prominent phosphatic bed occurs 0.60 m below the top of the Woodford. Soft green-brown shales of the pre-Welden shale lie with a sharp contact on the black shale of the Woodford.

The Welden type section (Text-fig. 3; Locality C-1 of Hass and Huddle, 1965), is located along an abandoned railroad cut ~2.5 km north-northwest of the Hass G section (SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 27, T. 3 N., R. 6 E.). The upper 1.8 m of the Woodford shale is exposed, overlain by 0.60 m of pre-Welden shale. The Woodford consists predominantly of hard, black to dark-brown, platy shale. Phosphate beds and laminae consisting of light-colored pelloidal phosphate grains occur throughout the exposure; prominent phosphate beds occur 1.12, 0.56, and 0.25 m below the top of the Woodford and at the contact with the pre-Welden shale. The uppermost Woodford consists of soft, brown shale containing phosphatic beds and flattened nodules. Nodular chert

is also present. The contact between the Woodford and the overlying pre-Welden shale is less distinct than at Hass G. The pre-Welden shale consists of soft, green-brown shale similar to that at the Hass G section.

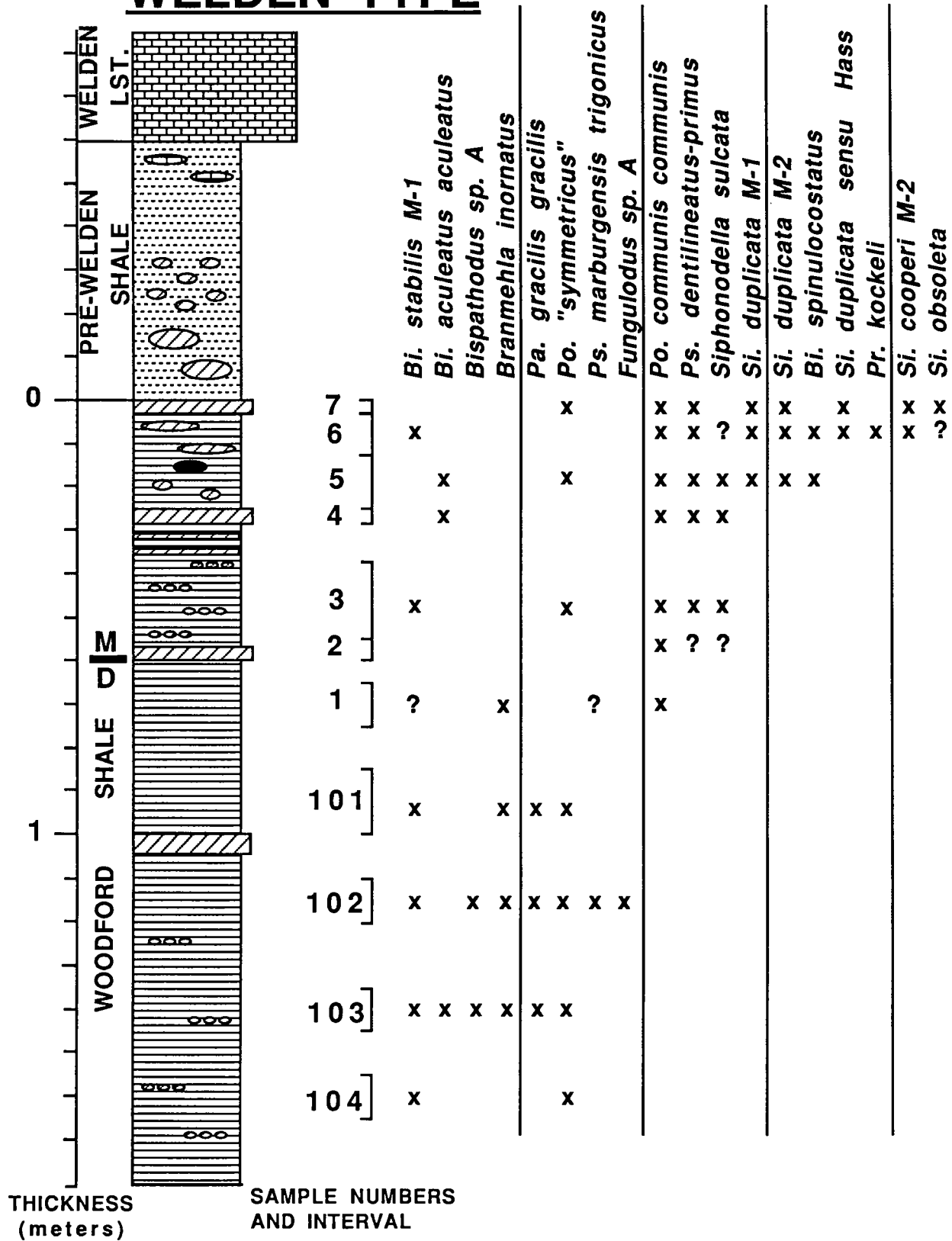
The Guest Ranch section (Text-fig. 4) is located ~1.0 km northwest of the Welden type section (NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 27, T. 3 N., R. 6 E.). The upper 1.6 m of the Woodford Shale is present, overlain by 0.60 m of pre-Welden shale. The Woodford consists of hard, dark-brown to black, platy shale, bearing abundant phosphate laminae and nodules in the lower meter. A thick nodular-phosphate zone occurs 1.35 m below the top of the Woodford in an interval of brown, fissile shale. Hard, brown to black shales continue above this unit and contain abundant phosphate laminae and a distinct phosphate bed 0.60 m below the top of the Woodford. Above this bed, phosphate laminae are less common, with the exception of a nodular zone 0.20 m below the contact of the Woodford and the pre-Welden shale. The pre-Welden shale consists of soft, green to green-brown shale containing discrete phosphate nodules.

HASS - G



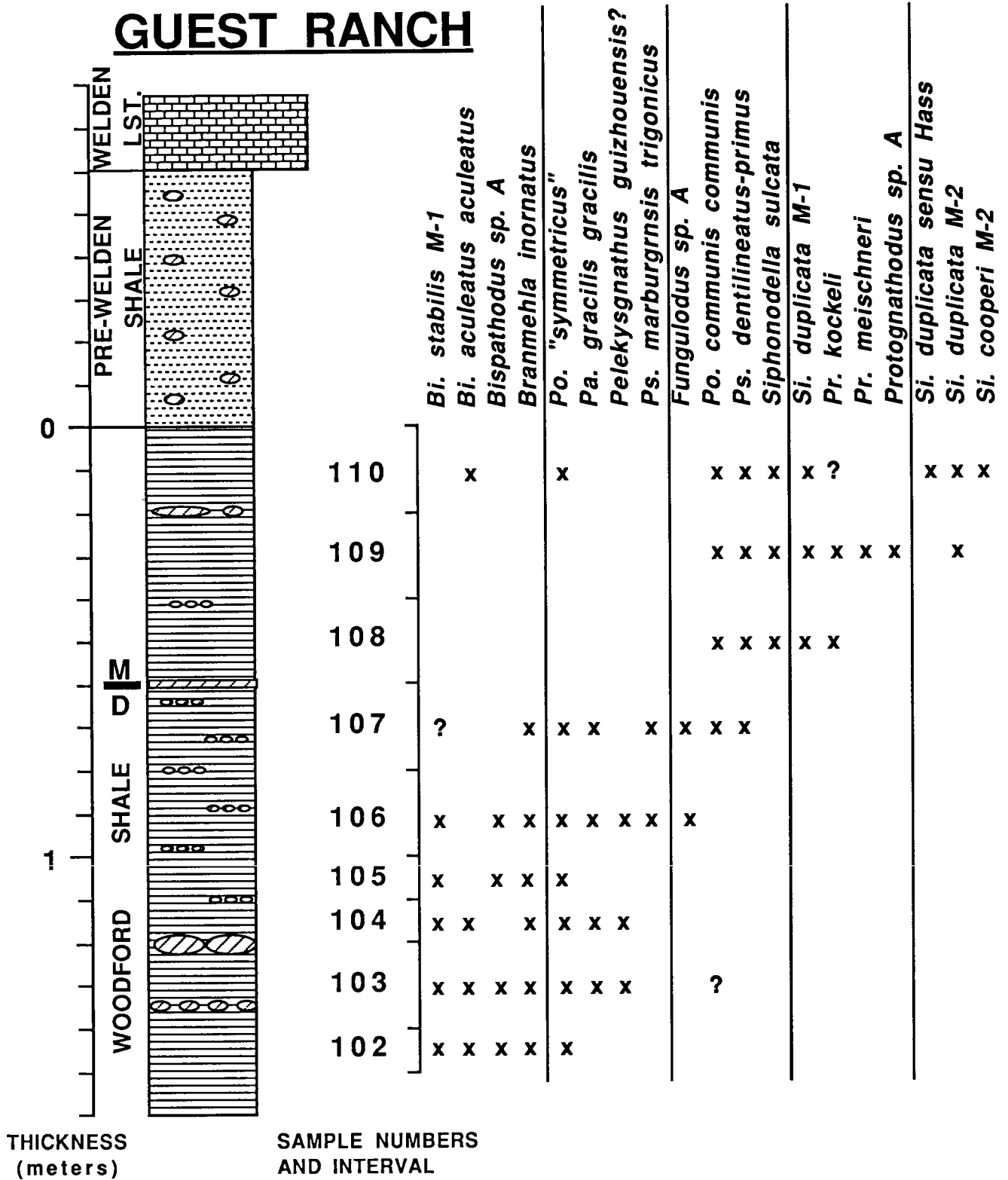
Text-figure 2. Lithologic sequence and conodont distribution in the Woodford Shale at the Hass G section. *Bi.* = *Bispathodus*, *Pa.* = *Palmatolepis*, *Po.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *Si.* = *Siphonodella*.

WELDEN TYPE



Text-figure 3. Lithologic sequence and conodont distribution in the Woodford Shale at the Welden type section. See Text-figure 2 for explanation of symbols. *Bi.* = *Bispathodus*, *Pa.* = *Palmatolepis*, *Po.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *Si.* = *Siphonodella*.

GUEST RANCH



Text-figure 4. Lithologic sequence and conodont distribution in the Woodford Shale at the Guest Ranch section. See Text-figure 2 for explanation of symbols. *Bi.* = *Bispathodus*, *Pa.* = *Palmatolepis*, *Po.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *Si.* = *Siphonodella*.

DEPOSITIONAL SETTING

The black shales, interbedded black cherts, and phosphates of the Woodford Shale represent deep-water deposition on a clastic-starved cratonic margin. Black-shale deposition is likely to occur near or at the oxygen-minimum zone where sediments and overlying waters are dysoxic or anoxic, allowing preservation of organic material. Deposition of the Upper Devonian and Lower Mississippian black shales in oxygen-limited settings has been discussed by Byers (1977), Gutschick and Sandberg (1983), Etensohn and Elam (1985), Beier and Hayes (1989), and others. The faunal assemblage preserved in the Woodford (radiolarians, rare inarticulate brachiopods, ammonoids, nautiloids, sponge spicules, offshore conodonts), coupled with a lack of bioturbation, also suggests an offshore, quiet-water environment.

Phosphate beds and nodules within the upper Woodford Shale are common to sporadic. Phosphate deposition is associated with organic-rich deposits during periods of slow deposition or nondeposition (Slansky, 1986). The phosphate is derived from organic material or from solution in upwelling waters. Accumulations are greatest as interstitial deposition in sediments in dysoxic waters. This suggests that phosphate beds developed during periods of oxygen influx into the depositional area that affected the organic-rich Woodford muds. The presence of uncrushed radiolarians and compaction structures around the nodules and beds demonstrates that phosphate formation occurred prior to compaction of the shale (Siy, 1988). The numerous horizons of pelloidal phosphate in the upper meter of the Woodford and the overlying pre-Welden shale on the Lawrence uplift indicate small disconformities and intervals of nondeposition and erosion within the sequence.

The transition from black to green and brown shale is a function of organic content. The green to green-brown shales of the pre-Welden shale probably represent deposition when bottom waters were oxygenated, resulting in a decrease in the amount of organic material incorporated and preserved in the sediment. The water depth during Woodford deposition—based on time-equivalent strata, modern studies of depth to the oxygen-minimum zone, and phosphatic sedimentation in upwelling areas—is estimated to have been from 50 m to as much as 400 m.

CONODONT FAUNA

The uppermost Woodford contains a well-preserved and diverse conodont fauna of late Famennian and early Kinderhookian age (Text-fig. 5). Conodonts were extracted from the organic-rich black shales using bleach, either alone or in combination with sodium hydroxide (Stone, 1987), to destroy the organic material; the bleached shale was then disaggregated using Stoddard solvent. Abundances of conodont elements are variable, but tend to be greater (>100 Pa elements/kg) across the Devonian/Carboniferous boundary and in

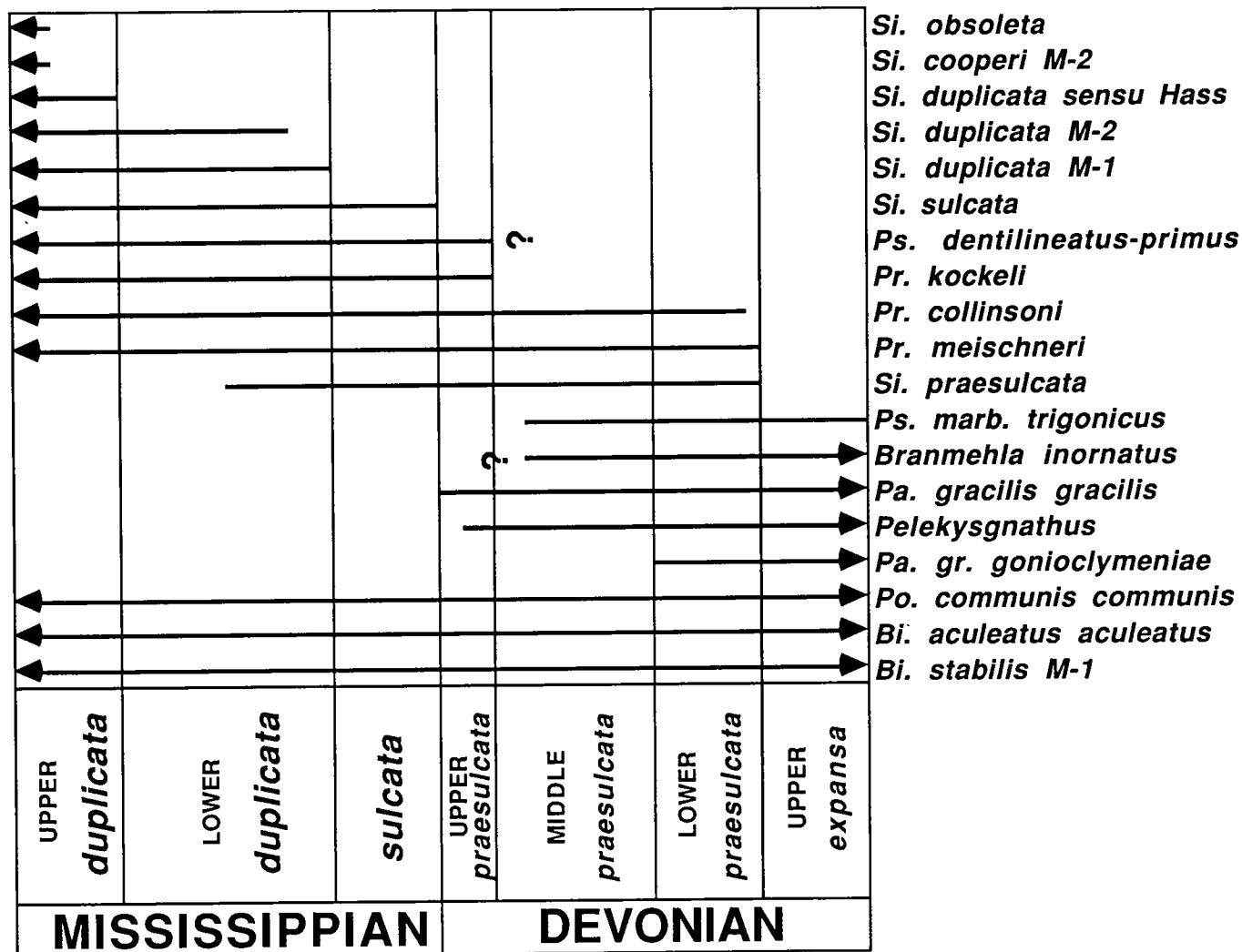
Lower Mississippian strata, where phosphate laminae and beds are more common.

The Late Devonian fauna that occurs near the top of the Woodford Shale is characterized by *Pseudopolygnathus marburgensis trigonicus* Ziegler, *Palmatolepis gracilis gracilis* Branson and Mehl, and ?*Pelekysgnathus guizhouensis* Wang and Wang, but is dominated by species bearing carminate Pa elements in their apparatuses. *Bispathodus stabilis* (Branson and Mehl) Morphotype 1 of Ziegler and others (1974), *Bispathodus aculeatus aculeatus* (Branson and Mehl), and *Branmehla inornatus* (Branson and Mehl) constitute 60–100% of the Pa elements in the Devonian samples. Only one sample, Guest Ranch 107, differs, consisting predominantly of *Ps. marburgensis trigonicus*, *Bispathodus stabilis* Morphotype 1, *Branmehla inornatus*, and *Polygnathus "symmetricus"* Branson, including the morphotypes *Po. longiposticus* Branson and Mehl, *Po. spicatus* Branson, and *Po. symmetricus* Branson. A species of *Fungulodus* Gagiev is also present. *Fungulodus* elements consist of small, squat, ornamented cones, initially described as fish remains by Gagiev (1979), but now interpreted as conodont elements (Wang and Klapper, 1987). *Fungulodus* sp. A is the first representative of the genus recognized in North America.

The range of *Pseudopolygnathus marburgensis trigonicus*, Upper *expansa* Zone through Middle *praesulcata* Zone of Ziegler and Sandberg (1984a), establishes a late, but not latest Famennian age for the highest Devonian fauna.

The *sulcata* Zone is the lowest Carboniferous conodont zone and is defined by the first occurrence of *Siphonodella sulcata* Huddle (Sandberg and others, 1978). Conodonts of the *sulcata* Zone appear abruptly above a Devonian conodont fauna at a prominent phosphate bed at Hass G and the Welden type sections. *Polygnathus communis communis* Branson and Mehl, the *Pseudopolygnathus dentilineatus* Branson–*primus* Branson and Mehl species group, and species of *Protognathodus*, *Pr. collinsoni* Ziegler, *Pr. kockeli* Bischoff, *Pr. meischneri* Ziegler, and *Pr. sp. A* appear at the same stratigraphic level as *S. sulcata*. Other species occurring in the *sulcata* Zone include *B. aculeatus aculeatus*, *B. stabilis* Morphotype 1, *Po. "symmetricus,"* and *Siphonodella praesulcata* Sandberg. At the Guest Ranch section, *Siphonodella duplicata* (Branson and Mehl) Morphotype 1 of Sandberg and others (1978) appears in the same sample (108) as *S. sulcata* (Text-fig. 4). The underlying sample, Guest Ranch 107, contains late Famennian conodonts and two species, *Po. communis communis* and *Ps. dentilineatus*, which appear with *S. sulcata* in the other two sections. It is possible that sample 107 at the Guest Ranch section may include strata of both Devonian and Carboniferous age.

The Lower *duplicata* Zone overlies the *sulcata* Zone. The base of the Lower *duplicata* Zone is defined by the first occurrence of *Siphonodella duplicata* Morphotype 1 (Sandberg and others, 1978). With the exception of *S. praesulcata*, all species present in the *sulcata* Zone range into the Lower *duplicata* Zone. *Bispathodus spinulicostatus* (Branson) appears in this zone. *Protognathodus collinsoni*, *Pr. meischneri*, *Pr. sp. A*, and ?*Bispathodus*



Text-figure 5. Latest Devonian–early Mississippian conodont zonation and ranges of important taxa. *Bi.* = *Bispathodus*, *Pa.* = *Palmatolepis*, *Po.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *Si.* = *Siphonodella*. Information derived from Sandberg and others (1978) and Ziegler and Sandberg (1984a).

aculeatus anteposicornis (Scott) last occur in the Lower *duplicata* Zone.

The Upper *duplicata* Zone is defined by the first occurrence of *Siphonodella cooperi* Hass Morphotype 1 of Sandberg and others (1978), which has not been recovered from the Woodford Shale. Sandberg and others (1978, fig. 1, p. 104) indicated that *S. duplicata sensu Hass* appears at or slightly above the base of the Upper *duplicata* Zone, and this species is used to identify the Upper *duplicata* Zone in the Woodford Shale. Species occurring in the Upper *duplicata* Zone in the Woodford are *S. sulcata*, *S. duplicata* Morphotype 1, *S. duplicata* Morphotype 2 of Sandberg and others (1978), *S. cooperi* Hass Morphotype 2 of Sandberg and others (1978), *S. obsoleta* Hass, *Bispathodus aculeatus aculeatus*, *B. spinulicostatus*, *B. stabilis* Morphotype 1, *Po. communis communis*, *Po. "symmetricus"*, and the *Pseudopolygnathus dentilineatus-primus* group.

CONODONT BIOFACIES

The Late Devonian conodont fauna of the upper few meters of the Woodford on the Lawrence uplift is similar to the late Famennian palmatolepid–bispathodid biofacies of Sandberg (1976; Sandberg and Ziegler, 1979; Ziegler and Sandberg, 1984a). *Bispathodus stabilis* and species of genera morphologically similar to *Bispathodus*, such as *Branmehla* and *Mehlina*, dominate this biofacies. The palmatolepid–bispathodid biofacies occurs in strata of the continental rise and slope in the western United States, as well as in deep-water settings in West Germany (Sandberg, 1976). The Woodford fauna is strongly dominated by elements of *Bispathodus stabilis*, other *Bispathodus* species, and *Branmehla*, but elements of *Polygnathus "symmetricus"* and *Pelekysgnathus guizhouensis?* are more abundant than those of *Palmatolepis* (Table 1). Species of *Bispathodus* and similar

TABLE 1. DISTRIBUTION OF PA AND I ELEMENTS OF CONODONTS FROM THE UPPERMOST WOODFORD SHALE

		<i>Bi. aculeatus aculeatus</i>	<i>Bi. aculeatus anteposicornis?</i>	<i>Bi. spinullocostatus</i>	<i>Bi. stabilis M-1</i>	<i>Bispathodus sp. A</i>	<i>Branmehia inornatus</i>	<i>Branmehia sp. A</i>	other carminate Pa elements	<i>Fungulodus sp. A</i>	<i>Pa. gracilis gracilis</i>	<i>Pelekysgnathus guizhouensis?</i>	<i>Po. communis communis</i>	<i>Po. "symmetricus"</i>	other Polygnathus species	<i>Pr. collinsoni</i>	<i>Pr. meischneri</i>	<i>Pr. kockelli</i>	<i>Protognathodus sp. A</i>	<i>Ps. dentilineatus-primus</i>	<i>Ps. marburgensis trigonicus</i>	<i>Si. cooperi M-2</i>	<i>Si. duplicata M-1</i>	<i>Si. duplicata M-2</i>	<i>Si. duplicata sensu Hass</i>	<i>Si. obsoleta</i>	<i>Si. praesulcata</i>	<i>Si. sulcata</i>	SAMPLE WEIGHT (GRAMS)	YIELD (PA ELEMENTS/KG)
Hass G	0.01	3	2	-	9	-	-	-	-	-	-	-	2	1	-	-	-	-	18	-	-	6	13	-	-	-	15	50	>5000	
	1	37	-	-	-	-	-	-	-	-	-	96	36	-	-	-	-	-	24	-	-	36	55	-	-	-	22	150	5090	
	2	-	-	-	-	-	-	-	-	-	-	124	-	2	2	15	6	-	20	-	-	-	-	-	-	6	1200	600		
	2A	-	-	-	3	-	-	-	-	-	-	17	1	-	-	2	8	2	21	-	-	-	-	-	-	1	1500	200		
	3	-	-	-	11	-	-	-	-	-	-	(1)	48	-	3	2	10	4	9	3	-	-	-	-	-	-	6	2800	68	
	3A	-	-	-	-	2	-	-	-	-	1	-	-	2	-	-	-	-	-	-	10	-	-	-	-	-	-	2100	41	
	4	-	-	-	6	2	3	-	36	-	4	(2)	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	1300	38	
	5	-	-	-	136	5	26	-	23	-	4	1	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	1600	108	
6	2	-	-	34	7	8	-	28	-	-	(4)	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-	1600	50		
7	-	-	-	?	-	-	-	2	1	-	(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1600	6		
Weiden Type	7	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-	x	-	x	x	x	x	x	-	-	1000	>5000	
	6	-	-	1	2	-	-	-	-	-	-	7	-	-	-	-	1	-	2	-	6	17	112	5	?	-	-	1000	>5000	
	5	33	-	2	5	-	-	-	-	-	-	22	29	10	-	-	-	-	30	-	-	40	35	?	-	-	8	850	240	
	4	1	-	-	-	-	-	-	-	-	-	31	4	-	-	-	-	-	3	-	-	-	-	-	-	-	8	1000	50	
	3	-	-	-	5	-	-	-	-	-	-	59	1	-	-	-	-	-	5	-	-	-	-	-	-	-	16	900	100	
	2	-	-	-	-	-	-	-	1	-	-	7	-	-	-	-	-	-	2	-	-	-	-	-	-	-	1	900	12	
	1	-	-	-	?	-	4	-	21	-	-	1	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	1000	37	
	101	-	-	-	10	-	1	-	12	-	7	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	1200	40	
	102	-	-	-	15	5	13	-	29	2	5	-	-	11	-	-	-	-	-	1	-	-	-	-	-	-	-	1400	56	
	103	3	-	-	9	1	4	2	2	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1000	24	
104	-	-	-	5	-	?	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1300	6		
Guest Ranch	110	2	-	-	-	-	-	4	-	-	-	6	10	-	-	-	?	-	6	-	3	24	6	5	-	-	-	750	>5000	
	109	-	-	-	-	-	-	-	-	-	-	23	7	-	1	2	2	14	-	-	2	2	-	-	-	-	41	750	130	
	108	-	-	-	-	-	-	-	-	-	-	42	2	-	-	1	-	16	-	-	3	-	-	-	-	22	800	114		
	107	-	-	-	?	-	5	-	1	1	-	3	9	-	-	-	-	-	2	19	-	-	-	-	-	-	-	900	50	
	106	-	-	-	23	4	6	-	8	2	4	1	5	-	-	-	-	-	-	3	-	-	-	-	-	-	-	900	60	
	105	-	-	-	8	6	6	-	3	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	750	40	
	104	7	-	-	18	21	21	-	28	-	2	2	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	500	170	
	103	2	-	-	16	2	5	-	3	-	1	1	?	8	-	-	-	-	-	-	-	-	-	-	-	-	-	500	75	
102	1	-	-	6	1	1	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	500	22		

Notes: () indicates coniform elements of *Pelekysgnathus*. *Bi.* = *Bispathodus*; *Pa.* = *Palmatolepis*, *Po.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *Si.* = *Siphonodella*. Localities are shown in Text-figure 1.

genera are interpreted to have lived in the euphotic zone in the highest part of the water column. Thus, they occur widely, independent of bottom conditions, in all but the most nearshore, restricted environments (Ziegler and Sandberg, 1984a). *Polygnathus* "symmetricus" should be characteristic of the more nearshore palmatolepid-polygnathid biofacies, which Sandberg (1976) reported from shallow to moderately deep water on the continental shelf. However, Sandberg and Dreesen (1984) interpreted pelekysgnathids to be nearshore genera that lived in water depths so shallow

that the habitat was controlled by substrate conditions. The presence of *Pelekysgnathus guizhouensis?* in a bispathodid-dominated biofacies is puzzling, but the species must have been able to exist in a quiet-water setting of at least moderate depth that was characterized by a low sedimentation rate and dysoxic to anoxic bottom waters.

Species of five genera dominate Lower Mississippian samples from the Woodford Shale: *Bispathodus*, *Polygnathus*, *Protognathodus*, *Pseudopolygnathus*, and *Siphonodella*. In all collections, elements of *Siphonodella*

species and *Po. communis communis* constitute 40–80% of the fauna. Like *Bispathodus stabilis*, *Po. communis communis* is interpreted to have been pelagic, living in the euphotic zone (Sandberg and Gutschick, 1979). Ziegler and Sandberg (1984a, p. 185) stated that *Siphonodella* was an offshore, pelagic genus, and *Pseudopolygnathus* is interpreted to have been a nektobenthic dweller in regions of the shelf-slope transition in the western United States (Sandberg and Gutschick, 1979). In contrast, *Protognathodus* species occur nearer shore than siphonodellids (Ziegler, 1969; Ziegler and Sandberg, 1984b). This mixture of conodont species in the Woodford Shale on the Lawrence uplift appears to represent a Lower Mississippian transitional biofacies of offshore and nearshore taxa.

THE DEVONIAN/CARBONIFEROUS BOUNDARY

A conspicuous phosphate bed, at or just below the occurrence of the oldest Mississippian (Kinderhookian) conodonts, marks the base of the Carboniferous in the Woodford on the Lawrence uplift. The persistence of this bed between the sections, representing erosion or non-deposition, suggests that the Devonian/Carboniferous boundary is disconformable in the Woodford Shale. At least the Upper *praesulcata* Zone appears to be missing at the unconformity. *Siphonodella praesulcata*, *Protognathodus* species, and *Pseudopolygnathus denti-*

lineatus do not occur below *S. sulcata* in the Woodford. These forms are present in strata of the Upper *praesulcata* Zone (approximately equivalent to the *Protognathodus* biofacies) at several candidate sections for the boundary stratotype (Ziegler and others, 1988), and in other sections (see papers in Flajs and others, 1988). *Palmatolepis gracilis gonioclymeniae* Müller, the extinction of which marks the base of the Middle *praesulcata* Zone, was not recovered from the upper Woodford. Its absence suggests that the top of the Woodford may range into the Middle *praesulcata* Zone.

The presence of an unconformity at the base of the Carboniferous in the Woodford on the Lawrence uplift is similar to the situation at many other sections that cross the Devonian/Carboniferous boundary. A eustatic fall in sea level produced shallow-water sedimentation, changes of lithology, or gaps in deposition from the upper part of the Middle *praesulcata* Zone into the Upper *praesulcata* Zone in most areas (Ziegler and others, 1988). This is the same interval of time that appears to be missing in the Woodford sections.

ACKNOWLEDGMENTS

The authors wish to thank the Donors of the Petroleum Research Fund, administered by the American Chemical Society (Grant 17283AC), for support of this research.

PLATE 1

Conodonts from Devonian (Figs. 7,8,11,14–26) and Mississippian (Figs. 1–6,9,10,12,13) strata of the upper Woodford Shale, Lawrence uplift, Pontotoc County, Oklahoma. Specimens are repositied in the paleontology collections of the University of Iowa (SUI).

Figure 1.—*Siphonodella cooperi* Hass, 1959 Morphotype 2 of Sandberg and others (1978); upper view of Pa element, $\times 60$ (SUI 54895); Guest Ranch section, sample 110, 0.0–0.20 m below top of Woodford.

Figures 2,3.—*Siphonodella duplicata* (Branson and Mehl, 1934) Morphotype 1 of Sandberg and others (1978). 2, upper view of Pa element, $\times 40$ (SUI 54896). 3, lower view of Pa element, $\times 40$ (SUI 54897). Welden type section, sample 5, 0.12–0.25 m below top of Woodford.

Figures 4,5.—*Siphonodella sulcata* (Huddle, 1934). 4, lower view of Pa element, $\times 60$ (SUI 54898). 5, upper view of Pa element, $\times 60$ (SUI 54899). Guest Ranch section, sample 108, 0.40–0.60 m below top of Woodford.

Figure 6.—*Pseudopolygnathus dentilineatus* Branson, 1934. Upper view of Pa element, $\times 40$ (SUI 54900). Guest Ranch section, sample 108, 0.40–0.60 m below top of Woodford.

Figure 7.—*Branmehla* sp. A. Inner lateral view of Pa element, $\times 70$ (SUI 54901). Welden type section, sample 103, 1.35–1.45 m below top of Woodford.

Figure 8.—*Protognathodus kockeli* Bischoff, 1957. Upper view of Pa element, $\times 70$ (SUI 54902). Hass G section, sample 2a, 0.35–0.47 m below top of Woodford.

Figure 9.—*Protognathodus* sp. A. Upper view of Pa element, $\times 90$ (SUI 54903). Hass G section, sample 2a, 0.35–0.47 m below top of Woodford.

Figures 10,11,14–16.—?*Pelekysgnathus guizhouensis* Wang and Wang, 1978. 10, inner lateral view of coniform element, $\times 110$ (SUI 54904). 11, inner lateral view of coniform element, $\times 110$ (SUI 54905). 16, lateral view of coniform element, $\times 110$ (SUI 54906). Hass G section, sample 5, 1.10–1.25 m below top of Woodford. 14, upper view of I element, $\times 70$ (SUI 54907). 15, outer lateral view of I element, $\times 70$ (SUI 54908). Ryan Shale Pit section (1 km south of Hass G section), 28 m below top of Woodford.

Figures 12,13.—*Bispathodus aculeatus aculeatus* (Branson and Mehl, 1934). 12, upper view of Pa element, $\times 40$ (SUI 54909). 13, inner lateral view of Pa element, $\times 40$ (SUI 54910). Hass G section, sample 1, 0.03–0.12 m below top of Woodford.

Figures 17,18.—*Bispathodus stabilis* (Branson and Mehl, 1934) Morphotype 1 of Ziegler and others (1974). 17, upper view of Pa element, $\times 70$ (SUI 54911). 18, inner lateral view of Pa element, $\times 70$ (SUI 54912). Welden type section, sample 103, 1.35–1.45 m below top of Woodford.

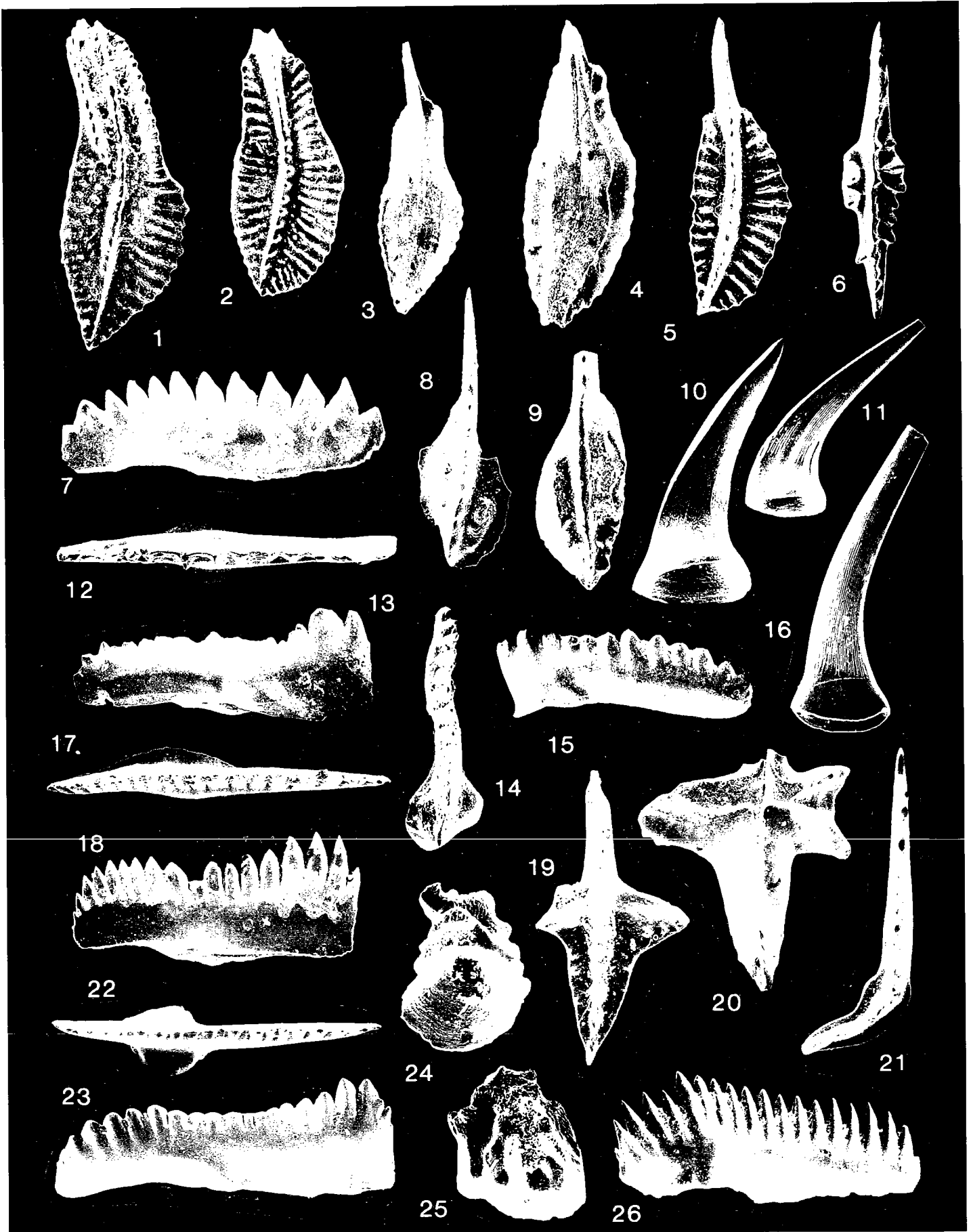
Figures 19,20.—*Pseudopolygnathus marburgensis trigonicus* Ziegler, 1962. 19, upper view of Pa element, $\times 70$ (SUI 54913). 20, lower view of Pa element, $\times 70$ (SUI 54914). Guest Ranch section, sample 107, 0.60–0.80 m below top of Woodford.

Figure 21.—*Palmatolepis gracilis gracilis* Branson and Mehl, 1934; upper view of Pa element, $\times 40$ (SUI 54915). Hass G section, sample 4, 0.80–0.92 m below top of Woodford.

Figures 22,23.—*Bispathodus* sp. A. 22, upper view of Pa element, $\times 40$ (SUI 54916). 23, outer lateral view of Pa element, $\times 40$ (SUI 54917). Welden type section, sample 102, 1.10–1.20 m below top of Woodford.

Figures 24,25.—*Fungulodus* sp. A. 24, lower anterior view of coniform element, $\times 120$ (SUI 54918). 25, upper posterior view of coniform element, $\times 100$ (SUI 54919). Welden type section, sample 102, 1.10–1.20 m below top of Woodford.

Figure 26.—*Branmehla inornatus* (Branson and Mehl, 1934). Inner lateral view of Pa element, $\times 70$ (SUI 54920). Welden type section, sample 103, 1.35–1.45 m below top of Woodford.



Conodont Biostratigraphy of the Welden Limestone (Osagean, Mississippian), Lawrence Uplift, Southern Oklahoma

Jill N. Haywa-Branch and James E. Barrick

ABSTRACT.—The Welden Limestone of the Lawrence uplift, south-central Oklahoma, is a small remnant of the starved magnafacies of Lane and De Keyser (1980) which formed in deeper water, basinward of prograding Osagean carbonate shelves. The Welden comprises <2 m of trilobite and ostracode wackestones and packstones that contain abundant lower to middle Osagean conodonts of the Lower *typicus* through *anchoralis-latus* Zones of Lane and others (1980). It rests conformably on the pre-Welden shale (late Kinderhookian, *isosticha*–Upper *crenulata* Zone). The Welden is unconformably overlain by the Caney Shale (*texanus* Zone, late Osagean–early Meramecian?), except possibly at the Hass G section, where conodonts of the upper part of the *anchoralis-latus* Zone occur at the base of the Caney. No strata equivalent in age to Welden can be shown to exist elsewhere in the Arbuckle Mountains; carbonate beds at the base of the Sycamore Limestone contain conodonts of the *texanus* Zone and are equivalent in age to the base of the Caney Shale on the Lawrence uplift.

INTRODUCTION

The Welden Limestone is a thin (<2 m) Mississippian carbonate unit that is exposed in only a small area of the Lawrence uplift of south-central Oklahoma (Figs. 1,2). Although the Welden Limestone has been recognized since the early mapping work of Morgan (1924), its age is poorly documented, and its stratigraphic and paleogeographic significance not well understood. With recent improvements in our understanding of Mississippian conodont taxonomy and biostratigraphy (Lane and others, 1980; Chauff, 1981,1983) and Mississippian paleogeography (Lane, 1978; Lane and DeKeyser, 1980; Gutschick and Sandberg, 1983), it is now possible to better place the Welden and its abundant and diverse conodont fauna in a regional stratigraphic framework.

PREVIOUS STUDIES

In his report on the geology of the Stonewall Quadrangle, Morgan (1924) used the name "Sycamore Limestone" for the thin limestone that crops out above the Woodford Shale and below the Caney Shale on the Lawrence uplift. The Sycamore Limestone had originally been proposed by Taff (1903) to designate a thicker unit consisting of as much as 60 m of calcareous sandstones, limestones, and minor shale that lies above the Woodford and below the Caney in the central Arbuckle Mountains, 75 km southwest of the Lawrence uplift. Morgan collected a megafauna from the "Sycamore" at his locality 73 (E¹/₂ sec. 11, T. 2 N., R. 6 E.; Fig. 2) that was submitted to Charles Schuchert for analysis. Although index forms were absent, Schuchert (in Morgan, 1924, p. 50) decided that the fauna was Kinder-

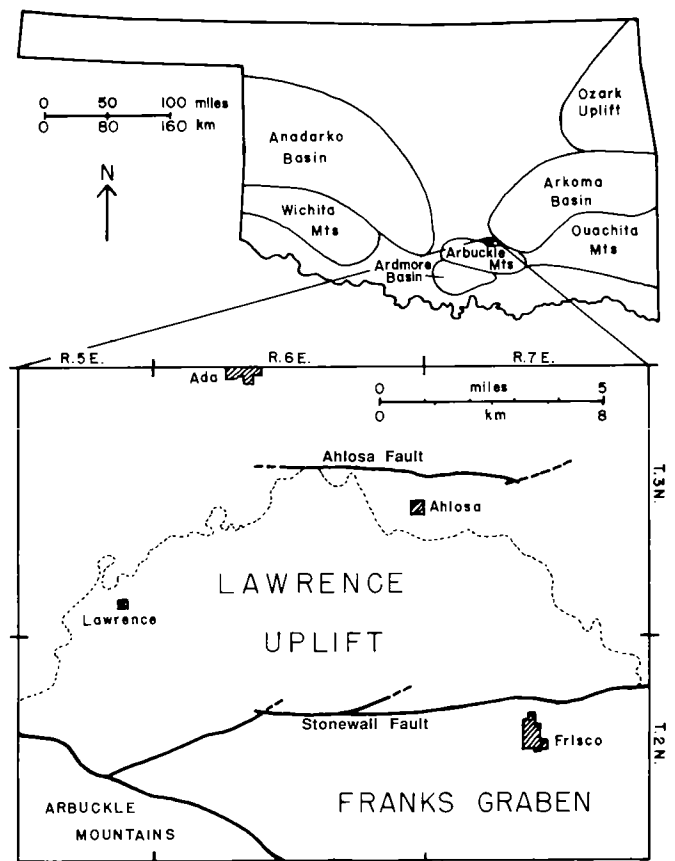


Figure 1. Map showing major geologic provinces of Oklahoma relative to the Arbuckle Mountains and a detailed view of the Lawrence uplift in the northeastern Arbuckle Mountains.

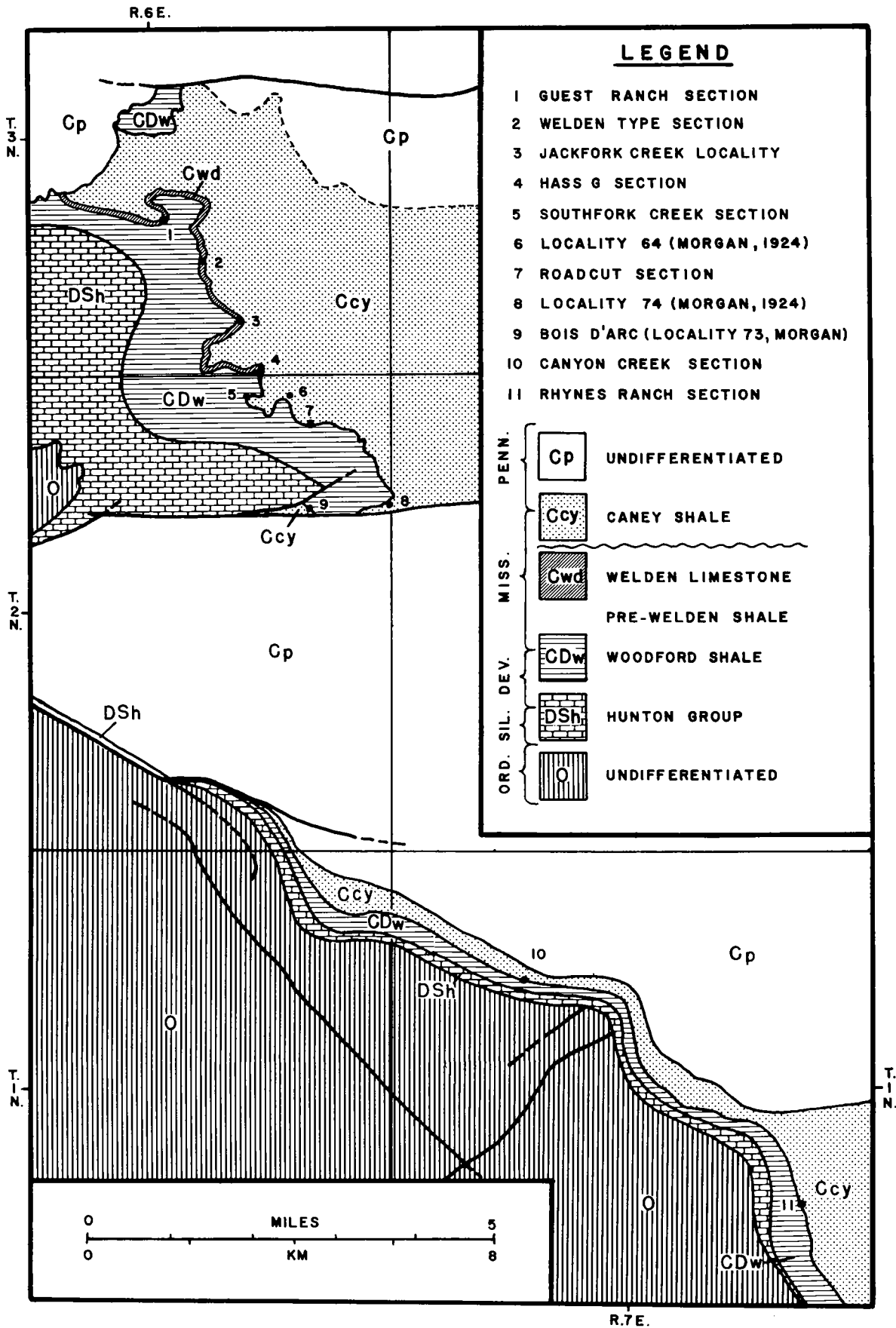


Figure 2. Geologic map of part of the Lawrence uplift, showing the outcrop belt of the Welden Limestone and adjacent strata. Refer to Figure 1 for regional setting of map. Modified from Decker and others (1931).

hookian in age. Morgan disagreed with Schuchert's age assignment and believed that faunas recovered from adjacent beds (underlying upper Woodford? and overlying lower Caney) were equivalent to Moorefield and Fayetteville faunas (Meramecian) in Arkansas. For this reason, Morgan decided that the "Sycamore" of the Lawrence uplift was Meramecian in age.

Cooper, on a map of the Arbuckle Mountains prepared by Decker and others (1931), first used the name Welden Limestone to designate the "Sycamore" of the Lawrence uplift. The name was apparently derived from Welden Creek (sec. 22, T. 3 N., R. 6 E.; Huffman and Barker, 1950). On the explanation of this map, Cooper placed the Welden below the Sycamore Limestone, indicating that the Welden was older than the Sycamore.

Eight years later, Cooper (1939) described the conodont fauna from the thin green shale underlying the Welden Limestone, the "pre-Welden shale", and correlated this fauna with the Bushburg and Hannibal Formations of Missouri, giving the pre-Welden shale a middle Kinderhookian age. Cooper designated a railroad cut in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 27, T. 3 N., R. 6 E., as the type section for the Welden Limestone. Girty (in Cooper, 1939) correlated the Welden Limestone with the crinoidal limestone of the Chappel Limestone in San Saba County, Texas, based on macrofossils collected from the Welden type section by Cooper and Girty in 1929. Girty further observed that the fauna collected from the overlying lower Caney limestone beds was the same as that found in the Sycamore Limestone, and concluded that the Sycamore is younger than the Welden. However, Cooper (1939) disagreed with Girty's conclusions and placed the Sycamore in the Kinderhookian. He claimed that Girty's conclusions were based on the mistaken belief that the lower Caney limestone beds were correlative with the Sycamore. Cooper proposed that the Welden was younger than the Sycamore and claimed that the Welden could be as young as the St. Louis (middle Meramecian) based on the conodonts present in the pre-Welden shale, which he placed as high as the Salem (middle Meramecian).

Branson and Mehl (1941a) collected a conodont fauna from shales immediately overlying the Welden Limestone on the South Fork of Jackfork Creek (Hass G section, Hass and Huddle, 1965; SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 35, T. 3 N., R. 6 E.). A new conodont genus, *Staurognathus*, and several new species were described, but no exact age assignment was proposed. Branson and Mehl designated the specimens as coming from the Sycamore, but acknowledged that some workers would describe the collection as coming from the lower Caney Shale, or equivalent Mayes Shale (a term used in the Ozark Region).

Barker (1951) considered the Welden Limestone to be Kinderhookian in age, based on megafaunal evidence collected at his localities 2 (SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 35, T. 3 N., R. 6 E.; Fig. 2, near locality 3) and 6 (Morgan's locality 73). Several genera and species of brachiopods and trilobites obtained from at least one of these localities were known from the Chappel Limestone in Texas (*Proetus roundyi* Girty, *P. roundyi depressus* Girty, *Selenella?*

subcircularis Girty, *Cholentina subcarninata* Girty, and *Rhipiomella perminuta* Girty). Because the Chappel Limestone had been correlated with the Chouteau Limestone of Missouri, which is Kinderhookian in age, Barker correlated the Welden with the Chouteau. However, one species of brachiopod reported from the Welden, *Brachythyris suborbicularis* Hall, was considered to be a characteristic Osagean species.

Hass (1959) collected a conodont fauna from the lower 0.2 m of the Welden Limestone and the upper part of the pre-Welden shale at the Welden type section. Using this information, conodont faunas from the Chappel Limestone, and data from the pre-Welden Shale (Cooper, 1939) and the shale overlying the Welden (Branson and Mehl, 1941a), Hass correlated the Welden with that part of the Chappel assigned to his *Gnathodus punctatus* Zone of late Kinderhookian (Chouteau) age.

Gutschick and others (1961) described 20 species of agglutinated foraminifers from the Welden Limestone at two localities, the Welden type section and along Jackfork Creek near Barker's locality 2. The Welden fauna was compared with faunas from the Chappel Limestone, Rockford Limestone of Indiana, and Lodgepole Limestone of Montana. Their correlation chart (text-fig. 1) shows the Welden Limestone to be Kinderhookian in age, but the age assignment is not discussed.

Hessler (1963, 1965) reported several species of trilobites from the Welden Limestone, which he compared closely with forms from the Chappel Limestone and Chouteau Limestone of central Missouri. However, the source of his collections was not given in these papers.

As part of a restudy of the Chappel conodont faunas, Hoyle (1978) collected conodonts from the upper part of the Welden at the type section and near locality 2 of Barker (1951) on Jackfork Creek. Hoyle recognized three conodont zones in the Chappel Limestone, the lower Zone 1 being uppermost Kinderhookian, and Zones 2 and 3 being lower Osagean. In the upper Welden at the type section, only Zone 3 conodonts were reported. No conodonts were obtained from the Jackfork Creek locality.

The term "Welden Limestone" has been used occasionally outside of the Lawrence uplift area. Champlin (1959) reported 15 cm of limestone in the southern Arbuckle Mountains (Courtney Creek) overlying 30 cm of glauconitic shale that rests on the Woodford Shale. He called this limestone the Welden and correlated it with the Welden Limestone in its type area, based on stratigraphic position and lithologic similarities. Previously, Cooper (1931) had placed this interval in the lower part of the Sycamore Limestone. A similar limestone also occurs near the base of the Sycamore in the northern Arbuckle Mountains (unit 28 of Fay, 1969, 1989), which Ormiston and Lane (1976) correlated with the Welden, based on stratigraphic position, lithology, and its conodont fauna. The Welden Limestone has been reported from the subsurface of the Anadarko and Ardmore basins by a number of workers (Bennison, 1956; Prestidge, 1959; Braun, 1959; Chenoweth and others, 1959; Culp, 1961). In each case the subsurface Welden was described as 18–21 m of argillaceous lime-

stones interbedded with gray, platy shales overlying the black shales of the Woodford Shale.

STRATIGRAPHY

Morgan (1924) and Cooper (1939) showed the Welden Limestone as cropping out in a narrow winding belt on the Lawrence uplift, starting in sec. 20, T. 3 N., R. 6 E., and extending southwest into sec. 12, T. 2 N., R. 6 E., where the outcrop belt is terminated by the Stonewall fault (Fig. 2). A second belt of pre-Pennsylvanian strata that was shown to include the Welden originates southeast of the Franks graben (sec. 2, T. 2 N., R. 6 E.) and stretches farther to the southeast before disappearing. Kuhleman (1951) demonstrated that the Welden is completely absent south of the Franks graben and that basal calcareous strata of the Caney rest directly on the Woodford Shale. Despite Kuhleman's evidence, other workers (Bennison, 1956; Champlin, 1959) have reported the Welden as occurring southeast of the Franks graben.

During field work for this study, we could identify with certainty only three outcrops of Welden Limestone (Fig. 2): (1) the Welden type section; (2) the Guest Ranch section, an outcrop in an abandoned railroad cut 1 km northwest of the type section (NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 27, T. 3 N., R. 6 E.); and (3) the Hass G section, along the South Fork of Jackfork Creek. We examined the locations of the two macrofossil localities of Morgan (1924, locality 73) and Barker (1951, localities 2,6), but at both localities the beds were so poorly exposed that we could not be confident that the Welden was present.

At each of our three sections, the Welden Limestone is a medium-bedded, slightly argillaceous, bluish-gray limestone that weathers light-brown to yellow. It forms a distinct ledge that separates the Woodford slope from the slope of the Caney. The proportion of argillaceous material varies little, and no shaly interbeds are present. However, at the Hass G section a thin interval in the middle of the Welden is more thinly bedded and weathers more deeply than the rest of the limestone. The thickness of the Welden varies only slightly among the sections: Guest Ranch, 0.85 m; Welden type section, 1.35 m; Hass G, 1.40 m.

In thin-section, the Welden Limestone is primarily a biowackestone with some intervals of biopackstone and biograinstone. Skeletal fragments of trilobites and ostracodes dominate, and remains of bryozoans, brachiopods, pelmatozoans, and foraminifers are common. No obvious petrographic facies differences exist among the sections. Some evidence of erosional events within the Welden is present in the upper part of the Welden at the Hass G section. In a sample 0.30–0.35 m from top, an irregular boundary separates the typical biowackestone from an overlying biopackstone layer. Between these two textures is an interval less than a millimeter thick in which skeletal grains and borings are mineralized. Because no truncated grains were observed, it is not certain whether this presents a true hardground surface. Orth and others (1988) reported two levels of unusually high concentrations of noble metals in the Welden Limestone at the Hass G section, 0.10 m from

the base and 0.11 m from the top, the origin of which is not clear.

The Welden Limestone rests with a sharp, nongradational contact on the green-gray clay shale of the pre-Welden shale at each section. The pre-Welden shale is <0.6 m thick, and overlies the black phosphatic shales of the Woodford Shale. The Caney Shale rests with a sharp, nongradational contact on the Welden. At the Guest Ranch and Welden type sections the base of the Caney consists of brownish-gray clay shale that is partially covered by vegetation. The base of the Caney at the Hass G section includes a basal interval (0.25 m) of glauconitic sandy and silty shale, followed by brown clay shale (0.30 m) that is overlain by a distinctive green-gray clay shale (0.20 m). The next few meters of partial exposure consist of dark-brown, silty shales and silty, argillaceous carbonates.

Just south of the Hass G section, on the high bank overlooking the South Fork of Jackfork Creek (Southfork section, Fig. 2), the Welden Limestone disappears, and the basal beds of the Caney rest directly on the Woodford Shale. Above the black, phosphatic shale of the Woodford lies a thin interval of greenish-gray glauconitic shale (0.15 m) capped by a thin (0.05 m) bed of phosphatic sand. Above the phosphate layer, the dark-brown, silty shale characteristic of the Caney is present. In all good exposures south of the Southfork section, no Welden Limestone is present, but thinly bedded, yellow-weathering, argillaceous carbonate beds may occur above the greenish-gray, glauconitic shale (e.g., Kuhleman, 1951). The fresh surfaces of these limestones vary from yellow-brown to dark brown, in the latter cases emitting a fetid odor when broken. The basal Caney carbonates are strongly discontinuous, and at some localities (e.g., Canyon Creek, Fig. 2), dark Caney Shale rests directly on the Woodford. One of the Welden macrofossil localities (73 of Morgan, 1924; 6 of Barker, 1951) lies south of where we believe the Welden disappears, and at a nearby exposure (locality 74 of Morgan, CE $\frac{1}{2}$ sec. 12, T. 2 N., R. 6 E.) Caney carbonates rest directly on the Woodford Shale. We suspect that these macrofossils were obtained from the basal beds of the Caney Shale, rather than from the Welden Limestone.

Even in the restricted band that includes our three Welden localities, there is some question whether the Welden is a continuous unit. A search for Barker's megafossil locality 2, which lies along Jackfork Creek between the Hass G and Welden type sections, revealed isolated blocks of a thick (0.5 m) carbonate bed, apparently lying below the thinly bedded limestones of the Caney Shale, but not obviously in place. Above a shale pit in the Woodford Shale a short distance to the west (S $\frac{1}{2}$ NE $\frac{1}{4}$ sec. 34, T. 3 N., R. 6 E.), there is no evidence of the Welden Limestone, but float material of Caney-like carbonate beds is present.

CONODONT FAUNA

The Welden Limestone contains a large, diverse conodont fauna. The preservation of elements is generally excellent, and a wide variety of ramiform elements

are present, in addition to pectiniform elements. The quality of preservation varies slightly among the three sections, the best preservation occurring at the Hass G section, and the worst at the Welden type section. The discussion below focuses on the pectiniform-bearing taxa, the primary purpose being biostratigraphic subdivision and correlation. Although our samples are not completely analyzed, we believe that the Welden faunas support most, if not all, of the multielement reconstructions proposed by Chauff (1981,1983), which are based on material from the Mississippi Valley and the Chappel Limestone of Texas.

The taxonomy of species of *Gnathodus* from the Welden Limestone has caused us considerable anguish, and we are not comfortable with the application of species names to the morphologic groups that are present. For the most part, we attempt to follow the taxonomy and nomenclature proposed by Lane and others (1980). Our samples include a large number of Pa elements of moderate to small size, and the development of the expanded posterior blade, which is used as an important criterion by these authors, is often difficult to evaluate. Also, we see morphologic intergradation among morphotypes that are reported to belong to

unrelated species. The Welden *Gnathodus* fauna in some respects is more closely comparable with the variety of morphotypes that have been described by Thompson (1967) and Thompson and Fellows (1970) from the Mississippi Valley, and further work may result in a modification of *Gnathodus* taxonomic concepts to better accommodate these morphotypes.

Cooper (1939) illustrated a large number of conodonts from the pre-Welden Shale at the Welden type section and named several new genera and numerous new species. Description of this diverse and abundant fauna (thousands of Pa elements per kilogram) is beyond the scope of this report, but a few observations can be made. The pre-Welden conodont fauna appears to be extremely condensed and slightly admixed. Detailed sampling of the interval suggests that part of the *Siphonodella* zonation of Sandberg and others (1978) can be distinguished. The uppermost part of the pre-Welden shale is dominated by elements of *Siphonodella* and *Pseudopolygnathus*, and appears to represent the *isosticha*-*Upper crenulata* Zone at the Welden type and Hass G sections.

The Welden Limestone contains three distinct faunal intervals that are distinguished by the presence/absence

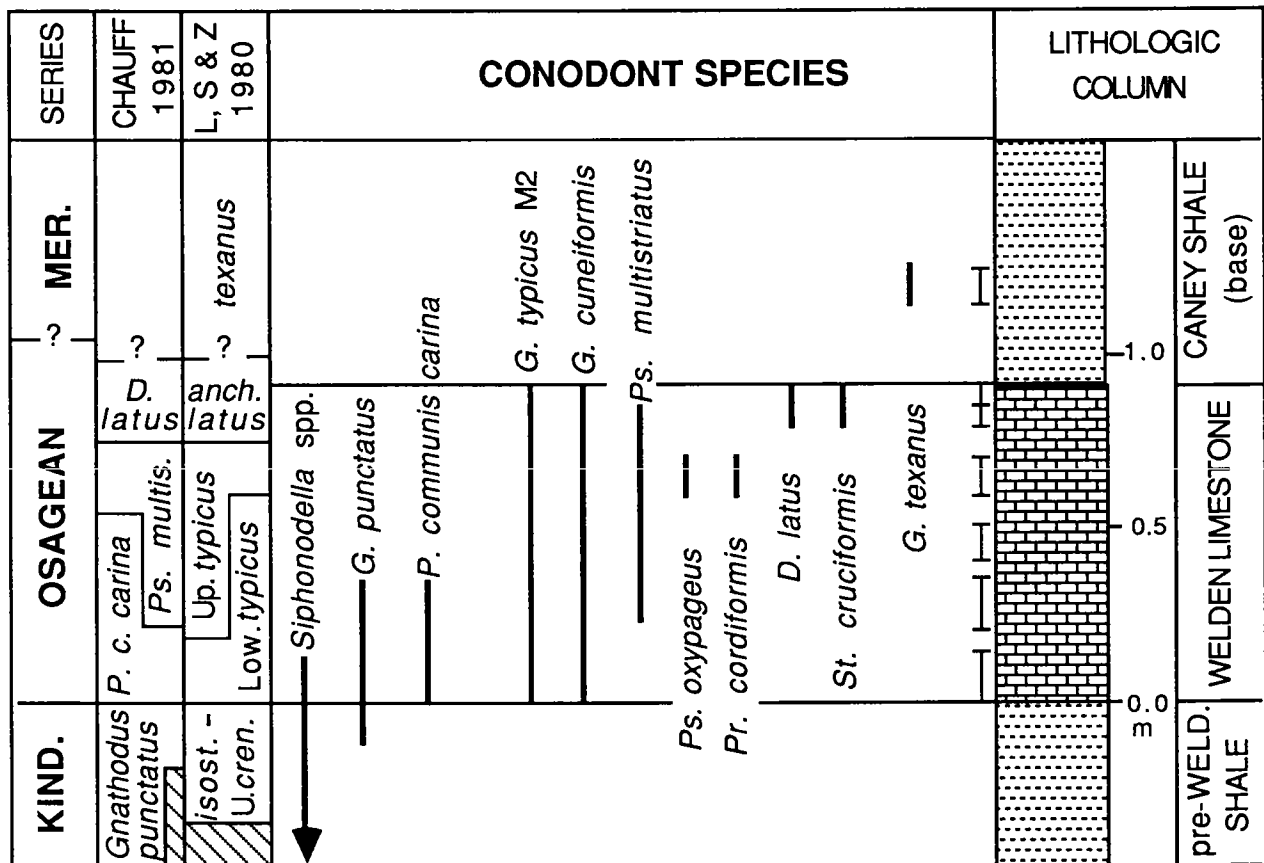


Figure 3. Stratigraphic distribution of selected conodont species in the pre-Welden shale, Welden Limestone, and base of the Caney Shale at the Guest Ranch section. Conodont zones of Chauff (1981) and Lane and others (1980) are both shown. See Figure 6 for complete names of zones. Abbreviations for conodont genera: *B.* = *Bactrognathus*, *D.* = *Doliognathus*, *G.* = *Gnathodus*, *P.* = *Polygnathus*, *Pr.* = *Protognathodus*, *Ps.* = *Pseudopolygnathus*, *S.* = *Siphonodella*, *St.* = *Staurogathus*.

of taxa, differences in the absolute and relative abundance of Pa elements, and the total number of species. Percentages of taxa given are only approximate and refer to relative proportions of Pa elements. Ranges of important taxa are shown on Figures 3-5.

Faunal Interval 1

The basal portion (lower 0.20-0.30 m) of the Welden Limestone yields abundant conodonts (150-400 Pa elements/kg), and a moderate number of species. The fauna is dominated by morphotypes of *Gnathodus punctatus* (Cooper) (45%), *Polygnathodus communis communis* Branson and Mehl (25%), and *P. communis carina* Hass (10%). A few specimens of *Siphonodella* are present, including *S. crenulata* Cooper, *S. obsoleta* Hass, *S. isosticha* Cooper, and *S. quadruplicata* (Branson and Mehl). A single specimen of *Dollymae sagittula* Hass was obtained from the Welden type section.

Few of the specimens of *Gnathodus punctatus* correspond to morphotypes considered characteristic of the species, or to morphotypes found in the underlying pre-Welden shale, the type stratum for the species. Instead of the typical radiating rows of nodes on the outer platform and the expanded posterior tip, many Welden specimens possess concentric rows of nodes on the outer platform and an unexpanded to very slightly expanded posterior tip. A distinct row of fine nodes may be present on one or both sides of the carina, like that found on *G. cuneiformis* Mehl and Thomas and *G. delicatus* Branson and Mehl. However, these atypical forms of *G. punctatus* grade into the more typical morphotypes of the species.

The second group of *Gnathodus* morphotypes (15%) is characterized by a relatively narrow platform. Many specimens lack a parapet and an expanded posterior tip, and are assigned to *G. typicus* Cooper, morphotypes M1 and M2 of Lane and others (1980). Those with an

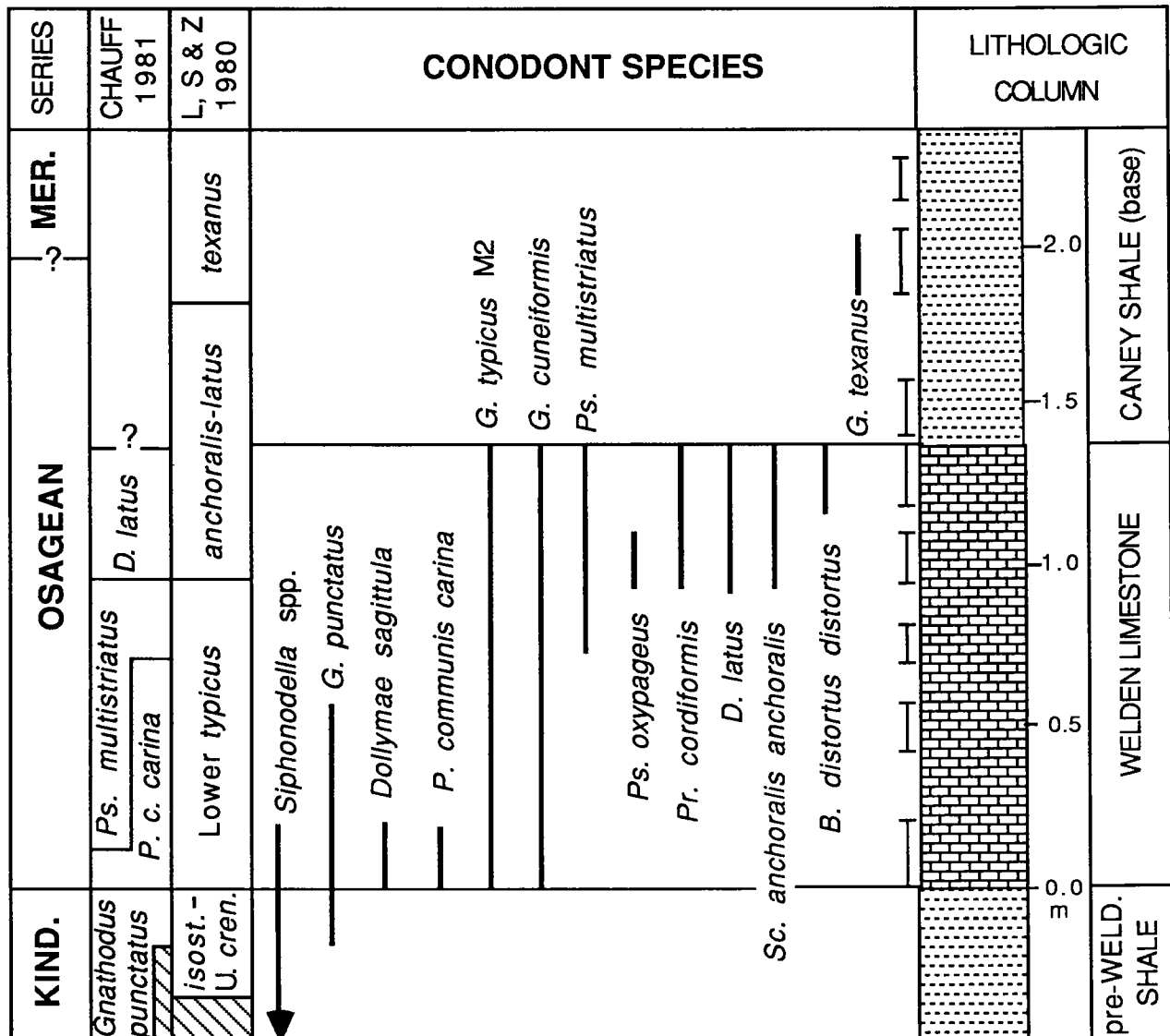


Figure 4. Stratigraphic distribution of selected conodont species in the pre-Welden shale, Welden Limestone, and base of the Caney Shale at the Welden type section. See caption to Figure 3 for further explanation.

expanded posterior tip, but only a weakly developed parapet, are placed in *G. semiglaber* Bischoff. A few Pa elements possess the row of nodes that parallels the carina on one side (*G. delicatus*), or both sides (*G. cuneiformis*).

Faunal Interval 2

Above the basal faunal interval is a 0.30–0.75 m interval in which the abundance of Pa elements drops to 30–70 per kilogram. *Polygnathus communis communis* is common (25%), but *P. communis carina* is absent. Relatively simple morphotypes of *Gnathodus* occur: *G. semiglaber* (30%), *G. typicus* (30%), and few Pa elements of *G. cuneiformis* and *G. delicatus*. Because most of these Pa elements are relatively small, identifications of many specimens are only tentative. *Pseudopolygnathus multistriatus* Mehl and Thomas first occurs in the Welden in this interval in small numbers (<5%).

Faunal Interval 3

The upper portion (0.30–0.45 m) of the Welden Limestone contains the most abundant and diverse conodont fauna of the unit. The abundance of Pa elements varies from 100 to over 1500 Pa elements per kilogram. *Gnathodus cuneiformis* (30%), *G. semiglaber* (25%), and *Polygnathus communis communis* (20%) dominate the fauna, but the most characteristic feature is the appearance and abundance of elements of the *Bactrognathus* species, *B. hamatus* Branson and Mehl and *B. excavatus* Branson and Mehl (10%). A diverse assemblage of other, less abundant species is present: *B. anchorarius* (Hass), *B. distortus distortus* Branson and Mehl, *Doliognathus latus* Branson and Mehl, *Scaliognathus anchoralis anchoralis* Branson and Mehl, *Protognathodus cordiformis* Lane, Sandberg, and Ziegler, *Pr. praedelicatus* Lane, Sandberg, and Ziegler, *Pseudopolygnathus multistriatus*, *Ps. pinnatus* Voges, *Ps.*

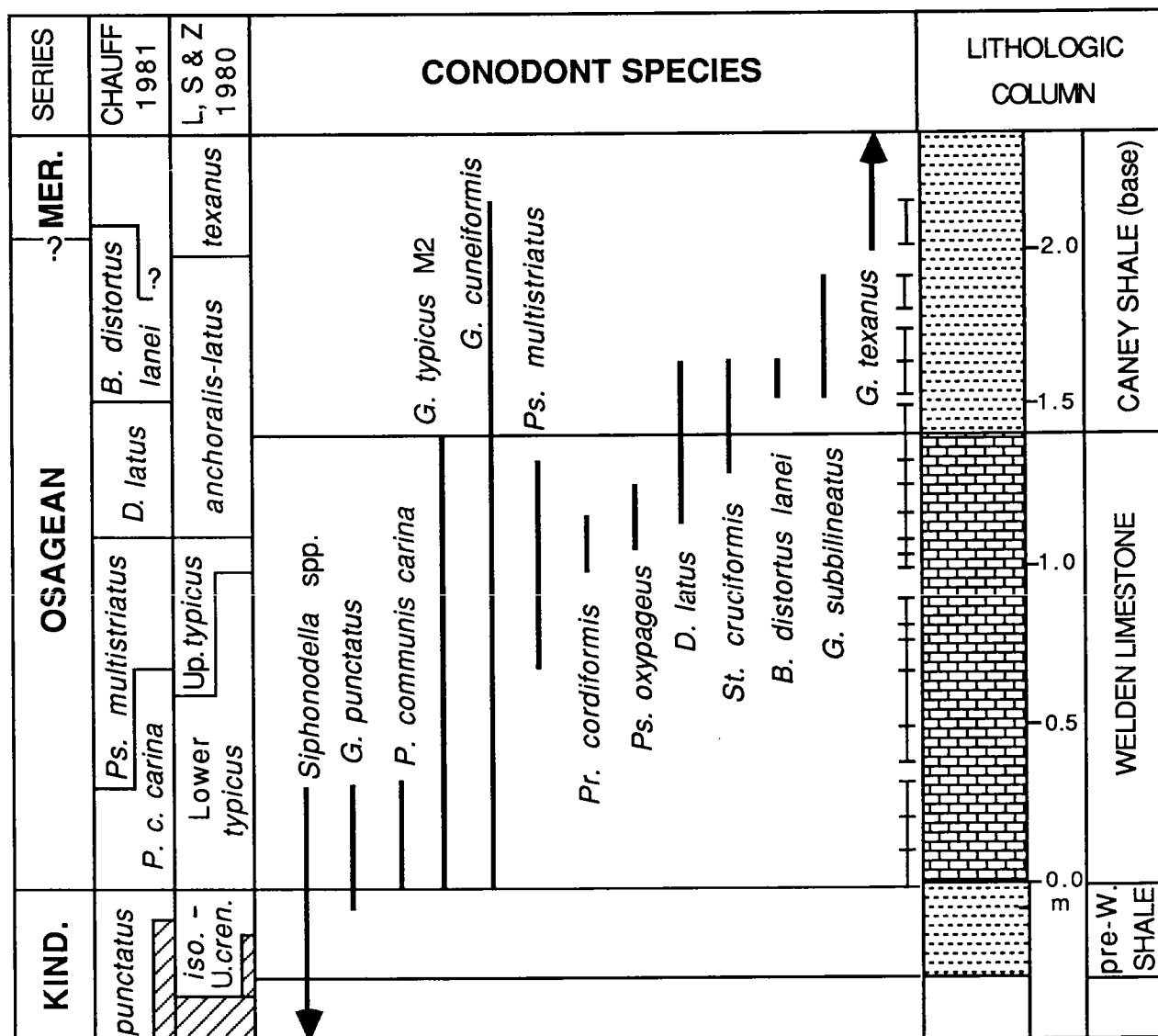


Figure 5. Stratigraphic distribution of selected conodont species in the pre-Welden shale, Welden Limestone, and base of the Caney Shale at the Hass G section. See caption to Figure 3 for further explanation.

oxypageus Lane, Sandberg and Ziegler, and *Staurognathus cruciformis* Branson and Mehl.

Gnathodus Pa elements in this interval display a wide range of morphologic variation. The forms assigned to *G. cuneiformis* generally possess a wide outer platform, which may have additional rows of nodes; these forms are similar to the atypical forms of *G. punctatus* from the basal faunal interval. In the lower part of the third faunal interval, numerous *Protognathodus praedelicatus* occur. In the upper part of the interval, near the top of the Welden, the distinct morphotype *G. antetexanus* Rexroad and Scott becomes common. Morphotypes approaching *G. bulbosus* Thompson, which Lane, Sandberg, and Ziegler (1980) included in *G. semiglaber*, appear in the uppermost part of the Welden, at least at the Hass G section. Relatively small numbers of elements of *G. typicus*, *G. delicatus*, and ?*G. pseudosemiglaber* Thompson and Fellows are present in the third faunal interval.

The conodont fauna at the base of the Caney Shale differs among the three Welden sections. The most prolific faunas occur in the 0.80 m of shale that overlies the Welden at the Hass G section. The basal 0.25 m yields abundant conodonts that include an admixture of pre-Welden (*Siphonodella* spp.) and Welden forms, apparently a lag concentrate. This is probably the interval from which Branson and Mehl (1941a) described new species of Mississippian conodonts. In addition to typical Welden species, *Bactrognathus distortus lanei* Chauff, *Scaliognathus anchoralis anchoralis*, *S. anchoralis europensis* Lane and Ziegler, and *Gnathodus subbilineatus* Lane and Ziegler occur in the basal shale of the Caney. The next 0.30 m of shale contains a smaller fauna dominated by *G. subbilineatus* and morphotypes of *G. semiglaber*. Few reworked elements are present. In the green-gray shale 0.60–0.80 m above the Welden, a fauna dominated by *G. semiglaber*, including *G. bulbosus* and *G. texanus* Roundy, occurs. The most distinctive morphotype of *G. texanus* in this sample possesses a curved to loop-shaped parapet that is usually connected to the carina by a short ridge. This form was illustrated by Branson and Mehl (1941b, pl. V, figs. 23–25) from the Caney at another locality. Elias (1956) applied the name *G. pretexanus* to the same specimens.

At the Welden type section, a sparse fauna of apparently reworked conodonts appears at the base of the Caney, and *Gnathodus texanus* appears 0.50 m above the top of the Welden. The shale immediately overlying the Welden was not exposed at the Guest Ranch section, but *G. texanus* appears in an abundant, but apparently reworked fauna 0.25–0.35 m above the top of the Welden. The limestones that occur at the base of the Caney where the Welden is absent contain the *Gnathodus texanus* fauna, including the "pretexanus" morphotype.

CONODONT ZONATION

Two recent conodont zonations for the interval above the *Siphonodella* zones of Sandberg and others (1978) and below the first appearance of *Cavusgnathus*, corresponding approximately to the interval of the Osagean to middle Meramecian in North America,

were independently proposed by Lane and others (1980) and Chauff (1981) (Fig. 6). The zonation of Lane and others (1980) is an attempt to synthesize information from North America, Europe, and Australia to produce a zonation with global application. Chauff's zonation (1981) represents a revision of older zonations of the conodont faunas of the Mississippi Valley area of North America (Thompson, 1967; Thompson and Fellows, 1970; Collinson and others, 1971; Lane, 1978). Because species characteristic of both zonations occur in the Welden Limestone, the two schemes can be directly compared (Figs. 3–5).

The early Osagean Lower *typicus* Zone of Lane and others (1980) is based on the first occurrence of *Gnathodus typicus* Morphotype 2. The only significant other first occurrence in this zone is the appearance of *G. cuneiformis*. Because both *G. typicus* and *G. cuneiformis* are present at the base of the Welden Limestone at all three sections, the base of the Welden lies in the Lower *typicus* Zone. The base of the *Polygnathus communis carina* Zone of Chauff (1981) is defined by the first occurrence of the nominate species. This species is present at the base of the Welden at all sections. Although defined differently, the base of the Lower *typicus* Zone, at least in the Welden, corresponds exactly to the base of the *P. communis carina* Zone. Species of *Siphonodella* are not thought to range into the *typicus* Zone, nor into the *carina* Zone, but are present at the base of the Welden. It is not possible to determine if any or all of these speci-

	Lane, Sandberg & Ziegler, 1980	Chauff, 1981
OSAGEAN	<i>texanus</i>	?
	<i>anchoralis-latus</i>	" <i>Polygnathus mehli</i> "
		<i>Bactrognathus distortus lanei</i>
		<i>Doliognathus latus</i>
	Upper <i>typicus</i>	<i>Pseudopolygnathus multistriatus</i>
Lower <i>typicus</i>	<i>Polygnathus communis carina</i>	
KIND.	<i>isosticha</i> – Upper <i>crenulata</i>	<i>Gnathodus punctatus</i>
		?

Figure 6. Lower Mississippian conodont zonations of Lane and others (1980) and Chauff (1981).

mens represent reworking from the underlying, *Siphonodella*-rich pre-Welden shale, but no specimens of *Pseudopolygnathus*, which is also abundant in the pre-Welden Shale, were recovered from the basal samples of the Welden.

The base of the *Pseudopolygnathus multistriatus* Zone of Chauff (1981) is defined by the first occurrence of the nominate species. Although Lane and others (1980) showed this species as occurring as low as the Kinderhookian *isosticha*-Lower *crenulata* Zone, in Chauff's (1981) sections *Ps. multistriatus* appears above the *carina* Zone. In the Welden Limestone, *Ps. multistriatus* first occurs at the same stratigraphic position, in the second faunal interval.

The base of the Upper *typicus* Zone of Lane and others (1980) is defined by the first occurrence of *Pseudopolygnathus oxypageus* or *Ps. nudus*, and *Protognathodus cordiformis* and possibly *Doliognathus dubius* first appear in this zone. Both *Ps. oxypageus* and *Pr. cordiformis* occur in small numbers at the base of the third faunal interval of the Welden. At the Guest Ranch section, the two species appear in the same sample, and at the Hass G type section *Pr. cordiformis* appears in the sample below *Ps. oxypageus*. However, at the Welden type section, both species first occur with *Doliognathus latus*, the taxon that defines the base of the succeeding zone, and the Upper *typicus* Zone cannot be recognized.

The base of the *anchoralis-latus* Zone of Lane and others (1980) and the base of the *Doliognathus latus* Zone of Chauff (1981) are both defined by the first appearance of *D. latus*. *Doliognathus latus* and other species characteristic of the lower part of both zones appear just above the base of the third faunal interval in the Welden.

The *anchoralis-latus* Zone extends to the base of the *Gnathodus texanus* Zone of Lane and others, defined by the first occurrence of the nominate species. The upper part of the *anchoralis-latus* Zone is divided into three zones (Chauff, 1981), the *Bactrognathus distortus lanei* Zone, the "*Polygnathus*" *mehli* Zone, and the *G. bulbosus* Zone. Chauff (1983) suggests that in the Mississippi Valley region parts of these three zones, as well as the underlying zones, could have been partly contemporaneous as a result of ecological factors over the early Osagean carbonate shelf. *Bactrognathus distortus lanei* was not recovered from the Welden, and appears 0.15 cm above the base of the Caney Shale at the Hass G section. "*Polygnathus*" *mehli* Thompson was not obtained from any samples of the Welden or Caney. Specimens approaching *G. bulbosus* in morphology are present in the top of the Welden at the Hass G section, and more typical forms occur in the Caney, 0.15 m above the base, in association with *G. subbilineatus*. *Gnathodus subbilineatus* was described by Lane and Ziegler (1983) from strata containing "*P.*" *mehli* in the Sacramento Mountains of New Mexico. The presence of *G. subbilineatus* and *G. bulbosus* 0.15–0.40 m above the base of the Caney suggests that this interval may correspond to Chauff's "*P.*" *mehli*-*G. bulbosus* Zones. At the other Welden sections (Guest Ranch and Welden type section), the shales directly overlying the Welden lack diagnostic conodonts.

Lane and others (1980) used the appearance of *Gnathodus texanus* to define the base of their *texanus* Zone. *Gnathodus texanus* appears a short distance above the base of the Caney at the three Welden sections (Hass G, 0.60 m; Welden type section, 0.50 m; Guest Ranch, 0.25 m).

Based on our understanding of the relations of the conodont zones to chronostratigraphic units (e.g., Lane, 1982), the base of the Welden Limestone is early Osagean in age (Lower *typicus* Zone), and the top is no younger than middle Osagean (upper part of *anchoralis-latus* Zone). The base of the overlying Caney Shale is late Osagean in age at the Hass G section (uppermost part of the *anchoralis-latus* Zone), and latest Osagean to early Meramecian at the other Welden sections (*texanus* Zone).

The presence of the *texanus* Zone fauna in argillaceous carbonates at the base of the Caney at other sections confirms observations based on lithology and field mapping that a second limestone unit, one younger than the Welden, lies between the Woodford Shale and typical Caney shales on the southeastern part of the Lawrence uplift. The conodonts described by Ormiston and Lane (1976) from near the base of the Sycamore Limestone in the northern Arbuckle Mountains also include the *Gnathodus texanus* fauna. Our collections from the carbonate bed 1.0 m above the base (Sample 1 of Ormiston and Lane) include elements of the *G. texanus* fauna, including the "*pretexanus*" morphotype, which have been admixed with elements reworked from older pre-Welden and Welden-equivalent units. This lower carbonate unit in the Sycamore, which had been correlated with the Welden, is equivalent in age with the lower part of the Caney on the Lawrence uplift.

SIGNIFICANCE

The Osagean Welden Limestone is a good example of the Lower Mississippian starved magnafacies of Lane and De Keyser (1980). It is a thin, condensed carbonate section underlain (pre-Welden shale) and overlain, at least locally (basal Caney Shale at Hass G) by condensed shale intervals. The Welden lies well south of the Burlington shelf of Lane (1978), and east of the carbonate shelf in the Texas Panhandle called the Chappel shelf by Gutschick and Sandberg (1983). However, it is not clear to which of the two shelf regions the Welden Limestone is most closely related, for there is no information available to demonstrate the lateral continuity of the Welden Limestone with either shelf region. The Welden sections and conodont sequence show a remarkable similarity to the coeval Chappel Limestone of central Texas as described at the Zesch Ranch section by Chauff (1981). However, the Chappel Limestone at other sections is known to contain abundant conodonts reworked from older, mostly Devonian, stratigraphic units (Hass, 1959; Ellison, 1986). In the Welden Limestone, there is little evidence for stratigraphic admixture.

Chauff (1983) interpreted the succession of conodont zones on the Burlington shelf to represent biofacies

shifts related to a cycle of transgression and regression. The Welden Limestone shows a rise in generic diversity comparable with that of the Burlington shelf from the *Polygnathus communis carina* Zone into the *Doliognathus latus* Zone. The *D. latus* Zone contains the most-offshore conodont biofacies as interpreted by Chauff (1983) as well as by Sandberg and Gutschick (1979) and Sandberg (in Lane and others, 1980, p. 123–126). The association of species of *Doliognathus*, *Scaliognathus*, and *Bactrognathus* with abundant *Gnathodus* species is characteristic of platform-margin and upper-foreslope deposits, at least on the carbonate shelf flanking the Deseret starved basin of Utah, Nevada, and Idaho (Gutschick and Sandberg, 1983).

However, less information is available on the paleoecologic significance of conodont biofacies in the underlying zones. Chauff (1983) indicated that the *Gnathodus punctatus* and *Polygnathus communis carina* Zones represent a shallow-water, nearshore assemblage. This interpretation is difficult to apply to the basal part of the Welden Limestone, because the Welden rests on apparently continuously deposited, condensed shales bearing a *Siphonodella* conodont biofacies. The *Siphonodella* biofacies is characteristic of offshore, pelagic to hemipelagic settings (Dreesen and others, 1986). With respect to the supposed deepening trend postulated by Chauff (1983, text-fig. 4), there are no lithofacies variations in the Welden to suggest any change in its environmental setting as the conodont faunas changed in composition and diversity. It is equally possible that the conodont succession from the *P. c. carina* Zone into the *Doliognathus latus* Zone is a result of an evolutionary diversification of conodonts, as described by Ziegler

and Lane (1987), which may be related in a more general way to a eustatic sea level event (e.g., Sandberg and others, 1986).

Only the Hass G section shows any evidence for deposition and preservation of upper Osagean strata above the Welden Limestone. Southeast of the Lawrence uplift, the Caney Shale rests unconformably on the Woodford Shale, and the pre-Welden shale and Welden Limestone are absent. Similarly there are apparently no strata equivalent in age to the Welden present beneath the Sycamore Limestone in the Arbuckle Mountains outcrop belts. A geographically widespread break in deposition, probably an erosional event, seems to have occurred near the Osagean/Meramecian boundary in the southern Oklahoma region, predating the accumulation of the thick clastic sequences of later Mississippian age. This event may correspond to the major eustatic lowering of sea level that occurred in the early Meramecian (Sandberg and others, 1986). The timing of this event also appears to coincide with the termination of chert deposition (Arkansas Novaculite) and the start of rapid deposition of clastics (Stanley Shale) in the Ouachita facies to the south of the cratonic region of southern Oklahoma (Hass, 1956).

ACKNOWLEDGMENTS

The authors wish to thank the Donors of the Petroleum Research Fund, administered by the American Chemical Society (Grant 17283AC), for support of this research.

Canyon Creek: A Significant Exposure of a Predominantly Mudrock Succession Recording Essentially Continuous Deposition from the Late Devonian through the Middle Pennsylvanian

Robert C. Grayson, Jr.

ABSTRACT.—The Canyon Creek locality is the most complete and significant exposure of the predominantly mudrock Late Devonian through Middle Pennsylvanian succession in southern Oklahoma. Conodonts from this important section contribute significantly to resolution of problems in Carboniferous chronostratigraphy, biostratigraphy, taxonomy, and paleoecology.

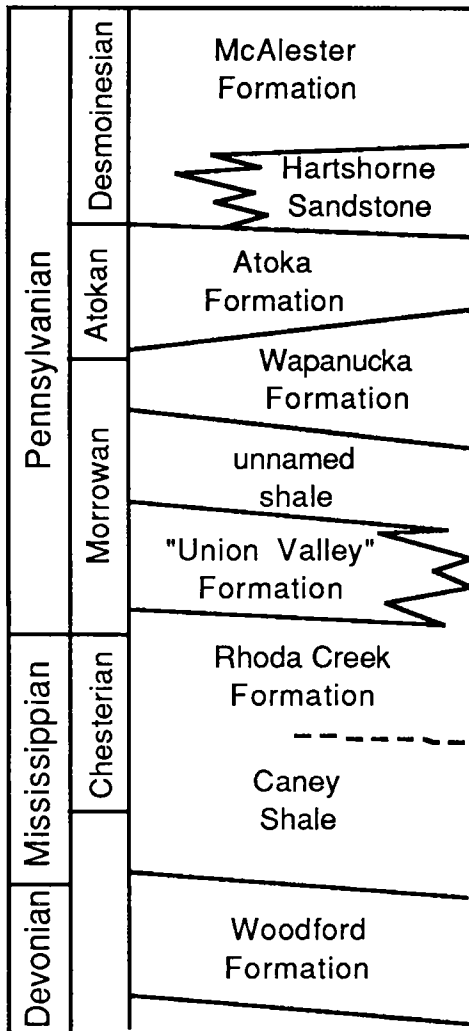
The Mississippian/Pennsylvanian boundary occurs in a conformable shale sequence in the middle of the Rhoda Creek Formation. At Canyon Creek this boundary coincides with a change from conodonts characteristic of the latest Chesterian "*Adetognathus unicornis* Zone to those indicative of Higgins's (1975) *Idiognathoides noduliferus*–*Streptognathodus lateralis* Zone. Coincidence of the paleontological change with shifts in lithology and geochemistry suggests that the boundary represents a stratal (diachronous) event. The position of the Morrowan/Atokan series boundary cannot be approximated with the same precision as that of the Mississippian/Pennsylvanian boundary. In part, this reflects the lack of specific knowledge of conodont ranges relative to those of fusulinids, which historically have been important in boundary definitions. Nonetheless, the conodont succession demonstrates that an Atokan Series can be biostratigraphically distinguished from either the older Morrowan or younger Desmoinesian Series.

Canyon Creek conodonts include representatives of biostratigraphically important lineages that have figured prominently in Pennsylvanian zonation. A model for phylomorphogenetic speciation within the lineages *Declinognathodus*, *Idiognathodus*, and *Neognathodus* is illustrated. If confirmed, the model could serve as a basis for constructing a more universally applicable conodont zonation for the Lower and lower Middle Pennsylvanian.

INTRODUCTION

The relatively continuous sequence of mid-Carboniferous rocks exposed in the channel and along the banks of Canyon Creek include the Rhoda Creek, "Union Valley," unnamed shale, Wapanucka and Atoka Formations (Text-fig. 1). This succession, previously known from incomplete, isolated exposures, has figured prominently in the development of frequently inseparable concepts regarding Carboniferous chronostratigraphy, biostratigraphy, and lithostratigraphy in Oklahoma. For example, the usage of such terms as "Mississippian Caney" and "Pennsylvanian Caney" (Morgan, 1924) or the newer names Rhoda Creek (Elias, 1956) and Springer (Kuhleman, 1948) reflected known or, more often, presumed geologic ages based on goniatites. In addition, occurrences of the fusulinids *Profusulinella* and *Fusulinella* in the Atoka Formation (Thompson, 1935) led to the usage of the term Atoka for the early Middle Pennsylvanian Atokan Series (Spivey and Roberts, 1946). Furthermore, the predominantly mudrock character of this succession has been critical to regional stratigraphic and basin analyses (Ham, 1950; Wickham, 1978).

Grayson reported on conodonts from Carboniferous rocks exposed along Canyon Creek in two separate reports: Grayson (1984) reported on the conodont faunas from the Wapanucka and Atoka Formations, and Grayson and others (1985) described conodonts from the Rhoda Creek Formation. These studies were largely concerned with the biostratigraphic significance of the conodonts and treated only the Pa elements of the faunas. Since then the importance of the non-platform elements has become apparent. This is particularly true when attempting to reconstruct phylogenetic and evolutionary relationships. Also, some faunal changes then considered to have had biostratigraphic significance now seem to be almost entirely paleoecological, and newer criteria are being discovered that appear to offer the potential for a more universally applicable conodont biostratigraphy. In addition, the two previous reports did not treat the significant conodont-bearing interval between the upper Rhoda Creek and Wapanucka Formations. Consequently, some of the evidence critical to my current opinions regarding Carboniferous chronostratigraphic, conodont biostratigraphic, and evolutionary relationships was not previously available.



Text-figure 1. Stratigraphic column for south-central Oklahoma, including stratigraphic interval exposed along Canyon Creek.

The present contribution partly fills the gap left by previous work, but also permits evaluation of newer ideas that need testing and refining. The Late Mississippian through early Middle Pennsylvanian part of the Canyon Creek conodont succession is complete enough to address current issues in Carboniferous chronostratigraphy, conodont biostratigraphy, phylogeny, taxonomy, and paleoecology. The following questions exemplify some of the problems currently being debated. Are there Mississippian/Pennsylvanian boundary localities in North America where the boundary is not coincident with an interregional unconformity? Has the position of the boundary been consistently located? Is the early Middle Pennsylvanian Atokan Series biostratigraphically distinct from either the older Morrowan or younger Desmoinesian Series? Can the multiple, competing conodont zonation for Upper Mississippian and Lower Pennsylvanian strata be synthesized into a more universally applicable zonation based on evolutionary relationships within and between lineages? Can such a

zonation be successfully extended into the lower Middle Pennsylvanian? These questions seemingly can be answered with an affirmative, and the unusually complete exposures at Canyon Creek provide important confirmatory evidence.

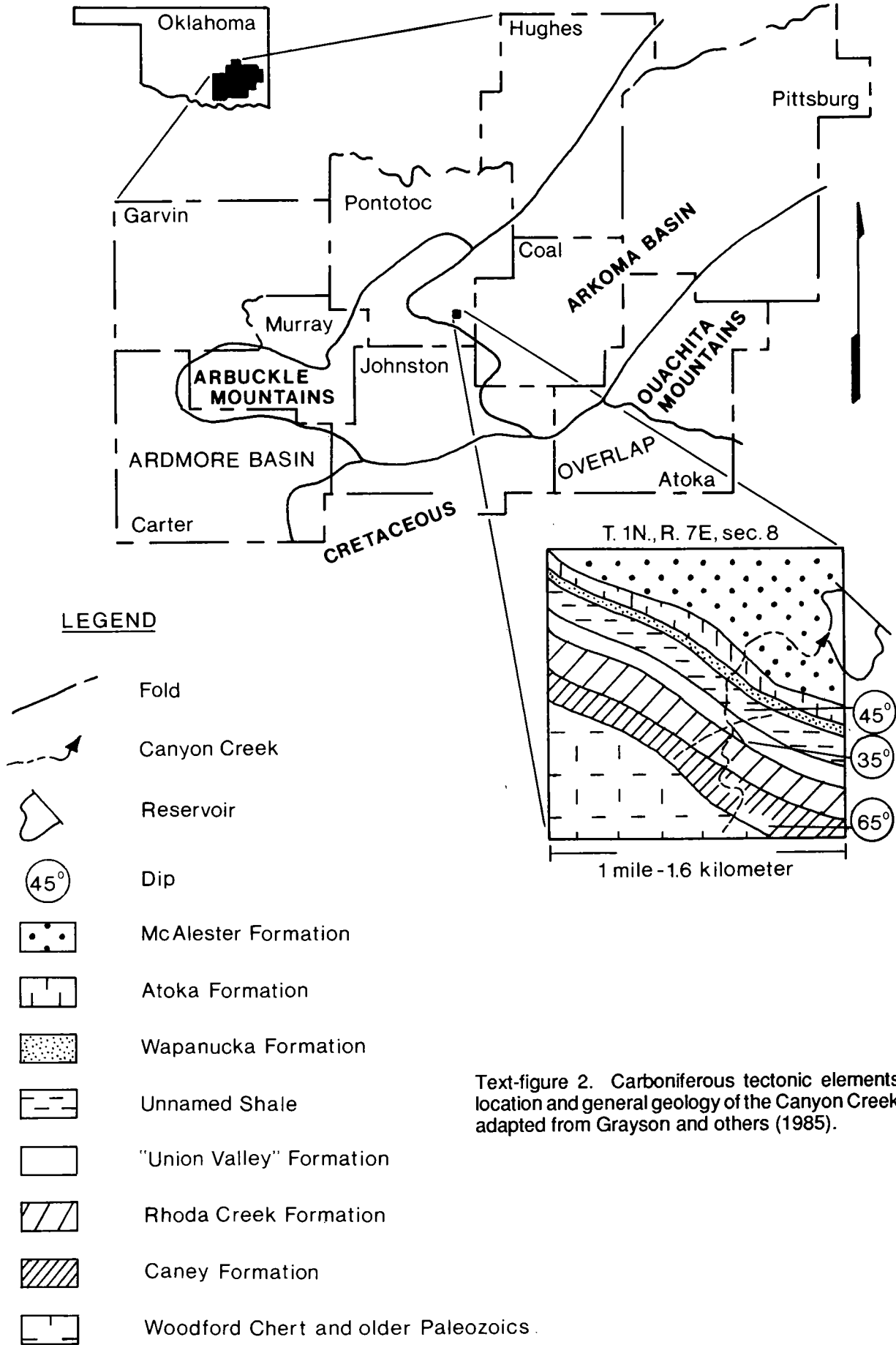
STRATIGRAPHIC SUCCESSION

Of the eight stratigraphic units exposed along Canyon Creek (Text-fig. 2) only five (Text-fig. 3) have currently been sampled for conodonts. The character of these units and their conodont faunas is discussed in the following sections.

Rhoda Creek Formation

The Rhoda Creek Formation was established by Elias (1956) with the apparent intent of separating shale lithologies previously referred to as "Mississippian Caney" and "Pennsylvanian Caney." Although Elias's concepts were largely paleontologic he did use the appearance of clay-ironstone concretions in vertical section to distinguish his presumed Pennsylvanian Rhoda Creek from the underlying Mississippian Caney. Modern usage of the term Rhoda Creek has demonstrated the fallacy of his supposition (Saunders, 1973), and in fact has resulted in the boundary falling within his Rhoda Creek Formation (Grayson and others, 1985). The paleontologically located chronostratigraphic boundary coincides with a change in lithology from silty black shale to laminated silty black shale (Text-fig. 3), and with the platinum-group (iridium) anomaly documented by Orth and others (1987). However, it should be noted that there are no major lithologic or mappable differences between the Caney and Elias's Rhoda Creek. Minor differences include a somewhat lesser abundance of limestone septaria, the appearance of locally abundant ironstone concretions, and greater frequency of silty intervals in the Rhoda Creek compared to the Caney.

Water depths during deposition of the Caney and Rhoda Creek were clearly shallow (<200 m). How much less than 200 m is problematic, although the lithologic and biologic evidence leads me to conclude that water depths were quite shallow, possibly no more than 30 m on average. Some paleoenvironmental conclusions are less inferential and more strongly supported by lithologic and paleontologic evidence. Low-energy, dys-aerobic and anaerobic conditions are suggested by the dark-colored mudrocks, abundant organic matter, pelagic fossil assemblage, and preservation of millimeter-thick laminations. Varying rates of sedimentation and organic productivity may be inferred to account for variation in abundance of phosphatized pellets, quartz silt, and conodonts. As the depositional setting appears to have been largely open marine in nature, mixing of dissimilar water masses may have been responsible for conodont-biofacies variations. Some combination of these paleoenvironmental conditions may also have resulted in sedimentary extraction of the platinum-group metals from sea water to produce the anomaly seen at the Mississippian/Pennsylvanian boundary.



Text-figure 2. Carboniferous tectonic elements, and location and general geology of the Canyon Creek area, adapted from Grayson and others (1985).

"Union Valley" Formation

Grayson and others (1985, fig. 1) showed the Union Valley Formation to be present in the Canyon Creek exposures. This interval, now referred to as "Union Valley," differs somewhat from the type Union Valley in the Hunton uplift area (northeastern Arbuckle Mountains) to the northwest. There, the Union Valley consists of a lower, major interval of sandstone and shale, and an upper sandy limestone (Barker, 1951). The upper sandy limestone is particularly well known because of its prolific conodont (Harris and Hollingsworth, 1933) and ammonoid cephalopod faunas (Unklesbay, 1962). At Canyon Creek, the "Union Valley" consists of a lower interval of shale, calcareous siltstone, and silty, argillaceous limestone, and an upper argillaceous, biomicritic limestone and shale interval (Text-fig. 3). Kuhleman (1948) apparently considered the "Union Valley" to represent basal Pennsylvanian Springer Formation. Elias seemingly never visited this locality, but he probably would have recognized this as Union Valley or as its equivalent based on the somewhat similar sequences and comparable occurrences of middle Morrowan ammonoid cephalopods. Conodonts from the upper predominantly limestone interval also compare with those documented from the upper limestone of the Union Valley in the type area.

The lithologic succession, the more-diverse calcareous fauna, and paleogeographic considerations indicate that the Union Valley Formation accumulated under normal marine, shallow-shelf conditions. The formation probably represents laterally discontinuous offshore bar and interbar depositional environments. In terms of this general model, the Canyon Creek "Union Valley" would be characterized as representing bar-margin and interbar depositional environments.

Unnamed Shale

Kuhleman (1948) mapped parts of Stonewall and Atoka Counties, including the Canyon Creek area, with the purpose of locating the Mississippian/Pennsylvanian boundary. He used the term "Caney" for rocks presumed to be Mississippian, and applied the Ardmore basin term "Springer" for rocks presumed to be Pennsylvanian. At Canyon Creek, he apparently considered the unnamed shale and the "Union Valley" to represent Springer. Extension of Springer from its type area (Ardmore basin) to the Arkoma basin is not accepted, owing to marked lithologic differences in the local successions and indeterminable lack of lateral continuity.

The unnamed shale marks a substantial change both in the character of mudrock lithologies and in conodont faunas (Text-fig. 3). In underlying units, the shales are largely dark-colored or black, and produce relatively diverse conodont assemblages. In this and higher intervals, the shales are predominantly a lighter blue-gray color, and conodont assemblages, when present, represent low-diversity, restricted faunas. These significant differences probably reflect a change from highly productive, low-oxygen conditions to better-oxygenated,

but variably saline environments associated with a carbonate-shelf depositional system.

A diverse megafossil assemblage including gastropods, bivalves, corals, and brachiopods in the upper part of the unnamed shale has been interpreted by Rowett and Sutherland (1964) to represent a lagoonal community.

Wapanucka Formation

The Wapanucka Formation has been the subject of modern study. In the general area, Rowett (1963) and Rowett and Sutherland (1964) have done the most detailed studies. Their work dealt primarily with the lithologic and rugose-coral succession from the Wapanucka, and the nature of the Wapanucka/Atoka formational boundary. Also, Grayson (1984) illustrated platform elements of the conodont fauna in a biostratigraphic study dealing with the Morrowan/Atokan boundary.

The lithologic succession at Canyon Creek is somewhat unusual in that shale predominates over carbonate, and only three carbonate intervals are developed (Text-fig. 3). These limestones produce modest conodont faunas that seem to be indicative of conditions less restricted than those associated with either the unnamed shale or shales within the Wapanucka.

Interregionally, the Wapanucka Formation records the development and progradation of a carbonate shelf prior to and overlapping with the tectonic activity that resulted in breakup of the shelf into rapidly subsiding basins and positive uplifts.

Atoka Formation

Details of the Atoka Formation in this area have been discussed by Archinal and others (1982); Sutherland and others (1982) treated the formation on a more regional basis. Marked thickness variations, rapid lithologic changes, and diachronous age relationships characterize the formation. Archinal (1977,1979) documented growth faulting during deposition of the Atoka Formation, which accounts for much of its lateral variability. The general picture beginning to emerge from ongoing studies by Sutherland and Grayson in the belt of exposures along the boundary between the Arbuckle Mountains and the Arkoma basin is similar to that known for the formation in the eastern Arkoma basin. In the Arkoma basin, the formation exhibits marked thickening of the middle Atoka, which is restricted to more-basinward settings, and subsequent onlap by the upper Atoka Formation (Houseknecht and Kacena, 1983). Mapping and conodont biostratigraphic evidence points toward a conclusion that the majority of the formation in this area (Text-figs. 2,3) represents upper Atoka.

CONODONT SUCCESSION

Introduction

Twenty-seven indigenous species are recognized in the Canyon Creek succession (Text-fig. 3; Pls. 1-4). In

addition, reworked elements, neither specifically identified nor figured, occur in the highest exposure of the Rhoda Creek and throughout the Atoka Formation. Reworked specimens from the Rhoda Creek apparently were derived from Ordovician rocks, whereas those from the Atoka Formation were reworked from rocks ranging in age from Late Devonian to Early Pennsylvanian. Twenty-two of the indigenous species represent genera that bore Pa elements. Apparatus representation for these or the non-Pa element-bearing taxa is not spectacular. The most complete, although often fragmented apparatuses are those of the latter genera, which include *Ellisonia*, *Idiopriodontus*, and *Kladognathus*. Unfortunately, the Mississippian specimens of *Idiopriodontus* are too rare and fragmentary to evaluate possible divergence from the Pennsylvanian *I. conjunctus* (Pl. 2, Figs. 15–24). *Kladognathus* (Pl. 2, Figs. 27–31), a postulated ancestor for *Ellisonia* (von Bitter and Merrill, 1983) is also poorly represented, and its occurrences are separated by a significant interval from those of *Ellisonia* (Text-fig. 3). The *Ellisonia latilaminata* apparatus is represented by relatively well-preserved material (Pl. 2, Figs. 9–14) containing elements not found by von Bitter and Merrill (1983). Apparatus representation of the Pa-element-bearing genera is typically poor. Exceptions to the general rule include *Gnathodus higginsii* (Pl. 1, Figs. 1–3, 8; Pl. 3, Figs. 14–17, 34, 36, 37, 40, 41) and *Lochriea commutata* (Pl. 1, Figs. 14–24). The remaining Pa-element-bearing taxa are represented by occasional occurrences of their Pb elements, and even more spotty occurrences of M and S elements.

Biostratigraphy

Although there are several competing conodont zonations for the Upper Mississippian and Lower Pennsylvanian or their equivalents, none of them can be precisely related to the Canyon Creek conodont succession (Text-fig. 4). Several factors contribute to the lack of zonal congruence and consequent divergent opinions: (1) zones have been erected on the basis of ranges of a single taxon, or at most two taxa, without a phylogenetic basis; (2) the existing zonations are actually biofacies successions and primarily reflect differences in their respective geologic settings and associated paleoenvironmental differences; and (3) differences in conodont taxonomy. One effect of conodont biofacies is illustrated by the fact that in most zonations the taxa that distinguish a zone belong to lineages different from those defining the subjacent and superjacent zones. Interpretation of the temporal relationship of zones established by utilizing this philosophy inherently presents uncertainties, the principal uncertainty being the degree to which the duration of the zone and the events represented by the zonal boundaries reflect evolutionary or environmental signals. This uncertainty can be ameliorated if speciation (phylomorphogenetic changes) within lineages can be recognized, and if the relative timing of such phenomena within and between evolving lineages is well known. In the following paragraphs an application of Carboniferous conodont lineages for biostratigraphy (Text-fig. 5) is treated.

Cavusgnathus

An interpretation that I accept is the commonly held assumption that *Cavusgnathus lautus* evolved from "*A.*" *unicornis* (Dunn, 1970a; Lane and Straka, 1974). Their overlapping ranges and their apparent morphologic intergradation documented from the Wayside Shale by Rexroad and Merrill (1985) support a relationship for these two taxa. In addition, their essentially identical apparatuses (Rexroad and Merrill, 1985) further confirm their close relationship. Because of the presumed evolutionary significance of this relationship, the transition from "*A.*" *unicornis* to *C. lautus* would make a useful paleontologic criterion for recognizing a Mississippian/Pennsylvanian boundary (Wardlaw, 1985; Rexroad and Merrill, 1985). Unfortunately, a barren interval between the highest occurrence of "*A.*" *unicornis* and the lowest occurrence of *C. lautus* obscures the transition between these two taxa in the Canyon Creek succession. This interval of ~5 m contains the Mississippian/Pennsylvanian boundary (Text-fig. 3).

Declinognathodus

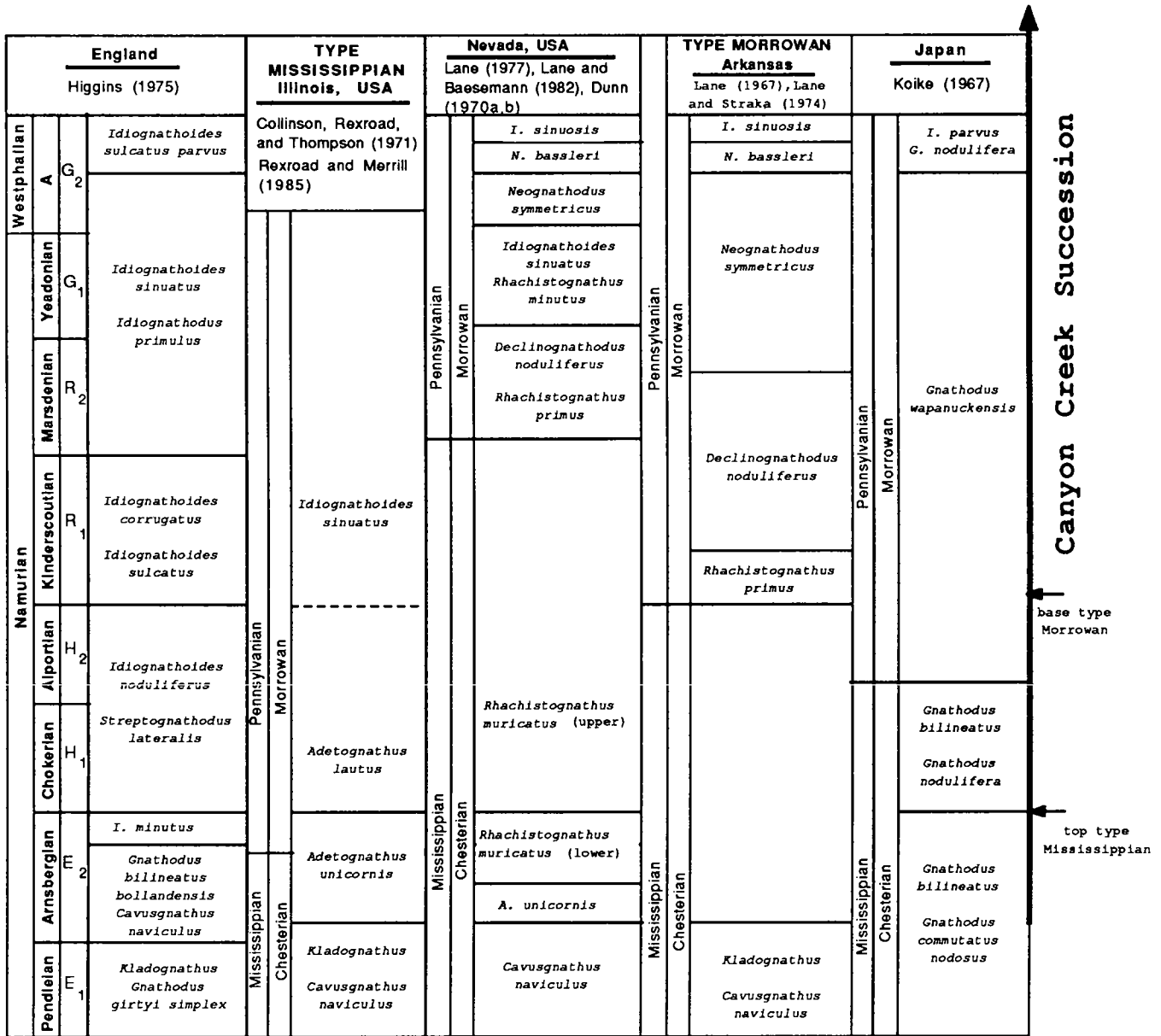
The conodont genus *Declinognathodus* has figured prominently in recognition of a Mississippian/Pennsylvanian boundary (Lane and others, 1985), and in proposals to establish an international mid-Carboniferous boundary (Lane and Manger, 1985; Riley and others, 1987). The importance attached to this genus would suggest that its taxonomy and phylogeny are well known. This, however, does not seem to be the case. Several workers (Dunn, 1970; Lane and others, 1985; Lane and Manger, 1985) have suggested that *Declinognathodus* evolved from *Gnathodus girtyi* at the level of the Mississippian/Pennsylvanian boundary. Grayson and others (in press), utilizing evidence from apparatus reconstructions, argued that *Gnathodus bilineatus* was a more likely ancestor for *Declinognathodus*. Pa elements apparently transitional between *G. bilineatus* and *Declinognathodus* from the upper Barnett Formation in Texas (Grayson and others, 1987, stop 1) also support their interpretation.

The largely typological species concept most workers have applied to *Declinognathodus* has resulted in clearly intergradational morphotypes being assigned to different species and even different genera. It has also precluded uniform recognition of the proposed boundary index taxon *D. noduliferus*. *Declinognathodus noduliferus* includes both Ellison and Graves's (1941) holotype and paratype (presumed reworked); some specimens assigned by workers to *D. noduliferus noduliferus*, *D. noduliferus japonicus*, *D. noduliferus inaequalis*, and *D. lateralis*; and the specimens of *Declinognathodus* from the Rhoda Creek (Pl. 1, Figs. 9–13; Pl. 3, Figs. 29–32, 42). The completely intergradational morphology of these forms has been well illustrated by Austin (1972) as his *Idiognathoides noduliferus*–*Streptognathodus lateralis* morphologic-transition series. In some *S. lateralis* morphotypes, the carina tends to partially separate from the margin, resulting in a neognathodontid-like morphology. This variant has been incorrectly identified as *N.*

symmetricus by Wang and others (1987, pl. 8, figs. 2-5) and by Riley and others (1987, pl. 3, figs. 19-21).

There are four distinct intervals where *Declinognathodus* occurs in the Canyon Creek succession (Text-fig. 3). These arguably represent different species. Like those in the Rhoda Creek, the stratigraphically higher occurrences consist of a completely intergradational morphologic transition series. The younger part of this complex is tentatively subdivided into three species that reflect shifts in the range of morphologic variation and ornamentation. *Declinognathodus* sp. A largely conforms to the intergradational morphotypes figured by Lane (1967) as *Idiognathoides* sp. A. Thus, this "species"

includes a morphotype not developed in *D. noduliferus*, and one that most workers have recognized as *Idiognathoides sulcatus*. Concurrently, the *D. lateralis* morphotype as observed by Higgins (1975) differs slightly from the same morphotype in the older *D. noduliferus*. *Declinognathodus* sp. B, *D. sp. C*, and *D. marginodosus* are largely distinguished by the nature of their ornamentation. The transverse ridges and nodes characteristic of older species become noticeably more rounded in *D. sp. B* (Pl. 3, Figs. 23-28) and younger representatives. *D. sp. C* (Pl. 3, Figs. 18-22) is distinguished largely on the criteria Higgins and Bouckaert (1968) used to erect *Idiognathoides sulcatus parvus*.



Text-figure 4. Mid-Carboniferous conodont zonations. Correlations shown are those developed using the species and range model in Text-figure 5. The position of the Mississippian/Pennsylvanian boundary relative to zonations is that of the various authors; their correlation of this boundary differs from that shown. Bold line at right shows relative relationship of Canyon Creek conodont succession to zonations; top of type Mississippian based on Rexroad and Merrill (1985), base of type Morrowan based on Lane (1967).

Carboniferous		Pennsylvanian																																																							
Mississippian		Morrowan			Alaskan			Dermolnesian		Missourian																																															
Mississippian	Chesterian	(Neo)Gnathodus girtyi	Gnathodus bilineatus	Declinognathodus noduliferus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
		(Neo)Gnathodus higginsi																																																							
		Neognathodus symmetricus																																																							
		Neognathodus bassleri																																																							
	Morrowan	Morrowan	Neognathodus sp. A	Gnathodus bilineatus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
														Neognathodus sp. A	Gnathodus bilineatus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																	
																									Neognathodus sp. B	Gnathodus bilineatus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																						
																																				Neognathodus sp. C	Gnathodus bilineatus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus											
																																															Neognathodus sp. D	Gnathodus bilineatus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus
Alaskan	Alaskan	Neognathodus atokaensis	Gnathodus bilineatus	Declinognathodus noduliferus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
		Neognathodus "bothrops"												Neognathodus sp. A	Neognathodus sp. B	Neognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																			
Dermolnesian	Dermolnesian	Neognathodus spp.	Gnathodus bilineatus	Declinognathodus noduliferus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
		Idiognathoides pacificus												Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																							
Missourian	Missourian	Idiognathus magnificus	Gnathodus bilineatus	Declinognathodus noduliferus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
		Idiognathus claviformis												Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																							
Missourian	Missourian	Idiognathus magnificus	Gnathodus bilineatus	Declinognathodus noduliferus	Declinognathodus sp. A	Declinognathodus sp. B	Declinognathodus sp. C	Idiognathoides sinuatus	Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																												
		Idiognathus magnificus												Idiognathus klapperi	Cavusgnathus lautus	Hindeodus minutus	Diplognathodus spp.	Rhachistognathus prolixus																																							

Text-figure 5. Upper Mississippian–Middle Pennsylvanian conodont biostratigraphic model.

Declinognathodus marginodosus (Pl. 4, Figs. 9–13) is similar, but differs primarily in the nature of the spacing of the nodes on the platform margins, particularly in the wider spacing of nodes on the posterior margins.

Neognathodus and *Gnathodus*

Neognathodus is probably the most important conodont genus for Lower and lower Middle Pennsylvanian conodont biostratigraphy. However, no consensus has been reached concerning either its phylogeny or taxonomy, nor has there been agreement regarding the stratigraphic significance of its occurrences. *Neognathodus*, as previously mentioned, has been assumed to have evolved from *Declinognathodus* in the late early Morrowan or early middle Morrowan by the evolution of a *G. girtyi*-like Pa element. Grayson and others (in press), using evidence from apparatus reconstructions, argue that *Gnathodus girtyi* was ancestral to *Neognathodus*, not *Declinognathodus*. Their interpretation is supported by range considerations, and it eliminates the necessity of redeveloping a *G. girtyi*-like morphology. Eventually, it may become appropriate to place *G. girtyi* and *G. higginsi* in *Neognathodus*.

Gnathodus higginsi includes specimens Higgins (1975) identified from the Namurian of England as *Neognathodus bassleri*, and possibly some of the specimens assigned to *N. symmetricus* by Wang and others (1987, pl. 3, figs. 6 and ?7). If the ammonoid cephalopod correlations are accepted, and Higgins's identification is correct, then *N. bassleri* would be older than *N. symmetricus*, its ancestor. Presumably as a response to this apparent contradiction, Lane and Baesemann (1982) interpreted Higgins's specimens to be *N. symmetricus*. Nonetheless, there were still differences in the conodont successions in England and the succession that has been proclaimed the North American "standard." To account for these range dissimilarities, Lane and Baesemann exported the peculiarly North American concept of a Mississippian/Pennsylvanian boundary "unconformity" to England. However, it is more likely that their range dissimilarities are largely a result of differences in conodont-biofacies successions, taxonomic treatment, and conodont provinces.

In the Rhoda Creek, the conodont assemblage containing *Gnathodus higginsi* constitutes a conodont biofacies that interfingers with a *Declinognathodus* biofacies, a relationship very much like that shown by higher occurrences of *Declinognathodus* and *Neognathodus*. An evolutionary transition from *Gnathodus girtyi* to *G. higginsi* (Grayson and others, 1985) apparently is recorded by the distribution of these taxa within the Rhoda Creek. This interpretation stems from the fact that lower samples yield more specimens comparable to *G. girtyi* than do higher samples. *Gnathodus girtyi* (Pl. 1, Figs. 4–7) is distinguished by the greater anterior extent of its inner platform margin compared to its outer platform margin, by the relatively equal height of its margins and carina, and by the nearly straight outline of its margins. In *G. higginsi* (Pl. 1, Figs. 1–3; Pl. 3, Figs. 14–17), the outer margin is characteristically flared, and both margins

typically extend upward above the level of the carina. As in *G. girtyi*, most specimens of *G. higginsi* exhibit the greater anterior extent of the outer margin; their ontogenetic sequence is similar and is characterized by development from a relatively unornamented blade-like element to an element with fully developed inner and outer parapet-like margins. Both margins develop initially as nodes that then coalesce as the margins progressively develop toward the posterior tip.

At Canyon Creek a significant covered interval separates occurrences of *G. higginsi* from those of *N. symmetricus* (Text-fig. 3). Consequently the exact nature of any possible evolutionary transition between these taxa cannot be thoroughly assessed. Nonetheless it is evident that there is some overlap in the morphotypes of the Pa elements developed in *G. girtyi*, *G. higginsi*, *N. symmetricus*, *N. bassleri*, and younger species of *Neognathodus*. For example, the margins of *N. symmetricus* are commonly straight, and the parapet-like margins generally extend no higher than the carina. In these respects, *N. symmetricus* is comparable to *G. girtyi*. Unlike either *G. girtyi* or *G. higginsi*, the anterior terminations of the margins in *N. symmetricus* (Pl. 3, Figs. 8–13) are more or less equal. Some specimens of *N. symmetricus* (Pl. 3, Fig. 11) show an incipient flaring of the outer margin, which is a typical morphologic feature of *N. bassleri*. This flaring of the outer margin and the generally higher margins relative to the carina in *N. bassleri* (Pl. 3, Figs. 1–7) is reminiscent of *G. higginsi*.

The important middle Morrowan transition from *N. symmetricus* to *N. bassleri* is approximately located in the middle of the "Union Valley" Formation. Occurrences of *Neognathodus* between those of *N. symmetricus* and *N. bassleri* in the "Union Valley" and those in the Atoka Formation are separated by a significant stratigraphic interval from which the genus was excluded for paleoenvironmental reasons. Lance L. Lambert and I have collections that demonstrate that Merrill's (1972, 1975) Desmoinesian species have ancestors that overlap in range with *N. bassleri*. We are currently working on a phylogeny-based taxonomy for these species. The taxon that Merrill called *Neognathodus bassleri* in his Appalachian and Illinois basin material was derived from rocks that are approximately coeval with the Atoka Formation. Lane and others (1972) and Lane and Straka (1974) regarded Merrill's *N. bassleri* as a homeomorph best assigned to Stibane's (1967) *N. colombiensis*. Grayson (1984), primarily using criteria based on oral outline, recognized two overlapping taxa in the Atoka Formation: an older *N. atokaensis* (a new taxon, distinguished by an asymmetrical outline; Pl. 4, Figs. 14–16) and a younger *N. bothrops* (characterized by a more symmetrical outline; Pl. 4, Figs. 17–19). This latter taxon does not appear to actually belong in Merrill's *N. bothrops*, so it is shown on Figure 3 as *N. "bothrops"*. It is this latter taxon that appears to have been confused with either older Morrowan or younger Desmoinesian species of *Neognathodus*. In addition to oral outline and relative position of the carina, Grayson and Lambert (1987) pointed out that the cross-sectional view can be used as a criterion to distinguish Atokan species of *Neognathodus* from Merrill's Desmoinesian taxa.

Idiognathodus

The ranges of species of *Idiognathodus* provide stratigraphically significant zones that are often more useful than zones established using the environmentally more restricted genus *Neognathodus*. Populations of *Idiognathodus* in the Canyon Creek succession exhibit the extremely broad range of morphological variation that is characteristic of the genus throughout its range. The majority of the specimens from any given population fall within the historical definition of *Idiognathodus* (Ellison, 1941). An exception to this is the occurrences of forms identified from the upper "Union Valley" and unnamed shale as *I. sinuosus* (Pl. 4, Figs. 37–39). This group of specimens contains morphologic variants that fall within the historical definition of *Streptognathodus* (Stauffer and Plummer, 1932). Similar, but fewer numbers, of troughed (streptognathodontoid) versus the more common non-troughed (idiognathodontoid) variants occur throughout the remainder of the Canyon Creek section.

Grayson and others (1989) outlined a methodology for distinguishing species of *Idiognathodus* that focused on the character of the anterior region rather than the presence or absence of a trough or accessory lobes. Utilizing their methodology, three species can be recognized in the Canyon Creek succession: *I. sinuosus*, *I. klapperi*, and *I. incurvus*. *I. sinuosus* is the oldest species of the genus that is recognizable in North America. Higgins's (1975) *I. primulus* is apparently an older species from which *I. sinuosus* evolved by development of adcarinal ridges and accessory lobes. The adcarinal ridges in Pa elements of *I. sinuosus* (Pl. 4, Figs. 36–39) extend anteriorly from the platform, where they more or less parallel the free blade. Incorporation of the anterior extensions of the adcarinal ridges into the platform led to a morphology that is characteristic of *I. klapperi* (Pl. 4, Figs. 23–27). *I. incurvus* (Pl. 4, Figs. 4–8) subsequently evolved from *I. klapperi* by anterior and downward extension of skeletal material from the adcarinal ridges onto the free blade.

CHRONOSTRATIGRAPHY

Mid-Carboniferous Boundary

The position of the Mississippian/Pennsylvanian boundary at Canyon Creek coincides with a change in shale lithology, the onset of a geochemical anomaly, the appearance of conodonts having a Pennsylvanian aspect (including the frequently cited boundary index species *Declinognathodus noduliferus*), and the disappearance of most taxa historically associated with the Mississippian (Text-fig. 3). Because the faunally defined boundary is coincident with a lithologic boundary, it is concluded that the faunal change is in part the result of shifting facies. Other faunal indications of the differing paleoenvironmental conditions include the nearly complete exclusion of *Cavusgnathus* above the boundary, and that of *Gnathodus girtyi* below the boundary.

All of the Rhoda Creek samples below the boundary

yield a conodont fauna indicative of the latest Chesterian "Adetognathus" *unicornis* Zone. This fauna includes the zonal taxon "A." *unicornis*, and other characteristically Mississippian elements, such as *Lochriea commutata*, *G. bilineatus*, *Cavusgnathus naviculus*, and *Kladognathus* spp. One of the more interesting Mississippian faunal relationships is the nearly mutually exclusive occurrences of "A." *unicornis* and *G. bilineatus*. This may have biostratigraphic implications. For example, the occurrence of *G. bilineatus* without "A." *unicornis* at localities in Texas, Japan, and Europe has been cited as evidence for a boundary unconformity (Liner and others, 1979; Manger and others, 1985; Lane and Baesemann, 1982). Seemingly, the absence of "A." *unicornis* at those localities might only indicate unfavorable paleoenvironmental conditions, and for that reason its absence might be completely devoid of temporal significance. Further confirmation of their generally non-overlapping distributions comes from the mid-Carboniferous boundary in Illinois, where "A." *unicornis* and *Cavusgnathus lautus* occur without *G. bilineatus* (Rexroad and Merrill, 1985).

The lowest Pennsylvanian conodont faunas at Canyon Creek (Text-fig. 3) contain two taxa, *L. commutata* and *Idioproniodus*, that are also present in the Mississippian part of the Rhoda Creek. It could be argued that this occurrence of *L. commutata* above the Mississippian/Pennsylvanian boundary represents reworking of Mississippian specimens. However, reworking seems unlikely, because the species is abundant, well preserved, and represented by nearly all elements of its apparatus. Preservation in this manner is unlikely if erosion and redeposition were actually involved. It therefore seems probable that under certain paleoenvironmental conditions *L. commutata* lived on into the Pennsylvanian, but only in limited paleoenvironmental settings. Comparable occurrences of *G. bilineatus* in Belgium (Higgins and Bouckaert, 1968) and Japan (Koike, 1967) probably represent a similar phenomenon. Overlap in species of Mississippian and Pennsylvanian aspect is essentially equivalent to Higgins's (1975) *Idiognathoides noduliferus*–*Streptognathodus lateralis* Zone (Text-fig. 4). Higgins's zone coincides with the Chokierian and Arnsbergian Stages (middle Namurian) of Europe. Significantly, this is the minimal hiatus assumed to be developed in the southern Midcontinent as a consequence of a boundary unconformity (Manger and Sutherland, 1984). Hence, Canyon Creek probably represents a conformable lithologic succession across the mid-Carboniferous boundary. As shown in Text-figure 4, not all workers place the Mississippian/Pennsylvanian boundary at this relative position.

Intra-Morrowan

Basal type-Morrowan conodonts were not recovered from the Canyon Creek succession. Their position probably coincides with the covered interval between exposures of the Rhoda Creek and "Union Valley" Formations. The "Union Valley" contains the important mid-Morrowan conodonts *N. symmetricus*, *N. bassleri*, *Declinognathodus* sp. B, *D.* sp. C, and *Idiognathodus sinuosus*.

Morrowan/Atokan Boundary

The position of the Morrowan/Atokan boundary cannot be as firmly established as that of the Mississippian/Pennsylvanian boundary. This reflects the lack of consistent criteria for recognition of the boundary and the relatively less dramatic changes in the conodonts. Thus, the Morrowan/Atokan boundary could be located at Canyon Creek at one or the other of several different positions. The varying criteria used to establish a boundary and possible boundary positions are discussed in the following paragraphs.

Lane and Straka (1974) established two late Morrowan conodont zones on the ranges of *Idiognathodus klapperi* and *Idiognathoides convexus*. Grayson's (1984) *Idiognathoides ouachitensis*-*Neognathodus* n. sp. A, *Diplognathodus* spp.-*Idiognathodus* n. sp., *Declinognathodus marginodosus*, and *Neognathodus atokaensis* assemblages were thought to follow sequentially the *I. convexus* Zone, and the Morrowan/Atokan boundary was located at the initial appearance of either *Idiognathodus* n. sp., or the diplognathodontids identified as *Diplognathodus orphanus* and *D. coloradoensis*. The latter taxon has also been regarded as an Atokan index fossil by Lane and others (1972) and Dunn (1976). At Canyon Creek, Grayson (1984) recognized the *I. convexus* Zone in the lower, major portion of the Wapanucka, the *I. ouachitensis*-*Neognathodus* n. sp. C (*N. n. sp. A* of Grayson) assemblage in the uppermost portion of the Wapanucka, and the laterally equivalent *D. marginodosus* and *N. atokaensis* assemblages in the Atoka Formation. An unconformity between the Wapanucka and Atoka Formations was used to explain the inability to establish the presence of the *Idiognathodus* n. sp.-*Diplognathodus* spp. assemblage. Although these conclusions may prove to be more or less correct, it can now be demonstrated that none of these late Morrowan and Atokan conodont subdivisions represent the isochronous packages originally envisioned. In fact, their relationship is more a case of biofacies than anything else. Furthermore, species concepts and ideas regarding the Morrowan/Atokan boundary have evolved through the influence of other workers and their contributions.

Lane and Straka's concept of *I. klapperi* was based on only six specimens from two basal Dye Shale (type Morrowan) localities. The present concept of this species is based on different criteria, which has resulted in its range overlapping with the ranges of *D. coloradoensis*, *D. orphanus*, and *Neognathodus* n. sp. C. Specimens previously identified as *Idiognathodus* n. sp. are now regarded as troughed morphotypes of *I. klapperi*. *I. convexus* and *I. ouachitensis* are actually one of many paleoenvironmentally induced morphotypes of the long-ranging *I. sinuatus*. The potentially more significant occurrences of specimens identified as *Diplognathodus* spp. and as *Neognathodus* n. sp. C are stratal rather than evolutionary events, since these occurrences have not been related to any knowledge of their ancestry. Consequently, the significance of their appearances for correlation are uncertain.

The nature of the Wapanucka/Atoka formational

boundary and its relationship to the Morrowan/Atokan boundary also needs to be reevaluated. At the Canyon Creek locality, there is no obvious lithologic evidence for an unconformity, and the conodont evidence previously used is insufficient to make a firm case for a hiatus. Tectonic activity was increasing during accumulation of the two formations. Thus, the onlap and lenticular conglomerates (Archinal, 1979; Brown, 1987) may reflect only local effects, and not a regional, truncating, erosional surface. Whether the Morrowan/Atokan chronostratigraphic boundary should be located at the formational boundary—or whether the Atokan Series should even be recognized—are more-thorny questions.

The biostratigraphic evidence from several organic groups leads me to conclude that regardless of terminology there is a more or less recognizable interval between the Morrowan and the Desmoinesian. This interval may not be as readily distinguishable as some chronostratigraphic subdivisions (Sutherland and Manger, 1983), but this fact alone will not prevent workers from attempting to recognize or use an Atokan Series. Some workers have argued that the Atokan Series should not be recognized, either because the Desmoinesian overlaps the Morrowan (Shaver, 1984), or because the Atokan is not biostratigraphically distinguishable from the Desmoinesian (Wilson, 1976). Certainly, overlap exists when only certain long-ranging organic groups such as ostracodes and palynomorphs are used for correlation. However, this overlap can be eliminated by using more-time-significant groups such as the conodonts, and perhaps foraminifers, including fusulinids.

Historically, fusulinids have been the principal basis for defining and recognizing the Atokan Series. Early in its history, the Atokan Series came to be equated with the fusulinid *Profusulinella* and *Fusulinella* Zones. The base of the series is now lowered by some workers to coincide with the appearance of *Eoschubertella* (Mamet and Skipp, 1970). Unfortunately, these taxa do not occur in either the type area for the Morrowan (northwestern Arkansas, Ozark Mountains region) or the Atokan Series (southeastern Oklahoma, Ouachita Mountains region). Therefore, their application to recognition of these chronostratigraphic intervals from their respective types areas is exceedingly uncertain. Although the paleogeographic distribution of all organic groups was limited by the lateral and temporal extent of the paleoenvironments they could tolerate, some groups, such as the conodonts, were relatively less sensitive environmentally.

The attempt to locate the base of the Atokan Series in the Canyon Creek conodont succession as defined by foraminifers or plant fossils is at best tentative and could be presumed to be entirely speculative. The florally defined boundary is equated with the base of the Dye Shale by the United States Geological Survey (Gordon, 1984). If this correlation is accepted, the evolutionary appearance of the conodont *I. klapperi* would provide an essentially equivalent biostratigraphic position. This would locate the boundary somewhere between the occurrences of *I. sinuosus* and *I. klapperi* in the

unnamed shale (Text-fig. 3). Groves and Grayson (1984) recorded an occurrence of *Eoschubertella* from the Wapanucka Formation as developed in the frontal Ouachita Mountains. There, *Eoschubertella* occurs in the uppermost part of the *I. ouachitensis*-*Neognathodus* n. sp. C assemblage, or the lowest part of the *Idiognathodus* n. sp.-*Diplognathodus* spp. assemblage. If *Eoschubertella* is used to define the boundary, at Canyon Creek this position would likely be either in the uppermost part of the Wapanucka or in the largely covered interval at the base of the Atoka Formation (Text-fig. 3). Unfortunately, the appearance of *Eoschubertella* does not provide a consistent basis for boundary recognition. Based on associated conodonts, the appearance of *Eoschubertella* in the Western U.S. (Dunn, 1976) is significantly lower (older) than the Ouachita Wapanucka occurrence. Although *Profusulinella* was reported by Thompson (1935) from the Atoka Formation in this area, subsequent workers have not been able to duplicate his findings (Douglass and Nestell, 1984). *Fusulinella* does occur at Canyon Creek in the Atoka Formation (Archinal and others, 1982), where it is associated with conodonts distinct from those considered either Morrowan or Desmoinesian. The taxa most germane to this conclusion are *I. incurvus*, *N. atokaensis*, and *N. "bothrops."* This assemblage is characteristic of the middle or, more reasonably, the late Atokan. These taxa occur in my lowest samples from the Atoka Formation, suggesting that the Morrowan/Atokan boundary placement shown in Text-figure 3 is not unreasonable.

CONCLUSIONS

The Canyon Creek succession includes rocks ranging in age from Devonian to Middle Pennsylvanian. It is an exceptionally complete stratigraphic sequence that records portions of several conodont lineages. Phylomorphogenetic species within these lineages provide a biostratigraphic basis for locating a Mississippian/Pennsylvanian boundary and a Morrowan/Atokan bound-

ary. The Mississippian/Pennsylvanian boundary at Canyon Creek is located within a conformable shale succession at a lithologic and geochemical change that coincides with the shift from conodonts characteristic of the "*Adetognathus unicornis* Zone to those characteristic of Higgins's *Idiognathoides noduliferus*-*Streptognathodus lateralis* Zone. Thus, the Mississippian/Pennsylvanian boundary at Canyon Creek is essentially equivalent with the mid-Carboniferous boundary. An exact correlation is not expected, because of the shifting paleoenvironmental conditions that probably controlled the appearance of *D. noduliferus* and slightly higher *Gnathodus higginsii*. Although a transition between "*A. unicornis* and *Cavusgnathus lautus* has not been found at Canyon Creek, their presumed evolutionary divergence would have occurred within a 5-m interval that contains the Mississippian/Pennsylvanian boundary.

The Morrowan/Atokan boundary cannot be located with as much confidence as the Mississippian/Pennsylvanian boundary. This partly stems from uncertainties regarding the boundaries of the Atokan Series, but also (at Canyon Creek) from less-dramatic faunal changes within the more paleoenvironmentally restricted conodont succession. As various competing faunal and floral criteria have been used to locate a boundary, several possible boundary locations exist. Integration of these data with those from the conodonts has not reached a level of understanding that promotes confidence in a boundary located with conodonts. A boundary located in the unfossiliferous, poorly exposed shales at the base of the Atoka Formation is at least consistent with the historically significant fusulinids. This boundary position at Canyon Creek separates occurrences of the conodont taxa *Idiognathodus klapperi* and *I. incurvus*.

ACKNOWLEDGMENTS

Glen K. Merrill and Scott M. Ritter contributed by critically reading and editing the manuscript.

Plates

PLATE 1

Conodonts from the Rhoda Creek Formation.

Figures 1-3.—*Gnathodus higginsi*. Upper view of Pa elements. 1, ×50. 2,3, ×30. All from sample 18.

Figures 4-7.—*Gnathodus* sp. aff. *G. girtyi*. Upper view of Pa elements. 4, ×50. 5-7, ×30. 4, sample 16; 5-7, sample 18.

Figure 8.—Vicarious Pb element of *G. higginsi* and *G. sp. aff. G. girtyi*. ×50. Sample 15.

Figures 9-13.—*Declinognathodus noduliferus*. Upper views of Pa elements. 9, ×100. 10-13, ×50. All from sample 14.

Figures 14-24.—*Lochriea commutata*. 14-16, upper views of Pa elements. 17-19, lateral views of Pb elements. 20,21, lateral views of Sc elements. 22, lateral view of ?Sa element. 23,24, lateral view of M elements. 14,17,21-24, ×50; 15,16,18,19, ×30. 14,16, sample 14; 15, sample 16; all others, sample 4.

Figures 25-31.—*Gnathodus bilineatus*. 25,26, upper views of Pa elements. 27, lateral view of Sa element. 28, view of ?Sd element. 29, lateral view of M element. 30, lateral view of Pb element. 31, lateral view of ?Sc element. 25, ×30; 26, ×100; all others, ×50. 25, sample 7; all others, sample 4.

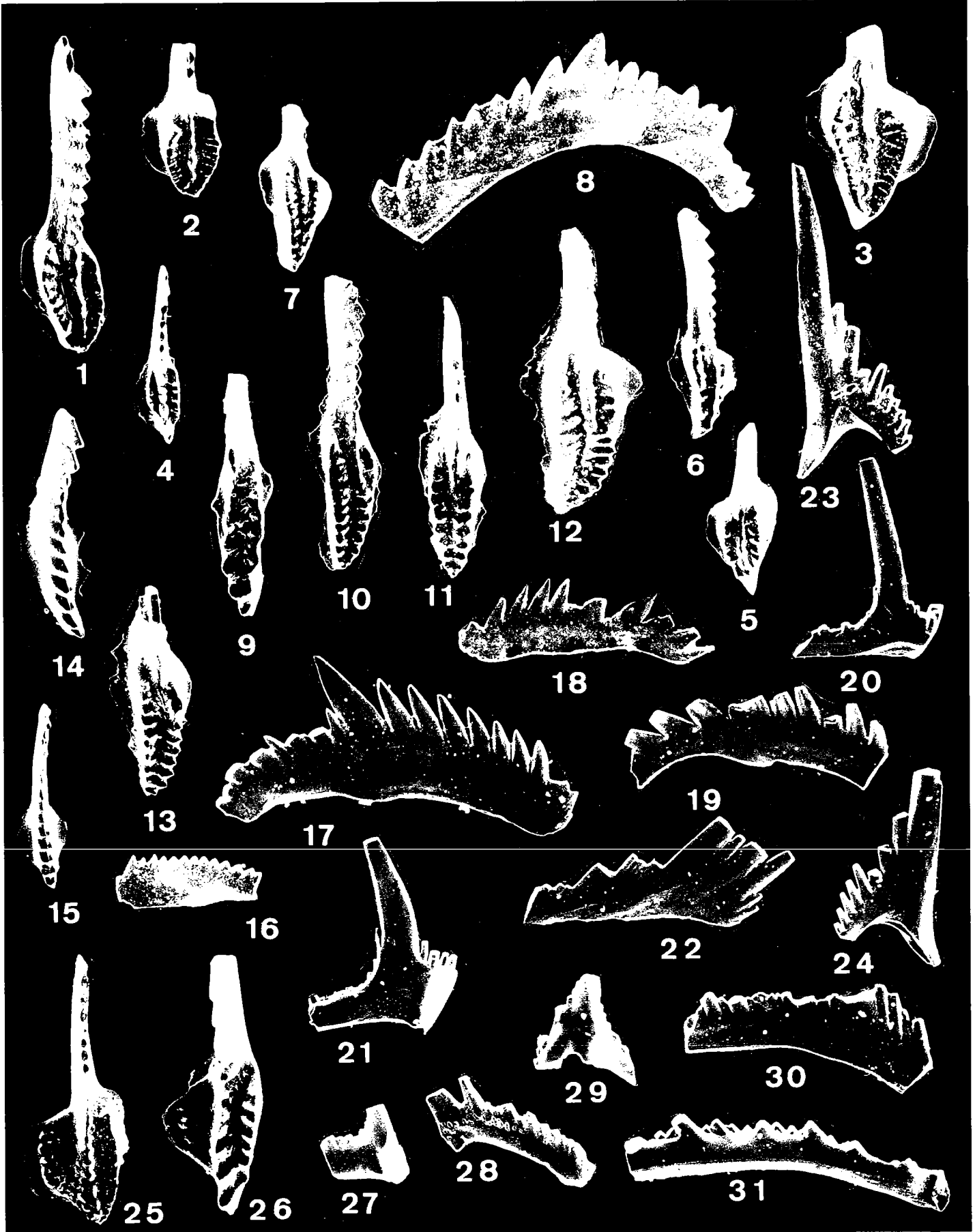


PLATE 2

Conodonts from the Rhoda Creek Formation (1,15–31); from the unnamed shale (2,3,7,10); from the Wapanucka Formation (4,5,8,9,11–14); and from the Atoka Formation (6).

Figures 1–5.—*Cavusgnathus lautus*. 1, view of Sa element. 2,4, posterior view of Pa elements. 3, lateral view of Pb element. 5, lateral view of Pb element. 1,3,4, ×50; 2,5, ×30. 1, sample 14; 2, sample 43; 3, sample 40; 4,5, sample 52.

Figures 6–8.—*Hindeodus minutus*. 6, lateral view of Pa element. 7, lateral view of Sb element. 8, lateral view of Pb element. 6,7, ×50; 8, ×30. 6, sample 57; 7, sample 40; 8, sample 49.

Figures 9–14.—*Ellisonia latilaminata*. 9, lateral view of element possibly analogous to Sb. 10, lateral view of element possibly analogous to Pa *sensu* Sweet. 11, view of Sa element. 12, lateral view of Sc element. 13, lateral view of Pb element. 14, lateral view of element possibly analogous to M element. All ×30. 9,12–14, sample 49; 10, sample 38; 11, sample 52.

Figures 15–24.—*Idioproniodus conjunctus*. 15, lateral view of M element. 16–18, lateral view of ponderosiform elements. 19,20, lateral view of Sc elements. 21,22, view of Sa elements. 23, lateral view of clarkiform element. 24, view of bidentatiform element. 15–21,24, ×50; 22,23, ×30. 15,16,18,20, sample 16; 17,19,22,23, sample 15; 21, sample 20; 24, sample 118.

Figures 25,26.—“*Adetognathus unicornis*”. 25, upper view of Pa element. 26, lateral view of Pb element. 25, ×30; 26, ×50. Both from sample 8.

Figure 27.—*Kladognathus primus*. Lateral view. ×50. Sample 4.

Figure 30.—? *Kladognathus typus*. Lateral view. ×50. Sample 4.

Figures 28,29,31.—Vicarious elements of *Kladognathus*. 28,29, lateral view of M elements. 31, view of ?Sb element. All ×50. All from sample 4.

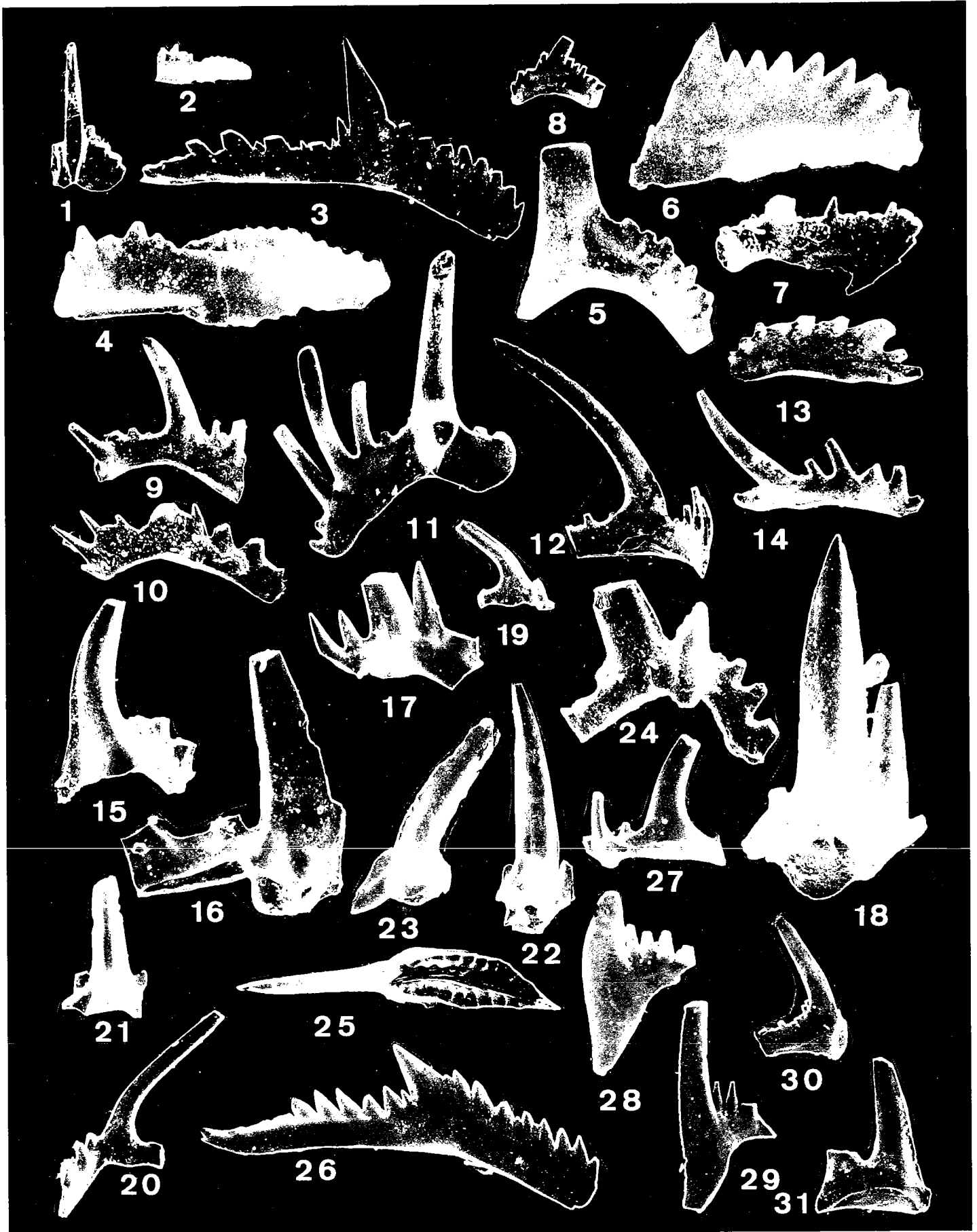


PLATE 3

Conodonts from the "Union Valley" Formation (1-13,18-28,33,35,38,39) and the Rhoda Creek Formation (14,29-32,34,36,37,40,42).

Figures 1-7.—*Neognathodus bassleri*. Upper view of Pa elements. 1,2,5, ×50; all others, ×30. 1,5, sample 36; all others from sample 35.

Figures 8-13.—*Neognathodus symmetricus*. Upper view of Pa elements. 8, ×50; all others, ×30. 8,9,11, sample 26; all others from sample 27.

Figures 14-17.—*Gnathodus higginsi*. 14-16, upper view of Pa elements. 14,17, ×50; 15,16, ×30. 14, sample 17; 15-17, sample 18.

Figures 18-22.—*Declinognathodus* sp. C. Upper view of Pa elements. All ×50. 18,19,21,22, sample 35; 20, sample 35.

Figures 23-28.—*Declinognathodus* sp. B. Upper view of Pa elements. All ×50. All from sample 25.

Figures 29-32.—*Declinognathodus noduliferus*. Upper view of Pa elements. All ×50. All from sample 23.

Figures 33-42.—Possibly vicarious gnathodontid elements. 33,34, view of Sd elements. 35-37, lateral view of Sc elements. 38-40, lateral view of M elements. 41, view of Sa element; 42, hindeodelliform element. All ×50. 33, sample 35; 34,36,39, sample 36; 35,39, sample 27; 40, sample 19; 41, sample 16; 42, sample 14.

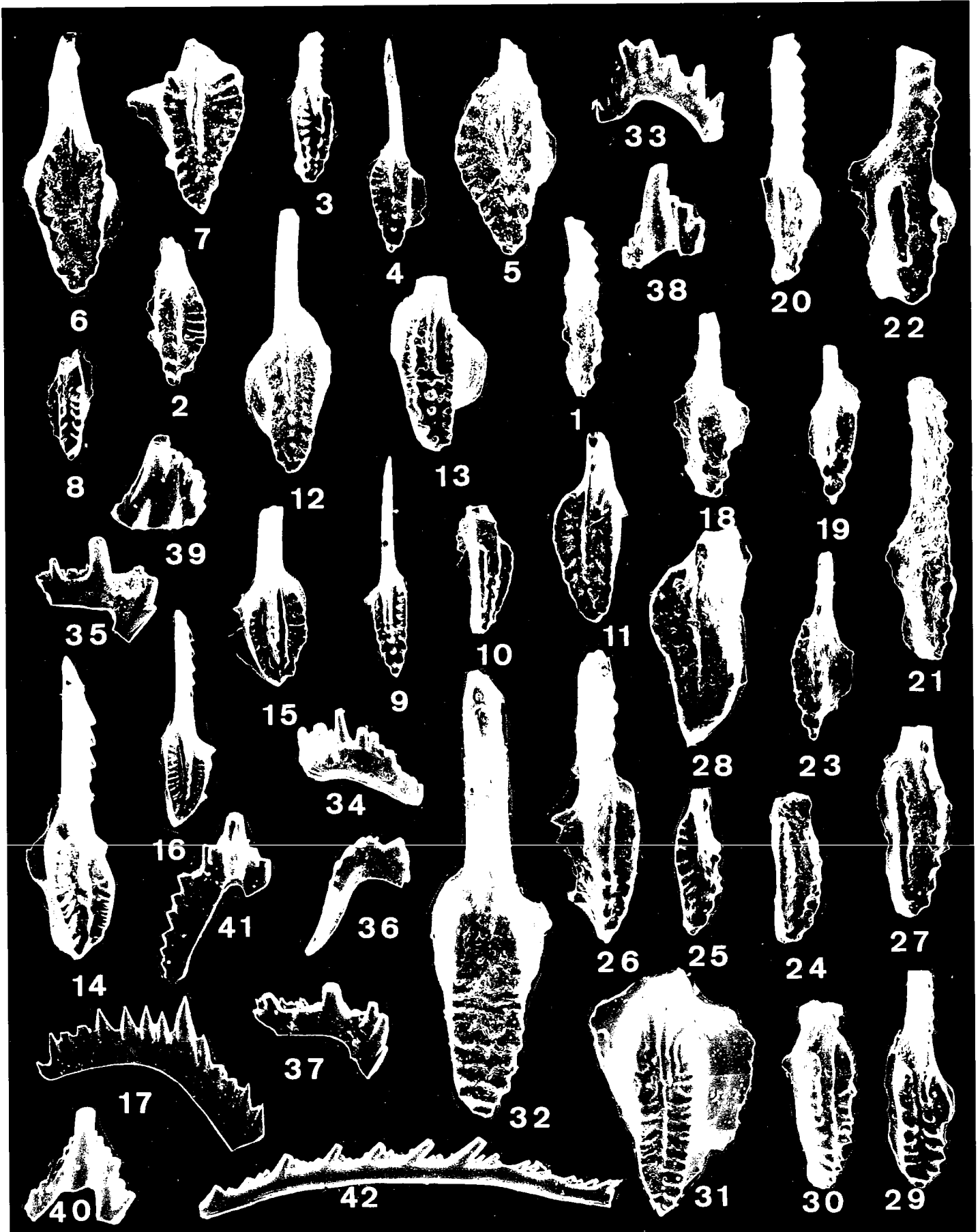


PLATE 4

Conodonts from the Atoka Formation (1–22), Wapanucka Formation (23–33,43), unnamed shale (34–38,42), and "Union Valley" Formation (39).

Figure 1.—Possible element of *Aethotaxis apparatus*. ×30. Sample 57.

Figures 2,3.—*Ellisonia conflexa*. 2, lateral view of element possibly analogous to ?Sc. 3, view of element possibly analogous to ?M. All ×30. All from sample 57.

Figures 4–8.—*Idiognathodus incurvus*. 4–7, upper view of Pa elements. 8, lateral view of Pb element. 6–8, ×50; 4,5, ×30. All from sample 57.

Figures 9–13.—*Declinognathodus marginodosus*. Upper view of Pa elements. 9–11, 13, ×50; 12, ×30. All from sample 54.

Figures 14–16.—*Neognathodus atokaensis*. Upper view of Pa elements. 14, ×50; 15,16, ×30. 14,16, sample 58; 15, sample 57.

Figures 17–19.—*Neognathodus "bothrops"*. Upper view of Pa elements. 17, ×50; 18,19, ×30. 17,19, sample 57; 18, sample 58.

Figures 20–22.—Possibly vicarious gnathodontid elements. 20, lateral view of Sc element. 21, lateral view of Sb element. 22, view of M element. All ×30. All from sample 57.

Figures 23–27.—*Idiognathodus klapperi*. Upper view of Pa elements. 23, ×50; all others, ×30. All from sample 52.

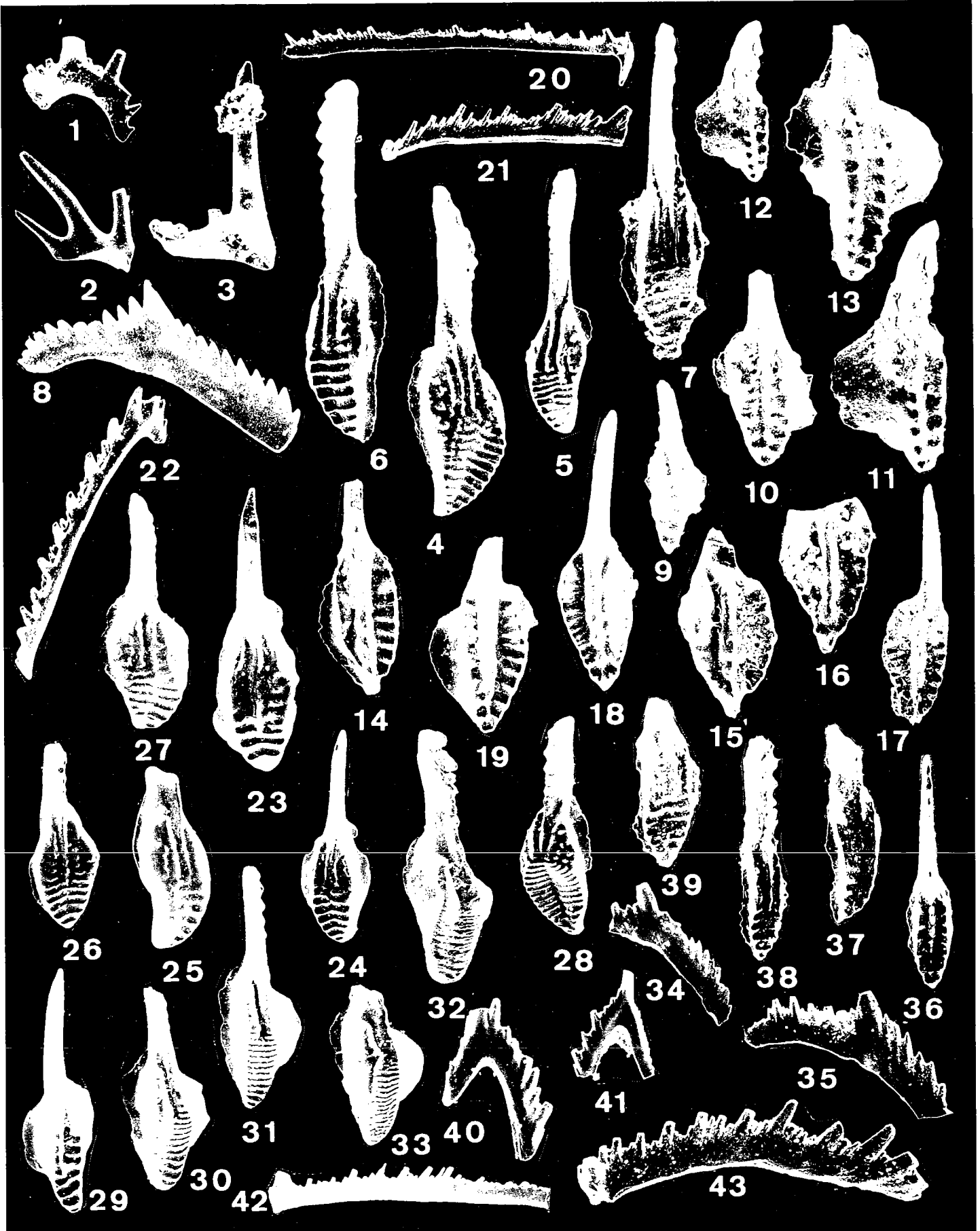
Figure 28.—*Streptognathodus expansus*. Upper view of Pa element. ×30. Sample 52.

Figures 29–33.—*Idiognathoides sinuatus*. Upper view of Pa elements. All ×30. All from sample 52.

Figures 34,35.—Vicarious element of *Idiognathoides* and *Declinognathodus*. Lateral view of Pb elements. 34, ×30; 35, ×50. All from sample 40.

Figures 36–39.—*Idiognathodus sinuosus*. Upper view of Pa elements. All ×50. 36–38, sample 37; 39, sample 38.

Figures 40–43.—Vicarious gnathodontid elements. 40,41, lateral view of M elements. 42, lateral view of Sc element. 43, lateral view of Sa element. 40,41,43, ×50; 42, ×30. 40,41, sample 40; 42, sample 43; 43, sample 52.



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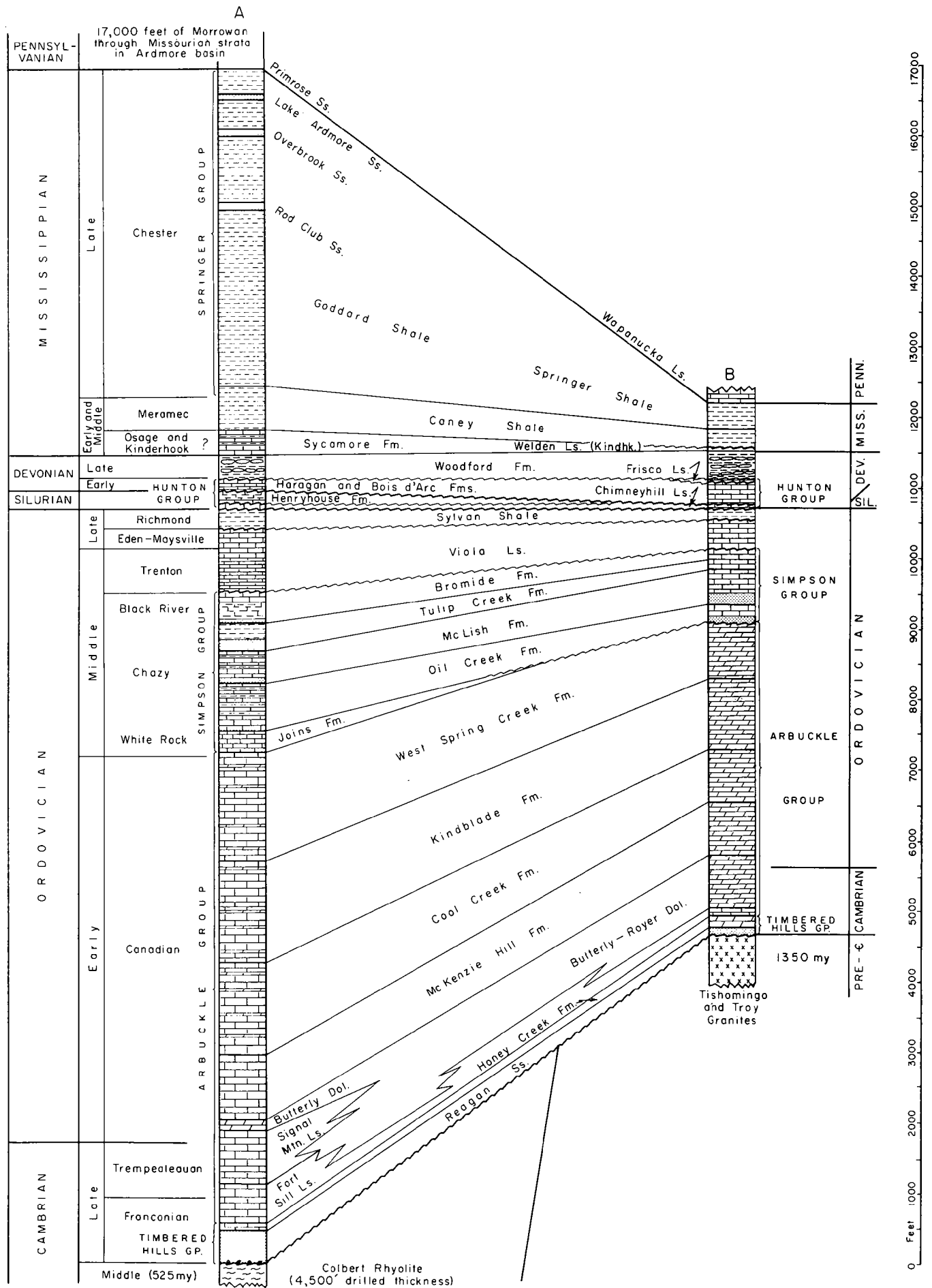
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Pre-Pennsylvanian stratigraphic columns for the Arbuckle anticline and Ardmore basin (A), and for the Hunton anticline (B). From Ham (1969).