OKLAHOMA GEOLOGICAL SURVEY
Charles J. Mankin, *Director*

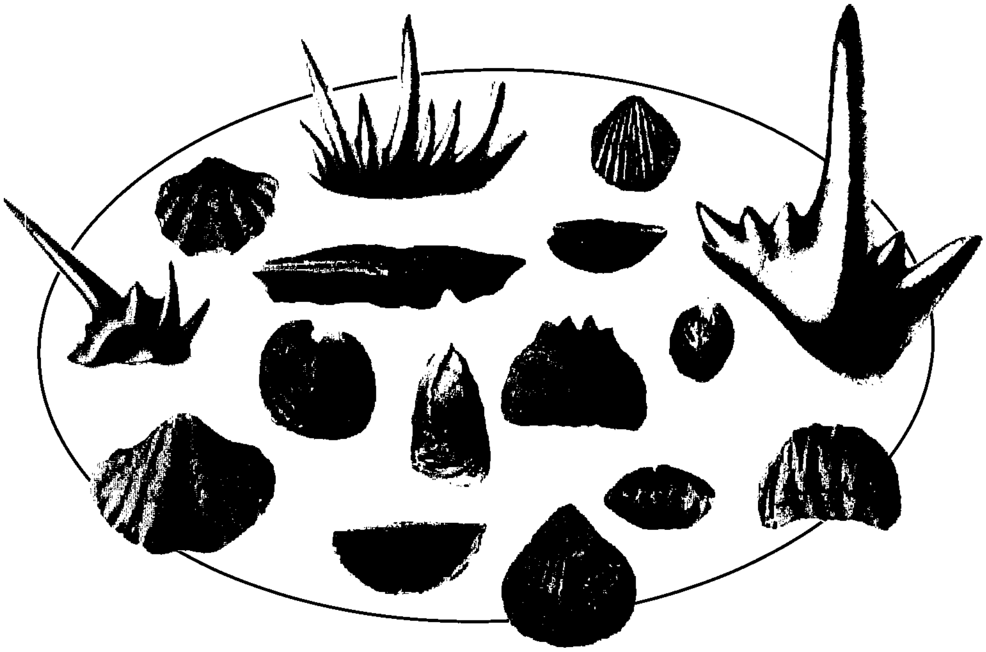
BULLETIN 145 ISSN 0078-4389

SPECIAL PAPERS IN PALEONTOLOGY AND STRATIGRAPHY: A TRIBUTE TO THOMAS W. AMSDEN

Editors:

JAMES R. CHAPLIN
Oklahoma Geological Survey

JAMES E. BARRICK
Texas Tech University



The University of Oklahoma
Norman

1992

DEDICATION

Dr. Thomas W. Amsden joined the Oklahoma Geological Survey in 1955 and retired officially in 1985. During his 30-year tenure with the OGS, Tom compiled an exemplary record of research. His publication list is impressive by any standard of measure.

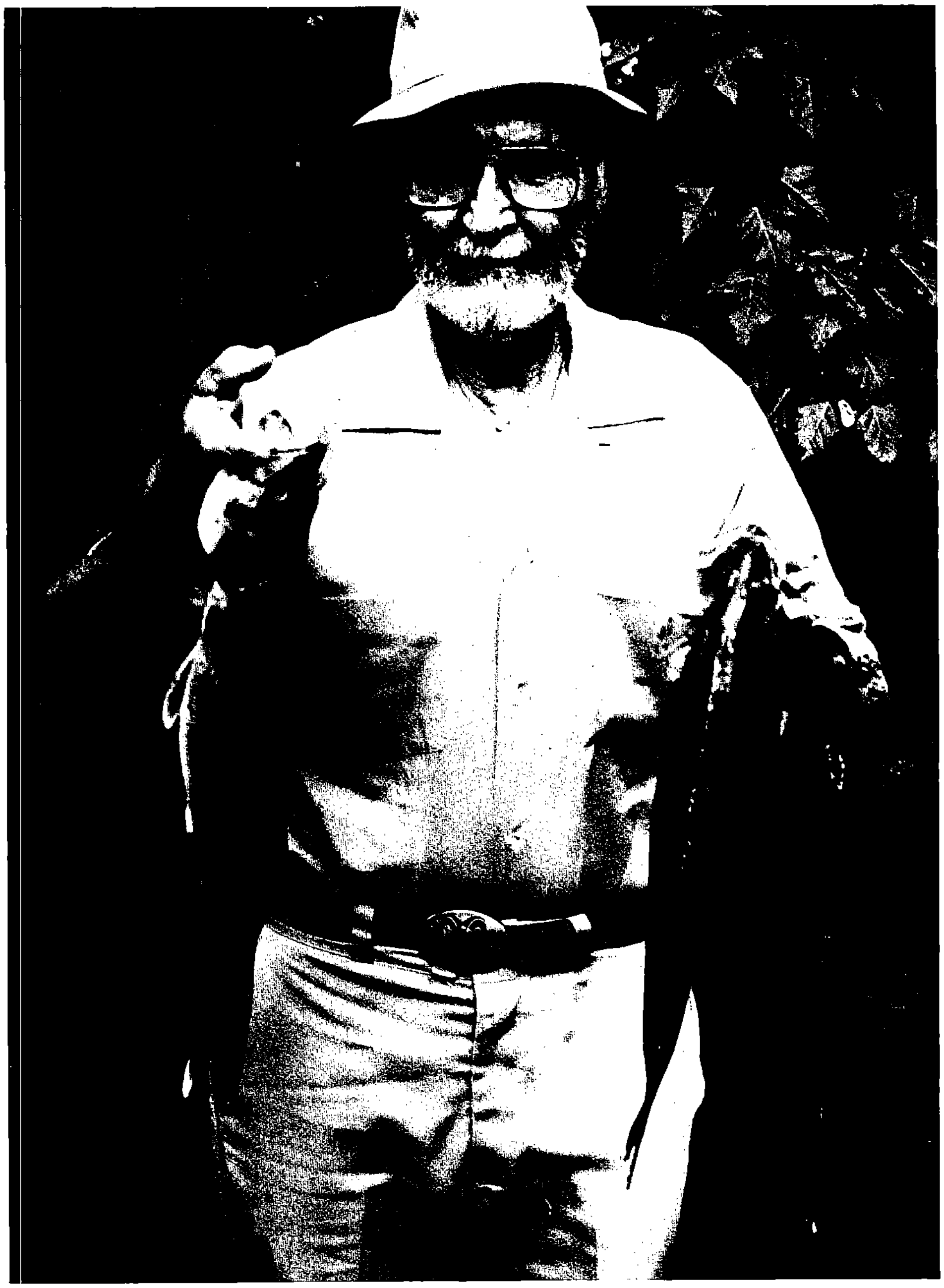
Beyond this statistical measure of performance, Tom is in every sense a professional. He pursues his studies with quiet diligence. He has a strong work ethic and holds himself, and those that support his efforts, to the highest professional standards in both quality and quantity. He does not suffer frivolity and lame excuses for poor performance lightly. In short, Tom has established the benchmark at the OGS for what a professional geologist should be.

The contributions Tom has made to our understanding of lower Paleozoic litho- and biostratigraphy are well recognized by all who have had reason to read his publications or have discussed his studies with him. Among the few investigators who have differed with his findings, none has questioned his exacting standards of analysis. All have benefited from his years of meticulous study.

Beyond his quiet and, at times, gruff exterior, Tom is a very human and caring person. I have had the pleasure of working with him for most of his tenure with the OGS, and continue to value his wise advice, as I did during my early years as director of the Survey when he, and the late Bill Ham, were my sources of counsel, inspiration, and comfort. I am pleased to have Tom as a colleague and friend, and am honored that he considers me in a similar way.

Although Tom has been officially retired since 1985, he continues to pursue a life-long love affair with "his Silurian and Devonian rocks and fossils." All of us who have had the privilege to know, work, and play with Tom are clearly the better for it. My colleagues join me in dedicating this special volume of papers in his honor, and look forward to many years of further collaboration with this uncommon man.

CHARLES J. MANKIN



Thomas W. Amsden

OKLAHOMA GEOLOGICAL SURVEY

CHARLES J. MANKIN, *Director*
KENNETH S. JOHNSON, *Associate Director*

SURVEY STAFF

JAMES H. ANDERSON, *Cartographic Draftsperson II*
ROBERT H. ARNDT, *Economic Geologist*
BETTY D. BELLIS, *Word-Processing Operator II*
TOM L. BINGHAM, *Geologist II*
MITZI G. BLACKMON, *Clerk-Typist*
JOCK A. CAMPBELL, *Petroleum Geologist IV*
BRIAN J. CARDOTT, *Organic Petrologist*
JAMES R. CHAPLIN, *Geologist III*
JANISE COLEMAN, *Office Assistant II*
CHRISTIE L. COOPER, *Editor*
VELMA L. COTTRELL, *Chief Clerk*
ELDON R. COX, *Manager, Core and Sample Library*
TAMMIE K. CREEL, *Data-Entry Specialist*
CHARLES DYER III, *Drilling Technician*
WALTER C. ESRY, *Core and Sample Library Assistant*
ROBERT O. FAY, *Geologist IV*
SAMUEL A. FRIEDMAN, *Senior Coal Geologist*
T. WAYNE FURR, *Manager of Cartography*
L. JOY HAMPTON, *Petroleum Geologist III*
PATRONALIA HANLEY, *Chemist*
LEROY A. HEMISH, *Coal Geologist III*
SHIRLEY A. JACKSON, *Research Specialist I*
PRISCILLA A. JOHNSON, *Office Assistant III*
RUTH KING, *Research Specialist I*
JAMES E. LAWSON, JR., *Chief Geophysicist*
CHARLOTTE C. LLOYD, *Cartographic Draftsperson I*
KENNETH V. LUZA, *Engineering Geologist*
TODD MCCORMICK, *Electronic Technician*
RICHARD MURRAY, *Copy Center Operator*
LINDA NERO, *Receptionist-Clerk*
DAVID O. PENNINGTON, *Operations Assistant*
JO LYNN PIERCE, *Publications Assistant*
JUDY A. SCHMIDT, *Office Manager*
CONNIE G. SMITH, *Promotion and Information Specialist*
PAUL E. SMITH, *Supervisor, Offset Press Copy Center*
MICHELLE J. SUMMERS, *Coordinator Geological Computer Systems*
NEIL H. SUNESON, *Stratigrapher / Geologist IV*
DANNY L. SWINK, *Drilling Technician*
JANE L. WEBER, *Organic Chemist*
STEPHEN J. WEBER, *Chief Chemist*
GWEN C. WILLIAMSON, *Assistant to Director*

Title-Page Illustration

Ordovician conodont specimens are from Tom Amsden's master's thesis, done in the Bighorn Mountains of Wyoming and later published in the *Journal of Paleontology,* v. 16 (Amsden and Miller, 1942). Brachiopod specimens are from Tom's earliest published work on the Henryhouse Formation of Oklahoma (*Journal of Paleontology,* v. 25, 1951).

This publication, printed by BookCrafters, Chelsea, Michigan, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1981, Sections 231–238. 1,500 copies have been prepared for distribution at a cost of $10,050 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

Contributors

B. Gudveig Baarli
Department of Geology
Williams College
Williamstown, Massachusetts 01267

James E. Barrick
Department of Geosciences
Texas Tech University
Lubbock, Texas 79409

Stig M. Bergström
Department of Geological Sciences
The Ohio State University
Columbus, Ohio 43210

Robert B. Blodgett
U.S. Geological Survey
Paleontology and Stratigraphy Branch
National Center, MS 970
Reston, Virginia 22092

Scott Brande
Department of Geology
University of Alabama at Birmingham
Birmingham, Alabama 35294

J. Thomas Dutro, Jr.
U.S. Geological Survey
E-308 Natural History Building
Smithsonian Institution
Washington, D.C. 20560

Robert J. Elias
Department of Geological Sciences
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2

J. G. Johnson
Department of Geosciences
Oregon State University
Corvallis, Oregon 97331

Markes E. Johnson
Department of Geology
Williams College
Williamstown, Massachusetts 01267

Gilbert Klapper
Department of Geology
University of Iowa
Iowa City, Iowa 52242

Robert F. Lundin
Department of Geology
Arizona State University
Tempe, Arizona 85287

Charles E. Mitchell
Department of Geology
State University of New York at Buffalo
Buffalo, New York 14260

William A. Oliver, Jr.
U.S. Geological Survey
E-305 Natural History Building
Smithsonian Institution
Washington, D.C. 20560

Lee E. Petersen
Anadarko Petroleum Corp.
16855 Northchase Drive
Houston, Texas 77251

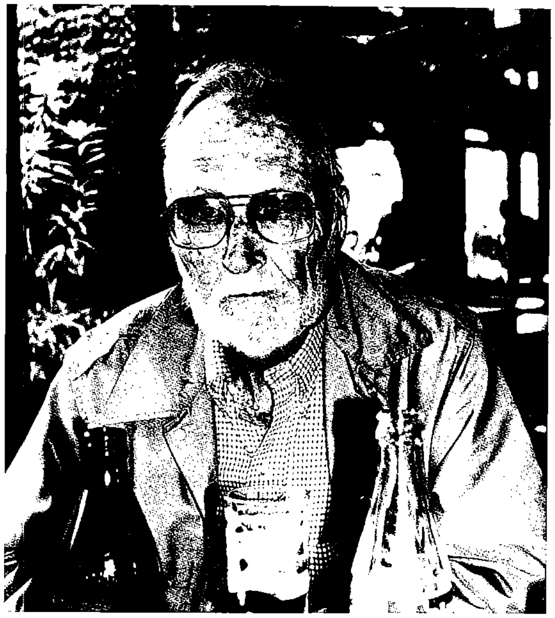
Walter C. Sweet
Department of Geology and Mineralogy
The Ohio State University
Columbus, Ohio 43210

Donald Francis Toomey
Conoco Inc. (retired)
25 Tierra Madre Court
Placitas, New Mexico 87043

Biographical Note

Thomas W. Amsden, one of the Oklahoma Geological Survey's most respected and widely published geologists, was born January 31, 1915, in Wichita, Kansas. Tom received his secondary education in Wichita. He attended the University of Kansas in 1933–34. From 1934 to 1936, Tom managed a lumberyard belonging to his grandfather in Blackwell, Oklahoma, but decided the business was not for him. He returned to college at Wichita State University where he studied under the distinguished petroleum geologist, Walter Wer Wiebe, receiving his bachelor's degree in 1939. At the time of his graduation, the oil industry was again in one of its periodic slumps and Tom proceeded on to The University of Iowa where he became one of A. K. Miller's numerous graduate assistants. Tom's master's thesis was a study of an Ordovician conodont fauna collected from the Bighorn Mountains of Wyoming. He received his master's degree in 1941.

Tom was married in 1940 in Wichita, Kansas, to Virginia McCoy. They have two children, a son Thomas, a physician in Minneapolis, Minnesota, and a daughter Kathy, a school teacher in Oklahoma City. Reportedly, Tom wished to name the children *Pentamerus siluricus* and *Dictyonella devonica*, but Mrs. Amsden had other suggestions. There are three grandchildren.



Tom in Nairobi, Kenya.

From Iowa, Tom pursued his developing paleontological interest at Yale (1941–43) where he enlisted as a student of Professor C. O. Dunbar. He started a stratigraphic and paleontologic study of the Brownsport Formation of western Tennessee, but the war interrupted his project. He joined the Strategic Minerals Section of the U.S. Geological Survey where he worked (1943–45) under several able party chiefs, including Walter White, Gil Espenshade, and John Cooper. His work mainly involved geologic mapping and mineral investigations in a variety of terranes, including the slate belt of Vermont, the metasediments of the Great Smoky Mountains, and a fossiliferous Paleozoic sequence in the Little Dragoon Mountains of southern Arizona.

When the war was over, Tom completed his Ph.D. degree at Yale in 1947 and started teaching paleontology at The John Hopkins University. While teaching at The John Hopkins University (1947–55), Tom spent much time at the U.S. National Museum where he first became acquainted with Dr. G. Arthur Cooper. In addition, he spent much time in the field with the distinguished structural geologist, Professor Ernst Cloos, assisting him with the Hopkin's Field Camp and with his various consulting endeavors.

In 1955, Tom moved from Baltimore, Maryland, to Norman, Oklahoma, to join the Oklahoma Geological Survey. His 30 years of investigations with the Oklahoma Geological Survey have concentrated on the taxonomy, lithofacies, and biofacies of brachiopod faunas from Late Ordovician through Early Devonian strata in the southern Midcontinent region of the United States. Since 1960, Tom has at various times received financial support from the National Science Foundation and the Oklahoma Geological Survey to collect and examine brachiopods from strata of Late Ordovician–Early Devonian age in Great Britain, Sweden, Norway, Poland, Czechoslovakia, Russia, China, and Australia.

One of the highlights of Tom's brilliant career was his selection in 1989 as the recipient of the Paleontological Society Medal for contributions not only to paleontology but also to geology as a whole. At the award ceremony in St. Louis, J. Thomas Dutro, Jr., of the U.S. Geological Survey, noted, "Tom's monograph studies of the Anadarko and Arkoma Basins, in 1975 and 1980, respectively, are models of sedimentary basin analysis. . . . Tom Amsden is a warm, generous, helpful scientist who has been both mentor and friend to younger paleontologists whom he has influenced during his long and fruitful career."

Tom has always had a keen interest in fishing, especially fly fishing, and in bird hunting. Since coming to Norman, he spent several years growing orchids in his greenhouse. He also is an avid rose grower, having exhibited in many rose shows. He was a rose judge for the American Rose Society for many years. Since his official retirement from the Oklahoma Geological Survey in 1985, he has enjoyed traveling with his charming wife Virginia to India, Africa, Peru, and the Galapagos Islands. Tom continues his studies and remains actively involved in research on a part-time basis with the Oklahoma Geological Survey.

The Oklahoma Geological Survey is most grateful to Tom Amsden for his creative and imaginative graphics and scientific thoroughness in the wealth of publications he has produced on Oklahoma geology which have brought him international acclaim. The Oklahoma Geological Survey has honored itself by honoring Dr. Thomas W. Amsden, this cultured and illustrious paleontologist, geologist, educator, and humanitarian.

Tom and Virginia in China at the 1987 International Congress on Carboniferous Stratigraphy and Geology.

CONTENTS

Oklahoma Geological Survey Bulletin 145, 1992

Proximality Trends in the Red Mountain Formation (Lower Silurian) of Birmingham, Alabama

B. Gudveig Baarli
Williams College, Williamstown, Massachusetts

Scott Brande
University of Alabama at Birmingham

Markes E. Johnson
Williams College, Williamstown, Massachusetts

ABSTRACT.—The Red Mountain Formation (Lower Silurian, Llandoverian Series) exposed at Birmingham, Alabama, was deposited in a shallow marine environment. It displays an array of facies from the littoral beach to the offshore mud shelf. The method of proximality analysis was used successfully to obtain detailed relative depth data throughout the formation. The results of proximality analysis for two different localities are closely comparable, demonstrating good lateral continuity of proximality characters. A master sea-level curve for the central Birmingham area generated by means of proximality analysis demonstrates four distinct highstands in sea level. At least three of the four conform in timing to the global record for the Llandoverian Series. The best dated of the Birmingham deepening episodes is marked by an early development of *Costistricklandia lirata*, indicating a late Telychian age.

Fossils preserved in situ are rare, but there is a well-developed *Costistricklandia* Community occurring in the offshore mud shelf facies. A *Pentamerus* Community is found in the transition zone, whereas a trace fossil community is defined in cobbles related to a transgressive ravinement surface. This community demonstrates the first Silurian occurrence of the trace fossil *Trypanites*.

INTRODUCTION

Four cycles of eustatic change commonly are recorded in Lower Silurian strata assigned to the Llandoverian Series. Most of these cycles have been correlated on three independent paleocontinents, Laurentia (North America), South China, and Baltica (Johnson and others, 1985,1991; Johnson, 1987). Highstands in sea level occurred approximately every 2.5 Ma, in the late Rhuddanian, middle Aeronian, early Telychian, and late Telychian epochs.

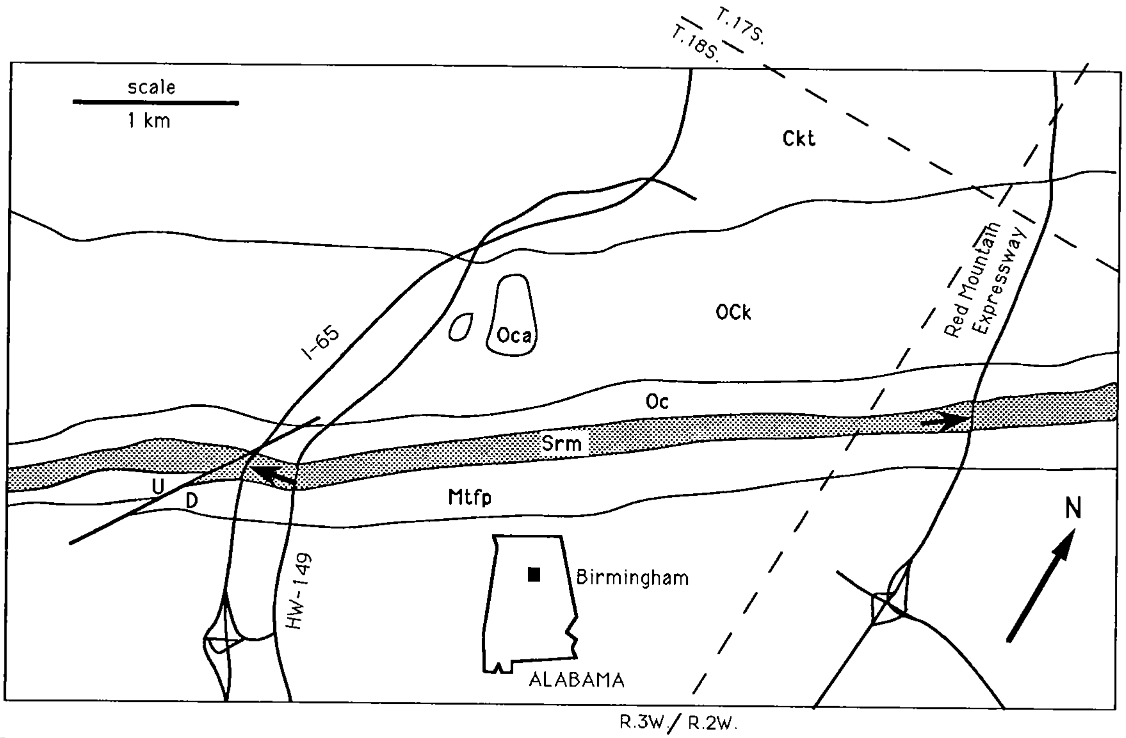
Stratigraphic replacement patterns in fossil communities attributed to different water depths are the indicators most often used to interpret Silurian sea-level curves. The concept of proximality analysis, as applied by Easthouse and Driese (1988) to the Lower Silurian of Tennessee and by Baarli (1988) to the Lower Silurian of southern Norway, has proven to be a strong auxillary method for indexing bathymetric change. Where it has been possible to apply both methods, as in Norway, the paleontological and sedimentological data are found to be compatible. A clear advantage of the community approach is that some members of key communities are of biostratigraphic value in dating eustatic events. Thus, for example, middle Aeronian highstands are linked to the lower part of the *Monograptus sedgwickii* or *Stricklandia lens progressa* biozones, and early Telychian highstands are linked to the *M. turriculatus* or *S. laevis* biozones (Johnson, 1987). Proximality analysis allows for the systematic inclusion of bathymetric data of an independent sedimentological nature. In sections barren of fossils, this approach lacks strict time control but does allow access to useful bathymetric data.

The Red Mountain Expressway in Birmingham, Alabama, exposes a nearly complete section >70 m thick through the Lower Silurian Red Mountain Formation (Thomas and Bearce, 1986). Nearby sections on Interstate 65 and Highway 149 expose much of the same sequence. The object of our study is to expand the available bathymetric data base for the Silurian of the southern Appalachians by applying an analysis of proximality trends to a sequence lacking extensive community information. The Red Mountain Formation in the iron-ore district of Birmingham is an appropriate target because it includes a wide range of sedimentary rocks and structures representing beach to offshore-shelf environments. Furthermore, the Red Mountain Expressway locality may be one of the few sites in the world where all four Lower Silurian cycles of sea-level change can be viewed together in a single exposure.

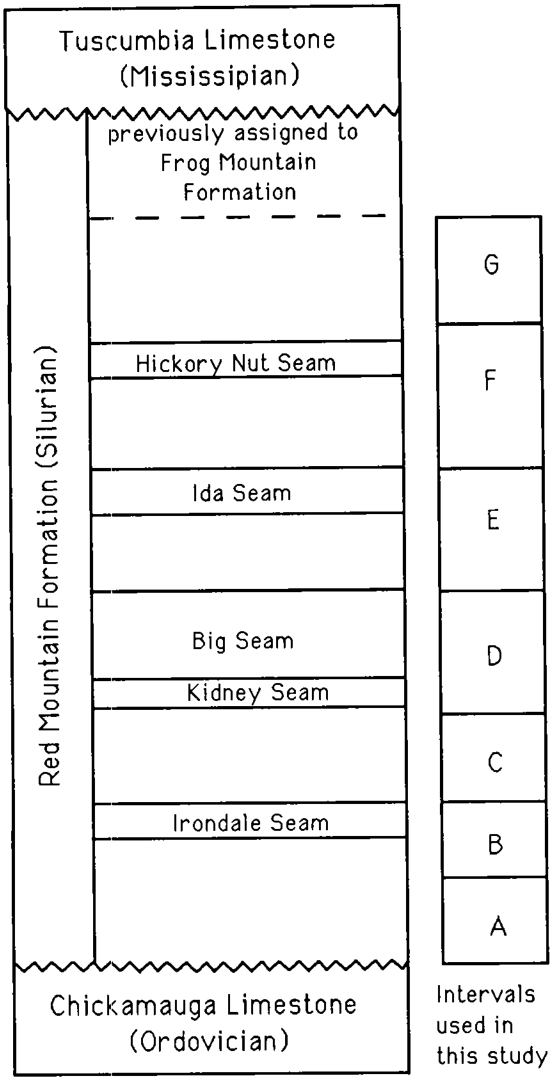
GEOLOGIC SETTING AND HISTORICAL DEVELOPMENT

The Red Mountain Formation crops out in ridges of the southern Appalachian fold-and-thrust belt, which terminates in north-central Alabama beneath the Atlantic Coastal Plain. The prominent Red Mountain ridge forms the southeastern limb of the Birmingham Anticlinorium (Text-fig. 1), and it was the source of rich hematite ores for nearly two centuries. Iron ore came from the major seams of the Red Mountain Formation, exposed along strike of the fold belt in the central and northeastern portions of the state.

The lateral physical equivalency of the Birmingham ore-bearing beds with strata belonging to New York State's Silurian Clinton Group was recognized by geologists at an early date. The Red Mountain Group was formally named by Eugene Smith in 1876, and Charles Butts subsequently referred to a portion of Smith's section as the Red Mountain Formation (Wilmarth, 1938, p. 1786). Within the Red Mountain Formation, iron ore is concentrated variably in several discrete beds, or seams, as they were locally named (Text-fig. 2). In stratigraphic order from oldest to youngest, the major seams are the Irondale, Big, and Ida seams. The Irondale seam was named for the town of Irondale (northeast of Birmingham) and the nearby furnace and ironworks built during the Civil War by Wallace S. McElwain. The Big seam, so named for its thickness of nearly 7 m and rich ore concentration, was the main basis for iron and steel production in the Birmingham district. The Ida seam was named for Ida McElwain, daughter of Wallace McElwain (M. D. Barefield, personal communication, 1990), who supplied pig iron from his furnaces to the Confederacy. The Ida seam generally contains less iron than either the Irondale or the Big seam (Phillips, 1912, p. 56).



Text-figure 1. Geological map of the central Birmingham area, showing the location of study sections along the Red Mountain Expressway (arrow, right) and Interstate 65 (arrow, left). Beds of Cambrian to Mississippian age shown in this map area form the southeast limb of the Birmingham Anticlinorium. Abbreviations for rock units are as follows: Ckt = Cambrian Ketona Dolomite; OCk = Ordovician–Cambrian Knox Group (undifferentiated); Oca = Ordovician Attalia Chert Conglomerate Member (Chickamauga Limestone); Oc = Ordovician Chickamauga Limestone; Srm = Silurian Red Mountain Formation; and Mtfp = Mississippian Tuscumbia Limestone, Fort Payne Chert, and Maury Shale (modified from Thomas and Bearce, 1986, fig. 1). Base map was constructed from portions of the USGS Birmingham North Quadrangle and Birmingham South Quadrangle topographic maps.



Text-figure 2. The Red Mountain Formation is shown in its stratigraphic context with overlying and underlying units. The miners' terminology for the various hematite-rich seams is included. They are correlated stratigraphically with the intervals A–G used in this study.

Two additional "seams" with insufficient iron concentration for mining were named for distinctive features. The Hickory Nut seam, stratigraphically above the Ida seam, exhibits an abundance of the Silurian brachiopod *Pentamerus oblongus*. The name derives from the superficial similarity in shape between the hull of a hickory nut and the internal mold of the brachiopod. A fifth "seam," the Kidney, is between the Irondale and Big seams stratigraphically. This seam derives its name from its distinctive conglomerate of discoid pebbles and cobbles, often several inches in diameter (Bearce, 1973, p. 688).

Hard, unweathered red ore, dominated by hematite, was mined from the several major seams within the formation; the iron content range is about 35–50% metallic iron. Brown ore, dominated by limonite, occurs in more or less isolated deposits. Overall, the discontinuous stratigraphic distribution of the hematitic ores follows preferred environments of secondary enrichment, indicating a natural cyclicity.

REVIEW OF RECENT STRATIGRAPHIC WORK

Previous work on the stratigraphy of sedimentary iron ores, both in general and with particular reference to the Birmingham ores, is fairly extensive.

Oolitic Ironstones

Oolitic ironstones figure prominently in various facies models and the interpretation of bathymetric patterns. Kimberley (1978,1979) reviewed the origin and paleoenvironment of oolitic ironstones with an extensive list of known occurrences, including the Red Mountain Formation. The mode of origin favored in his earlier work is secondary replacement of calcareous ooids with iron leached from mud covers. More recently, Kimberley (1989a,b) favors a model of direct sea-floor precipitation, within fecal pellet mud, of ooids as berthierine or chamosite that then converts by dehydration to hematite. In a summary of Phanerozoic occurrences by Van Houten and Bhattacharyya (1982) and a general review of the Silurian Clinton oolitic ironstones by Van Houten (1991), emphasis is placed on authigenic models constrained by variables in climate, sea level, and tectonic activity. Hallam and Bradshaw (1979) and Van Houten (1986) refer specifically to oolitic ironstone formation in response to sea-level cycles, with differences primarily in the periodicity of recorded events.

Red Mountain Sequence

Berry and Boucot (1970) reported that the Red Mountain Formation contained successive elements of an evolutionary brachiopod lineage including *Stricklandia lens progressa* and *S. lens ultimata* (= *S. laevis*). These distinctive brachiopods act as the name donor for a relatively deep-water fauna called the *Stricklandia* Community and its recurrence in the Red Mountain Formation was used to infer middle Aeronian and early Telychian highstands in sea level for north-central Alabama (Johnson, 1987, fig. 6B). Until the descendent species *Costistricklandia* sp. cf. *C. lirata* was discovered in the Birmingham area (Berdan and others, 1986), it was assumed that rocks of Late Llandoverian and Early Wenlockian age were absent in the southern Appalachians. More recently, Bolton (1990, p. 374) illustrated a population of *Costistricklandia lirata* preserved in growth position from the Red Mountain Formation near Gadsden, north of Birmingham.

Stratigraphic logs of the Expressway cut were published previously by Thomas and Bearce (in Drahovzal and Neathery, 1971, p. 231–240), Bearce (1973), Chowns and McKinney (1980), and Thomas and Bearce (1986). The earlier logs indicate an unconformity between the Silurian Red Mountain Formation and the Devonian Frog Mountain Sandstone. In Birmingham, the latter unit includes hematitic sandstones with granules of oolite size and shape, not unlike parts of the Red Mountain Formation. These sandstones are now assigned to the upper part of the Red Mountain Formation (Thomas and Bearce, 1986, p. 196). A slight angular discordance of 1.6° separates the base of the Red Mountain Formation from the underlying Chickamauga Limestone (Thomas and Bearce, 1986, fig. 7). The Sequatchie Formation (Upper Ordovician) is locally absent between these formations.

In terms of bathymetric analysis, the work of Chowns and McKinney (1980) is the most detailed previous study. They divided the Red Mountain Formation into depth-related facies and defined three depositional cycles based on coarsening-upward sequences through shale, turbidite beds, and hummocky cross-stratified sandstone. The various ironstone lithologies associated with cross-stratified sandstone and intraformational conglomerate were interpreted by Chowns and McKinney (1980) as having formed in peritidal environments. Van Houten and Bhattacharyya (1982, p. 447) cite those observations of Chowns and McKinney (1980) as compatible with their basically authigenic model of oolitic ironstone formation.

Whereas all previous logs included information on changing lithologies through the Silurian of the Birmingham area, no attempt was made to collect and interpret composition and thickness information strictly on a bed-by-bed basis as required by the method of proximality analysis.

PROXIMALITY ANALYSIS

The term "proximality analysis" was first proposed and formalized by Aigner and Reineck (1982). A good summary of the methodology is given by Aigner (1985). It is based on the assumption that the effects of storms and generation of tempestites (i.e., storm beds) decrease gradually with distance from shore and increasing water depth. Notable trends are: (1) the percent of storm layers decreases gradually from the shoreface through the transition zone to further offshore, (2) storm-layer frequency reaches a maximum in the transition zone, (3) mean bed thickness of tempestites decreases strongly from the shoreface into the transition zone and then gradually decreases offshore, (4) their maximum bed thickness decreases gradually offshore, and (5) the percent of cross-lamination shows a strong maximum in the transition zone.

The shoreface stretches from the mean low-water level to the fair-weather wave base. The transition zone occurs immediately below fair-weather wave base down to mean storm wave base, with the offshore zone thereafter. Thus, analysis of proximality trends indicates the positions on the shelf and relative changes in water depth. Definitions of the shoreface, transition zone, and the offshore zone follow those given by Reading (1978, p. 146).

Methodology

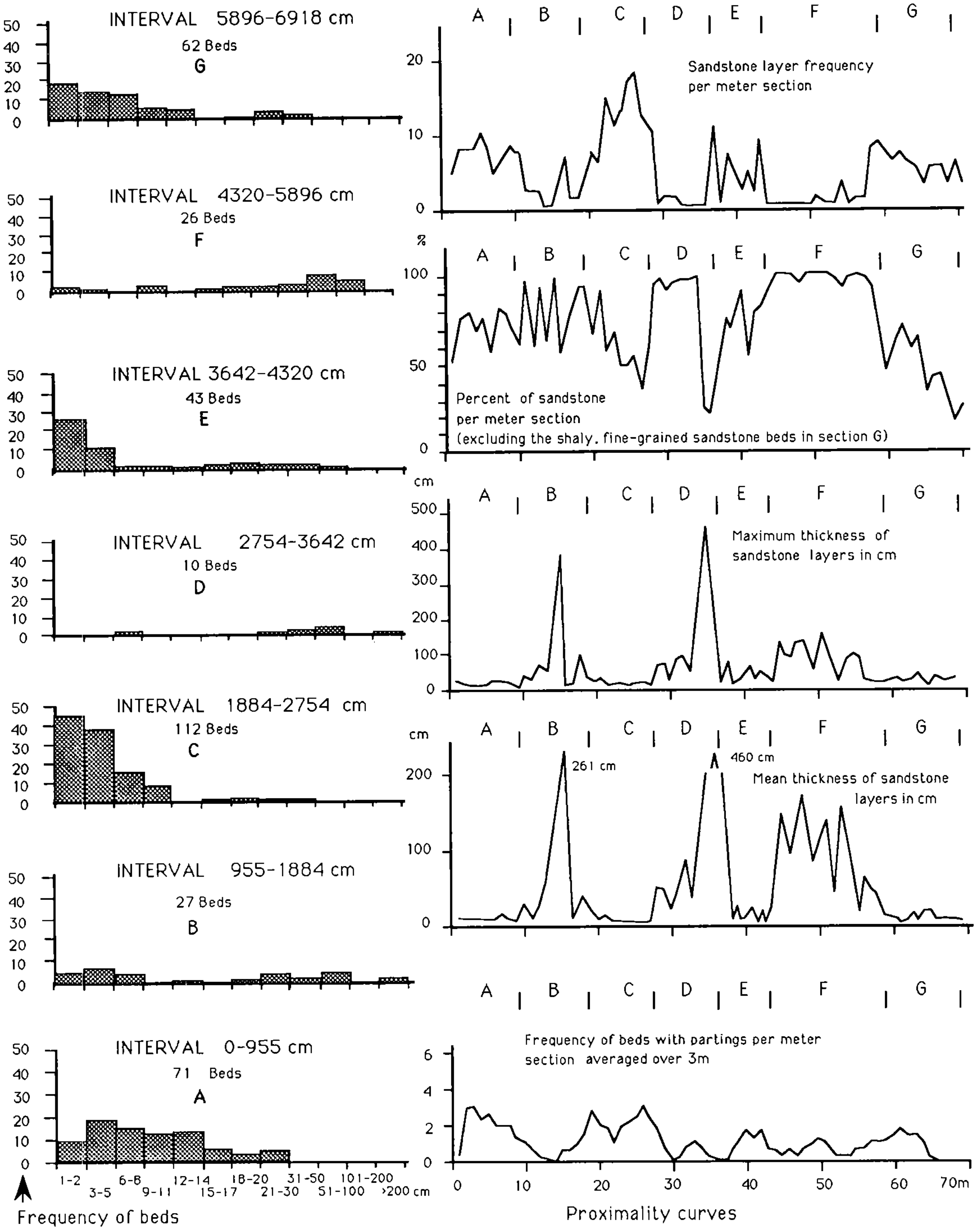
The study sections were described and measured on a centimeter-by-centimeter scale. Care was taken to identify vertical and lateral variations in primary sedimentary and biogenic structures. Ideally, special emphasis should be given to registering the unit percent of sandstone layers with cross-laminations. The replacement at irregular stratigraphic intervals of primary sediments by secondary iron ore, however, tends to obliterate such structures. Thus, at times we had to rely unduly on sandstone thickness, bed frequency, and unit percent data.

Red Mountain Expressway Section

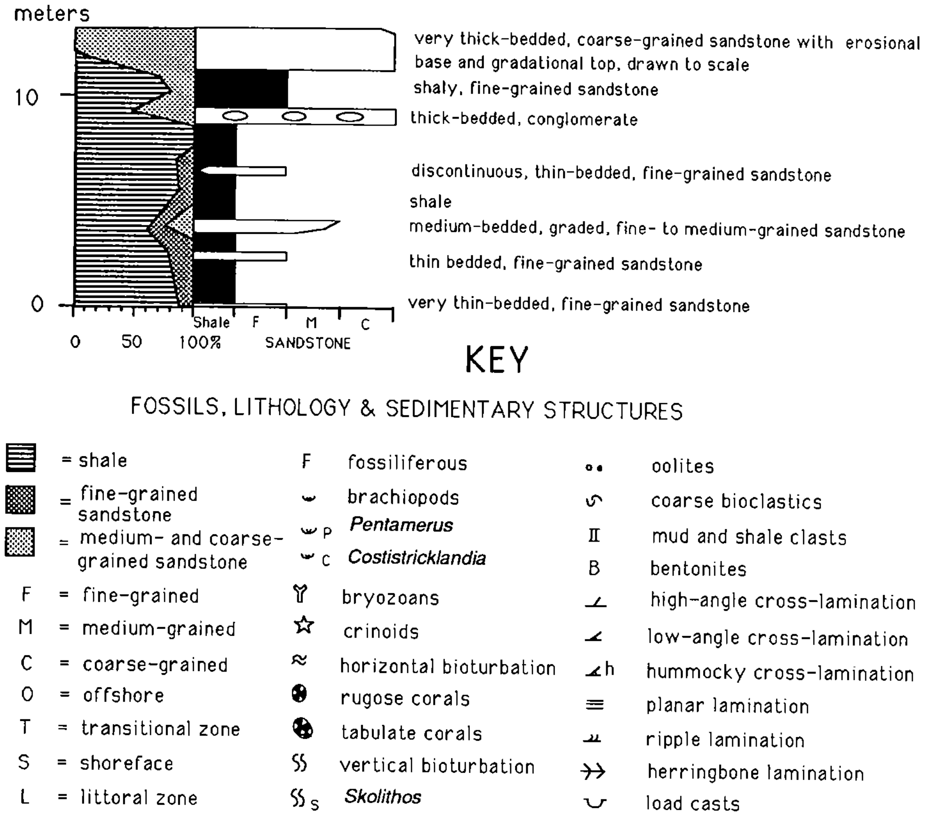
Proximality trends for the Red Mountain Formation (Lower Silurian), as recorded in the Red Mountain Expressway section in Birmingham, Alabama, are shown by the graphs in Text-figure 3. Variance through the Red Mountain Expressway section in terms of the different proximality curves is depicted on the right side of Text-figure 3. On the left side are histograms showing the distribution of sandstone-layer thicknesses for each identified interval A–G. An interpretive key to our stratigraphic logs is presented in Text-figure 4; an idealized section through the Red Mountain Expressway cut is shown on the left side of Text-figure 5. This section marks the stratigraphic positions of intervals A–G. Text-figure 6 is a photograph of the central parts of the Red Mountain Expressway cut. The facies assigned to these intervals are described in detail below.

A) The interval (0–9.55 m above the formational base) displays shale alternating with very thin- to medium-bedded, fine-grained calcareous quartz sandstone. Average thickness of sandstone beds is 9.4 cm. Common structures are planar lamination and ripple lamination, often found in succession within individual sandstone layers. Hummocky cross-lamination also is present.

B) The interval (9.55–18.84 m above formational base) consists of thin- to thick-bedded, fine- to medium-grained sandstone interbedded with very thin- to thin-bedded shale. Average sandstone thickness is 20.5 cm. The thicker sandstone interbeds often are hematitic. Many of these beds swell and



Text-figure 3. Proximality trend data (right) and sandstone-layer thickness histograms from intervals A–G (left) in the Red Mountain Formation at the Red Mountain Expressway cut in Birmingham, Alabama. Stratigraphic positions of intervals A–G are shown in Text-figure 5.



Text-figure 4. Key to the stratigraphic logs compiled for this report and the symbols denoting various fossils, lithologies, and sedimentary structures.

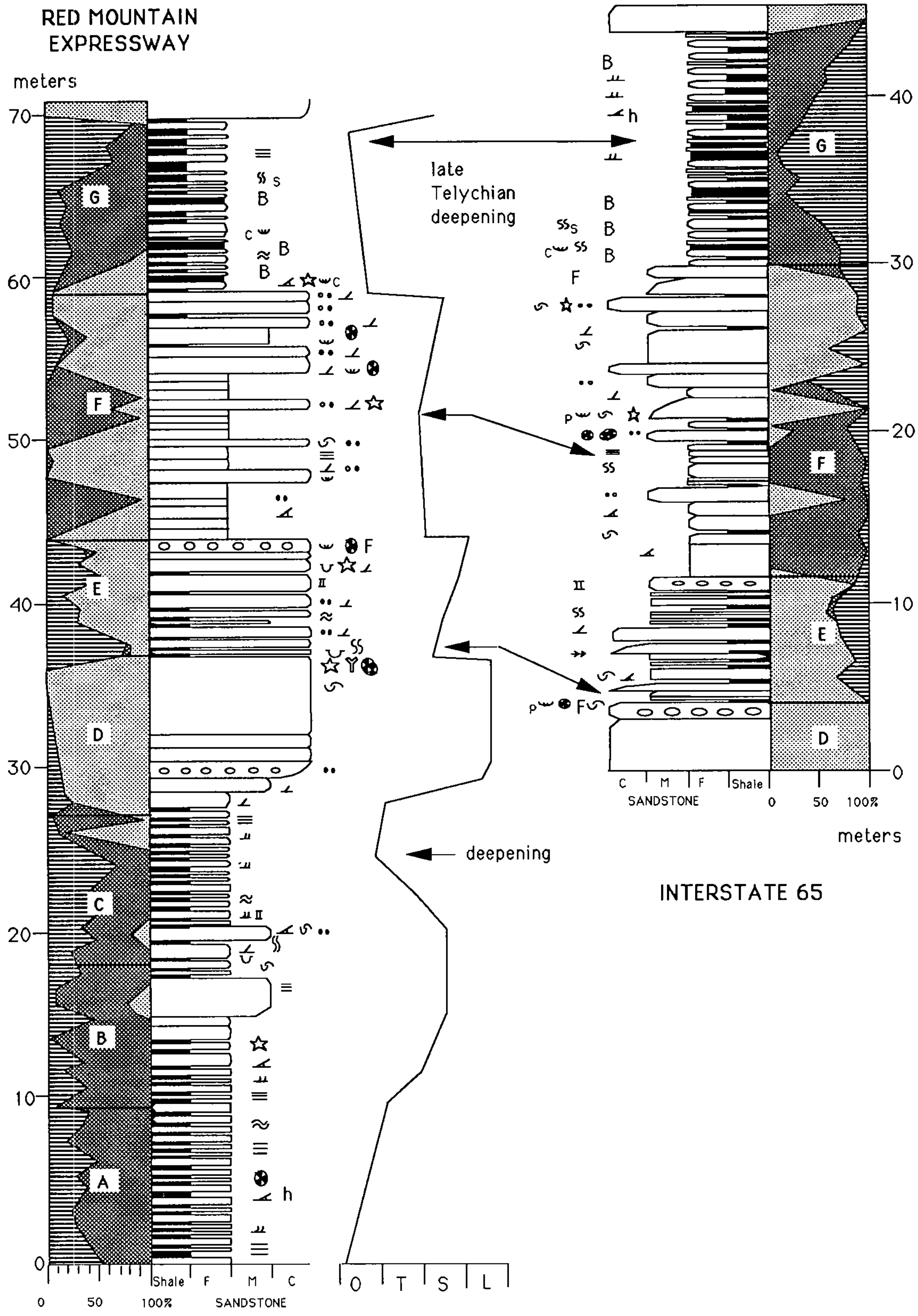
pinch and show traces of planar or very low-angle cross-lamination. Coarse-grained bioclastic beds and lenses occur toward the top of the interval.

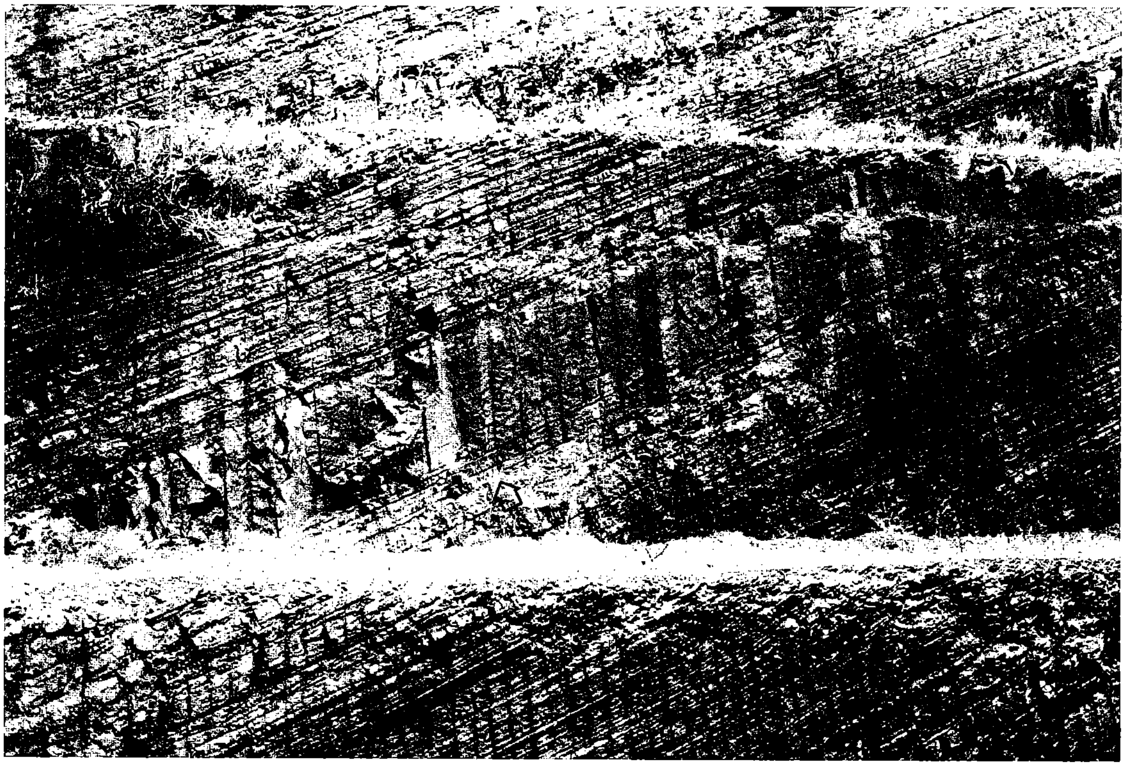
C) The interval (18.84–27.54 m above the formational base) displays frequent very thin- to thin-bedded, fine-grained sandstone beds interbedded with sandy, less fissile shale. A few massive, medium- to thick-bedded, fine-grained sandstone beds occur near the base. Average sandstone bed thickness is 5.3 cm. Also near the base of the interval is the first thin oolite bed along with mud clasts and thin coarse bioclastic beds. It is difficult to see structures in interval C due to weathering, but ripple lamination, low-angle and high-angle cross-lamination, and planar lamination are present.

D) This interval extends from 27.54 to 36.42 m above the formational base. Average thickness of sandstone beds, excluding the massive 4.6-m-thick bed, is 43.6 cm. Medium-bedded, fine-grained sandstone beds near the base give way to thick-bedded, medium- to coarse-grained, hematitic sandstone with carbonate-rich ironstone clasts and scattered oolites. Beginning at a level 29.6 m above the formational base, clasts with an average diameter of 5 cm increase in abundance through a 1.6-m-thick bed, reaching 60% by volume in the uppermost 40 cm. The clasts occur in bands and are discoid and flattened, with the flat surface parallel with the bedding of the matrix. High-angle cross-lamination is common, and mud drapes on reactivation surfaces of megaripples are found at the base of the section

---

Text-figure 5 (opposite page). Detailed stratigraphic section through the Red Mountain Formation at the Red Mountain Expressway cut (left) correlated with the section on Interstate 65. In the logs, variations in the main lithological components are expressed as a percent-per-meter unit in the left column for the Red Mountain Expressway section and in the right column for the Interstate 65 section. The central column is an idealized section indicating bedding characteristics; sedimentological and biological structures are denoted in the right and left columns for the Red Mountain Expressway and Interstate 65 sections, respectively. Between the two logs is a sea-level curve keyed to the expressway section, with four major deepening events marked by arrows: O = offshore mud; T = transition zone; S = shoreface; L = littoral facies. A detailed key to the stratigraphic logs is given in Text-figure 4.


RED MOUNTAIN EXPRESSWAY
meters
70
60
50
40
30
20
10
0
G
F
E
D
C
B
A
0
50
100%
Shale
F
M
C
SANDSTONE
O
T
S
L
late Telychian deepening
deepening
INTERSTATE 65
40
30
20
10
0
C
M
F
Shale
SANDSTONE
0
50
100%
meters



Text-figure 6. Middle part of the Red Mountain Expressway cut (west side). Arrows delimit the Big seam, the top of interval D as logged in Text-figure 5. The black arrow marks the top of the Big seam; the open arrow marks its base. Thickness at this locality is 4.6 m. Cobbles bearing *Trypanites* borings occur in the Kidney seam, just below the Big seam. More thinly bedded strata above and below these units are readily apparent.

between pebble bands. Coarse-grained, massive hematitic sandstone follows with a 4.6-m-thick bed at the top.

E) The lithology of this interval (36.42–43.20 m) is relatively heterogeneous. Silty shale with numerous very thin, coarse-grained sandstone beds, which often pinch and swell, occur through the first 2 m. This is followed by a mixture of mainly medium-bedded, hematitic oolite beds and thin- to medium-bedded, coarse-grained sandstones interbedded with thin shale beds. Mean thickness of interbeds is 12.9 cm. Many of the beds show high-angle cross-lamination and less common trough cross-lamination. All beds are discontinuous, with pinch and swell. Shale clasts and fossil debris are relatively common. Above follows a 1.5-m-thick sequence of coarse-grained sandstones with shale drapes on reactivation surfaces of megaripples. The sequence is topped by a 55-cm-thick conglomeratic bed. The pebbles are a mix of large (average diameter 5 cm) ironstone pebbles, gravel-sized quartz pebbles, and fossil fragments.

F) This interval (43.20–58.96 m above the formational base) starts out with medium-bedded, fine-grained and hematitic oolitic sandstone. Above follow thick-bedded, shaly, fine-grained sandstone beds interbedded with thick-bedded, coarse-grained oolitic and hematitic sandstone. In the top half of the interval the shaly, fine-grained sandstone is replaced by very thin, discontinuous shale lenses. The average thickness of interbeds is 85.2 cm. The oolitic sandstone beds are fossil rich and often show high-angle cross-lamination.

G) The interval (58.96–69.18 cm above the formational base) displays common very thin- to thin-bedded, fine-grained sandstone interbedded with thin- to medium-bedded silty shale or shaly, fine-grained sandstones. Average thickness of sandstone interbeds is 10.1 cm. The beds seem continuous. Structures are very hard to discern due to nonpreservation, but planar lamination may be observed. Possible bentonitic layers occur near the base and middle of this interval, associated with fossil-rich beds.

Applying criteria 1–5 for proximality analysis (listed above), the following results are obtained.

Offshore shelf mud facies occur in most of interval A and throughout interval G of the section. The transition zone is best developed in the upper portion of interval A into B and in interval C. Shoreface or littoral facies are evident in the other parts of the section, much of interval B and intervals D and F. These intervals correspond to the main hematitic "seams," in the miners' terminology (Text-fig. 2). That is, the Irondale seam occurs in the upper part of interval B, the Kidney and Big seams occur in interval D, the Ida seam occurs in the upper part of interval E, and the Hickory Nut seam occurs in the upper part of interval F.

Bearce (1973) suggested that the clasts in the conglomeratic beds identified in intervals D and E formed in place before lithification by reworking and breaking up of cohesive muddy sediments in a well-protected intertidal environment. We agree that the conglomeratic beds were deposited at shallow depths within the shoreface as indicated by high-angle cross-lamination and mud-draped reactivation surfaces on megaripples. Some pebbles from the Kidney seam, however, show signs of biological boring (attributed to *Trypanites*) and encrustation, indicating prior lithification (Pl. 1, Figs. 1,2). Also, the iron clasts at the top of interval E are mixed with some gravel-sized quartz pebbles and abraded fossils indicating a high degree of reworking. A likely mechanism of transgressive reworking and retreat of a predominantly sandy shoreface formed "ravinement" surfaces (Swift, 1968). The repetition of conglomeratic beds succeeding each other in interval D may indicate a stepwise transgression.

Interval E shows an anomalous development. It begins with very thin- to thin-bedded, and often discontinuous, coarse-grained sandstone beds of relatively high frequency. This combination normally signifies inner offshore conditions. The rest of the interval, however, is interpreted as deposited in the shoreface. The transition zone, which should be evident in-between, is missing. Throughout interval E, reworking by waves is indicated by mud clasts and abundant discontinuous, medium-bedded, hematitic oolite layers. These traits are representative of the shoreface. Therefore, we support the interpretation by Chowns and McKinney (1980) that suggests the entire facies was deposited seawards of the littoral zone (i.e., in the shoreface zone after the onset of a transgression). The lack of quartz sand is attributed to shoreline retreat while the oolites were formed in situ by winnowing, reworking, and replacement of abraded shell debris.

Proximality analysis does not differentiate the shoreface from the littoral zone. Only the massive coarse-grained ironstones atop the conglomerate in interval D are interpreted as having been deposited within the littoral zone (lower beach face).

Interstate 65 Section

The same procedure for proximality trend analysis was applied to the Interstate 65 section as in the Red Mountain Expressway section. Four similarly developed intervals (D–G) were identified (Text-fig. 5). The section starts with littoral facies in interval D, capped by conglomerate deposits of transgressive ravinement surfaces. The continuation into interval E is a clear development of the transition zone with an abundance of graded beds. Evidence of tidal-current activity also is present in the form of herringbone ripple cross-lamination and preserved megaripples with mud drapes on reactivation surfaces (Reading, 1978). Throughout interval E there is a shallowing-upward trend into the shoreface again, capped by transgressive conglomerate deposits. Interval F is characterized by fine-grained sandstone, and is identified as a shoreface facies followed by a thin interval of the transition zone facies and back again to the shoreface. A rapid change to the offshore facies occurs at the base of interval G, with reappearance of the transition zone immediately below the thick sandstone deposits of the upper-most Red Mountain Formation (formerly misidentified as the Devonian Frog Mountain Formation). These upper sandstone deposits formed in the shoreface.

Comparison of Trends

The Silurian section on Interstate 65 is situated 4 km southwest of the Red Mountain Expressway cut (Text-fig. 1). A close lateral match in facies between the two sections is apparent in Text-figure 5. The Interstate 65 section is thinner, because intervals A–C are not exposed. This is compensated for somewhat by a thicker and more complete representation of interval G, probably due to deposition in a slightly more distal position than the Red Mountain Expressway section.

The bathymetric curve shown in Text-figure 5 is keyed specifically to stratigraphic trends from the expressway section. Arrows directed to the left indicate the stratigraphic levels at which maximum transgressions were recorded in the expressway section. A separate bathymetric curve was not constructed for the interstate section, but arrows directed to the right indicate comparable levels of maximum transgression. Four highstands in sea level are represented in the Red Mountain Expressway section. The Interstate 65 section faithfully reflects three of the same highstands in sea level, with strata representing the oldest event presumably unexposed (interval C).

The results of the proximality analysis for the Interstate 65 section show no signs of anomalies, as in the case of the expressway section. The results from interval E of the expressway section indicate a sudden deepening from the littoral to the offshore zone, followed by an upward shallowing to the shoreface. Pending additional field data to the contrary, we suggest interval E was deposited entirely within the shoreface. The Interstate 65 section confirms this interpretation. A definite and clear deepening occurred at the transition from D to E, as indicated by a transgressive ravinement surface. The deepening was not a major one, however.

The proximality analysis for the Interstate 65 section provides additional details from interval F, where shoreface conditions are punctuated by a brief appearance of the transition zone (middle of interval F) recording a slight deepening between the 17- and 20-m levels. This is not observed in interval F of the Red Mountain Expressway section, where only shoreface conditions are recorded. An increase in fine-grained sandstone relative to coarse-grained sandstone is observed at the same horizons there, however, indicating the same deepening trend.

The basal 5 m of interval G are remarkably similar in the two sections. They both consist of very thin- to thin-bedded, shaly, fine-grained sandstone interbedded with shale with at least three horizons of bentonites. Close to the base of both intervals is the first occurrence of the biostratigraphically important brachiopod *Costistricklandia* (see below). These are associated in both sections with two very distinctive horizons, occurring within a 1-m interval, of the trace fossil *Skolithos*.

Additional sections representing the upper half of the Red Mountain Formation are available for study in the Birmingham area, for example, along strike farther to the northeast on Interstate 20 (near Century Plaza) and farther to the southwest in the Ishkooda area. Our preliminary data show that these sections generally exhibit finer grained sedimentary rocks consistent with a slightly more offshore setting. Some of the traditional miners' seams from the central Birmingham area are absent from these outlying areas.

FOSSIL COMMUNITIES AND BIOSTRATIGRAPHY

Silurian fossils present in the expressway cut generally are sparse and indicative of post-mortem transport. The Hickory Nut seam, for example, contains internal molds of disarticulated *Pentamerus oblongus* shells replaced by hematite. A significant fossil community preserved in situ does occur in the uppermost fine-grained sandstone and siltstone deposits ~5.5 m above the last main ironstone (interval G), but below the hematitic units formerly attributed to the Frog Mountain Sandstone (Text-fig. 2). The principal fossil in this community is the brachiopod *Costistricklandia* sp. cf. *C. lirata*. These brachiopods are uncharacteristically small, but signs of faint ribbing clearly set them apart from their ancestral species *Stricklandia laevis*. Forms transitional between the two species are late Telychian in age. Associated with *Costistricklandia* at the expressway cut are at least eight other species (mostly brachiopods) typical of a stricklandiid community (Table 1). The stricklandiid communities belong to Benthic Assemblage Zone 4, indicative of offshore environments between 60 and 90 m deep (Johnson, 1987).

TABLE 1. — COMPOSITION OF THE *COSTISTRICKLANDIA* COMMUNITY IN THE UPPER RED MOUNTAIN FORMATION

Phyla/genera	Brachial valve	Pedicle valve	Individual	%
Coelenterata				
Rugose coral			14	29.8
Bryozoa			2	4.3
Brachiopoda				
Costistricklandia	10	13	13	27.7
Atrypa	5	6	6	12.7
Eospirifer	0	3	3	6.4
Eoplectodonta	0	3	3	6.4
Isorthis	2	1	2	4.3
Salopina	0	2	2	4.3
rhynchonellid	0	2	2	4.3
species: 9			47	100.2

The *Costistricklandia* Community not only provides paleontological evidence corroborating a local deepening event, but its namesake brachiopod confirms that the age of this event was coeval with the late Telychian eustatic highstand in sea level recognized widely throughout the rest of North America, South China, and northern Europe (Johnson and others, 1985,1991).

Reworked pentamerid shell debris from the expressway and interstate sections (Hickory Nut seam and lower horizons) have no real value in terms of community bathymetry, but are important biostratigraphically. In North America, the stratigraphic range of *Pentamerus oblongus* is middle Aeronian to lower Telychian (Johnson, 1987, fig. 5). The middle two transgressions recorded in the expressway section and their lateral equivalents in the interstate section fall within the range of *Pentamerus oblongus*.

The dating of these events could be made more precise with additional biostratigraphic markers, such as *Stricklandia lens progressa* and *S. laevis* cited from the Red Mountain Formation by Berry and Boucot (1970), but we were unable to recover these brachiopods from our two study sections. We found some loose specimens of *Stricklandia lens progressa* above the Big seam at an outcrop off Highway 149 parallel to Interstate 65 (see Text-fig. 1), but we were unable to locate the precise level from which they came. In any case, the available pentamerid biostratigraphy shows that the second and third highstands in sea level recorded in the expressway and interstate sections are not inconsistent in timing with the middle Aeronian and early Telychian events noted globally.

Where populations of *Pentamerus oblongus* are preserved in growth position, they are assigned to Benthic Assemblage Zone 3 with an estimated bathymetric range of 30–60 m (Johnson, 1987). Such populations have been recovered previously from the Red Mountain Formation in Alabama (Ziegler and others, 1966, pl. 121), but outside the Birmingham iron-ore district. We have discovered a cliff section in the Ishkooda area, southwest from central Birmingham on Red Mountain ridge that includes horizons with *Pentamerus oblongus* preserved in growth position (Pl. 2). The internal molds of these populations are replaced entirely with hematite, and this example serves to underscore the secondary nature of mineralization in the Birmingham district.

More importantly, both our material (Pl. 2) and that of Ziegler and others (1966) represent a very late evolutionary stage of *Pentamerus oblongus* transitional to *Pentameroides subrectus*, as indicated by the extremely narrow, almost convergent outer plates of the brachial valve. A more precise, early Telychian age is registered by pentamerids at this transition (Johnson, 1987, fig. 5). Unfortunately, the Ishkooda section is thin (11 m) and our proximality analysis shows only one bathymetric cycle from shoreface conditions through the transition zone and back again, with the brachiopods well within the transition zone. This fluctuation in sea level probably correlates with the third deepening in the Red Mountain Expressway section.

A third community from the Red Mountain Formation, and one previously unreported from any strata of Silurian age, is a cobble-substrate community consisting of *Trypanites* borings (Pl. 1, Figs. 1,2) and probably an encrusting "button" coral (Pl. 1, Figs. 3,4). All material illustrated in Plate 1 was collected from the Kidney seam (Text-fig. 2) on the west side of the Red Mountain Expressway cut. There may be other elements belonging to this community, but access to relatively thin cobble beds like the Kidney seam (~1 m thick) is limited due to the steep dip of the beds in outcrop. Without special equipment, it is not possible to collect cobbles from a position much above eye height.

In his historical review of the dynamics of organic colonization on large clasts, Wilson (1987, table 2) shows that *Trypanites* is characteristic of both low- and high-energy marine environments, but it is more dominant in high-energy settings. His data base includes information spanning the Cambrian to the Cretaceous (Wilson, 1987, table 1). No previous reports of Silurian *Trypanites* are cited. The only previous record of corals encrusting large clasts is from the Upper Ordovician (Johnson and Baarli, 1987). The low diversity of colonizers represented on the Kidney seam cobbles is consistent with our interpretation of a depositional setting at the shoreface within the zone of breaking waves.

SUMMARY AND CONCLUSIONS

The Red Mountain Formation (Lower Silurian) in the iron-ore district of Birmingham, Alabama, presents a suitable subject for an analysis of proximality following the methodology advanced by Aigner (1985). Traditional fossil communities used to gauge water depth are sparse, but critical biostratigraphic markers are represented well enough to provide adequate time control. The recurrence of oolitic iron-ore seams through the Silurian section is so striking a feature that the roll call of old miners' terms invokes a feeling of cyclicity.

Ghost limestone clasts in some of the major cobble beds and the complete hematitic replacement of pentamerid brachiopod populations preserved in growth position make it clear that the development of ironstones was, at least in part, a secondary enrichment that selectively followed certain stratigraphic levels. The ironstones are superimposed on a framework of original depositional environments ranging between offshore muds and littoral sands.

A master sea-level curve for the central Birmingham area generated by means of proximality analysis demonstrates four distinct highstands in sea level typified by thinner sandstone beds with a higher percentage of shale interbeds. Lowstands in sea level characteristically are represented by coarse-grained, oolitic sandstone and conglomerate. Lateral continuity of these cycles is remarkably faithful over a distance of several kilometers.

Previously, a more traditional analysis of sequential facies within the Red Mountain Formation by Chowns and McKinney (1980) detected only three coarsening-upward cycles relevant to changes in water depth through time. The last of four deepening events is coeval with the occurrence of a *Costistricklandia* Community in the upper part of the Red Mountain Formation. The diagnostic stricklandiid brachiopod of this community is limited to a Late Llandoverian or Early Wenlockian age, but forms with incipient ribbing are strictly Llandoverian. The two earlier deepening events are constrained biostratigraphically by the range of *Pentamerus oblongus*.

On a global basis, four eustatic highstands in sea level are well known from the Llandoverian Series (Johnson and others, 1985,1991), and at least three of the four local deepenings in the Birmingham area conform in timing to the global record. Easthouse and Driese (1988) also used proximality analysis to distinguish a comparable record of sea-level fluctuations in the Lower Silurian of nearby Tennessee. The bathymetric coordination of the locally available fossil communities with the shelf zones demarcated by proximality analysis also is consistent with findings by Baarli (1988) from the Lower Silurian of Norway. Although the main objective of this study was sedimentological, a new fossil community consisting of *Trypanites* borings and an encrusting button-coral form was recognized in association with the cobbles of the prominent Kidney seam in the Red Mountain Formation. An earlier interpretation of this interval (Bearce, 1973) suggested that the cobbles were torn up from unlithified lenses of shelly, sandy, and carbonate-mud sediments. This specialized fauna indicates that the cobbles provided an ecological hard substrate for colonization.

ACKNOWLEDGMENTS

Thomas W. Amsden brought a great measure of insight and ingenuity to the study of Silurian strata in the central part of the North American Craton. His approach to solving large-scale problems with novel techniques was manifested early in his career by his influential contribution of a Lower Silurian lithofacies map covering nearly half of the North American Craton (Amsden, 1955). The approach we attempt to follow here is an appropriate acknowledgment to the zeal consistently shown by Amsden for the detection and integration of facies data into a larger picture.

We believe the "big picture" of Silurian facies may be brought into sharper focus on a continental to global scale through the study of eustatic sea-level patterns. During the Early Silurian, the Alabama area was situated near the mouth of a prominent depression tracking the Reelfoot Trough onto the Laurentian Craton (Johnson, 1987, figs. 7–10), but until now it has been difficult to integrate local bathymetric data with the rest of the Silurian platform. Field work in Alabama during the summer of 1989 was supported in full by a grant to M. E. Johnson from the Petroleum Research Fund (administered by the American Chemical Society). Andrew Brill (Williams College) served as a field assistant. Benjamin A. Ferrill (University of Alabama at Tuscaloosa) kindly demonstrated the Red Mountain sequence at the Century Plaza section. Early drafts of this paper were reviewed by Steven G. Driese (University of Tennessee, Knoxville) and Alfred M. Ziegler (University of Chicago).

REFERENCES CITED

Aigner, T., 1985, Storm depositional systems: Springer-Verlag, Berlin, 174 p.

Aigner, T.; and Reineck, H. E., 1982, Proximality trends in modern storm sands from the Helgoland Bight (North Sea) and their implications from basin analysis: Senkenbergiana Maritima, v. 14, p. 183–215.

Amsden, T. W., 1955, Lithofacies map of Lower Silurian deposits in central and eastern United States and Canada: American Association of Petroleum Geologists Bulletin, v. 39, p. 60–74.

Baarli, B. G., 1988, Bathymetric coordination of proximality trends and level-bottom communities: a case study from the Lower Silurian of Norway: Palaios, v. 3, p. 577–587.

Bearce, D. N., 1973, Origin of conglomerates in Silurian Red Mountain Formation of central Alabama; their paleogeographic and tectonic significance: American Association of Petroleum Geologists Bulletin, v. 57, p. 688–701.

Berdan, J. M.; Boucot, A. J.; and Ferrill, B. A., 1986, The first fossiliferous Pridolian beds from the southern Appalachians in northern Alabama, and the age of the uppermost Red Mountain Formation: Journal of Paleontology, v. 60, p. 180–185.

Berry, W. B. N.; and Boucot, A. J., 1970, Correlation of the North American Silurian rocks: Geological Society of America Special Paper 102, 289 p.

Bolton, J. C., 1990, Sedimentological data indicate greater range of water depths for *Costistricklandia lirata* in the southern Appalachians: Palaios, v. 5, p. 371–374.

Chowns, T. M.; and McKinney, F. K., 1980, Depositional facies in Middle–Upper Ordovician and Silurian rocks of Alabama and Georgia: Excursions in southeastern geology; guidebook for field trip no. 16, Geological Society of America annual meeting, Atlanta, p. 323–348

Drahovzal, J. A.; and Neathery, T. L. (eds.), 1971, The Middle and Upper Ordovician of the Alabama Appalachians: Field-Trip Guidebook for the Alabama Geological Society ninth annual meeting, 240 p.

Easthouse, K. A.; and Driese, S. G., 1988, Paleobathymetry of a Silurian shelf system: application of proximality trends and ichnofacies distributions: Palaios, v. 3, p. 473–486.

Hallam, A.; and Bradshaw, M. J., 1979, Bituminous shales and oolitic ironstones as indicators of transgression and regression: Journal of the Geological Society of London, v. 136, p. 157–164.

Johnson, M. E., 1987, Extent and bathymetry of North American platform seas in the Early Silurian: Paleoceanography, v. 2, p. 185–211.

Johnson, M. E.; and Baarli, B. G., 1987, Encrusting corals on a latest Ordovician to earliest Silurian rocky shore, southwest Hudson Bay, Manitoba, Canada: Geology, v. 15, p. 15–17.

Johnson, M. E.; Rong, J. Y.; and Yang, X. C., 1985, Intercontinental correlation by sea-level events in the Early Silurian of North America and China (Yangtze Platform): Geological Society of America Bulletin, v. 96, p. 1384–1397.

Johnson, M. E.; Baarli, B. G.; Nestor, H.; Rubel, M.; and Worsley, D., 1991, Eustatic sea-level patterns from the Lower Silurian (Llandovery Series) of southern Norway and Estonia: Geological Society of America Bulletin, v. 103, p. 315–335.

Kimberley, M. M., 1978, Paleoenvironmental classification of iron formations: Economic Geology, v. 73, p. 215–229.

______1979, Origin of oolitic iron formations: Journal of Sedimentary Petrology, v. 49, p. 111–132.

______1989a, Nomenclature for iron formations: Ore Geology Review, v. 5, p. 1–12.

______1989b, Exhalative origins of iron formations:

Ore Geology Review, v. 5, p. 12–145.

Phillips, W. B., 1912, Iron making in Alabama: Geological Survey of Alabama, Tuscaloosa, 254 p.

Reading, H. G., 1978, Sedimentary environments: Blackwell Scientific Publications, Oxford, 557 p.

Smith, E. A., 1876, Red Mountain Group: Alabama Geological Survey Report on Progress for 1876, p. 11, 23, 25, 34, 42, 207–208.

Swift, D. J. P., 1968, Coastal erosion and erosional stratigraphy: Journal of Geology, v. 76, p. 444–456.

Thomas, W. A.; and Bearce, D. N., 1986, Birmingham Anticlinorium in the Appalachian fold-thrust belt, basement fault system, synsedimentary structure, and thrust ramp, *in* Neathery, T. L. (ed.), Centennial Field Guide, vol. 6, Southeastern Section of the Geological Society of America: Geological Society of America, Boulder, p. 191–200.

Van Houten, F. B., 1986, Search for Milankovitch patterns among oolitic ironstones: Paleoceanography, v. 1, p. 459–466.

______ 1991, Interpreting Silurian Clinton oolitic ironstones—1850–1975: Journal of Geological Education, v. 39, p. 19–22.

Van Houten, F. B.; and Bhattacharyya, D. D., 1982, Phanerozoic oolitic ironstones—geologic record and facies model: Annual Review of Earth and Planetary Sciences, v. 10, p. 441–457.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geological Survey Bulletin 896, part 2, 2396 p.

Wilson, M. A., 1987, Ecological dynamics on pebbles, cobbles, and boulders: Palaios, v. 2, p. 594–599.

Ziegler, A. M.; Boucot, A. J.; and Sheldon, R. P., 1966, Silurian pentameroid brachiopods preserved in position of growth: Journal of Paleontology, v. 40, p. 1032–1036.

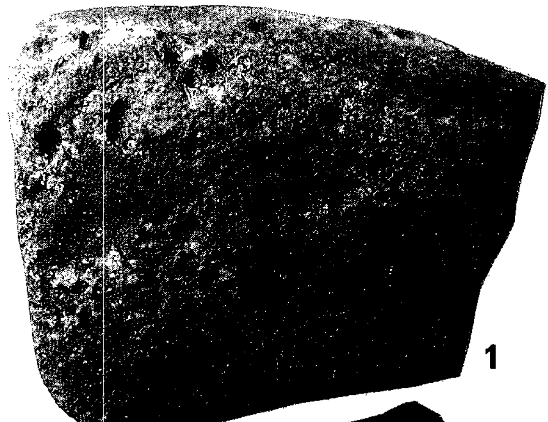
PLATE 1

Conglomeratic clasts from the Kidney seam (Interval D)
of the Red Mountain Formation

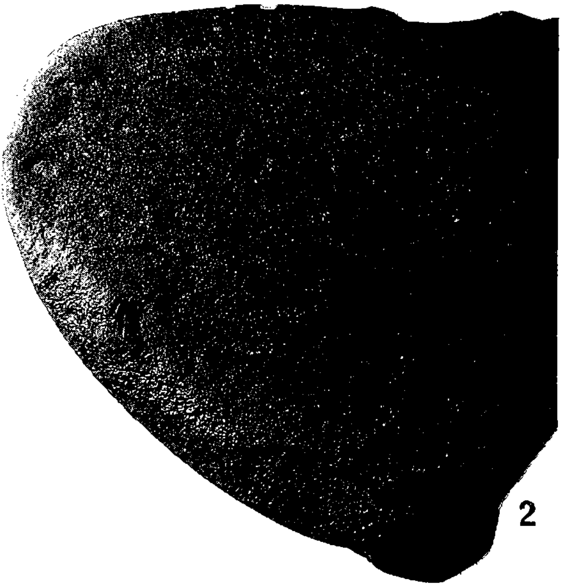
Figured specimens: FMNH—Field Museum of Natural History, Chicago, Illinois.

Figures 1,2.—Cobbles from the Kidney seam of the Red Mountain Formation at the Red Mountain Expressway exposure in Birmingham, SC½ sec. 6, T. 18 S., R. 2 W., Jefferson County, Alabama. **1**, small limestone cobble with borings of the trace fossil *Trypanites* (×1) (FMNH PE 53955); **2**, another example replaced by hematite but exhibiting the same borings (×1) (FMNH PE 53956).

Figures 3,4.—Part of a large cobble from the Kidney seam (same locality), exhibiting an encrusting "button" coral. **3**, oblique view of hematized cobble and part of the enclosing matrix, with arrow pointing to coral (×1) (FMNH PE 53957); **4**, close-up view of "button" coral in cross section resting directly on the irregular microtopography of the cobble (×3) (FMNH PE 53957).



1



2

3

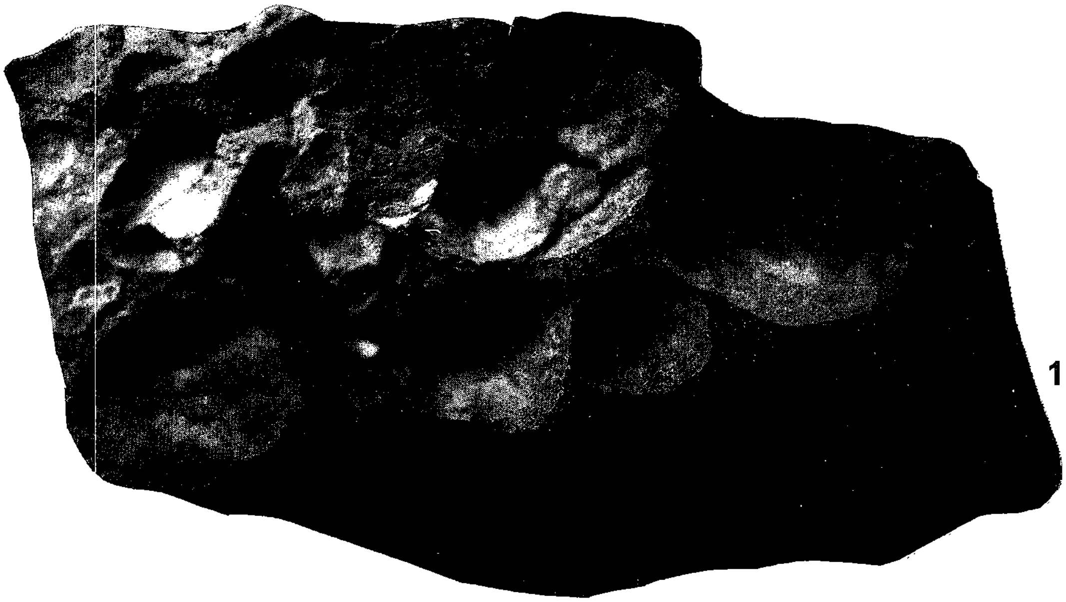
4

PLATE 2

Pentamerus from Red Mountain Formation

Figured specimens: FMNH—Field Museum of Natural History, Chicago, Illinois.

Figures 1,2.—*Pentamerus oblongus* (Sowerby), Red Mountain Formation, southeast of the railroad tracks, on a line running southwest from SE¼NE¼SE¼ sec. 20 through NE¼SE¼SE¼ sec. 20 to SW¼SE¼SE¼ sec. 20, T. 18 S., R. 3 W. in Ishkooda, Jefferson County, Alabama. **1**, external mold of a cluster of *Pentamerus oblongus* preserved in growth position, hematitic replacement (×0.6) (FMNH PE 53958a); **2**, internal mold of a cluster of *Pentamerus oblongus* preserved in growth position, hematitic replacement (×0.6) (FMNH PE 53958b).



1

2

Oklahoma Geological Survey Bulletin 145, 1992

Late Silurian–Early Devonian Conodonts from the Hunton Group (Upper Henryhouse, Haragan, and Bois d'Arc Formations), South-Central Oklahoma

James E. Barrick
Texas Tech University

Gilbert Klapper
University of Iowa

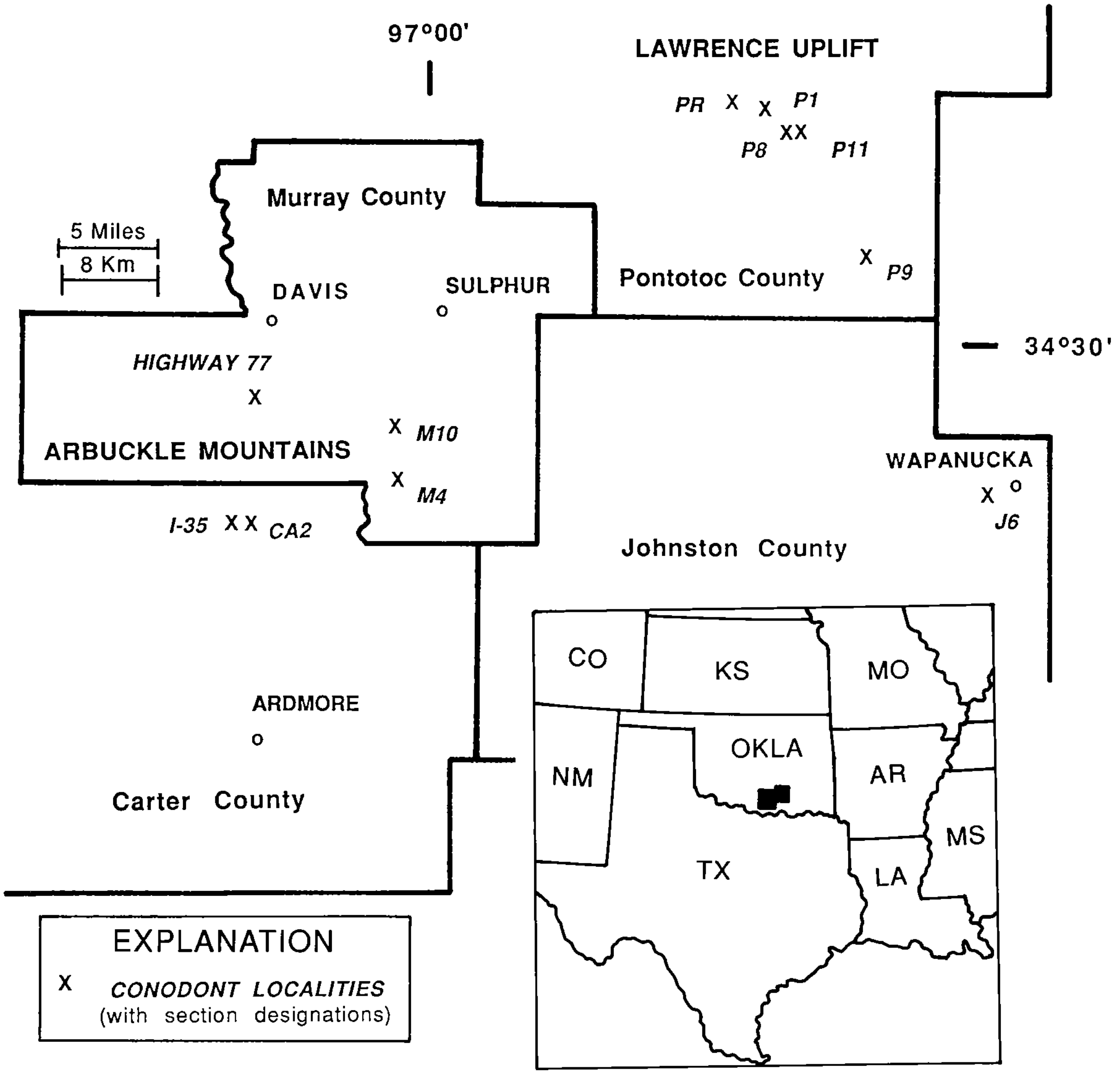
ABSTRACT.—The lower Henryhouse Formation spans three Ludlovian conodont zones, which are succeeded by a thick interval of Pridolian (Upper Silurian) strata, the lower part of which is characterized by a fauna with *Ozarkodina remscheidensis eosteinhornensis* and *Oulodus elegans elegans*. The upper part of the Henryhouse has a fauna with *O. elegans detorta*, indicative of the uppermost Pridolian, and new species of *Belodella* and *Dvorakia*. Slightly above the base of the Haragan Formation is a fauna with *Icriodus postwoschmidti* and *Pedavis biexoramus*, correlative with the *eurekaensis* Zone, the second zone above the base of the lower Lochkovian Stage (Lower Devonian). The break in the conodont sequence between these two faunas coincides with that seen in the megafauna and ostracodes. There is, however, a thin interval of uppermost Henryhouse and lowermost Haragan strata containing a zonally indeterminate fauna with the long-ranging *O. remscheidensis remscheidensis* and several coniform species. The Cravatt and the lower part of the Fittstown Members of the Bois d'Arc Formation contain a fauna mainly characterized by *Icriodus postwoschmidti*, regarded as correlative with the *eurekaensis* Zone, whereas the upper part of the Fittstown has a fauna with *Ancyrodelloides transitans* of the succeeding Lochkovian *delta* Zone. Newly described species are *Belodella anfracta*, *B. coarctata*, *Dvorakia amsdeni*, and *Ancyrodelloides secus*.

INTRODUCTION

Hunton Group strata of the Henryhouse, Haragan, and Bois d'Arc Formations in the Arbuckle Mountains of south-central Oklahoma (Text-fig. 1) have been the subject of intensive lithostratigraphic and biostratigraphic research since the 1950s. The lithostratigraphy was comprehensively treated by Amsden (1960) and the brachiopods of the three formations were described in a series of papers (Amsden, 1951,1958a,b,c,1963). Among other groups, the ostracodes of the Henryhouse and Haragan (Lundin, 1965,1968) and the trilobites of the three formations (Campbell, 1967,1977) have been systematically described. Recently, Amsden (1988) presented a comprehensive summary and range charts of the articulate brachiopods of the entire Hunton Group.

All of the accumulated evidence indicates that there is a major biostratigraphic change between the brachiopods, trilobites, and ostracodes of the Henryhouse Formation (Silurian) and those of the Haragan–Bois d'Arc Formations (Lower Devonian). Not a single species of any of these groups crosses the Henryhouse–Haragan boundary. This has led to the inference that there is an unconformity between the Henryhouse and Haragan (Amsden, 1960,1962,1988), despite the fact that the lithostratigraphic distinction across this boundary is obscure because of essentially identical lithology below and above. Nonetheless, evidence for local discordance is developed at Bois d'Arc Creek (Amsden, 1962, p. 1510; 1988, p. 7), and regionally within the Arbuckle Mountains the Haragan truncates the Henryhouse coming to rest directly on the subjacent Clarita and Cochrane Formations.

The description and biostratigraphic analysis of the conodonts of the Henryhouse–Haragan–Bois d'Arc sequence is the subject of the present paper. A general outline of the conodont sequence in these formations has been summarized previously by Barrick (1988) and Barrick and others (1990a). In the present paper we focus on the sequence and provide systematic descriptions of conodonts from all three formations, but omit a detailed account of the lower three zones developed in the lowest part of the Henryhouse. Their biostratigraphic implications are considered, however. Note that the term "zone" as used throughout the present paper is in the conventional biostratigraphic sense and that the cited Silurian and Lower Devonian zones are all well established in the literature.



Text-figure 1. Location of Henryhouse, Haragan, and Bois d'Arc conodont localities in the Arbuckle Mountains (including Lawrence Uplift) in south-central Oklahoma. Modified from Panel I of Amsden (1960). For locations of sections M4 and M10, see Amsden (1960).

As with the other fossil groups, there is a marked change in the conodont sequence across the Henryhouse–Haragan boundary. The fauna of the upper part of the Henryhouse Formation with *Oulodus elegans detorta,* indicating the uppermost part of the Pridolian Stage of the Silurian, is separated by a very thin stratigraphic interval with zonally indeterminate conodonts from the fauna of the lower part of the Haragan Formation with *Icriodus postwoschmidti* and *Pedavis biexoramus.* The latter association indicates correlation with the *eurekaensis* Zone of the lower but not lowermost Lochkovian Stage of the Lower Devonian. The position of this change in the conodont faunas across the Henryhouse–Haragan boundary coincides with the well-known change in the megafauna and ostracodes.

HENRYHOUSE CONODONTS

A summary of the conodont succession within the Henryhouse Formation has previously been given by Barrick and others (1990a,b). Although the concern of the present paper is focused on the faunas of the upper part of the Henryhouse and those of the overlying Haragan and Bois d'Arc Formations, the faunas of the lower part of the Henryhouse are worthy of mention. The conodont fauna in the lowest beds of the Henryhouse Formation is that of the *Kockelella variabilis* Zone as developed in Oklahoma, which appears to be equivalent to the *crassa* Zone of Walliser (1964). The latter zone has generally been assumed to be lower Ludlovian (Barrick and Klapper, 1976, p. 65–68, includes discussion of the problem of classification of the *crassa* Zone). As noted by Barrick and others (1990a, p. 59; 1990b, stop 1, p. 9), a fauna with *Polygnathoides siluricus* representing the middle Ludlovian zone of the same name occurs at 3.44–3.75 m above the base of the Henryhouse Formation on the north side of the Arbuckle Anticline. Higher in the same section at ~8 m above the Henryhouse base is a fauna of the upper Ludlovian *snajdri* Zone (Schönlaub, 1980b, 1986), with *Ozarkodina snajdri* and *O.* n. sp. of Schönlaub (1980b, pl. 17, figs. 6–8). The *crassa* and *siluricus* Zones have not been recognized at sections in the Lawrence Uplift (Barrick and others, 1990a, p. 59), for example at section P1 (Chimneyhill Creek, Text-fig. 2) where lower Henryhouse strata contain a fauna of the *snajdri* Zone.

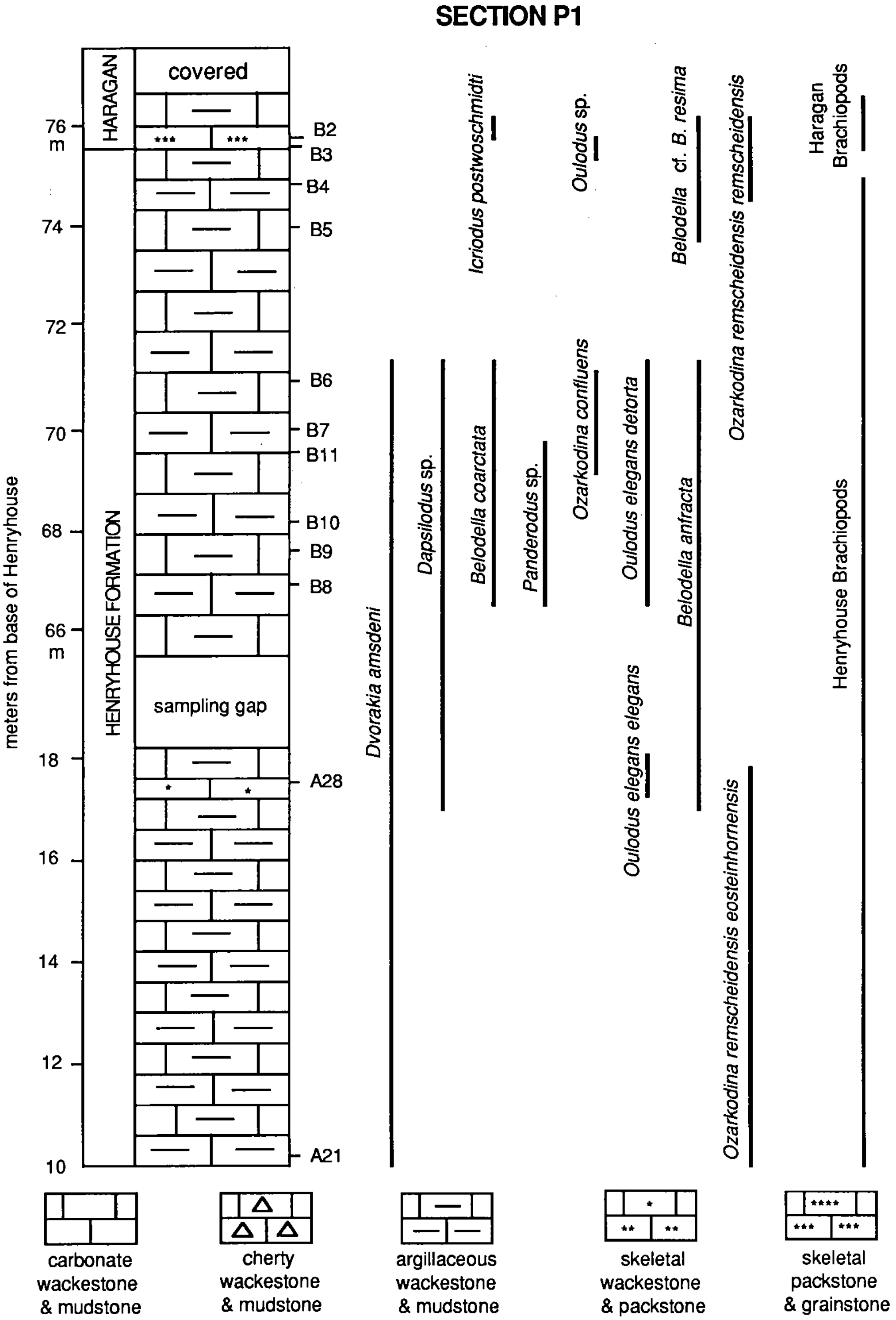
At Chimneyhill Creek, the lowest Henryhouse conodont fauna of interest is that in a sample at ~10 m above the base, which contains *Ozarkodina remscheidensis eosteinhornensis*. This subspecies is known to range as low as the upper Ludlovian *crispa* Zone, and even lower into the *snajdri* Zone in the Barrandian sequence of Czechoslovakia (Schönlaub, 1986). Nonetheless, there is a considerable interval of Pridolian strata in the Barrandian, above the *crispa* Zone at the top of the Ludlovian, characterized by *O. r. eosteinhornensis* as the main diagnostic species. A higher collection at 17.5 m above the base of the Henryhouse at Chimneyhill Creek (P1, Text-fig. 2) includes *O. r. eosteinhornensis* and *Oulodus elegans elegans*. Presumably, these two Chimneyhill Creek collections correlate with some part of the Pridolian range of *O. remscheidensis eosteinhornensis*, although an upper Ludlovian correlation cannot be completely excluded.

The conodont fauna of the upper part of the Henryhouse Formation is characterized primarily by two species: *Oulodus elegans detorta* and *Ozarkodina remscheidensis remscheidensis*. This association occurs in upper Henryhouse strata at a number of sections (e.g., section P1 [Text-fig. 2]; section I-35 [Text-fig. 3]; section Ca2 [Text-fig. 4]; section Highway 77 [Text-fig. 5]; section PR [Text-fig. 6]). *Ozarkodina confluens* is a less common species of the fauna. The stratigraphic range of *Oulodus elegans detorta* is extremely short, as it is restricted to the uppermost part of the Pridolian Stage of the Silurian at the Klonk section in the Barrandian area of Czechoslovakia and at Cellon in the Carnic Alps, Austria (Jeppsson, 1988). The former is the stratotype section for the base of the Devonian. Another significant, and again similarly restricted occurrence, of *Oulodus elegans detorta* is in strata just below the lowest occurrence of *Icriodus woschmidti woschmidti* in the Mason Porcus section in Sardinia (Gnoli and others, 1988; Olivieri and Serpagli, 1990, p. 69). Denkler and Harris (1988) illustrate specimens of *O. elegans detorta* from low in the upper limestone member of the Keyser Limestone of West Virginia. In their study, the highest occurrence of this taxon does not overlap the lowest occurrence of *Icriodus woschmidti* (Denkler and Harris, 1988, fig. 2, table 1).

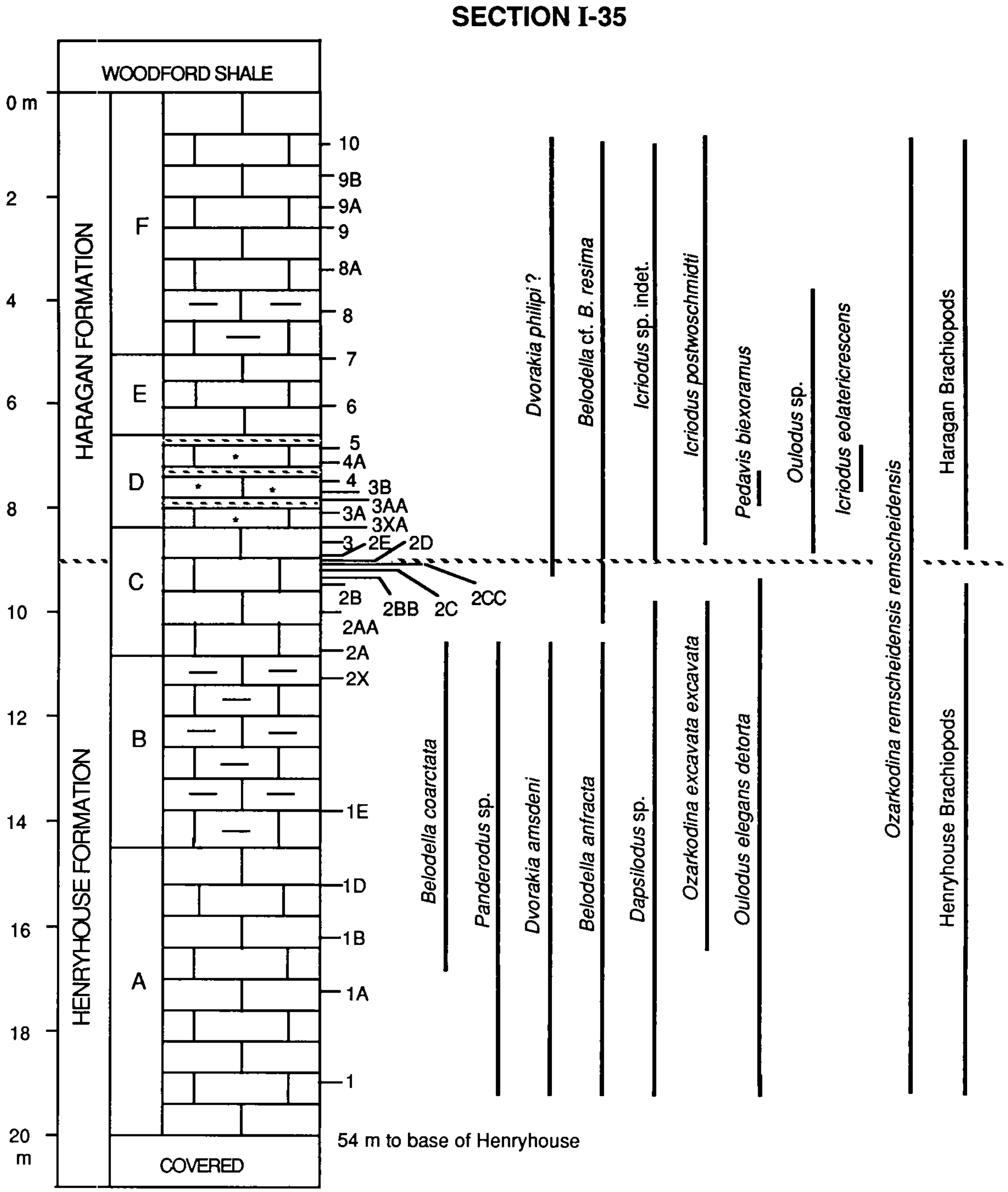
Three fragmentary specimens of *Icriodus* occur in the upper part of the Henryhouse Formation in the fauna with *Oulodus elegans detorta* at section Highway 77 (Text-fig. 5, samples 37 and 39) and at section Ca2 (Text-fig. 4, sample 24). Although these specimens are indeterminate at the specific level, the morphologic features preserved are not in conflict with those characteristic of *Icriodus woschmidti*. These rare occurrences are viewed as representing the known downward range of the earliest specimens of *Icriodus* into highest Pridolian strata, which are more significantly characterized by the presence of *O. elegans detorta*. The *woschmidti* Zone, presumably equivalent to the *hesperius* Zone in some Cordilleran and Australian sections (Klapper and Johnson, 1980, p. 408), extends across the Pridolian–Lochkovian, or Silurian–Devonian boundary. This has been noted in the literature many times, for example by Klapper and Murphy (1975, p. 19–20, fig. 10), Klapper and Johnson (1980, fig. 1), Gnoli and others (1988, p. 328), and Uyeno (1990, table 1), because rare specimens of *I. woschmidti* are known to range below the base of the *Monograptus uniformis* Zone at the base of the Lochkovian.

The upper part of the Henryhouse Formation with *Oulodus elegans detorta* also contains a distinctive, short-ranging coniform fauna. *Belodella coarctata* is a dominant component of this fauna, ranging through just a few meters but not into the uppermost Henryhouse. Jeppsson (1988, table 1) reported a comparable interval of high abundance for this species ("*Belodella mira*") in beds 10–14 at the Klonk section, below its highest occurrence in bed 19. *Belodella anfracta* ranges up to the same stratigraphic level as the highest *B. coarctata*. Jeppsson (1988, 1989) reported a *Belodella* sp. S from the upper Pridolian at Klonk, but the diagnostic Sc (doc) element was not illustrated, making the comparison with *B. anfracta* uncertain. *Dvorakia amsdeni* has its highest occurrence about at the same level as *B. coarctata* and *B. anfracta*, and the succeeding *D. philipi*? has its lowest occurrence slightly higher in the Henryhouse, but still below the top of the range of *O. elegans detorta*. The type material of *D. philipi* is from the Borshchov Formation at the base of the Lochkovian Stage, Lower Devonian of Podolia (Drygant, 1974,1984).

Above this short-ranged fauna with *Belodella coarctata*, *B. anfracta*, etc., the uppermost beds of the Henryhouse Formation show a nearly complete turnover in coniform species. The fauna of the turnover consists of species that characterize Loch-



Text-figure 2. Stratigraphic column of section P1 (Amsden, 1960) showing ranges of conodont taxa. Section in Chimneyhill Creek and a hillside exposure north of creek (NW¼SW¼ sec. 4, T. 2 N., R. 6 E., Ahloso Quadrangle, Pontotoc County). Sample numbers are indicated along the right side of the column. Brachiopod distribution and formational contact from Amsden (1960, p. 263–264).



Text-figure 3. Stratigraphic column of section I-35 (Barrick and others, 1990b) showing ranges of conodont taxa. Section is a road cut along west side of south lane of Interstate 35 (NW¼SE¼ sec. 25, T. 2 S., R. 1 E., Springer Quadrangle, Carter County). Refer to Table 1 for complete data. Lithologic symbols are the same as in Text-figure 2. Highest Henryhouse brachiopod occurs in sample 2B and lowest Haragan brachiopod in sample 2E (identified by T. W. Amsden). Base of Haragan placed at sample 2D where conodont biofacies change abruptly (see Conodont Biofacies).

TABLE 1. — DISTRIBUTION OF CONODONT ELEMENTS AT SECTION I-35

SECTION I-35		Henryhouse												Haragan
Sample		1	1A	1B	1D	1E	2X	2A	2AA	2B	2BB	2C	2CC	2D
Base (m)		19.10	17.30	16.20	15.25	13.90	11.30	10.85	10.10	9.50	9.40	9.25	9.15	9.00
Top (m)		18.90	17.20	16.15	15.10	13.70	11.20	10.70	10.00	9.40	9.25	9.15	9.00	8.90
Weight (kg)		2.5	2.5	2.0	2.5	2.5	2.5	2.0	4.0	2.5	3.5	4.0	3.5	5.0
Dapsilodus sp.		11			3	1		1	160					
Panderodus sp.		35	7	12	23	26	5	6						
Belodella	M	3		2	2			1						
anfracta	S	15	1	22	9	10	2	16						
Belodella	M				5	3	2							
coarctata	S			19	64	43	15	13						
Belodella	M								17	22	4	57	29	40
cf. *B. resima*	S								57	96	18	308	77	105
Dvorakia amsdeni	S	11	9	5	10	6	1	2						
Dvorakia philipi ?	S											1		
Decoriconus fragilis		15	6	2	22	26	12	26	205	43	15	251	142	7
Pseudooneotodus beckmanni							2		3		1	82	132	240
Ozarkodina	Pa	10	1	3					20	24	11	27	11	34
remscheidensis	Pb	6	2	1					10	10		5	8	14
remscheidensis	M	1							6	2			4	3
	S	13							20	17		6	22	20
Ozarkodina	Pa			1	1				6					
excavata	Pb			1	1				9					
excavata	M			1					6					
	S				2				21					
Oulodus	Pa									2	1			
elegans	Pb	3				1				6	2			
detorta	M	2	1	2				1	3	8	4			
	S	13	1	10	5	1	2	2	5	20	20			
Icriodus	Pa													
postwoschmidti	Pb													
	M													
	S													
Icriodus eolatericrescens	Pa													
	Pb													
	S													
Icriodus sp. indet.	Pa													1
Pedavis biexoramus	Pa													
Oulodus sp.														
Indet. ramiforms		11		3		4	1			19	17	3		6
Total		149	28	82	147	121	42	68	548	269	93	740	425	470

NOTE: Datum is top of the Hunton Group/base of Woodford Formation. Indeterminate Pb, M, and S elements of *Icriodus* arbitrarily tabulated under *I. postwoschmidti*, but noted separately in Systematic Paleontology. *(continued on next page)*

kovian strata, especially *Belodella* cf. *B. resima*, but the lower boundary of the turnover is in uppermost Pridolian beds, just below the highest occurrence of *Oulodus elegans detorta* in the Henryhouse. Uyeno (1990) described *B.* cf. *B. resima* from a probable *hesperius* Zone sample from the Canadian Arctic. Comparative material from the Cellon section in the Carnic Alps, beds 47A and 47B, just below and with the first occurrence of *Icriodus woschmidti*, contains *B.* cf. *B. resima*.

In summary, one may conclude that the lower Henryhouse Formation spans from the *Kockelella variabilis* Zone inferred to be lower Ludlovian, through the middle Ludlovian *siluricus* Zone and the upper Ludlovian *snajdri* Zone. Higher beds in the Henryhouse span the Pridolian, characterized first by the association of *Ozarkodina r. eosteinhornensis* and *Oulodus elegans elegans*, but near the top of the formation by a fauna with *O. r. remscheidensis* and *O. e. detorta*, the latter indicating the uppermost Pridolian. Lastly, in the uppermost part of the Henryhouse Formation at all analyzed sections, there is a zonally indeterminate fauna characterized mainly by *B.* cf. *B. resima* and *Ozarkodina rem-*

TABLE 1. — *Continued*

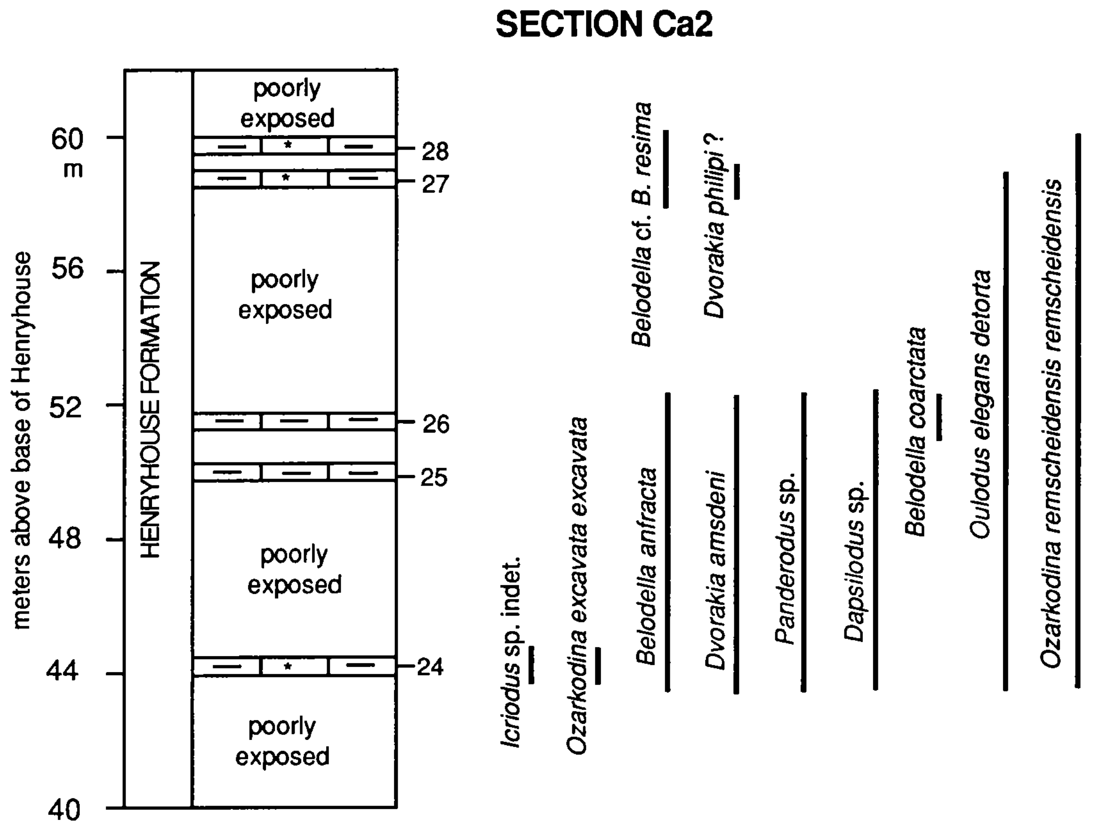
Haragan																
2E	3	3XA	3A	3AA	3B	4	4A	5	6	7	8	8A	9	9A	9B	10
8.90	8.70	8.50	8.15	7.90	7.75	7.55	7.20	6.85	6.05	5.20	4.25	3.45	2.65	2.25	1.75	1.05
8.75	8.65	8.35	8.08	7.80	7.65	7.45	7.10	6.75	5.90	5.10	4.15	3.53	2.50	2.15	1.60	0.95
3.5	7.0	3.5	6.0	3.5	6.5	13.0	4.8	2.0	2.0	2.0	2.0	3.5	5.5	4.0	4.5	7.0
16	24	11	7	10	10	8	2	4	4	10	2	28	271	194	30	160
108	72	45	32	52	33	44	6	16	3	43	4	145	1752	1497	166	1221
	1	1	8	1	3	17	2	7	3	3	1	6	4		10	31
2	12	30	2	2	8	16		6	8	7	2	29	1	18	20	123
5	64	36	23	35	25	38	11	44	2	5	7	2	19	12	18	35
26	103	1	3	3	1	1			1	2	9	4	27	17	19	82
13	28		1	2						2	1	2	6	5	5	12
1	17		2										3	3		4
21	41	1	1						1	6	2		16	17	6	10
	2	4	5	2		21			3		2					2
	4	6	9			10					2					
		1	6			3										
1	3	1	1		2	1						2				
						10		4								
								4								
								1								
	2	7		8	1	51						2				4
				1	1	8										
1		1				3		1	1		1					
						5										1
194	373	144	101	116	83	236	21	87	26	78	33	220	2109	1763	270	1684

Some M elements of *Dvorakia* species may be tabulated under co-occurring *Belodella* species (see Systematic Paleontology).

scheidensis remscheidensis. The latter is a long-ranging subspecies that extends at least from the Pridolian through the entire Lochkovian Stage of the Lower Devonian (e.g., Schönlaub, 1985, fig. 17). The correlation of the fauna in this uppermost thin interval of the Henryhouse, therefore, is uncertain.

HARAGAN CONODONTS

Conodont collections very near the base of the Haragan Formation (e.g., section P1, sample B2 [Text-fig. 2]; section I-35, sample 3 [Text-fig. 3]; section Highway 77, sample 43 [Text-fig. 5]) are significant in showing the lowest occurrence in Oklahoma of *Icriodus postwoschmidti*. These levels are not very much above the fauna with *Oulodus elegans detorta* in the upper part of the Henryhouse Formation. Collections at the very base of the Haragan mainly contain *Ozarkodina remscheidensis remscheidensis*, which ranges up from the upper Henryhouse fauna, but do not in any instance have *Oulodus elegans detorta*, which as noted above seems to be restricted to uppermost Pridolian strata in Europe. The former subspecies is long ranging, as already



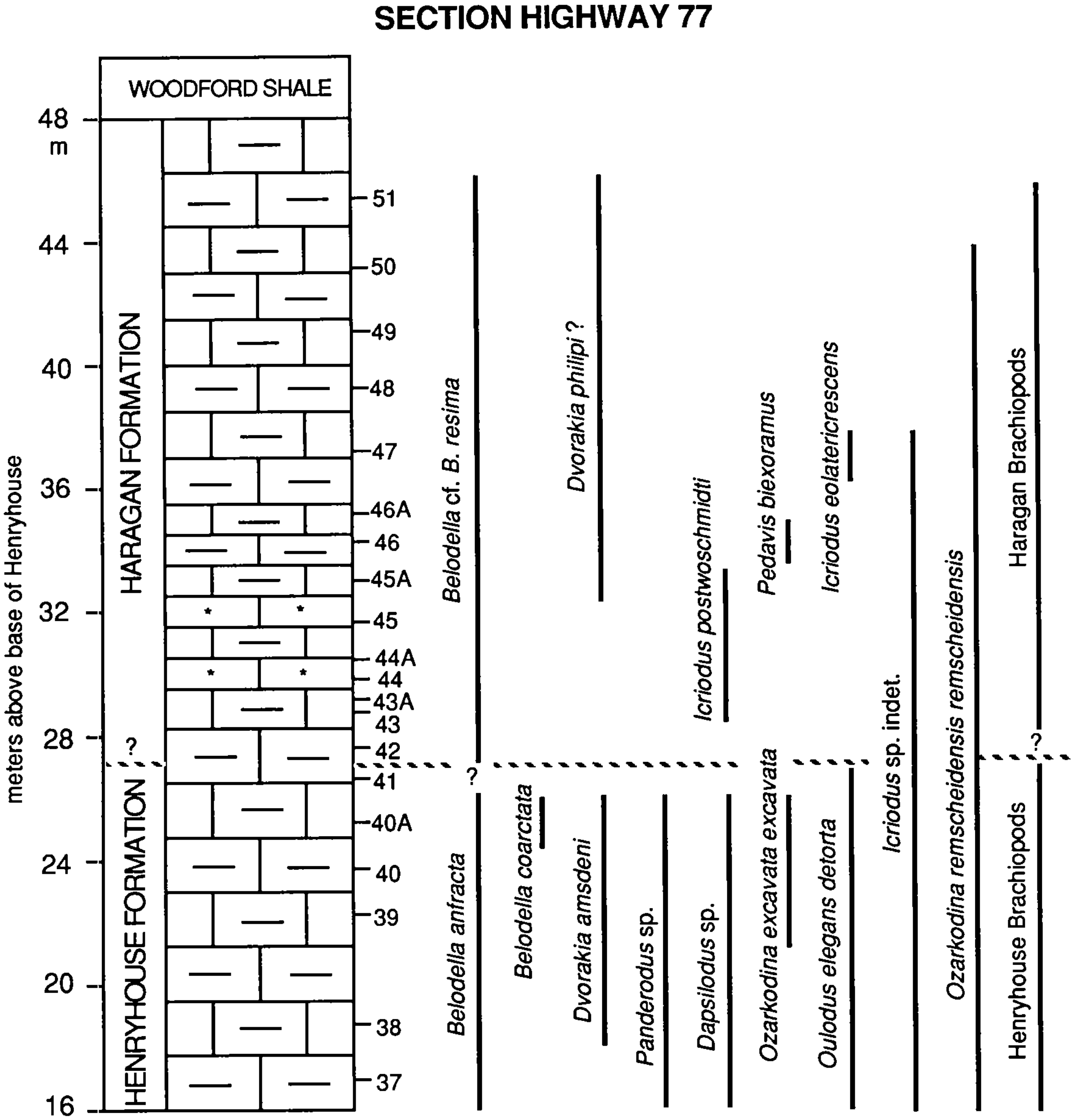
Text-figure 4. Stratigraphic column of section Ca2 (Barrick and Klapper, 1976) showing ranges of conodont taxa. Section is natural exposure in a field 0.2 km southeast of section Ca2 of Amsden (1960) and 0.5 km southeast of section I-35 (NE¼SE¼ sec. 25, T. 2 S., R. 1 E., Springer Quadrangle, Carter County). Lithologic symbols are the same as in Text-figure 2.

mentioned, and thus its occurrence in both the upper Henryhouse and Haragan is congruent with its known range elsewhere.

Pedavis biexoramus appears slightly higher in the Haragan sequence (e.g., section I-35, sample 3AA [Text-fig. 3]; section Highway 77, sample 46 [Text-fig. 5]). This species is a characteristic element of the fauna of the *eurekaensis* Zone in central Nevada (Klapper and Murphy, 1975, p. 20; Murphy and Matti, 1983). *Pedavis biexoramus* is associated with *Icriodus postwoschmidti* and *I. eolatericrescens* sensu Drygant (1984) section at section I-35 (samples 3AA and 4 [Text-fig. 3]). Both species of *Icriodus* are characteristic of the Chortkov Formation, according to Drygant (1984), which lies above the Borshchov Formation at the base of the Lochkovian Stage of the Lower Devonian in Podolia. In the Barrandian sequence, *P. biexoramus* is associated with *I. postwoschmidti* about in the middle of the *Monograptus uniformis* Zone of the lower Lochkovian (Schönlaub, 1985, fig. 17). One may conclude, therefore, that the association of *I. postwoschmidti* and *P. biexoramus* represents the *eurekaensis* Zone, the second conodont zone up from the base of the Lochkovian, and that the *woschmidti*, or *hesperius*, Zone is unrepresented in the Haragan Formation. It should be kept in mind, however, that there is a very thin interval of uppermost Henryhouse and lowest Haragan strata below the lowest occurrence of *I. postwoschmidti*, but as yet there is no positive evidence for the presence of the *woschmidti* Zone in the Oklahoma sequence.

BOIS D'ARC CONODONTS

A fauna with *Icriodus postwoschmidti*, accompanied by *Ozarkodina remscheidensis remscheidensis*, ranges through about the upper half of the Cravatt Member into the lower part of the Fittstown Member of the Bois d'Arc Formation at Bois d'Arc Creek (Text-fig. 7, section P8, samples 12–15). The specimens of *I. postwoschmidti* in several of the lower Fittstown collections are robust and very typical of the species. On the evidence of *I. postwoschmidti*, which does not range above a medial position within the *Monograptus uniformis* Zone and which



SECTION HIGHWAY 77

Text-figure 5. Stratigraphic column of section Highway 77 (Barrick and Klapper, 1976) showing ranges of conodont taxa. Section is a road cut on west side of U.S. Highway 77, just east of original section M17 of Amsden (1960) (NE¼NE¼NW¼ sec. 30, T. 1 N., R. 2 E., Turner Falls Quadrangle, Murray County). Lithologic symbols are the same as in Text-figure 2. Brachiopod distribution from Amsden (1960, section M17, p. 257). Base of Haragan determined in part by conodont biofacies (see Conodont Biofacies).

lies entirely below species indicative of the *delta* Zone in the Barrandian (Schönlaub, 1985, fig. 17), this Cravatt–lower Fittstown fauna is referable to the *eurekaensis* Zone, the same conodont zone that is present in most of the underlying Haragan Formation. The only other section of the Cravatt Member that has been sampled in detail for conodonts is that at and near section J6. The collections there are sparse but are dominated by *Ozarkodina wurmi* in the upper part of the exposed Cravatt section (Text-fig. 8, section J6, samples 10–14). The exact range of this Lochkovian species is not well known, as it has been confused with the long-ranging Silurian–Early Devonian species, *O. excavata excavata*.

Faunas with *Icriodus postwoschmidti* also occur in the Fittstown Member in the subsurface in the Gulf No. 1 Dyer in McClain County, Oklahoma, at 9,025–9,035 ft (Amsden, 1975, p. 84). A low-diversity fauna chiefly composed of *Ancyrodelloides transitans* occurs in the upper part of the Fittstown Member at the P11 section (Text-fig. 9, samples 14, 14B, 15). This species is one of many components that make up the Lochkovian *delta* Zone (e.g., Klapper and Johnson, 1980, p. 408, table 2, right columns; Murphy and Matti, 1983, fig. 4, table 3—Mill Canyon, Toquima Range, central Nevada; the isolated record of *Ancyrodelloides delta* in the *sulcatus* Zone at Mill Canyon is regarded as a reworked specimen by M. A. Murphy and N. Valenzuela-Rios, 1991, personal communication). The upper Fittstown occurrences presumably are correlative with those in the *delta* Zone in Nevada and elsewhere. The range of *A. transitans* in the Barrandian sequence is, along with other species of the *delta* Zone, in strata correlative with the *Monograptus hercynicus* Zone of the upper Lochkovian Stage, according to Schönlaub (1985, p. 26 and fig. 17).

In addition to the Fittstown fauna with *Ancyrodelloides transitans*, there is an unusual and again low-diversity fauna with a new species of *Ancyrodelloides*, *A. secus*, in about the middle of the Fittstown Member of the Bois d'Arc Formation at Coal Creek (Text-fig. 10, section P9, sample 34). As this is a new species of the genus and a unique occurrence, its correlative value would at first seem doubtful. Nonetheless, all of the species of *Ancyrodelloides* are confined to the *delta* Zone. A testable hypothesis, therefore, would be that the Coal Creek occurrence of *A. secus* within the Fittstown Member is also indicative of the *delta* Zone of the upper Lochkovian.

CONODONT BIOFACIES

Upper Henryhouse Formation

Conodont faunas from the upper portion of the Henryhouse Formation are relatively sparse and possess only moderate diversity. Characteristic faunas are like those from section Highway 77 (Text-fig. 5, samples 37–41) and section Ca2 (Text-fig. 4, samples 24–26). Fewer than 50 elements per kilogram are present and *Belodella anfracta* is the dominant species. *Oulodus elegans*, *Ozarkodina remscheidensis remscheidensis*, *O. excavata excavata*, *Dvorakia amsdeni*, *Dapsilodus* sp., *Panderodus* sp., and *Decoriconus fragilis* occur in widely varying abundances from sample to sample. *Ozarkodina confluens* and *Pseudooneotodus beckmanni* are uncommon. Amsden (1981) described slightly different brachiopod biofacies in the Henryhouse from the central Arbuckle Mountains and Lawrence Uplift, but our limited sampling of the Henryhouse shows no obvious difference in conodont biofacies between the two areas, except near the top of the unit.

In the uppermost beds of the Henryhouse, dramatic changes occur in the conodont biofacies, the nature and magnitude of which reflect a significant ecologic response to changing environmental conditions (Text-figs. 11–14, Tables 1–4). The first event is an interval of high abundance of the short-ranging species *Belodella coarctata*. Just above this acme, over a stratigraphic interval of less than a meter, *Panderodus* sp., *Dapsilodus* sp., *Ozarkodina excavata excavata*, and *O. confluens* (indeterminate morphotype), disappear. The first three of these species are believed to range into younger strata elsewhere. *Belodella coarctata*, *B. anfracta*, and *Dvorakia amsdeni* become extinct, the latter two species being replaced by related taxa. As these taxa disappear, *Decoriconus fragilis* increases in abundance to dominate the fauna and *Pseudooneotodus beckmanni* becomes more common. The faunal turnover is most dramatic at sections on the Lawrence Uplift (sections PR [Text-fig. 11, Table 2]), but is still obvious at sections in the central Arbuckle Mountains (sections I-35 [Text-fig. 13, Table 1] and Highway 77 [Text-fig. 12, Table 3]). This event occurs in the latest Pridolian, just below the highest occurrence of *Oulodus elegans detorta* in each section. At all sections the topmost beds of the Henryhouse bear a *D. fragilis*-dominated fauna, with smaller numbers of *B.* cf. *B. resima*, *P. beckmanni*, and *O. remscheidensis remscheidensis*.

Haragan Formation

A shift in conodont biofacies corresponds to the change in brachiopod faunas at the base of the Haragan Formation. The uppermost Henryhouse acme of *Decoriconus fragilis* abruptly ends and is replaced by an acme of *Pseudooneotodus beckmanni*. This shift in biofacies is most dramatic on the Lawrence Uplift (sections PR [Text-fig. 11, Table 2] and P8 [Text-fig. 14, Table 4]), and occurs in sections where no corresponding lithologic change is present (sections P8 and I-35 [Text-fig. 13, Table 1]). The abrupt rise of dominance of *P. beckmanni* serves as an additional marker for the base of the Haragan Formation.

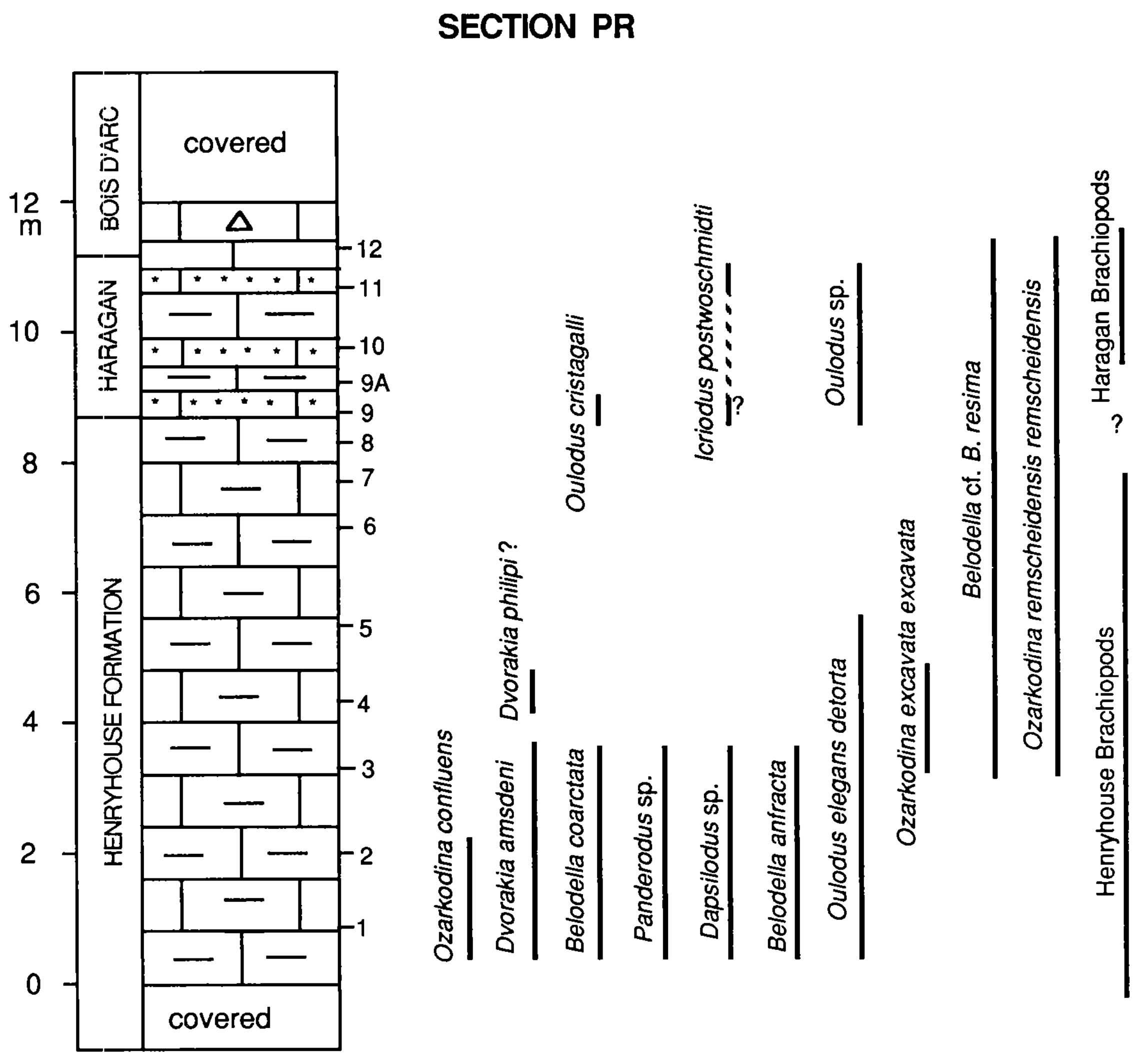
In the Arbuckle Mountains, an interval of skeletal wackestones and packstones interbedded with marls occurs near the base of the Haragan. Occurring in these beds is a sparse fauna dominated by elements of *Belodella* cf. *B. resima* and bearing the most abundant collections of *Icriodus* and *Pedavis* elements. Unfortunately, the conodont fauna of this interval is atypical of the majority of the Haragan. Most collections from argillaceous Haragan strata yield extremely sparse and nondiverse conodont faunas, like those in samples 44–51 at section Highway 77 (Text-fig. 12, Table 3) and samples 21–26 at section P9 (Text-fig. 10). Twelve samples from the Haragan at the important shelly fauna locality, White Mound (M4 of Amsden, 1960) (Text-fig. 1), yielded 43 conodont elements from 24 kg. Six samples from Amsden's (1960) locality M10 yielded 51 elements from 11 kg. Samples from a number of other localities are comparable. The faunas average fewer than 10 elements per kilogram, of which *P.*

beckmanni and *B.* cf. *B. resima* comprise a majority. The only exception to these poor faunas occurs at section I-35 (samples 9–10) (Text-fig. 13, Table 1), where the lower Haragan is characterized by an abundant conodont fauna, which is strongly dominated by elements of *B.* cf. *B. resima.*

On the Lawrence Uplift only a thin interval of Haragan overlies the Henryhouse Formation. At section PR (Text-fig. 11, Table 2), thin skeletal grainstones containing abundant elements of *Ozarkodina remscheidensis remscheidensis* occur with the *Pseudooneotodus beckmanni* acme. One unusual feature is the presence of a few elements of *Belodella anfracta, B. coarctata,* and *Dvorakia amsdeni* in samples B3 and B2 at section P1, which were probably reworked from a level a few meters lower in the Henryhouse. At section P8 (Text-fig. 14, Table 4), the thin Haragan interval yields moderately more diverse, but typical, faunas.

Bois d'Arc Formation

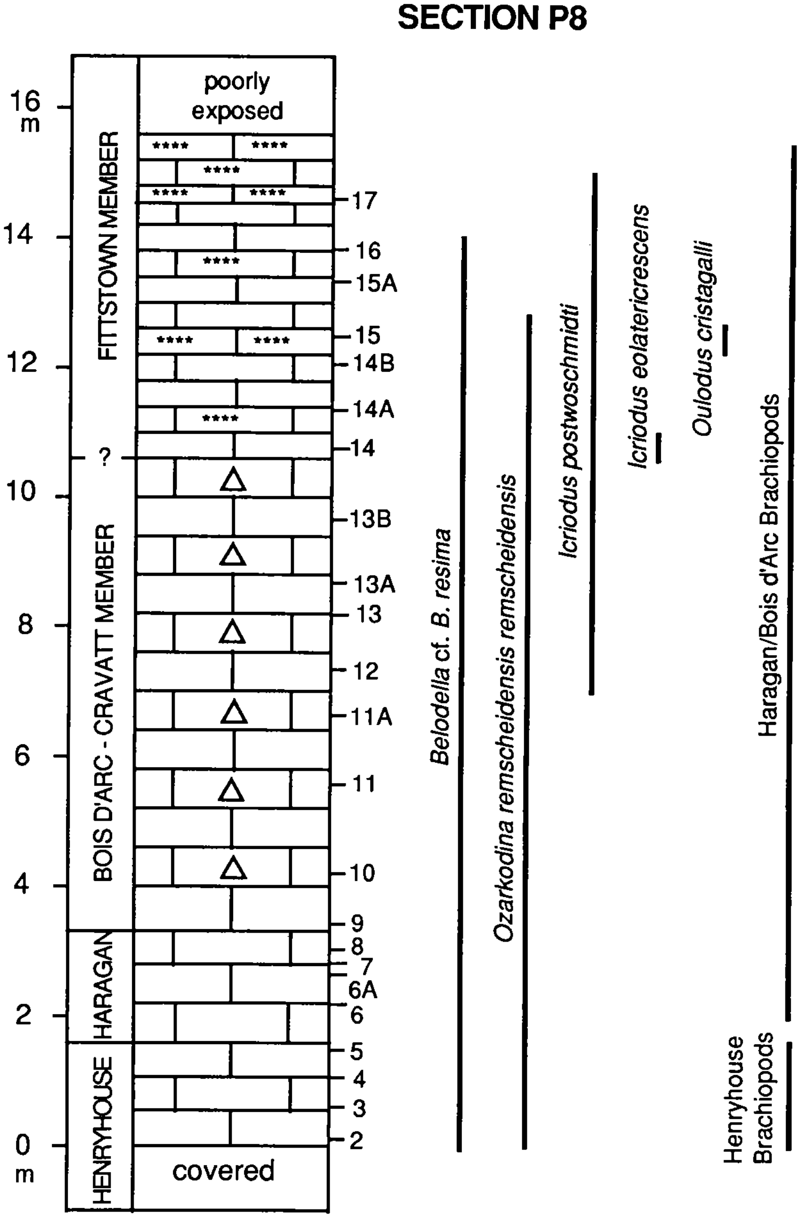
The siliceous carbonate mudstones of the Cravatt Member yielded few conodont elements. These sparse faunas are like those of the Haragan, but *Pseudooneotodus beckmanni* is less common. Where thin beds of skeletal wackestones to packstones appear in the middle to upper part of the member, as at sections J6 (Text-fig. 8) and P8 (Text-fig. 14,



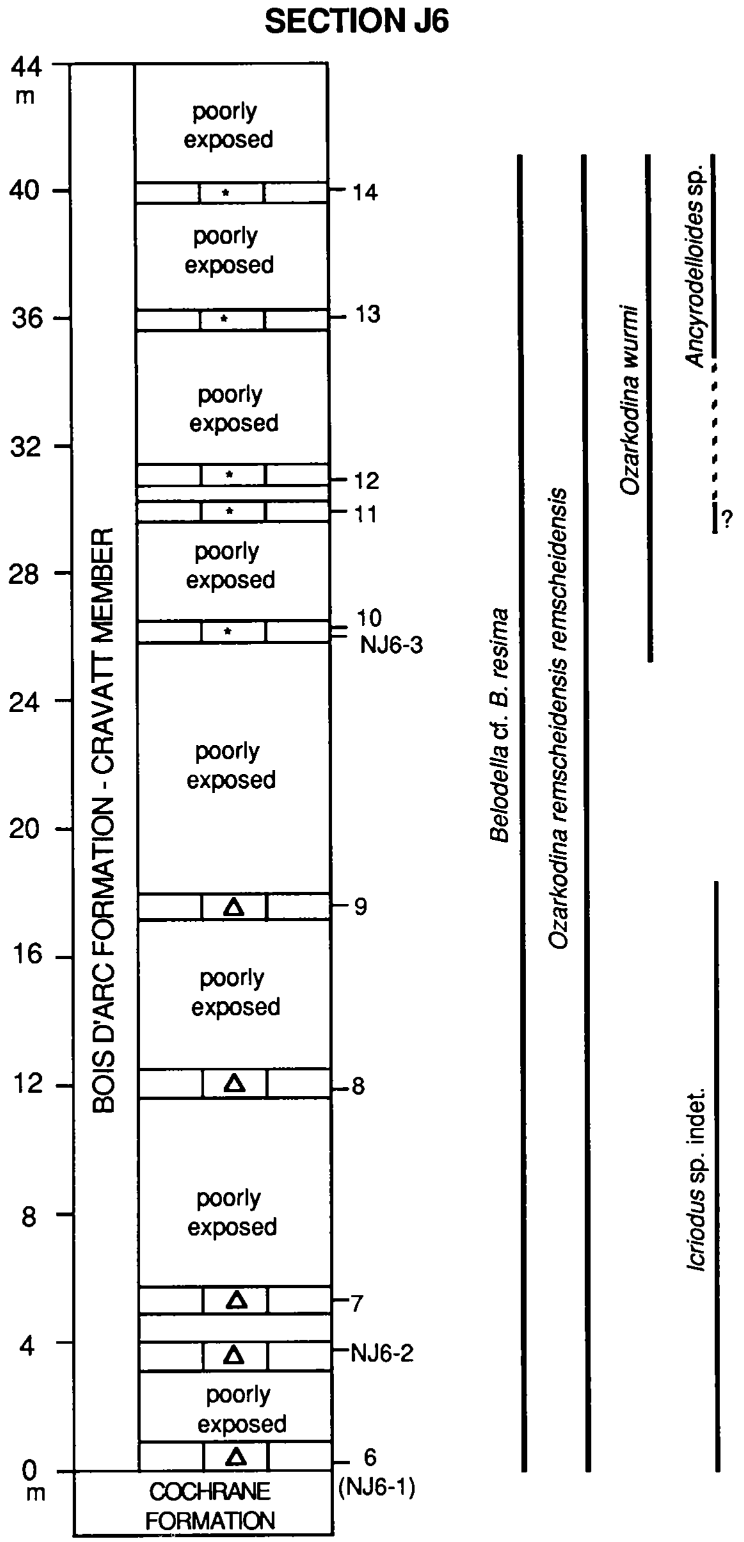
Text-figure 6. Stratigraphic column of section PR showing ranges of conodont taxa. Section PR is a road cut located 1.2 km northwest of section P1 (center of north line, sec. 5, T. 2 N., R. 6 E., Ahloso Quadrangle, Pontotoc County). Lithologic symbols are the same as in Text-figure 2. Lowest occurrence of Haragan brachiopods (sample 10) identified by T. W. Amsden in the field; uppermost extent of Henryhouse brachiopods is unknown. Base of Haragan placed at lowest grainstone, as at section P1.

Table 4), more abundant conodont elements occur, apparently concentrated by sedimentological processes. At section P8 the upper part of the Cravatt grades into the Fittstown Member through an increasing proportion of skeletal grainstones. These grain-dominated beds are characterized by relatively abundant elements of *Icriodus* species and *Ozarkodina remscheidensis remscheidensis*. Coniform species are uncommon until the base of the Fittstown, where *P. beckmanni* becomes the dominant form. The Cravatt section at J6 is unusually thick, and the upper skeletal beds contain a moderately abundant conodont fauna dominated by *O. wurmi*.

The skeletal grainstones of the Fittstown Mem-



Text-figure 7. Stratigraphic column of section P8 (Amsden, 1960) showing ranges of conodont taxa. Section is a hillside exposure along north bank of Bois d'Arc Creek (SW¼NW¼ sec. 11, T. 2 N., R. 6 E., Ahloso Quadrangle, Pontotoc County). Brachiopod distribution and base of Haragan from Amsden (1960, p. 279). Lithologic symbols are the same as in Text-figure 2. Base of Bois d'Arc identified by T. W. Amsden in the field. Base of the Fittstown Member uncertain due to interbedding of Cravatt and Fittstown lithofacies.



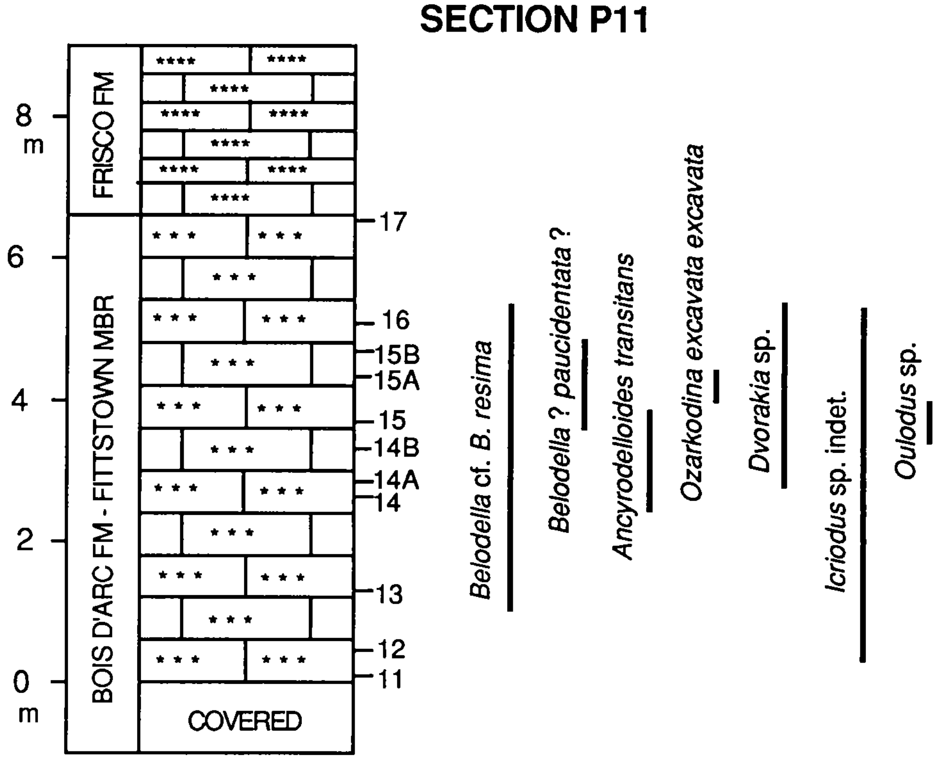
Text-figure 8. Stratigraphic column of section J6 (Amsden, 1960) showing ranges of conodont taxa. Section is a natural exposure along a small stream (SE¼SW¼ sec. 18, T. 2 S., R. 8 E., Connerville NE Quadrangle, Johnston County). Lithologic symbols are the same as in Text-figure 2.

ber yielded sparse and generally broken to abraded conodont elements. Coniform elements are sparse and poorly preserved, and when larger faunas are present, they consist of robust Pa elements of *Icriodus*, *Ancyrodelloides*, and *Ozarkodina* (sections P11 [Text-fig. 9] and P9 [Text-fig. 10]).

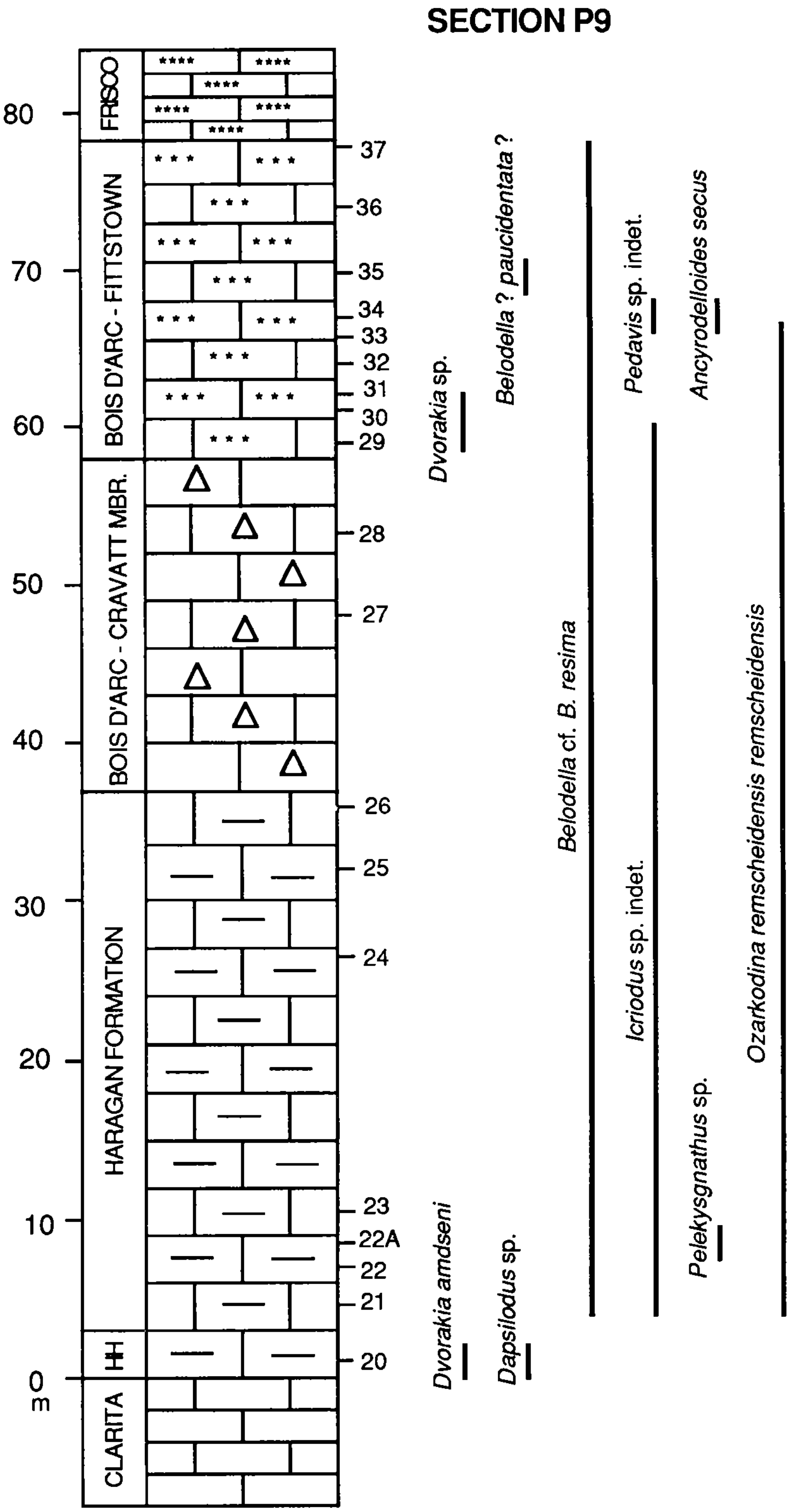
CONODONTS AND THE HENRYHOUSE–HARAGAN BOUNDARY

Although conodont faunas do not completely resolve the problem of the Henryhouse–Haragan boundary, they do contribute important information. The top of the Henryhouse ranges into at least the uppermost Pridolian at the sections studied here (sections I-35, Ca2, Highway 77, PR, P1, P8), and one cannot completely exclude the possibility that some Lochkovian-age beds locally lie at the top of the formation. The base of the Haragan Formation, identified by the abrupt change in brachiopod and ostracode faunas, corresponds exactly to an equally abrupt shift in conodont biofacies. A conodont fauna very near the base of the Haragan with *Icriodus postwoschmidti* correlates with the *eurekaensis* Zone, the second conodont zone above the base of the Lochkovian. The maximum biostratigraphic hiatus that could be represented by the Henryhouse–Haragan boundary would correspond at least to the interval of the *woschmidti* Zone, and possibly some minor part of the overlying *eurekaensis* Zone.

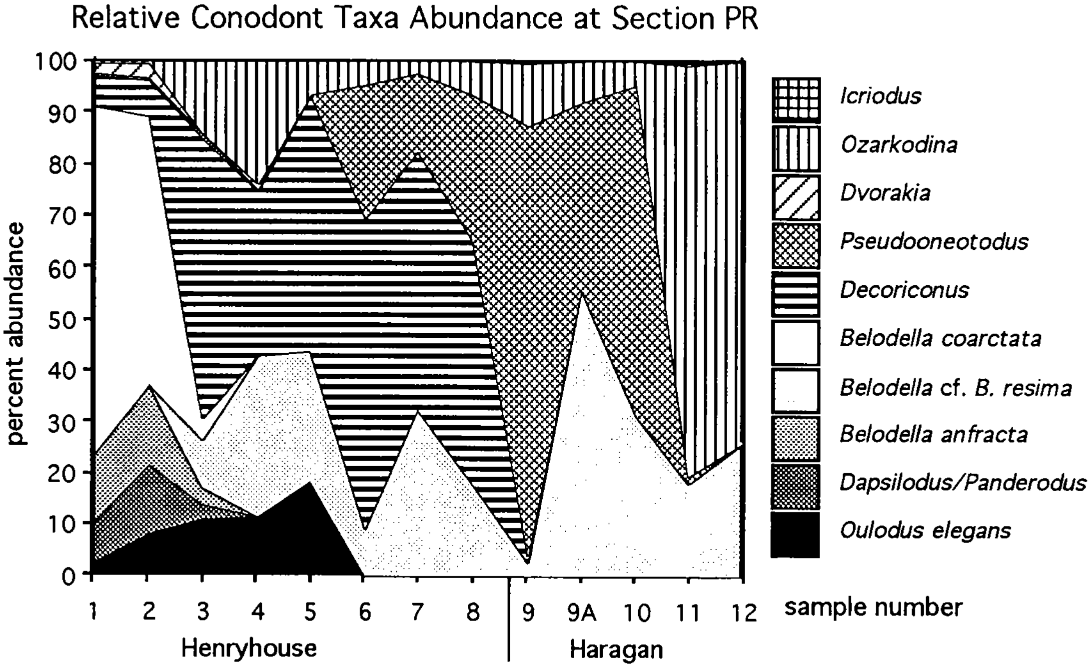
Amsden (1988 and earlier references therein) presented physical evidence, in addition to the changes in the shelly fauna, to demonstrate the unconformable nature of the Henryhouse–Haragan contact. Careful sampling for conodonts on the Lawrence Uplift confirms an erosional surface along Bois d'Arc Creek (section P8, Text-fig. 7), exactly as Amsden (1988, fig. 4) interpreted it. At section P8, a thin interval of Haragan, lithologically indistinguishable from the underlying Henryhouse, was reported to lie beneath the Bois d'Arc. The conodont sequence supports this interpretation. The uppermost Henryhouse *Decoriconus fragilis*-dominated fauna is replaced by the *Pseudooneotodus beckmanni*-dominated fauna at the point previously identified by Amsden (1960) as the boundary. Approximately 40 m to the east, Amsden described the Bois d'Arc as resting directly on the Henryhouse, the intervening Haragan beds being absent. Samples at the top of the Henryhouse at this location contain the association of *Belodella coarctata*, *B. anfracta*, *Dvorakia amsdeni*, and *Oulodus elegans detorta*, which characterizes the upper Henryhouse



Text-figure 9. Stratigraphic column of section P11 (Amsden, 1960) showing ranges of conodont taxa. Section is exposed in the bed of Bois d'Arc Creek (NW¼NE¼ sec. 11, T. 2 N., R. 6 E., Ahloso Quadrangle, Pontotoc County). Lithologic symbols are the same as in Text-figure 2.



Text-figure 10. Stratigraphic column of section P9 (Amsden, 1960) showing ranges of conodont taxa. Section is a hillside exposure north of Coal Creek (NW¼NW¼ sec. 22, T. 1 N., R. 7 E., Hardin City Quadrangle, Pontotoc County). Lithologic symbols are the same as in Text-figure 2. The lowest 1.5 m of the section is interpreted to be Henryhouse because of the presence of *Dvorakia amsdeni*.



Text-figure 11. Relative abundance of conodont taxa across the Henryhouse/Haragan boundary at section PR. Samples are graphed at equal spacing; see Text-figure 6 and Table 2 for correct stratigraphic intervals of samples.

several meters below its top at sections PR (Text-fig. 6) and P1 (Text-fig. 2) a short distance to the west. The basal Bois d'Arc strata yield a fauna like that found in the formation at section P8. Thus, the uppermost beds of the Henryhouse are missing, as one expects below an unconformity.

Lundin (1968, p. 11–12) reported abraded Henryhouse ostracodes mixed with the basal Haragan fauna at a number of sections including his section P3, which is in close proximity to our collections from sections PR and P1. We recovered reworked conodonts in the basal calcarenite at section P1 (Text-fig. 2, samples B3 and B2). A small number of elements of *Belodella coarctata*, *B. anfracta*, and *Dvorakia amsdeni* occur in these samples, although these three species do not range to the top of the Henryhouse in this section, nor in the adjacent PR section (Text-fig. 6). The reworked elements must have been derived from the erosion of upper Henryhouse beds elsewhere, such as in the P8 area (Text-fig. 7), and were then transported as part of the skeletal lag that lies at the base of the Haragan at section P1.

Conodonts obtained from sections crossing the Henryhouse–Haragan boundary support the interpretation of the stratigraphic relations presented by Amsden (1988, fig. 5) from the Lawrence Uplift to the Wapanucka area in Johnston County, Oklahoma. The narrowest stratigraphic interval between the upper Henryhouse fauna with *Oulodus elegans detorta* and the lower Haragan fauna with *Icriodus postwoschmidti* occurs in the central part of the Arbuckle Mountains (sections I-35 and Highway 77, Text-figs. 3,5), where physical evidence for a break between the Henryhouse and Haragan has not been observed. This intermediate interval carrying a zonally indeterminate conodont fauna is much narrower than it is in the Lawrence Uplift, suggesting that these central Arbuckle sections may also be broken by a hiatus between the Henryhouse and Haragan.

CONCLUSIONS

A fauna characterized mainly by *Oulodus elegans detorta* is in the upper Henryhouse Formation at all analyzed sections; this subspecies is known in highest Pridolian (Silurian) strata in Europe. The upper Henryhouse fauna is separated by a very thin stratigraphic interval from a fauna slightly above the base of the Haragan Formation and characterized by *Icriodus postwoschmidti* and *Pedavis biexoramus* and lacking any representative of *Oulodus elegans*. This lower Haragan fauna is correlative with the *eurekaensis* Zone, the second zone above the base of the Lochkovian Stage of the Lower Devonian. Apparently missing between the upper Henryhouse fauna with *O. elegans detorta* and the lower Haragan fauna with *I. postwoschmidti* is the fauna of the *woschmidti* Zone, which is well known to span across

TABLE 2. — DISTRIBUTION OF CONODONT ELEMENTS AT SECTION PR

SECTION PR		Henryhouse								Haragan				Bd'A
Sample		1	2	3	4	5	6	7	8	9	9A	10	11	12
Base (m)		0.80	1.90	3.25	4.25	5.45	6.85	7.65	8.25	8.75	9.20	9.75	10.60	11.25
Top (m)		1.00	2.05	3.45	4.45	5.65	7.05	7.85	8.45	8.85	9.30	9.90	10.75	11.35
Weight (kg)		1.84	2.00	2.00	1.90	1.87	2.00	1.90	1.84	4.00	1.90	2.00	7.85	2.00
Dapsilodus sp.		88	94	23										
Panderodus sp.		30	30	7										
Belodella	M	25	18	11										
anfracta	S	168	125	25										
Belodella	M	46	42	4										
coarctata	S	958	436	42										
Belodella	M			34	8	1	1	1	5	2	4	14	4	1
cf. *B. resima*	S			72	63	3	3	14	18	12	10	37	24	11
Dvorakia amsdeni	S	33	24	2										
Dvorakia philipi ?	S				3									
Decoriconus fragilis		93	63	601	71	8	26	23	61	6				
Pseudooneotodus beckmanni		4	6	12	1		11	7	36	410	9	105	2	
Ozarkodina confluens	Pa	1	2											
	Pb		1											
	M		1											
Ozarkodina	Pa			20	1									
excavata	Pb			20										
excavata	M			22	1									
	S			65	1									
Oulodus	Pa		6	16	2	2								
elegans	Pb	3	5	7	5									
detorta	M	4	15	13	2									
	S	15	45	54	18	1								
Ozarkodina	Pa			13	29	1	2		3	48		3	76	11
remscheidensis	Pb			6	15				2	6	1	1	16	8
remscheidensis	M			3								1	2	3
	S			3	7			1	3	5		2	18	12
Icriodus postwoschmidti	Pa									1?			1	
Oulodus cristagalli	Pb									2				
Oulodus sp.										5			3	
Ancyrodelloides? sp.	Pa													1
Indet. ramiforms		1	8	124	32	1	1		1		3		4	
Total		1469	921	1199	259	17	44	46	129	497	27	163	150	47

NOTE: Datum is base of road cut. See caption of Table 1 for further explanation. For sample 3, M elements have been divided between *Belodella anfracta* and *B.* cf. *B. resima* according to the relative proportions of S elements present.

the Silurian–Devonian boundary in Europe. There is, however, a thin interval of uncertainty between the cited Henryhouse and Haragan conodont faunas occupied by an undiagnostic fauna with the long-ranging subspecies, *Ozarkodina remscheidensis remscheidensis*. This interval mainly involves uppermost Henryhouse strata, but a very minor interval of the lowermost Haragan is also included. Of course, one could infer that this zonally indeterminate fauna represents the missing *woschmidti* Zone, but there is no positive evidence for such a view.

SYSTEMATIC PALEONTOLOGY

Class Cavidonti Sweet, 1988

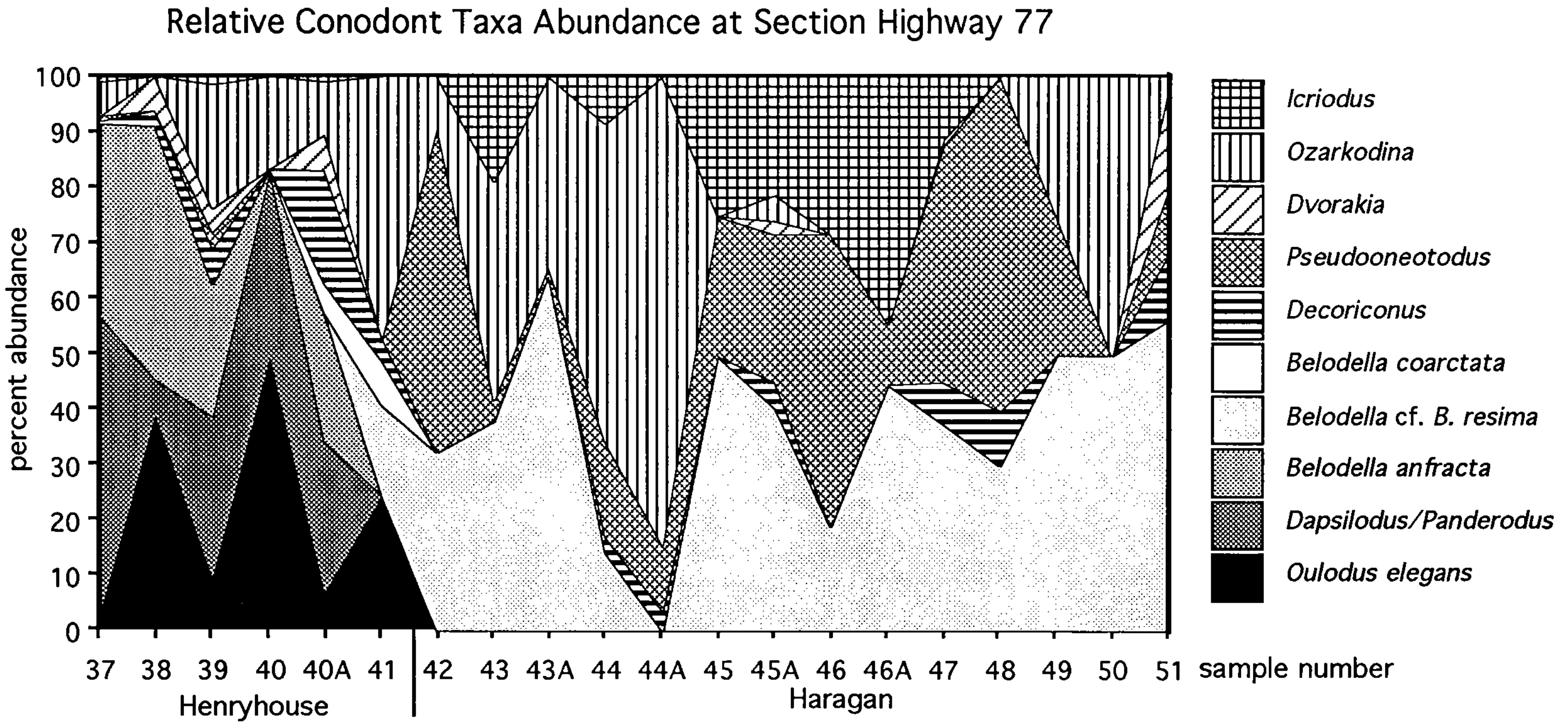
Order Belodellida Sweet, 1988

Family Belodellidae Khodalevich and Chernikh, 1973

Genus **Belodella** Ethington, 1959

Belodella ETHINGTON, 1959, p. 271–272.

Haplobelodella KHODALEVICH AND CHERNIKH, 1973, p. 43–44.



Text-figure 12. Relative abundance of conodont taxa across the Henryhouse/Haragan boundary at section Highway 77. See Text-figure 5 and Table 3 for correct stratigraphic intervals of samples.

TABLE 3. — DISTRIBUTION OF CONODONT ELEMENTS AT SECTION HIGHWAY 77

SECTION HIGHWAY 77		Henryhouse						Haragan													
SAMPLE		37	38	39	40	40A	41	42	43	43A	44	44A	45	45A	46	46A	47	48	49	50	51
Base (m)		16.95	18.60	22.20	23.80	25.15	26.35	27.85	28.90	29.15	29.50	30.40	31.60	32.90	34.15	35.20	37.10	39.15	41.20	43.10	45.30
Top (m)		17.15	18.80	22.40	23.95	25.30	26.50	27.95	29.05	29.30	29.90	30.60	31.80	33.30	34.35	35.35	37.25	39.25	41.30	43.20	45.50
Weight (kg)		4.00	1.98	4.09	1.90	1.99	2.00	2.00	3.05	1.89	2.00	2.00	2.00	2.00	4.00	1.99	5.27	1.98	2.00	2.00	1.85
Dapsilodus sp.		56	2	18		9															
Panderodus sp.		6		3	2	23															
Belodella	M	11	2			2	4?														
anfracta	S	29	13	17		27	8?														
Belodella coarctata	S					6															
Belodella	M							3	2	7				4	1	1	9			1	3
cf. *B. resima*	S							19	18	29	5		2	13	3	3	27	3	2		6
Dvorakia amsdeni	S		2	3		6															
Dvorakia philipi ?	S													1			1				3
Decoriconus fragilis		1	1	5		24	2				1	1		2			8	1			2
Pseudooneotodus beckmanni		1		2				27	2	1	6	3	1	11	11	1	46	6	1		2
Ozarkodina	Pa	4		8		1	15	2	10	15	8	1		1					1	1	
remscheidensis	Pb	3		3			2	1	6	2	1									1	
remscheidensis	M									1	3										
	S					1	6	3	5	2	10			1							
Ozarkodina	Pa					1															
excavata	Pb			2		1															
excavata	M																				
	S			3		7															
Oulodus	Pa			1		1															
elegans	Pb		1		1		1														
detorta	M	1	2		1		4														
	S	3	10	2	2	7	7														
Icriodus	Pa								2	1				3							
postwoschmidti	Pb									1					1						
	M									1					1						
	S													1		3					
Icriodus eolatericrescens	Pa																6				
	Pb																1				
	M																2				
	S																1				
Icriodus sp. indet	Pa	1		1					3				1	4	3	5	2				
Pedavis biexoramus	Pa														1						
Pelekygnathus sp.	Pa					1															
Oulodus sp.				3		4															
Indet. ramiforms		1		12		4	4				3							1			5
Total		117	33	83	6	125	53	55	48	60	37	5	4	41	21	13	103	11	4	3	21

NOTE: Datum is base of Henryhouse Formation. See caption of Table 1 for further explanation.

Type species.—*Belodus devonicus* Stauffer, 1940.

Remarks.—Klapper and Barrick (1983) gave a multielement diagnosis for the genus *Belodella*, based on attributes of species inferred to be congeneric with the type species, *B. devonica* (Stauffer, 1940), the apparatus of which remains unconstructed. Their concept of the apparatus included a symmetry-transition series (Sa, Sb, Sc, and Sd elements), the posterior margin of each of which is set with numerous fine, closely spaced to fused denticles. Another element, the M? element, is undenticulated. The presence of an apparatus of this nature in *Belodella* species has been confirmed by other workers (e.g., Kozur, 1984; Jeppsson, 1989; Uyeno, 1990), but Ramovš (1989,1990) has described three Early Devonian species that apparently lack an undenticulated element.

Jeppsson (1989) recently discussed the *Belodella* apparatus and proposed several new elemental designations. The undenticulated element of *Belodella* has been interpreted to be homologous with the falciform element (Sweet, 1979) of *Panderodus*, *Belodina*, and related genera. Jeppsson (1989) proposed the symbol "f" to designate the falciform element. Jeppsson (1989) also identified a series of short, denticulated elements with more broadly expanded bases (u element and a elements), in addition to the symmetry transition series of slender elements (d elements). Examples illustrated by Jeppsson (1989) and specimens in our collections do not show any significant differences in morphology between elements of the two groups except for overall shape. We interpret the two series to represent variation within the symmetry-transition series and prefer to treat them just as long slender and short broad forms of the Sa, Sb, and Sc elements.

Besides the typical broad forms of the symmetry-transition series, another short, strongly asymmetrical, denticulated element occurs in our collections, which is characterized by a broadly expanded base and a distinctively recurved cusp. This element may be homologous with the "tortiform" element recognized in the apparatus of *Panderodus* (Sweet, 1979). An extremely rare, short, perfectly symmetrical element that is related to the tortiform element is present in *Panderodus* (Jeppsson, 1983; Sweet, 1988) and may also occur in *Belodella* (?tr element of Jeppsson, 1989).

In this paper, the symbols Sa, Sb, Sc, and Sd are used to denote the symmetry-transition series of intergrading denticulated elements. Numbered symbols (e.g., Sb1, Sb2) indicate different forms that may have occupied much the same position in the apparatus. Despite questions about how the symmetry-transition series of coniform apparatuses is related to that of ramiform apparatuses (Armstrong, 1990), the S notation clearly designates regular changes in element symmetry governed by position in the apparatus. The strongly asymmetrical, recurved "tortiform" element is not assigned a position, pending better understanding of its relationship to other S elements. We continue to designate the falciform element as the M element, as did Sweet (1988).

Belodella cf. **B. resima** (Philip, 1965)

Pl. 1, Figs. 1–3,7,14–17

Belodella sp. Uyeno, 1981, p. 48, pl. 10, figs. 13,15.

Belodella cf. *B. resima* (Philip). Uyeno, 1990, p. 74, pl. 16, figs. 18–22,25.

Diagnosis.—Sc element has a strongly compressed lenticular cross section, a single anterolateral costa, and curves smoothly inward from base to tip.

Description.—M element. The unit is indistinguishable from most typical M elements of *Belodella* species.

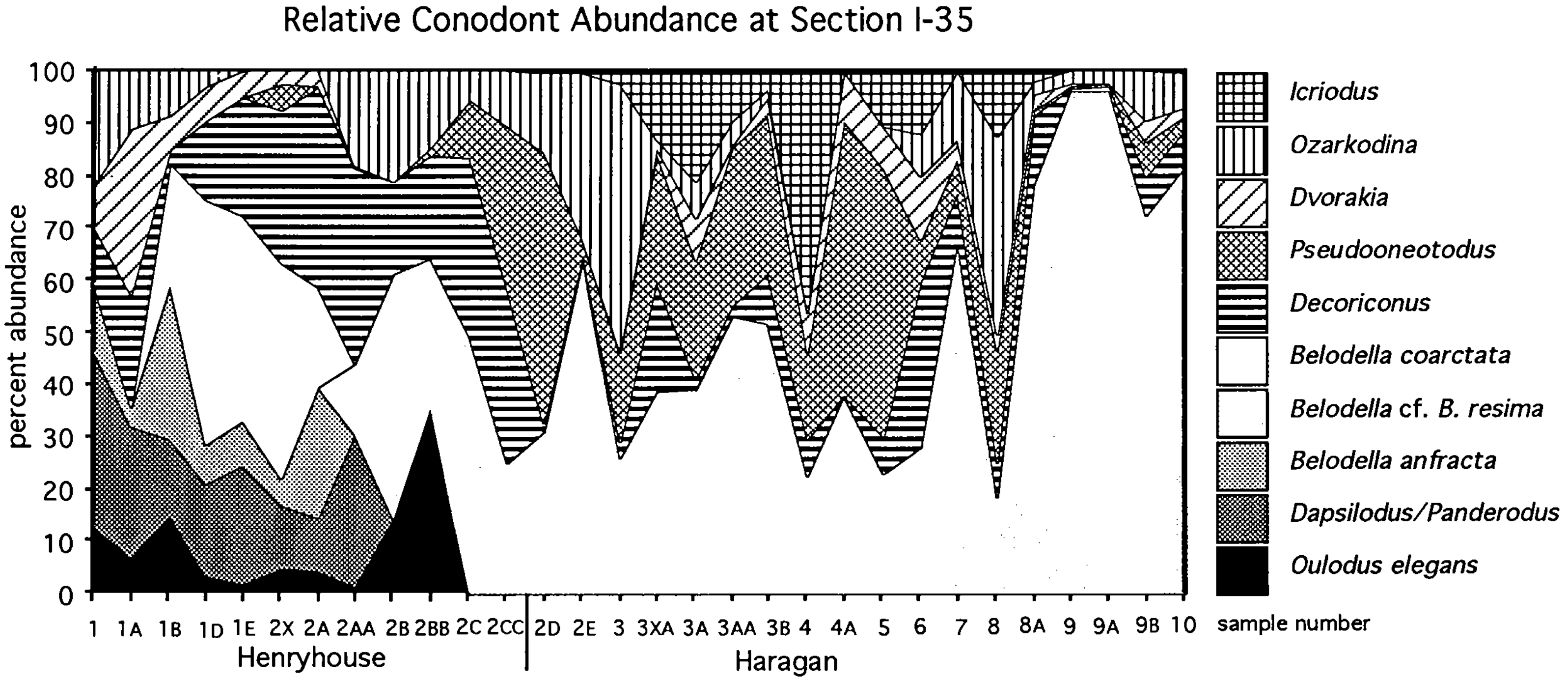
Sa element. Untwisted unit is nearly straight and possesses a compressed, symmetrical triangular cross section with laterally directed costae. Numerous fine, compressed denticles, fused at the base, extend the entire length of the posterior edge onto the base of the cusp. Slender forms have a weak, evenly proclined cusp and a length to width ratio of about 4 to 1. Broad forms have a more robust proclined cusp, more conspicuous anterolateral costae, a less compressed cross section, and a length to width ratio of 3 to 1.

Sb element. The Sb element is like the Sa element in most respects, except that the cusp is curved and twisted noticeably inward. Specimens lacking the distal portion of the unit cannot be distinguished from Sa elements.

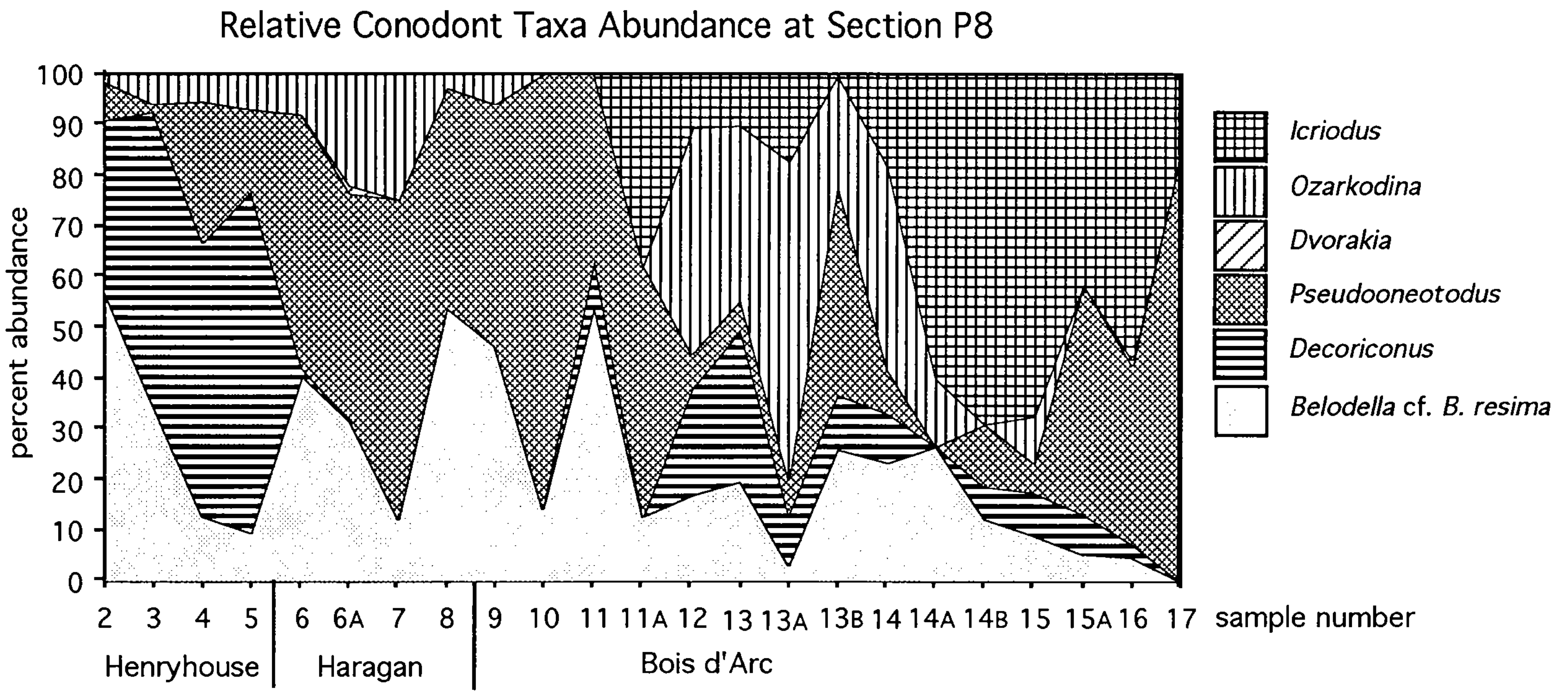
Sc element. The Sc element has a compressed, asymmetrically lenticular cross section and curves smoothly inward along its entire length, with little twisting of the cusp. The anterior margin bears a narrow costa that is usually laterally directed, but may extend in a more anterior direction in some specimens. Both slender and broad forms occur.

Tortiform element. This element is slightly shorter and smaller than the broad S elements and has a characteristic strongly asymmetrical cross section. The anterior face is almost equal in width to the outer lateral face, to which it joins at a slightly oblique angle. A weak costa marks the junction of the two faces, and in some small specimens the costa is absent. The inner face is significantly wider than either the outer or anterior face, both of which it joins at an acute angle. A well-developed, laterally directed costa lies along the anterior margin; the posterior margin bears numerous fine denticles like the S elements that extend up to, but apparently not onto the base of the cusp. The round robust cusp is erect to slightly recurved.

Remarks.—Although the apparatus of *Belodella resima* (Philip, 1965) has not been confidently reconstructed, sufficient information is available to effect some comparisons. The symmetry-transition series



Text-figure 13. Relative abundance of conodont taxa across the Henryhouse/Haragan boundary at section I-35. See Text-figure 3 and Table 1 for correct stratigraphic intervals of samples.



Text-figure 14. Relative abundance of conodont taxa across Henryhouse/Haragan boundary and into lower Bois d'Arc Formation at section P8. See Text-figure 7 and Table 4 for correct stratigraphic intervals of samples.

TABLE 4. — DISTRIBUTION OF CONODONT ELEMENTS AT SECTION P8

SECTION P8		Henryhouse				Haragan				Bois d'Arc-Cravatt				Fittstown										
Sample		2	3	4	5	6	6A	7	8	9	10	11	11A	12	13	13A	13B	14	14A	14B	15	15A	16	17
Base (m)		0.00	0.55	1.00	1.45	2.10	2.55	2.70	3.00	3.35	4.20	5.45	6.55	7.20	8.10	8.60	9.60	10.70	11.30	12.00	12.40	13.30	13.70	14.70
Top (m)		0.10	0.65	1.20	1.65	2.30	2.70	2.85	3.10	3.50	4.30	5.65	6.65	7.40	8.30	8.70	9.70	10.80	11.40	12.10	12.50	13.40	13.90	14.80
Weight (kg)		2.00	1.88	1.90	1.75	1.80	1.80	1.85	3.71	1.93	2.00	2.00	2.00	2.00	1.90	2.00	1.85	2.00	2.00	2.00	4.00	2.00	3.90	2.00
Belodella cf.	M	50	4	20	2	7	2		9	13		1		1	2		1	1	1	2				
B. resima	S	201	33	54	8	19	14	4	52	19	1	5	1	9	12	1	4	16	3		7	2	4	
Dvorakia philipi ?	S						1																1	
Decoriconus fragilis		146	61	316	71	1						1		12	21	3	2	7		1	7	3	2	
Pseudooneotodus beckmanni		33	2	161	17	32	23	21	49	42	6	4	4	4	4	2	8	6		2	5	17	32	66
Ozarkodina	Pa	3	3	7	4	3	3	6	2	2				15	12	12	2	4	1		4			
remscheidensis	Pb	2		8			4			1				2	5	3	1	7	1		3			
remscheidensis	M			6				1							1		1	1						
	S	2	3	9	3	2	4	1	1	1				9	6	3		17						
Icriodus	Pa													2				3	1	3	11	1	41	4
postwoschmidti	Pb												1	3	2	2		2	3	6	17	2	2	4
	M														2			4	3	2	15	4	3	3
	S												2	1	3	3		2	2		7	5	2	
I. eolatericrescens	Pa																	1						
Icriodus sp indet.	Pa																	1			3	3		
Oulodus cristagalli	Pb																				1			
Total		437	106	581	105	64	51	33	113	78	7	11	8	58	70	29	19	72	15	16	80	37	87	77

NOTE: Datum is base of natural exposure near bed of stream. Indeterminate Pb, M, and S elements of *Icriodus* arbitrarily tabulated under *I. postwoschmidti*, but noted separately in Systematic Paleontology. See caption of Table 1 for further explanation.

apparently consists only of a group of compressed triangular elements like the Sa and Sb elements described here (Philip, 1965, pl. 8, figs. 15–17,19). No lenticular Sc element was described by Philip, nor was any present in topotype material examined by Jeppsson (1989, p. 23). Excellent examples of tortiform elements were illustrated as *Belodus triangularis* (Philip, 1965, pl. 8, figs. 22,26–28). Two of the three specimens of *Paltodus valgus* Philip (pl. 8, figs. 7,8; excluding the holotype, fig. 12), appear to be M elements (Jeppsson, 1989).

Belodella cf. *B. resima*, as reconstructed here, possesses a lenticular Sc element that is absent in *B. resima*. Also, the tortiform element of *B. resima* appears to be broader and to have more prominent costae than that of *B.* cf. *B. resima*. The younger species, *B. resima* (*sulcatus* Zone), may represent a case where an element with a triangular cross section has assumed the Sc position, as was suggested by Jeppsson (1989).

Range.—Uppermost Henryhouse into the Bois d'Arc Formations (?latest Pridolian–Lochkovian).

Material studied.—1,225 M elements (may include some M elements of *Dvorakia* species); 7,035 S elements.

Belodella anfracta Barrick and Klapper, new species
Pl. 1, Figs. 4–6,8–12,18

Derivation of name.—*anfracta* (Lat.) = winding, crooked.

Holotype.—Henryhouse Formation, section PR, sample 2; Pl. 1, Fig. 6; SUI 64712.

Diagnosis.—Sc element has a teardrop-shaped cross section and a winding posterior margin characterized by a major medial curve protruding into the inner side followed by a tight curve to the outer side before joining to the base of the cusp.

Description.—M element. Indistinguishable from the M element of most *Belodella* species.

Sa element. Slender and broad forms are identical with the Sa elements of *Belodella* cf. *B. resima* described above.

Sb element. The slender cusp of the Sb element curves gently inward and is moderately proclined. The degree of curvature varies from elements that are close in shape to the Sa element to ones that are strongly curved. In the latter forms, the triangular cross section is noticeably asymmetrical and the weak outer anterolateral costa lies about midway between the posterior edge and the inner anterolateral costa.

Sc element. The Sc element has a moderately compressed teardrop-shaped cross section in both slender and broad forms. The posterior margin curves gently inward at one-third of the element length, then outward at two-thirds of the length, before bending sharply inward to join with the inwardly curved slender cusp. Like the other S elements, the posterior margin bears numerous fine denticles that extend onto the base of the cusp.

Tortiform element. Unit is distinctly shorter and wider at the base than short forms of S elements. It has a strongly asymmetrically triangular cross section like the tortiform element of *B.* cf. *B. resima*. The round cusp is strongly recurved and lacks denticles at its base. Two types of tortiform elements can be recognized. One form possesses a strong outer anterolateral costa. The other form lacks the costa completely and the anterolateral margin consists of a sharply rounded corner.

Remarks.—The sigmoidal deflection of the posterior margin of the Sc element distinguishes *Belodella anfracta* from the closely related species *B.* cf. *B. resima*. Although at first glance the curvature of the Sc element appears to represent postmortem deformation, it is present in every Sc element examined, numbering more than a hundred examples. The degree of curvature varies from being barely noticeable in small slender Sc elements to strongly deflected in broad elements, in which almost the entire element is involved in the curvature. Minor differences between the Sb and tortiform elements of *B. anfracta* and *B.* cf. *B. resima* occur, but are not as reliable in separating the two species. The Wenlockian species, *B. silurica* Barrick, 1977, lacks the tortiform element found in *B. anfracta*, but the Sc element may show some slight sigmoidal curvature.

Jeppsson (1989) described elements of *Belodella* sp. S from latest Pridolian beds at Klonk, Czechoslovakia, the Devonian boundary stratotype. The elements illustrated (pl. 1, figs. 8–14; figs. 6,7 are probably *Decoriconus* elements) are similar to those of *B. anfracta*, but it is not possible to tell if the Sc (doc) element of *B.* sp. S is like that of *B. anfracta*.

Range.—Upper Henryhouse Formation (Pridolian; Upper Silurian).

Material studied.—152 M elements (may include some M elements of *Dvorakia* species); 905 S elements.

Belodella coarctata Barrick and Klapper, new species
Pl. 2, Figs. 3,4,8,9,12–14

Belodella mira Khodalevich and Chernikh, 1973. JEPPSSON, 1989, p. 24–25, pl. 1, figs. 1–5.

Derivation of name.—*coarctata* (Lat.) = pressed together.

Holotype.—Henryhouse Formation, section PR, sample 2, Pl. 2, Fig. 8; SUI 64732.

Diagnosis.—M element compressed, with a short base and long slender cusp. S and tortiform elements very strongly compressed to flat, bearing numerous fine denticles on posterior edge.

Remarks.—Jeppsson (1989) described and illustrated the elements of *Belodella coarctata* including the diagnostic M element. The element that Jeppsson assigned to the "u" position is interpreted to be the tortiform element. This element differs from the S elements by its short broad shape, the presence of an outer anterolateral costa that does not lie on the anterior margin, and a curved flange-like inner anterolateral costa. As in other species of *Belodella*, both slender and broad forms of S elements occur in our collections.

Jeppsson (1989) assigned the present species to *Belodella mira* Khodalevich and Chernikh, 1973, a Middle Devonian form, because of the compressed nature of the S elements. However, the diagnostic M and distinctive tortiform elements of this Late Silurian species are not known from Devonian strata. *Belodella coarctata* has an extremely short range in the upper beds of the Henryhouse, where it is relatively abundant. At Klonk (Jeppsson, 1988), *B. coarctata* displays a similar peak in abundance below its highest occurrence just below the base of the Devonian.

Range.—A short interval in the upper Henryhouse Formation (Pridolian, Upper Silurian).

Material studied.—150 M elements; 2,490 S elements.

Belodella? paucidentata Moskalenko and Chegodaev, 1988?
Pl. 1, Fig. 13

?*Belodella paucidentata* Moskalenko and Chegodaev, 1988, p. 137–138, pl. 18, figs. 12–18.

Remarks.—A few specimens of a thin-walled element with sparse, widely spaced, peg-like denticles on the posterior margin were recovered from the Fittstown Member of the Bois d'Arc Formation. Too few specimens were recovered from our collections to make a confident assignment to a previously described species. Elements described and illustrated by Moskalenko and Chegodaev (1988) as *Belodella paucidentata* resemble our material most closely. Our material and elements of *B. paucidentata* are more like elements of Early Devonian *Dvorakia* species than those of finely denticulated *Belodella* species. We are uncertain whether Devonian coniform elements with widely spaced posterior denticles (e.g., *B. erecta* [Rhodes and Dineley], *B. asiatica* [Moskalenko], *B. subtriangularis* [Moskalenko]) are related to *Belodella*, or instead represent a separate lineage of denticulated elements derived from a *Dvorakia*-like ancestor.

Range.—Fittstown Member, Bois d'Arc Formation (Lochkovian, Lower Devonian).

Material studied.—4 S elements.

Genus **Dvorakia** Klapper and Barrick, 1983

Dvorakia Klapper and Barrick, 1983, p. 1226–1227.

Type species.—*Dvorakia chattertoni* Klapper and Barrick, 1983.

Remarks.—Klapper and Barrick (1983) erected the genus *Dvorakia* to include high, thin-walled, undenticulated coniform elements with deep basal cavities. The symmetry-transition series of Middle Devonian species consists of a biconvex Sd element, an asymmetrically rounded to subtriangular Sb element, and a strongly asymmetrical, more compressed Sc element. The M element is an erect coniform element like that of *Belodella* species. Although the Late Silurian and Early Devonian species described here possess a somewhat different apparatus, they are still included in *Dvorakia*.

Dvorakia amsdeni Barrick and Klapper, new species
Pl. 2, Figs. 11,15–19

Derivation of name.—In honor of Thomas W. Amsden, in recognition of his monumental contributions to Hunton stratigraphy and paleontology.

Holotype.—Henryhouse Formation, section P1, sample A28; Pl. 2, Fig. 15; SUI 64739.

Diagnosis.—Elements possess unornamented surfaces and a broad, flange-like anterior keel or inner anterolateral costa.

Description.—Sd element. Unit has a symmetrically compressed biconvex cross section. Base is wide and narrows smoothly to a broad, biconvex, proclined cusp. Broad anterior keel merges smoothly with one lateral side (outer); a distinct indentation separates the keel from the inner lateral side. Posterior edge bears a slight to moderate keel. The Sd element varies from tall slender forms to shorter, wider forms with extremely broad keels and a more erect cusp.

Sb1 element. The Sb1 element is similar to the Sd element in overall shape. The unit has a slightly asymmetrically biconvex cross section and the cusp is twisted slightly inward. A broad inner anterolateral costa is directed 30–45° away from the anterior-posterior plane. The outer lateral face is gently rounded and merges smoothly with the anterior surface of the inner costa.

Sb2 element. Unit has a relatively short base with an asymmetrically round to subtriangular cross section. The broad cusp is sharply recurved to lie at a right angle with the weakly keeled posterior margin and is strongly twisted inward. The inner anterolateral costa extends at a right angle from the anterior-posterior plane. The outer lateral side wraps around the anterior edge of the element to join smoothly with the anterior surface of the inner costa.

Sc element. Unit has a short broad base with a compressed, slightly asymmetrical cross section. Broad biconvex cusp is straight, proclined and longer than height of base. Anterior margin of element is a broad keel that is slightly deflected to the inner side. Posterior margin is weakly keeled.

?Tortiform element. Some elements otherwise identical to the Sb1 element possess a cusp that is distinctly twisted to the outer side. The outer side is defined as that side which blends smoothly with the anterior keel, or the lateral costa in forms lacking a keel. On the inner side is an indentation that separates the keel or costa from the lateral side.

Remarks.—The broad flange-like keel and inner anterolateral costa and unornamented surfaces distinguish *Dvorakia amsdeni* from other species of the genus. The round cross section of the base and position of the inner anterolateral costa of the Sb2 element is like that of the Sb element in Middle Devonian species (e.g., *D. chattertoni* Klapper and Barrick, 1983, figs. 8M,Q,S). The Sb1 element represents a morphology transitional between the Sd and Sb2 positions. The M element of *D. amsdeni* could not be identified and may be identical with the M element of *Belodella anfracta*.

Range.—Upper Henryhouse Formation (Pridolian, Upper Silurian).

Material studied.—425 S elements (M elements may be included under *Belodella* species).

Dvorakia philipi (Drygant, 1974)?
Pl. 2, Figs. 6,7,10

?*Paltodus philipi* DRYGANT, 1974, p. 68, pl. 1, figs. 26–28; DRYGANT, 1984, p. 73–74, pl. 1, figs. 27,28.
?*Paltodus nudus* DRYGANT, 1974, p. 68, pl. 1, figs. 21,29; DRYGANT, 1984, p. 74, pl. 1, figs. 34,35.

Diagnosis.—Elements possess an unornamented surface and a minute keel or inner anterolateral costa. Sb1 element is subtriangular in cross section; Sb2 element has a hook-like curvature of distal part and cusp.

Description.—Sd element. Tall slender unit has a symmetrically biconvex cross section. Element tapers evenly from base to small gently proclined cusp. Anterior keel is narrow, blending smoothly with the outer side, and set off from the inner side by a slight indentation. Posterior margin is weakly keeled.

Sb1 element. The Sb1 element is similar to the Sd element in overall shape. The unit has a slightly asymmetrically subtriangular cross section and the cusp is weakly twisted inward. A narrow flat face forms the anterior margin of the element. The junction of the inner face with the anterior face is a small laterally directed costa. The junction of the outer face with the anterior face is a sharp corner that may be smoothly rounded, or forms a sharp right-angle, especially near the base.

Sb2 element. Unit is shorter and has a broader, more rounded cross section than the Sb1 element. The small anterolateral costa separates the anterior face from the inner side, but the junction of the anterior face with the outer lateral side is always smoothly rounded. Posterior margin lacks a keel. Distal part of element and small cusp are round in cross section and curved posteriorly in a hook-like arc. The cusp may lie in the plane of the element, or be twisted to either the inner or outer sides.

Remarks.—The small keel and anterolateral costa distinguish even fragments of *Dvorakia philipi*? from elements of *D. amsdeni*. The distinctive hook-shaped Sb2 element also does not occur in *D. amsdeni*. The types of *Paltodus philipi* Drygant, 1974, and its probable synonym, *P. nudus*, closely resemble our material in morphology and age, but we lack sufficient information about Drygant's material to make a confident species assignment.

The complete apparatus of *D. philipi*? is poorly known due to the scarcity of unbroken elements in our small collections. No Sc or M elements could be clearly identified. The unusual subtriangular cross section of the Sb1 element may represent the reappearance of a *Walliserodus*-like Sa element with a triangular cross section in the apparatus.

Range.—Uppermost Henryhouse, Haragan, and lower Bois d'Arc Formations.

Material studied.—112 S elements (M elements may be included under *Belodella* species).

Dvorakia sp.
Pl. 2, Fig. 1

Remarks.—A few fragmentary *Dvorakia* elements from the upper part of the Bois d'Arc Formation differ from those assigned to *D. philipi*?. The most distinctive feature of the Bois d'Arc species is the presence of an element with a triangular cross section and well-developed anterolateral costae on both the inner and outer lateral sides (an Sa element ?).

Material studied.—28 S elements.

Family Dapsilodontidae Sweet, 1988
Genus **Dapsilodus** Cooper, 1975
Dapsilodus sp.
Pl. 2, Fig. 2

Remarks.—The S elements of *Dapsilodus* that occur in the upper Henryhouse possess a distinctive shape which differs from that of previously recognized species. The overall shape of the base resembles that of *D. obliquicostatus* (Branson and Mehl, 1933a), but the cusp-to-base proportion is more like that of *D. praecipuus* Barrick, 1977.

Material studied.—505 elements.

Class Conodonti Branson, 1938
Order Panderodontida Sweet, 1988
Family Panderodontidae Lindström, 1970
Genus **Panderodus** Ethington, 1959
Panderodus sp.

Remarks.—Elements assigned to *Panderodus* sp. are like those forms usually referred to *P. unicostatus* (Branson and Mehl, 1933a) or *P. equicostatus* (Rhodes, 1953) (see Jeppsson, 1983).

Material studied.—335 elements.

Order Prioniodontida Dzik, 1976
Family Icriodellidae Sweet, 1988

Remarks.—Sweet (1988, p. 65) separated the Icriodellidae from the Icriodontidae, although the apparatuses of *Icriodella* and *Pedavis* are quite comparable especially in terms of the Pa, Pb, and M elements to that of the early species of *Icriodus* s.l., *I. woschmidti* and *I. postwoschmidti* (compare Sweet, 1988, figs. 5.18 and 5.20). The apparatuses of *Pelekysgnathus* and the later species of *Icriodus* are different from those of the Icriodellidae, however, perhaps justifying Sweet's separation. For the purposes of the present paper, Sweet's (1988) classification is followed throughout.

Genus **Pedavis** Klapper and Philip, 1971

Pedavis Klapper and Philip, 1971, p. 446–447.

Type species.—*Icriodus pesavis* Bischoff and Sannemann, 1958.

Pedavis biexoramus Murphy and Matti, 1983
Pl. 3, Figs. 1–3

Pedavis sp. nov. C Klapper and Murphy, 1975, p. 50, pl. 12, fig. 12; Klapper and Johnson, 1980, p. 451.

Pedavis sp. Lane and Ormiston, 1979, p. 60, pl. 1, fig. 14.

Pedavis cf. *biexoramus* Murphy and Matti [nomen nudum]. Schönlaub, 1980a, p. 28, pl. 1, fig. 14.

Pedavis biexoramus Murphy and Matti, 1983, p. 51–54, pl. 5, figs. 28,33; Schönlaub, 1985, p. 26, text-fig. 17-5.

Pedavis n. sp. E Broadhead and McComb, 1983, p. 153, text-fig. 3A,B,E–G.

Remarks.—*Pedavis biexoramus* is restricted to the *eurekaensis* Zone in Nevada (Klapper and Murphy, 1975, p. 20; Murphy and Matti, 1983, table 1) and in east-central Alaska (Lane and Ormiston, 1979, table 2, loc. 2, sample 17). Specimens identical to those illustrated here from Oklahoma occur in the Rockhouse Limestone of Tennessee (Broadhead and McComb, 1983). Schönlaub (1980a) illustrated a partly broken specimen, which however shows the diagnostic characteristics of the species, from lower but not lowermost Lochkovian strata in the Carnic Alps, Austria. *Pedavis biexoramus* occurs at a position near the top of the range of *Icriodus postwoschmidti* in strata within the *Monograptus uniformis* Zone of the Lochkovian Stage in the Barrandian area of Czechoslovakia (Schönlaub, 1985).

Range.—Lower part of Haragan Formation.

Material studied.—10 Pa elements at section I-35 (samples 3AA, 3B, 4); 1 Pa element at section Highway 77 (sample 46).

Family Icriodontidae Müller and Müller, 1957
Genus **Icriodus** Branson and Mehl, 1938

Icriodus Branson and Mehl, 1938, p. 159.
Acodina Stauffer, 1940, p. 418.
Latericriodus Müller, 1962, p. 114.
Caudicriodus Bultynck, 1976, p. 19.
Praelatericriodus Bultynck, 1976, p. 40.

Type species.—*Icriodus expansus* Branson and Mehl, 1938.

Icriodus postwoschmidti Mashkova, 1968
Pl. 3, Figs. 7–12

Icriodus woschmidti postwoschmidti Mashkova, 1968, p. 943–944, pl. 1, figs. 1–3; Olivieri and Serpagli, 1990, p. 63, pl. 1, figs. 15,16.

Icriodus woschmidti Ziegler. Drygant, 1968, p. 46–47, pl. 1, figs. 1–4.

Icriodus woschmidti transiens Carls and Gandl, 1969, p. 174–175, pl. 15, fig. 7 (not figs. 1–6; see Remarks under *I. eolatericrescens*); Mashkova, 1970, pl. 1, figs. 7–9.

Icriodus postwoschmidti Mashkova. Mashkova, 1971, p. 163, pl. 3, figs. 1,8,9; Schönlaub, 1980b, p. 159, pl. 19, figs. 2,3; Drygant, 1984, p. 135–136, pl. 16, figs. 20–26; Schönlaub, 1985, p. 26, text-fig. 17-4; Moskalenko and Chegodaev, 1988, p. 143–144, pl. 21, figs. 13–15.

Icriodus serus Drygant, 1984, p. 136, pl. 16, figs. 27–29.

Remarks.—A much wider basal cavity, a wider spindle, and a distinctly developed middle row of denticles distinguishes the Pa elements of *Icriodus postwoschmidti* from those of *I. woschmidti woschmidti* Ziegler. Although the width of the basal cavity is similar, the spindle is narrower and the middle denticle row is not as distinct in Pa elements of *I. woschmidti hesperius* Klapper and Murphy.

An S element (Pl. 3, Fig. 9) associated with Pa elements of *I. postwoschmidti* in Oklahoma is similar to those reconstructed in the apparatus of *I. woschmidti woschmidti* by Serpagli (1983, text-fig. 3M–R).

The Oklahoma specimens represent the first North American occurrence of *Icriodus postwoschmidti*. The species is known to have a range within the Lochkovian *Monograptus uniformis* Zone, but not in the lowest part of that zone, in the Barrandian area of Czechoslovakia (Schönlaub, 1980b, 1985).

Range.—Lower Haragan Formation to lower Fittstown Member, Bois d'Arc Formation.

Material studied.—41 Pa elements (section I-35), 1 Pa (section PR), 66 Pa (P8), 2 Pa (P1), 6 Pa (Highway 77), 8 Pa (Gulf No. 1 Dyer) (Amsden, 1975); 13 Pb elements (I-35; 18 indeterminate Pb elements arbitrarily tabulated under this species in Table 1), 35 Pb (P8; 9 indeterminate Pb elements, see caption for Table 4), 1 Pb (Highway 77, sample 43A; 1 indeterminate Pb element, see Table 3), 6 Pb (Gulf No. 1 Dyer); 7 M elements (I-35; 3 indeterminate M elements in sample 4, see Table 1), 26 M (P8, 10 indeterminate M elements, see caption for Table 4), 1 M (Highway 77, sample 43A; 1 indeterminate M, see Table 3); 1 S element (I-35; 10 indeterminate S elements, Table 1), 4 S (P8; 15 indeterminate S elements, Table 4); 1 S (Gulf No. 1 Dyer); 8 Sa elements (P8), 1 Sa (Highway 77, sample 45A; 4 indeterminate S elements, Table 3).

Icriodus eolatericrescens Mashkova
sensu Drygant, 1984
Pl. 3, Figs. 4–6

?*Icriodus eolatericrescens* MASHKOVA, 1968, p. 942–943, pl. 1, figs. 4–5.

?*Icriodus woschmidti transiens* CARLS AND GANDL, 1969, p. 174–175, pl. 15, figs. 1–6 (not fig. 7 = *I. postwoschmidti*); DRYGANT, 1984, p. 134–135, pl. 16, figs. 5–16.

Caudicriodus postwoschmidti Mashkova. BULTYNCK, 1976, p. 26–28, pl. 6, figs. 1,2.

Icriodus woschmidti Ziegler. BROADHEAD AND MCCOMB, 1983, p. 153, text-fig. 3C (Sc element), H–J (Pa elements).

Icriodus eolatericrescens Mashkova. DRYGANT, 1984, p. 135, pl. 16, figs. 17–19.

Remarks.—A somewhat narrower basal cavity and a narrower spindle distinguish Pa elements of *Icriodus eolatericrescens* Mashkova sensu Drygant from those of *I. postwoschmidti*; the development of the middle denticle row is comparable in the two, however. Specimens illustrated by Bultynck (1976) and Broadhead and McComb (1983) match Drygant's usage of *I. eolatericrescens*. Broadhead and McComb (1983, text-fig. 3C) illustrated an Sc element from the same locality of the Rockhouse Limestone as the Pa element, but the specimen in their text-fig. 3D may be an element of *Pedavis biexoramus*.

Whether the specimens illustrated by Drygant (1984) from the Chortkov Formation in Podolia are the same as the types of *I. eolatericrescens*, also from the Chortkov (Mashkova, 1968), can only be answered by a restudy of the type material. The majority of the types of *Icriodus woschmidti transiens* Carls and Gandl (1969, pl. 15, figs. 1–6), as well as most, if not all, of the specimens identified under this same designation by Drygant (1984, pl. 16, figs. 5–16), resemble the Pa elements of *I. eolatericrescens* sensu Drygant. As in the previous instance, their confident identification with this category can only be resolved by restudy of all of the relevant types.

Range.—Lower Haragan Formation to lower Fittstown Member, Bois d'Arc Formation.

Material studied.—14 Pa elements (section I-35), 1 Pa (section P8), 6 Pa (section Highway 77); 4 Pb elements (section I-35), 1 Pb (section Highway 77); 2 M elements (section Highway 77); 1 S element (section I-35), 1 S (section Highway 77).

Genus **Pelekysgnathus** Thomas, 1949

Pelekysgnathus THOMAS, 1949, p. 424.
Drepanodina MOUND, 1968, p. 480.

Type species.—*Pelekysgnathus inclinatus* Thomas, 1949.

Pelekysgnathus sp.

Remarks.—A single Pa element in the Haragan collection P9, sample 22A, resembles *Pelekysgnathus index* Klapper and Murphy (1975) from the Pridolian of Nevada. The similarity is in the shape of the basal cavity, but the denticles are discreet and fewer in number (only six), as compared with the more highly fused denticles and more prominent cusp in the Nevada species. A second Pa element of *Pelekysgnathus* from Henryhouse collection Highway 77, sample 40A, resembles *P.* n. sp. B of Uyeno (1981, pl. 7, figs. 28–32) from the Sophia Lake Formation, Lochkovian of Cornwallis Island in the Canadian Arctic. The Oklahoma specimen is very small, however, and cannot be certainly identified with Uyeno's species. As the Oklahoma material of the genus is too rare to lend confidence either to a specific identification or to the establishment of new species, both specimens are held in open nomenclature.

Order Prioniodinida Sweet, 1988
Family Prioniodinidae Bassler, 1925
Genus **Oulodus** Branson and Mehl, 1933b

Oulodus BRANSON AND MEHL, 1933b, p. 116.

Type species.—*Cordylodus serratus* Stauffer, 1930, p. 124.

Remarks.—For reviews of the generic synonymy and the synonymy of the type species, see Sweet and Schönlaub (1975, p. 45–46) and Mawson (1986, p. 45–46).

Oulodus elegans detorta (Walliser, 1964)

Pl. 4, Figs. 3–7

Lonchodina detorta WALLISER, 1964, p. 43, pl. 9, fig. 20, pl. 30, figs. 34,36.

Ligonodina elegans detorta Walliser. JEPPSSON, 1975, p. 21–22; JEPPSSON, 1988, p. 25, text-fig. 1; JEPPSSON, 1989, p. 26, pl. 3, figs. 1–4.

Oulodus elegans (Walliser). DENKLER AND HARRIS, 1988, p. B10, pl. 1, figs. U–AA.

Oulodus elegans detorta (Walliser). OLIVIERI AND SERPAGLI, 1990, p. 69, pl. 4, figs. 1–8.

Remarks.—Jeppsson (1975) first proposed the biostratigraphically useful distinction between *Oulodus elegans elegans* and *O. elegans detorta*, on the alternation of denticle size in the latter subspecies. As noted by Olivieri and Serpagli (1990, p. 69), this distinction is most easily seen in the Sc element, in which one to two small denticles occur in some of the spaces between the large denticles in *O. elegans detorta*. In contrast, the denticles are of uniform size in the Sc, as well as the other elements of the nominal subspecies (Pl. 4, Figs. 1,2).

The evidence of the Henryhouse collections supports the interpretation that the apparatus of *Oulodus elegans detorta* consisted of seven elements. That is, the element called *Lonchodina walliseri* Ziegler by Walliser (1964) is part of the apparatus (compare Jeppsson, 1975, p. 21). A review of different apparatus reconstructions of *Oulodus elegans* is given by Sparling (1981, p. 302–305). The "ortuform" element is listed here in the Pa position, with the "walliseriform" element in the Pb position, more or less following the homologies advanced by Sweet and Schönlaub (1975). The two elements, however, could just as well be reversed as indicated by Sparling (1981, table 7). The "detortiform" element is viewed here as part of the symmetry transition series occupying the Sd position (Nicoll, 1987); it is closely similar in morphology to the Sa element of the apparatus, differing primarily in its extreme asymmetry.

Range.—Upper part of Henryhouse Formation.

Material studied.—Total of 38 Pa elements, 32 Pb, 67 M, 183 Sc, 44 Sb, 41 Sa, and 34 Sd at sections I-35, PR, P1, Highway 77, and Ca2.

Oulodus cristagalli (Ziegler, 1960)

Lonchodina cristagalli ZIEGLER, 1960, p. 189–190, pl. 14, figs. 1,3,5.

Oulodus cristagalli Ziegler. DENKLER AND HARRIS, 1988, p. B9–B10, pl. 1, figs. I–T (see synonymy).

Remarks.—Two specimens in section PR, sample 9, match the Pb1 (cristagalliform) element and one specimen in section P8, sample 15, matches the Pb2 (walliseriform) element in the multielement reconstruction given by Denkler and Harris (1988, pl. 1, figs. K,L,M–O, respectively) and thus are identified as *Oulodus cristagalli*. Other elements of *Oulodus* in the same, or stratigraphically similar, collections differ considerably from the elements of *O. cristagalli*. For example, the lateral processes are much more strongly incurved and tightly arched, and the processes bear far fewer, more massive denticles in the Sb element in section I-35, samples 4 and 6. The Sc element of section I-35, sample 2E, and comparable collections has a much longer anterolateral process that is directed straight downward, as opposed to that of *O. cristagalli*. These and similar elements are identified as *Oulodus* sp. in the present study.

Range.—Haragan into lower Fittstown Member, Bois d'Arc Formation.

Material studied.—1 Pb element (section P8, sample 15); 2 Pb elements (section PR, sample 9).

Order Ozarkodinida Dzik, 1976
Family Spathognathodontidae Hass, 1959
Genus **Ancyrodelloides** Bischoff and Sannemann, 1958

Ancyrodelloides BISCHOFF AND SANNEMANN, 1958, p. 91.

Type species.—*Ancyrodelloides trigonicus* Bischoff and Sannemann, 1958.

Ancyrodelloides secus Barrick and Klapper, new species

Pl. 5, Figs. 6–9

Derivation of name.—*secus* (Lat.) = otherwise, different.

Holotype.—SUI 64775, the specimen illustrated on Pl. 5, Figs. 8,9.

Diagnosis.—Platform developed at midlength, high, pillarlike. Row of high nodes on outer platform forming a broad V-shaped pattern, open outward and are connected to blade by single node; on inner side, high row in form of shallow concave curve, open inward.

Description.—The blade is high, declining gradually and incurved posteriorly. Platform asymmetrical, outer side developed farther to the posterior. Denticles of blade high and relatively broad longitudinally; high nodes on outer and inner platform like those of blade. Basal cavity open under platform, inverted under posterior blade.

Remarks.—The Pa element of *Ancyrodelloides secus* differs from all established species of the genus (consult review in Murphy and Matti, 1983) in the character of the platform and pattern of high nodes on the platform. However, the blade is identical with that of some other species of the genus (e.g., *A. transitans*). A juvenile specimen of the new species has a strong resemblance to *A. transitans*, but already shows the beginnings of the characteristic platform development of *A.* secus.

A comparable though less well-developed platform than in *A. secus* occurs in a Nevada form cited as *Pandorinellina*? cf. *P.*? *boucoti* by Murphy and Matti (1983, p. 28–29, pl. 3, figs. 12–17). In the Nevada specimens, however, the blade anterior of the platform consists of a single high and broad denticle, distinctly offset to the right, among other differences.

Range.—Fittstown Member, Bois d'Arc Formation.

Material studied.—17 Pa elements from section P9, sample 34.

Ancyrodelloides transitans (Bischoff and Sannemann, 1958)

Pl. 4, Fig. 13; Pl. 5, Figs. 1–5

Spathognathodus transitans BISCHOFF AND SANNEMANN, 1958, p. 107–108, pl. 13, figs. 4,5,12,14; SERPAGLI AND OTHERS, 1978, p. 308, pl. 27, fig. 5.

Ozarkodina transitans (Bischoff and Sannemann). LANE AND ORMISTON, 1979, p. 58, pl. 1, fig. 41, pl. 2, figs. 4,5,8,9,12,13, pl. 3, fig. 21; MASTANDREA, 1985, p. 255, pl. 2, fig. 2, pl. 5, figs. 14,15,17–19.

Ancryodelloides [sic] *transitans* (Bischoff and Sannemann). MURPHY AND MATTI, 1983, p. 22, pl. 2, figs. 9–11, pl. 3, figs. 9,10.

Ancyrodelloides transitans (Bischoff and Sannemann). SCHÖNLAUB, 1985, p. 26, text-fig. 17-8; BARCA AND OTHERS, 1986, p. 306, pl. 31, fig. 6; MURPHY AND CEBECIOGLU, 1987, p. 592; MOSKALENKO AND CHEGODAEV, 1988, p. 135–136, pl. 17, figs. 9–15.

Remarks.—A thorough review of this well-known species and comparison with the closely related *Ancyrodelloides trigonicus* is given by Murphy and Matti (1983, p. 21–22). A morphometric analysis of these two and closely related species of *Ancyrodelloides* has been published by Murphy and Cebecioglu (1987). According to Schönlaub (1985), *A. transitans* has a range more or less coincident with the *Monograptus hercynicus* Zone of the upper Lochkovian in the Barrandian area of Czechoslovakia.

Range.—Upper part of Fittstown Member, Bois d'Arc Formation.

Material studied.—5 Pa elements, 1 Pb element at section P11.

Ancyrodelloides? sp.

Pl. 4, Figs. 10,11,14,15

Remarks.—Two specimens in the Oklahoma collections resemble certain species of *Ancyrodelloides*, e.g., *A. transitans* (Bischoff and Sannemann) and *A. limbacarinatus* Murphy and Matti, in the development of denticulation on the blade, but the shape of the small platform does not accord with any described species of the genus. The denticulation of the blade of the Oklahoma Pa elements is quite distinct from that seen in such characteristic species of *Ozarkodina* as *O. remscheidensis* (Ziegler) and *O. excavata* (Branson and Mehl). Consequently, they are referred to *Ancyrodelloides* with question.

Range.—Cravatt Member of Bois d'Arc Formation.

Material studied.—1 Pa element (section PR, sample 12); 1 Pa element (section J6, sample 11).

Genus **Ozarkodina** Branson and Mehl, 1933a

Ozarkodina BRANSON AND MEHL, 1933a, p. 51.

Type species.—*Hindeodella confluens* Branson and Mehl, 1933a.

Remarks.—For generic synonymies and synonymy of the type species, see Klapper and Murphy (1975, p. 29–30) and Klapper (in Clark and others, 1981, p. W165).

Ozarkodina remscheidensis eosteinhornensis (Walliser, 1964)

Pl. 6, Figs. 2–4

Spathognathodus steinhornensis eosteinhornensis WALLISER, 1964, p. 85–86, pl. 9, fig. 15, pl. 20, figs. 7, 8,12–16,19–25 (not figs. 9–11 = *O. snajdri* [Walliser]), text-fig. 9.

Ozarkodina remscheidensis eosteinhornensis (Walliser). KLAPPER AND MURPHY, 1975, p. 40–42, pl. 7, figs. 11–21,23,24; OLIVIERI AND SERPAGLI, 1990, p. 69–70, pl. 4, figs. 11–15; UYENO, 1990, p. 94–95, pl. 5, figs. 4,5.

Hindeodella steinhornensis eosteinhornensis (Walliser). JEPPSSON, 1975, p. 38.

Ozarkodina steinhornensis eosteinhornensis (Walliser) sensu Jeppsson 1975. JEPPSSON, 1989, p. 28, pl. 2, figs. 1–4 (Pa element), pl. 3, fig. 10 (Pb element).

Remarks.—Jeppsson (1975, p. 38, 1989) has advocated a restricted definition of this subspecies including only Pa elements that have the cusp and adjacent denticles highly fused into a ridge, causing the individual denticles to be indiscernible. Such a restricted concept includes material of Walliser (1964) from the type and closely adjacent strata at Cellon in the Carnic Alps, but excludes much of the range of variation originally ascribed to the subspecies. Walliser's broader concept of the variation of the Pa element has generally been followed in most of the subsequent literature and is followed here as well. The foregoing synonymy list necessarily cites only representative illustrations of the subspecies.

Range.—Lower Henryhouse Formation.

Material studied.—26 Pa elements, 8 Pb, 4 M, 7 Sc, 3 Sb, and 1 Sa at section P1 (samples A21 and A28).

Ozarkodina remscheidensis remscheidensis
(Ziegler, 1960)
Pl. 4, Figs. 8,9; Pl. 6, Figs. 1,5–16

Spathognathodus remscheidensis ZIEGLER, 1960, p. 194–196, pl. 13, figs. 1,2,4,5,7,8,10,14.
Ozarkodina steinhornensis remscheidensis (Ziegler). MASHKOVA, 1972, p. 83, pl. 2, figs. 19–24.
Ozarkodina remscheidensis remscheidensis (Ziegler). KLAPPER AND MURPHY, 1975, p. 41–43, pl. 7, figs. 22,25–30; MAWSON, 1986, p. 49, pl. 6, figs. 1–20; UYENO, 1990, p. 93–94, pl. 4, figs. 4–6, pl. 5, figs. 1–3,6–8,30–33,36,37, pl. 6, fig. 11, pl. 13, figs. 11,12,20, pl. 15, figs. 27,28,32–34, pl. 16, figs. 34–40, pl. 17, figs. 29–34.

Remarks.—The apparatus of *Ozarkodina remscheidensis remscheidensis* has been reconstructed by Mashkova (1972), Klapper and Murphy (1975), Mawson (1986), and Uyeno (1990), among others; a rather comprehensive synonymy of the subspecies can be found in Uyeno (1990).

The Pa element of *O. r. remscheidensis* is characterized by the irregular height of the denticles; that is the cusp, several denticles at the anterior end, as well as one at or near the posterior end of the blade, are higher than the rest. This contrasts with the Pa element of *O. r. eosteinhornensis* in which the denticles are of nearly uniform height. Specimens illustrated by Jeppsson (1989, pl. 2, figs. 6–11) have the denticles declining gradually in a curve from the high anterior end and thus do not conform to the Pa element of either subspecies.

Although the upper surface of the cavity of the Oklahoma specimens of *O. r. remscheidensis* is commonly smooth, some specimens (e.g., Pl. 6, Fig. 15) carry a single prominent node on the outer lobe. Also, the range of variation of the Oklahoma material extends to several large specimens in which there is a high degree of fusion of the denticles in the central part of the blade (e.g., Pl. 6, Fig. 11). Thus, such a feature is not limited to Pa elements of *O. r. eosteinhornensis* in the restricted sense of Jeppsson (1975, 1989).

Range.—Upper part of Henryhouse Formation to lower part of Fittstown Member, Bois d'Arc Formation.

Material studied.—Total of 661 Pa elements, 222 Pb, 60 M, 169 Sc, 116 Sb, and 46 Sa at sections I-35, PR, P8, P1, Highway 77, P9, J6, Ca2, and at Gulf No. 1 Dyer (Amsden, 1975).

Ozarkodina wurmi (Bischoff and Sannemann, 1958)
Pl. 4, Fig. 12

Spathognathodus wurmi BISCHOFF AND SANNEMANN, 1958, p. 108–109, pl. 14, figs. 4–10.
Spathognathodus inclinatus wurmi Bischoff and Sannemann. BULTYNCK, 1971, p. 5–6, pl. 2, figs. 1,2,10, 12,13.
Ozarkodina wurmi (Bischoff and Sannemann). SCHÖNLAUB, 1980a, p. 40, pl. 6, fig. 10; SCHÖNLAUB, 1980b, p. 159, pl. 19, fig. 17; MOSKALENKO AND CHEGODAEV, 1988, p. 157–158, pl. 23, figs. 22–26.

Remarks.—Although the Pa elements of *Ozarkodina wurmi* and *O. excavata excavata* (Branson and Mehl) are closely similar, their apparatuses can be distinguished on differences in the Sb and Sa elements. The basal cavity of the Sa element of *O. wurmi* (illustrated by Bultynck, 1971, pl. 2, fig. 9) and the Sb element (Oklahoma collections) does not extend very high up the base of the cusp. This is in contrast to the high extent of the basal cavity in the same elements of *O. excavata excavata* (e.g., Klapper and Murphy, 1975, pl. 6, figs. 1,2,4 = Sb element, figs. 5,6 = Sa element; Mawson, 1986, pl. 4, figs. 17–20 = Sb element, figs. 10–16 = Sa element). This distinction in the two apparatuses was suggested earlier by Klapper and Murphy (1975, p. 36–37).

The Pa element of *Ozarkodina wurmi* is closely comparable to that of *O. tuma* Murphy and Matti (1983, p. 7–8), as each has a swelling on both sides of the blade above the basal cavity. The Pa element of *O. tuma*, however, characteristically lacks a prominent cusp and has lower anterior denticles in contrast with the same element of *O. wurmi*. The maximum number of denticles in the largest Oklahoma Pa element of *O. wurmi* (section J6, sample 11) is 17, which is below the range counted for Nevada collections of *O. tuma* (Murphy and Cebecioglu, 1986, text-fig. 2).

Range.—Cravatt Member, Bois d'Arc Formation.

Material studied.—22 Pa elements, 28 Pb, 14 M, 23 Sc, 23 Sb, and 13 Sa at section J6.

ACKNOWLEDGMENTS

Klapper's collecting of the Henryhouse–Haragan–Bois d'Arc conodont sequence began in the 1960s while he was at the Amoco Research Center in Tulsa; he was accompanied in the field by Allen R. Ormiston on several occasions. Collecting continued in the 1970s together with Barrick, who was then a graduate student at the University of Iowa and whose primary effort in Oklahoma was directed to the conodonts of the underlying Clarita Formation. Since joining Texas Tech University, Barrick's collecting continued into the 1980s. In the preparation of this paper, important photographic assistance was given by Ronald A. Metzger at the University of Iowa and Mark Grimson of the Scanning Electron Microscope Laboratory of the Department of Biological Sciences, Texas Tech University. We thank Anita G. Harris, Michael A. Murphy, and Nacho Valenzuela-Rios for thoughful reviews of the manuscript. Barrick wishes to thank the Donors of the Petroleum Research Fund, administered by the American Chemical Society (Grant 17283AC), for support of this research.

On many occasions throughout the years, we were guided in the field by Tom Amsden, who generously shared his immense knowledge of Hunton stratigraphy and paleontology with us. His research on the Hunton has been inspirational.

REFERENCES CITED

Amsden, T. W., 1951, Brachiopods of the Henryhouse Formation (Silurian) of Oklahoma: Journal of Paleontology, v. 25, p. 69–96.

______1958a, Haragan articulate brachiopods, *part 2 of* Amsden, T. W.; and Boucot, A. J., Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 11–144.

______1958b, Supplement to the Henryhouse brachiopods, *part 3 of* Amsden, T. W.; and Boucot, A. J., Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 145–157.

______1958c, Bois d'Arc articulate brachiopods, *part 5 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 82, 110 p.

______1960, Hunton stratigraphy, *part 4 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 84, 311 p.

______1962, Silurian and Early Devonian carbonate rocks of Oklahoma: American Association of Petroleum Geologists Bulletin, v. 46, p. 1502–1519.

______1963, Supplement to the Haragan (Devonian) brachiopods, *part 3 of* Amsden, T. W.; and Ventress, W. P. S., Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, p. 193–205.

______1975, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko basin of Oklahoma: Oklahoma Geological Survey Bulletin 121, 214 p.

______1981, Biostratigraphic and paleoenvironmental relations: a Late Silurian example, *in* Broadhead, T. W. (ed.), Lophophorates, notes for a short course organized by J. T. Dutro, Jr., and R. S. Boardman: University of Tennessee, Department of Geological Sciences, Studies in Geology 5, p. 154–169.

______1988, Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., *part 1 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, p. 1–53.

Armstrong, H. A., 1990, Conodonts from the Upper Ordovician–Lower Silurian carbonate platform of north Greenland: Gronlands Geologiske Undersogelse Bulletin 159, 151 p.

Barca, S.; Gnoli, M.; Olivieri, R.; and Serpagli, E., 1986, New stratigraphic data and evidence of Lower and Upper Devonian based on conodonts in Sarrabus area (southeastern Sardinia): Rivista Italiana di Paleontologia e Stratigrafia, v. 92, p. 299–320.

Barrick, J. E., 1977, Multielement simple-cone conodonts from the Clarita Formation (Silurian), Arbuckle Mountains, Oklahoma: Geologica et Palaeontologica, v. 11, p. 47–68.

______1988, Silurian–Early Devonian conodont succession in the Hunton Group, southern Oklahoma, *part 2 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, p. 54–56.

Barrick, J. E.; and Klapper, G., 1976, Multielement Silurian (late Llandoverian–Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of *Kockelella*: Geologica et Palaeontologica, v. 10, p. 59–100.

Barrick, J. E.; Klapper, G.; and Amsden, T. W., 1990a, Late Ordovician–Early Devonian conodont succession in the Hunton Group, Arbuckle Mountains and Anadarko basin, Oklahoma, *in* Ritter, S. M. (ed.), Early to Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 55–62.

______1990b, Stop 1: Hunton Group (Late Ordovician–Early Devonian), *in* Ritter, S. M. (ed.), Early to Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 5–9.

Bischoff, G.; and Sannemann, D., 1958, Unterdevonische Conodonten aus dem Frankenwald: Hessisches Landesamt für Bodenforschung, Notizblatt, v. 86, p. 87–110.

Branson, E. B.; and Mehl, M. G., 1933a, Conodonts from the Bainbridge (Silurian) of Missouri: University of Missouri Studies, v. 8, no. 1, p. 39–52.

______1933b, Conodonts from the Plattin (Middle Ordovician) of Missouri: University of Missouri Studies, v. 8, no. 2, p. 101–119.

______1938, The conodont genus *Icriodus* and its stratigraphic distribution: Journal of Paleontology, v. 12, p. 156–166.

Broadhead, T. W.; and McComb, R., 1983, Paedomorphosis in the conodont family Icriodontidae and the evolution of *Icriodus*: Fossils and Strata, no. 15, p. 149–154.

Bultynck, P., 1971, Le Silurien Supérieur et le Dévonien Inférieur de la Sierra de Guadarrama (Espagne centrale); Deuxième partie: assemblages de Conodontes à *Spathognathodus*: Institut royal des Sciences naturelles de Belgique Bulletin, v. 47, no. 3, 43 p.

______1976, Le Silurien Supérieur et le Dévonien Inférieur de la Sierra de Guadarrama (Espagne centrale); Troisième partie: elements icriodiformes, pelekysgnathiformes et polygnathiformes: Institut royal des Sciences naturelles de Belgique Bulletin, v. 49, Sciences de la Terre no. 5, 74 p.

Campbell, K. S. W., 1967, Trilobites of the Henryhouse Formation (Silurian) in Oklahoma: Oklahoma Geological Survey Bulletin 115, 68 p.

______1977, Trilobites of the Haragan, Bois d'Arc, and Frisco Formations (Early Devonian), Arbuckle Mountains region, Oklahoma: Oklahoma Geological Survey Bulletin 123, 227 p.

Carls, P.; and Gandl, J., 1969, Stratigraphie und Conodonten des Unter-Devons der östlichen Iberischen Ketten (NE-Spanien): Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 132, p. 155–218.

Clark, D. L.; and others, 1981, Conodonta, *in* Robinson, R. A. (ed.), Treatise on invertebrate paleontology, Pt. W, Miscellanea, Supplement 2: Geological Society of America and University of Kansas Press, Lawrence, p. W1–W202.

Denkler, K. E.; and Harris, A. G., 1988, Conodont-based determination of the Silurian–Devonian boundary in the Valley and Ridge province, northern and central Appalachians: U.S. Geological Survey Bulletin 1937, p. B1–B13.

Drygant, D. M., 1968, Nekotorye vidy konodontov Silura Podolii: Paleontologicheskii Sbornik, no. 5, p. 46–52.

______1974, Prostye konodonty Silura i nizov Devona Volyno-Podol'ia: Paleontologicheskii Sbornik, no. 10, p. 64–70.

______1984, Korreliatsiia i konodonty Siluriiskikh-Nizhnedevonskikh otlozhenii Volyno-Podolii: Akademiia Nauk Ukrainskoi SSR, Institut Geologii i Geokhimii Goriuchikh Iskopaemykh, Kiev, 192 p.

Ethington, R. L., 1959, Conodonts of the Ordovician Galena Formation: Journal of Paleontology, v. 33, p. 257–292.

Gnoli, M.; Leone, F.; Olivieri, R.; and Serpagli, E., 1988, The Mason Porcus section as reference section for uppermost Silurian–Lower Devonian in SW Sardinia: Bollettino della Società Paleontologica Italiana, v. 27, p. 323–334.

Jeppsson, L., 1975 [imprint, 1974], Aspects of Late Silurian conodonts: Fossils and Strata, no. 6, 54 p.

______1983, Silurian conodont faunas from Gotland: Fossils and Strata, no. 15, p. 121–144.

______1988, Conodont biostratigraphy of the Silurian–Devonian boundary stratotype at Klonk, Czechoslovakia: Geologica et Palaeontologica, v. 22, p. 21–31.

______1989, Latest Silurian conodonts from Klonk, Czechoslovakia: Geologica et Palaeontologica, v. 23, p. 21–37.

Khodalevich, A. N.; and Chernikh, V. V., 1973, Konodonty iz zhivetskikh otlozhenii vostochnogo sklona iuzhnogo Urala: Trudi Sverdlovskogo ordena trudovogo krasnogo znameni gornogo instituta, no. 93, p. 27–41.

Klapper, G.; and Barrick, J. E., 1983, Middle Devonian (Eifelian) conodonts from the Spillville Formation in northern Iowa and southern Minnesota: Journal of Paleontology, v. 57, p. 1212–1243.

Klapper, G.; and Johnson, J. G., 1980, Endemism and dispersal of Devonian conodonts: Journal of Paleontology, v. 54, p. 400–455.

Klapper, G.; and Murphy, M. A., 1975 [imprint, 1974], Silurian–Lower Devonian conodont sequence in the Roberts Mountains Formation of central Nevada: University of California Publications in Geological Sciences, v. 111, 62 p.

Klapper, G.; and Philip, G. M., 1971, Devonian conodont apparatuses and their vicarious skeletal elements: Lethaia, v. 4, p. 429–452.

Kozur, H., 1984, Preliminary report about the Silurian to Middle Devonian sequences near Nekézseny (southernmost Uppony Mts., northern Hungary): Geologisch–Paläontologische Mitteilungen Innsbruck, v. 13, p. 149–176.

Lane, H. R.; and Ormiston, A. R., 1979, Siluro–Devonian biostratigraphy of the Salmontrout River area, east-central Alaska: Geologica et Palaeontologica, v. 13, p. 39–96.

Lundin, R. F., 1965, Ostracodes of the Henryhouse Formation (Silurian) in Oklahoma: Oklahoma Geological Survey Bulletin 108, 104 p.

______1968, Ostracodes of the Haragan Formation (Devonian) in Oklahoma: Oklahoma Geological Survey Bulletin 116, 121 p.

Mashkova, T. V., 1968, Konodonty roda *Icriodus* Branson et Mehl, 1938 iz Borshchovskogo i Chortkovskogo gorizontov Podolii: Doklady Akademii Nauk SSSR, v. 182, p. 941–944.

______1970, Ob utochnenii ob"ema zony *woschmidti* v Podolii: Doklady Akademii Nauk SSSR, v. 190, p. 654–657.

______1971, Zonal'nye kompleksy konodontov pogranichnykh sloev Silura i Devona Podolii, *in* Granitsa Silura i Devona i biostratigrafiia Silura: Trudy III Mezhdunarodnogo Simpoziuma, Leningrad, v. 1, p. 157–164.

______1972, *Ozarkodina steinhornensis* (Ziegler) apparatus, its conodonts and biozone, *in* Lindström, M.; and Ziegler, W. (eds.), Symposium on conodont taxonomy: Geologica et Palaeontologica, Sonderband 1, p. 81–90.

Mastandrea, A., 1985, Early Devonian (Lochkovian) conodonts from southwestern Sardinia: Bollettino della Società Paleontologica Italiana, v. 23, p. 240–258.

Mawson, R., 1986, Early Devonian (Lochkovian) conodont faunas from Windellama, New South Wales: Geologica et Palaeontologica, v. 20, p. 39–71.

Moskalenko, T. A.; and Chegodaev, L. D., 1988, Konodonty, *in* Obut, A. M.; Morozova, F. I.; Moskalenko, T. A.; and Chegodaev, L. D., Graptolity, konodonty i stratigrafiia Silura, nizhnego Devona severnogo Kavkaza: Akademiia Nauk SSSR Sibirskoe otdelenie, Trudy Instituta Geologii i Geofiziki, no. 698, p. 132–168.

Mound, M. C., 1968, Upper Devonian conodonts from southern Alberta: Journal of Paleontology, v. 42, p. 444–524.

Müller, K. J., 1962, Zur systematischen Einteilung der Conodontophorida: Paläontologische Zeitschrift, v. 36, p. 109–117.

Murphy, M. A.; and Cebecioglu, M. K., 1986, Statistical study of *Ozarkodina excavata* (Branson and Mehl) and *O. tuma* Murphy and Matti (Lower Devonian, *delta* Zone, conodonts, Nevada): Journal of Paleontology, v. 60, p. 865–869.

______1987, Morphometric study of the genus *Ancyrodelloides* (Lower Devonian, conodonts), central Nevada: Journal of Paleontology, v. 61, p. 583–594.

Murphy, M. A.; and Matti, J. C., 1983 [imprint, 1982], Lower Devonian conodonts (*hesperius–kindlei* Zones), central Nevada: University of California Publications in Geological Sciences, v. 123, 83 p.

Nicoll, R. S., 1987, Form and function of the Pa element in the conodont animal, *in* Aldridge, R. J. (ed.), Palaeobiology of conodonts: Ellis Horwood Limited, Chichester, p. 77–90.

Olivieri, R.; and Serpagli, E., 1990, Latest Silurian–early Devonian conodonts from the Mason Porcus section near Fluminimaggiore, southwestern Sardinia: Bollettino della Società Paleontologica Italiana, v. 29, p. 59–76.

Philip, G. M., 1965, Lower Devonian conodonts from the Tyers area, Gippsland, Victoria: Royal Society of Victoria Proceedings, v. 79, p. 95–117.

Ramovš, A., 1989, Two new *Belodella* apparatuses (Conodonta) from the Lower Devonian of Bosnia, Yugoslavia: Geologica et Palaeontologica, v. 23, p. 39–51.

______ 1990, Genus *Belodella* (Conodonta) in the Lower Devonian of Yugoslavia: Courier Forschungsinstitut Senckenberg, v. 117, p. 71–79.

Rhodes, F. H. T., 1953, Some British Lower Palaeozoic conodont faunas: Royal Society of London Philosophical Transactions, ser. B, Biological Sciences, v. 237, p. 261–334.

Schönlaub, H. P., 1980a, Carnic Alps, with contributions by H. Jaeger and others, *in* Schönlaub, H. P. (ed.), Second European conodont symposium (ECOS II), Guidebook, Abstracts: Abhandlungen der Geologischen Bundesanstalt, v. 35, p. 5–57.

______ 1980b, Conodont biostratigraphy for Stop 1, Stop 2, and Stop 9, *in* Chlupáč, I.; and others, Silurian and Devonian conodont localities of the Barrandian, *in* Schönlaub, H. P. (ed.), Second European conodont symposium (ECOS II), Guidebook, Abstracts: Abhandlungen der Geologischen Bundesanstalt, v. 35, p. 153–159, 175–177.

______ 1985, Conodonts, *in* Chlupáč, I.; and others, The Lochkovian–Pragian boundary in the Lower Devonian of the Barrandian area (Czechoslovakia): Jahrbuch der Geologischen Bundesanstalt, v. 128, p. 24–27.

______ 1986, Conodonts, *in* Kříž, J.; and others, Pridoli—the fourth subdivision of the Silurian: Jahrbuch der Geologischen Bundesanstalt, v. 129, p. 334–337.

Serpagli, E., 1983, The conodont apparatus of *Icriodus woschmidti woschmidti* Ziegler: Fossils and Strata, no. 15, p. 155–161.

Serpagli, E.; Gnoli, M.; Mastandrea, A.; and Olivieri, R., 1978, Palaeontological evidence of the Gedinnian (Lower Devonian) in southwestern Sardinia: Rivista Italiana di Paleontologia e Stratigrafia, v. 84, p. 305–312.

Sparling, D. R., 1981, Middle Devonian conodont apparatuses with seven types of elements: Journal of Paleontology, v. 55, p. 295–316.

Stauffer, C. R., 1930, Conodonts from the Decorah Shale: Journal of Paleontology, v. 4, p. 121–128.

______ 1940, Conodonts from the Devonian and associated clays of Minnesota: Journal of Paleontology, v. 14, p. 417–435.

Sweet, W. C., 1979, Late Ordovician conodonts and biostratigraphy of the western Midcontinent Province: Brigham Young University Geology Studies, v. 26, no. 3, p. 45–74.

______ 1988, The Conodonta: morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum: Clarendon Press, Oxford, 212 p.

Sweet, W. C.; and Schönlaub, H. P., 1975, Conodonts of the genus *Oulodus* Branson and Mehl, 1933: Geologica et Palaeontologica, v. 9, p. 41–59.

Thomas, L. A., 1949, Devonian–Mississippian formations of southeast Iowa: Geological Society of America Bulletin, v. 60, p. 403–437.

Uyeno, T. T., 1981 [imprint, 1980], Systematic study of conodonts, *in* Thorsteinsson, R.; and Uyeno, T. T., Stratigraphy and conodonts of Upper Silurian and Lower Devonian rocks in the environs of the Boothia Uplift, Canadian Arctic Archipelago: Geological Survey of Canada Bulletin 292, p. 39–75.

______ 1990, Biostratigraphy and conodont faunas of Upper Ordovician through Middle Devonian rocks, eastern Arctic Archipelago, with contributions by U. Mayr and R. F. Roblesky: Geological Survey of Canada Bulletin 401, 211 p.

Walliser, O. H., 1964, Conodonten des Silurs: Hessisches Landesamt für Bodenforschung, Abhandlungen, no. 41, 106 p.

Ziegler, W., 1960, Conodonten aus dem Rheinischen Unterdevon (Gedinnium) des Remscheider Sattels (Rheinisches Schiefergebirge): Paläontologische Zeitschrift, v. 34, p. 169–201.

Plates

PLATE 1

Belodella

Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figures 1–3,7,14–17.—*Belodella* cf. *B. resima* (Philip), Haragan Formation, section I-35, sample 9. **1**, inner lateral view of Sc element (70×), SUI 64707; **2**, posterior view of Sc element (70×), SUI 64708; **3**, outer lateral view of Sc element (70×), SUI 64709; **7**, outer lateral view of M element (80×), SUI 64713; **14**, inner lateral view of broad Sb element (80×), SUI 64720; **15**, lateral view of Sa element (80×), SUI 64721; **16**, inner lateral view of tortiform element (80×), SUI 64722; **17**, outer lateral view of slender Sb element (80×), SUI 64723.

Figures 4–6,8–12,18.—*Belodella anfracta* Barrick and Klapper, new species. Henryhouse Formation, section PR, sample 2. **4**, outer lateral view of Sc element (80×), SUI paratype 64710; **5**, posterior view of Sc element (80×), SUI paratype 64711; **6**, outer lateral view of Sc element (80×), SUI holotype 64712; **8**, inner lateral view of tortiform element (80×), SUI paratype 64714; **9**, outer lateral view of M element (80×), SUI paratype 64715; **10**, outer lateral view of tortiform element (80×), SUI paratype 64716; **11**, outer lateral view of tortiform element (80×), SUI paratype 64717; **12**, lateral view of Sa element (80×), SUI paratype 64718; **18**, outer lateral view of Sb element (80×), SUI paratype 64724.

Figure 13.—*Belodella*? *paucidentata* Moskalenko and Chegodaev 1988?, Fittstown Member, Bois d'Arc Formation, section P11, sample 15. **13**, inner lateral view of Sb element (80×), SUI 64719.

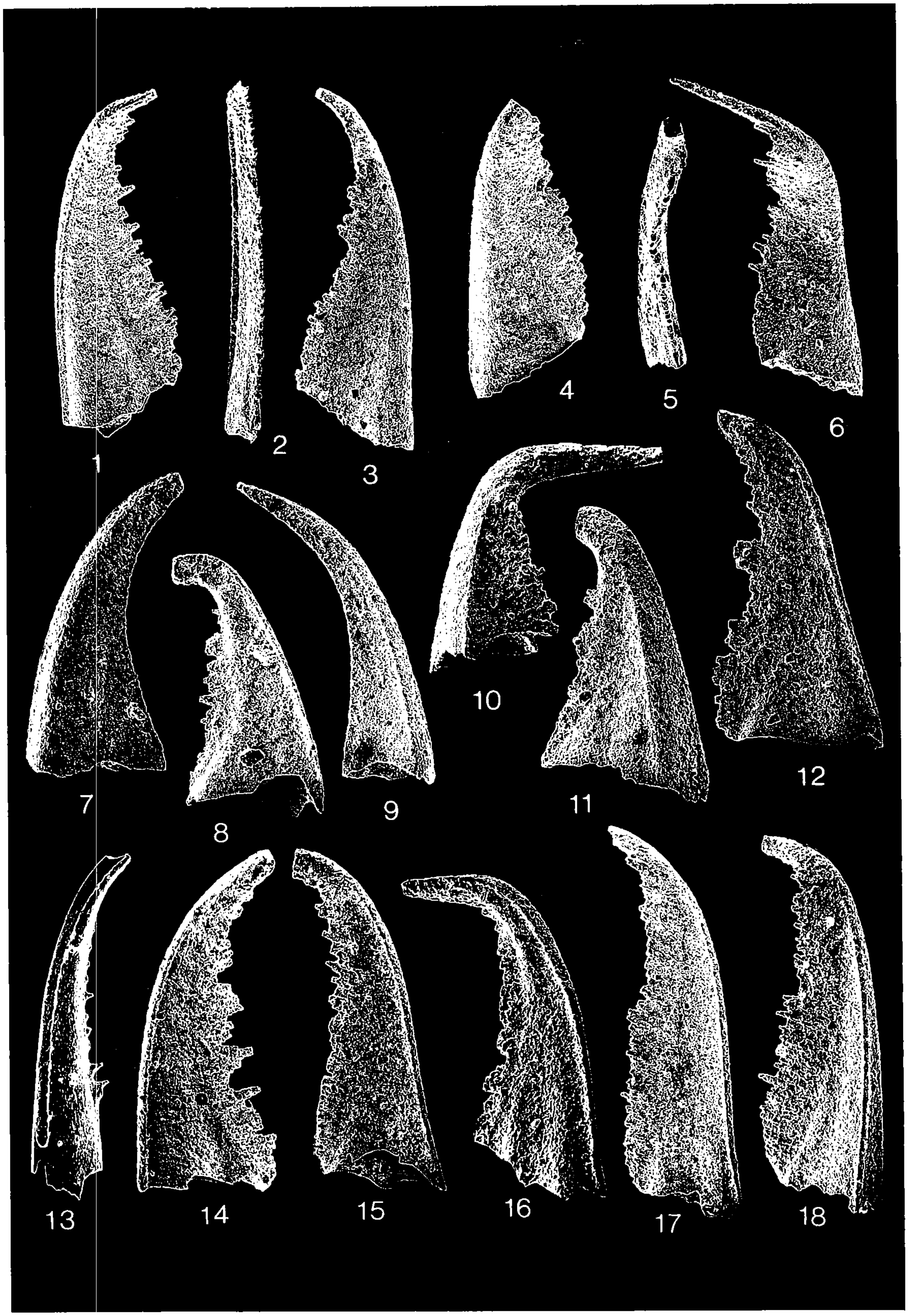

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

PLATE 2

Belodella, Dapsilodus, Decoriconus, and Dvorakia

Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figure 1.—*Dvorakia* sp. Fittstown Member, Bois d'Arc Formation, section P11, sample 14B. **1**, lateral view of Sa? element (80×), SUI 64725.

Figure 2.—*Dapsilodus* sp. Henryhouse Formation, section PR, sample 2. **2**, inner lateral view of SbSc element (87×), SUI 64726.

Figures 3,4,8,9,12–14.—*Belodella coarctata* Barrick and Klapper, new species. Henryhouse Formation, section PR, sample 2. **3**, inner lateral view of M element (87×), SUI paratype 64727; **4**, outer lateral view of M element (87×), SUI paratype 64728; **8**, inner lateral view of tortiform element (87×), SUI holotype 64732; **9**, inner lateral view of Sc element (87×), SUI paratype 64733; **12**, outer lateral view of tortiform element (87×), SUI paratype 64736; **13**, outer lateral view of Sa element (80×), SUI paratype 64737; **14**, inner lateral view of Sb element (80×), SUI paratype 64738.

Figure 5.—*Decoriconus fragilis* (Branson and Mehl), Henryhouse Formation, section PR, sample 2. **5**, inner lateral view of Sc element (100×), SUI 64729.

Figures 6,7,10.—*Dvorakia philipi* (Drygant)?, Haragan Formation, section I-35. **6**, inner lateral view of Sb1 element (80×), SUI 64730, sample 4; **7**, outer lateral view of Sb2 element (80×), SUI 64731, sample 3; **10**, inner lateral view of Sb2 element (80×), SUI 64734, sample 4.

Figures 11,15–19.—*Dvorakia amsdeni* Barrick and Klapper, new species. Henryhouse Formation, section P1. **11**, inner lateral view of Sb2 element (87×), SUI paratype 64735, sample B10; **15**, lateral view of slender Sd element (80×), SUI holotype 64739, sample A28; **16**, inner lateral view of Sb1 element (80×), SUI paratype 64740, sample A28; **17**, outer lateral view of Sc element (87×), SUI paratype 64741, sample A28; **18**, outer lateral view of Sb1 element (87×), SUI paratype 64742, sample A28; **19**, lateral view of broad Sd element (80×), SUI paratype 64743, sample A28.

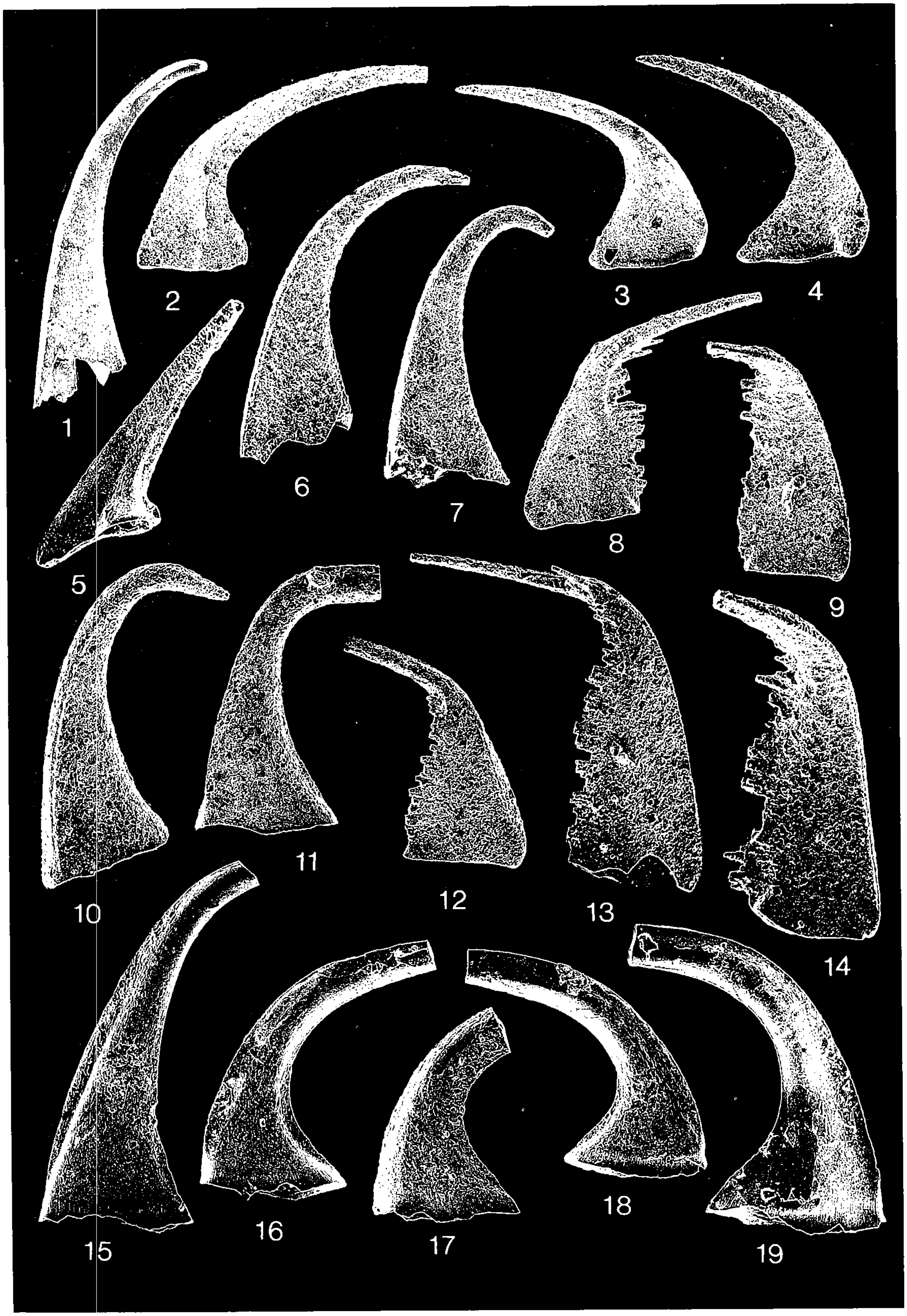

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

PLATE 3

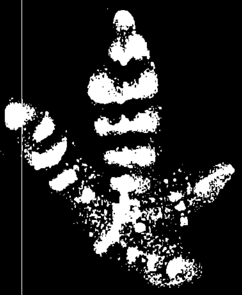
Pedavis, Icriodus

All figures ×40, all Pa elements unless noted otherwise. Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figures 1–3.—*Pedavis biexoramus* Murphy and Matti. Haragan Formation, section I-35. **1**, upper view of SUI 64744, sample 4; **2**, upper view of SUI 64745, sample 4; **3**, upper view of SUI 64746, sample 3AA.

Figures 4–6.—*Icriodus eolatericrescens* Mashkova sensu Drygant. Haragan Formation. **4**, upper view of SUI 64747, section I-35, sample 4; **5**, upper view of SUI 64748, section I-35, sample 4; **6**, upper view of small specimen, SUI 64749, section Highway 77, sample 47.

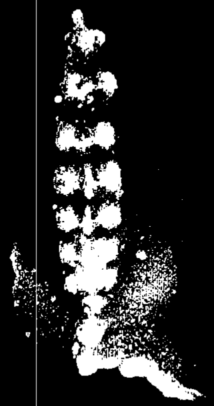
Figures 7–12.—*Icriodus postwoschmidti* Mashkova. Bois d'Arc Formation, except Figure 7. **7**, upper view of SUI 64750, Haragan Formation, section I-35, sample 4; **8**, upper view of SUI 64751, Cravatt Member, section P8, sample 12; **9**, lateral view of S element, SUI 64752, Fittstown Member, section P8, sample 15; **10**, upper view of SUI 64753, Fittstown Member, section P8, sample 15; **11**, upper view of SUI 64754, Fittstown Member, Gulf No. 1 Dyer, McClain County, Oklahoma (Amsden, 1975, p. 84), 9,025–9,035 ft; **12**, upper view of SUI 64755, Fittstown Member, section P8, sample 15.



1

2

3



4

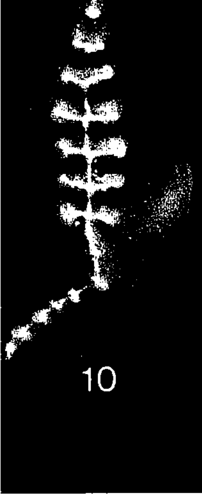
5

6

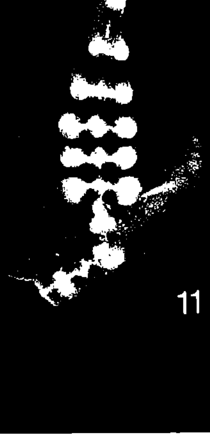
7

8

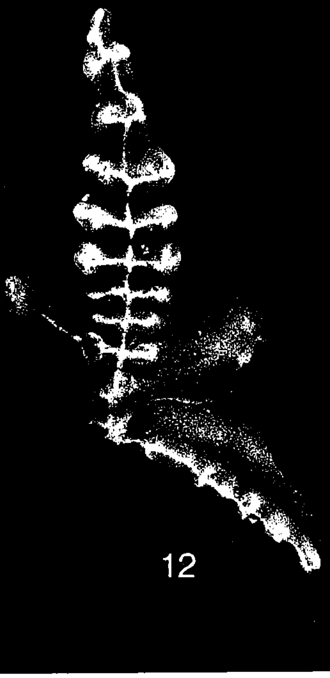
9



10



11



12

PLATE 4

Oulodus, Ozarkodina, Ancyrodelloides

All figures ×40. Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figures 1,2.—*Oulodus elegans elegans* (Walliser). Henryhouse Formation, section P1, sample A28. **1**, inner lateral view of Sc element, SUI 64756; **2**, inner lateral view of Sc element, SUI 64757.

Figures 3–7.—*Oulodus elegans detorta* (Walliser). Henryhouse Formation. **3**, inner lateral view of Sc element, SUI 64758, section I-35, sample 1B; **4**, inner lateral view of Sc element, SUI 64759, section PR, sample 3; **5**, inner lateral view of Sc element, SUI 64760, section I-35, sample 2BB; **6**, lateral view of Sd element, SUI 64761, section I-35, sample 1B; **7**, lateral view of M element, SUI 64762, section PR, sample 3.

Figures 8,9.—*Ozarkodina remscheidensis remscheidensis* (Ziegler). Haragan Formation, section P1. **8**, inner lateral view of Pa element, SUI 64763, Sample B3; **9**, outer lateral view of Pa element, SUI 64764, Sample B3.

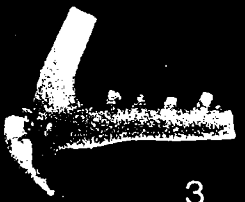
Figures 10,11,14,15.—*Ancyrodelloides*? sp. Bois d'Arc Formation, Cravatt Member. **10,11**, upper and inner lateral views of Pa element, SUI 64765, section PR, sample 12; **14,15**, outer lateral and upper views of Pa element, SUI 64766, section J6, sample 11.

Figure 12.—*Ozarkodina wurmi* (Bischoff and Sannemann). Bois d'Arc Formation, Cravatt Member. **12**, inner lateral view of Pa element, SUI 64767, section J6, sample 11.

Figure 13.—*Ancyrodelloides transitans* Bischoff and Sannemann. Bois d'Arc Formation, Fittstown Member. **13**, inner lateral view of Pa element, SUI 64768, section P11, sample 15.


1


2


3


4


5


6

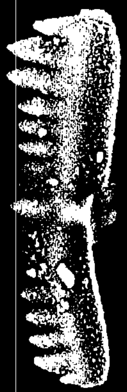

7


8


9


10


11


12


13


14


15

PLATE 5

Ancyrodelloides

All figures ×40, all Pa elements unless noted otherwise. Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figures 1–5.—*Ancyrodelloides transitans* (Bischoff and Sannemann). Bois d'Arc Formation, Fittstown Member. **1**, upper view of specimen in Pl. 4, Fig. 13, SUI 64768, section P11, sample 15; **2**, upper view of SUI 64769, section P11, sample 14B; **3**, outer lateral view of Pb element, SUI 64770, section P11, sample 14B; **4**, upper view of SUI 64771, section P11, sample 15; **5**, upper view of SUI 64772, section P11, sample 14B.

Figures 6–9.—*Ancyrodelloides secus* Barrick and Klapper, new species. Bois d'Arc Formation, Fittstown Member, section P9, sample 34. **6**, upper view of SUI paratype 64773; **7**, upper view of SUI paratype 64774, posterior process partially broken; **8,9**, upper and lower views of SUI holotype 64775, specimen in two pieces, fitted together.

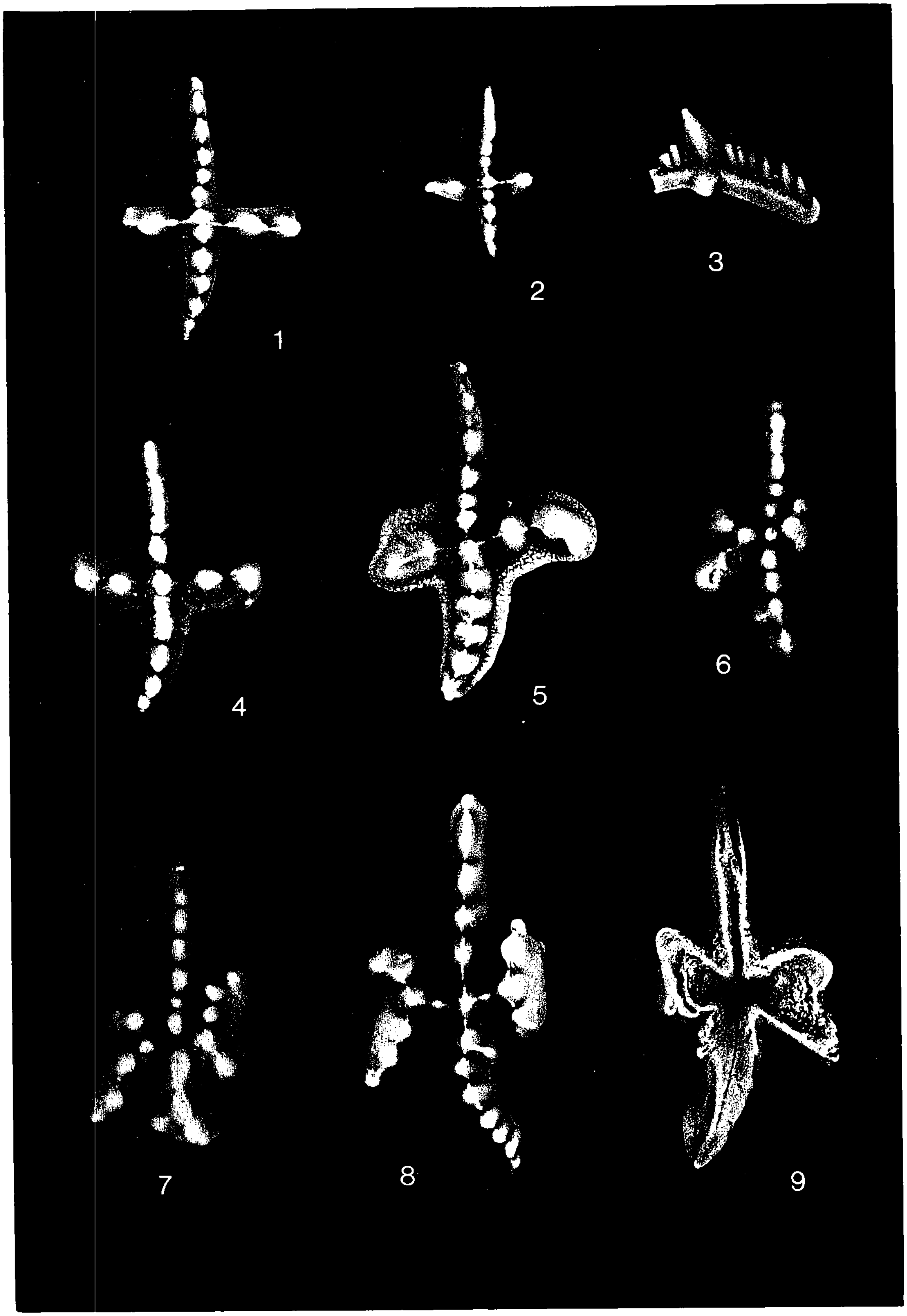

1
2
3
4
5
6
7
8
9

PLATE 6

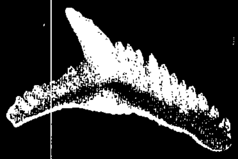
Ozarkodina

All figures ×40, all Pa elements unless noted otherwise. Figured specimens: SUI—University of Iowa, Iowa City, Iowa.

Figure 1.—*Ozarkodina remscheidensis remscheidensis* (Ziegler). Haragan Formation. **1**, outer lateral view of Pb element, SUI 64776, section P1, sample B3.

Figures 2–4.—*Ozarkodina remscheidensis eosteinhornensis* (Walliser). Henryhouse Formation. **2**, outer lateral view of SUI 64777, section P1, sample A21; **3**, outer lateral view of SUI 64778, section P1, sample A28; **4**, outer lateral view of SUI 64779, section P1, sample A28.

Figures 5–16.—*Ozarkodina remscheidensis remscheidensis* (Ziegler). Haragan Formation, except Figures 9,12,13,16. **5**, outer lateral view of SUI 64780, section P1, sample B2; **6**, outer lateral view of SUI 64781, section P1, sample B3; **7**, outer lateral view of SUI 64782, section P1, sample B3; **8**, outer lateral view of SUI 64783, section P1, sample B3; **9**, outer lateral view of SUI 64784, Bois d'Arc Formation, Cravatt Member, section P8, sample 12; **10,11**, upper and outer lateral views of SUI 64785, section PR, sample 9; **12**, outer lateral view of SUI 64786, Bois d'Arc Formation, Fittstown Member, section P9, sample 33; **13**, outer lateral view of SUI 64787, Bois d'Arc Formation, Cravatt Member, section PR, sample 12; **14,15**, outer lateral and upper views of SUI 64788, section P1, sample B3; **16**, outer lateral view of SUI 64789, Bois d'Arc Formation, Cravatt Member, section P8, sample 12.



1

2

3

4

5

6

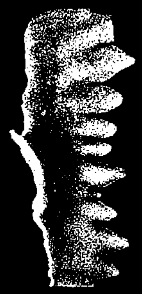
7

8

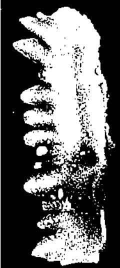
9

10

11



12



13

14

15

16

Oklahoma Geological Survey Bulletin 145, 1992

The Ordovician Utica Shale in the Eastern Midcontinent Region: Age, Lithofacies, and Regional Relationships

Stig M. Bergström
The Ohio State University

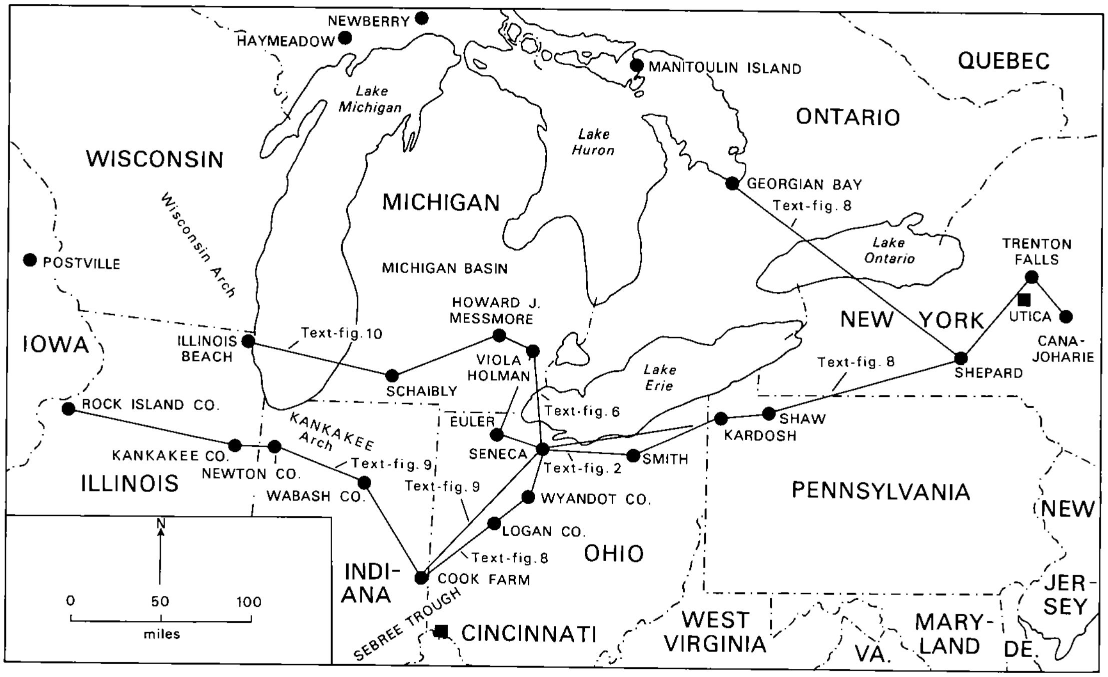
Charles E. Mitchell
State University of New York at Buffalo

ABSTRACT.—In the northern Ohio subsurface, the Middle Ordovician Trenton Limestone, a significant oil and gas producer, is disconformably overlain by a few hundred feet of black, gray, and green shales and subordinate limestones. The lower 200–300 ft of this succession consist of black to dark-brown shales long referred to as the Utica Shale. Previously, there has been no biostratigraphic control of this unit, but the present study shows that it contains relatively abundant and taxonomically diverse graptolites. In a core from Seneca County, the lower part of the Utica Shale yielded graptolites typical of the *Geniculograptus pygmaeus* Zone, which is middle Edenian to middle–upper Maysvillian in age. This zone is well known from the Utica Shale of New York/Quebec, the Collingwood Shale of Ontario, and the middle and upper Kope and Fairview Formations in the Cincinnati region. Graptolites from the Utica Shale in several other drill-cores from Ohio permit assessment of the relations between the Utica Shale in northern Ohio and lithologically similar, but partly older, shales in the Sebree Trough in the Cincinnati region. Regional lithostratigraphical comparisons, correlation of geophysical logs, and biostratigraphic evidence from graptolites and conodonts indicate that a tongue of the Utica Shale extends across much of the eastern Midcontinent and can be traced into the lower Maquoketa Group in the Upper Mississippi Valley. The main distributional area of this Utica Shale lithofacies is east of the Wisconsin/Michigan and Illinois/Indiana border region. West of this region, this lithofacies is sporadic in occurrence and biostratigraphically younger than the typical Utica Shale. It is concluded that the Utica Shale lithofacies, although occurring in a continuous body over most of the eastern Midcontinent, is not a blanket-type deposit but rather a complex mosaic showing considerable age differences locally and regionally. Likewise, there is evidence suggesting that the environment of deposition of these shales was not uniform regionally but showed local variations, especially in water depth. However, much of the Late Ordovician part of this shale was deposited during a transgression that can be traced regionally over much of North America and possibly also in northern Europe.

INTRODUCTION

For more than a century (Orton, 1888), a several-hundred-foot-thick sequence of black, dark-brown, and dark-gray shales overlying the Trenton Limestone in northern Ohio has been referred to as the Utica Shale. Although nowhere exposed at the surface within the state, the distinctive lithology of this unit has made it readily recognizable to the drillers. Because it rests directly on the Trenton Limestone, a major oil and gas producer, it has been penetrated by literally thousands of wells, particularly from the 1880s to World War I. In view of this, it is somewhat surprising that apart from occasional brief descriptions in subsurface geology reports (see, for instance, Calvert, 1963; Wickstrom and others, 1985; Wickstrom and Gray, 1989) very little has been published on the geology and paleontology of this unit in northern Ohio. For instance, as far as we are aware, these rocks have never been subjected to a biostratigraphic study, and there are virtually no data available on the occurrence of any fossil group. This is undoubtedly due, at least in part, to the fact that these shales are known only from the subsurface, and, with very few exceptions, they have not been cored during the search for Trenton oil and gas. However, our studies of some of the existing Utica Shale cores show that biostratigraphically useful fossils such as graptolites and conodonts occur abundantly in many intervals. These fossils provide significant new information about the local and regional relations of this widespread lithofacies.

The present study is an outgrowth of our investigations of brownish shales of late Middle (Mohawkian) and early Late Ordovician (Cincinnatian) age in the Sebree Trough, which extends from southwestern Ohio, through eastern Indiana, westernmost Kentucky and into northwestern Tennessee (Bergström and Mitchell, 1990; Mitchell and



Text-figure 1. Geographic location of sections and cross sections discussed in the text. Text-figure numbers on cross sections refer to text-figures in the present paper.

Bergström, 1991). A reconnaissance study of a core from Seneca County, northern Ohio, showed that the Utica Shale contains relatively abundant graptolites, including some biostratigraphically highly diagnostic forms. This discovery prompted us to study the Utica Shale in several other cores. In order to clarify some stratigraphical relations, it was also necessary to include the subjacent Trenton Limestone in these investigations. The principal goals of the project may be defined as follows:

1) To date the Utica Shale and the Trenton Limestone locally and regionally in northern Ohio in terms of standard graptolite and conodont zones.

2) To assess the nature of the much-discussed Trenton–Utica contact. This is commonly a very uneven, corroded, mineralized surface that may be associated with a thin conglomerate or breccia. Was this contact formed under submarine or subaerial conditions? Does it represent a significant depositional break?

3) To clarify whether or not the shale body classified as the Utica Shale in northern Ohio is in lateral continuity with the Utica Shale of New York. Is the name Utica Shale appropriate for these rocks in Ohio?

4) To examine whether or not the Utica Shale of northern Ohio is in lateral continuity with the dark shales in the Sebree Trough in eastern Indiana and southwestern Ohio. Is the designation Utica Shale appropriate for this shale unit in the Sebree Trough?

5) To trace the lateral extent of the Utica Shale lithofacies westward toward the Mississippi Valley and clarify its relations to the Maquoketa and Galena Groups of the Upper Mississippi Valley.

This is an ongoing study, and additional data are needed to fill in some obvious gaps in our understanding of the local and regional geology of the Utica Shale. However, the data now in hand provide preliminary answers to most of the questions just posed, including some conclusions of more than local interest. Thus, it appears timely to summarize our principal results. We plan to present more detailed data in a projected monograph on Middle and Upper Ordovician graptolites and graptolite biostratigraphy of the eastern Midcontinent region.

Although our project is centered in Ohio, it extends over a large part of the eastern Midcontinent; in the text below, we refer to more than two dozen localities in some 10 states. To facilitate this regional discussion, the geographic location of most of these localities and the position of several transects illustrated in other figures are given in Text-figure 1.

It is with great pleasure that we dedicate this paper to Dr. Thomas W. Amsden in recognition of his very important contributions to our knowledge about the Lower Paleozoic geology of North America.

UTICA SHALE SUCCESSIONS IN NORTHERN OHIO AND ADJACENT AREAS

Lithological Sequence and Stratigraphical Classification

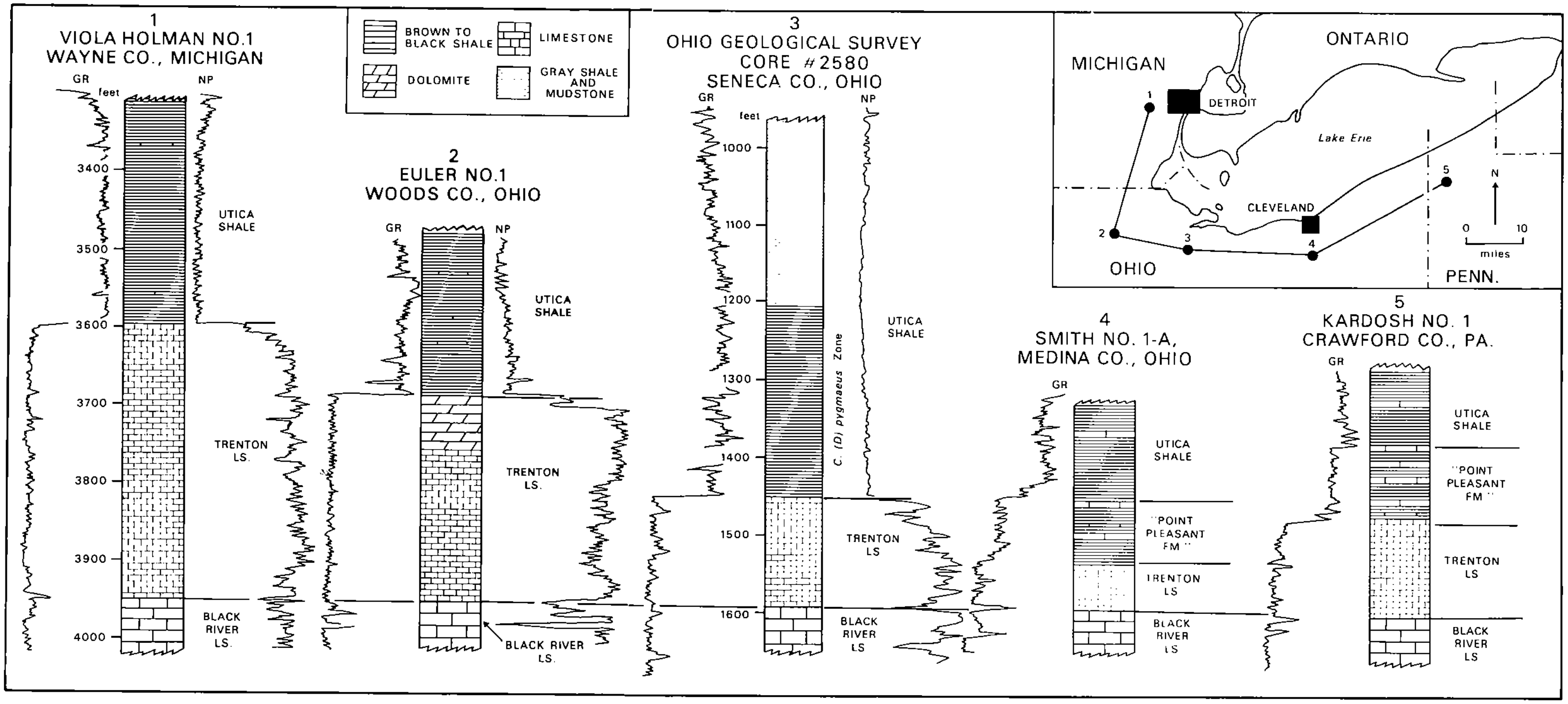
In the subsurface of northern Ohio, the upper Middle Ordovician is subdivided into two limestone formations, the Black River Limestone and the Trenton Limestone. These are overlain by several hundred feet of shales, mudstones, and subordinate limestones that are collectively classified as "Cincinnatian Series undifferentiated" or as "Cincinnati Group." In most wells, the basal 200–300 ft of this fine-clastic succession consist of dark-brown to black shales that have been referred to as the Utica Shale from the time of Orton (1888). In some areas, the lower 100–150 ft of this shaly interval contain an appreciable amount of argillaceous fine-grained limestone. This calcareous development of the lower Utica Shale has been distinguished as the Cynthiana Formation (Calvert, 1963), the Point Pleasant Formation (Wickstrom and Gray, 1989), or the "Point Pleasant" Equivalent(?) (Wickstrom and others, 1985). It should be noted that these dark-colored rocks are lithologically quite different from the type Cynthiana Limestone of northern Kentucky and the type Point Pleasant Formation in the Ohio River Valley southeast of Cincinnati. See Wickstrom and Gray (1989) for a recent general review of the upper Middle and Upper Ordovician stratigraphy of northern Ohio.

In Text-figure 2, we compare the upper Middle–lower Upper Ordovician lithological succession in five wells along a transect from the southeastern part of the Michigan Basin across northern Ohio to northeasternmost Pennsylvania. As shown in this figure, the thickness of the Trenton Limestone varies considerably from <100 ft to ~350 ft. Likewise, the stratigraphical interval above the Trenton Limestone recognized as the "Point Pleasant Formation" differs between the wells both in lithology and in stratigraphic position in terms of its height above the base of the Trenton Limestone. Similar variations in lithology and thicknesses have been recorded previously by Calvert (1963, pl. 1) and by Wickstrom and Gray (1989, fig. 4). However, in the absence of biostratigraphical control, it has not been clear whether these relationships reflect different local depositional rates of the Trenton Limestone, or lateral facies relationships between the Trenton Limestone, the "Point Pleasant Formation," and the Utica Shale, or, perhaps, a combination of these alternatives. Our new biostratigraphical data provide not only significant evidence useful for interpretation of formational relations locally, but also show that the regional relations between major lithic units are more complex than has been suspected previously. For clarity, we will first discuss each core separately, and then attempt a regional comparison.

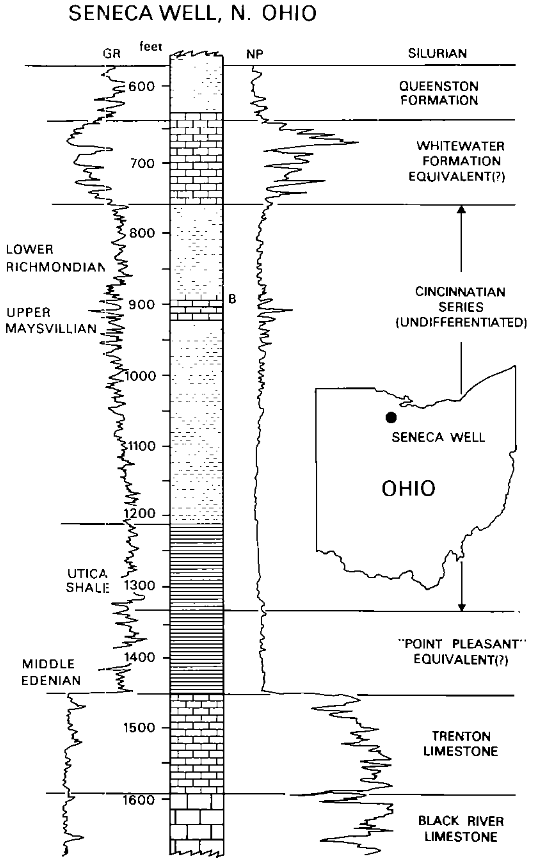
The Seneca Well

In 1985, the Ohio Division of Geological Survey drilled a well to a depth of 2,870 ft in Liberty Township, Seneca County (Text-fig. 1). The entire sequence from the middle Silurian to the uppermost part of the Precambrian basement was cored. A lithological description of this well, along with geophysical logs, was published by Wickstrom and others (1985). In this core, the Trenton and Black River Limestones attain a total thickness of ~660 ft and are overlain by ~900 ft of Upper Ordovician rocks (Text-fig. 3). Unfortunately, the small core diameter (1 7/16 in.) precludes collecting conodont samples of adequate size from the Trenton Limestone–Black River Limestone interval. The top of the Trenton Limestone marks a sharp lithological break. The contact is a distinctive irregular surface above a thin, pyrite-rich brecciated zone. The appearance of this contact is closely similar to that at the top of the Trenton Limestone in wells from Indiana (Keith, 1985) and northern Illinois (Kolata and Graese, 1983). The Trenton Limestone is directly overlain by ~250 ft of black to light-gray shales that we refer to as the Utica Shale. Above this unit, with gradational contact, follow >600 ft of light-gray to greenish shales and mudstones. Within the top part of this sequence, between 635 and 750 ft, is a limestone-dominated interval classified as the Whitewater Formation Equivalent(?) by Wickstrom and others (1985). The topmost 75 ft of the Ordovician succession, which include red, green, and gray shales and mudstones, were identified as the Queenston Formation by Wickstrom and others (1985).

We have searched most of the core between 800 and 1,450 ft for graptolites. The vertical distribution of identified taxa in the interval below 1,100 ft is shown in Text-figure 4, and some of the species are illustrated in Text-figure 5. The very lowermost portion of the Utica Shale, just above the top of the Trenton Limestone, yielded numerous specimens of *Geniculograptus pygmaeus*, the biostratigraphic marker of the *G. pygmaeus* Zone in the New York/Quebec graptolite zone succession (Riva, 1969a,b; 1974). This species ranges up to at least the 1,100-ft level in the Seneca core suggesting that the *G. pygmaeus* Zone has a thickness of at least 350 ft. The lowermost part of the zone also contains *Cryptograptus*? sp., *Dicellograptus* sp. cf. *D. flexuosus* (Text-fig. 5M), *Geniculograptus typicalis typicalis* (Text-fig. 5F,L), *Normalograptus* n. sp. (Text-fig. 5N), and *Orthoretiolites hami* Whittington (Text-fig. 5C,I), a species assemblage characteristic of the lowermost



Text-figure 2. Comparison of Trenton Limestone–Utica Shale successions in five wells along a transect from northwestern Pennsylvania (Kardosh no. 1) to easternmost Michigan Basin (Viola Holman no. 1). Note variations in thickness of the Trenton Limestone and lithological development of the post-Trenton shaly interval. The well succession in Euler no. 1 is slightly modified from Calvert (1963); that of the Seneca well (core no. 2580) is from Wickstrom and others (1985) with minor changes in stratigraphic classification; and data about the Viola Holman no. 1 well are from Faber (1979) with modification of conodont biostratigraphy. GR = gamma ray; NP = neutron porosity.



Text-figure 3. Lithologic succession and geophysical logs of the Seneca well (Ohio Division of Geological Survey core no. 2580). Stratigraphic terms to the right are after Wickstrom and others (1985); those to the left are ours based mainly on graptolite biostratigraphy. Shown vertical extent of the Utica Shale is approximate because of the gradational nature of the contact between this unit and overlying strata. For explanation of lithologic symbols, see legend on Text-figure 2. GR = gamma ray; NP = neutron porosity.

G. pygmaeus Zone in the Cincinnati region (Bergström and Mitchell, in press), where it occurs in rocks of middle Edenian age. Hence, the graptolite evidence at hand suggests that the base of the Utica Shale in the Seneca core is equivalent to a level well above the base of the Cincinnatian in its typical development in the Cincinnati region.

A 100-ft interval above the 1,180-ft level in the Seneca core contains a distinctive graptolite species assemblage (Text-fig. 4), including specimens of what may be *Geniculograptus typicalis magnificus* (Text-fig. 5G), which we have not found in older strata. Because these graptolites occur within the local range of *G. pygmaeus,* and the species association is similar to that known from the upper *G. pygmaeus* Zone in New York/Quebec and Ontario (Riva, 1969a), we interpret this portion of the core to represent a high segment of the *G. pygmaeus* Zone. Based on the recent graptolite correlation of the Cincinnatian Series (Bergström and Mitchell, 1986), this interval is likely to be of Maysvillian age.

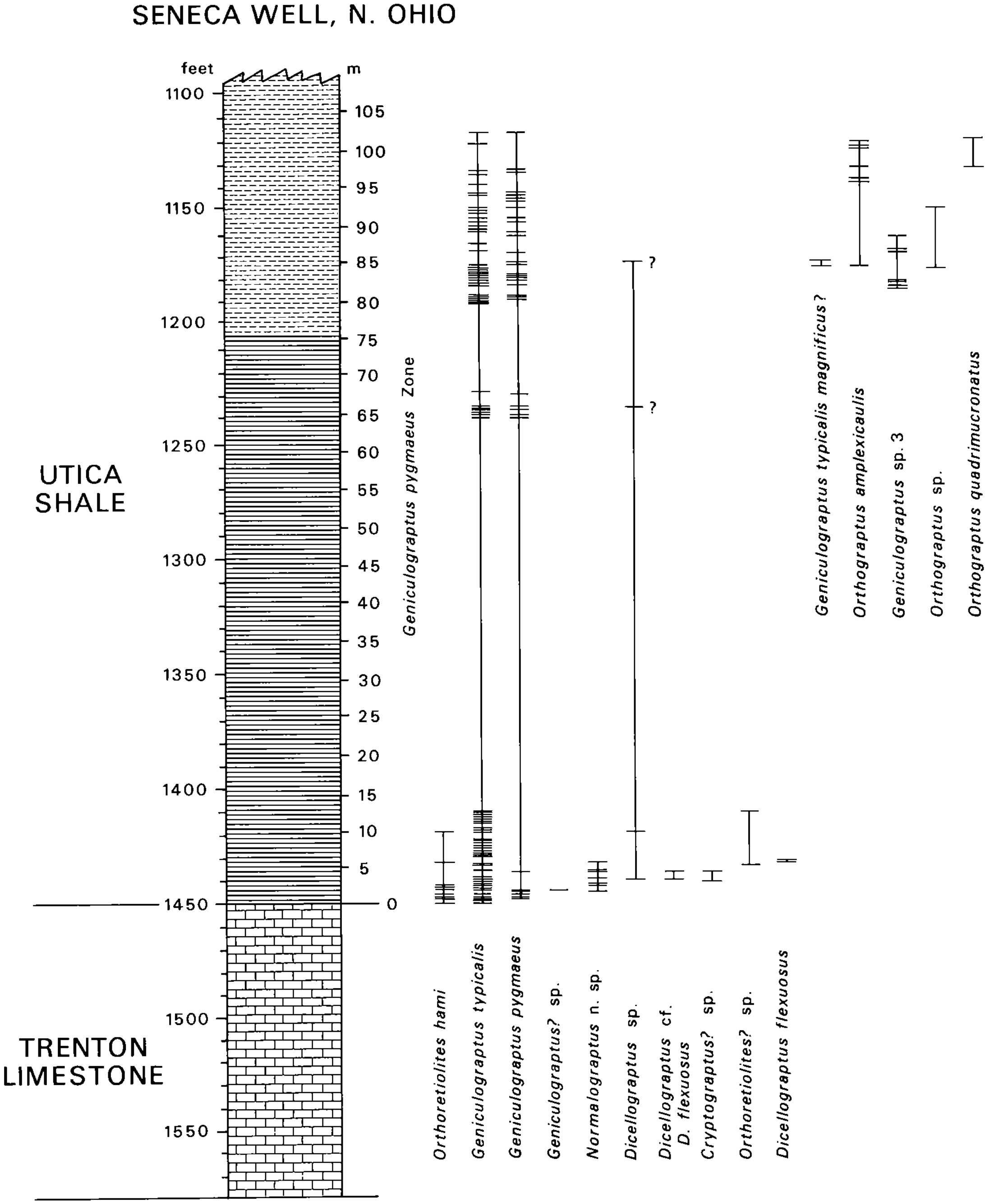
The Seneca core succession between 810 and 860 ft (Text-fig. 3) has produced scattered graptolites, the most significant of which are several specimens (Text-fig. 5B,H) of *Arnheimograptus anacanthus* (Mitchell and Bergström) found between 810 and 817 ft. Walters (1977) and Walters and others (1982) reported the occurrence of this species (listed as *Glyptograptus* sp. and *Glyptograptus anacanthus,* respectively) from strata of the *Amplexograptus manitoulinensis* Zone in the Nicolet River Formation of Quebec. In southwestern Ohio and eastern Indiana, this species is known from several localities where it occurs in the early Richmondian Arnheim Formation (Mitchell and Bergström, 1977). It seems likely that the Seneca core occurrence is of the same age and that the limestone-rich interval between 880 and 920 ft reflects the same regional shallowing in the depositional environment in late Maysvillian time that produced the Bellevue Limestone and associated strata in the Cincinnati region. Likewise, the prominent 100-ft limy interval across the 700-ft level may correspond to the middle Richmondian shallowing episode in the Cincinnati region. Hence, the suggestion by Wickstrom and others (1985) that this limy interval is an equivalent of the Whitewater Formation is likely to be correct.

As noted above, the small diameter of the Seneca core makes it impossible to obtain conodont biostratigraphic control of the 150-ft-thick Trenton Limestone. However, comparison of geophysical logs (Text-figs. 2,6) suggests that it corresponds to the lower part of the unit in those northern Ohio sections where the Trenton Limestone attains a greater thickness.

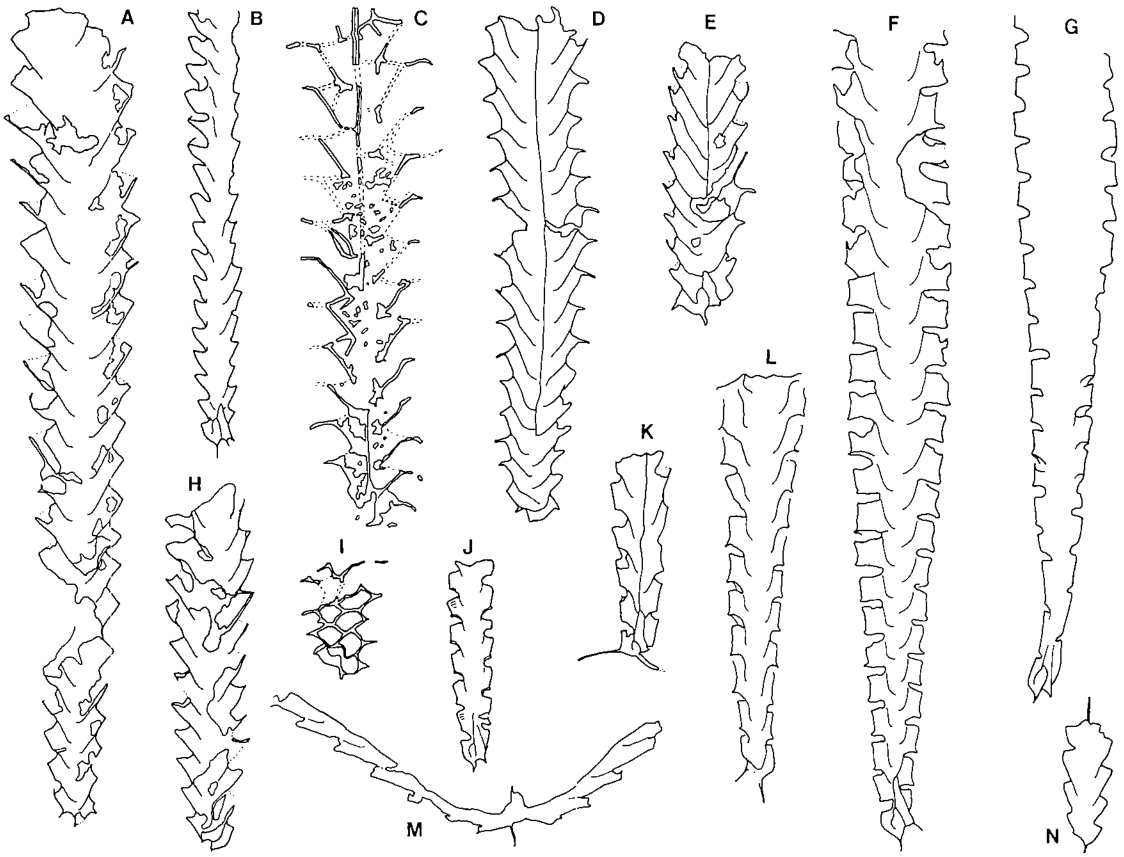
The Viola Holman Well

The Viola Holman well was drilled in 1966 near the southeastern edge of the Northville oil and gas field, ~15 mi northwest of the center of Detroit, Wayne County, Michigan (Text-fig. 1). Because this well is currently the only one in the Lake Erie region with conodont control through a thick development of the Trenton Limestone, it is of potential importance for assessment of the Trenton Limestone–Utica Shale relations in northern Ohio. A stratigraphic comparison between this well and two Ohio wells is given in Text-figure 6.

Below 3,601 ft of Devonian, Silurian, and Upper Ordovician strata in the Viola Holman well, there are 360 ft of Trenton Limestone, all of which was cored. In connection with a geomagnetic reversal study, Faber (1979) studied a long series of conodont samples through the Trenton Limestone. Di-



Text-figure 4. Known vertical ranges of graptolites in the Seneca well. Note that the interval between 1,250 and 1,400 ft has not yet been investigated. The species association in the lower 50 ft of the Utica Shale is typical of that in the lowermost *Geniculograptus pygmaeus* Zone in the Cincinnati region, and that between 1,100 and 1,180 ft is similar to that in the upper *G. pygmaeus* Zone in New York, Ontario, and Quebec. The level of the top of the *G. pygmaeus* Zone has not yet been established, but it is likely to be in the interval between 1,000 and 1,100 ft that has not yet yielded stratigraphically diagnostic graptolites. As indicated in the text, the interval between 800 and 810 ft (not shown in the text-figure) has produced specimens of *Arnheimograptus anacanthus* (Text-fig. 5B,H), a widespread species in the lower Richmondian Arnheim Formation in southwestern Ohio. For explanation of lithologic symbols, see legend on Text-figure 2.



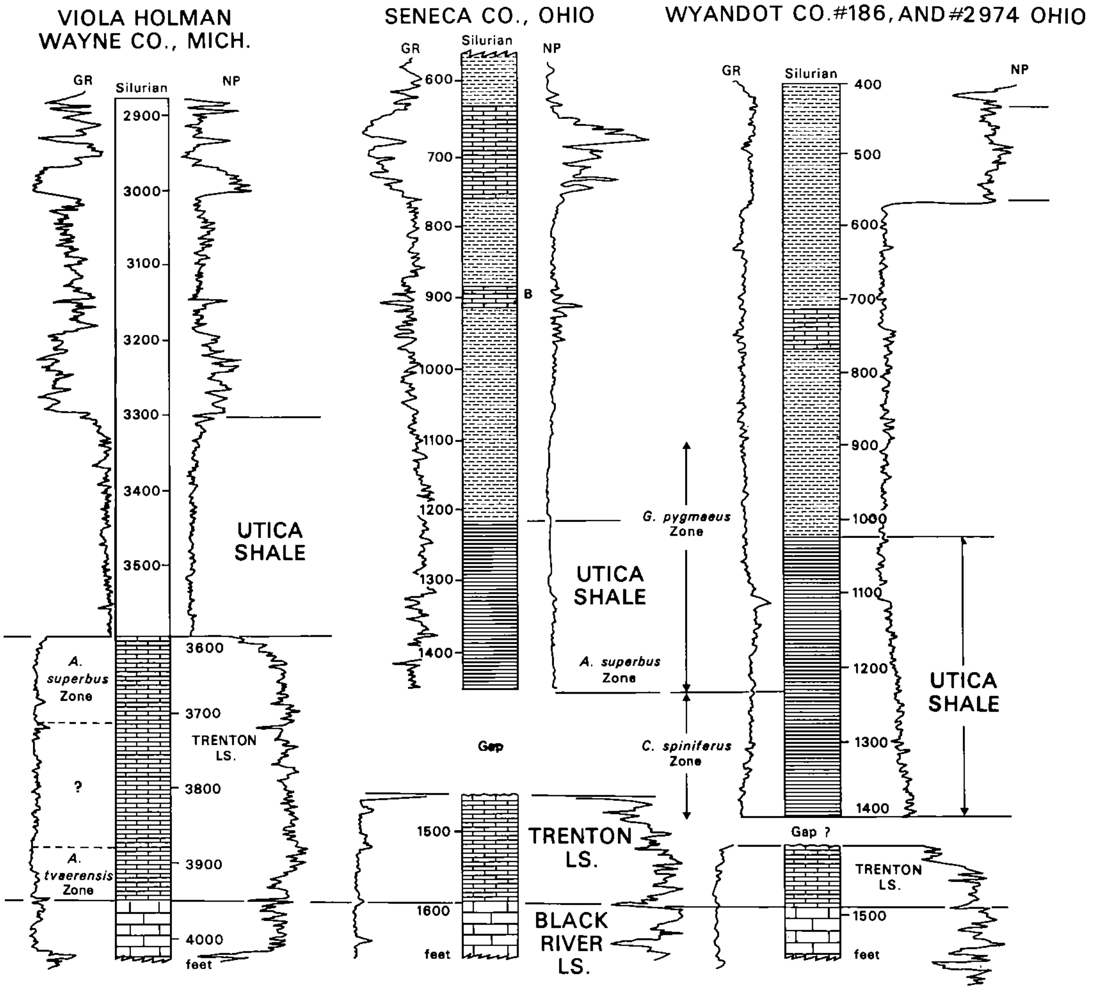
Text-figure 5. Camera lucida drawings of representative graptolite specimens from the *Climacograptus* (*D.*) *spiniferus*, *Geniculograptus pygmaeus*, and *Amplexograptus manitoulinensis* Zones in Ohio Division of Geological Survey core no. 2580, Seneca County, and core no. 2974, Wyandot County, northern Ohio. All specimens are ×6 and are identified by the core (SC and WC, respectively) and the footage from which they were obtained. *A—Orthograptus amplexicaulis* (Hall), SC 1,121 ft 2 in., upper *G. pygmaeus* Zone. *B,H—Arnheimograptus anacanthus* (Mitchell and Bergström), SC 810 ft 10 in., *A. manitoulinesis* Zone. *C,I—Orthoretiolites hami* Whittington, SC 1,447 ft 11 in., lower *G. pygmaeus* Zone. *D,E—Orthograptus quadrimucronatus* (Hall), SC 856 ft 10 in. and 856 ft 4 in., respectively, *A. manitoulinensis* Zone. *F,L—Geniculograptus typicalis typicalis* (Hall), SC 1,417 ft and 1,443 ft 4 in., respectively, lower *G. pygmaeus* Zone. *G—Geniculograptus typicalis magnificus* (Twenhofel), SC 1,170 ft 5 in., upper *G. pygmaeus* Zone. *J—Geniculograptus pygmaeus* (Ruedemann), WC 1,143 ft 2 in., lower *G. pygmaeus* Zone. *K—Climacograptus* (*D.*) *spiniferus* Ruedemann, WC 1,248 ft 8 in., *C.* (*D.*) *spiniferus* Zone. *M—Dicellograptus* sp. cf. *D. flexuosus* Lapworth, SC 1,433 ft 4 in., lower *G. pygmaeus* Zone. *N—Normalograptus* n. sp. 1, SC 1,438 ft 5 in., lower *G. pygmaeus* Zone.

agnostic conodont species were relatively sparse in his samples, but he tentatively placed the *Amorphognathus tvaerensis–A. superbus* Zone boundary 250 ft above the base of the Trenton Limestone at the 3,711-ft level in the core. A restudy of Faber's (1979) collections indicates that this zonal boundary is between the 3,702- and 3,880-ft levels, but additional collections are needed to establish its precise position. A comparison of the geophysical logs from the Seneca and Viola Holman wells suggests that the conodont zone boundary broadly corresponds to a level in the topmost Trenton Limestone, or slightly higher, in the Seneca well. The Utica Shale was not cored in the Viola Holman well, but the geophysical logs suggest a thickness of 200–300 ft, about the same as in the Seneca well. Although no graptolite evidence is available, it seems likely that the entire unit may belong to the *Geniculograptus pygmaeus* Zone, based on conodont-graptolite zone relationships documented in the Cincinnati region (Mitchell and Bergström, 1991). The Utica Shale–Trenton Limestone contact is abrupt, suggesting a depositional break, probably of small magnitude.

Wyandot County Wells

Several wells have been drilled in Wyandot County just south of Seneca County. We have examined the graptolite succession in the Utica Shale in Wyandot County core no. 2974, which is stored at the Ohio Division of Geological Survey in Columbus, Ohio. No geophysical logs are available for this well. In Text-figure 6 we use logs from well no. 186, which was drilled near well no. 2974 and has a virtually identical lithologic succession. Both wells were drilled in Pitt Township ~35 mi south of the site of the Seneca well (Text-fig. 1).

The Trenton Limestone in well no. 2974 is only 90 ft thick, hence considerably thinner than in the Seneca well (150 ft). The top of the Trenton Limestone is marked by accumulation of pyrite and brecciated limestone pieces. Immediately above this



Text-figure 6. Interpretation of the stratigraphic relations between the late Middle and Upper Ordovician successions in three wells in the Lake Erie region. For the locations of these wells, see Text-figure 1. The geophysical logs in the Wyandot County succession are from well no. 186, and the graptolite data are from the lithologically closely similar nearby well no. 2974 for which no geophysical logs are available. Note that in the Seneca core the lowermost part of the Utica Shale belongs in the *Geniculograptus pygmaeus* Zone, whereas in the Wyandot well there is a 165 ft sequence of the *Climacograptus spiniferus* Zone beneath the base of the *G. pygmaeus* Zone in the lower part of the Utica Shale. This fact, along with geophysical log correlations, suggest the existence of a 100–150-ft gap between the Trenton Limestone and the Utica Shale corresponding to the lower Edenian and, probably, the upper Mohawkian in the Cincinnati region. If there is also a significant stratigraphic gap beneath the Utica Shale in the Viola Holman well, which cannot be established at the present time because of lack of biostratigraphical control of its lower Utica Shale, the stratigraphic gap in the Seneca well is even larger than shown in this text-figure. For explanation of lithologic symbols, see legend on Text-figure 2. GR = gamma ray; NP = neutron porosity.

level follow dark-brown, dark-gray, or almost black shales with numerous thin layers of fine-crystalline dark limestone in the basal 50 ft above the top of the Trenton Limestone. The graptolite fauna in the lower part of these shales, which are referred to as the Utica Shale, is older than that at the base of the Utica Shale in the Seneca well but closely similar to that in the *Climacograptus* (*D.*) *spiniferus* Zone in the Cincinnati region (Mitchell and Bergström, 1991; Bergström and Mitchell, 1990, in press) and New York/Quebec (Riva, 1969b) with the zonal marker (Text-fig. 5K) appearing ~4 ft above the top of the Trenton Limestone. Highly significant biostratigraphically is the appearance of *Geniculograptus pygmaeus* (Text-fig. 5J) at the 1,245.5-ft level, ~168 ft above the base of the Utica Shale. This level is taken as the base of the *G. pygmaeus* Zone, which continues upward to at least the 1,143-ft level (higher parts of the core have not yet been searched for graptolites).

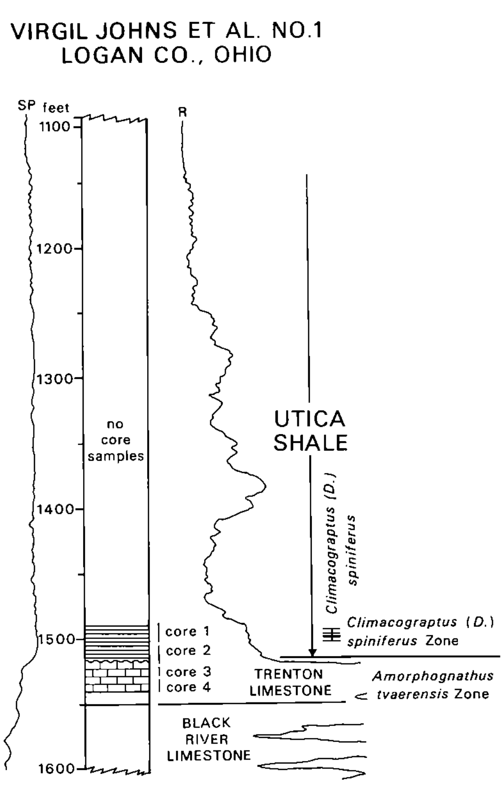
Despite the fact that the sites of the Seneca and Wyandot wells are in adjacent counties and no more than 35 mi apart, there are conspicuous differences in the development of the Trenton Limestone and the Utica Shale. Not only is the thickness of the Trenton Limestone 60% greater in the Seneca core, but the 165-ft-thick *Climacograptus* (*D.*) *spiniferus* Zone in well no. 2974 has no graptolite shale equivalent in the Seneca core. It is possible, but cannot be proved, that the uppermost portion of the Trenton Limestone in the Seneca core is a facies equivalent of the lowermost Utica Shale in well no. 2974, but we believe it is highly unlikely that the equivalents of the entire 165-ft thickness of the *C.* (*D.*) *spiniferus* Zone are present in the upper 60 ft of the Trenton Limestone in the Seneca core. Rather, we believe that there is a substantial gap at the top of the Trenton Limestone in the Seneca core (Text-fig. 6) that corresponds to the lower Edenian and possibly uppermost Mohawkian. Geophysical log correlations suggest that there may be a stratigraphic gap, of much smaller magnitude, at the base of the Utica Shale also in well no. 2974; however, presently available data are insufficient to firmly establish this. The notable stratigraphical gap between the Utica Shale and the Trenton Limestone in the Seneca core is unexpected and calls for an explanation. This well is located in the Findlay Arch area (Wickstrom and Gray, 1989, fig. 10,12), and it is possible that the gap reflects movements along that structure in latest Middle and earliest Late Ordovician time. Interestingly, Kolata and Graese (1983) noted uplift on the LaSalle Anticlinorium and the Wisconsin Arch at approximately this time.

The Logan County Well

In order to clarify the relations between the Utica Shale in northern Ohio and the succession of brown shales in the Sebree Trough just northwest of the Cincinnati Arch in eastern Indiana and southwestern Ohio (Mitchell and Bergström, 1991; Bergström and Mitchell, 1990), we have examined a core from a site about halfway between the sites of the Seneca well and the Cook Farm well (Mitchell and Bergström, 1991). This well, the Virgil Johns et al. Unit 1, was drilled 3,361 ft to the Precambrian basement in McArthur Township, Logan County in 1947 (Text-fig. 1). Only minor parts of the drilled succession (Text-fig. 7) were cored, but the cored portions, which are stored at the Ohio Division of Geological Survey (core no. 645), include parts of the lowermost 100 ft of dark shales referred to as the Utica Shale and the top 27 ft of the underlying Trenton Limestone. According to a core log filed with the Ohio Division of Geological Survey, the thicknesses of the Trenton Limestone and the Utica Shale are 38 and 383 ft, respectively. The contact between the Trenton Limestone and the Utica Shale is sharp and marked by pyrite accumulation, suggesting a disconformity. A few samples collected from the Trenton Limestone in this core produced relatively abundant and well-preserved conodont elements (Table 1), including many specimens of the zonal marker *Amorphognathus tvaerensis* (Pl. 1, Figs. 24–30) in a sample from the 1,528-ft level, that is, ~15 ft below the top of the Trenton Limestone. The conodonts at hand (Pl. 1) show that most, if not all, of this unit belongs in the *A. tvaerensis* Zone. This is in good agreement with the fact that graptolites from the basal 20 ft of the overlying Utica Shale includes *Climacograptus* (*D.*) *spiniferus*, the biostratigraphic marker of the *C.* (*D.*) *spiniferus* Zone. Among the wells discussed above, the Wyandot County wells compare most closely with the Logan County well although the thickness of the Trenton Limestone in the latter well is less than half (38 ft) of that in the former well (90 ft). Interestingly, this decrease in thickness of the Trenton Limestone is associated with an increase of the Utica Shale from 270 to 383 ft. It should, however, be noted that the last two figures are only approximate because of the transitional nature of the contact between the Utica Shale and overlying strata.

The Cook Farm Well

The upper Middle and lower Upper Ordovician succession in the Cook Farm well (Indiana Geological Survey hole no. 57), which was drilled in Wayne County, Indiana, near the Ohio border (Text-fig. 1), is representative of the northwestern portion of the Sebree Trough, and important for the interpretation of the regional relations of the Utica Shale in northern Ohio. The succession in this well has been discussed by Gray (1972) and Mitchell and Bergström (1991), and little needs to be added here. The Trenton Limestone has about the same thickness (33 ft) as in the Logan County well and is overlain, with sharp contact, by >300 ft of dark shales referred to as the Utica Shale. The relatively abundant graptolites in these shales show that the lower 240 ft of this unit belongs to the *Climacograptus* (*D.*) *spiniferus* Zone and the overlying 60+ ft to the *Geniculograptus pygmaeus* Zone. As shown in Text-figure 8, the evidence from both graptolites and lithofacies indicates that the Utica Shale of northern Ohio has a physical connection across northwest-central Ohio with the Sebree Trough succession of dark-brown to dark-gray shales long identified as the Utica Shale, hence justifying the latter lithostratigraphic designation.



Text-figure 7. Geophysical log, biostratigraphy, and Trenton Limestone–Utica Shale succession in the Logan County well. Cores 1–4 refer to core sections stored at the Ohio Division of Geological Survey (core no. 645). Conodonts (Pl. 1) from the 38-ft-thick Trenton Limestone are typical of the *Amorphognathus tvaerensis* Zone, and graptolites in the lower 25 ft of the Utica Shale include *Climacograptus* (*D.*) *spiniferus* Ruedemann, the biostratigraphic marker of the *C.* (*D.*) *spiniferus* Zone. Stratigraphic thicknesses are according to well-log kept at the Ohio Division of Geological Survey; in this log, the thickness of the Utica Shale is given as 383.5 ft, and that of the entire post-Trenton Limestone, pre-Silurian succession is calculated to be ~1,000 ft. For explanation of lithologic symbols, see legend on Text-figure 2. SP = self-potential; R = resistivity.

UTICA SHALE RELATIONS BETWEEN NEW YORK AND OHIO

The regional relations of the lithic unit referred to as the Utica Shale in northern Ohio can be schematically illustrated by means of east–west cross sections based on well and surface sections. The first such transect to be discussed here extends from Ohio to east-central New York (Text-figs. 1,8). It includes surface successions at Canajoharie and Trenton Falls in New York and two well sections between Trenton Falls and northern Ohio. Several additional well sections are available along this transect, but, because their stratigraphy is very similar to that in the wells illustrated in Text-figure 8, they are not discussed or illustrated here.

The stratotype area of the Utica Shale is at the city of Utica, New York (Text-fig. 1), where it consists of ~400 ft of black, graptolite-bearing shale (Kay, 1953). At Trenton Falls (Text-fig. 1), the thickness of the unit was estimated by Rickard (1973) to be on the order of 300–400 ft. In both these successions, the oldest part of the Utica Shale belongs to the *Geniculograptus pygmaeus* Zone (Riva, 1969a; Rickard, 1973) but toward the southeast, the biostratigraphic scope of the unit increases considerably. Hence, in the well-known Canajoharie section in the Mohawk Valley (Text-fig. 1), a >1,000-ft-thick succession of the Utica black shales contains diagnostic faunas of the *Corynoides americanus*, *Orthograptus ruedemanni*, and *Climacograptus* (*D.*) *spiniferus* Zones (Riva, 1969a,b; Rickard, 1973; Fisher, 1977). The relations between this expanded section of the Utica Shale and that at Trenton Falls are shown schematically in Text-figure 8 (also see Mitchell and Bergström, 1991).

In wells along an essentially east–west transect from New York across northern Pennsylvania into northern Ohio, the Trenton Limestone, of rather uniform thickness (Bergström and Mitchell, in press), is overlain by a body of dark shales having very similar lithology and the same stratigraphic position as the Utica Shale in its type area in New York (Rickard, 1973, pl. 15) (Text-fig. 8). This lithofacies appears to form a continuous shale body of relatively uniform appearance from New York to Ohio, hence justifying the use of the term Utica Shale also in northern Ohio.

Lithologically similar rocks, referred to as the Collingwood Shale (or the Whitby or Blue Mountain Formations) can be traced from New York northwestward (Text-fig. 8) across southern Ontario to Georgian Bay and Manitoulin Island (Russell and Telford, 1983). The graptolite species assemblage of this unit (Ruedemann, 1947) includes, among others, *Geniculograptus pygmaeus* and *G. typicalis magnificus*, indicating the upper *G. pygmaeus* Zone.

As shown diagrammatically in Text-figure 8, we conclude that the Utica Shale lithofacies can be

TABLE 1. — OCCURRENCE OF CONODONT SPECIES IN THE TRENTON LIMESTONE OF THE LOGAN COUNTY WELL

Species	Samples					
	90B3-1515	-1516–17	-1518	-1526	-1528	-1539
Amorphognathus tvaerensis Bergström	?	?	?	?	x	—
Belodina compressa (Branson and Mehl)	—	—	—	x	—	x
Dapsilodus mutatus (Branson and Mehl)?	x	x	x	—	x	x
Drepanoistodus suberectus (Branson and Mehl)	x	x	x	x	x	x
Icriodella superba Rhodes	—	x	—	—	x	—
"*Oistodus venustus* Stauffer"	x	x	x	x	—	—
Panderodus sp.	x	x	—	—	x	x
Periodon grandis (Ethington)	x	x	x	—	x	—
Phragmodus undatus Branson and Mehl	x	x	x	x	x	x
Plectodina sp.	—	—	—	—	x	x
Polyplacognathus ramosus Stauffer	—	—	—	x	—	x
Protopanderodus liripipus Kennedy et al.	x	—	—	—	—	—
Rhodesognathus elegans (Rhodes)	x	x	x	—	x	—

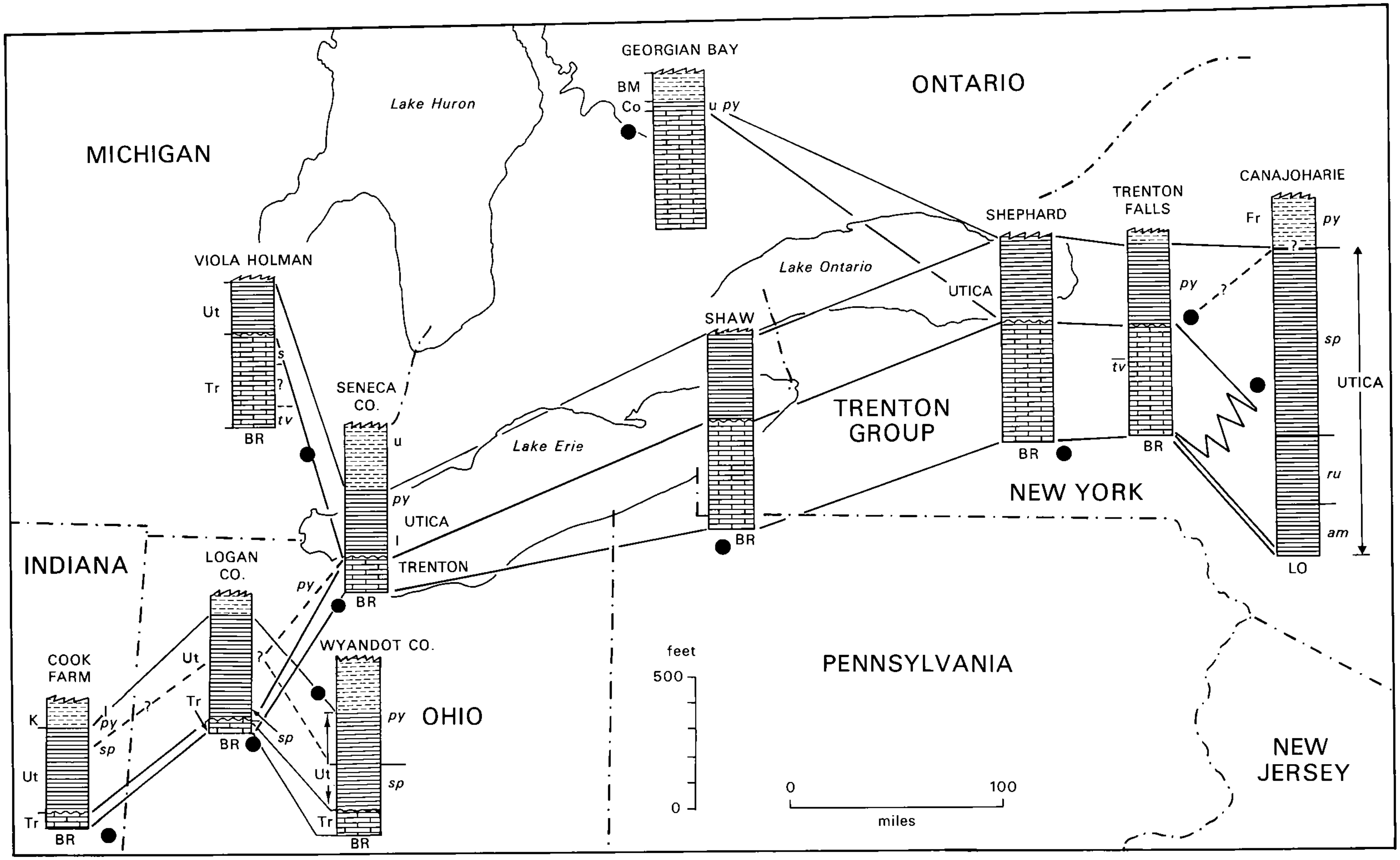
NOTE: Sample numbers are footage levels in the core. The top of the Trenton Limestone is at 1,513.5 ft and the samples are from the top 25.5 ft of the 38-ft-thick Trenton Limestone. The occurrence of *Amorphognathus tvaerensis* in sample 1528, 14.5 ft below the top of the Trenton Limestone, indicates the *A. tvaerensis* Zone. For illustrations of species, see Plate 1.

traced from eastern New York across a very wide area in the eastern Great Lakes region into the Michigan Basin and the Sebree Trough in southwestern Ohio and eastern Indiana. This lithofacies can also be traced northeastward from New York across the St. Lawrence Lowlands as far as Lake St. John and Anticosti Island, Quebec (Riva, 1969a). Graptolite evidence shows that deposition of these dark-brown to black sediments first started in the Mohawk Valley, New York (*Corynoides americanus* Zone), and somewhat later (*Orthograptus ruedemanni* Zone) on Anticosti Island, in the St. Lawrence Lowlands (Riva, 1969a,1972), and in the Sebree Trough (Bergström and Mitchell, 1990, in press; Mitchell and Bergström, 1991). The greatest regional extent of this lithofacies in the eastern Great Lakes region and eastward was during middle Edenian to middle Maysvillian time (*Geniculograptus pygmaeus* Zone).

UTICA SHALE–MAQUOKETA GROUP RELATIONS FROM INDIANA TO THE UPPER MISSISSIPPI VALLEY

Dark-brown to black shales representing a lithofacies similar to that of the Utica Shale are also widely distributed in the central Midcontinent region from Indiana and Michigan to the Upper Mississippi Valley (Gutstadt, 1958, fig. 5). We have carried out only preliminary biostratigraphic work on these shales, but the data obtained and the available literature data can be used for a preliminary regional comparison. In Text-figure 9 we illustrate the occurrence of the Utica Shale lithofacies in sections along a 460-mi transect from the Seneca well to a well in Rock Island County, westernmost Illinois. In this text-figure, the correlation of the Indiana sections follows Gray (1972) and that of the Illinois sections is based on Kolata and Graese (1983). The succession in westernmost Illinois is closely similar to that in eastern Iowa and the lithic units can be readily traced westward across the Mississippi River. Hence, the Rock Island County stratigraphic succession in Text-figure 9 is also applicable to eastern Iowa.

The pre-Silurian sequence of shales, mudstones, and limestones above the Trenton Limestone in Indiana and above the Galena Group in the Upper Mississippi Valley is now referred to as the Maquoketa Group in Indiana and Illinois (Gray, 1972; Kolata and Graese, 1983) and the Maquoketa Formation in Iowa and Minnesota (Witzke and Kolata, 1988). Except in the Sebree Trough in southeasternmost Indiana (Text-fig. 9, section 5), the Maquoketa Group (Formation) is of Late Ordovician (Cincinnatian) age. As shown in Text-figure 9, the base



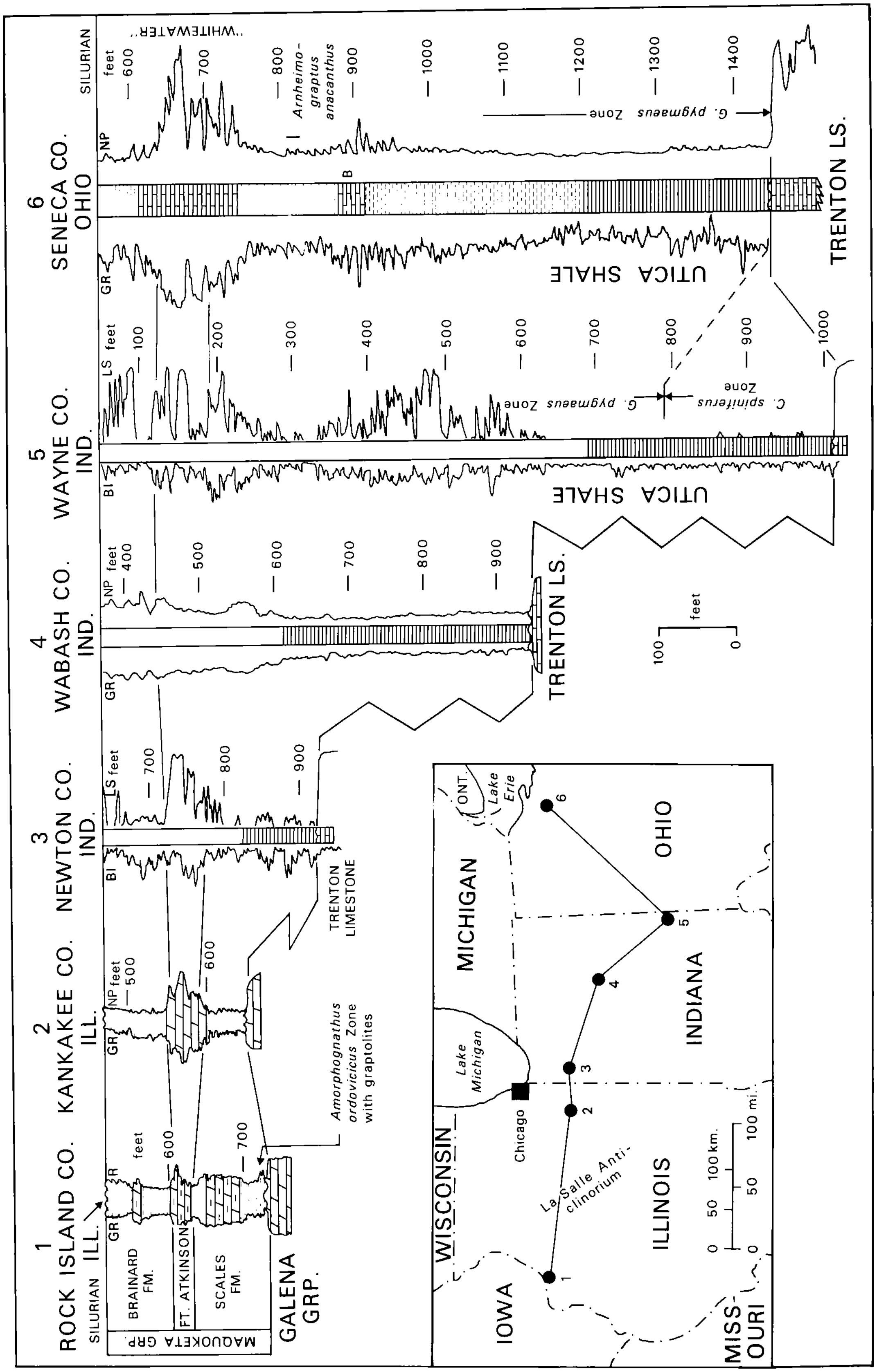
Text-figure 8. Comparison of Trenton Limestone–Utica Shale successions in the eastern Midcontinent region. Black dots mark geographic location of each section. Abbreviations are as follows: LO = Lower Ordovician; *am* = *Corynoides americanus* Zone; *ru* = *Orthograptus ruedemanni* Zone; *sp* = *Climacograptus* (*D.*) *spiniferus* Zone; *py* = *Geniculograptus pygmaeus* Zone; l = lower; u = upper; *s* = *Amorphognathus superbus* Zone; *tv* = *Amorphognathus tvaerensis* Zone; Fr = Frankfort Shale; BR = Black River Limestone; BM = Blue Mountain Formation; Co = Collingwood Shale; Tr = Trenton Limestone; Ut = Utica Shale; K = Kope Formation. Note the variable stratigraphic range of the Utica Shale lithofacies in different areas.

of the Maquoketa Group becomes progressively younger to the west across Indiana, but detailed biostratigraphic studies are needed to clarify whether this is due to a facies relationship with the underlying Trenton Limestone, or an increasingly large stratigraphic gap at the base of the Maquoketa Group. In Illinois and Iowa, the base of the Maquoketa Group (Formation) is Richmondian in age as shown by the fact that Glenister (1957) and Webers (1966) illustrated specimens of *Amorphognathus ordovicicus*, the index of the *A. ordovicicus* Zone, from the lowermost Maquoketa Formation of Iowa and Minnesota (also see Bergström, 1971). This is somewhat younger than recently published correlations (Sloan, 1987, fig. 2.6; Sweet, 1984,1987) and reflects new data on, among others, the vertical distribution of *A. superbus*, the evolutionary ancestor of *A. ordovicicus*, in the Cincinnati region (Izold, 1989). Interestingly, our interpretation of the relationships between the lower Maquoketa Group (Formation) and the Cincinnatian standard succession is closely similar to the interpretation advocated by many past workers based mainly on megafossils (e.g., Ladd, 1929; Twenhofel and others, 1954). As suggested by faunal evidence and geophysical log correlation (Text-fig. 9), the shales in the lowermost Maquoketa Group in Illinois (Scales Formation), and in the Elgin Member of the Maquoketa Formation of Iowa, may well have been deposited during the same transgressive event (the lower Maquoketa Subcycle of Witzke and Kolata, 1988) as that represented by the early Richmondian Waynesville Formation in the Cincinnati region. This interpretation is also supported by the fact that a conspicuous accumulation of biotite, interpreted by us as representing a K-bentonite bed, at the 899-ft level in the Seneca core in Ohio may well correspond to one of the two K-bentonite beds in the lower Dubuque Formation of Iowa recorded by Levorson and others (1987, p. 33). It also appears possible to trace the limestone-rich interval of the Fort Atkinson Formation across Illinois (Kolata and Graese, 1983) and Indiana (Gray, 1972), into the middle Richmondian limestones in easternmost Indiana and Ohio (Text-fig. 9). This correlation is in good agreement with the distribution of the fossil faunas.

As shown in Text-figure 9, dark-brown or black shales similar to the Utica Shale are present in the basal part of the Maquoketa Shale in subsurface sections across Indiana. Such shales, in the same stratigraphic position, are also exposed in the Kentland structure, northwestern Indiana, where they contain two K-bentonite beds (Templeton and Willman, 1963, p. 132), which may be the same as those in the upper Galena Group or the two in the lower Maquoketa Formation in eastern Iowa and Minnesota (Sloan, 1987). Shales of the Utica Shale lithofacies are present locally also in the lower Scales Formation of Illinois (Kolata and Graese, 1983) and in the Elgin Member of the Maquoketa Formation in Iowa (Sloan, 1987; Witzke and Kolata, 1988). Although graptolites are known from these dark shales at many localities, for instance, the Postville North section (Sloan and others, 1987, p. 215, fig. 1), the species recorded are in obvious need of taxonomic reassessment and existing records are of little, if any, use for detailed regional correlations. They do suggest, however, that the Illinois–Iowa lower Maquoketa graptolite faunas are younger than those of the *Geniculograptus pygmaeus* Zone in Ohio and elsewhere in the eastern Midcontinent. Accordingly, it appears that the Utica Shale lithofacies varies considerably in age from eastern Indiana to the westernmost sections of the transect in Text-figure 9. That the Ordovician dark shale lithofacies in the Upper Mississippi Valley is younger than that in Ohio, Pennsylvania, New York, and Quebec is also shown by the fact that black shales of the Maquoketa Formation in eastern Missouri contain graptolites interpreted to represent the Richmondian *Dicellograptus complanatus* Zone (Berry and Marshall, 1971).

UTICA SHALE LITHOFACIES IN THE MICHIGAN–WISCONSIN TRANSECT

In Text-figure 10 we illustrate the development of the upper Middle Ordovician and the Upper Ordovician in east–west transect from the Viola Holman well in the eastern part of the Michigan Basin to the Illinois Beach State Park well near the Illinois/Wisconsin border north of Chicago. A lithologically distinctive, 200–300-ft-thick unit of dark shale overlying the Trenton Limestone in the Michigan Basin subsurface is customarily referred to as the Utica Shale. Both this unit, and the underlying Trenton Limestone, are remarkably uniform in lithofacies and thickness across the Michigan Basin (Lilienthal, 1978), and there is little doubt that these units occupy a stratigraphic interval closely similar to that of the same units in the Viola Holman no. 1 well near Detroit. No graptolites have been described from the Utica Shale of the Michigan Basin, but regional stratigraphic relations suggest that this unit most likely represents the *Geniculograptus pygmaeus* Zone. Interestingly, Ruedemann and Ehlers (1924) recorded a *G. pygmaeus* Zone fauna from blocks of brownish shale near Newberry, Luce County, northern Michigan (Text-fig. 1), and a somewhat similar fauna was described by Berry (1970) from the Haymeadow Creek Shale at Haymeadow Creek, 10 mi northeast of Rapid River, Delta County, northern Michigan (Text-fig. 1). Both these graptolite faunas are from localities just outside the Michigan Basin. Although they are in need of taxonomic reassessment, the faunal data at hand do suggest that Utica Shale lithofacies of middle Cincinnatian age extends into the region between Lake Michigan and Lake Superior. In Wis-


1
ROCK ISLAND CO.
ILL.
2
KANKAKEE CO.
ILL.
3
NEWTON CO.
IND.
4
WABASH CO.
IND.
5
WAYNE CO.
IND.
6
SENECA CO.
OHIO
SILURIAN
MAQUOKETA GRP.
BRAINARD FM.
FT. ATKINSON
SCALES FM.
GALENA GRP.
GR
R
NP
LS
BI
feet
Amorphognathus ordovicicus Zone with graptolites
TRENTON LIMESTONE
TRENTON LS.
UTICA SHALE
G. pygmaeus Zone
C. spiniferus Zone
Arnheimograptus anacanthus
B
"WHITEWATER"
100
0
IOWA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
MISSOURI
ONT.
Lake Michigan
Lake Erie
Chicago
La Salle Anticlinorium
0 50 100 km.
0 50 100 mi.

consin the Maquoketa Formation has a similar lithofacies as in Iowa, although Froming (1971) recorded as much as 30–40 ft of brown shale in the Elgin Member in southwestern Wisconsin. Although no modern graptolite data are available from these rocks, there is little doubt that they are Richmondian in age.

A comparison between Text-figures 9 and 10 suggests that there is a conspicuous change in the general stratigraphical development of the interval under discussion in the Illinois/Indiana and Wisconsin/Michigan border region. Both east and west of this area, similar lithic units can be traced over large regions. We have been unsuccessful in directly relating this change to any known prominent structural feature but it occurs in the western portion of the Kankakee Arch (Collinson and others, 1988, fig. 5). However, the latter strikes WNW–ESE (Droste and Shaver, 1983, fig. 1), and its influence on the recognized regional depositional pattern of the Maquoketa Group is not very obvious and requires further study.

SUMMARY AND CONCLUSIONS

The Utica Shale is geographically one of the most widely recognized Lower Paleozoic stratigraphic units in the eastern Midcontinent of North America, but, surprisingly, its geology has been little studied, especially outside New York/Quebec. The present investigation, which is centered on the unit in Ohio, is not yet completed, but the following conclusions can be made based on the data at hand.

1) Graptolites show that the Utica Shale in Ohio and Indiana ranges from the *Orthograptus ruedemanni* Zone to the *Geniculograptus pygmaeus* Zone, hence from the late Middle Ordovician to the mid-Late Ordovician. The stratigraphically most extensive succession is in the Sebree Trough in southwestern Ohio and southeastern Indiana, whereas the Utica Shale in northern Ohio represents only the *G. pygmaeus* Zone, and, locally, the *Climacograptus (D.) spiniferus* Zone.

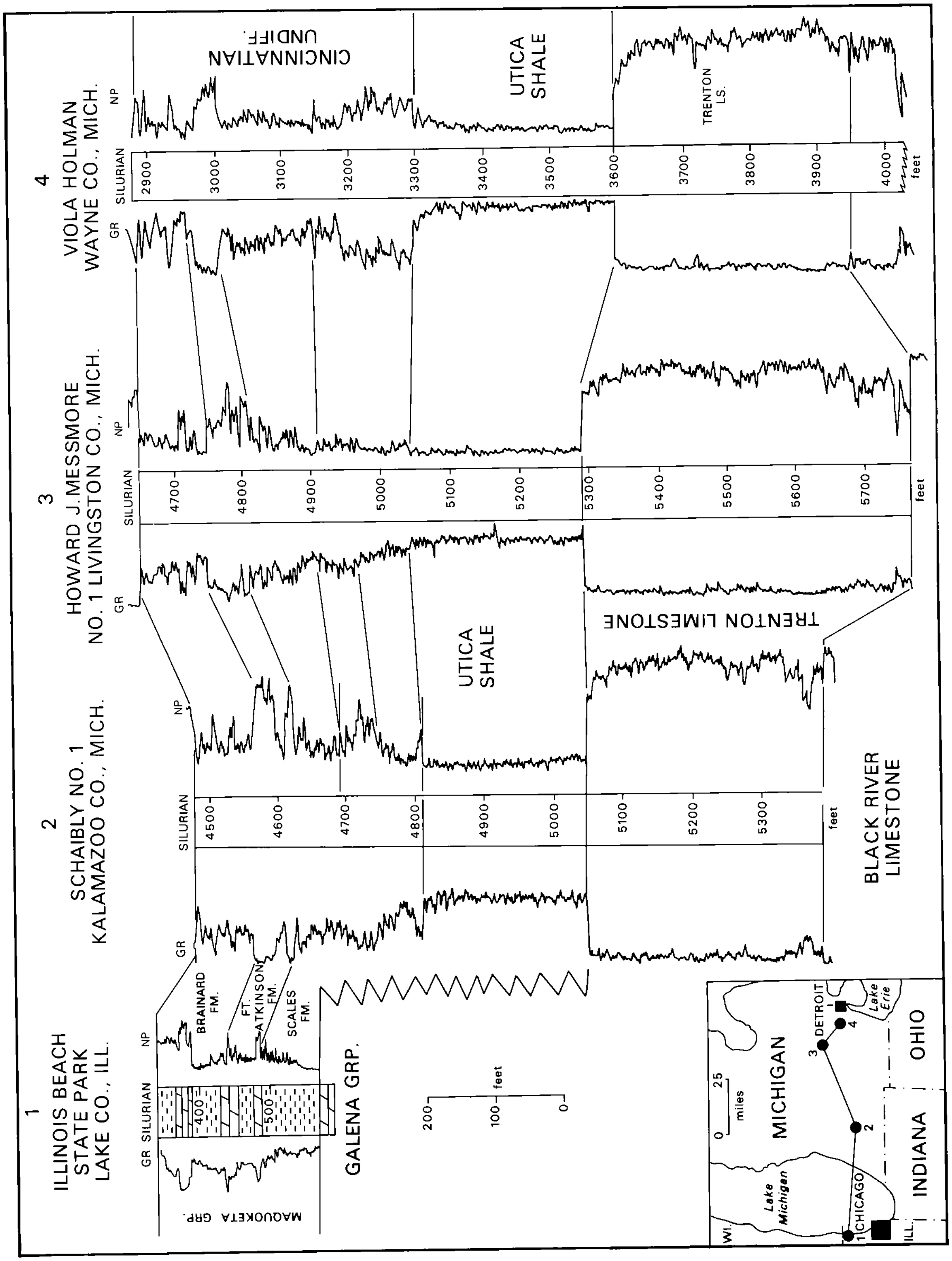
2) The contact between the Utica Shale and underlying Trenton Limestone is apparently disconformable over much of the Great Lakes region. In the Seneca core in northern Ohio, graptolite evidence indicates that this contact is associated with a substantial gap in the succession corresponding to the lower Edenian and possibly also to the upper Mohawkian. Similar gaps may well be present in other areas, but additional detailed biostratigraphic investigations are needed to clarify the existence of such gaps. We have found no clear evidence in support of the idea that the formation of the hardground at the top of the Trenton Limestone was associated with a regression and subaerial exposure; rather, we believe it represents a period of very slow, or interrupted, deposition in a submarine environment experiencing transition from relatively oxygen-rich to oxygen-poor conditions and increase in water depth. The contact between the Galena Group and the Maquoketa Group in Iowa and Illinois may reflect similar depositional conditions (Witzke and Kolata, 1988).

3) The dark shales overlying the Trenton Limestone in northern Ohio and in the Michigan Basin can be considered a western tongue of the type Utica Shale in New York, and in view of the close lithologic similarity and lateral continuity of the shale body between these areas, the use of the stratigraphic term Utica Shale in Ohio, as well as in the Michigan Basin, seems appropriate.

4) The Utica Shale in northern Ohio is physically connected with similar, but partly older, dark shales in the subsurface Sebree Trough of the Cincinnati region. These shales can be traced southward in the Sebree Trough from the Cincinnati region across westernmost Kentucky into northwestern Tennessee (Keith, 1989; Bergström and Mitchell, 1990).

5) The Utica Shale lithofacies extends in the subsurface across much of the Great Lakes region to

Text-figure 9 (opposite page). Comparison of the range of the Utica Shale lithofacies (horizontal ruling) in successions along a cross section from northern Ohio (Seneca well) to western Illinois (Rock Island County well). Sections 1 and 2 are based on Kolata and Graese (1983); 3–5 on Gray (1972); and 6 on Wickstrom and others (1985). Graptolite data are from studies by the present authors. The reference of the basal Maquoketa Group to the *Amorphognathus ordovicicus* Zone in section 1 is based on a projection across the Mississippi River from eastern Iowa, where the stratigraphic succession is closely similar to that in westernmost Illinois. Brown shales of the Utica Shale lithofacies are present locally in the lower Scales Formation in Illinois (Kolata and Graese, 1983), but are not known from the Illinois sections illustrated in this text-figure. Note the diachrony of this lithofacies from Ohio–eastern Indiana to western Indiana and Illinois. Based on this figure, the Maquoketa Group would correspond to part of the Richmondian of Ohio. The shaly Scales Formation would reflect the same regional transgression as the Waynesville Formation and associated strata in Ohio. Additional support for these suggested relationships may be the presence of a stratigraphically quite isolated K-bentonite bed (B) in the lower Richmondian of the Seneca core, which may correspond to one of the two locally preserved K-bentonite beds in the lower Dubuque Formation in eastern Iowa and Minnesota. For explanation of lithologic symbols, see legend on Text-figure 2. GR = gamma ray; R = resistivity; NP = neutron porosity; BI = bedding index; LS = limestone content.


1
ILLINOIS BEACH STATE PARK LAKE CO., ILL.
2
SCHAIBLY NO. 1 KALAMAZOO CO., MICH.
3
HOWARD J. MESSMORE NO. 1 LIVINGSTON CO., MICH.
4
VIOLA HOLMAN WAYNE CO., MICH.
GR
NP
SILURIAN
MAQUOKETA GRP.
BRAINARD FM.
FT. ATKINSON FM.
SCALES FM.
GALENA GRP.
400
500
4500
4600
4700
4800
4900
5000
5100
5200
5300
4700
4800
4900
5000
5100
5200
5300
5400
5500
5600
5700
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
feet
UTICA SHALE
CINCINNATIAN UNDIFF.
TRENTON LS.
TRENTON LIMESTONE
BLACK RIVER LIMESTONE
200
100
0
feet
0
25
miles
WI.
ILL.
Lake Michigan
CHICAGO
MICHIGAN
INDIANA
OHIO
DETROIT
Lake Erie
1
2
3
4

the Upper Mississippi Valley. There appears to be a significant facies change in the Wisconsin/Michigan and Illinois/Indiana border region where the Utica Shale lithofacies grades into the dominantly greenish gray shales and mudstones of the lower Maquoketa Group. Possibly, there may also be a facies relationship between the Utica Shale lithofacies and the limestones of the upper part of the Galena Group. West of this region, the typical Utica Shale lithofacies is irregularly distributed in the lower part of the Maquoketa Group (Formation), and in most sections it is thin. The Utica Shale lithofacies occurs also over much of southern Ontario and is present in outcrops as far north as Georgian Bay and Manitoulin Island, where it is referred to as the Collingwood Shale. In these distal parts of its distribution area, and also in the Upper Mississippi Valley, it is thin and of late Maysvillian–Richmondian age.

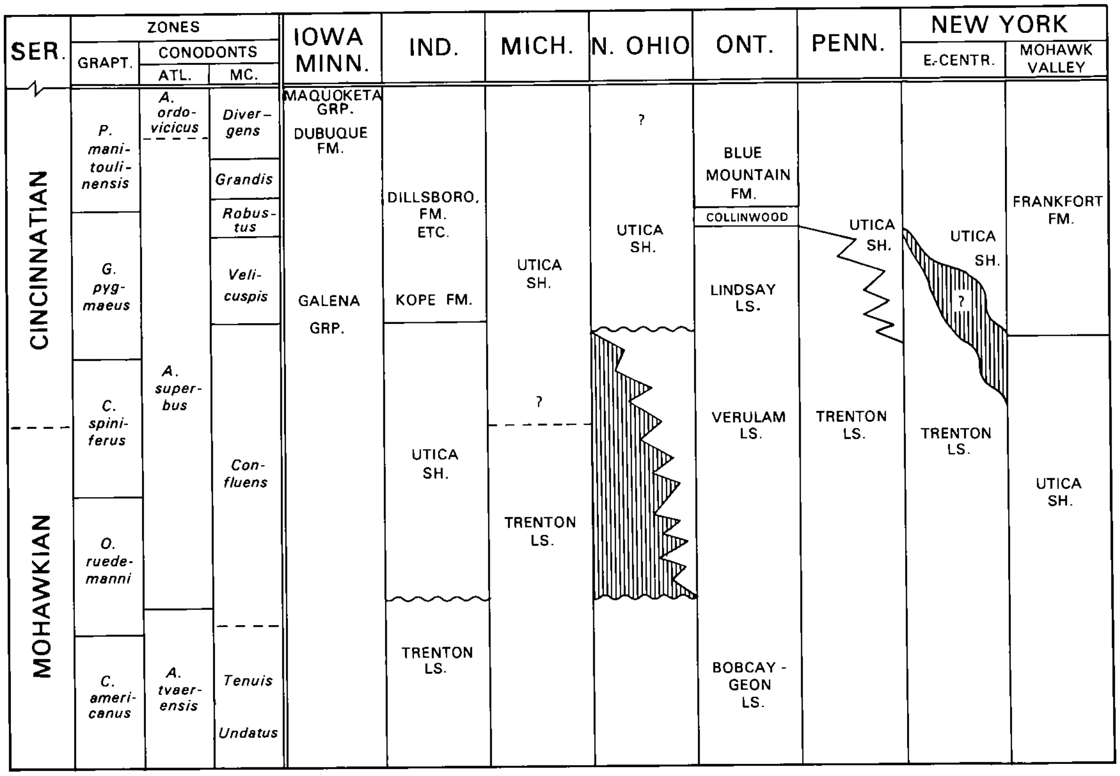
6) Our regional study shows that it is an oversimplification to consider the Utica Shale a thin blanket-type deposit laid down during a brief time interval. Rather, it is a complex mosaic of rocks with some significant local variations in age and lithology. However, the main body of this unit can be traced over literally thousands of square miles indicating a remarkable horizontal uniformity in depositional conditions in large areas of the cratonic interior during a part of Late Ordovician time. Clearly, without reliable biostratigraphic control—that has to be based mainly on graptolites—it would be impossible to unravel many interesting and important details in the depositional pattern in the vast Utica sea. This is shown by the fact that previous attempts to trace these shales regionally based on lithology (Gutstadt, 1958; Templeton and Willman, 1963) resulted in some significant correlation errors. Although much additional work is needed before the regional biostratigraphy of the Utica Shale is fully clarified, we attempt to summarize its known biostratigraphic extent in some key areas in Text-figure 11.

7) The environment of deposition of the Utica Shale lithofacies is still not well understood. In the Mohawk Valley, New York, it was clearly an anoxic environment at considerable water depth, perhaps several hundred feet or more. On the other hand, as recently described by Johnson and Rong (1989), dark graptolite-bearing shales were laid down under oxygen-poor conditions locally on Manitoulin Island, Ontario, as close as 1 ft above the Precambrian basement. This suggests that shales of the Utica Shale lithofacies could also have been deposited in relatively shallow water. Also, it may be significant that, in many cases, the Utica Shale lithofacies is present immediately on the top of Middle or Upper Ordovician carbonates (Trenton Limestone, Dubuque Formation, etc.), which were probably deposited in moderately shallow water. The fact that the age of the base of the Utica Shale succession shows considerable local and regional variation is not in good agreement with the interpretation that this lithofacies is present only in rocks that represent a sudden major transgression across the eastern Midcontinent. It appears that these dark shales were not deposited at a specific water depth, but rather reflect the dominance of specific environmental conditions, including a substantial influx of organic material, restricted circulation, and low-energy conditions. Witzke and Kolata (1988) suggested that the dark shales in the lower Maquoketa Group in the Upper Mississippi Valley were deposited in an environment with a stratified water mass with oxygen-poor phosphate-rich bottom waters.

8) It has been assumed generally that the major source area of the Utica siliciclastics was the Taconic highlands in the east, although some influx of clastics might have come also from the Ozark Dome and the Transcontinental Arch, particularly in the Upper Mississippi Valley (Witzke and Kolata, 1988). Based on the regional facies relationships, we favor this interpretation for the Great Lakes region, and in the case of the Sebree Trough, the Ozark Dome is likely to have been a very significant source area (Freeman, 1953, fig. 5). It is also conceivable that some siliciclastics might have been transported from the Ouachita basinal area into the trough by means of trough-parallel currents such as those envisioned by Cressman (1973, pl. 11).

9) Regionally, the peak of deposition of Utica Shale and related dark shales in Maysvillian time coincides with a general transgression over much of North America, particularly the southern and western parts of the Midcontinent (Sweet, 1979,1984). The fact that widespread dark shales similar to the Utica Shale are also known from the same stratigraphic interval in northwestern Europe (for instance, the Fjäcka Shale in the Baltoscandic region) might be taken as an indication of a global sea level change, but much additional evidence from other continents is required to confirm this.

Text-figure 10 (opposite page). Comparison of the Trenton Limestone–Utica Shale successions along a cross section across the Michigan Basin. Note lateral continuity of lithic units between sections 2–4 and the conspicuous facies change in the Trenton Limestone–Utica Shale interval between sections 1 and 2. This evidently corresponds to the facies change between sections 2 and 4 in Text-figure 9. Section 1 is after Kolata and Graese (1983); sections 2 and 3, after Lilienthal (1978); and section 4, after Faber (1979). For explanation of lithologic symbols, see legend on Text-figure 2. GR = gamma ray; NP = neutron porosity.



Text-figure 11. Summary diagram showing biostratigraphic classification of the Utica Shale and associated strata in key areas from New York to the Upper Mississippi Valley. The Iowa–Minnesota column refers to sections in northeastern Iowa and southeastern Minnesota; that of Indiana (IND.) to Sebree Trough sections in the easternmost part of the state; that of Michigan (MICH.), to the Michigan Basin; that of N. Ohio to sections described in the text; that of Ontario (ONT.), to eastern Manitoulin Island; and that of Pennsylvania (PENN.), to the Lake Erie region. Atlantic (ATL.), and Midcontinent (MC.) conodont zones are after Bergström (1971) and Sweet (1984,1987), respectively. Vertical ruling denotes stratigraphic gaps.

ACKNOWLEDGMENTS

We are indebted to the authorities of the Ohio Division of Geological Survey and the Indiana Geological Survey for making drill-cores available for study. Special thanks are due to T. M. Berg, G. Schumacher, B. Keith, C. B. Rexroad, H. Hayes, K. Tyler, S. Huelsman, J. R. Johnston, J. Mitchell, and B. Daye for helpful assistance. We gratefully acknowledge constructive reviews of the manuscript by R. L. Ethington and D. Kolata that resulted in several improvements of the text. The present research is an outgrowth of our studies on the evolution of the Sebree Trough, and acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support to S.M.B. for this research.

REFERENCES CITED

Bergström, S. M., 1971, Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and eastern North America: Geological Society of America Memoir 127, p. 83–157.

Bergström, S. M.; and Mitchell, C. E., 1986, The graptolite correlation of the North American Upper Ordovician standard: Lethaia, v. 19, p. 247–266.

______1990, Trans-Pacific graptolite faunal relations: the biostratigraphic position of the base of the Cincinnatian Series (Upper Ordovician) in the standard Australian graptolite zone succession: Journal of Paleontology, v. 64, p. 992–997.

______[in press], Regional relationships between late Middle and early Late Ordovician standard successions in New York–Quebec and the Cincinnati region in Ohio, Indiana, and Kentucky: New York State Museum Bulletin.

Berry, W. B. N., 1970, Late Ordovician graptolites from northern Michigan: Journal of Paleontology, v. 44, p. 270–275.

Berry, W. B. N.; and Marshall, F. C., 1971, Late Ordovician graptolites from the Maquoketa Formation in eastern Missouri: Journal of Paleontology, v. 45, p. 253–257.

Calvert, W. L., 1963, Sub-Trenton rocks of Ohio in cross sections from West Virginia and Pennsylvania to Michigan: Ohio Division of Geological Survey Report of Investigations 49, 5 p.

Collinson, C.; Sargent, M. L.; and Jennings, J. R., 1988, Illinois Basin region, *in* Sloss, L. L. (ed.), Sedimentary cover—North American Craton; U.S.: Geological Society of America, The Geology of North America, v. D-2, p. 383–426.

Cressman, E. R., 1973, Lithostratigraphy and depositional environments of the Lexington Limestone (Ordovician) of central Kentucky: U.S. Geological Survey Professional Paper 768, 59 p.

Droste, J. B.; and Shaver, R. H., 1983, Atlas of Early and Middle Paleozoic paleogeography of the southern Great Lakes area: Indiana Geological Survey Special Report 32, 32 p.

Faber, J. A., 1979, Geomagnetic reversal stratigraphy and conodont biostratigraphy of the Middle Ordovician Trenton Limestone, Michigan Basin: The Ohio State University unpublished M.S. thesis, 80 p.

Fisher, D. W., 1977, Correlation of the Hadrynian, Cambrian and Ordovician rocks in New York State: New York State Museum and Science Service Map and Chart Series 25, 75 p.

Freeman, L. B., 1953, Regional subsurface stratigraphy of the Cambrian and Ordovician in Kentucky and vicinity: Kentucky Geological Survey Bulletin 12, 352 p.

Froming, G. T., 1971, Maquoketa Shale, *in* Clark, D. L. (ed.), Conodonts and biostratigraphy of the Wisconsin Paleozoic: Wisconsin Geological and Natural History Survey Information Circular 19, p. 42–52.

Glenister, A. T., 1957, The conodonts of the Ordovician Maquoketa Formation in Iowa: Journal of Paleontology, v. 31, p. 715–736.

Gray, H. H., 1972, Lithostratigraphy of the Maquoketa Group (Ordovician) in Indiana: Indiana Geological Survey Special Report 7, 31 p.

Gutstadt, A. M., 1958, Upper Ordovician stratigraphy in eastern Interior Region: American Association Petroleum Geologists Bulletin, v. 42, p. 513–547.

Izold, M. D., 1989, Conodont biostratigraphy and paleoecology of the Upper Ordovician Miamitown Shale in the Cincinnati region, Ohio: The Ohio State University unpublished B.Sc. thesis, 43 p.

Johnson, M. E.; and Rong, Jia-yu, 1989, Middle to Late Ordovician rocky bottoms and rocky shores from the Manitoulin Island area, Ontario: Canadian Journal of Earth Sciences, v. 26, p. 642–653.

Kay, M., 1953, Geology of the Utica Quadrangle, New York: New York State Museum Bulletin 347, 126 p.

Keith, B. D., 1985, Facies, diagenesis, and the upper contact of the Trenton Limestone of northern Indiana, *in* Cecone, K. R.; and Budai, J. M. (eds.), Ordovician and Silurian rocks of the Michigan Basin and its margin: Michigan Basin Geological Society Special Paper 4, p. 15–32.

______1989, Regional facies of the Upper Ordovician Series of eastern North America, *in* Keith, B. D. (ed.), The Trenton Group (Upper Ordovician Series) of eastern North America. Deposition, diagenesis, and petroleum: American Association of Petroleum Geologists Studies in Geology, v. 29, p. 1–16.

Kolata, D. R.; and Graese, A. M., 1983, Lithostratigraphy and depositional environments of the Maquoketa Group (Ordovician) in northern Illinois: Illinois State Geological Survey Circular 528, 49 p.

Ladd, H. S., 1929, The stratigraphy and paleontology of the Maquoketa Shale of Iowa: Iowa Geological Survey Annual Report 34, p. 307–417.

Levorson, C. O.; Gerk, A. J.; Sloan, R. E.; and Bisango, L. A., 1987, General section of the Middle and Late Ordovician strata of northeastern Iowa, *in* Sloan, R. E. (ed.), Middle and Late Ordovician lithostratigraphy and biostratigraphy of the Upper Mississippi Valley: Minnesota Geological Survey Report of Investigations 35, p. 25–39.

Lilienthal, R. T., 1978, Stratigraphic cross-sections of the Michigan Basin: Michigan Geological Survey Report of Investigations 19, 36 p.

Mitchell, C. R.; and Bergström, S. M., 1977, Three-dimensionally preserved Richmondian graptolites from southwestern Ohio and the graptolite correlation of the North American Upper Ordovician standard: Bollettino della Societá Paleontologica Italiana, v. 16, p. 257–270.

______1991, On the definition and correlation of the base of the Cincinnatian Series (Upper Ordovician): new graptolite and lithostratigraphic evidence from the Cincinnati region, Indiana, Ohio, and Kentucky: Geological Survey of Canada Paper 90-9, p. 59–77.

Orton, E., 1888, The geology of Ohio, considered in its relations to petroleum and natural gas: Geological Survey of Ohio Report 6, 409 p.

Rickard, L. V., 1973, Stratigraphy and structure of the subsurface Cambrian and Ordovician carbonates of New York: New York State Museum and Science Service Map and Chart series 18, 26 p.

Riva, J., 1969a, Middle and Upper Ordovician graptolite faunas of St. Lawrence Lowlands of Quebec, and of Anticosti Island: American Association of Petroleum Geologists Memoir 12, p. 513–556.

______1969b, Utica and Canajoharie shales in the Mohawk Valley: New England Intercollegiate Geological Conference Guidebook, 61st annual meeting, p. 13-1–13-7.

______1972, Geology of the environs of Quebec City: 24th International Geological Congress, Guidebook for excursion B-19, p. 1–53.

______1974, A revision of some Ordovician graptolites of eastern North America: Palaeontology, v. 17 p. 1–40.

Ruedemann, R., 1947, Graptolites of North America: Geological Society of America Memoir 19, 651 p.

Ruedemann, R.; and Ehlers, G. M., 1924, Occurrence of the Collingwood Formation in Michigan: University of Michigan Museum Geological Contributions, v. 2, p. 13–18.

Russell, D. J.; and Telford, P. G., 1983, Revisions to the stratigraphy of the Upper Ordovician Collingwood beds of Ontario—a potential oil shale: Canadian Journal of Earth Sciences, v. 20, p. 1780–1790.

Sloan, R. E., 1987, Tectonics, biostratigraphy and lithostratigraphy of the Middle and Late Ordovician of the Upper Mississippi Valley, *in* Sloan, R. E. (ed.), Middle and Late Ordovician lithostratigraphy and biostratigraphy of the Upper Mississippi Valley: Minnesota Geological Survey Report of Investigations, v. 35, p. 7–20.

Sloan, R. E.; Kolata, D. E.; Witzke, J.; and Ludvigson, G. A., 1987, Descriptions of major outcrops in Minnesota and Iowa, *in* Sloan, R. E. (ed.), Middle and Late Ordovician lithostratigraphy and biostratigraphy of the Upper Mississippi Valley: Minnesota Geological Survey Report of Investigations, v. 35, p. 197–223.

Sweet, W. C., 1979, Late Ordovician conodonts and biostratigraphy of the western Midcontinent Province: Brigham Young University Geology Studies, v. 26, p. 45–85.

______ 1984, Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, U.S.A., *in* Bruton, D. L. (ed.), Aspects of the Ordovician System: University of Oslo, Palaeontological Contributions 295, p. 23–35.

______ 1987, Distribution and significance of conodonts in Middle and Upper Ordovician strata of the Upper Mississippi Valley region, *in* Sloan, R. E. (ed.), Middle and Late Ordovician lithostratigraphy and biostratigraphy of the Upper Mississippi Valley: Minnesota Geological Survey Report of Investigations, v. 35, p. 167–172.

Templeton, J. S.; and Willman, H. B., 1963, Champlainian Series (Middle Ordovician) in Illinois: Illinois State Geological Survey Bulletin 89, 260 p.

Twenhofel, W. H.; and others, 1954, Correlation of the Ordovician formations of North America: Geological Society of America Bulletin, v. 65, p. 247–298.

Walters, M., 1977, Middle and Upper Ordovician graptolites from the St. Lawrence Lowlands, Quebec, Canada: Canadian Journal of Earth Sciences, v. 14, p. 932–952.

Walters, M.; Lespérance, P. J.; and Hubert, C., 1982, The biostratigraphy of the Nicolet River Formation in Quebec and intra-North American correlation in Middle and Upper Ordovician strata: Canadian Journal of Earth Sciences, v. 19, p. 571–588.

Webers, G. F., 1966, The Middle and Upper Ordovician conodont faunas of Minnesota: Minnesota Geological Survey Special Publication SP-4, 123 p.

Wickstrom, L. H.; and Gray, J. D., 1989, Geology of the Trenton Limestone in northwestern Ohio, *in* Keith, B. D. (ed.), The Trenton Group (Upper Ordovician Series) of eastern North America. Deposition, diagenesis, and petroleum: American Association of Petroleum Geologists Studies in Geology, v. 29, p. 159–172.

Wickstrom, L. H.; Botoman, G.; and Stith, D. A., 1985, Report on a continuously cored hole drilled into the Precambrian in Seneca County, northwestern Ohio: Ohio Division of Geological Survey Information Circular 51, 1 p.

Witzke, B. J.; and Kolata, D. R., 1988, Changing structural and depositional patterns, Ordovician Champlainian and Cincinnatian Series of Iowa–Illinois, *in* Ludvigsen, G. A.; and Bunker, B. J. (eds.), New perspectives on the Palaeozoic history of the Upper Mississippi Valley. An examination of the Plum River fault zone: Iowa Department of Natural Resources, Geological Survey Bureau Guidebook 8, p. 55–77.

Plate

PLATE 1

SEM micrographs of conodonts from the Trenton Limestone of the Logan County well. Second part of sample number indicates the footage level from which the specimen was obtained. All specimens are registered and housed in the type collection of the Orton Geological Museum (OSU) at The Ohio State University.

Figures 1,2.—*Protopanderodus liripipus* Kennedy et al., lateral views, sample 90B3-1515. **1**, ×36, OSU 45701. **2**, ×43, OSU 45702; note that this type of element has a considerably shorter base than does OSU 45701 (Fig. 1).

Figure 3.—*Dapsilodus mutatus* (Branson and Mehl)?, lateral view, sample 90B3-1518, ×78, OSU 45703.

Figure 4.—"*Oistodus venustus* Stauffer," lateral view, sample 90B3-1518, ×110, OSU 45704. This element may possibly belong to the same apparatus as OSU 45703 (Fig. 3); if this is the case, this apparatus probably should be referred to *Besselodus* Aldridge, 1982, but the collections are insufficient to evaluate this possibility.

Figures 5,6.—*Panderodus* sp., lateral views, sample 90B3-1539. **5**, ×100, OSU 45705. **6**, ×90, OSU 45706.

Figures 7–9.—*Drepanoistodus suberectus* (Branson and Mehl), lateral views, sample 90B3-1518. **7**, ×30, OSU 45707. **8**, ×30, OSU 45708. **9**, ×25, OSU 45709.

Figures 10–13.—*Phragmodus undatus* Branson and Mehl. **10**, lateral view, Pb element, sample 90B3-1515, ×40, OSU 45710. **11**, lateral view, Pa element, sample 90B3-1539, ×52, OSU 45711. **12**, lateral view, M element, sample 90B3-1539, ×55, OSU 45712. **13**, lateral view, Sc element, sample 90B3-1539, ×55, OSU 45713.

Figures 14,15.—*Icriodella superba* Rhodes, upper views, Pa element. **14**, sample 90B3-1528, ×45, OSU 45714. **15**, sample 90B3-1516–1517, ×32, OSU 45715; note that compared with OSU 45714 (Fig. 14), this is a larger and more robust specimen, indicating that the lateral expansions on the element became relatively more prominent during the ontogeny.

Figures 16,17.—*Rhodesognathus elegans* (Rhodes). **16**, lateral view, Pa element, sample 90B3-1515, ×70, OSU 45716. **17**, antero-lateral view, Pb element, sample 90B3-1518, ×80, OSU 45717.

Figure 18.—*Belodina compressa* (Branson and Mehl), lateral view, denticulate rostrate element, sample 90B3-1539, ×100, OSU 45718.

Figures 19–21.—*Periodon grandis* (Ethington). **19**, lateral view, P element, sample 90B3-1518, ×70, OSU 45719. **20**, lateral view, S element, sample 90B3-1515, ×60, OSU 45720. **21**, lateral view, M element, sample 90B3-1515, ×90, OSU 45721.

Figures 22,23.—*Polyplacognathus ramosus* Stauffer, stelliform platform element, sample 90B3-1526, ×47. **22**, lower view, OSU 45722. **23**, upper view, OSU 45723.

Figures 24–30.—*Amorphognathus tvaerensis* Bergström, sample 90B3-1528. **24**, lateral view, right Pb element, ×45, OSU 45724. **25**, lateral view, left Pb element, ×45, OSU 45725. **26**, lateral view, Sa element, ×90, OSU 45726. **27**, lateral view, Sd element, ×100, OSU 45727. **28**, postero-lateral view, M element, ×100, OSU 45728. **29**, upper view, posterior portion of Pa element, ×48, OSU 45729. **30**, upper view, posterior portion of Pa element, ×48, OSU 45730. Note that each of OSU 45729 (Fig. 29) and OSU 45730 (Fig. 30) has a distinctly bifid posterior process, which is one of the diagnostic features of *A. tvaerensis*.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

Oklahoma Geological Survey Bulletin 145, 1992

Stringocephalus (Brachiopoda) from Middle Devonian (Givetian) Rocks of the Baird Group, Western Brooks Range, Alaska

Robert B. Blodgett
U.S. Geological Survey, Reston, Virginia

J. Thomas Dutro, Jr.
U.S. Geological Survey, Washington, D.C.

ABSTRACT.—Stringocephalid brachiopods are described for the first time from Middle Devonian carbonate rocks of the western Brooks Range, Alaska. This large collection, probably representing a single shell bed, contains a wide range of shell shape and size that permits an analysis of growth from early maturity to extreme old age. Effects of crowding are also evident. Despite a wide range in strength and massiveness of internal structures, we interpret all the specimens, save one, as representing a single species of *Stringocephalus* (*Stringocephalus*). These fossils indicate a Givetian age for the lower part of the Baird Group as mapped in the De Long Mountains Quadrangle. Co-occurring conodonts suggest a Lower or Middle *varcus* Subzone age, compatible with the classical interpretation of the age-significance of *Stringocephalus*. The stringocephalid shell bed probably accumulated very near where these shells lived, on the shoreward side of a reefoid mass on a shallow, warm-water carbonate shelf. From a paleobiogeographic point of view, stringocephalids were widely distributed in the tropical and subtropical Old World Realm, and northwestern Alaska falls at ~15° north paleo-latitude in the path of the North Equatorial Current, according to the reconstruction of Heckel and Witzke (1979).

INTRODUCTION

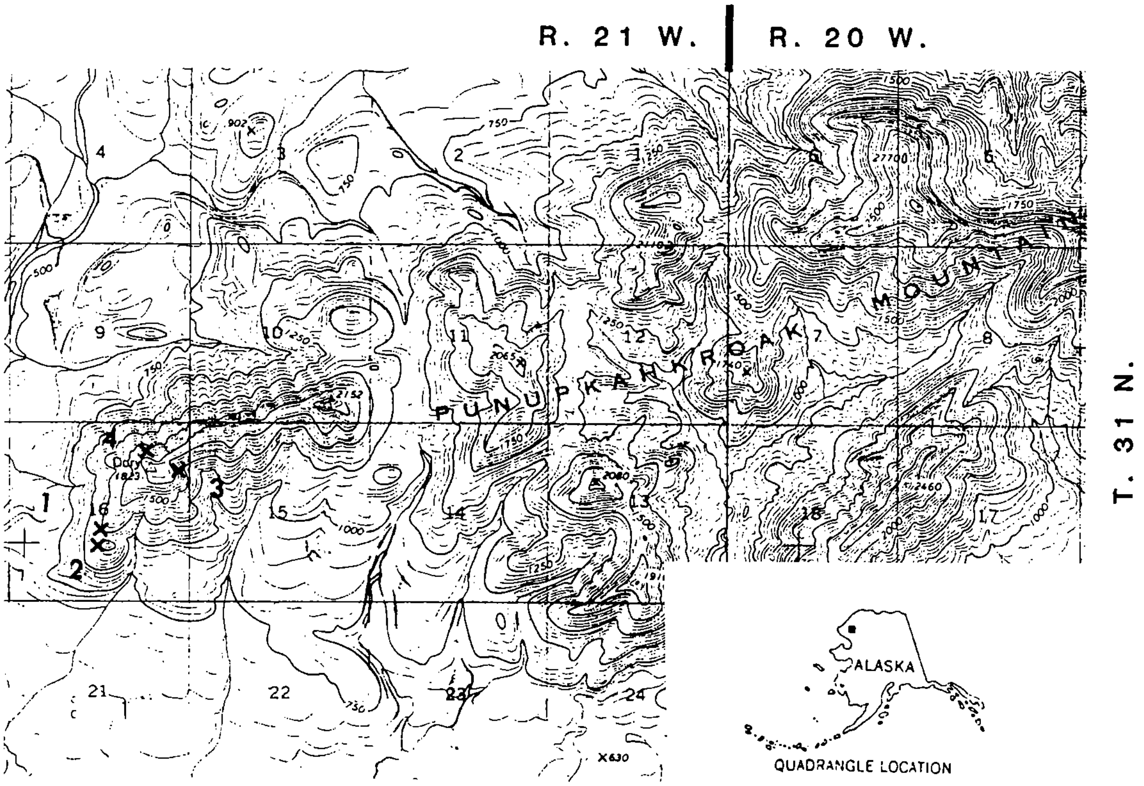
This paper presents the first taxonomic descriptions of stringocephalid brachiopods from Alaska. Citations to their presence in Alaska are found in the literature, but no descriptions have been published previously. Two localities were noted off the west coast of Prince of Wales Island, southeastern Alaska (Kirk, 1927, p. 219–220; Boucot and others, 1966, p. 1360). Two other stringocephalid-bearing localities were previously recorded from the Brooks Range of northern Alaska. One is J. B. Mertie's "*Conchidium*" locality (lat 67°58'N., long 149° 25'W.), 50–100 ft below the top of the Skajit Limestone, in the Chandalar Quadrangle of the central Brooks Range (J. T. Dutro, Jr., in Boucot and others, 1966, p. 1360). The other locality, USGS locality 11925-SD of this paper, is from the southwest end of Punupkahkroak Mountain, De Long Mountains A-3 Quadrangle, western Brooks Range. Here was collected the only previously illustrated specimen of an Alaskan stringocephalid, a form identified as "undetermined stringocephalid" (Blodgett and others, 1988, figs. 1.7–1.9). Our purpose here is to document the entire stringocephalid fauna from Punupkahkroak Mountain.

The described specimens were collected by the senior author on July 17, 1984, from the west side of Punupkahkroak Mountain, De Long Mountains A-3 Quadrangle, western Brooks Range, Alaska, at four separate localities (Text-fig. 1):

Locality 1.—USGS 11106-SD (84RB118), north side of topographic saddle at point where rubble slope intersects saddle at southwest end of Punupkahkroak Mountain, NW¼NW¼SE¼ sec. 16, T. 31 N., R. 21 W., De Long Mountains A-3 Quadrangle (lat 68°05'03"N., long 163°28'54"W.). Dark-gray lime mudstone with common silicified fossils, including brachiopods (predominantly stringocephalids), stromatoporoids, solitary rugose corals, and gastropods.

Locality 2.—USGS 11925-SD (84RB119), southwest side of same saddle as Locality 1, SW¼NW¼ SE¼ sec. 16, T. 31 N., R. 21 W., De Long Mountains A-3 Quadrangle (lat 68°05'03"N., long 163°28' 57"W.). Silicified fossils found in dark-gray lime mudstone (stringocephalids and solitary rugose corals).

Locality 3.—USGS 11926-SD (84RB121), abundant silicified stringocephalid brachiopods recovered from talus rubble on northeast side of hill (elevation approximately 2,000–2,050 ft), 500 ft slightly



Text-figure 1. Index map showing location of collecting area in the De Long Mountains A-3 Quadrangle, western Brooks Range, Alaska. Collecting localities: 1 = USGS 11106-SD; 2 = USGS 11925-SD; 3 = USGS 11926-SD; 4 = USGS 11927-SD. Latitude and longitude at corner just west of Locality 2 are 68°05′N. and 163°30′W.

north of due east of triangulation station Dory, SW¼ SE¼NE¼NE¼ sec. 16, T. 31 N., R. 21 W., De Long Mountains A-3 Quadrangle (lat 68°05′23″N., long 163°28′12″W.).

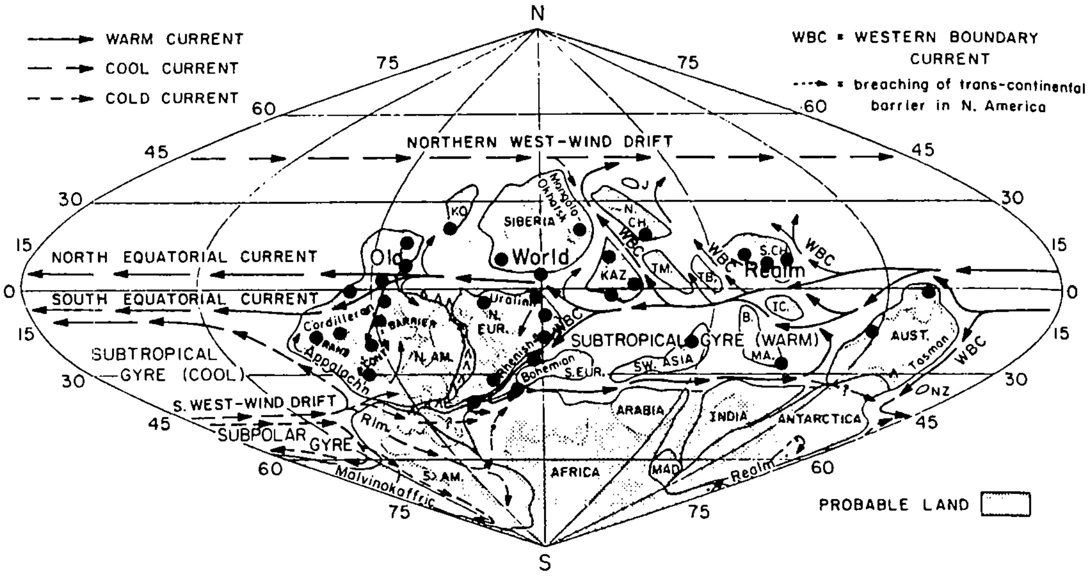
Locality 4.—USGS 11927-SD (84RB122), silicified stringocephalid brachiopods and corals weathered-free and recovered from talus rubble on northwest side of hill, ~280 ft N.30°W. of triangulation station Dory, SE¼NW¼NE¼ sec. 16, T. 31 N., R. 21 W., De Long Mountains A-3 Quadrangle (lat 68°05′22″N., long 163°28′31″W.).

Age of the Localities

Although there have been some reports of earlier and later occurrences, all verified records of stringocephalids appear restricted to the Givetian (late Middle Devonian). Boucot and others (1966) summarized the biostratigraphic arguments clearly. Johnson and others (1980) discussed the upper limit of *Stringocephalus* occurrences and indicated that the range is limited to the Middle Devonian. Since about 1980, various decisions of the Devonian Subcommission on Stratigraphy have had the effect of moving the Middle–Upper Devonian boundary higher than had previously been the case (Ziegler and Klapper, 1982,1985; Ziegler, 1986). Consequently, there is no longer any doubt about the late Middle Devonian signature of stringocephalid occurrences.

Conodonts collected at one of the Alaskan localities (USGS 11106-SD) include *Polygnathus linguiformis* Hinde and *Polygnathus pseudofoliatus* Wittekindt (Anita G. Harris, personal communication, 1985). According to Harris, "Its [*P. pseudofoliatus*] co-occurrence with stringocephalid brachiopods further restricts the age of the sample to the Lower and Middle *varcus* Subzones." In other words, the age is early Givetian.

The rocks from which these fossils were collected in the De Long Mountains Quadrangle, western Brooks Range, were mapped by Mayfield and others (1983) as an unnamed limestone unit in the lower part of the Baird Group, a dominantly Devonian carbonate sequence that occurs in many places throughout the western Brooks Range. This unit is also the age equivalent to the lower part of the Kugururok Formation as mapped by Mayfield and others (1988).



Text-figure 2. Paleogeographic map of the world showing the distribution of stringocephalids plotted on a base prepared by Heckel and Witzke (1979) for a Middle Devonian paleogeography with expected oceanic currents indicated.

Distribution and Paleogeography

Most occurrences of the stringocephalid biofacies are concentrated in what has been interpreted by most paleogeographers as tropical or marginal-subtropical regions during Middle Devonian time. One of the more useful paleogeographical reconstructions is that of Heckel and Witzke (1979) who presented several versions of maps of Devonian geographies. Particularly applicable is their figure 5A, a reconstruction of the Middle Devonian including an expected pattern of oceanic circulation. When stringocephalid localities are plotted on this base, the latitudinal spread is from about 30°N. to 35°S. (Text-fig. 2). All distributions can be accounted for by postulating east–west movement of larvae in the Equatorial Current and its subsidiary gyres, as positioned by Heckel and Witzke (1979). The geographic occurrences are taken mostly from Boucot and others (1966), with additions from the literature of the past two decades. None of this later information changes the basic pattern. It is quite striking that all distributions can be accounted for, in detail, by the currents as drawn by Heckel and Witzke (1979). The more southern and northern occurrences, in northwest Africa and Siberia, respectively, are in the direct paths of branches of the Equatorial Current called the Western Boundary Current (WBC). Likewise, splits off the South Equatorial Current in North America account for the widespread distribution in the western Cordillera, Manitoba, and even Indiana. Australian and east Asian localities are all in the region swept by the Subtropical Gyre.

SYSTEMATIC PALEONTOLOGY

Subfamily **Stringocephalinae** King, 1850

Diagnosis.—"Large genera of Stringocephalidae with prominent, incurved ventral beak and umbo. Ventral median septum present; dorsal median septum present or absent. Stalk-like cardinal process present. Outer hinge plates prominent, curved, closely spaced near the midline. Crural plates absent in known species" (Johnson, 1975, p. 981).

Discussion.—Two genera are assigned to this subfamily: *Stringocephalus* Defrance, 1825, and *Omolonia* Alekseeva (in Alekseeva and Nuzhdina, 1967). The former genus was split into two subgenera by Struve (1965): *S.* (*Stringocephalus*) (type species, *Terebratula burtini* Defrance, in Blainville, 1825) and *S.* (*Parastringocephalus*) Struve, 1965 (type species, *Strygocephalus dorsalis* D'Archiac and De Verneuil, 1842). The essential differences between the two subgenera are the presence in the latter of a median sinus in both valves and a fine, radially striate external ornament. According to Struve (1965), a median sinus is always absent from the dorsal valve, as is an ornament of fine radial striations, in the former. The genus *Omolonia* Alekseeva differs from *Stringocephalus*, according to Alekseeva (in Alekseeva and Nuzhdina, 1967), in its lack of a dorsal median septum, as well as in having a differing form ("mushroom-like") of cardinal process. Because of the variability in the presence or absence of a dorsal median septum both in these Alaskan stringocephalids and in comparable Manitoban species, we are not certain that any real differences exist between

Stringocephalus (*Stringocephalus*) and *Omolonia*. The problem of the different form of cardinal process remains unresolved, but judging from the tranverse serial sections of the type species, *Omolonia antiqua* Alekseeva (in Alekseeva and Nuzhdina, 1967, fig. 1), we are uncertain that there are any differences in the cardinal process. These matters should be pursued further by a study of a larger population of specimens of the type species of *Omolonia*.

Genus **Stringocephalus** Defrance, 1825
Subgenus **Stringocephalus (Stringocephalus)** Defrance, 1825

Stringocephalus (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968

Plate 1, Figures 1–8; Plate 2, Figures 1–8;
Plate 3, Figures 1–7; Plate 4, Figures 1–6;
Plate 5, Figures 1–8; Plate 6, Figures 1–7

Synonomy.—

cf. *Stringocephalus noctua* Crickmay, 1968, p. 10, pl. 8, figs. 1–7; pl. 9, figs. 1–8; pl. 14, figs. 6–7; pl. 15, figs. 1–5; pl. 16, figs. 1–7; pl. 17, figs. 1–4.

cf. *Omolonia noctua* (Crickmay) Johnson, 1975, pl. 1, figs. 1–10.

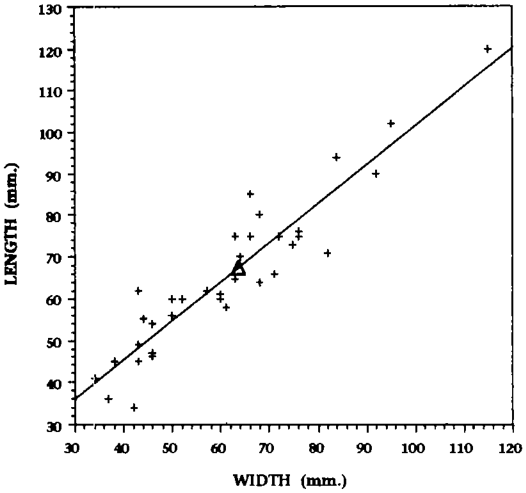
Undetermined stringocephalid Blodgett and others, 1988, p. 47, 49–50, figs. 1.7–1.9.

Description.—Medium- to large-sized, smooth, subglobose, ventribiconvex shells; cardinal margin submegathyrid, lateral margins rounded; ventral valve two to three times thicker than dorsal valve; ventral valve outline pyriform, dorsal valve outline subellipsoidal; ventral valve strongly convex in lateral profile, greatest convexity in umbonal region, greatest width of ventral valve slightly anterior of valve midlength; dorsal valve moderately convex, its greatest width located slightly posterior of valve midlength; a weak, broad, shallow sulcus is commonly developed in the posterior-most (umbonal) part of dorsal valve; ventral beak slightly incurved, strongly projecting posteriorly beyond cardinal margin, beak varying from suberect in young specimens (Pl. 3, Fig. 1) to strongly incurved in more mature specimens (Pl. 1, Fig. 2; Pl. 2, Fig. 8); beak ridges sharp, well defined; pedicle foramen marginally hypothyrid, rounded; delthyrium subtending an angle of 60–70°, closed by conjunct deltidial plates (henidium); anterior commissure seemingly rectimarginate or weakly sulcate; ornament consists of only wide-spaced growth lines; punctae not observed; color patterns, consisting of narrow, concentric bands, noted previously in one specimen (USNM 412325) (Blodgett and others, 1988, figs. 1.7–1.9); ventral interior with strong dental ridges, teeth prominent, blunt; ventral median septum arising in umbonal cavity and extending to anterior commissure as a high, thin blade; dorsal interior with two large, medially disjunct, curved hinge plates; strongly curved, distally bifid, cardinal process lies between the hinge plates; low, thick, anteriorly tapering median septum extends anteriorly from cardinal process, median septum restricted to posterior half of valve; in several valves the median septum is absent; adductor muscle scars moderately impressed, expanding anteriorly; loop unknown.

Comparison.—In both external and internal characters, the Alaskan specimens compare most closely with *Stringocephalus noctua* Crickmay, 1968, from the Winnipegosis Formation ("quarry on the west side of The Narrows . . . also from Salt Point"), Manitoba. The general similarity of shape is best made by comparison with the illustrations of Crickmay's paratype no. 1 (pl. 15, figs. 1–5), a specimen which retains external shell material. Both the Alaskan and Manitoban forms are characterized by an unusually strong, posteriorly projecting, incurved ventral beak, a ventral valve with a pyriform outline, and a short, low posteriorly restricted dorsal median septum, which may or may not be present. The two forms are also approximately contemporaneous, according to conodont evidence. Referring to conodonts from the Winnipegosis Formation, Norris and others (1982, p. 37) stated that the "only highly productive Winnipegosis sample came from an abandoned quarry just east of the Narrows. . . . The conodont fauna belongs to the Lower *P. varcus* Subzone." As noted above, the conodonts associated with the Alaskan specimens suggest a range of Lower to Middle *varcus* Subzones (Anita G. Harris, personal communication, 1985). Johnson (1975) referred *Stringocephalus noctua* to the genus *Omolonia* Alekseeva with the assumption that it lacked a dorsal median septum. However, Crickmay's illustrations of internal molds and transverse serial sections show a dorsal median septum to be present, as does Johnson's re-illustration of Crickmay's paratype 5 (Johnson, 1975, pl. 1, figs. 6,10). Indeed, Crickmay (1968, p. 10) reported, concerning the character of the dorsal median septum, "Dorsal mesial septum, very low in apical vicinity (from some it is absent), becoming thick in most specimens, low and round in all its length, disappearing posterior to the centre of disk." A very similar description can be applied to the Alaskan material. Pending acquisition of, and comparison with, an adequate-sized population of the Manitoban species, we cannot confirm the species-level identification of the Alaskan material, but we suggest that the forms are probably closely related, if not conspecific.

Variability.—Seldom are we fortunate enough, when dealing with big shells like *Stringocephalus*, to make a representative collection of measureable specimens to address the problem of population variability. However, in three of these collections there is a total of 67 specimens, 55 of them from a single locality.

Ontogeny of these large species has rarely been discussed, mainly because poor preservation in massive carbonate rocks makes collecting whole specimens difficult, if not impossible. When silicified material is available, the smaller specimens may be freed from the matrix and examined. The only comprehensive treatment of shell growth was by Boucot and others (1966), who showed that stringocephalid internal morphologic characters are preserved in the smallest specimens available to them (3 mm wide). They sorted the growth into two stages which they called "small" and "large." Their large stage appears to be defined as beginning at a width of ~20 mm.

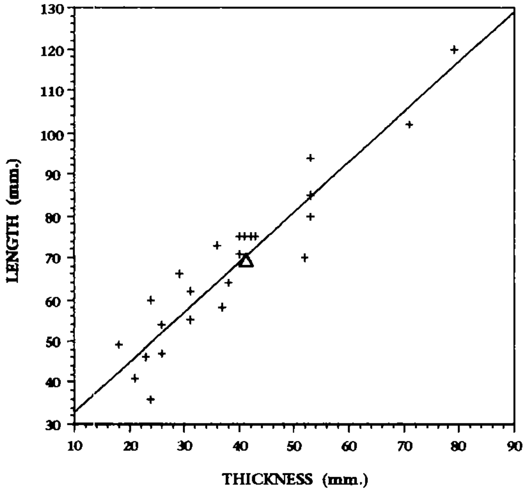


Text-figure 3. Length–width plot of measurements of 35 specimens for which both dimensions were measurable (in mm). Δ = arithmetic mean. Diagonal line is a regression line, fitted by eye.

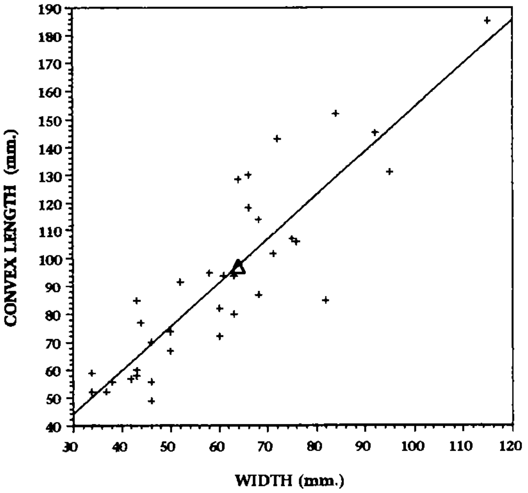
All our Alaskan specimens fall within the "large" stage of Boucot and others (1966); the smallest is 34 mm wide and the largest is ~120 mm wide. Because most of the specimens were collected from a single bed, we have an opportunity to examine variability in what almost certainly was a valid genetic population. Additionally, the overall shape of the shells reflects the effect of crowding in what appears to have been the customary environmental mode for these large shells—shallow-water, near-reef areas. As was pointed out by both Frost and Langenheim (1966) and Boucot and others (1966), these lime-mud shallows were most often on the landward side of reefoid patches.

The size-range of the Alaskan stringocephalid population is shown graphically in Text-figures 3–5. The length–width and length–thickness graphs (Text-figs. 3,4, respectively), as expected from earlier published general studies of brachiopod growth (Boucot and others, 1966; Hallam, 1962; Grinnell and Andrews, 1964; Sutherland and Harlow, 1973), reflect most accurately the growth vectors of this species.

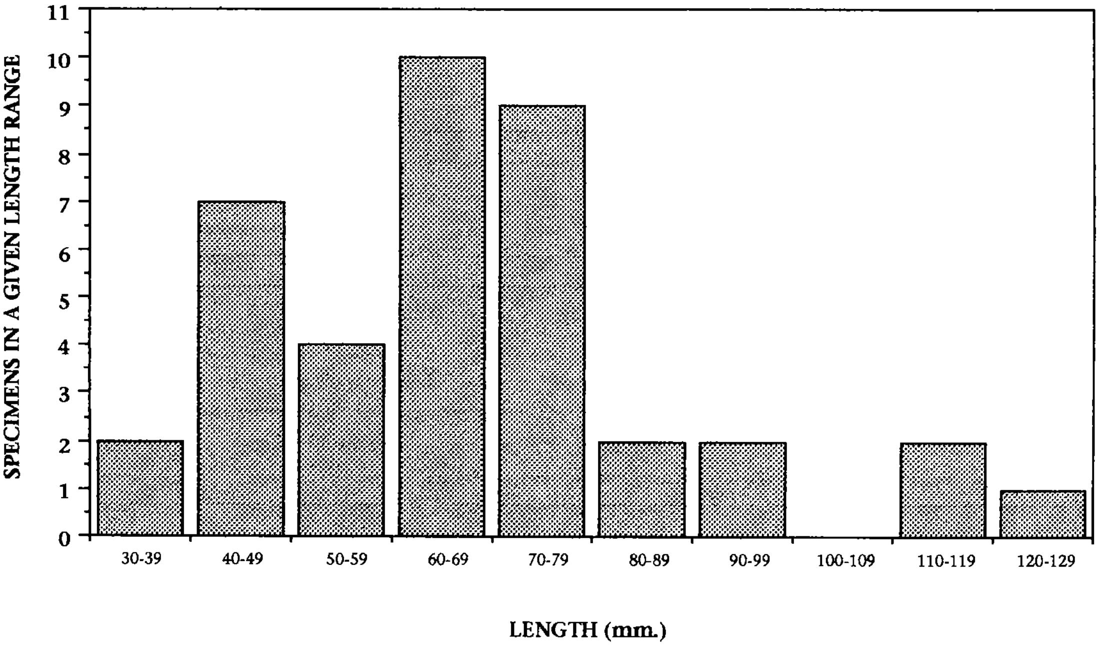
The greatest length (measured as convex length along the midline of the ventral valve) partially reflects shape modifications due to crowded growth conditions. This is best shown in Text-figure 5 in which the convex length is plotted against width. Other effects of crowding are unusually narrow shells, skewed and twisted ventral beaks, pinched umbos, and other shape irregularities that diverge from normal biconvexity.



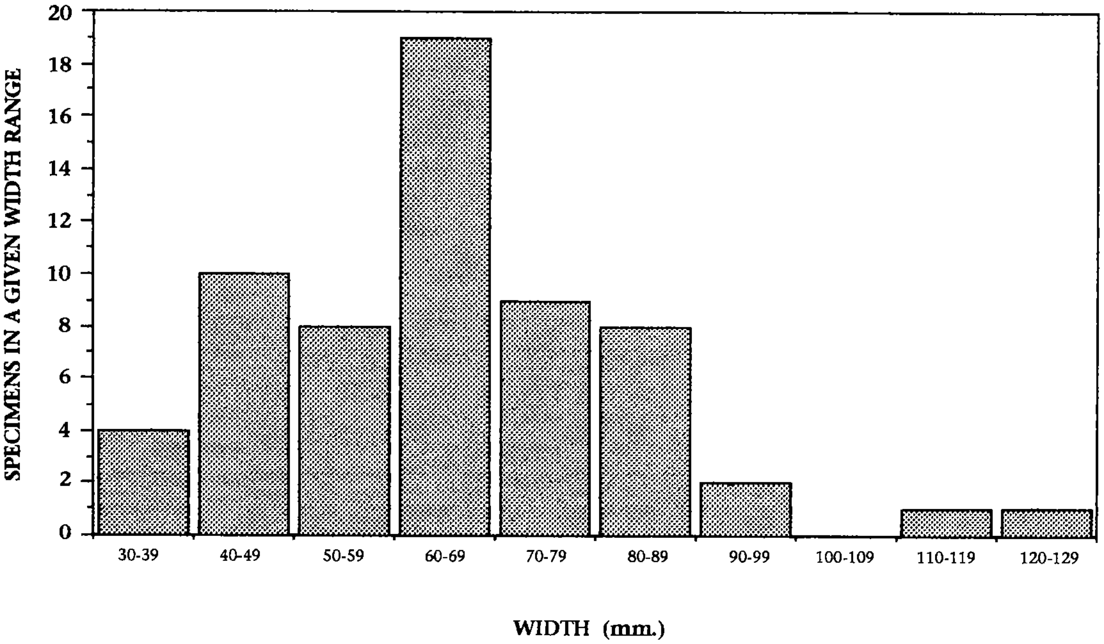
Text-figure 4. Length–thickness plot of measurements of 24 specimens for which both dimensions were measurable (in mm). Δ = arithmetic mean. Diagonal line is a regression line, fitted by eye.



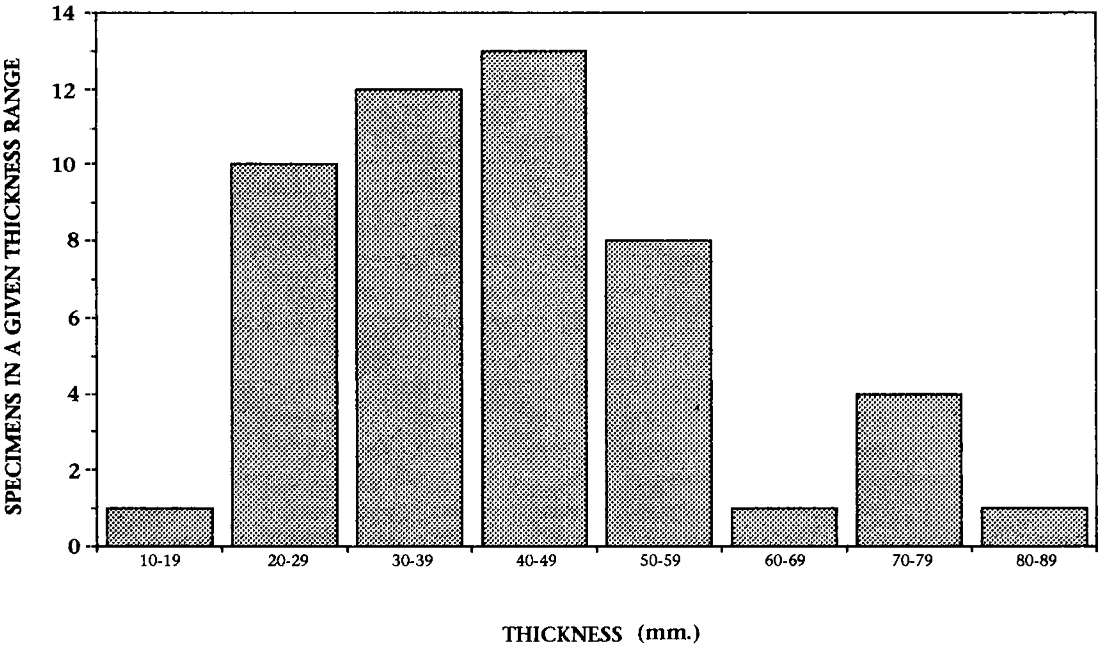
Text-figure 5. Convex-length/width plot of measurements of 35 specimens for which both dimensions were measurable (in mm). Δ = arithmetic mean. Diagonal line is a regression line, fitted by eye.



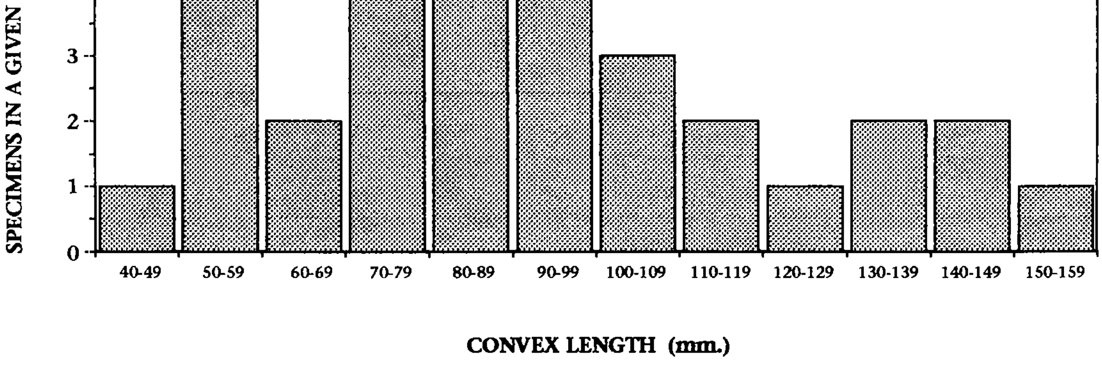
Text-figure 6. Histogram showing number of specimens in 10-mm classes for the 39 specimens in which length could be measured.



Text-figure 7. Histogram showing number of specimens in 10-mm classes for the 62 specimens in which width could be measured.



Text-figure 8. Histogram showing number of specimens in 10-mm classes for the 50 specimens in which thickness could be measured.



Text-figure 9. Histogram showing number of specimens in 10-mm classes for the 37 specimens in which convex-length could be measured. Specimens with CL = 185 and 214 are not plotted.

Another way to show graphically the nature of this population is by the use of histograms (Text-figs. 6–9). Mixoperipheral growth is clearly indicated by the length and width histograms (Text-figs. 6,7, respectively). The greatest number of specimens fall in the 60–69 mm class for both width and length. The mathematically average shell would be 66 mm long, 63 mm wide, 42 mm thick and would have a convex length of ~95 mm. Of course, there is no such shell in the collections, but the nearest one, selected as most typical (USNM 455576, Pl. 1 , Figs. 7,8) is 64 mm long, 68 mm wide, 38 mm thick, and 87 mm in convex length. The convex-length changes shown in Text-figure 9 are characteristic of growth of biconvex shells in which curvature is approximately exponential.

Material.—A total of 67 specimens from three localities, many partial; all but two specimens have at least two of the four dimensions measureable.

Illustrated specimens.—USNM 455575, 455576, 455577, 455578, 455579, 455580 (all articulated specimens); USNM 455582, 455583 (ventral interiors); USNM 455584 (dorsal interior); USNM 455585, 455586, 455587, 455588 (all dorsal valves); and USNM 455589 (cardinal process).

Measured specimens.—All used in the construction of Text-figures 3–9; USNM 455590 through 455648.

Subfamily **Geranocephalinae** Johnson, 1975

Diagnosis.—"Relatively small- to medium-sized Stringocephalidae with ventral beak commonly straight or nearly straight, lacking a prominent ventral umbo. Median septum absent from both valves. Cardinal process short, stalk-like, bifid at its base and attached to subhorizontal outer hinge plates. Crural plates present or absent" (Johnson, 1975, p. 981).

Discussion.—Two genera were recognized by Johnson (1975) as belonging to this subfamily: *Geranocephalus* Crickmay (including its junior subjective synonyms *Acrothyris* Hou and *Conomimus* Johnson, Boucot, and Gronberg) and *Paracrothyris* Wu. The major difference between the two genera is the presence of crural plates in the latter. Struve (1965) proposed that *Geranocephalus* be separated into two separate subgenera: *G.* (*Geranocephalus*) Crickmay and *G.* (*Stringomimus*) Struve, 1965. The type species of the latter subgenus is *G.* (*S.*) *pseudopaedicus* Struve, 1965, from the Givetian of the Eifel district of Germany. The primary differences between the two subgenera seem to be the presence of a distally broadened, bifid cardinal process in the former, and the presence of a slender, distally narrow, unforked cardinal process in the latter.

Genus **Geranocephalus** Crickmay, 1954

Type species.—*Geranocephalus inopinus* Crickmay, 1954, from the Givetian of Redfern Lake, British Columbia.

Geranocephalus? sp.
Plate 3, Figures 8–11

Description.—Medium-sized smooth shell; moderately dorsibiconvex, dorsal valve slightly thicker than ventral valve; shell outline subellipsoidal; both valves considerably broader than long; ventral valve moderately arched in lateral profile, dorsal valve strongly arched; ventral beak suberect, ventral interarea large, nearly straight, pedicle foramen prominent, situated submedially in deltidium, the character of the latter uncertain due to coarse silicification; anterior commissure broadly sulcate, anterior deflection low, broad and evenly arched.

Discussion.—A single articulated stringocephalid shell from Locality 3 (USGS locality 11926-SD) conforms very closely to the generalized concept of the subfamily Geranocephalinae in lacking an inflated, prominent umbo and in possessing a nearly straight ventral beak. No other stringocephalid in the examined Alaskan material closely compares to this shell in form. This shell is assigned questionably to the genus *Geranocephalus* Crickmay. Because nothing is known of its internal characters, it might also be assigned to the other genus in the subfamily, *Paracrothyris* Wu, but the latter assignment is deemed unlikely because representatives of that genus are unknown from Canada, Alaska, or the Soviet Arctic, although known in Nevada (Johnson, 1975).

Material.—One specimen from Locality 3 (USGS locality 11926-SD).

Illustrated specimen.—USNM 455581.

ACKNOWLEDGMENTS

Helicopter support, kindly provided by Michael Churkin, Jr. (in 1984, an employee of ARCO Alaska, Inc.), allowed Blodgett to collect the specimens described here. We also thank Rex A. Doescher, Department of Paleobiology, Smithsonian Institution, Washington, D.C., for providing us with an extensive bibliographic file of references pertaining to the occurrence of stringocephalid brachiopods. Bruce Wardlaw and John Repetski of the U.S. Geological Survey, J. G. Johnson, Oregon State University, and Peter Sheehan, Milwaukee Public Museum, provided helpful suggestions that improved the final version of this paper.

REFERENCES CITED

Alekseeva, R. E.; and Nuzhdina, N. A., 1967, Nekotorie srednedevonskie terebratulidi omolonskogo massiva (severo-vostok SSSR): Paleontologicheskii Zhurnal, v. 1967, p. 137–143.

Blainville, H. M. D. de, 1825, Manuel de malacologie et de conchyliologie: Levrault, Paris, 647 p.

Blodgett, R. B.; Boucot, A. J.; and Koch, W. F., II, 1988, New occurrences of color patterns in Devonian articulate brachiopods: Journal of Paleontology, v. 62, p. 46–51.

Boucot, A. J.; Johnson, J. G.; and Struve, Wolfgang, 1966, *Stringocephalus*, ontogeny and distribution: Journal of Paleontology, v. 40, p. 1349–1364.

Crickmay, C. H., 1954, Paleontological correlation of Elk Point and equivalents, *in* Clark, L. M. (ed.), Western Canada sedimentary basin—a symposium: American Association of Petroleum Geologists, Tulsa, p. 143–158.

______ 1968, Discoveries in the Devonian of western Canada: Published by author, Calgary, 13 p.

D'Archiac, E. J. A.; and De Verneuil, E. P., 1842, On the fossils of the older deposits in the Rhenish Provinces, preceded by a general survey of the fauna of Palaeozoic rocks, and followed by a tabular list of the organic remains of the Devonian system in Europe: Transactions of the Geological Society of London, v. 6, p. 303–410.

Frost, S. H.; and Langenheim, R. L., Jr., 1966, Paleontology of the *Stringocephalus* biostrome, Piute Formation (Middle Devonian), Arrow Canyon Range, Clark County, Nevada: Journal of Paleontology, v. 40, p. 911–930.

Grinnell, R. S.; and Andrews, G. W., 1964, Morphologic studies of the brachiopod genus *Composita:* Journal of Paleontology, v. 38, p. 227–248.

Hallam, Anthony, 1962, Brachiopod life assemblages from the marlstone rock-bed of Leicestershire: Palaeontology, v. 4, p. 653–659.

Heckel, P. H.; and Witzke, B. J., 1979, Devonian world palaeogeography determined from distribution of carbonates and related lithic palaeoclimatic indicators, *in* House, M. R.; Scrutton, C. T.; and Bassett, M. G. (eds.), The Devonian System: The Palaeontological Association, Special Papers in Palaeontology, no. 23, p. 99–123.

Johnson, J. G., 1975, Asian stringocephaloid brachiopod genera *Omolonia* and *Paracrothyris* in the Middle Devonian of western North America: Journal of Paleontology, v. 49, p. 979–983.

Johnson, J. G.; Klapper, Gilbert; and Trojan, W. R., 1980, Upper range of *Stringocephalus* (Devonian Brachiopoda): Newsletters on Stratigraphy, v. 8, p. 232–235.

King, William, 1850, A monograph of the Permian fossils of England: Palaeontographical Society Monograph 3, 258 p.

Kirk, Edwin, 1927, New American occurrences of *Stringocephalus*: American Journal of Science, ser. 5, v. 13, p. 219–222.

Mayfield, C. F.; Curtis, S. M.; Ellersieck, Inyo; and Tailleur, I. L., 1983, Reconnaissance geologic map of the De Long Mountains A3, B3, and parts of A4, B4 Quadrangles, Alaska: U.S. Geological Survey Open-File Report 83-183, 60 p., 2 sheets, scale 1:63,360.

Mayfield, C. F.; Tailleur, I. L.; and Ellersieck, Inyo, 1988, Stratigraphy, structure, and palinspastic syntheses of the western Brooks Range, northwestern Alaska, *in* Gryc, George (ed.), Geology and exploration of the National Petroleum Reserve in Alaska, 1974–1982: U.S. Geological Survey Professional Paper 1399, p. 143–186.

Norris, A. W.; Uyeno, T. T.; and McCabe, H. R., 1982. Devonian rocks of the Lake Winnipegosis—Lake Manitoba outcrop belt, Manitoba: Geological Survey of Canada Memoir 392, 280 p.

Struve, Wolfgang, 1965, Über *Geranocephalus* (*Stringomimus*) n. sg. und Verwandte: Senckenbergiana lethaea, v. 46, p. 459–472.

Sutherland, P. K.; and Harlow, F. H., 1973, Pennsylvanian brachiopods and biostratigraphy in southern Sangre de Cristo Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 27, 173 p.

Ziegler, Willi, 1986, Applications of the new intra-Devonian series boundaries—a summary: Courier Forschunginstitut Senckenberg, v. 75, p. 411–415.

Ziegler, Willi; and Klapper, Gilbert, 1982, Devonian series boundaries: Decisions of the IUGS Devonian Subcommission: Episodes, 1982, p. 18–21.

______ 1985, Stages of the Devonian System: Episodes, v. 8, p. 104–109.

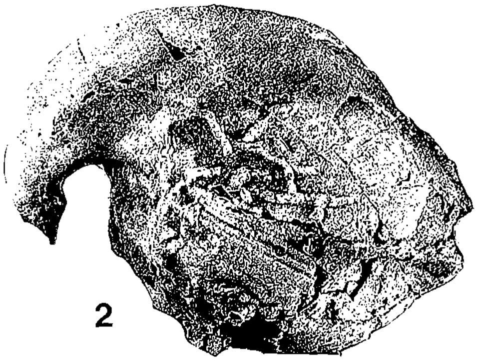
PLATE 1

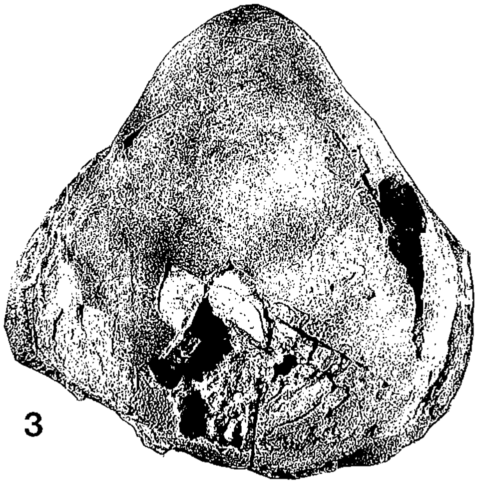
Stringocephalus (Stringocephalus)

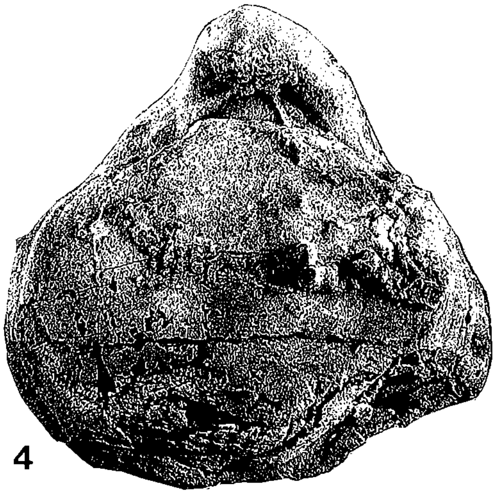
All specimens are deposited in the National Museum of Natural History (USNM).

Figures 1–8.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11926-SD. **1–6**, posterior, left-lateral, ventral, dorsal, right-lateral, and anterior views of articulated specimen (×1) (USNM 455575). **7,8**, left-lateral and posterior views of articulated specimen (×1) (USNM 455576).

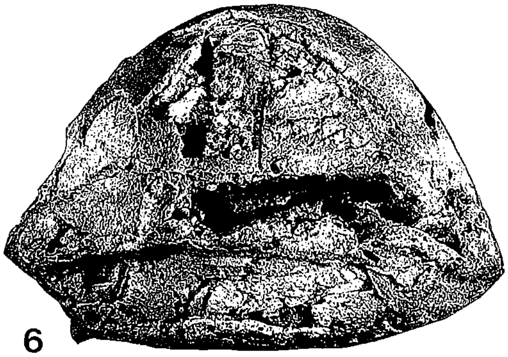

1

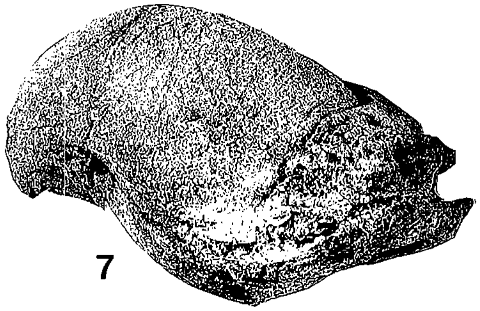

2


3


4


5


6


7

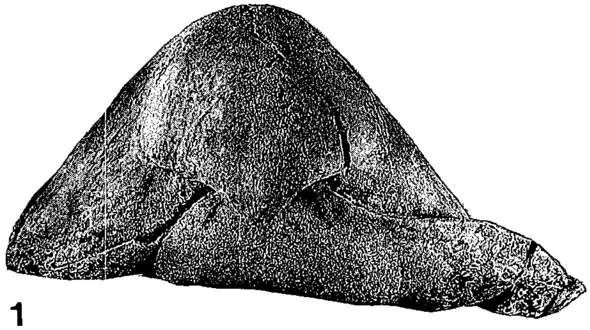

8

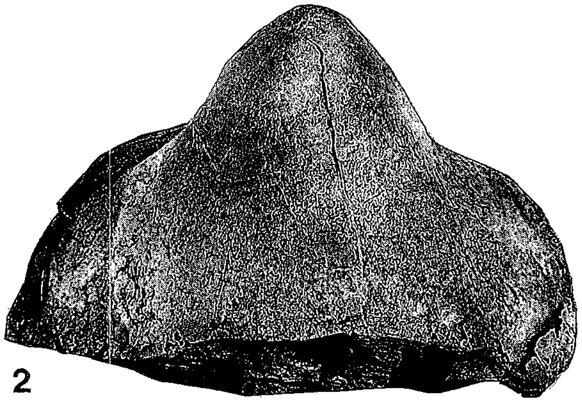
PLATE 2

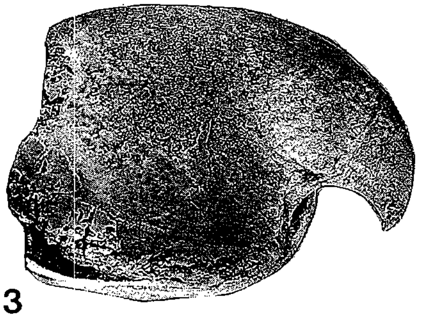
Stringocephalus (Stringocephalus)

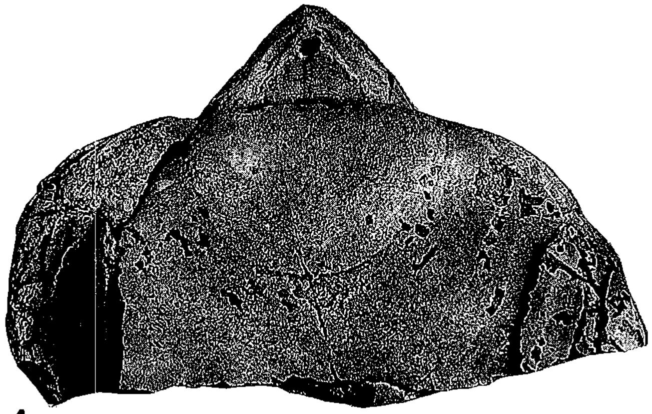
All specimens are deposited in the National Museum of Natural History (USNM).

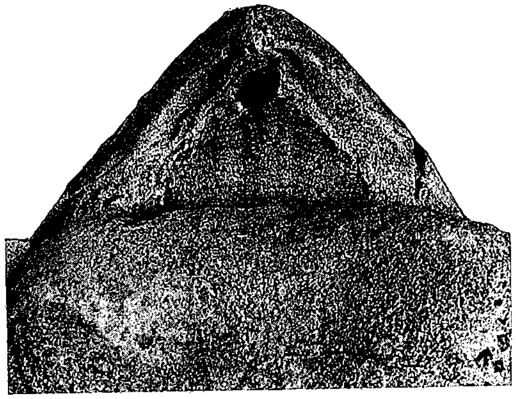
Figures 1–8.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11926-SD. **1–5**, posterior, ventral, right-lateral, dorsal views (×1) and enlarged dorsal view (×2) to show ventral interarea of articulated specimen (USNM 455577). **6–8**, posterior, dorsal, and left-lateral views of articulated specimen (×1) (USNM 455578).


1

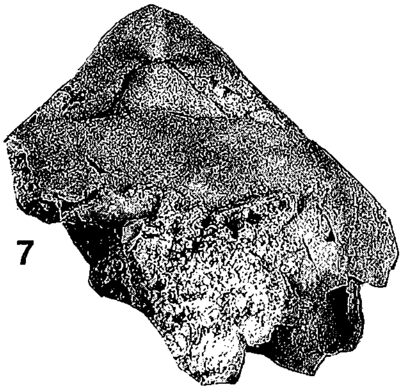

2


3


4


5


6


7

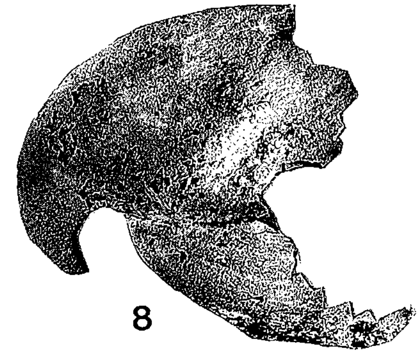

8

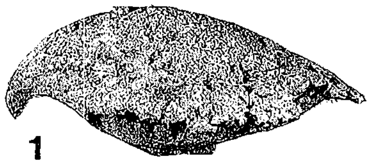
PLATE 3

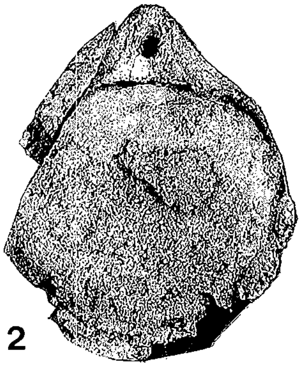
Stringocephalus (*Stringocephalus*), *Geranocephalus*?

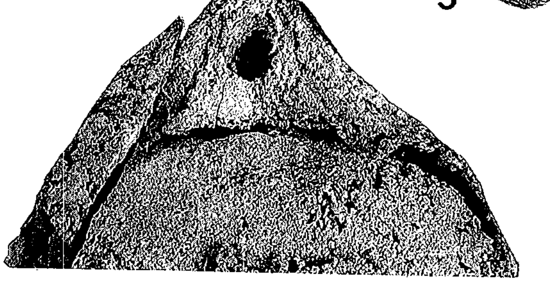
All specimens are deposited in the National Museum of Natural History (USNM).

Figures 1–7.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11926-SD. **1–3**, left-lateral and dorsal views (×1), and enlarged view of ventral interarea (×2), of articulated specimen (USNM 455579). **4–7**, posterior, left-lateral, ventral, and dorsal views of articulated specimen (×1) (USNM 455580).

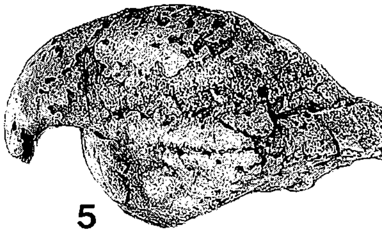
Figures 8–11.—*Geranocephalus*? sp., USGS locality 11926-SD. **8–11**, left-lateral, posterior, dorsal, and ventral views of articulated specimen (×1) (USNM 455581).

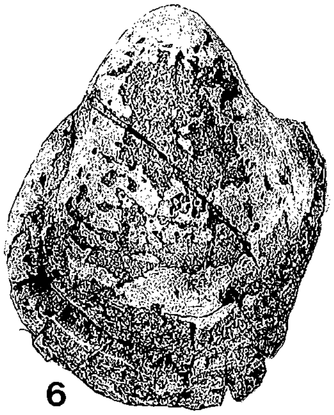

1

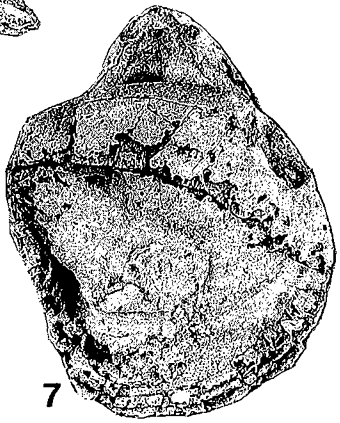

2

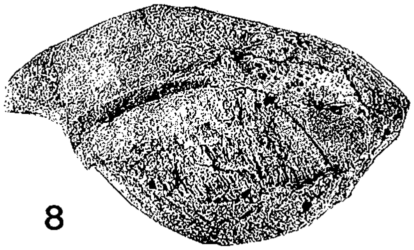

3

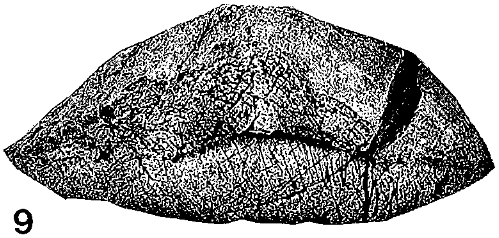

4

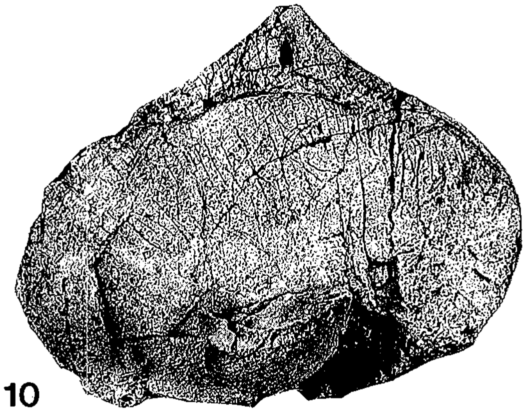

5


6


7


8


9


10

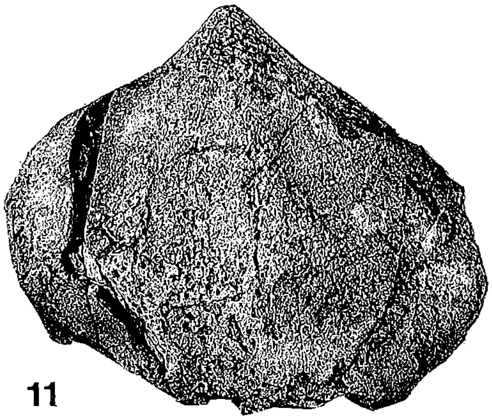
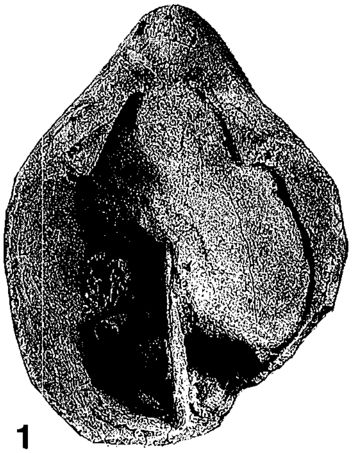

11

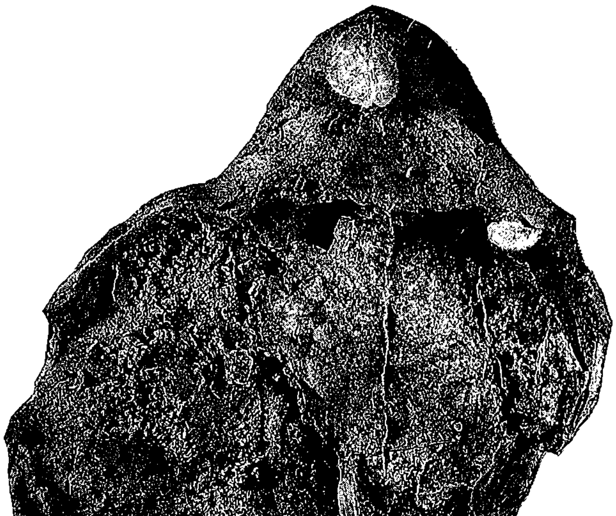
PLATE 4

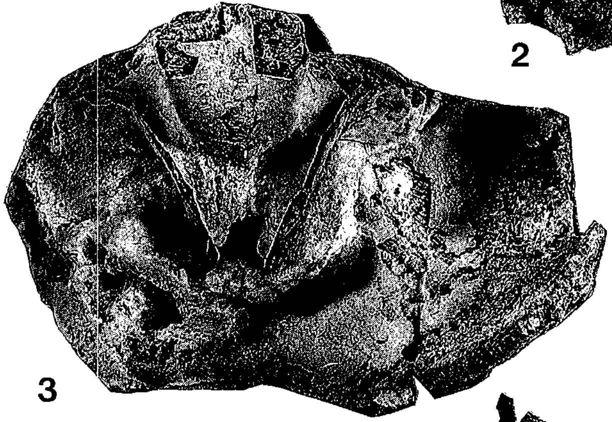
Stringocephalus (*Stringocephalus*)

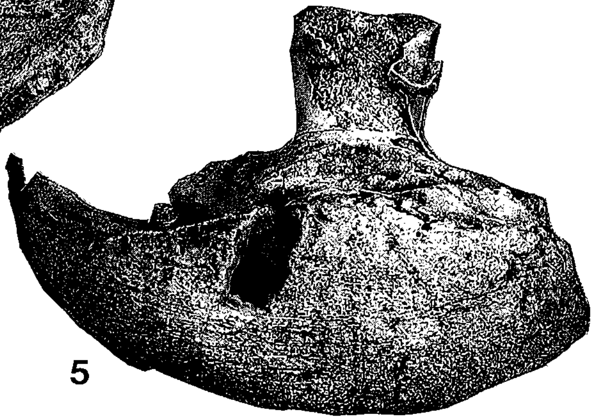
All specimens are deposited in the National Museum of Natural History (USNM).

Figures 1–6.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11926-SD. **1**, interior view of ventral valve (×1) (USNM 455582). **2**, interior view of ventral valve (×1) (USNM 455583). **3–6**, interior, left-lateral, posterior, and oblique posterior (cardinal process oriented parallel to viewing plane) views (×1.5) (USNM 455584).


1


2


3


5


4

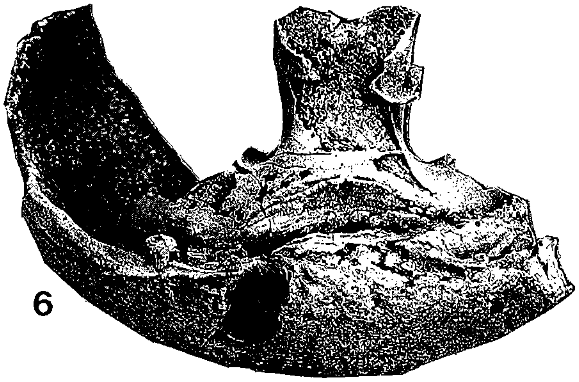
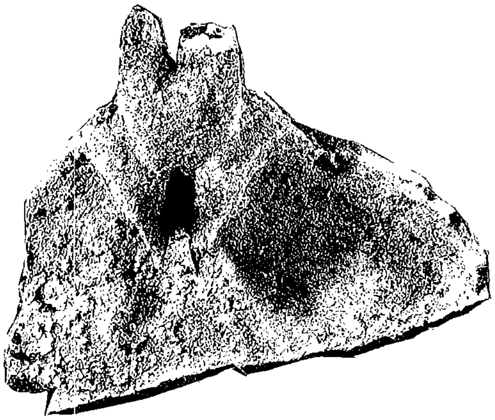

6

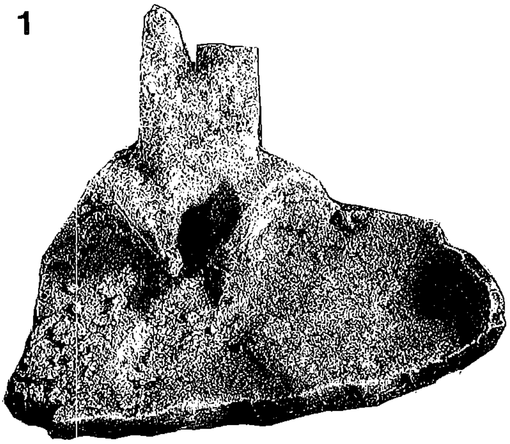
PLATE 5

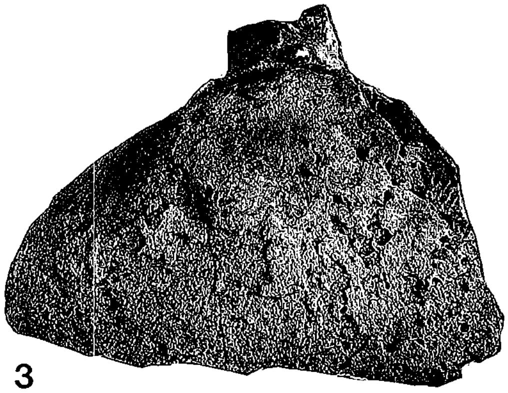
Stringocephalus (*Stringocephalus*)

All specimens are deposited in the National Museum of Natural History (USNM).

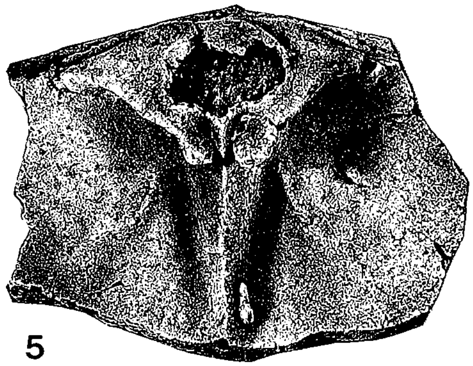
Figures 1–8.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11926-SD. **1–4**, interior, oblique interior, exterior, and posterior views of dorsal valve (×1.5) (USNM 455585). **5–8**, interior, oblique interior, exterior and posterior views of dorsal valve (×1.5) (USNM 455586).

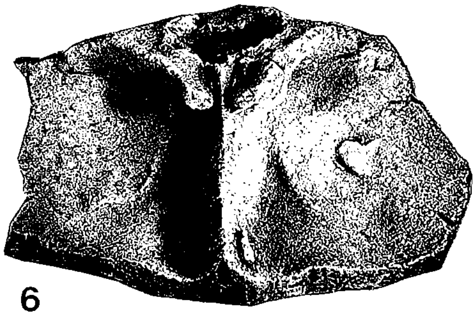

1

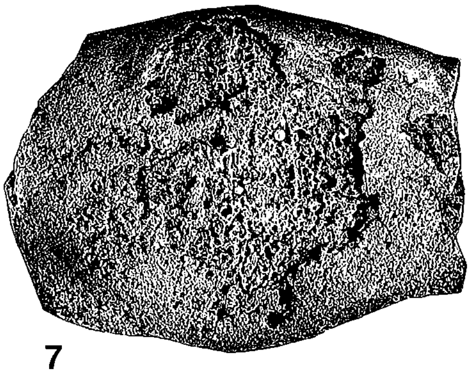

2


3


4


5


6


7


8

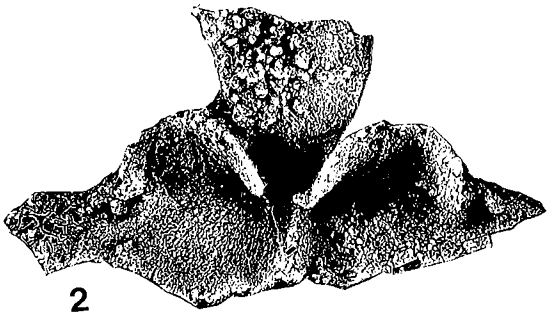
PLATE 6

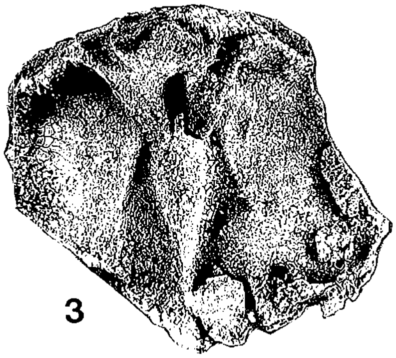
Stringocephalus (*Stringocephalus*)

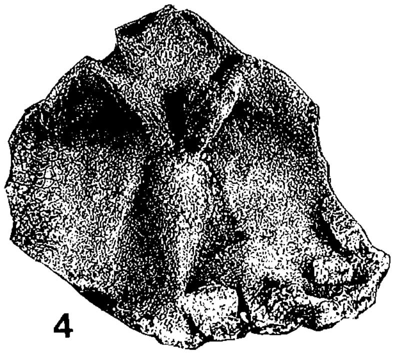
All specimens are deposited in the National Museum of Natural History (USNM).

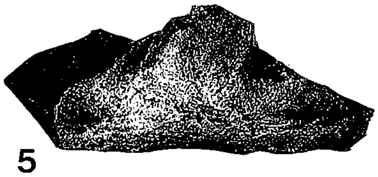
Figures 1–7.—*Stringocephalus* (*Stringocephalus*) cf. *S.* (*S.*) *noctua* Crickmay, 1968, USGS locality 11106-SD. **1,2**, posterior and anterior views of incomplete dorsal valve (×3) (USNM 455587). **3–5**, interior, oblique interior, and posterior views of dorsal valve (×2) (USNM 455588). **6,7**, posterior and anterior views of cardinal process (×1.5) (USNM 455589).

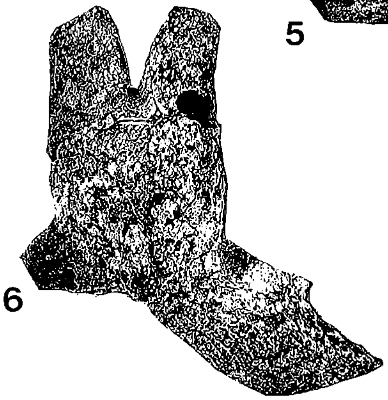

1

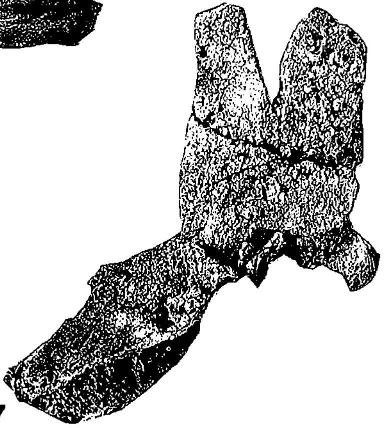

2


3


4


5


6


7

Oklahoma Geological Survey Bulletin 145, 1992

New Information on Latest Ordovician to Earliest Silurian Solitary Rugose Corals of the East-Central United States

Robert J. Elias
University of Manitoba

ABSTRACT.—New information on latest Ordovician to earliest Silurian solitary Rugosa of the east-central United States is of biostratigraphic, paleoecologic, and paleoenvironmental significance. The distribution of these corals indicates an age of early Early Llandoverian for the youngest strata of the Keel Formation in south-central Oklahoma. Basal beds of the Cochrane Formation, which overlies the Keel, are evidently diachronous, ranging in age from early Early Llandoverian to late Early or younger Llandoverian. In west-central Illinois and northeastern Missouri, solitary corals indicate that the Bowling Green Dolomite is a discrete unit that is younger than the Noix Limestone and Bryant Knob Formation and the Cyrene Formation, which is a lateral facies equivalent of the Noix–Bryant Knob. In northeastern Illinois, *Streptelasma subregulare* occurs beneath a bed containing Early Llandoverian graptolites in the Schweizer Member of the Wilhelmi Formation. That coral has a range of Gamachian to early Early Llandoverian, and it remains a possibility that Schweizer strata below the position of the graptolite bed are Gamachian in age. Coralla of *S. subregulare* are abundant on several beds immediately above stromatolites in the basal Wilhelmi at one locality, suggesting that the species could live in very shallow water and thrived when normal marine conditions appeared during the latest Ordovician–earliest Silurian transgression that brought seawater over the eroded surface of the underlying Maquoketa Group. Directional orientations of those coralla indicate currents from the south and possibly southwest. Data from the Mosalem Formation in northwestern Illinois and eastern Iowa confirm that solitary rugose corals of the Edgewood and Silurian assemblages do not co-occur and that the Edgewood assemblage was succeeded by the Silurian assemblage.

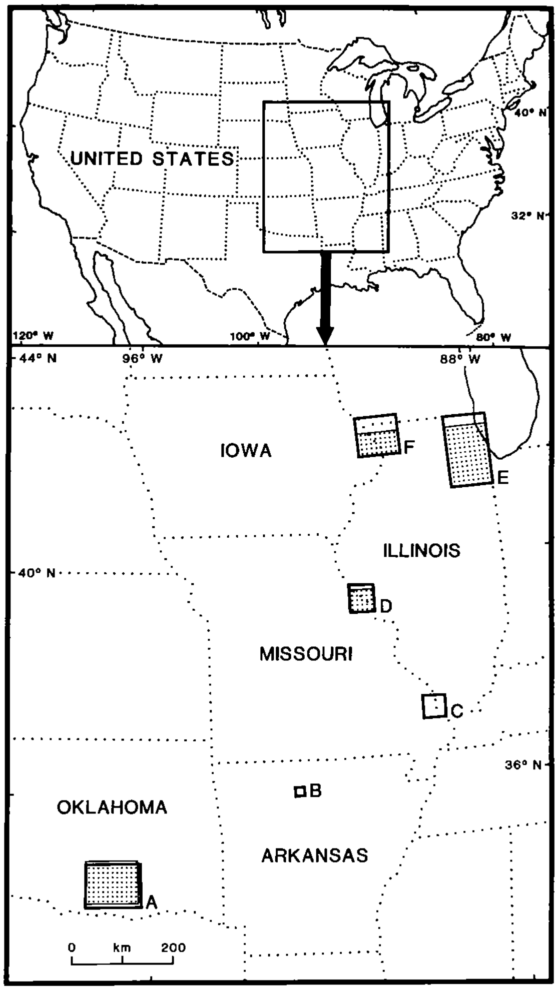
INTRODUCTION

The results of a comprehensive, long-term study of latest Ordovician to earliest Silurian solitary rugose corals of the east-central United States were recently presented by McAuley and Elias (1990). It was recognized that an Edgewood assemblage of Gamachian (latest Ordovician) to early Early Llandoverian (earliest Silurian) age was succeeded by a Silurian assemblage in the late Early Llandoverian. The *Streptelasma*-dominated Edgewood assemblage occurs in six outcrop areas and represents the Edgewood Solitary Rugose Coral Province (Text-fig. 1). *Streptelasma subregulare* (Savage, 1913) is by far the most common and widely distributed species in the province. The Edgewood assemblage existed during a regressive phase corresponding to the Late Ordovician glacial maximum and the early stage of a transgressive phase caused by subsequent deglaciation. As water depth and temperature increased during the Early Llandoverian, the Silurian assemblage, characterized by *Rhegmaphyllum* sp., *Dinophyllum* sp., *Dalmanophyllum* sp., and *Cyathactis*? sp., succeeded the Edgewood assemblage, possibly after a minor regressive event.

In 1990, Dr. Graham A. Young (University of Manitoba) and I began a comparable study of latest Ordovician to earliest Silurian colonial corals of the east-central United States. A number of solitary rugosan coralla found during our field work provide information additional to that presented by McAuley and Elias (1990). The specimens are from south-central Oklahoma, west-central Illinois and northeastern Missouri, northeastern Illinois, and northwestern Illinois and eastern Iowa (Text-fig. 1). The purpose of this paper is to present the new data and consider their paleontologic and geologic significance. The taxa identified herein were treated systematically by McAuley and Elias (1990). Specimens are deposited in the National Museum of Natural History (USNM; Smithsonian Institution, Washington, D.C.).

SOUTH-CENTRAL OKLAHOMA

The Keel Formation is overlain unconformably by the Cochrane Formation (Text-fig. 2), and there is evidence of pre-Cochrane lithification and erosion (Amsden, 1960, p. 43, 49; 1963, p. 631, 633, pl. 2, figs. 1,2; 1986, p. 6). The Keel is mainly Gamachian (Hirnantian) in age (Amsden, 1971b, p. 22, fig. 1; 1974, p. 26; 1986, p. 18; Barrick, 1986, p. 64, 66; McAuley and Elias, 1990, p. 25). Those strata contain solitary rugose corals of the Edgewood assemblage (McAuley and Elias, 1990, fig. 2). Beds at the top of the Keel Formation immediately above the laminated calcilutite unit at two localities including section 24 (Coal Creek) yield a conodont fauna different from that in the lower Keel but almost identical to that in the overlying Cochrane Formation (Barrick, 1986, secs. P9, J1, p. 57, fig. 39, tables 4,5). This upper Keel fauna has been considered Llandoverian (position uncertain) in age (Barrick, 1986, p. 67). Brachiopods have not been obtained from those strata (Amsden, 1988, p. 17), and solitary rugose corals had not been found prior to the specimens documented in the present study.



Text-figure 1. Index map showing study region in east-central United States, and detail map showing outcrop areas (outlined) of latest Ordovician and earliest Silurian strata within the Edgewood Solitary Rugose Coral Province: A, south-central Oklahoma; B, western north-central Arkansas; C, southern Illinois and southeastern Missouri; D, west-central Illinois and northeastern Missouri; E, northeastern Illinois; F, northwestern Illinois and eastern Iowa. For detail maps and stratigraphic sections in those areas, see McAuley and Elias (1990, figs. 2–5,7,8). The four areas studied herein are stippled, and detail maps and stratigraphic sections are provided in Text-figures 2–4,6.

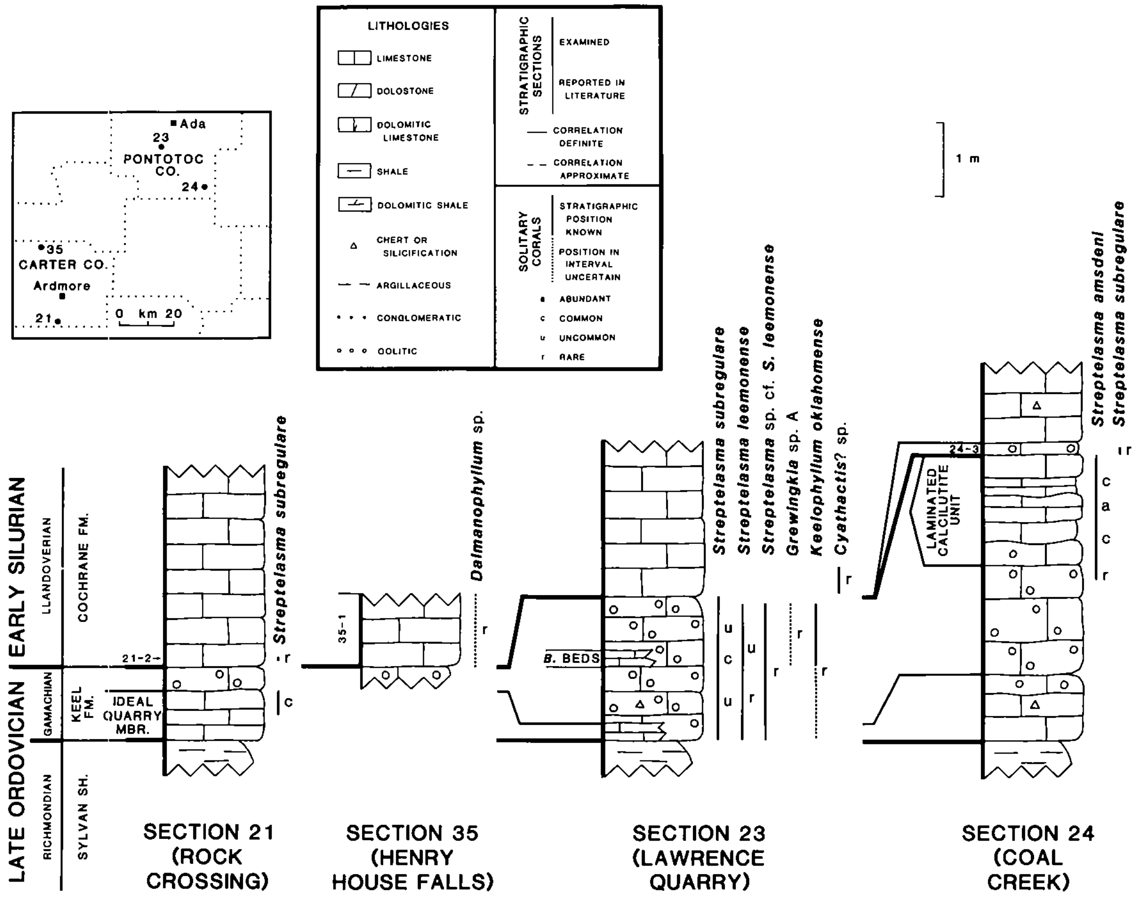
The brachiopod *Triplesia alata* Ulrich and Cooper, 1936, apparently ranges through most of the Cochrane Formation (Amsden, 1971a, p. 145). Amsden (1986, p. 6) considered it to indicate an early Late Llandoverian (C$_{1-2}$) age, although he noted that it could be younger or older. Conodonts in the basal part of the Cochrane at section 21 (Rock Crossing), section 23 (Lawrence Quarry), and elsewhere are Llandoverian (position uncertain) according to Barrick (1986, secs. Ca11, AQL, p. 57, 64, 67, fig. 39, tables 3,6). Conodont species of the late Late Llandoverian (C$_5$) *Pterospathodus celloni* Zone occur in the uppermost Cochrane (Barrick and Klapper, 1976, p. 66; Barrick, 1986, p. 64, 67; 1988, p. 54). Amsden (1988, p. 5) placed the Cochrane in the Late Llandoverian (C), but noted that "these strata are not abundantly fossiliferous, and in a region where diachroneity is common, some part of the Llandoverian A or B units may be represented." Previously, a single specimen of *Cyathactis*? sp. from section 23 (Lawrence Quarry) was the only solitary rugose coral known from the basal Cochrane (McAuley and Elias, 1990, fig. 2). It represents the Silurian assemblage.

New Information

Two specimens of *Streptelasma subregulare* were found in the 15-cm-thick upper oolitic unit of the Keel Formation above the laminated calcilutite unit at section 24 (Coal Creek) (Text-fig. 2, interval 24-3). One is from the base of the unit (USNM 458198; Pl. 1, Fig. 1) and the other is from 8 cm above the base (USNM 458199; Pl. 1, Fig. 2). Septal grooves and interseptal ridges were removed from the walls of both coralla prior to burial; this is attributed to abrasion. Micritization of the exterior surfaces is attributed to the activity of algae.

Four specimens of *Streptelasma subregulare* were obtained from a single hand sample taken 10 cm above the base of the Cochrane Formation at section 21 (Rock Crossing) (USNM 458200–458203; Pl. 1, Figs. 3–5; Text-fig. 2, interval 21-2). Scattered grains of glauconite in the matrix are characteristic of the Cochrane. The coralla show effects of fracturing and pressure solution, but part of the exterior of one specimen is well preserved (USNM 458201). Septal grooves and interseptal ridges are present, indicating that it was not abraded prior to burial.

A corallum of *Dalmanophyllum* sp. is identified from the basal 1 m of the Cochrane Formation at section 35 (Henry House Falls) (USNM 458216; Pl. 1, Fig. 12; Text-fig. 2, interval 35-1).



Text-figure 2. Locality map in south-central Oklahoma (see Text-fig. 1) and stratigraphic sections (to scale; legend of symbols is shown in larger box; collecting intervals are numbered; *B.* = *Brevilamnulella*). For references and precise locations of sections, see Appendix.

Paleoenvironmental Significance

Virtually all solitary rugosan coralla known previously from the Keel Formation are nonabraded (McAuley and Elias, 1990, table 2). The abraded specimens of *Streptelasma subregulare* in the upper oolitic unit at section 24 (Coal Creek) suggest particularly high energy conditions and/or low sedimentation rates during deposition of that unit (see McAuley and Elias, 1990, p. 29). Micritization of the exterior surfaces of these coralla indicates exposure prior to burial. *Streptelasma amsdeni* McAuley and Elias, 1990, is the only solitary rugose coral in the Keel beneath the upper oolitic unit at section 24, and is known only from that locality. It is abundant in the laminated calcilutite unit, which was evidently deposited in lower energy conditions than other facies of the Keel (Amsden, 1986, p. 12, 13, 43). *Streptelasma subregulare* occurs in the Keel Formation at other localities (McAuley and Elias, 1990, fig. 2; Text-fig. 2).

The nonabraded condition of a corallum of *Streptelasma subregulare* in the Cochrane Formation at section 21 (Rock Crossing) indicates that it did not undergo significant transportation prior to burial.

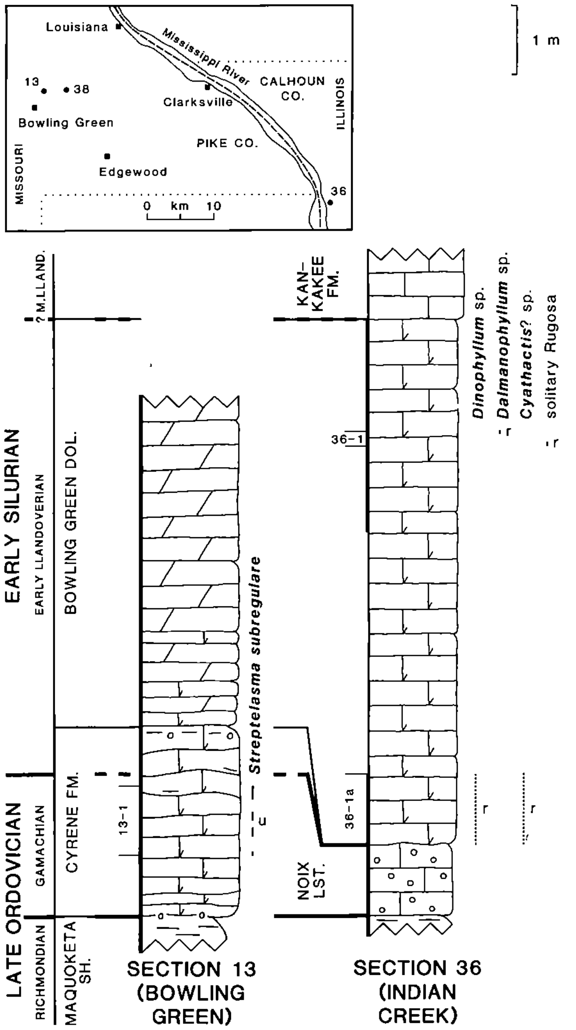
Biostratigraphic Significance

Streptelasma subregulare is characteristic of the Edgewood assemblage, and has a range of Gamachian to early Early Llandoverian (McAuley and Elias, 1990, p. 24–26, fig. 10). Its presence in the upper oolitic unit of the Keel Formation at section 24 (Coal Creek) and the basal Cochrane Formation at section 21 (Rock Crossing), in association with a Llandoverian (position uncertain) conodont fauna, suggests that those strata are early Early Llandoverian in age. *Cyathactis*? sp., in association with the Llandoverian (position uncertain) conodont fauna, and *Dalmanophyllum* sp. occur in the basal Cochrane at section 23 (Lawrence Quarry) and section 35 (Henry House Falls), respectively. They represent the Silurian assemblage and suggest that those strata are younger than early Early Llandoverian.

The new data on solitary rugose corals indicate an age of early Early Llandoverian for the youngest strata of the Keel Formation. Basal strata of the Cochrane Formation are apparently diachronous, ranging in age from early Early Llandoverian to late Early or younger Llandoverian. If there was a hiatus between deposition of the youngest Keel and oldest Cochrane strata, it was of short duration.

WEST-CENTRAL ILLINOIS AND NORTHEASTERN MISSOURI

In northeastern Missouri near the Mississippi River, in the vicinity of Louisiana and Clarksville (for locations see Text-fig. 3), the complete Gamachian–Early Llandoverian sequence comprises the following units in ascending stratigraphic order: Noix Limestone, unnamed member and Kissenger Limestone Member of the Bryant Knob Formation, and Bowling Green Dolomite (McAuley and Elias, 1990, p. 12, 14–16, fig. 5). Solitary rugose corals are rare in the Noix but common and widespread in the Bryant Knob. They represent the Edgewood assemblage. Solitary Rugosa in the Bowling Green at Clarksville, the only section from which they were previously documented, represent the Silurian assemblage. The Noix is Gamachian, the Bryant Knob is tentatively considered to be Early Llandoverian in age, and the Bowling Green is Early Llandoverian (McAuley and Elias, 1990, p. 25, 26). Across the Mississippi River in west-central Illinois, the Bryant Knob is apparently absent, and the Bowling Green is underlain by the Noix and overlain by the Kankakee Formation (Brassfield or Sexton Creek Limestone of some authors; see Willman, 1973, p. 16). McAuley and Elias (1990) did not study those strata. In the vicinity of Bowling Green and Edgewood, Missouri (for locations see Text-fig. 3), the Cyrene Formation, which is considered to be a facies equivalent of the combined Noix and Bryant Knob, is overlain by the Bowling Green. Solitary rugose corals of the Cyrene were documented by McAuley and Elias (1990) from section 13 (Bowling Green) and near Edgewood. They represent the Edgewood assemblage.



Text-figure 3. Locality map in west-central Illinois and northeastern Missouri (see Text-fig. 1) and stratigraphic sections (to scale; see Text-fig. 2 for legend of symbols; collecting intervals are numbered). For references and precise locations of sections, see Appendix.

Amsden (1974, p. 16–18, figs. 12–14; 1986, p. 36, 37, fig. 34) considered two hypotheses for the relationship between the Cyrene–Noix–Bryant Knob and the Bowling Green. One is that the Bowling Green is a distinct lithostratigraphic unit that is younger than the other units, as inferred by Thompson and Satterfield (1975, p. 103). The other is that Cyrene–Noix–Bryant Knob strata grade laterally and vertically into the dolomitized Bowling Green facies. On the basis of the distribution of solitary rugose corals and the nature of contacts between units, McAuley and Elias (1990, p. 15, 16) concluded that the Bowling Green is a discrete, younger unit.

New Information

Solitary rugosan coralla were found in the Bowling Green Dolomite at section 36 (Indian Creek) in Illinois (Text-fig. 3). *Dinophyllum* sp. (USNM 458215; Pl. 1, Fig. 11) and *Cyathactis*? sp. (USNM 458219; Pl. 1, Fig. 15) were obtained in rubble from the basal 1 m of the unit (interval 36-1a), and a corallum identified as *Dalmanophyllum* sp. (USNM 458217; Pl. 1, Fig. 13) was collected 1.6 m below the top of the Bowling Green (in interval 36-1).

A specimen of *Streptelasma subregulare* collected from the Cyrene Formation at section 13 (Bowling Green) extends the range of that species down to a position 90 cm above the base of the unit (USNM 458204; Pl. 1, Fig. 6; Text-fig. 3, interval 13-1). *Streptelasma subregulare* was also found in rubble of the

Cyrene at section 38 (Buckner Hollow) (USNM 458205; Pl. 1, Fig. 7; for location see Text-fig. 3).

Biostratigraphic Significance

At section 36 (Indian Creek), Rubey (1952, p. 27) noted that the contact between the Noix Limestone and Bowling Green Dolomite is "undulatory and suggests an unconformity." However, Amsden (1974, p. 85) found that ooids cross this boundary and occur in the lower few centimeters of the Bowling Green. If basal Bowling Green strata at this locality are the dolomitized equivalent of the upper Noix–Bryant Knob Formation recognized across the Mississippi River in Missouri, then solitary rugose corals of the Edgewood assemblage would be expected (Edgewood corals occur in limestone as well as dolomitic beds of the Bryant Knob). However, coralla in the basal strata and higher in the Bowling Green represent the Silurian assemblage, as at the Clarksville section. This provides additional support for the interpretation that the Bowling Green is a distinct unit that is younger than the Bryant Knob.

Streptelasma subregulare, a characteristic species of the Edgewood assemblage, remains the only solitary rugose coral known from the Cyrene Formation. This provides additional support for the interpretation that the Cyrene is a facies equivalent of the Noix–Bryant Knob and is distinct from the Bowling Green Dolomite.

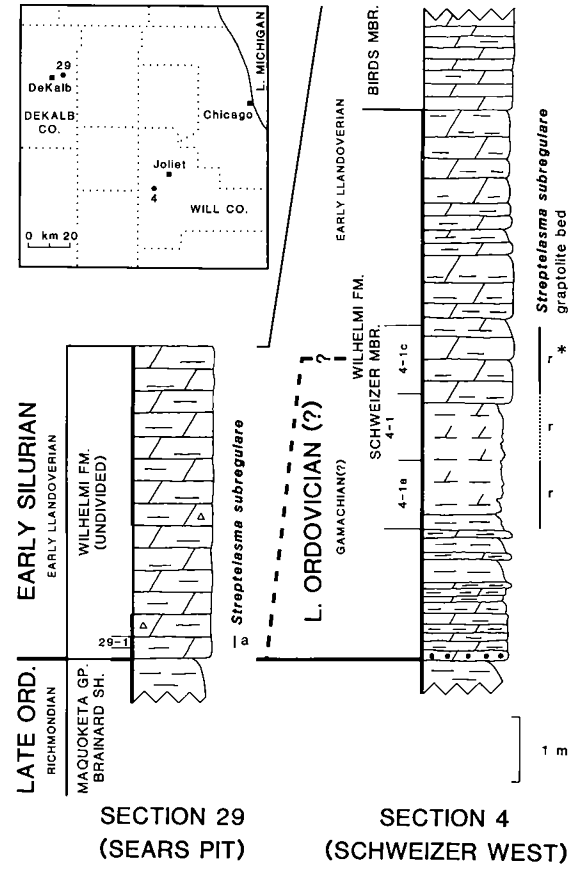
NORTHEASTERN ILLINOIS

The Wilhelmi Formation is as much as 30 m thick where it fills or nearly fills channels eroded into the underlying Maquoketa Group, but it is thin or absent elsewhere in the area (Willman, 1973, p. 12–14). The lower unit of the Wilhelmi, the Schweizer Member, is as much as 24 m thick but is generally present only where the formation is relatively thick. The upper unit is the Birds Member. *Streptelasma subregulare*, the only solitary rugose coral known from the Schweizer and Birds, represents the Edgewood assemblage (McAuley and Elias, 1990, p. 20, fig. 7). Biostratigraphically significant Early Llandoverian graptolites have been obtained from a bed in the Schweizer Member at section 4 (Schweizer West) (Text-fig. 4; Ross, 1962; Berry and Boucot, 1970, p. 145). The Wilhelmi is considered to be early Early Llandoverian in age. However, it is possible that lower Schweizer strata infilling the deepest channels, below the position of the graptolite bed, are Gamachian (McAuley and Elias, 1990, p. 21, 25).

All identifiable solitary rugose corals obtained previously at section 4 (Schweizer West) were from uncertain positions within a 3-m interval that includes the graptolite bed (position of graptolite bed based on Ross, 1962, fig. 1; McAuley and Elias, 1990, fig. 7; Text-fig. 4, interval 4-1). At section 29 (Sears Pit), coralla were thought to be uncommon a short distance above the base of the Wilhelmi Formation (interval 29-1).

New Information

In the Schweizer Member of the Wilhelmi Formation at section 4 (Schweizer West), a specimen of *Streptelasma subregulare* was found in interval 4-1a (USNM 458206; Pl. 1, Fig. 8; Text-fig. 4). Beside it was another corallum that has an epizoic bryozoan on one side (USNM 458213, probably *S. subregulare*). *Streptelasma subregulare* was also found in interval 4-1c, and that corallum has *Trypanites* borings in the wall (USNM 458207; Pl. 1, Fig. 9). In the quarry at section 29 (Sears Pit), strata exposed in a new sump were found to contain abundant coralla of *S. subregulare* on several beds 25–30 cm above the base of the Wilhelmi (USNM 458208, slab with 18 coralla; Text-fig. 4, interval 29-1). Domical stromatolites occur in the basal 20–25 cm of the Wilhelmi at that section.



Text-figure 4. Locality map in northeastern Illinois (see Text-fig. 1) and stratigraphic sections (to scale; see Text-fig. 2 for legend of symbols; collecting intervals are numbered). For references and precise locations of sections, see Appendix.

Biostratigraphic Significance

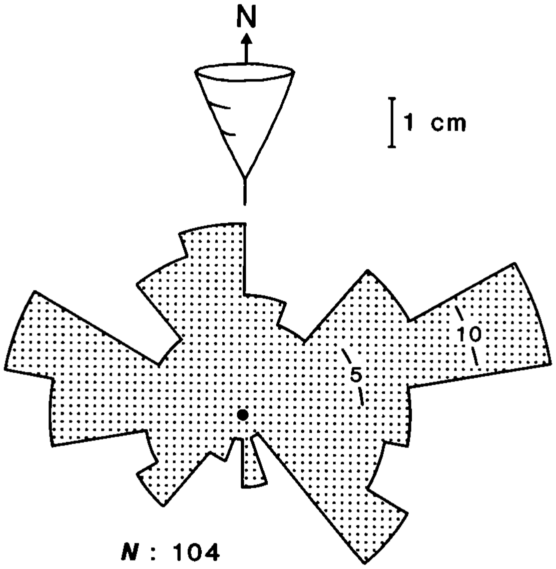
The identification of *Streptelasma subregulare* in interval 4-1a at section 4 (Schweizer West) confirms that the species occurs beneath the bed containing Early Llandoverian graptolites in the Schweizer Member of the Wilhelmi Formation (Text-fig. 4). *Streptelasma subregulare* has a range of Gamachian to early Early Llandoverian, and it remains a possibility that Schweizer strata infilling the deepest channels, below the position of the graptolite bed, are Gamachian in age (McAuley and Elias, 1990, p. 21, 25).

Paleoecologic Significance

The epizoic bryozoan and *Trypanites* borings observed in specimens from the Schweizer Member are noteworthy. Epizoans had not been found previously on solitary coralla from the Wilhelmi Formation and are rare in the Edgewood Province except in bioherms of the Leemon Formation at one locality in southeastern Missouri (McAuley and Elias, 1990, p. 30). *Trypanites* borings had not been observed previously in Edgewood coralla from Illinois and are extremely rare in the Edgewood Province (McAuley and Elias, 1990, p. 30).

The abundant coralla of *Streptelasma subregulare* observed on several beds 25–30 cm above the base of the Wilhelmi Formation at section 29 (Sears Pit) are trochoid in form and oriented sideways in what would have been stable depositional positions after being overturned. It was possible to measure a sufficiently large number of directional orientations (Text-fig. 5) to permit statistical analysis using the methods of Elias and others (1987, p. 808). The coralla are preferentially oriented and the distribution is bimodal, with anomalous maxima at 60–80° and 280–300°, and anomalous minima at 140–160° and 180–220°. The maxima are opposite one another but skewed slightly toward the north, and the minima are in the south. Such a distribution indicates that the coralla were rolled almost perpendicular to water flow or nearly parallel to wave crests, with the apical end facing either way but directed slightly into currents from the south (see Elias and others, 1987, p. 810). Peaks at 120–140° and 340–360° are not statistically significant, but it is noteworthy that they are of similar magnitude and are opposite one another but skewed slightly toward the northeast. They may represent a group of coralla that was preferentially oriented by currents from the southwest. A bimodal distribution with maxima that are opposite one another but skewed slightly has been documented for ceratoid coralla of *Streptelasma subregulare* in the Bryant Knob Formation at Louisiana in northeastern Missouri (Elias and others, 1987, p. 810, fig. 1f; McAuley and Elias, 1990, p. 31, fig. 12b).

At section 29 (Sears Pit), the presence of horn coral beds immediately above stromatolites in the basal Wilhelmi Formation suggests that *Streptelasma subregulare* could live in very shallow water and thrived when normal marine conditions appeared during the transgression that brought seawater over the eroded surface of the Maquoketa Group.

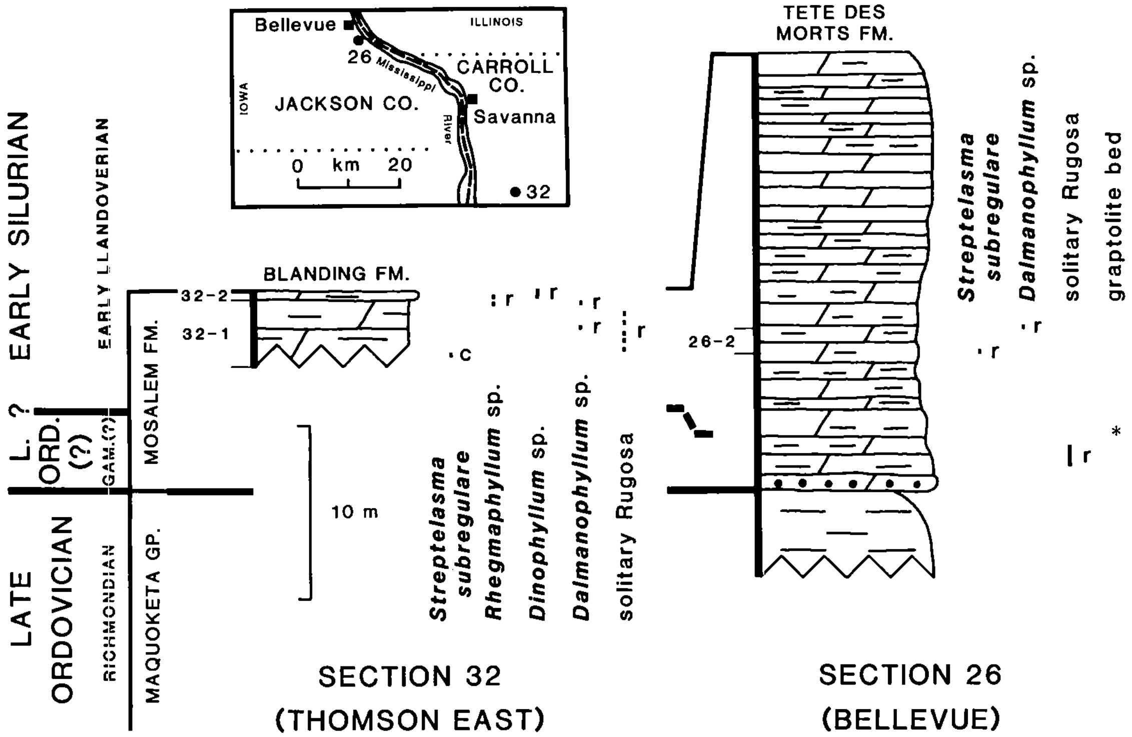


Text-figure 5. Rose diagram showing directional orientations of coralla (*N* = sample size): *Streptelasma subregulare*, interval 29-1, Wilhelmi Formation, section 29 (Sears Pit) (see Text-fig. 4). Orientation convention is illustrated using the north arrow and a typical specimen (to scale).

NORTHWESTERN ILLINOIS AND EASTERN IOWA

The Mosalem Formation is as much as 30 m thick where it fills channels eroded into the underlying Maquoketa Group, but thins to a feather edge above paleotopographic highs (Willman, 1973, p. 31–33). From section 26 (Bellevue) northward (for location see Text-fig. 6), the Mosalem is overlain by the Tete des Morts Formation, which in turn is overlain by the Blanding Formation. South of section 26, the Blanding lies directly on the Mosalem (see McAuley and Elias, 1990, fig. 8). The upper surface of the Mosalem appears to be conformable throughout the area. Willman (1973, p. 27, 32, fig. 7) noted that Lower Silurian strata, including the Mosalem, thin markedly over the Savanna Anticline, an E-trending structure situated just south of Savanna, Illinois (for location see Text-fig. 6).

In the lower level of the quarry at section 32 (Thomson East), 3.8 m of thick-bedded to massive argillaceous dolostone (interval 32-1) are overlain by a massive, 65-cm-thick bed of argillaceous dolostone that is vuggy in the upper 25 cm (interval 32-



Text-figure 6. Locality map in northwestern Illinois and eastern Iowa (see Text-fig. 1) and stratigraphic sections (to scale; see Text-fig. 2 for legend of symbols; collecting intervals are numbered; Gam. = Gamachian). For references and precise locations of sections, see Appendix.

2) (Text-fig. 6; McAuley and Elias, 1990, fig. 8). The top of the latter bed forms the floor of the upper level of the quarry. Strata in the upper level were examined during the present study, and clearly represent a distinct lithostratigraphic unit consisting of relatively thin-bedded dolostone. Beds of chert appear ~1.5 m above the base and have a vertical spacing of ~1 m. The frequency of chert beds increases upward until spacing varies from centimeters to tens of centimeters. As defined by Willman (1973, p. 31–33, 35, 36), the Mosalem does not contain layers of chert, whereas the Blanding is characterized by many chert layers. Therefore, the Mosalem–Blanding contact is placed at the top of interval 32-2. The same stratigraphic sequence is exposed in a quarry located 2.3 km to the northwest, and was illustrated by McAuley and Elias (1990, fig. 8, sec. 30), who placed the Mosalem–Blanding contact at the lowest position of closely spaced chert beds. Based on a reexamination of that section in light of further study at section 32, the contact is herein placed at a lower position, at the top of the 65-cm-thick bed of argillaceous dolostone that is vuggy in the upper 25 cm (McAuley and Elias, 1990, fig. 8, sec. 30, top of interval 30-2).

At section 32 (Thomson East), the characteristic Edgewood coral *Streptelasma subregulare* occurs in the fill of small channels and in a coral bed that is lateral to the channels, which cut down from a position 80 cm above the base of the Mosalem exposure (Text-fig. 6, interval 32-1; McAuley and Elias, 1990, p. 22, fig. 8, interval 32-1z,a,b). *Streptelasma subregulare* has been reported at the same stratigraphic position in a section ~2.3 km northwest of section 32 (Savage, 1926, p. 527, sec. along Johnson Creek, unit 3 is the Mosalem). All identifiable solitary corals collected above the position of *S. subregulare* at section 32 represent the Silurian assemblage (Text-fig. 6; McAuley and Elias, 1990, p. 22, fig. 8, intervals 32-1c, 32-2a,b). *Dalmanophyllum* sp. occurs at heights of 2.2 and 3.75 m above the base of the exposure (in interval 32-1). *Rhegmaphyllum* sp. is present at 3.95 m and *Dinophyllum* sp. was recovered between 3.95 and 4.45 m (in interval 32-2). Solitary corals of the Silurian assembage have also been documented from near the top of the Mosalem at two other localities in northwestern Illinois (McAuley and Elias, 1990, fig. 8). Identifiable solitary rugose corals had not been obtained previously from the Mosalem of eastern Iowa. Graptolites from a horizon in the lower Mosalem at section 26 (Bellevue) apparently represent the same Early Llandoverian zone as those in the Schweizer Member of the Wilhelmi Formation in northeastern Illinois (Text-fig. 6; Ross, 1964). The Mosalem is considered to be Early Llandoverian in age, although it is possible that strata infilling the deepest channels, below the position of the graptolite bed, are Gamachian (McAuley and Elias, 1990, p. 21, 25).

New Information

Three well-preserved coralla of *Streptelasma subregulare* (USNM 458209–458211) were collected from the coral bed in the Mosalem Formation at section 32 (Thomson East; Text-fig. 6, interval 32-1; McAuley and Elias, 1990, p. 22, interval 32-1z). All have septal grooves and interseptal ridges, indicating that they were not significantly abraded prior to burial. *Rhegmaphyllum* sp. was found near the top of interval 32-1, at a height of 3.6 m in the section (USNM 458214; Pl. 1, Fig. 10).

Two coralla were obtained from a single, enormous slump block at section 26 (Bellevue). The original stratigraphic position of the slump block and corals in the undisturbed section could be established with confidence. The stratigraphically lower specimen is poorly preserved, but the nature and arrangement of septa are characteristic of *Streptelasma subregulare* (USNM 458212). The specimen located 1.4 m higher is identified as *Dalmanophyllum* sp. (USNM 458218; Pl. 1, Fig. 14; Text-fig. 6, interval 26-2).

Paleoenvironmental Significance

On the basis of condition of the corallum exterior, McAuley and Elias (1990, p. 29, table 2) determined whether Edgewood corals at various localities and stratigraphic positions were abraded prior to burial. That information was used to make inferences regarding sedimentation rate and energy level of the environment. Previously, there were insufficient data to report on the Mosalem Formation. A total of 10 well-preserved specimens of *Streptelasma subregulare* are now known from the coral bed at section 32 (Thomson East; interval 32-1z of McAuley and Elias, 1990). All are nonabraded, suggesting a low-energy environment. Nonabrasion could also indicate rapid burial due to a high sedimentation rate. However, the bed must have remained exposed for a period of time in order for the surface to become colonized by numerous tabulate and solitary rugose corals. The coral bed appears to be at about the same stratigraphic position as small, local channels that suggest a break in deposition (McAuley and Elias, 1990, p. 22, fig. 9).

Biostratigraphic Significance

In the Mosalem Formation at section 32 (Thomson East), *Streptelasma subregulare* remains the only solitary rugosan known from the coral bed and strata lateral to it, and all coralla identified from above the position of that characteristic Edgewood species represent the Silurian assemblage. The change from Edgewood to Silurian assemblages occurs near the top of the Mosalem (Text-fig. 6). At section 26 (Bellevue), a coral of the Silurian assemblage has also been found a short distance above a specimen of *S. subregulare*, but it occurs well below the top of the Mosalem. Assuming that the change from Edgewood to Silurian assemblages was synchronous and the upper surface of the Mosalem is conformable throughout the area, this suggests relatively continuous and/or rapid sedimentation at section 26. The record of deposition is evidently less complete at section 32 on the southern flank of the Savanna Anticline, where the Silurian assemblage appears above local channels that may record a minor regressive event (McAuley and Elias, 1990, p. 23, fig. 9).

CONCLUSIONS

New information on latest Ordovician to earliest Silurian solitary Rugosa of the east-central United States is of biostratigraphic, paleoecologic, and paleoenvironmental significance. These corals indicate that the youngest strata of the Keel Formation in south-central Oklahoma are early Early Llandoverian in age. Basal beds of the Cochrane Formation, which overlies the Keel, are apparently diachronous, ranging in age from early Early Llandoverian to late Early or younger Llandoverian. In west-central Illinois and northeastern Missouri, the Bowling Green Dolomite is a discrete unit that is younger than the Noix Limestone and Bryant Knob Formation and the Cyrene Formation, which is a lateral facies equivalent of the Noix–Bryant Knob. In northeastern Illinois, strata beneath a bed containing Early Llandoverian graptolites in the Schweizer Member of the Wilhelmi Formation may be Gamachian in age. *Streptelasma subregulare*, which is abundant on several beds immediately above stromatolites in the basal Wilhelmi at one locality, could evidently live in very shallow water and thrived when normal marine conditions appeared during the latest Ordovician–earliest Silurian transgression that brought seawater over the eroded surface of the underlying Maquoketa Group. Directional orientations of those coralla indicate currents from the south and possibly southwest. Data from the Mosalem Formation in northwestern Illinois and eastern Iowa confirm that solitary rugose corals of the Edgewood and Silurian assemblages do not co-occur and that the Edgewood assemblage was succeeded by the Silurian assemblage.

ACKNOWLEDGMENTS

I am grateful for this opportunity to acknowledge the contributions Dr. Thomas W. Amsden has made to my research program on latest Ordovician to earliest Silurian corals of the east-central United States, from the geologic and paleontologic framework provided in his numerous publications to his personal assistance in offering specimens, information, and guidance in the field.

This project was supported by grants from the Natural Sciences and Engineering Research Council of Canada. Dr. Graham A. Young and I were ably assisted by Mrs. Vicki L. F. Young during field work in 1990. For helpful comments on the manuscript, I thank G. A. Young. The reviews by Dr. William A. Oliver, Jr. (U.S. Geological Survey) and Dr. James E. Sorauf (State University of New York at Binghamton) are greatly appreciated.

REFERENCES CITED

Amsden, T. W., 1957, Introduction to stratigraphy, *part 1 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Circular 44, 57 p.

______1960, Hunton stratigraphy, *part 6 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 84, 311 p.

______1961, Stratigraphy of the Frisco and Sallisaw Formations (Devonian) of Oklahoma: Oklahoma Geological Survey Bulletin 90, 121 p.

______1963, Silurian stratigraphic relations in the central part of the Arbuckle Mountains, Oklahoma: Geological Society of America Bulletin, v. 74, p. 631–636.

______1971a, *Triplesia alata* Ulrich and Cooper, *in* Dutro, J. T., Jr. (ed.), Paleozoic perspectives: a paleontological tribute to G. Arthur Cooper: Smithsonian Contributions to Paleobiology 3, p. 143–154.

______1971b, Late Ordovician–Early Silurian brachiopods from the central United States: Bureau de Recherches Géologiques et Minières Mémoires no. 73, Colloque ordovicien–silurien, Brest, p. 19–25.

______1974, Late Ordovician and Early Silurian articulate brachiopods from Oklahoma, southwestern Illinois, and eastern Missouri: Oklahoma Geological Survey Bulletin 119, 154 p.

______1986, Paleoenvironment of the Keel–Edgewood oolitic province and the Hirnantian strata of Europe, USSR, and China, *part 1 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician–Early Silurian strata in the central United States and the Hirnantian Stage: Oklahoma Geological Survey Bulletin 139, p. 1–55.

______1988, Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., *part 1 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, p. 1–53.

Anderson, W. I., 1983, Geology of Iowa: over two billion years of change: Iowa State University Press, Ames, 268 p.

Barrick, J. E., 1986, Conodont faunas of the Keel and Cason Formations, *part 2 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician–Early Silurian strata in the central United States and the Hirnantian Stage: Oklahoma Geological Survey Bulletin 139, p. 57–68.

______1988, Silurian–Early Devonian conodont succession in the Hunton Group, southern Oklahoma, *part 2 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, p. 54–56.

Barrick, J. E.; and Klapper, Gilbert, 1976, Multielement Silurian (Late Llandoverian–Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of *Kockelella:* Geologica et Palaeontologica, v. 10, p. 59–100.

Berry, W. B. N.; and Boucot, A. J. (eds.), 1970, Correlation of the North American Silurian rocks: Geological Society of America Special Paper 102, 289 p.

Elias, R. J., 1982, Latest Ordovician solitary rugose corals of eastern North America: Bulletins of American Paleontology, v. 81, no. 314, 116 p.

Elias, R. J.; McAuley, R. J.; and Mattison, B. W., 1987, Directional orientations of solitary rugose corals: Canadian Journal of Earth Sciences, v. 24, p. 806–812.

Koenig, J. W.; Martin, J. A.; and Collinson, C. W., 1961, Guidebook, 26th regional field conference, the Kansas Geological Society, northeastern Missouri and west-central Illinois: Missouri Division of Geological Survey and Water Resources Report of Investigations 27, 168 p.

Liebe, R. M.; and Rexroad, C. B., 1977, Conodonts from Alexandrian and early Niagaran rocks in the Joliet, Illinois, area: Journal of Paleontology, v. 51, p. 844–857.

McAuley, R. J.; and Elias, R. J., 1990, Latest Ordovician to earliest Silurian solitary rugose corals of the east-central United States: Bulletins of American Paleontology, v. 98, no. 333, 82 p.

Mikulic, D. G.; Sargent, M. L.; Norby, R. D.; and Kolata, D. R., 1985, Silurian geology of the Des Plaines River valley, northeastern Illinois: Illinois State Geological Survey Guidebook 17, 56 p.

Rose, J. N., 1967, The fossils and rocks of eastern Iowa: Iowa Geological Survey Educational Series Publication 1, 147 p.

Ross, C. A., 1962, Early Llandoverian (Silurian) graptolites from the Edgewood Formation, northeastern Illinois: Journal of Paleontology, v. 36, p. 1383–1386.

______1964, Early Silurian graptolites from the Edgewood Formation of Iowa: Journal of Paleontology, v. 38, p. 1107–1108.

Rubey, W. W., 1952, Geology and mineral resources of the Hardin and Brussels Quadrangles: U.S. Geological Survey Professional Paper 218, 179 p.

Savage, T. E., 1913, Stratigraphy and paleontology of the Alexandrian Series in Illinois and Missouri; Part I: Illinois State Geological Survey, Extract from Bulletin 23, 124 p.

______1926, Silurian rocks of Illinois: Geological Society of America Bulletin, v. 37, p. 513–534.

Thompson, T. L.; and Satterfield, I. R., 1975, Stratigraphy and conodont biostratigraphy of strata contiguous to the Ordovician–Silurian boundary in eastern Missouri: Missouri Geological Survey Report of

Investigations 57, Studies in Stratigraphy, Part 2, p. 61–108.

Ulrich, E. O.; and Cooper, G. A., 1936, New Silurian brachiopods of the Family Triplesiidae: Journal of Paleontology, v. 10, p. 331–347.

Whitlow, J. W.; and Brown, C. E., 1963, The Ordovician–Silurian contact in Dubuque County, Iowa: U.S. Geological Survey Professional Paper 475-C, p. 11–13.

Willman, H. B., 1962, Description of stops, second day, *in* Silurian rocks of the southern Lake Michigan area, Michigan Basin Geological Society, Annual Field Conference, 1962: Michigan Geological Survey, p. 81–96.

______1973, Rock stratigraphy of the Silurian System in northeastern and northwestern Illinois: Illinois State Geological Survey Circular 479, 55 p.

APPENDIX: STRATIGRAPHIC SECTIONS

The locations of stratigraphic sections are designated using U.S. Geological Survey topographic quadrangle maps (1:24,000 scale). Precise coordinates following the map name are measured first east and then north from the southwest corner of the map. Descriptions of the sections and lists of fossils are contained in the references cited.

South-Central Oklahoma

Section 21 (Rock Crossing). Overbrook, Oklahoma Quadrangle: 310 mm E., 348 mm N.; SE¼NE¼SW¼ sec. 35, T. 5 S., R. 1 E. Exposure on west bank of Hickory Creek, east side of road, 150 m south of bridge, Carter County, Oklahoma (Amsden, 1960, sec. Ca11, p. 208–210, panel 1; Barrick, 1986, sec. Ca11, fig. 39; McAuley and Elias, 1990, sec. 21, p. 8, 53, fig. 2).

Section 35 (Henry House Falls). Springer, Oklahoma Quadrangle: 65 mm E., 464 mm N.; SW¼NE¼SE¼ sec. 30, T. 2 S., R. 1 E. Exposure on west side of Henry House Creek at upper rim of Henry House Falls, Carter County, Oklahoma (Amsden, 1960, sec. Ca1 (2), p. 190–195, panel 1).

Section 23 (Lawrence Quarry). Ahloso, Oklahoma Quadrangle: 93 mm E., 302 mm N. to 98 mm E., 296 mm N.; NW¼SE¼NE¼ sec. 36, T. 3 N., R. 5 E. (northern site); and 92 mm E., 282 mm N.; NW¼NE¼SE¼ sec. 36, T. 3 N., R. 5 E. (southern site). East side of Ideal Cement Co. quarry at Lawrence, Pontotoc County, Oklahoma (Amsden, 1960, pl. 1, figs. 1,2, panel 2, pl. A; 1974, loc. P22, p. 87; 1986, figs. 5,6,15; Barrick, 1986, sec. AQL, fig. 39; McAuley and Elias, 1990, sec. 23, p. 8, 53, fig. 2).

Section 24 (Coal Creek). Harden City, Oklahoma Quadrangle: 253 mm E., 208 mm N.; NW¼SE¼NW¼ sec. 22, T. 1 N., R. 7 E. Exposure on north bank of Coal Creek, 400 m east of Gobbler Knob, Pontotoc County, Oklahoma (Amsden, 1957, fig. 5; 1960, sec. P9, p. 279–282, panel 1; 1961, fig. 25; 1986, fig. 13; Barrick, 1986, sec. P9, fig. 39; McAuley and Elias, 1990, sec. 24, p. 8, 53, fig. 2).

West-Central Illinois and Northeastern Missouri

Section 36 (Indian Creek). Hamburg, Illinois–Missouri Quadrangle: 183 mm E., 306 mm N.; NW¼NW¼NE¼ sec. 13, T. 10 S., R. 3 W. North- and west-facing exposures just south of Indian Creek and just east of County Route 2, 4.6 km south–southeast of Hamburg, Calhoun County, Illinois (Rubey, 1952, loc. 6, p. 25–27, 170; Amsden, 1974, loc. I, p. 85; Thompson and Satterfield, 1975, sec. 12, p. 106). Collecting interval 36-1 in in situ strata, 36-1a in loose blocks.

Section 38 (Buckner Hollow). Bowling Green, Missouri Quadrangle: 348 mm E., 517 mm N.; center SW¼ sec. 17, T. 53 N., R. 2 W. Exposure on east side of stream in Buckner Hollow, Pike County, Missouri.

Section 13 (Bowling Green). Bowling Green, Missouri Quadrangle: 197 mm E., 497 mm N.; NW¼NW¼ sec. 24, T. 53 N., R. 3 W. Cut on north side of U.S. Route 54, 1.5 km northeast of junction with U.S. Route 61, Pike County, Missouri (Koenig and others, 1961, fig. 15; Amsden, 1974, loc. D, p. 84, figs. 4,7; Thompson and Satterfield, 1975, sec. 8, p. 96, 99, fig. 11; Elias, 1982, Bowling Green sec., fig. 21; Amsden, 1986, sec. D, figs. 31, 34; McAuley and Elias, 1990, sec. 13, p. 54, fig. 5).

Northeastern Illinois

Section 4 (Schweizer West). Channahon, Illinois Quadrangle; 302 mm E., 418 mm N.; SW¼SE¼ sec. 35, T. 35 N., R. 9 E. Cuts on both sides of lower (western) railroad, southeast side of Des Plaines River valley, Will County, Illinois (Ross, 1962, fig. 1; Willman, 1962, stop 4, p. 84; 1973, sec. 17, p. 50, 51; Liebe and Rexroad, 1977, loc. 8, p. 854, fig. 1; Elias, 1982, Will County sec., fig. 21; McAuley and Elias, 1990, sec. 4, p. 20, 54, fig. 7).

Section 29 (Sears Pit). Sycamore, Illinois Quadrangle: 347 mm E., 336 mm N.; SE¼ NW¼ and SW¼NE¼ sec. 15, T. 40 N., R. 5 E. Quarry southeast of intersection of Barber Greene Road and Airport Road, 4 km northeast of Cortland, De Kalb County, Illinois (Mikulic and others, 1985, p. 21–23, figs. 6,7; McAuley and Elias, 1990, sec. 29, p. 20, 54, fig. 7).

Northwestern Illinois and Eastern Iowa

Section 32 (Thomson East). Thomson, Illinois Quadrangle: 270 mm E., 377 mm N.; SE¼NE¼NW¼ sec. 28, T. 23 N., R. 4 E. Quarry on rise east of Johnson Creek, 4.5 km east of Thomson, Carroll County, Illinois (McAuley and Elias, 1990, sec. 32, p. 22, 54, figs. 8,9).

Section 26 (Bellevue). Springbrook, Iowa–Illinois Quadrangle: 288 mm E., 559 mm N., to 262 mm E., 572 mm N.; NE¼ sec. 19, T. 86 N., R. 5 E. Exposure along west side of U.S. Route 52 and south side of road in Bellevue State Park, Jackson County, Iowa (Whitlow and Brown, 1963, p. 13; Ross, 1964, p. 1107, fig. 1; Rose, 1967, stop 3, p. 44, 45, figs. 20,21; Anderson, 1983, fig. 5.6; McAuley and Elias, 1990, sec. 26, p. 22, 54, 55, fig. 8).

PLATE 1

Latest Ordovician to earliest Silurian solitary rugose corals
of the east-central United States.

All figures are negative prints of transverse thin sections, oriented as they appear looking down from the calice toward the apex of the corallum, with the cardinal side facing the bottom of the page unless otherwise indicated.

Figures 1–9.—*Streptelasma subregulare* (Savage, 1913). **1,2**, USNM 458198, 458199, upper oolitic unit, Keel Formation, section 24 (Coal Creek), ×3; **3–5**, USNM 458203, 458201, 458200, Cochrane Formation, section 21 (Rock Crossing), ×4; **6**, USNM 458204, Cyrene Formation, section 13 (Bowling Green), ×3; **7**, USNM 458205, Cyrene Formation, section 38 (Buckner Hollow), ×3; **8,9**, USNM 458206, 458207, Schweizer Member, Wilhelmi Formation, section 4 (Schweizer West), ×4, ×3 (in 9, arrow points to *Trypanites* boring, position of cardinal side uncertain).

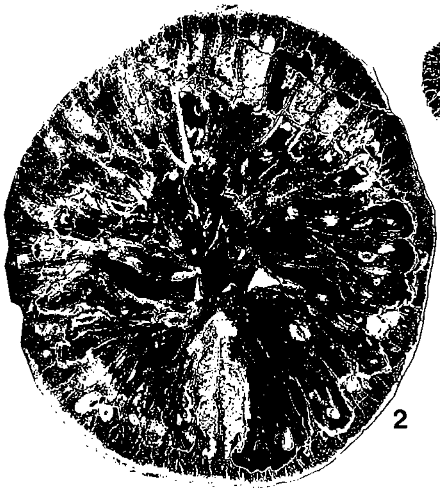
Figure 10.—*Rhegmaphyllum* sp., USNM 458214, Mosalem Formation, section 32 (Thomson East), ×6.

Figure 11.—*Dinophyllum* sp., USNM 458215, Bowling Green Dolomite, section 36 (Indian Creek), ×4.

Figures 12–14.—*Dalmanophyllum* sp. **12**, USNM 458216, Cochrane Formation, section 35 (Henry House Falls), ×5; **13**, USNM 458217, section 36 (Indian Creek), ×5; **14**, USNM 458218, Mosalem Formation, section 26 (Bellevue), ×5.

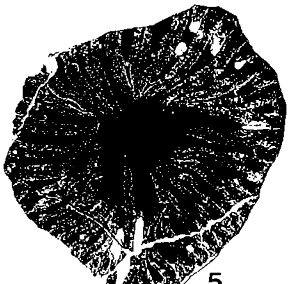
Figure 15.—*Cyathactis*? sp., USNM 458219, section 36 (Indian Creek), ×4.

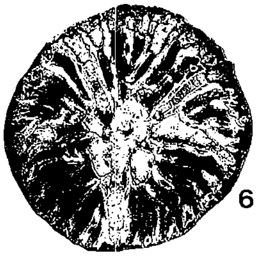

1


2

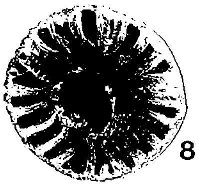

3

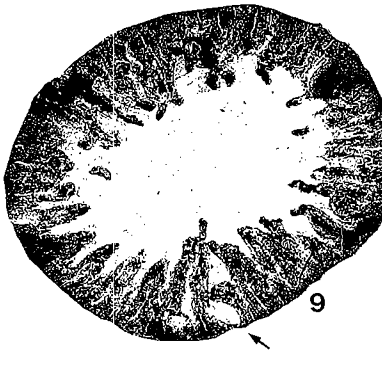

4

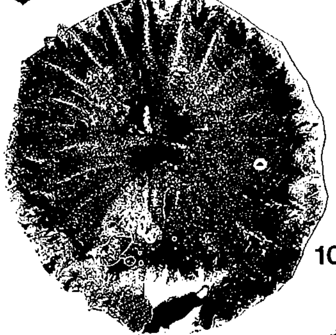

5

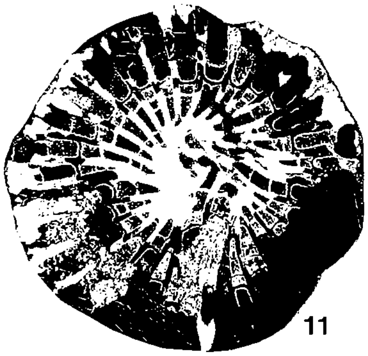

6

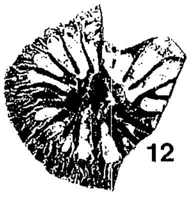

7

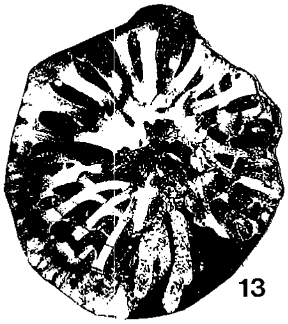

8

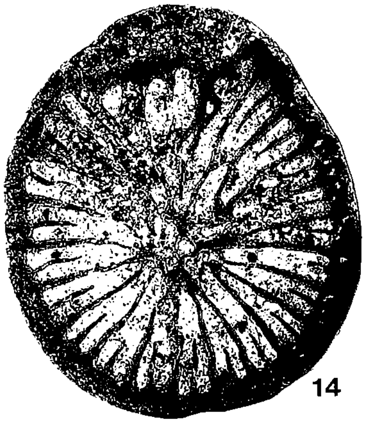

9

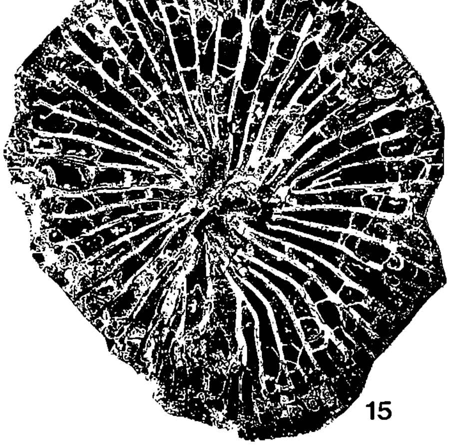

10


11


12


13


14


15

Oklahoma Geological Survey Bulletin 145, 1992

North American Midcontinent Devonian T-R Cycles

J. G. Johnson
Oregon State University

Gilbert Klapper
University of Iowa

ABSTRACT.—Twelve transgressive-regressive (T-R) cycles, established in the post-Lochkovian part of the Devonian on the basis of sequences in western and eastern North America and western Europe, were previously tested through an analysis of Midcontinent sequences. Correlations were achieved largely through conodont biostratigraphy but were supplemented with megafaunal evidence where the conodont data were inadequate. The Midcontinent sequences were found to replicate the T-R cycles established elsewhere with reasonable accuracy. We expand the analysis in the present study to include the Lochkovian Stage at the base of the Devonian by adding the Arbuckle Mountain sequence in the southern Midcontinent. Significant revisions in our previous correlation hypothesis for the Midcontinent include the following: (1) removal of the Prout of Ohio, and its lithostratigraphic equivalents, from Cycle If and transfer to the base of Cycle IIa, on the basis of new conodont data; (2) positioning of the base of the Solon in Iowa at a slightly higher level within Cycle IIa; (3) positioning of the Coralville of Iowa near the top of Cycle IIa and the base of the overlying Lithograph City at the base of Cycle IIb, as a result of lithostratigraphic and biostratigraphic revision; and (4) recognition that the basal Sweetland Creek Shale of Iowa, and equivalents elsewhere in the Midcontinent, represent the base of Cycle IId. Detailed distributional data on the upper Frasnian conodont sequence in the Sweetland Creek Shale is presented as a result of recent collecting and analysis.

INTRODUCTION

In our initial paper on Devonian eustatic fluctuations in Euramerica (Johnson and others, 1985), we constructed a qualitative eustatic sea-level curve and designated 12 transgressive-regressive (T-R) cycles above the Lochkovian, i.e., in the Devonian part of the Kaskaskia Sequence. The eustatic curve and T-R cycles were based on stratigraphic syntheses in the western United States, western Canada, New York, Belgium, and Germany and were correlated in terms of the conodont zonation. With the results of this synthesis as a guide, we constructed a correlation hypothesis for Midcontinent sections in Iowa, southwestern Ontario, and Ohio, compared with the western Canadian and New York sequences (Johnson and others, 1985, text-fig. 8). The results were two-fold: (1) Midcontinent sequences were found to conform with reasonable accuracy to the designated T-R cycles, and (2) the presence or absence of cratonic rock packages and the position of paleostrandlines in the cratonic interior were too dependent on local epeirogenic movements to serve as prime evidence for sea-level fluctuation. Now, seven years later, advances in knowledge of the stratigraphy and conodont biostratigraphy of Devonian rocks in Iowa and Ohio make possible significant revisions of our correlation hypothesis and suggest how the Devonian succession of Oklahoma can be joined to the eustatic synthesis. This is especially appropriate in the context of the present volume in honor of Tom Amsden.

ANALYSIS OF MIDCONTINENT T-R CYCLES

Pre-Ia T-R Cycles, Lochkovian

Definition of earliest Devonian T-R cycles was left unaccomplished by Johnson and others (1985), but they indicated the presence of two unnamed cycles. Dennison (1985), by evaluating stratigraphic indicators in Virginia and West Virginia, identified three deepening events, at essentially the same positions as plotted for the New York Helderbergian by Johnson and others (1985, text-fig. 2). In New York, these events are represented by the base of the Cobleskill–Chrysler–Rosendale, the base of the New Scotland, and the base of the Alsen, respectively. In Nevada, the single evident intra-Lochkovian deepening event has been identified in strata of the *delta* Zone (Johnson and others, 1989), i.e., synchronous with the Alsen deepening of New York.

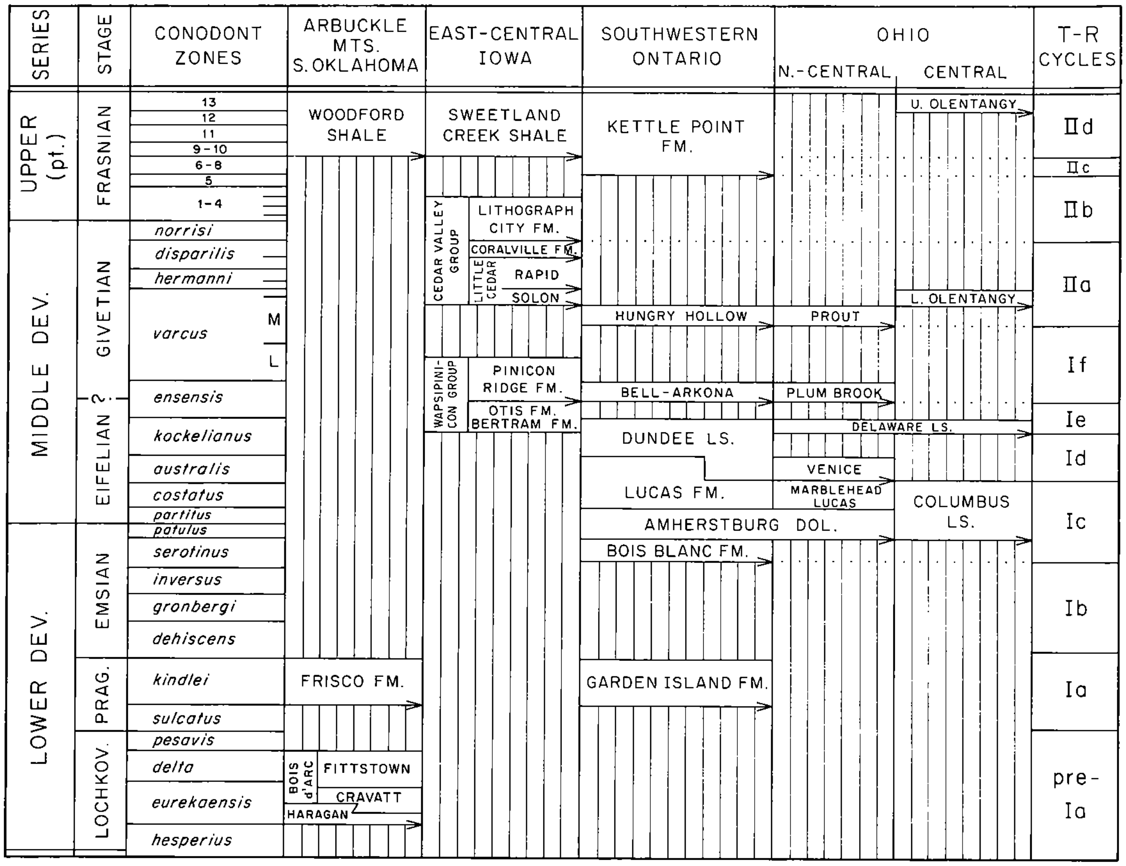


Figure 1. Correlation hypothesis for selected Devonian sections of the North American Midcontinent on the eastern side of the Transcontinental Arch. Devonian T-R cycles are indicated with roman numerals in the right-hand column, after Johnson and others (1985). Deepening events are shown by arrows pointing to the right. Numbered conodont zones in the Frasnian are those proposed by Klapper (1989); the *norrisi* Zone, at the top of the Middle Devonian, was proposed by Klapper and Johnson, in Johnson (1990). This chart revises text-figure 8 of Johnson and others (1985).

In the Arbuckle Mountains of southern Oklahoma, the only area in the present survey that contains a Lochkovian (Helderbergian) section, the combined fossil evidence of brachiopods and conodonts reveals a Haragan–Bois d'Arc sequence (Fig. 1) that is correlative with the New Scotland to Alsen interval of New York (Amsden, 1958a,b,1962). The Pinetop Chert represents part of this interval in the Ouachita Mountains of southeastern Oklahoma (Amsden, 1983).

The Haragan Formation and the Cravatt and the lower part of the Fittstown Members of the Bois d'Arc Formation contain a conodont fauna with *Icriodus postwoschmidti* and *Pedavis biexoramus*, indicating correlation with the *eurekaensis* Zone of the Nevada sequence. The same two species occur in the Rockhouse Limestone of Tennessee (Broadhead and McComb, 1983). A conodont fauna with *Ancyrodelloides transitans* occurs in the upper part of the Fittstown Member on Bois d'Arc Creek, indicating correlation with the next-higher *delta* Zone (Barrick and Klapper, 1992 [this volume]).

In a number of papers (most recently summarized in Amsden, 1988, p. 9–11), the view was expressed that the Haragan–Bois d'Arc represents a single brachiopod zone, correlative with the New Scotland part of the Helderbergian sequence in New York. He noted an alternate view (Boucot and Johnson, 1967; Campbell, 1977) that regarded part of the Cravatt and the Fittstown Members of the Bois d'Arc as younger than most of the Haragan and correlative with a post-New Scotland Helderbergian level (i.e., Becraft–Alsen–Port Ewen) in New York State. The latter viewpoint is supported by the recognition of *delta* Zone conodonts in the upper part of the Fittstown Member. Rare specimens of *Ancyrodelloides transitans* also occur in the Alsen Limestone (Rickard, 1975).

T-R Cycle Ia,
Pragian

In the area of our present survey, T-R Cycle Ia is represented by unconformity-bounded carbonate units correlative with the Oriskany: the Frisco Formation of Oklahoma and the Garden Island Formation of southwestern Ontario (Fig. 1). Both contain characteristic Oriskany brachiopod faunas that are well documented (Amsden and Ventress, 1963; Landes and others, 1945; Boucot and Johnson, 1967, p. 57). The Quall Limestone of western Tennessee is correlative. Conodonts are abundant in the Frisco but all are highly fragmentary. A specifically indeterminate species of *Icriodus* is the main Frisco conodont, and as noted by Klapper (in Amsden, 1985, p. 1–2) may be related to *Icriodus claudiae*.

T-R Cycle Ib,
lower Emsian

A thin Lower Devonian limestone in the Turkey Creek Inlier, Marshall County, southern Oklahoma, rests on Ordovician strata and is overlain by the Woodford Shale. It has yielded a sparse and enigmatic fauna of brachiopods (Amsden, 1985), conodonts, and trilobites (Ormiston, 1968) of an offshore biofacies. The Turkey Creek conodonts were originally regarded as intermediate in age between the faunas of the Frisco and the Sallisaw (Klapper, in Amsden and others, 1968), and the trilobites were correlated with closely similar faunas of the lower Emsian in the Harz Mountains, Germany (Ormiston, 1968). Although Campbell (1977, p. 10) questioned the Bohemian provincial affinity of the trilobites advocated by Ormiston, he did not question the early Emsian age assignment. A subsequent reevaluation of the conodonts (Klapper, in Amsden, 1985, p. 1–2) suggested that the species of *Icriodus* present most closely resembles *I. claudiae*, which supports the idea that the Turkey Creek Limestone is older than the Sallisaw but does not conclusively differentiate the fauna from that of the Frisco. Nonetheless, the fact that the problematic specimens of *Icriodus* in both the Frisco and the Turkey Creek may be related to *I. claudiae*, certainly does not prove that the two units are the same age since the cited species has a long range in Nevada through the *sulcatus* and *kindlei* Zones. Thus, if one accepts the trilobite evidence for an early Emsian age, the Turkey Creek Limestone would be the only representative of T-R cycle Ib in the Midcontinent.

T-R Cycle Ic,
upper Emsian–lower Eifelian

A transgressive carbonate blanket represents T-R Cycle Ic in all areas of the present survey except the Iowa Basin and the Arbuckle Mountains in southern Oklahoma. In northeastern Oklahoma, the Sallisaw Formation is in this cycle, as are the Camden and Clear Creek Formations of western Tennessee and southwestern Illinois. Amsden reviewed and discussed the brachiopod fauna of these named units (Amsden and Ventress, 1963). In the area of Ohio and southwestern Ontario, T-R Cycle Ic is represented by all of the Columbus Limestone below the Venice Member (Fig. 1), by the Bois Blanc Formation and the overlying Amherstburg and Lucas Dolomites of the Detroit River Group, and by the lowest part of the Dundee Limestone where it is a facies of the Lucas (Oliver, 1976; Sparling, 1988, fig. 19). The important conodont *Icriodus latericrescens robustus* has its first appearance in rocks at the base of this transgression, including the Sallisaw (Klapper, in Amsden, 1985, p. 1–2), the Bois Blanc of Ontario (Uyeno and others, 1982) and western New York, and the Schoharie Limestone of central New York (Klapper and Johnson, 1980, table 6). The lowest occurrence of this subspecies is taken as correlative with the *serotinus* Zone in Nevada (Klapper and Johnson, 1980, p. 409). Intracycle deepening events are represented at the base of the Detroit River Group and the base of the Marblehead Member of the Columbus Limestone. These events evidently enabled the migration into the Midcontinent of *Polygnathus* of the *costatus* group.

T-R Cycle Id,
middle to upper Eifelian

In the area of our present survey, T-R Cycle Id is represented by the Venice Member of the Columbus Limestone, an open-marine limestone that follows above shoal-water rocks of the upper Marblehead Member (Sparling, 1988, fig. 9; Sparling's fig. 11 illustrates conodonts from the Venice Member), and by the lower Dundee Limestone (Fig. 1). T-R Cycle Id rocks are unknown in Oklahoma and Iowa. The deepening event that initiates Id is represented by the Union Springs black shale in New York (Johnson and others, 1985).

T-R Cycle Ie,
upper Eifelian

Onlap and deepening associated with T-R Cycle Ie is especially significant in terms of paleogeographic consequences, concomitant with the first Devonian flooding of the Iowa Basin resulting in deposition of the Spillville Formation in northern Iowa and southernmost Minnesota and the Otis Formation in east-central Iowa (Witzke and others, 1989) (Fig. 1). These sequences provide evidence for the breaching of the Transcontinental Arch and a probable continuous seaway with the Elm Point lithotope of the Williston Basin and the Devonian outcrop belt in southwestern Manitoba. Conodont faunas of the Spillville Formation (Klapper and Barrick, 1983) with the characteristic species, *Polygnathus curtigladius* and *Icriodus orri*, are identical with those in the lower part of the outcropping Elm Point Formation (Norris and others, 1982). An alternative paleogeographic reconstruction includes a seaway connection from the north, through the James Bay lowlands and Hudson Bay, with the Northwest Territories of Canada (Ziegler, 1989, fig. 5).

Elsewhere in the area of our survey, the Delaware Limestone of Ohio (Sparling, 1983, fig. 13; 1988, fig. 15 illustrates representative Delaware conodonts), upper Dundee Limestone of southwestern Ontario (Uyeno and others, 1982) and upper Dundee and overlying lower part of the Rogers City Limestone of Michigan (Bultynck, 1976) represent T-R Cycle Ie. Two of the characteristic conodonts of these units are *Icriodus angustus* and *Icriodus orri* (called *I.* sp. aff. *I. retrodepressus* in earlier references). A possibly correlative unit is present in the subsurface of the western Anadarko Basin in the Texas Panhandle, on evidence of the report of *Icriodus angustus* (Barrick and others, 1990, p. 61). The Rogers City macrofauna includes a number of taxa in common with correlative Canadian units, e.g., *Carinatrypa dysmorphostrota* and *Variatrypa arctica* (Ehlers and Kesling, 1970). The deepening event that initiated Cycle Ie is represented by the Oatka Creek black shale in New York.

T-R Cycle If, lower Givetian

The upper Wapsipinicon Group, Kenwood and Spring Grove Members of the Pinicon Ridge Formation, represent two intra-If deepening events in the Iowa Basin (Witzke and others, 1989, fig. 13). Elsewhere in the area of our survey, the Bell, Rockport Quarry, and Arkona Formations (indicated as Bell–Arkona on Fig. 1) in southwestern Ontario and the Plum Brook Shale of north-central Ohio are in T-R Cycle If (Sparling, 1988, fig. 17 illustrates representative Plum Brook conodonts diagnostic of the *ensensis* Zone). However, we here remove the Hungry Hollow, Widder, and Ipperwash Formations of southwestern Ontario and the Prout Dolomite of north-central Ohio, from T-R Cycle If of our original correlation hypothesis (Johnson and others, 1985, text-fig. 8) because Sparling (1988, p. 14–15) has found conodonts of the Middle *varcus* Subzone in the Prout.

T-R Cycle IIa, upper Givetian

The quartz sandstone-carbonate sequence in the central and north-central Oklahoma subsurface, represented by the Misener Sandstone (Amsden and Klapper, 1972), and the approximately correlative Sylamore Sandstone in northeastern Oklahoma and northern Arkansas (Freeman and Schumacher, 1969) are products of the Taghanic onlap (Johnson, 1970). These units lie above a profound unconformity in which at least three T-R cycles (Id-Ie-If) are missing, perhaps best shown at sections in Sequoyah County, northeastern Oklahoma (described by Amsden, 1961), where the Sylamore lies directly on the Sallisaw Formation of T-R Cycle Ic. The Sylamore in the area is undetermined biostratigraphically, however. The oldest conodont zone recognized in the Misener is the *varcus* Zone in the Federal 1 Wolleson (Amsden and Klapper, 1972, fig. 6, table 1), which presumably represents T-R Cycle IIa. Higher levels in the Misener appear to represent Cycles IIb and IIc (Amerada 1 Richey and Amerada 1 Breckenridge, respectively). The Misener extends to even higher stratigraphic levels, up into the lower Famennian (Amsden and Klapper, 1972, table 1). The similarly diachronous base of the Sylamore Sandstone in northern Arkansas (Freeman and Schumacher, 1969) reportedly ranges from the *varcus* Zone through the Frasnian and Famennian into the lowest conodont zone of the Carboniferous.

In the Iowa Basin, recent analysis reported by Witzke and others (1989, fig. 13) has significantly revised the nomenclature of the Cedar Valley Group and has also interpreted the succession in terms of the T-R cycles of Johnson and others (1985). Witzke and others (1989) recognized three subcycles within T-R Cycle IIa, the lower two corresponding to the initiation of deposition of the Solon and Rapid Members of the Little Cedar Formation and the upper one corresponding to the beginning of deposition of the Coralville Formation. In our previously published correlation hypothesis (Johnson and others, 1985, text-fig. 8) we recognized these three deepening events, but revision of Iowa stratigraphic nomenclature results in the basal Coralville deepening arrow being shifted downward to a pre-*norrisi* position in the conodont zonation, i.e. down into Cycle IIa.

The cited revision was also significantly affected by new analysis of the conodont sequence (Witzke and others, 1985, p. 37–41; 1989), which shows that the Cou Falls Member at the base of the Coralville Formation in southeastern Iowa carries the upper *subterminus* Fauna, a low-diversity fauna approximately equivalent to part of the *disparilis* Zone. The lowermost part of the Gizzard Creek Member, which forms the base of the Coralville at the Glory Quarry in Black Hawk County, northern Iowa, contains the diagnostic brachiopod *Tecnocyrtina missouriensis missouriensis* (Day, 1989, p. 305, fig. 4). A related subspecies (*T. missouriensis teleta*) is restricted to the lower part of Faunal Interval 27, *disparilis* Zone in Nevada (Johnson and Trojan, 1982, fig. 2).

Correlative positions of the Hungry Hollow, Widder, and Ipperwash Formations of southwestern Ontario (indicated simply as Hungry Hollow on Fig. 1) and the Prout Dolomite of north-central Ohio have all been revised from our previous hypothesis (Johnson and others, 1985, text-fig. 8), as already noted. This revision is based on Sparling's

(1988, fig. 18 illustrates representative Prout conodonts) finding of *Polygnathus ansatus* and *P. ovatinodosus* in the Prout. We have followed Sparling's (1988, fig. 19) correlation hypothesis and assigned all of the cited lithostratigraphic units to the Middle *varcus* Subzone and to the base of T-R Cycle IIa, even though it is only the Prout that contains the conodonts critical for this inference. [A question beyond the scope of the present paper is the validity of the Givetian conodont zonation up through the Middle *varcus* Subzone. For example, the distinction between *Polygnathus ansatus*, the defining species of that subzone, and *P. hemiansatus* Bultynck, which appears at the base of the Givetian, is in doubt.] One possible interpretation is that the Prout Dolomite and its inferred lithostratigraphic equivalents in adjacent areas correlate with the lower part of the Tully Limestone in New York, as suggested by Sparling (1988, p. 15). This becomes clear if one considers the Beechwood Limestone of Indiana as also part of this correlation. The conspicuous occurrence of *Polygnathus timorensis* and the morphotype of *Icriodus latericrescens latericrescens* present in the Beechwood (Klug, 1983; the same as in the Prout) gives some evidence that we are dealing with an older fauna than that of the Solon of Iowa. The Solon instead correlates with the upper part of the Tully Limestone in New York. Thus, within the lower part of Cycle IIa (Fig. 1), the Prout and equivalents represent a slightly earlier onlap than that of the Solon and equivalents.

T-R Cycle IIb, uppermost Givetian–lower Frasnian

The very significant deepening event that initiated this cycle has usually been identified with the beginning of the Frasnian, but as that boundary has recently been defined, deepening preceded it. The IIb cycle begins with the *norrisi* Zone (formerly, the Lowermost *asymmetrica* Zone; Klapper and Johnson, in Johnson, 1990) and corresponds with the base of the *insita* Fauna or biofacies in the Midcontinent. In the Iowa Basin, T-R Cycle IIb is represented by the Lithograph City Formation (Witzke and others, 1989, figs. 12,13). The *insita* Fauna is well developed in the State Quarry Member of the Lithograph City in Johnson County, Iowa, including *Skeletognathus norrisi* at one locality (Watson, 1974; Witzke and others, 1985, p. 40), and the fauna is also present in all but the uppermost beds of the Andalusia Member of the same formation in Scott County, Iowa, and adjacent sections in Illinois. A late member of the *Tecnocyrtina* lineage (Johnson and Trojan, 1982, fig. 2), *T. curvilineata*, occurs in the State Quarry Member in Johnson County and the lower Andalusia Member at the Buffalo Quarry in Scott County (Day, 1989, p. 309) in strata with the *insita* Fauna.

The uppermost beds of the Andalusia Member at the Buffalo Quarry (Witzke and others, 1989, fig. 11) and due south at Fancy Creek near Andalusia, Illinois, have a conodont fauna including *Ancyrodella rugosa*, *A. africana*, and *A. alata* (late form) and thus correlative with Montagne Noire Frasnian Zone 3 (Klapper, 1989). The same three species of *Ancyrodella* occur at several localities of the Snyder Creek Shale in central Missouri (unpublished collections of A. R. Ormiston and G. Klapper).

T-R Cycle IIc, lower Frasnian

In the Iowa Basin, T-R Cycle IIc is represented by the Shell Rock Formation, which overlies the Lithograph City Formation in northern Iowa (Witzke and others, 1989, figs. 12,13). Anderson (1966, pl. 48, figs. 2,4,10,14) illustrated *Ancyrodella curvata* (early form) and *A. gigas* form 1 from the Shell Rock. Although the Shell Rock conodonts are not zonally diagnostic, the lowest occurrence of the former species is in Montagne Noire Frasnian Zone 6 (Klapper, 1989, p. 453). Brachiopods of the Shell Rock Formation (Day, 1989, p. 303) appear to correlate with Faunal Interval 30 in central Nevada. Strata equivalent to the Shell Rock are unrepresented in east-central Iowa, because of the demonstrated hiatus between the Sweetland Creek Shale and the Lithograph City Formation (Fig. 1).

A representative of T-R Cycle IIc shown on Figure 1 is the lower part of the Kettle Point Formation in southwestern Ontario. A distinctive morphotype presently included within *Palmatolepis punctata* has been illustrated from low in the Kettle Point in the Sombra 2-6 well (Winder, 1966, pl. 156, fig. 13, table 1). This morphotype is characteristic of Montagne Noire Frasnian Zone 6 faunas in unpublished collections from the Canning Basin, Western Australia.

T-R Cycle IId, upper Frasnian

Perhaps the best upper Frasnian conodont sequence developed in the North American Midcontinent is that of the type Sweetland Creek Shale in Muscatine County, southeastern Iowa. In terms of the Frasnian conodont zonation developed in the Montagne Noire, southwestern France (Klapper, 1989), Zones 9, 10, 12, and 13 are well delineated in the Iowa sequence (Fig. 2). The Sweetland Creek Shale, interpreted to have been deposited in quiet dysoxic environments well below effective wave base (Witzke, 1987, p. 242) is quite condensed in thickness compared with the zonal equivalents in the Montagne Noire.

Immediately above a thin representation of Zones 9 and 10 at Sweetland Creek (Fig. 2), there is a 73-cm-thick siltstone unit that has not yielded conodonts and which is in the stratigraphic position of Montagne Noire Zone 11. This siltstone interval is thought to represent Zone 11 for the following

Montagne Noire Frasnian Zone	9	10	12				13									
Meters above base of type Sweetland Creek Shale	0 - 0.3	0.3- 0.5	1.23- 1.29	1.40- 1.45	1.40- 1.50	1.55- 1.70	1.70- 1.90	1.85- 2.05	1.90- 2.05	1.90- 2.10	2.10- 2.30	2.10- 2.40	2.70- 2.90	2.70- 2.90	3.30- 3.40	3.80- 3.90
Sample number	1	2	3	3'	20	3"	4	5'	23	5	24	6	7	25	8	9
Conodont species																
Palmatolepis proversa	X	X														
Palmatolepis kireevae	X	X														
Ancyrodella lobata	X	X		X												
Ancyrognathus iowaensis	X	X		X	X											
Icriodus symmetricus	X	X	X	X	X	X										
Polygnathus spp.	X	X		X												X
Palmatolepis ljaschenkoae		X														
Palmatolepis domanicensis		X														
P. aff. *P. domanicensis*		X														
P. aff. *P. rhenana*		X														
P. n. sp.		X														
Ancyrodella gigas form 3		X														
Ancyrodella curvata early form		X														
Ancyrodella curvata late form		X		X	X	X										
Polygnathus unicornis		cf.	X	X	X		X			X	X	X			X	
Polygnathus samueli			X													
Palmatolepis foliacea			X	X	X	X										
Polygnathus decorosus			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Polygnathus brevis				X	X							X	X		X	
Palmatolepis winchelli				X	X	X	X	X	X	X	X	X	X	X	X	X
Ancyrodella nodosa				X	X	X	X	X	X	X	X	X	X		X	X
Palmatolepis hassi form 4					X											
Ancyrognathus triangularis					X											
Mehlina gradata					X	X	X			X					X	
Polygnathus webbi					X	X				X	X	X	X	X	X	X
Palmatolepis bogartensis							X	X	X	X	X	X	X	X	X	X
Ancyrognathus asymmetricus							X	X		X		X	X		X	X
Ancyrognathus calvini								X	X	X	X					
Palmatolepis juntianensis								X	X	X	X	X	X	X	X	
Ancyrodella subrotunda								X	X	X	X	X	X	X		X
Ancyrognathus aff. *A. altus*										X				X		
Palmatolepis linguiformis																X
Palmatolepis n. sp. T																X
Polygnathus brevicarina																X
Ozarkodina "confluens" (homeomorph)																X

Figure 2. Distribution of conodont species in the type section of the Sweetland Creek Shale, Muscatine County, southeastern Iowa, indicating the correlation with the Montagne Noire Frasnian zonation (Klapper, 1989). The early work on the Sweetland Creek was reviewed by Klapper and Furnish (1963). Their lists for the type section are revised herein on the basis of a later taxonomy used by Klapper and Foster (1986) and Klapper (1989,1990) and new collections made from 1979–89 (Klapper, 1990, p. 1006, 1010, 1025). Note that there is a 73-cm interval of siltstone (see text) between samples 2 and 3 that has not yielded conodonts.

reasons, in addition to its stratigraphic position between conodont faunas of Zones 10 and 12 (Fig. 2). A subsurface section of the Sweetland Creek Shale in Knox County, northeastern Missouri (Woodruff, 1990, loc. B, table 3, samples 28, 35) shows a Zone 10 fauna with *Palmatolepis domanicensis*, succeeded about 4 m higher by a collection with *P. semichatovae*. Similarly, in the Jerome Member of the Martin Formation near Globe, Arizona (Day, 1990, p. 619–620), the same two species are in direct succession as they are also in the Alberta sequence (Klapper and Lane, 1989). Thus, a fauna characterized primarily by *Palmatolepis semichatovae* in the middle to upper parts of the Juniper Hill and lower part of the Cerro Gordo Members of the Lime Creek Formation in northern Iowa (Day, 1990) is probably equivalent to the cited siltstone at Sweetland Creek.

The type Sweetland Creek Shale rests with marked unconformity on the Lithograph City Formation at the top of the Cedar Valley Group, with Shell Rock equivalents missing as already noted. Furthermore, the Sweetland Creek truncates down to a stratigraphic level as low as the Rapid Member of the Little Cedar Formation in the southeastern Iowa subsurface (B. J. Bunker and B. J. Witzke, 1991, personal communication). Thus, the lowermost beds of the Sweetland Creek represent the base of T-R Cycle IId in southeastern Iowa, in contrast with the previous interpretation (Johnson and others, 1985, text-fig. 8), which showed the base of the Sweetland Creek as a IIc-deepening event. Evidently, the level of *Palmatolepis semichatovae* is somewhat above the base of T-R Cycle IId in the Midcontinent, judging from the northern Iowa (Day, 1990) and northeastern Missouri (Woodruff,

1990) sequences. The same situation obtains in the Martin Formation of Arizona (Day, 1990), where *Palmatolepis domanicensis* underlies *P. semichatovae*, in contrast with sections in Nevada and Utah where the latter species seems to mark the base of Cycle IId (Sandberg and others, 1989).

The two samples immediately above the basal lag bed of the Woodford Shale at the Hass En section on the Lawrence Uplift in the northern Arbuckle Mountains, southern Oklahoma (Over, 1990, fig. 11, table 1, samples 012, 014) appear to represent Montagne Noire Zone 9. Thus, the basal beds of the Woodford on the Lawrence Uplift correlate with the base of the type Sweetland Creek Shale and also belong to T-R Cycle IId (Fig. 1). Collections loaned by Walter Sweet from the type section of the Olentangy Shale at Delaware in central Ohio, show a lag bed separating the Middle Devonian from the Frasnian part of the Olentangy. The conodonts of the type upper Olentangy are closely comparable to those in the Zone 13 part of the Sweetland Creek Shale (Fig. 2), extending from collections with *Ancyrognathus calvini* up to those with *Palmatolepis linguiformis*.

ACKNOWLEDGMENTS

Johnson's research has been supported by National Science Foundation Grant EAR90-03703 and Klapper's by EAR89-03475. The order of authorship is alphabetical. We are grateful to William A. Oliver, Jr., and Brian J. Witzke for constructive criticism of an earlier version of this paper.

REFERENCES CITED

Amsden, T. W., 1958a, Haragan articulate brachiopods, *part 2 of* Amsden, T. W.; and Boucot, A. J., Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 9–144.

______1958b, Bois d'Arc articulate brachiopods, *part 5 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 82, 110 p.

______1961, Stratigraphy of the Frisco and Sallisaw Formations (Devonian) of Oklahoma: Oklahoma Geological Survey Bulletin 90, 121 p.

______1962, Additional fossils from the Bois d'Arc Formation in the southeastern part of the Arbuckle Mountains region: Oklahoma Geology Notes, v. 22, p. 212–216.

______1983, *Coelospira concava* (Hall) from the Pinetop Chert (Early Devonian), Ouachita Mountains, Oklahoma: Journal of Paleontology, v. 57, p. 1244–1260.

______1985, Brachiopods from the Turkey Creek Limestone (Early Devonian), Marshall County, southern Oklahoma: Oklahoma Geological Survey Bulletin 138, 20 p.

______1988, Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., *part 1 of* Amsden, T. W.; and Barrick, J. E., Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, p. 1–53

Amsden, T. W.; and Klapper, Gilbert, 1972, Misener Sandstone (Middle–Upper Devonian), north-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 56, p. 2323–2334.

Amsden, T. W.; and Ventress, W. P. S., 1963, Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, 239 p.

Amsden, T. W.; Klapper, Gilbert; and Ormiston, A. R., 1968, Lower Devonian limestone of post-Hunton age, Turkey Creek Inlier, Marshall County, south-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 52, p. 162–166.

Anderson, W. I., 1966, Upper Devonian conodonts and the Devonian–Mississippian boundary of north-central Iowa: Journal of Paleontology, v. 40, p. 395–415.

Barrick, J. E.; and Klapper, Gilbert, 1992, Late Silurian–Early Devonian conodonts from the Hunton Group (upper Henryhouse, Haragan, and Bois d'Arc Formations), south-central Oklahoma, *in* Chaplin, J. R.; and Barrick, J. E. (eds.), Special papers in paleontology and stratigraphy: a commemorative volume for Thomas W. Amsden: Oklahoma Geological Survey Bulletin 145, p. 19–65.

Barrick, J. E.; Klapper, Gilbert; and Amsden, T. W., 1990, Late Ordovician–Early Devonian conodont succession in the Hunton Group, Arbuckle Mountains and Anadarko basin, Oklahoma, *in* Ritter, S. M. (ed.), Early to Middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 55–62.

Boucot, A. J.; and Johnson, J. G., 1967, Paleogeography and correlation of Appalachian province Lower Devonian sedimentary rocks, *in* Toomey, D. F. (ed.), Silurian–Devonian rocks of Oklahoma and environs: Tulsa Geological Society Digest, v. 35, p. 35–87.

Broadhead, T. W.; and McComb, R., 1983, Paedomorphosis in the conodont family Icriodontidae and the evolution of *Icriodus*: Fossils and Strata, no. 15, p. 149–154.

Bultynck, P., 1976, Comparative study of Middle Devonian conodonts from north Michigan (U.S.A.) and the Ardennes (Belgium–France), *in* Barnes, C. R. (ed.), Conodont paleoecology: Geological Association of Canada Special Paper 15, p. 119–141.

Campbell, K. S. W., 1977, Trilobites of the Haragan, Bois d'Arc, and Frisco Formations (Early Devonian), Arbuckle Mountains region, Oklahoma: Oklahoma Geological Survey Bulletin 123, 227 p.

Day, J., 1989, The brachiopod succession of the Late Givetian–Frasnian of Iowa, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 303–325.

______1990, The Upper Devonian (Frasnian) conodont sequence in the Lime Creek Formation of north-central Iowa and comparison with Lime Creek ammonoid, brachiopod, foraminifer, and gastropod sequences: Journal of Paleontology, v. 64, p. 614–628.

Dennison, J. M., 1985, Devonian eustatic fluctuations in Euramerica: discussion: Geological Society of America Bulletin, v. 96, p. 1595–1597.

Ehlers, G. M.; and Kesling, R. V., 1970, Devonian strata of Alpena and Presque Isle Counties, Michigan: Michigan Basin Geological Society Guide Book for Field Trips, Michigan State University, East Lansing, 130 p.

Freeman, T.; and Schumacher, D., 1969, Qualitative pre-Sylamore (Devonian–Mississippian) physiography delineated by onlapping conodont zones, northern Arkansas: Geological Society of America Bulletin, v. 80, p. 2327–2334.

Johnson, J. G., 1970, Taghanic onlap and the end of North American Devonian provinciality: Geological Society of America Bulletin, v. 81, p. 2077–2105.

______1990, Lower and Middle Devonian brachiopod-dominated communities of Nevada, and their position in a biofacies-province-realm model, with a section on Revision of Middle Devonian conodont zones, by G. Klapper and J. G. Johnson: Journal of Paleontology, v. 64, p. 902–941.

Johnson, J. G.; and Trojan, W. R., 1982, The *Tecnocyrtina* brachiopod fauna (?Upper Devonian) of central Nevada: Geologica et Palaeontologica, v. 16, p. 119–150.

Johnson, J. G.; Klapper, Gilbert; and Sandberg, C. A., 1985, Devonian eustatic fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567–587.

Johnson, J. G.; Sandberg, C. A.; and Poole, F. G., 1989, Early and Middle Devonian paleogeography of western United States, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 1, p. 161–182.

Klapper, G., 1989, The Montagne Noire Frasnian (Upper Devonian) conodont succession, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 449–468.

______1990, Frasnian species of the Late Devonian conodont genus *Ancyrognathus*: Journal of Paleontology, v. 64, p. 998–1025.

Klapper, G.; and Barrick, J. E., 1983, Middle Devonian (Eifelian) conodonts from the Spillville Formation in northern Iowa and southern Minnesota: Journal of Paleontology, v. 57, p. 1212–1243.

Klapper, G.; and Foster, C. T., Jr., 1986, Quantification of outlines in Frasnian (Upper Devonian) platform conodonts: Canadian Journal of Earth Sciences, v. 23, p. 1214–1222.

Klapper, G.; and Furnish, W. M., 1963 [imprint, 1962], Conodont zonation of the Early Upper Devonian in eastern Iowa: Iowa Academy of Science Proceedings, v. 69, p. 400-410.

Klapper, G.; and Johnson, J. G., 1980, Endemism and dispersal of Devonian conodonts: Journal of Paleontology, v. 54, p. 400–455.

Klapper, G.; and Lane, H. R., 1989, Frasnian (Upper Devonian) conodont sequence at Luscar Mountain and Mount Haultain, Alberta Rocky Mountains, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 469–478.

Klug, C. R., 1983, Conodonts and biostratigraphy of the Muscatatuck Group (Middle Devonian), south-central Indiana and north-central Kentucky: Wisconsin Academy of Sciences, Arts and Letters, v. 71, p. 79–112.

Landes, K. K.; Ehlers, G. M.; and Stanley, G. M., 1945, Geology of the Mackinac Straits region and the subsurface geology of the northern Southern Peninsula: Michigan Geological Survey Division Publication 44, geological series 37, 204 p.

Norris, A. W.; Uyeno, T. T.; and McCabe, H. R., 1982, Devonian rocks of the Lake Winnipegosis–Lake Manitoba outcrop belt, Manitoba: Geological Survey of Canada Memoir 392, 280 p.

Oliver, W. A., Jr., 1976, Noncystimorph colonial rugose corals of the Onesquethaw and lower Cazenovia Stages (Lower and Middle Devonian) in New York and adjacent areas: U.S. Geological Survey Professional Paper 869, 156 p.

Ormiston, A. R., 1968, Lower Devonian trilobites of Hercynian type from the Turkey Creek Inlier, Marshall County, south-central Oklahoma: Journal of Paleontology, v. 42, p. 1186–1199.

Over, D. J., 1990, Conodont biostratigraphy of the Woodford Shale (Late Devonian–Early Carboniferous) in the Arbuckle Mountains, south-central Oklahoma: Texas Tech University unpublished Ph.D. dissertation, 174 p.

Rickard, L. V., 1975, Correlation of the Silurian and Devonian rocks in New York State: New York State Museum and Science Service, Map and Chart Series, no. 24, 16 p.

Sandberg, C. A.; Poole, F. G.; and Johnson, J. G.; 1989, Upper Devonian of western United States, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 1, p. 183–220.

Sparling, D. R., 1983, Conodont biostratigraphy and biofacies of lower Middle Devonian limestones, north-central Ohio: Journal of Paleontology, v. 57, p. 825–864.

______1988, Middle Devonian stratigraphy and conodont biostratigraphy, north-central Ohio: Ohio Journal of Science, v. 88, p. 2–18.

Uyeno, T. T.; Telford, P. G; and Sanford, B. V., 1982, Devonian conodonts and stratigraphy of southwestern Ontario: Geological Survey of Canada Bulletin 332, 55 p.

Watson, M. G., 1974, Stratigraphy and environment of deposition of the State Quarry Limestone, Johnson County, Iowa: University of Iowa unpublished M.S. thesis, 140 p.

Winder, C. G., 1966, Conodont zones and stratigraphic variability in Upper Devonian rocks, Ontario: Journal of Paleontology, v. 40, p. 1275–1293.

Witzke, B. J., 1987, Models for circulation patterns in epicontinental seas applied to Paleozoic facies of North American craton: Paleoceanography, v. 2, p. 229–248.

Witzke, B. J.; Bunker, B. J.; and Klapper, G., 1985, Devonian stratigraphy in the Quad-Cities area, eastern Iowa–northwestern Illinois, *in* Hammer, W. R.; Anderson, R. C.; and Schroeder, D. A. (eds.), Devonian and Pennsylvanian stratigraphy of the Quad-Cities region, Illinois–Iowa: Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 15th Annual Field Conference Guidebook, p. 19–64.

Witzke, B. J.; Bunker, B. J.; and Rogers, F. S., 1989, Eifelian through Lower Frasnian stratigraphy and deposition in the Iowa area, central Midcontinent, U.S.A., *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 1, p. 221–250.

Woodruff, M. L., 1990, Middle and Upper Devonian (Givetian–Famennian) conodont biostratigraphy and lithostratigraphy in the subsurface of northeastern Missouri: University of Iowa unpublished M.S. thesis, 239 p.

Ziegler, P. A., 1989, Laurussia—the Old Red Continent, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world: Canadian Society of Petroleum Geologists Memoir 14, v. 1, p. 15–48.

Oklahoma Geological Survey Bulletin 145, 1992

Corals from the Turkey Creek Limestone (Lower Devonian), Southern Oklahoma

William A. Oliver, Jr.
U.S. Geological Survey, Washington, D.C.

ABSTRACT.—The Turkey Creek Limestone is known from one small outcrop in Marshall County, Oklahoma. This report describes the Turkey Creek corals and puts them into the stratigraphic, ecologic, and biogeographic context established by earlier studies of the brachiopod, trilobite, and conodont elements of the fauna. The corals are compatible with a middle Early Devonian, Pragian age suggested by the conodonts and trilobites, and give some support to a paleogeographic position within the Eastern Americas Realm (EAR) between the Appohimchi and Great Basin provinces on the southern margin of the North American plate. The corals belong to "basinal" genera, but this term is inappropriate for several EAR assemblages of this kind; the term laccophyllid assemblage is recommended for use in discussing Silurian–Devonian faunas. *Neaxon amsdeni* n. sp., *"Stereolasma"* sp., and *Favosites* sp. 1 are described.

INTRODUCTION

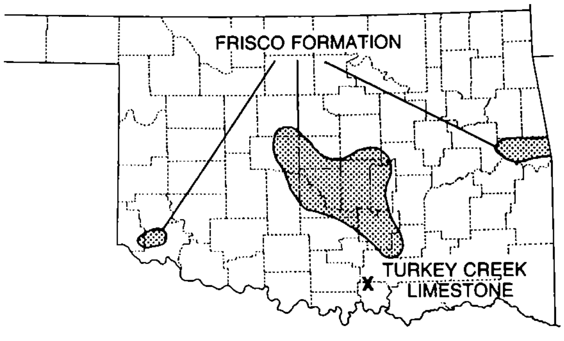
The Turkey Creek Limestone is an informally named, thin stratigraphic unit, known from a single small outcrop in an inlier in Marshall County, Oklahoma, now covered by a small reservoir. The geology of the inlier was discussed and described by Amsden (1960, p. 151–159, 259–262). Subsequent paleontologic work was reported by Amsden and others (1968), who named the unit informally. These and later works by Amsden and other individuals were reviewed, summarized, and brought up to date by Amsden (1985) in a paper primarily devoted to the Turkey Creek brachiopods. The following notes on stratigraphy are based on the three works cited.

The Turkey Creek Limestone consists of 1.5 m of skeletal (pelmatozoan) limestone in a single small outcrop along Turkey Creek, Marshall County, Oklahoma (Text-fig. 1). The unit is overlain by the Upper Devonian Woodford Shale and underlain by the Upper Ordovician Sylvan Shale. Aside from the abundant pelmatozoan debris, the megafossils, in order of decreasing abundance, are trilobites (Ormiston, 1968; Campbell, 1977), brachiopods (Amsden, 1985), gastropods (undescribed), and corals (herein); bryozoans appear in many thin sections. Microfossils include ostracodes (undescribed), and conodonts (Klapper and Ziegler, 1967, pl. 8; discussed by Klapper, in Amsden and others, 1968, and in Amsden, 1985, p. 1–2). The fauna was interpreted initially as indicating an Emsian age (late Early Devonian) by Amsden and others (1968) and Ormiston (1968), but later reviews of the trilobites (Campbell, 1977, p. 10) and conodonts (Klapper, in Amsden, 1985, p. 1–2; see also Amsden and Barrick, 1988, p. 52) suggest that a middle Early Devonian, Pragian age is more likely. In this paper, the age of the fauna is considered to be Pragian because this best fits the coral data as well, but an early Emsian age is not ruled out.

The Frisco Formation in Oklahoma (Text-fig. 1) is Pragian in age and rather similar to the Turkey Creek in overall lithology (Amsden, 1985, p. 4; Amsden and Ventress, 1963). However, the Turkey Creek brachiopods, trilobites, and corals have little in common with those of the Frisco (Amsden, 1985; Campbell, 1977; and herein). The Turkey Creek and Frisco corals are compared below.

Repositories

The Turkey Creek Limestone corals are preserved in the collections of the Oklahoma Museum of Natural History, University of Oklahoma, Nor-



Text-figure 1. Map of Oklahoma showing location of Turkey Creek Limestone outcrop and three areas of surface and subsurface distribution of the Frisco Formation (from Amsden, 1985, fig. 3).

man (OU). The illustrated specimen from New York is in the U.S. National Museum of Natural History, Washington, D.C. (USNM).

PRAGIAN CORALS

Rugose corals of Pragian age are uncommon everywhere (Oliver and Pedder, 1979a, table; Pedder and Oliver, unpublished tabulations). North American assemblages of this age can be divided into three groups: (1) Relatively large late Pragian faunas are known from the northern Yukon Territory and Alaska (Pedder, 1978, and personal communications, 1980–92); these include large dissepimented solitary and colonial rugosans which are distinct shelf assemblages and belong to the Old World Realm. (2) Small assemblages are known from the Rabbit Hill Limestone in the Great Basin, Nevada (reviewed by Johnson and Oliver, 1977; and Oliver and Johnson, 1977), the Frisco Formation and Turkey Creek Limestone in Oklahoma (following sections), and the Glenerie Limestone in New York; these are mostly small, nondissepimented corals belonging to "basin dwelling" or laccophyllid assemblage genera (see Coral Ecology); the corals are mostly undescribed but are the principal Eastern Americas Realm (EAR) faunules of this age. (3) Small faunas from the lower members of the McColley Canyon Formation in the Great Basin (see Johnson and Oliver, 1977) and from the Indian Cove Formation in the Gaspé area, Quebec, are "shallow" shelf assemblages within the EAR, but may be younger (late Pragian and/or early Emsian in age) than the laccophyllid assemblages. The EAR Pragian faunas were reviewed by Oliver (1977, p. 102–106), but the 1977 lists need revision and are useful now only to indicate the general nature of the assemblages.

The paucity of Pragian corals may be due to a late- or end-Lochkovian faunal crisis. Oliver (1990) showed that there was an extinction event that affected Lochkovian corals in eastern North America and that it may have been worldwide. Lochkovian corals are basically Silurian types, while the Pragian saw the beginning of the great Emsian to Givetian Eastern Americas Realm coral fauna. In a later section of this paper, I suggest that the nature of the Turkey Creek corals may be related to this crisis.

Turkey Creek Corals

Corals are uncommon in the Turkey Creek Limestone to judge by the published record and the collections I have seen. Fifteen rugose corals, all small and solitary, were found in available collections; these include eight specimens of *Neaxon amsdeni* n. sp., one specimen of *"Stereolasma"* sp., and six indeterminate fragments, some of which are probably *N. amsdeni*. Tabulate corals are even rarer; three specimens include two small *Favosites* colonies and a fragment of a pachyporid that appeared in serial thin sections of one of the rugosans.

The corals do not strongly support a Pragian age for the fauna because the genera are long ranging and the species new or undetermined. The most common species is closest to a Pragian species from Nevada and this, plus other available data, make a Pragian age somewhat more likely than early Emsian. The corals are of additional interest for ecological and biogeographical analyses.

Frisco Corals

Rugose corals in collections from the Frisco Formation (Pragian, Oklahoma) are more numerous than Turkey Creek corals, but this may be due entirely to the greater known extent of the Frisco (Text-fig. 1). I have little basis for comparing abundances in the rock. Amsden (personal communication, 1958) stated, "The Frisco coral fauna is a small one, both in number of species and in number of individuals. Aside from *Trachypora* (which is common), it consists mainly of horn corals and a branching type of *Favosites*. . . . The Frisco megafauna is dominated by the gastropods and brachiopods, especially the latter." Amsden and Ventress (1963, p. 24–25) mentioned colonial corals in the Frisco, but these are apparently the tabulates cited above because small solitary rugosans, *Favosites* and *"Trachypora,"* are the only corals listed. *"Trachypora* sp." (identified by Oliver) was discussed and illustrated by Amsden (1960, p. 133, pl. 17, figs. 1–4), who indicated that it is abundant in the lower part of the formation.

Photographs of 17 Frisco rugose corals are the basis for comparing the Frisco and Turkey Creek rugosans. Most of the Frisco specimens are photographically represented only by exteriors and transverse sections so I have not attempted to list the Frisco taxa. The photographed specimens were considered representative of the available collections when I surveyed them in 1968. The Frisco rugosans are small, simple, nondissepimented, and mostly conical corals; most are metriophyllids, but there are a few laccophyllids. None is assignable to *Neaxon* (the most common Turkey Creek genus), but there are three specimens that may be congeneric with *"Stereolasma"* sp. Thus, there is a family resemblance between the faunules but no species in common; this situation is comparable to that of the brachiopods and trilobites.

CORAL ECOLOGY

Paleozoic corals can be divided into two or three broad ecologic groupings on the basis of the rugosans. One is composed of small, solitary, nondissepimented rugosans, is of low diversity, and may be accompanied by small tabulate colonies (Hill, 1981, p. F47). This was termed the *Cyathaxonia* fauna by Hill (1939, p. 5), named for a Carboniferous coral. Devonian coral specialists have used the same term but have also referred to the fauna as "cephalopod facies" (Kullmann, 1965), "deeper water" (Pedder, 1982), "deep water" or "basinal" (Sorauf and Pedder, 1986), and "basin facies" or "basin dwelling" (Pedder and Oliver, 1990). All of these terms are objectionable, either because of their age or environmental implications, and the term laccophyllid assemblage is recommended and used in this paper. The laccophyllid assemblage is real and has worldwide distribution. The fauna is commonly found in noncalcareous shales and interpreted as "deep water," or "basinal" as the listed names imply. Pedder and Oliver (1990, p. 274), in a biogeographic analysis of Devonian rugosans, assigned metriophyllids, laccophyllids, polycoeliids, and three miscellaneous genera to this fauna. The Pragian faunules from the Rabbit Hill, Turkey Creek, Frisco, and Glenerie Limestones all belong to the laccophyllid assemblage.

A second major fauna includes larger, dissepimented, solitary and colonial rugosans and a variety of tabulates; this fauna is far more diverse than the first. It is most often found in limestones and calcareous shales and is interpreted as a "shallow water" or shelf fauna. Some authors separate this fauna into level-bottom and reef-associated faunas (for a total of three major groupings of corals). The Pragian assemblages from western Canada and the Gaspé belong to the shelf fauna. Broad aspects of these major coral faunas were reviewed by Hill (1981, p. F47–F49).

The Turkey Creek and Frisco faunules from Oklahoma belong to the laccophyllid assemblage. In addition to the rugosans, this includes the Turkey Creek tabulates illustrated here, the Frisco "*Trachypora*," and large favositids that are associated with the rugosans according to P. K. Sutherland (personal communication, 1991).

The Turkey Creek Limestone and the Frisco Formation were deposited in the southern part of an Early and Middle Devonian carbonate province; not far south was the Ouachita clastic province with few benthic fossils (Amsden, 1985, p. 6 and fig. 4). It is difficult to not consider the carbonate province as shelf and the clastic area as slope or basin.

Amsden (1985, p. 4, 6) interpreted the Turkey Creek environment as "clear, with little turbidity and a substrate composed largely of clean, washed organic sands not unlike the depositional environment of the Frisco Limestone" and "a part of the carbonate platform." Earlier, Amsden and Ventress (1963, p. 25–26) interpreted the Frisco environment as turbulent and close to shore. These views are not incompatible but emphasize that the laccophyllid coral assemblage is not necessarily basinal. Rather, it represents environments that were marginal for corals, where the larger, more complex corals of the "shelf" assemblage could not successfully develop and reproduce. Inhibiting conditions, at different times and places, may have been depth, terrigenous sediments, turbulence, etc. If physical conditions were decisive in the Turkey Creek and Frisco, water movements—either turbulence or shelf-margin currents—are the most likely limiting factors. However, the Pragian coral faunules in the Great Basin and New York are also laccophyllid assemblages. Possibly, these were all deposited before the recovery of "shelf" corals after a late Lochkovian crisis (Oliver, 1990, p. 174). The temporary absence of "shelf" corals would be as effective as deleterious environmental factors in giving the corals of the laccophyllid assemblage their opportunity.

BIOGEOGRAPHY

The Early Devonian was a time of marked provincialism. Three biogeographic realms are recognized; two of them are partly within North America. Rugose coral biogeography was most recently reviewed by Oliver and Pedder (1989) and Pedder and Oliver (1990). Text-figure 2 shows the general geographic relationship during Pragian time of areas mentioned in this paper. In North America, the Transcontinental Arch separated the Appohimchi Province of Eastern Americas Realm (EAR) from the Old World Realm (OWR), except during the Pragian and early Emsian when the Great Basin (Nevada and parts of adjacent states) was distinctly an EAR province. This general picture has developed through the efforts of students of brachiopods, trilobites, and other invertebrate groups in addition to the corals.

The Turkey Creek fauna has aroused interest because of the lack of clear ties to other EAR faunas. Previous work and ideas on Turkey Creek relationships were reviewed by Amsden (1985). Initial studies suggested that the fauna was Old World; later analyses have removed most of the suspected Old World elements without, however, demonstrating species-level similarities with other EAR faunas, including that of the Frisco. In contrast to the Turkey Creek, the Frisco brachiopods (Amsden and Ventress, 1963) and trilobites (Campbell, 1977) have distinct Appalachian (EAR) affinities.

Study of the corals adds little to the picture. Laccophylid assemblage genera are cosmopolitan and the Turkey Creek and Frisco laccophyllids and metriophyllids are widespread in both realms. As noted below, *Neaxon amsdeni*, the most common Turkey Creek coral, is similar to *Neaxon foerstei* from the Great Basin, but this means very little when knowledge of Pragian corals is so sparse. If the paleogeographic map (Text-fig. 2) is approximately correct, Oklahoma was along the marine coastal route between Appohimchi areas and the Great Basin. Possibly, the Turkey Creek Limestone represents too small a slice of time to have captured any of the migrating benthos.

SYSTEMATIC PALEONTOLOGY

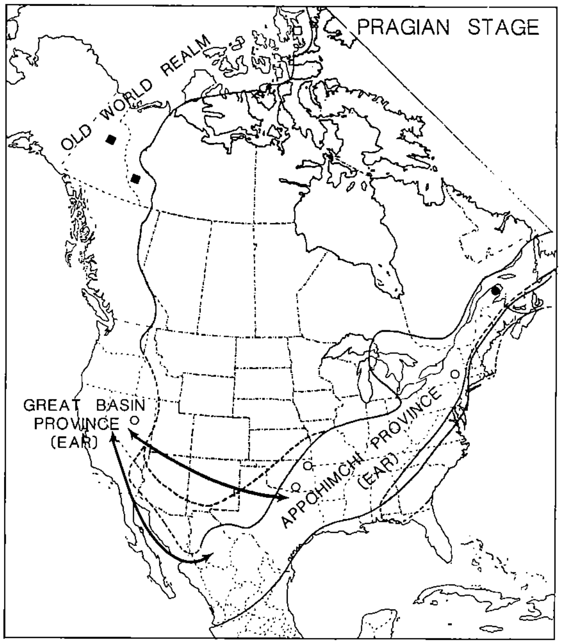
Rugose Corals

Family Laccophyllidae Grabau, 1928
Genus **Neaxon** Kullmann, 1965

1965 *Syringaxon* Lindström (part). Sutherland, p. 34–35.
1965 *Neaxon* Kullmann, p. 81–83.
1969 *Neaxon* Kullmann. Różkowska, p. 58–65.
1971 *Neaxon* Kullmann. Weyer, p. 294–300.
1973 *Syringaxon* Lindström (part). Merriam, p. 21–23.
1974 *Syringaxon* Lindström (part). Merriam, p. 39–40.
1978a *Neaxon* Kullmann. Weyer, p. 495–496.
1978 *Neaxon* Kullmann (part). Birenheide, p. 34–37.
1981 *Neaxon* Kullmann (part). Hill, p. F197.
1984 *Neaxon* Kullmann. Weyer, p. 5–12.
1989 *Neaxon* Kullmann. Weyer, p. 3–12.
1989 *Neaxon* Kullmann. Oliver, p. 8–9.

Type species.—*Neaxon regularis* Kullmann, 1965, p. 83–86, text-fig. 6, pl. 2, figs. 1–4; upper Emsian, Spain.

Diagnosis.—Small, solitary, horn corals. In early stages major septa join at axis; in later stages they are withdrawn from the axis and thickened at their axial ends to form an aulos. Cardinal and counter septa may be longer than other major septa; minor septa very short, not contratingent. Tabulae tend to be horizontal within aulos, inclined downward from aulos to wall. Wall more or less thick, formed by thickening of outer edges of septa. No dissepiments, cardinal fossula or septal flanges. Septa trabecular(?).



Text-figure 2. Paleogeographic map of North America during the Pragian (middle Early Devonian). Symbols mark areas from which rugose corals are known: circles, Eastern Americas Realm (EAR) corals; squares, Old World Realm corals; open circles or squares represent few taxa; solid symbols represent larger assemblages. Arrows suggest possible migration routes. Distribution of land (shaded) and sea is generalized; the eastern plate boundary is shown by the solid line extending from Mexico to the Maritimes. Modified from Oliver and Pedder (1979b). The dashed lines show possible shoreline positions and uncertainties.

Discussion.—Laccophyllids and metriophyllids are a complex of mostly related corals characterized by (1) an axial structure formed by the axial ends of the major septa, (2) a simple, fine-textured microstructure, and (3) the lack of a fossula. *Neaxon* and *Syringaxon* differ in that the former has very short minor septa, whereas those of the latter are long and contratingent. *Neaxon*, as used in most of the works cited in my synonymy, differs from other laccophyllids in including species with coarsely trabecular microstructure. Coarse monacanthine trabeculae in *Neaxon* were first described in Upper Devonian forms by Różkowska (1969) and Weyer (1971,1978a). Weyer (1971, p. 294) interpreted Kullmann's (1965) description and illustrations as indicating that the type species (upper Emsian) is coarsely trabecular also, and Kullmann (personal communication, 1991) agrees with this. The Pragian specimens of Merriam (1973) (Nevada) and this paper (Turkey Creek) have non- or finely trabeculate microstructure, and the Upper Silurian species of Sutherland (1965) (Oklahoma) is the same (see below). These data could be used to suggest that the early *Neaxon* species differ from the later ones in their microstructure (coarse trabeculae being more "advanced") or that two possibly unrelated taxa are involved. I tend to favor the second suggestion, but the examination of many more specimens and species is needed before this can be considered as more than a guess.

The known record of *Neaxon* sensu lato is described in the following paragraphs.

Late Silurian (Ludlovian and/or Pridolian).—*Syringaxon adaense* Sutherland, 1965, has the characters of *Neaxon* as pointed out by Weyer (1978a, p. 495); Weyer (1978b, p. 91) noted a similar species from Gotland but did not illustrate it. Later, however, Weyer (1984, p. 5) questioned the generic assignment of both on the grounds that they might have septal flanges. There are no indications of either flanges or coarse trabeculae in the published illustrations of *S. adaense* but, at my request, Prof. Sutherland reexamined the thin sections of both holotype and paratype and confirmed this analysis (P. K. Sutherland, personal communication, 1990), and I accept the species as a *Neaxon* s.l. with fine-textured microstructure.

Lochkovian.—*Syringaxon rudis* (Girty, 1895) is a characteristic *Syringaxon* with long, contratingent minor septa; it is common in the Kalkberg and New Scotland Limestones (middle part of the Helderberg Group), New York and adjacent states. Associated with *S. rudis* are rare specimens of an undescribed *Neaxon* species (Pl. 1) characterized by minor septa that are just long enough to lean slightly and permit the identification of the cardinal and counter septa. It is tempting to suggest that the specimens are individual variants of *S. rudis*, but morphologically they are *Neaxon* s.l. The microstructure is finely textured.

Pragian.—(1) *Neaxon amsdeni* Oliver, n. sp., Turkey Creek Limestone, southern Oklahoma, is described below (Pls. 2–5); the microstructure is finely trabeculate. (2) *Neaxon foerstei* (Merriam, 1973, p. 22–23, pl. 2, figs. 1–10; 1974, p. 39–40, pl. 1, figs. 1–16) was described as a *Syringaxon;* the type lot of specimens in the U.S. National Museum of Natural History includes specimens of *Neaxon, Syringaxon,* and at least one other genus, but the holotype, and three or four paratypes, are typical of *Neaxon* s.l., with very short minor septa. *Neaxon foerstei* is common in the Rabbit Hill Limestone, Nevada (see Oliver and Johnson, 1977, p. 109, for discussion of the age of the Rabbit Hill and Merriam's coral zone A; *N. foerstei* occurs in Pragian and ?Emsian parts of the formation). Most known specimens are silicified so that the microstructure is not certain, but there is no suggestion of coarse trabecular structure in any section or along the top and inner edges of the septa.

Emsian.—(1) Silicified specimens of *Neaxon* s.l. are associated with typical *Syringaxon* in the Indian Cove Member of the Grande Grève Formation, Gaspé, Quebec (upper Pragian or lower Emsian). Microstructure is uncertain, but there is no indication of coarse trabeculae. (2) *Syringaxon zeravshanicum* Gorianov, 1968 (p. 95–96, pl. 1, figs. 3a–4c) from the Lower Devonian (Emsian according to Weyer, 1984) of the southern Tian-Shan Mountains, "USSR," appears to be a *Neaxon* s.l. as stated by Weyer (1984, p. 5). The microstructure appears fine texured in the published illustrations. (3) *Neaxon regularis* Kullmann, 1965 (p. 83–86, fig. 6, pl. 2, figs. 1–4), upper Emsian, Spain, is the type species of the genus and therefore a key to some of the questions asked herein. Weyer (1971) interpreted Kullmann's description to indicate a coarsely trabecular microstructure, and Kullmann (personal communication, 1991), after reexamining the type specimens, stated that the holotype posesses coarse monacanthine trabeculae. However, enlarged (×10) prints of the original published photographs of the holotype do not show this and additional study is needed. (4) Undescribed specimens of *Neaxon* s.l. from Morocco (USNM collections) are non- or finely trabeculate.

Eifelian.—(1) *Neaxon* sp. A (Oliver, 1989, p. 8–9, pl. 6, figs. 1–3) is from the lower Eifelian(?) (possibly upper Emsian), Needmore Shale, south-central Pennsylvania. The microstructure is finely textured. (2) Weyer (1971, p. 294–295; 1984, p. 5) and Birenheide (1978, p. 35) cited two or three species from the Rheinisches Schiefergebirge: (a) *Neaxon symmetricus* (Frech, 1886, p. 95–96, pl. 7, figs. 3–5, 17–22) seems to have the gross morphology of *Neaxon* s.l. but the microstructure is unknown (there is the barest suggestion of monacanthine trabeculae in Frech's fig. 20). (b) Birenheide (1978, p. 35) suggested that *Syringaxon* cf. *nanus* of Flügel and Free (1962, p. 236–238, figs. 7-1–7-6) was synonymous with *N. symmetricus.* Weyer (1971, p. 295) had already suggested that *S.* cf. *nanus* was a *Neaxon.* Flügel and Free's silhouette illustrations are of a *Neaxon* s.l., but there is no indication of a coarse trabecular microstructure. (c) *Zaphrentis kochi* (Ludwig, 1865, p. 164–165, pl. 37, figs. 2a–d) (name suppressed, International Code on Zoological Nomenclature, 1971) was listed as *Neaxon* by Weyer (1971, p. 295; 1984, p. 5). *Zaphrentis kochi* is not identifiable from published illustrations, although Ludwig's drawings may be of a *Neaxon* s.l. No evidence of microstructure has been cited. Weyer (1984) noted that the species may be Emsian, rather than Eifelian, in age. (3) Undescribed specimens of *Neaxon* s.l. from Morocco (USNM collections) have septa of coarse monacanthine trabeculae.

Givetian.—No *Neaxon* of this age has been cited by Weyer, or is known to me. The "*Neaxon*" listed by Oliver and Pedder (1979a) from the Givetian of Morocco is probably not this genus.

Frasnian.—Weyer (1971, p. 295) stated that "*Ptychocyathus excelsus* Ludwig, 1866, from the basal Frasnian of the Rheinisches Schiefergebirge, is probably another *Neaxon* species." There is no further explanation and there is little useful information in Ludwig's monograph (1866, p. 195–196, pl. 49, figs. 2a–3c). No other citations of Frasnian *Neaxon* are known to me.

Famennian.—Numerous species have been described or cited by Różkowska (1969, p. 58–65), Weyer (1971,1978a,1984,1989), and Flügel (1980); see the various Weyer papers for analyses and discussions. Różkowska and Weyer have convincingly stated that many or all of these have septa composed of coarse monacanthine trabeculae.

Post-Devonian.—See Hill (1981, p. F197) and Weyer (1984, p. 5) for citations and discussion.

In summary, *Neaxon* in the broad sense occurs in rocks of Ludlovian to Famennian, and ?early Carboniferous age, although there are few if any known from the Givetian or Frasnian. The presence of coarse trabeculae has been suggested or demonstrated for Emsian to Famennian species; non- or finely trabecular septal structure is known or indicated for Ludlovian to Eifelian species. Possibly the early forms with fine structure are laccophyllids, closely allied to *Syringaxon*, and the later species with coarse trabeculae (possibly including *Neaxon* sensu stricto) are only distantly, if at all, related. Alternatively, one can note that the species with confirmed finely textured structure are all from the Eastern Americas Realm or northwest Africa (see Oliver, 1977, p. 120–121, for discussion of mixed EAR–OWR faunas in northwest Africa), whereas those with confirmed coarse trabeculae are from the Old World Realm. At this time, the available data is inadequate to answer questions concerning the distribution of the two kinds of septal microstructure or its significance. Weyer (1984, p. 5) has clearly expressed the opinion that coarse monacanthine trabeculae are "an essential *Neaxon* character." I tentatively agree that the finely textured species are generically distinct from the coarsely trabeculate ones, but it is necessary to know more about the microstructure of the various species assigned to "*Neaxon*" and other laccophyllids and metriophyllids before evaluating the importance of microstructure in this complex of "simple" corals.

Neaxon amsdeni Oliver, new species

Text-figure 3; Plates 2–5

Type specimens.—Holotype, OU 4977, paratypes, OU 4978-4983, 10673 (the last three are neanic specimens, as discussed below; OU 10673 is unillustrated); Turkey Creek Limestone, Turkey Creek, south of Mannsville, Marshall County, Oklahoma (stratigraphic section Ma2-A, B, C, of Amsden, 1960, p. 260–261).

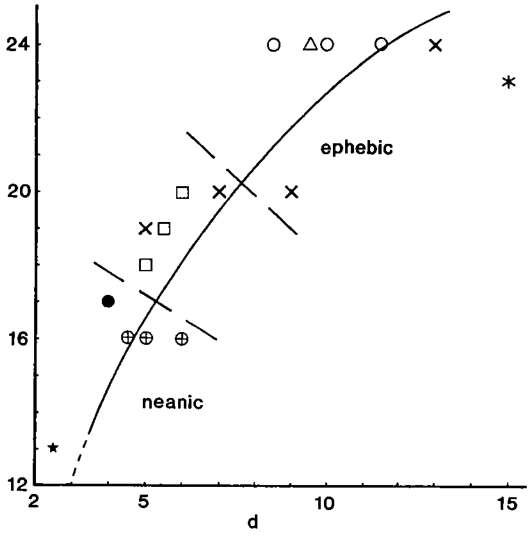
Diagnosis.—*Neaxon* with small aulos, medium-thick septa, and fine microstructure.

External features.—Trochoid coralla, straight or slightly curved; maximum known length, ~28 mm; diameter at calice margin 20–25 mm or more. Calice deep, one-half to two-thirds the length; aulos projects as low boss in bottom of calice; no fossula.

Septal grooves and interseptal ridges are prominent on the outer surface of the wall. Rugae are present but not prominent.

Internal features.—Septa radially arranged except where newly inserted, moderately thick and rhopaloid; thickened axial ends of major septa form axial structure with little or no additional sterome; in early stages (neanic), a solid column is formed that can persist to a diameter of 7 mm; in later stages (ephebic), withdrawal from the axis forms an aulos that can begin at a diameter of 5 mm or less. Major septa number 18–24 at ephebic diameters of 5–15 mm (Text-fig. 3). Microstructure finely trabecular.

The wall is a septotheca, formed by the thickened outer edges of the septa, and a very thin epitheca. Length of minor septa may be only slightly greater than the wall thickness so that they form low ridges on the inner face of the wall, or the minor septa can be as long as twice the wall thickness.



Text-figure 3. Number of major septa (n) plotted against diameter (d) in mm in *Neaxon amsdeni* Oliver, n. sp. Data are from 1 to 4 transverse sections in 8 specimens; a different symbol represents each individual specimen. The space between the dashed lines shows the observed overlap in n and d of sections without (neanic), and with (ephebic), an aulos. See discussion in text. The curved line was visually fitted to the data to suggest allometric growth.

Identification of cardinal (C) and counter (K) septa is based on morphology in thin sections. The two longest major septa tend to define a bilaterality; identification of these as C or K is based on the following criteria: (1) Newly inserted septa are in the usual four positions and lean away from C on either side, or toward K on the K side of each alar septum. (2) In one section (Pl. 3, Fig. 1) the minor septa adjacent to K are slightly longer than the others. Orientation of sections through the calice is based on known relationship to other sections from the same specimen. None of the calice sections shows any indication of a fossula.

The aulos diameter varies, approximately, from 0.3 to 1.5 mm, but is more or less constant once the aulos is formed.

Tabulae are horizontal and widely spaced within the aulos. Outside of the aulos, tabulae slope down toward the outer wall at various angles and may be complete or incomplete.

Neanic specimens.—Three specimens in the collection have the characters described above but lack the aulos (Pl. 5, Figs. 1–3,5). These are more or less complete, small individuals with calices; they are not fragments of larger specimens. In transverse sections below the calice they are similar to the lower, sub-aulos parts of the larger individuals. Identification of the four primary septa is as described, but C and K are even more distinct (Pl. 5). One specimen has counter-lateral minors that are longer than the other minors (Pl. 5, Figs. 1–3). It is convenient to consider the pre-aulos stage as neanic, and the later stage—with a well-developed aulos—as ephebic. The earliest, brephic, stage is not known.

Discussion.—The gross morphology and finely trabecular microstructure of *Neaxon amsdeni* place it in the early, or laccophyllid, group of *Neaxon* s.l. It is characterized by its small aulos and the moderate thickness of its septa. It is morphologically close to *Neaxon foerstei* (Merriam, 1973) from which it differs in its larger size and relatively greater thickening of septa and wall. The two species are of the same approximate age and from the same biogeographic realm at a time when east–west faunal exchanges were taking place between the Appohimchi and Great Basin provinces, and a close relationship is not unlikely. Comparison with *N. foerstei* is difficult because of the small size of the available samples and the different modes of preservation. *Neaxon amsdeni* is known only from thin sections of calcitic specimens; *N. foerstei* is known from silicified specimens etched from limestone. Nevertheless, the differences seem great enough to warrant species level separation.

The species is named for Thomas W. Amsden, friend and fellow Devonophile for more than three decades, to whom this festschrift is dedicated.

Distribution.—Known only from the Turkey Creek Limestone (Pragian), southern Oklahoma, U.S.A.

Family ?Metriophyllidae Hill, 1939
sensu Hill, 1981, p. F189–F191.

Genus **"Stereolasma"**

1900 not *Stereolasma* Simpson, p. 205.
1989 *Stereolasma* Simpson (part). Oliver, 1989, p. 7–8.

Discussion.—*Stereolasma* Simpson is a lindstroemiid (=stereolasmatid of Hill, 1981, p. F308), characterized by a cardinal fossula among other characters. It is homeomorphic with the metriophyllid-laccophyllid group, but only distantly related, if at all. *"Stereolasma" fereplena* Oliver, 1989 (p. 7–8, pl. 5, figs. 1–8) lacks a fossula and is morphologically closer to the metriophyllids than to *Stereolasma*. A single specimen from the Turkey Creek Limestone is morphologically like *"S." fereplena* and may be congeneric, but not conspecific, with it.

"Stereolasma" sp.
Plate 6

Material.—Illustrated specimen, OU 10674, Turkey Creek Limestone, Pragian, Marshall County, Oklahoma (same locality and collection as *Neaxon amsdeni*).

Description.—The specimen has a solid axial structure formed by the axial ends of the major septa. Minor septa are half the length of major septa and contratingent; those adjacent to the counter septum are longest and form a distinct triad with the counter septum. There are no septal flanges. The septa have a distinct dark line and may be trabeculate, at least in part. The wall is lamellar and apparently separate from the septa. There are marked septal grooves on the outside of the wall. The calice is moderately deep with no indication of a cardinal fossula.

No longitudinal section is available, but there is no suggestion of biform tabulae in any of the transverse sections.

Discussion.—The single specimen described here is strikingly different from all of the other rugose corals in the Turkey Creek collection because of its septal microstructure (dark line, ?trabecular), long minor septa and distinct separation of septa and wall. The significance of microstructural differences in the metriophyllid-laccophyllid group is unknown and controversial; the length of minor septa is generally considered a generic character.

Tabulate Corals

Tabulates are even less common than rugose corals in the Turkey Creek Limestone. Two incomplete specimens of *Favosites* are noted and illustrated. The only other tabulate seen in the collection is a small fragment of a pachyporid (Pl. 7, Figs. 4,5), possibly congeneric with *"Trachypora"* from the Frisco Limestone.

Favosites sp. 1
Plate 7, Figures 1–3

Material.—Two specimens, OU 10675 and 10676, Turkey Creek Limestone, Pragian, Marshall County, Oklahoma (same locality and collection as *Neaxon amsdeni*).

Description.—Maximum corallite diameter is 4.0–4.5 mm, mural pores are common, and tabulae are flat, spaced 1–2 mm apart. OU 10675 (Pl. 7, Figs. 1,2) is a more or less complete young colony with holotheca and calices; colony expands upward and includes numerous offsets. OU 10676 (Pl. 7, Fig. 3) is a fragment but also includes numerous offsets and has holotheca on one side. It is conspecific with the first specimen and also may be from a young colony.

ACKNOWLEDGMENTS

The Turkey Creek corals were loaned to me through the good offices of T. W. Amsden many years ago; I thank Tom and the Oklahoma Geological Survey for their patience. The collections were made in 1952 by J. L. Wilson, and in 1959 by T. W. Amsden and P. K. Sutherland. Prof. Sutherland showed me his collections of prepared rugose corals from the Haragan and Frisco Formations when I visited the University of Oklahoma in 1968; my comments on Frisco corals are based on prints of his photographs which he gave me at that time. Questions about the morphology of key specimens that they had described were readily answered by Prof. J. Kullmann, Tubingen, and by Prof. Sutherland. I thank all of these individuals for their direct and indirect help, and the organizers of this volume for inviting me to participate in the celebration of Tom's fruitful career.

Drafts of this paper were critically reviewed by J. M. Berdan, J. T. Dutro, Jr., and W. J. Sando, all U.S. Geological Survey, Washington, D.C.; J. E. Sorauf, S.U.N.Y., Binghamton; and P. K. Sutherland, University of Oklahoma; their helpful comments are appreciated.

REFERENCES CITED

Amsden, T. W., 1960, Hunton stratigraphy, *pt. 6 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 84, 311 p.

______1985, Brachiopods from the Turkey Creek Limestone (Early Devonian), Marshall County, southern Oklahoma: Oklahoma Geological Survey Bulletin 138, 20 p.

Amsden, T. W.; and Barrick, J. E., 1988, Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, 66 p.

Amsden, T. W.; and Ventress, W. P. S., 1963, Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, 238 p.

Amsden, T. W.; Klapper, Gilbert; and Ormiston, A. R., 1968, Lower Devonian limestone of post-Hunton age, Turkey Creek Inlier, Marshall County, south-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 52, pt. 1, p. 162–166.

Birenheide, Rudolf, 1978, Rugose korallen des Devon, *in* Krommelbein, K. (ed.), Leitfossilien No. 2: Borntraeger, Berlin and Stuttgart, 265 p.

Campbell, K. S. W., 1977, Trilobites of the Haragan, Bois d'Arc, and Frisco Formations (Early Devonian), Arbuckle Mountains region, Oklahoma: Oklahoma Geological Survey Bulletin 123, 227 p.

Flügel, H. W., 1980, *Neaxon* sp. aus der Gonioclymeniastufe von Gratwein bei Graz: Mitteilungen des naturwissenschaftlichen Vereines für Steiermark, v. 110, p. 55–56.

Flügel, H.; and Free, B., 1962, Laccophyllidae (Rugosa) aus dem Greifensteiner Kalk (Eiflium) von Wiede bei Greifenstein: Palaeontographica, Abt. A, v. 119, p. 222–247.

Frech, F., 1886, Die Cyathophylliden und Zaphrentiden des Deutschen Mitteldevon: Palaeontologische Abhandlungen, v. 3, no. 3, 120 p.

Girty, G. H., 1895, A revision of the sponges and coelenterates of the Lower Helderberg Group of New York: New York State Museum Annual Report 48, pt. 2, p. 259–322.

Gorianov, V. B., 1968, Devonian laccophyllids (Tetracoralla) from the southern Tian-Shan: Ezhegodnik vsesouznogo paleontologicheskogo obshchestva, v. 18, p. 90–102 [in Russian].

Grabau, A. W., 1928, Palaeozoic corals of China, Part I, Tetraseptata; II. Second contribution to our knowledge of the streptelasmoid corals of China and adjacent territories: Palaeontologia Sinica, ser. B, v. 2, fasc. 2, 175 p.

Hill, Dorothy, 1939, Western Australian Devonian corals in the Wade collection: Royal Society of Western Australia Journal, v. 25, p. 141–151.

______1981, Rugosa and tabulata, *supplement 1 of* Coelenterata, *part F of* Treatise on invertebrate paleontology: Geological Society of America and University of Kansas, 762 p.

International Commission on Zoological Nomenclature (ICZN), 1971, Opinion 946, Ludwig, R., 1865–66, "Corallen aus paläolithischen formationen" [Palaeontographica, v. 14]: suppressed under the plenary powers: Bulletin of Zoological Nomenclature, v. 27, p. 226.

Johnson, J. G.; and Oliver, W. A., Jr., 1977, Silurian and Devonian coral zones in the Great Basin, Nevada and California: Geological Society of America Bulletin, v. 88, p. 1462–1468.

Klapper, Gilbert; and Ziegler, Willi, 1967, Evolutionary development of the *Icriodus latericrescens* group (Conodonta) in the Devonian of Europe and North America: Palaeontographica, Abt. A, v. 127, p. 68–83.

Kullmann, Jurgen, 1965, Rugose Korallen der Cephalopodenfazies und ihre Verbreitung in Devon des südöstlichen Kantabrischen Gebirges (Nordspanien): Akademie der Wissenschaften und der Literatur, Abhandlungen der mathematisch-naturwissenschaftlichen Klasse, no. 2, 168 p.

Ludwig, Rudolph, 1865–66, Corallen aus paläolithischen formationen: Palaeontographica, v. 14, p. 133–244.

Merriam, C. W., 1973, Paleontology and stratigraphy of the Rabbit Hill Limestone and Lone Mountain Dolomite of central Nevada: U.S. Geological Survey Professional Paper 808, 50 p.

______1974, Lower and lower Middle Devonian rugose corals of the central Great Basin: U.S. Geological Survey Professional Paper 805, 83 p.

Oliver, W. A., Jr., 1977, Biogeography of Late Silurian and Devonian rugose corals: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 22, p. 85–135.

______1989, An early Middle Devonian coral faunule from the Needmore Shale in south-central Pennsylvania and adjacent areas of West Virginia and Virginia: U.S. Geological Survey Bulletin 1860-C, 11 p.

______1990, Extinctions and migrations of Devonian rugose corals in the Eastern Americas Realm: Lethaia, v. 23, p. 167–178.

Oliver, W. A., Jr.; and Johnson, J. G., 1977, Notes on Upper Silurian and Devonian coral zones in the

Great Basin, *in* Murphy, M. A.; Berry, W. B. N.; and Sandberg, C. A. (eds.), Western North America: Devonian: University of California Riverside, Campus Museum Contribution 4, p. 107–111.

Oliver, W. A., Jr.; and Pedder, A. E. H., 1979a, Rugose corals in Devonian stratigraphical correlation: Palaeontological Association, Special Papers in Palaeontology 23, p. 233–248.

______ 1979b, Biogeography of Late Silurian and Devonian rugose corals in North America, *in* Gray, Jane; and Boucot, A. J. (eds.), Historical biogeography, plate tectonics, and the changing environment: Oregon State University Press, Corvallis, p. 131–145.

______ 1989, Origins, migrations and extinctions of Devonian Rugosa on the North American Plate: Association of Australasian Palaeontologists Memoir 8, p. 231–237.

Ormiston, A. R., 1968, Lower Devonian trilobites of Hercynian type from the Turkey Creek Inlier, Marshall County, south-central Oklahoma: Journal of Paleontology, v. 42, p. 1186–1199.

Pedder, A. E. H., 1978, Corals, *in* Jackson, D. E.; Lenz, A. C.; and Pedder, A. E. H., Late Silurian and Early Devonian graptolite, brachiopod and coral faunas from northwestern and Arctic Canada: Geological Association of Canada Special Paper 17, p. 31–50.

______ 1982, The rugose coral record across the Frasnian–Famennian boundary: Geological Society of America Special Paper 190, p. 485–489.

Pedder, A. E. H.; and Oliver, W. A., Jr., 1990, Rugose coral distribution as a test of Devonian palaeogeographic models, *in* McKerrow, W. S.; and Scotese, C. R. (eds.), Palaeozoic palaeogeography and biogeography: Geological Society (London) Memoir 12, p. 267–275.

Różkowska, Maria, 1969, Famennian tetracoralloid and heterocoralloid fauna from the Holy Cross Mountains (Poland): Acta Palaeontologica Polonica, v. 14, p. 3–187.

Simpson, G. B., 1900, Preliminary descriptions of new genera of Paleozoic rugose corals: New York State Museum Bulletin 39, p. 199–222.

Sorauf, J. E.; and Pedder, A. E. H., 1986, Late Devonian rugose corals and the Frasnian–Famennian crisis: Canadian Journal of Earth Sciences, v. 23, p. 1265–1287.

Sutherland, P. K., 1965, Rugose corals of the Henryhouse Formation (Silurian) in Oklahoma: Oklahoma Geological Survey Bulletin 109, 92 p.

Weyer, Dieter, 1971, *Neaxon regulus* (Rh. Richter, 1848), ein Leitfossil der mitteleuropaischen *Wocklumeria*-Stufe (Anthozoa, Rugosa; Oberdevon): Geologie (Berlin), v. 20 p. 292–315.

______ 1978a, *Neaxon bartzschi*, eine neue Rugosa-Art aus der *Wocklumeria*-Stufe (Oberdevon) des Thüringischen Schiefergebirges: Zeitschrift für geologische Wissenschaften (Berlin), v. 6, p. 493–500.

______ 1978b, Neue Sutherlandiniinae (Rugosa) aus dem scandinavischen Silur und aus dem Thüringischen Devon: Freiberger Forschungsheft C (Leipzig), v. 342, p. 91–116.

______ 1984, *Neaxon cheilos* n. sp. aus dem Unterfamenne von Schleiz im Thüringer Schiefergebirge (Anthozoa, Rugosa; Oberdevon): Abhandlungen und Berichte für Naturkunde und Vorgeschichte (Magdeburg), v. 12 [for 1982], p. 3–16.

______ 1989, *Neaxon muensteri*, eine neue Koralle aus dem europaischen Oberfamenne: Abhandlungen und Berichte für Naturkunde und Vorgeschichte (Magdeburg), v. 14, p. 3–16.

PLATE 1

Neaxon sp. from the Lochkovian (New Scotland or Kalkberg Limestone), Schoharie, New York.

Figures 1–3.—Serial transverse thin sections (×5) (USNM 454960); the cardinal septum (as interpreted, see text) is toward the top of the page.

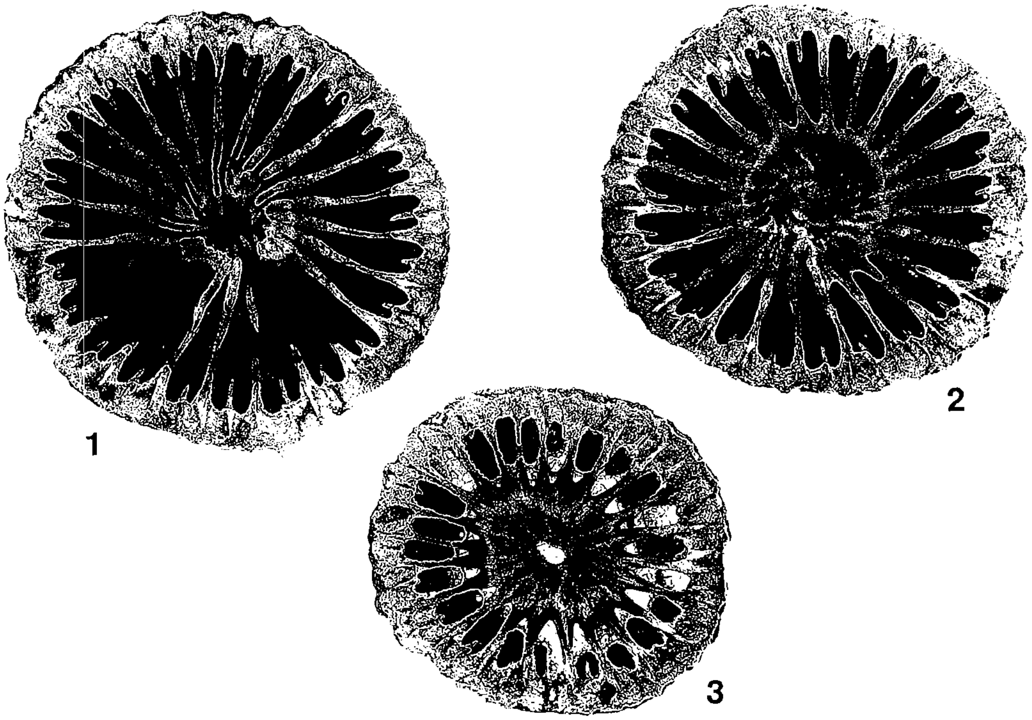
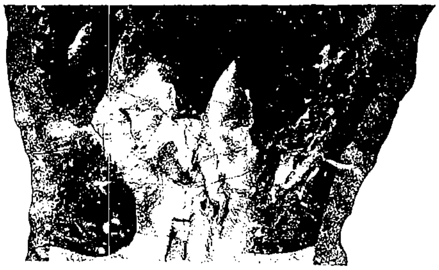

1
2
3

PLATE 2

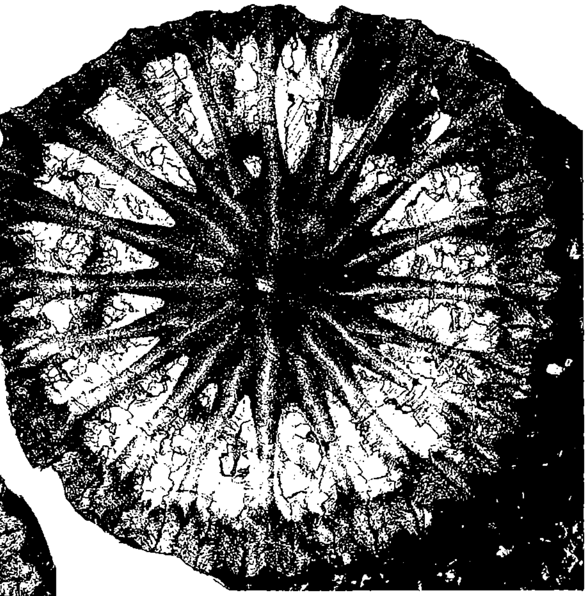
Neaxon amsdeni Oliver, new species, Turkey Creek Limestone, Pragian, Oklahoma (Holotype, OU 4977).

Figure 1.—Longitudinal thin section of upper part of aulos and lower calice (×5).

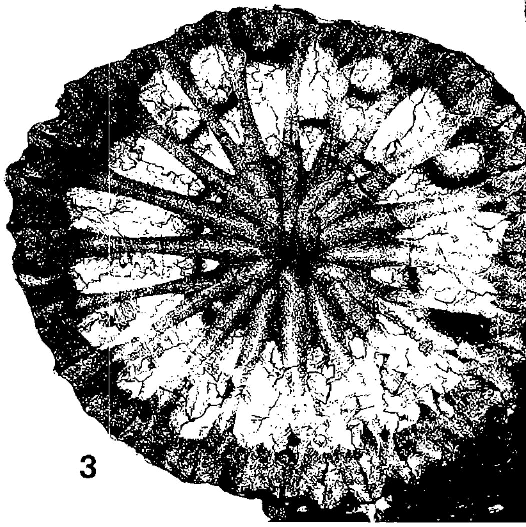
Figures 2–5.—Serial transverse thin sections looking down (×10). **2–4**, taken below the longitudinal section, in descending order, oriented with cardinal septum toward the top; **5**, part of calice margin above the longitudinal section, position of cardinal septum not known.



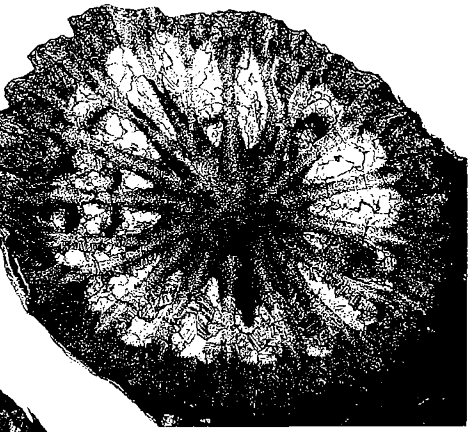
1



2



3



4

5

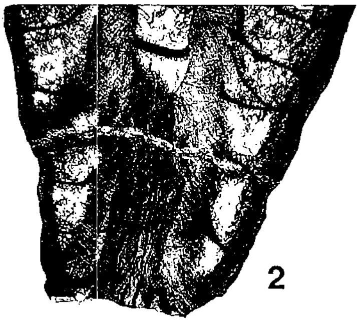
PLATE 3

Neaxon amsdeni Oliver, new species, Turkey Creek Limestone, Pragian, Oklahoma (×5). All transverse thin sections are oriented with the cardinal septum toward the top of the page and with the viewer looking down.

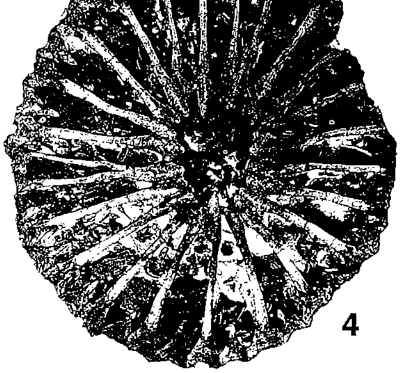
Figures 1,2.—Transverse section taken just below the calice and lower longitudinal section (Paratype, OU 4978).

Figures 3–5.—Serial transverse sections at intervals of 2–3 mm. **3**, through lower calice; **4**, at approximate base of calice; **5**, lowest (Paratype, OU 4979).


1


2


3


4

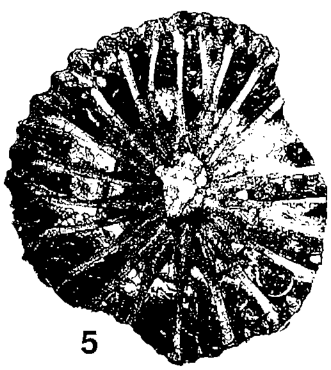
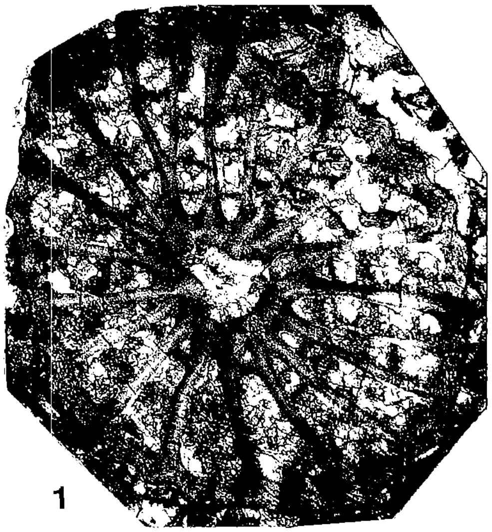

5

PLATE 4

Neaxon amsdeni Oliver, new species, Turkey Creek Limestone, Pragian, Oklahoma (×10) (Paratype, OU 4980).

Figures 1–3.—Serial transverse thin sections, oriented as in Plate 3; taken below the longitudinal section, in descending order at 2–3 mm intervals. Preservation in middle section is poor but shows the C–K orientation more convincingly than the others.

Figure 4.—Longitudinal thin section through lower calice and the upper part of the aulos.


1


2


4

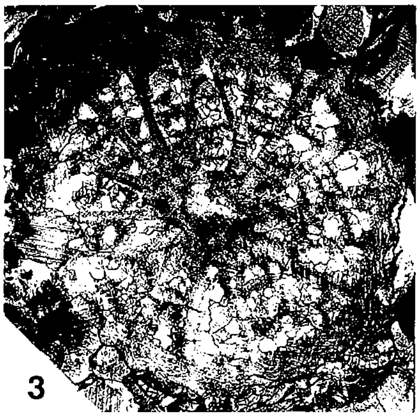

3

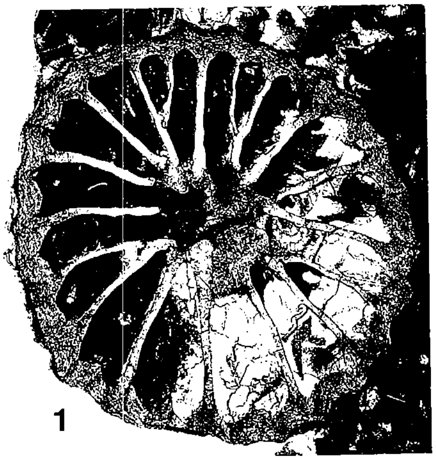
PLATE 5

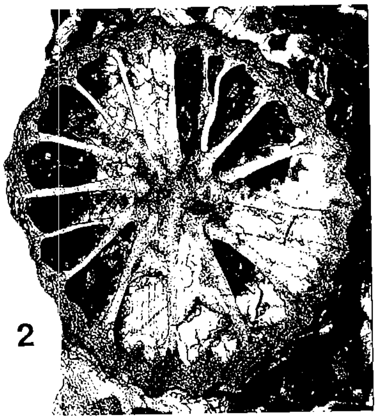
Neaxon amsdeni Oliver, new species, Turkey Creek Limestone, Pragian, Oklahoma. Transverse thin sections oriented as in Plate 3.

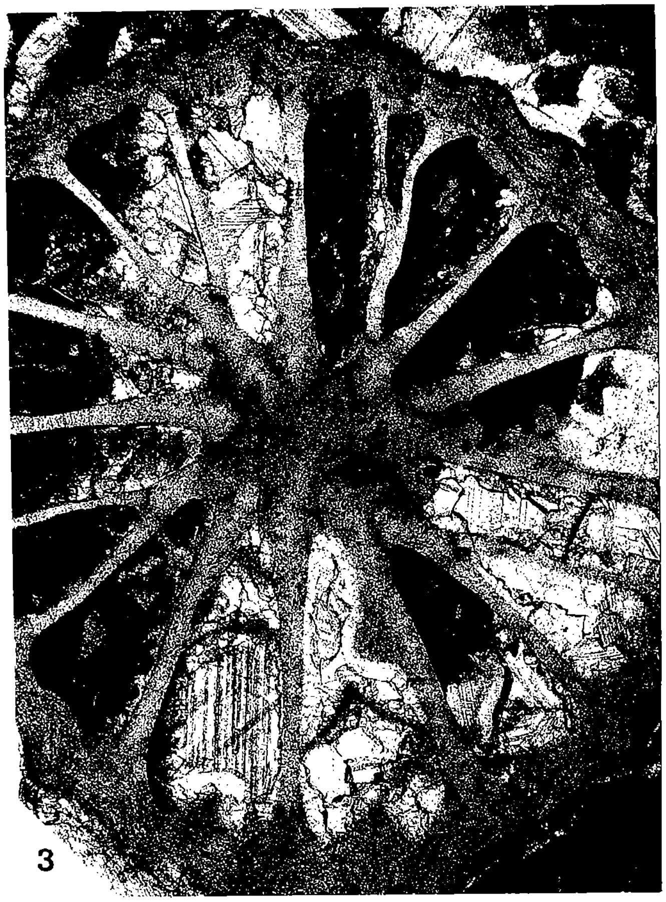
Figures 1–3.—Neanic (Paratype, OU 4982). **1**, near base of calice (×10); **2–3**, ~5 mm lower (×10, ×25).

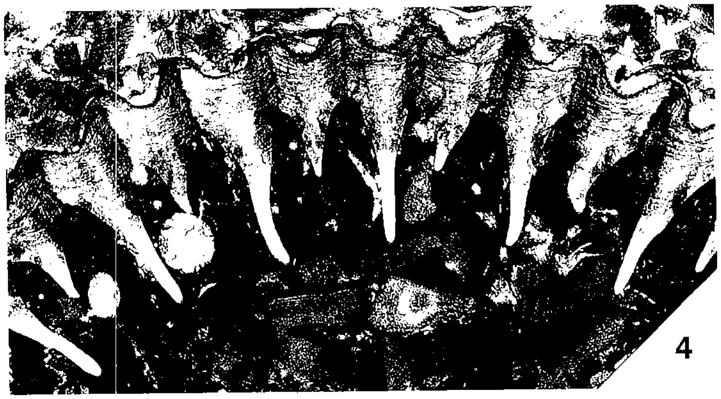
Figure 4.—Through middle calice, position of cardinal septum not known (×10) (Paratype, OU 4981).

Figure 5.—Neanic, near base of calice (×10) (Paratype, OU 4983).


1


2


3


4

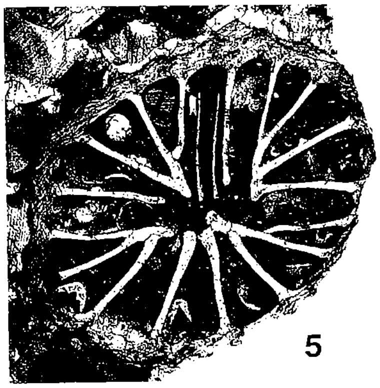

5

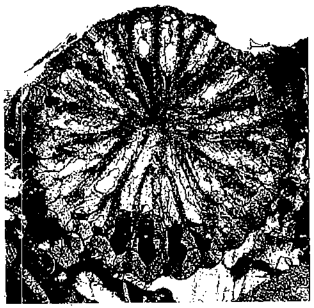
PLATE 6

"Stereolasma" sp., Turkey Creek Limestone, Pragian, Oklahoma. Transverse thin sections oriented as in Plate 3 (OU 10674).

Figures 1–3.—Descending order at 2–3 mm intervals (×10).

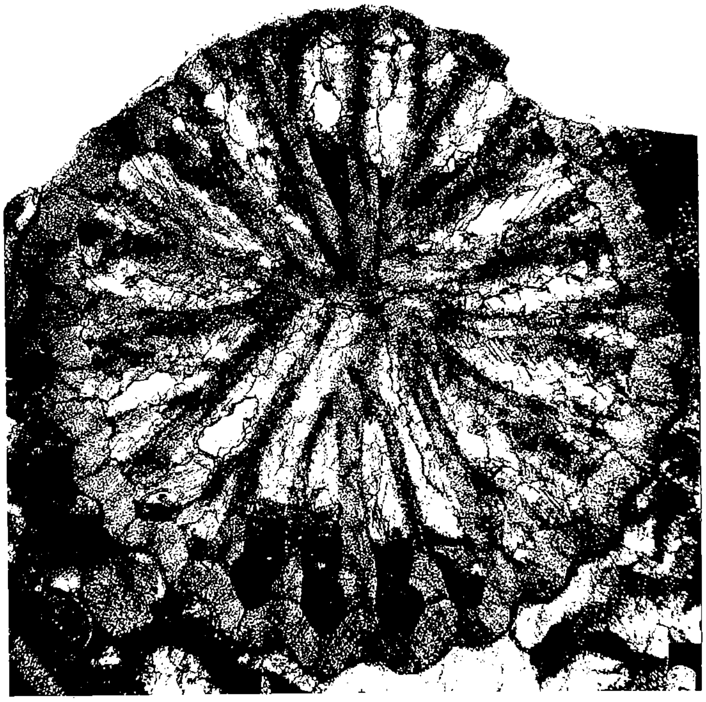
Figure 4.—Middle section (Fig. 2) (×25).

1



2

3



4

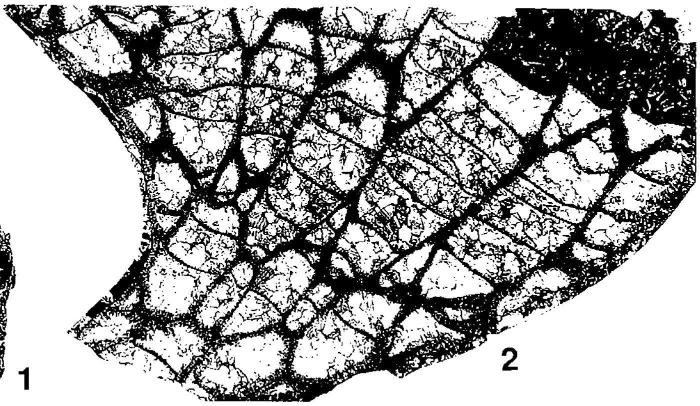
PLATE 7

Tabulate corals, Turkey Creek Limestone, Pragian, Oklahoma.

Figures 1–3.—*Favosites* sp. 1 (×3). **1–2** (OU 10675); **3** (OU 10676).

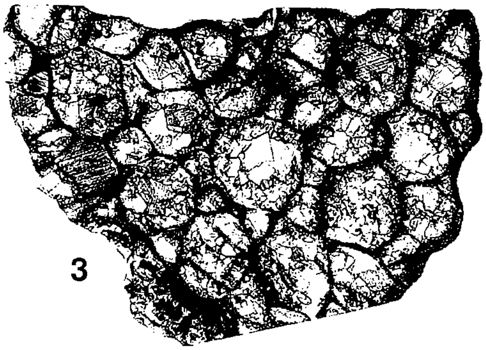
Figures 4,5.—Pachyporid, one branch seen in parallel sections (×10) (OU 4982).


1


2


4


5


3

Oklahoma Geological Survey Bulletin 145, 1992

Lower Devonian Ostracoda in Western Tennessee

Lee E. Petersen
Anadarko Petroleum Corp., Houston

Robert F. Lundin
Arizona State University

ABSTRACT.—Analysis of hundreds of samples containing tens of thousands of ostracodes from 27 localities in Lower Devonian strata of the Western Valley of Tennessee permits establishment of the stratigraphic and geographic distribution of ostracode species in these rocks. This work further aids in establishing refined age determinants and chronostratigraphic correlations with other Devonian units of eastern North America.

The ostracode faunas in the "Rockhouse" Limestone, Rockhouse Formation, Birdsong Formation, and Ross Limestone consist of 51 species representing 35 genera. They are typical of North American Midcontinental faunas belonging to the Appohimchi ostracode province, being dominated by the Pachydomellidae and Thlipsuridae.

Detailed plots of the stratigraphic distribution of ostracodes within the Rockhouse Formation and the content of that fauna indicate that the unit is entirely Lower Devonian and closely related in age to the Birdsong Formation. Meager evidence indicates that the lower beds of the Rockhouse Formation are somewhat older than lower Birdsong strata.

The Birdsong ostracode fauna strongly indicates that the Birdsong Formation is time-correlative with the Haragan Formation of Oklahoma and the Kalkberg Limestone of New York. All of the 12 species from the Ross Limestone and all of the 18 species from the "Rockhouse" Limestone are present in the Birdsong and Haragan Formations. The paleontologic evidence, as well as lithostratigraphic evidence, demonstrates that the "Rockhouse" Limestone, Rockhouse Formation, Ross Limestone, and Birdsong Formation are facies of a single depositional episode.

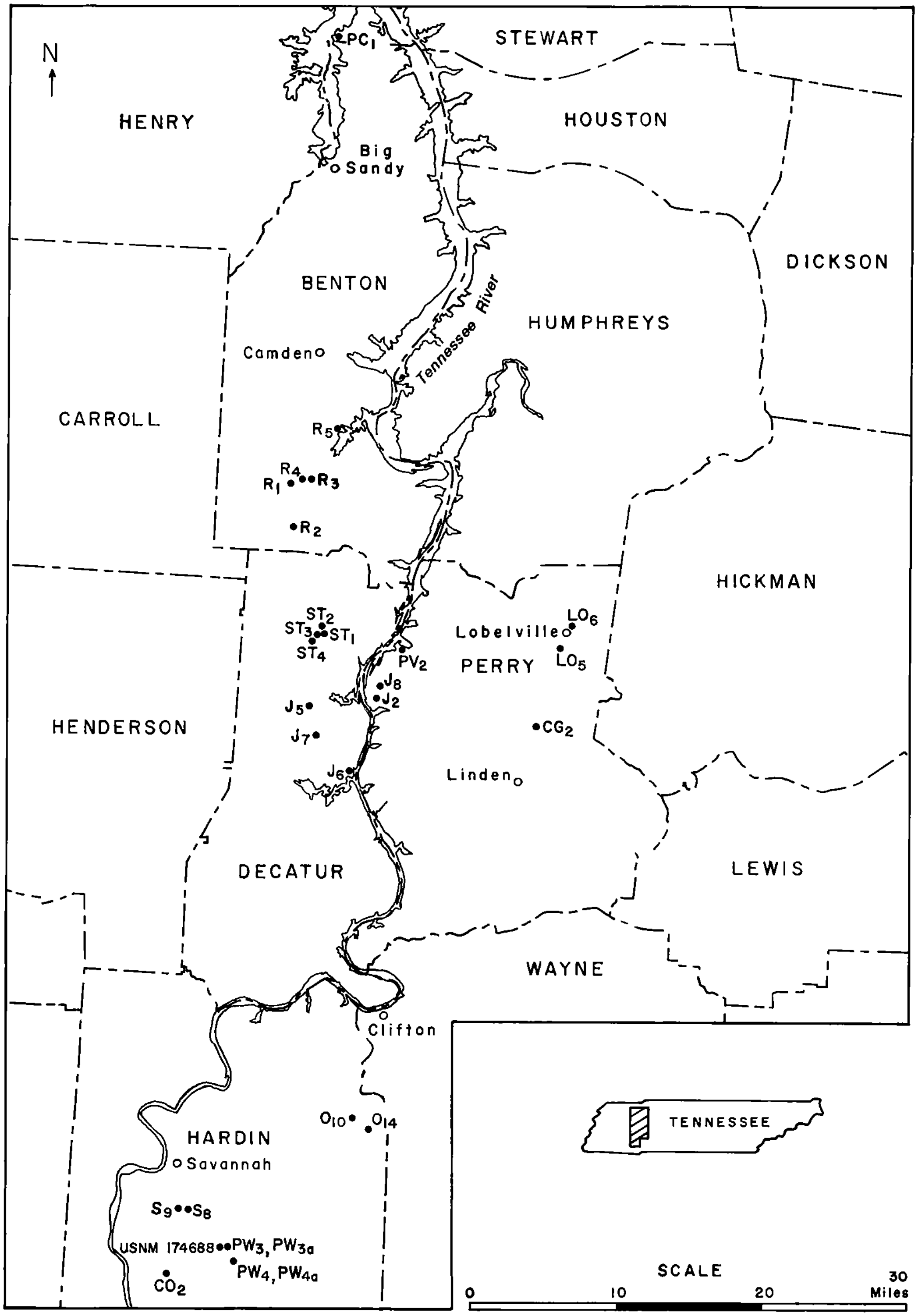
INTRODUCTION

Lower Devonian marine rocks exposed along the Western Valley of Tennessee (Text-fig. 1; Table 1) range in lithology from calcareous mudstones to skeletal packstones/grainstones and siliceous mudstones. This sequence of rocks is known for its abundant and diversified fauna, of which ostracodes are an important constituent. The purpose of this report is to summarize the content of the ostracode fauna and to evaluate its significance in age determination and chronostratigraphic correlation of the Tennessee sequence with other North American Lower Devonian sequences.

The first contribution to the stratigraphy of the Western Valley of Tennessee was made by Safford (1851). He placed all strata below the "black" shale (Chattanooga Shale) in one unit, the Harpeth Limestone, although he realized that the unit probably included Upper Silurian and Lower Devonian strata. Safford (1856,1869) refined his initial work in the Western Valley of Tennessee and recognized for the first time the presence of Helderbergian rocks in Tennessee. Helderbergian strata were first formally named by Safford and Killebrew (1876,1900) when they applied the name Linden to the sequence. They considered these strata to be Silurian, however. Foerste (1903) subdivided the Linden unit into two formations, the Ross Limestone and the Pyburn Limestone.

The first detailed work on the Lower Devonian of western Tennessee was that of Dunbar (1917,1918, 1919,1920). Dunbar divided Safford and Killebrew's (1876,1900) Linden unit into three formations: the Rockhouse Shale, the Olivehill Formation, and the Birdsong Shale. He further subdivided the Olivehill Formation into three members: the Ross Limestone, the Bear Branch–Pyburn Limestone, and the Flat Gap Limestone. Dunbar placed all of these units into the Lower Devonian.

The most comprehensive recent work on the Lower Devonian of western Tennessee was done by Wilson (1949). Wilson revised Dunbar's (1918, 1919) interpretation of the Helderbergian stratigraphy and placed all of Dunbar's units in a single formation, the Ross Formation, reducing all other units to member rank. The latter include the Birdsong Shale, Ross Limestone, Bear Branch Limestone, Decaturville Chert, and Rockhouse Shale. Other revisions made by Wilson (1949) include (1) the recognition of the basal limestone portion of the Birdsong Shale as a separate unit, which he named



Text-figure 1. Map showing the location in the Western Valley of Tennessee of sections sampled for this study. Sections PW_3 and PW_{3a} are the same localities sampled during different field seasons. The same is true for sections PW_4 and PW_{4a}.

TABLE 1. — GEOGRAPHIC LOCATION OF LOWER DEVONIAN SECTIONS USED IN THIS INVESTIGATION

Quadrangle	Section	Tennessee Coordinate System Reference Points	
Chestnut Grove	CG$_2$	469 500	1 460 500
Counce	CO$_2$	256 342	1 325 684
Jeannette	J$_2$	481 400	1 401 800
	J$_5$	479 400	1 374 900
	J$_6$	456 200	1 395 200
	J$_7$	469 900	1 379 100
	J$_8$	485 600	1 403 300
Lobelville	LO$_5$	500 000	1 469 200
	LO$_6$	509 200	1 472 700
Olivehill	O$_{10}$	327 421	1 394 553
	O$_{14}$	326 631	1 399 921
Pickwick	PW$_3$(PW$_{3a}$)	270 947	1 355 184
	PW$_4$(PW$_{4a}$)	265 342	1 363 000
	USNM 174688*		
Pine View	PV$_2$	494 500	1 411 400
Poplar Creek	PC$_1$	723 200	1 384 200
Rockport	R$_1$	563 500	1 372 300
	R$_2$	546 900	1 371 500
	R$_3$	565 200	1 382 800
	R$_4$	565 200	1 381 800
	R$_5$	570 200	1 391 700
Savannah	S$_8$	282 921	1 338 842
	S$_9$	282 919	1 338 526
Sugar Tree	ST$_1$	509 600	1 381 900
	ST$_2$	510 200	1 381 600
	ST$_3$	506 400	1 379 400
	ST$_4$	504 400	1 374 000

*Precise locality information for USNM 174688 is not available. The sample is known to be from a locality close to or at section PW$_3$.

NOTE: All the locations are given in terms of the Tennessee Coordinate System. Two sets of reference points are given. The first set represents the north reference point; the second set represents the east–west reference point. The base point for the system is located at the intersection of long 86°00′W. and lat 34°40′N. near Scottsboro, Alabama. This point is assigned the values 2,000,000 ft east and 100,000 ft north. The location of each of the sections is expressed with reference to its distance east or west and north of this base point.

the "Rockhouse" Limestone; (2) the recognition of the Birdsong Shale and Ross Limestone as lateral facies; (3) the recognition of the Rockhouse Shale and "Rockhouse" Limestone as lateral facies; (4) interpretation of the Bear Branch facies as a local, hematitic facies of the Ross Limestone; (5) recognition of the Pyburn Limestone as a synonym of the Ross Limestone; (6) the correct interpretation that the Flat Gap Limestone overlies rather than underlies (as indicated by Dunbar, 1919) the Birdsong Formation; and (7) placement of the Decaturville Chert as a "zone" within the Birdsong Shale and Ross Limestone. Wilson (1949) considered the Ross Formation with all its members to be Lower Devonian.

Broadhead and others (1988) accepted Wilson's (1949) interpretation of the stratigraphic relationships among the members of the Ross Formation, but disagreed with respect to the relationship between the Ross Formation and underlying Decatur

Limestone. Wilson (1949) interpreted the Ross–Decatur contact as unconformable. He placed the Ross Formation in the Lower Devonian and considered the Decatur Limestone to be Upper Silurian. Based on the presence of the conodont *Icriodus woschmidti* in the uppermost Decatur Limestone at Parsons Quarry (section J_5) (Text-fig. 1; Table 1) and the lower part of the "Rockhouse" Limestone member at Olivehill (section O_{10}) (Text-fig. 1; Table 1), Broadhead and others (1988) interpreted the Ross–Decatur to be conformable and the "Rockhouse" Limestone and Rockhouse Shale members to be at least partial facies of the Decatur Limestone. Furthermore, McComb and Broadhead (1981) and Broadhead and others (1988) considered the uppermost portion of the Decatur Limestone to be Early Devonian in age at its northernmost exposures and the lower part of the Ross Formation to be Late Silurian in age at its southernmost exposures.

Additional studies by Walker and Pruitt (1975) and Gibson and others (1988) consist of detailed stratigraphic and petrologic studies of the Decatur Limestone and "Rockhouse" Limestone and Birdsong Shale members of the Ross Formation at the Parsons Quarry exposure (section J_5) (Text-fig. 1; Table 1).

Wilson's (1949) basic interpretation of the Birdsong Shale and Ross Limestone and the Rockhouse Shale and "Rockhouse" Limestone, respectively, as lateral facies is herein considered correct. Furthermore, evidence accumulated during our investigation suggests that Wilson's "Rockhouse" Limestone and the Birdsong Shale are at least partial facies of each other. Some paleontological evidence suggests the same is true of the Ross Limestone and Rockhouse Shale. Although Wilson's (1949) interpretation of the physical stratigraphy is basically correct, his terminology is confusing and obscures the relationships of the units to each other. Accordingly, all the units, with the exception of the Bear Branch facies, which Wilson included in the Ross Formation, should be elevated to formational status (Text-fig. 2).

The stratigraphic terminology shown in Text-figure 2 is justified as follows:

1) "Rockhouse" Limestone.—The term Rockhouse should not be used because the same name is used for another unit (Rockhouse Formation) of a different lithology in a different geographic area. Proposing a new name is beyond the scope of this paper, so we use "Rockhouse" Limestone in quotations for rocks assigned by Wilson (1949) to the Rockhouse Limestone Member of his Ross Formation.

2) Birdsong Formation.—The unit exhibits diverse lithologies, therefore Birdsong Formation is preferred. The unit fulfills all requisites of the definition of a formation.

3) Rockhouse Formation.—As used herein, this unit is the same as Wilson's (1949) Rockhouse Shale Member of his Ross Formation and Dunbar's (1919) Rockhouse Shale. Although the outcrop area is small, the unit maintains a consistent stratigraphic position between the subjacent Decatur Limestone and superjacent Ross Limestone and is easily distinguished by lithologic differences. There is no true shale in the unit; accordingly, Rockhouse Formation is preferred.

4) Ross Limestone.—This unit is lithologically a fine-grained, siliceous limestone with mudstone partings and is exposed in the southern portion of the Western Valley of Tennessee. The use of Ross Formation (Wilson, 1949) to embrace all units listed above, as well as others, is confusing and should be discouraged. Ross Limestone as used herein is correlatable to the Ross Limestone Member (Wilson, 1949) and the Ross Limestone and Pyburn Limestone as used by Dunbar (1919).

5) Bear Branch Facies.—This is recognized as a local hematitic facies of the Ross Limestone as indicated by Wilson (1949) and Broadhead and others (1988).

LOWER DEVONIAN OSTRACODA

Previous Work

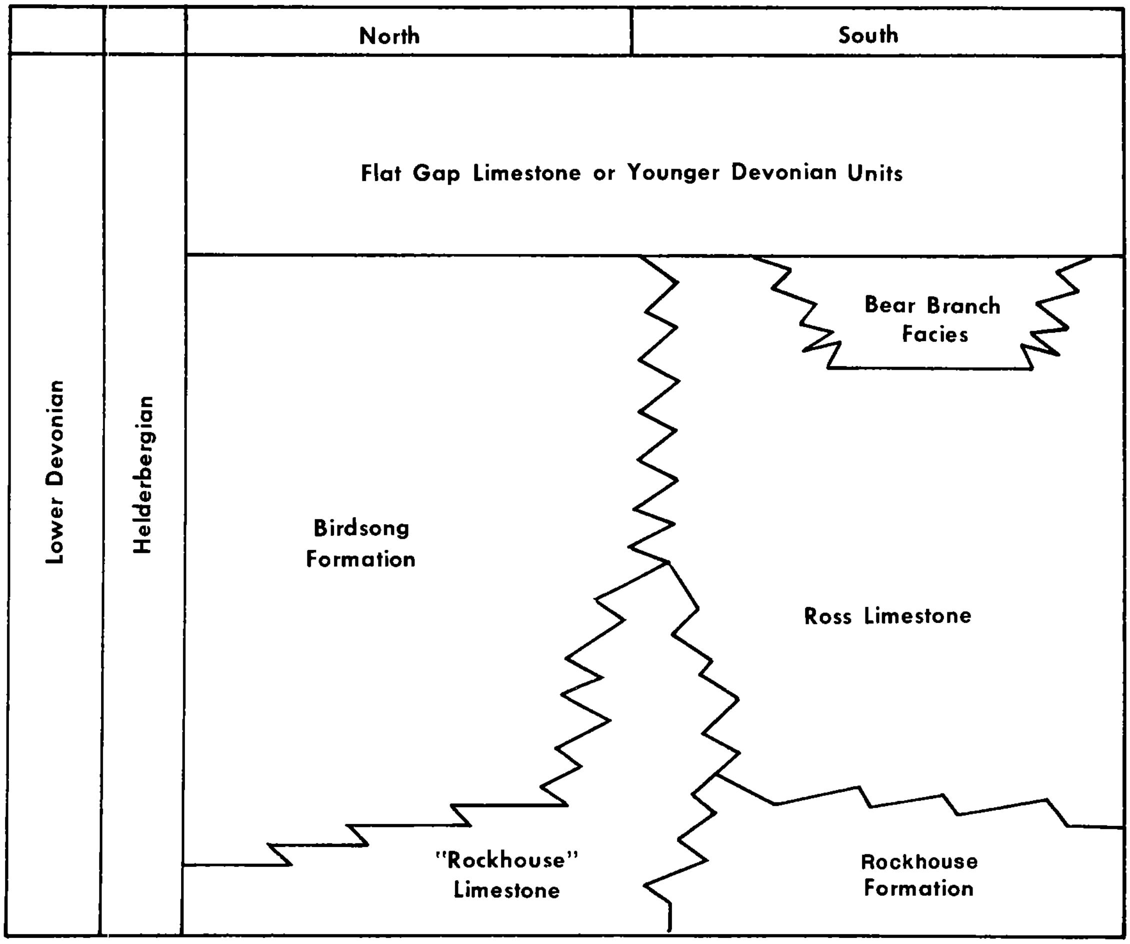
Ostracodes were first described from the Tennessee Lower Devonian sequence by Wilson (1935). Wilson's work was based on only five Birdsong Formation localities for which no stratigraphic information was presented. Cursory examination of a large number of samples yielded many species not reported by Wilson. Since Wilson's work, the Birdsong ostracode fauna has been referred to by numerous workers (e.g., Sohn, 1960,1961; Copeland, 1962,1977; Lundin, 1965,1968,1971; Lundin and Newton, 1970; Berdan, 1983,1986,1990). Rockhouse Formation ostracodes were described and evaluated for the first time by Lundin and Petersen (1974). Lists of Ross Limestone and "Rockhouse" Limestone ostracodes presented herein represent the first report of ostracodes from these units.

Limitations

The most abundant and diversified collections of ostracodes from this sequence are from the calcareous mudstones of the Rockhouse Formation and Birdsong Formation. Ostracode collections from the "Rockhouse" Limestone are limited to mudstone partings from several sections. Ross Limestone ostracodes are known from three sections (O_{10}, O_{14}, and CO_2) (Text-fig. 1; Table 1). Accordingly, geographic and stratigraphic information is primarily based on Rockhouse Formation and Birdsong Formation collections.

Taxonomy

The Lower Devonian ostracode faunas of western Tennessee contain eight new species and one new genus. Formal definition of these species is



Text-figure 2. Diagram showing schematically the stratigraphic relationships of Lower Devonian units in the Western Valley of Tennessee. The facies boundary between the Ross Limestone and "Rockhouse" Limestone/Birdsong Formation occurs in the northern part of Hardin County (see Text-fig. 1). General thickness of sequence (excluding Flat Gap and younger units) is 50–70 ft. Diagram not to scale.

beyond the score of this paper, and they are left in open nomenclature. The new species are referred to on the faunal lists by the designation "n. sp." The form that represents the new genus is designated as Genus A n. sp. 1. In addition, generic placement of several previously reported species will certainly change when detailed systematic studies, presently underway, are published. The generic placements of these species on the faunal lists are shown in quotation marks.

All illustrated specimens are in the type collections of the Department of Geology, Arizona State University (ASU), Tempe, Arizona.

Faunal Content

The Lower Devonian ostracode faunas of western Tennessee consist of 51 species representing 35 genera (Pls. 1–4). Evaluation of these faunas shows clearly that they are typical of Early Devonian ostracode faunas of the North American Midcontinent with respect to number and kinds of taxa included (Lundin, 1971). The faunas are easily correlated with Berdan's (1990) mixed association ostracode ecotype and are part of the Appohimchi ostracode province. Berdan (1990) related ostracode associations to water depth and interpreted the mixed association ecotype to be indicative of normal marine environments below wave base. This interpretation of the western Tennessee ostracode faunas contained in the Lower Devonian mudstone sequences is consistent with Broadhead and others' (1988) depositional interpretation for the Birdsong Formation and Rockhouse Formation.

In terms of the numbers of individuals, the Lower Devonian ostracode faunas of western Tennessee are like those of Oklahoma. The Pachydomellidae and Thlipsuridae contribute 17 species to the fauna and the Pachydomellidae dominate the fauna in number of individuals. Thousands of specimens of *Phanassymetria triserrata* Roth (Pl. 3, Fig. 14) and *Tubulibairdia simplex* (Roth) (Pl. 3, Fig. 9) are present. Likewise, moderate to large numbers (thousands) of thlipsurid specimens, including species of *Neothlipsura* Krandijevsky, *Eucraterellina* Wilson, *Rothella* Wilson, and *Thlipsorothella* Lundin and Petersen (see Pl. 4) are also present. Thus, although the Beyrichicopina dominate the fauna in number of taxa, the fauna is dominated in number of individuals by the Metacopina and Podocopina.

Table 2 shows the species present in the Rockhouse Formation, "Rockhouse" Limestone, Ross Limestone, and Birdsong Formation.

Geographic Distribution

Data on the geographic distribution of ostracodes are available only for the Birdsong Formation. Significant observations on geographic distribution of ostracodes in the Rockhouse Formation are prohibited by the limited outcrop area of the unit (Lundin and Petersen, 1974). Likewise, the small number of "Rockhouse" Limestone and Ross Limestone samples which yielded ostracodes prohibits evaluation of geographic distribution of ostracodes from these units.

The abundance of ostracodes in the Birdsong Formation varies greatly from one locality to another. Ostracodes are most abundant in samples from northern Decatur County and southern Benton County (Text-fig. 1). Large collections of ostracodes have also been recovered from the southernmost exposure of the Birdsong (section O_{10}) (Text-fig. 1). The northernmost exposures (PC_1 and R_5) and the easternmost exposures (CG_2, LO_5, and LO_6) were not especially productive (Text-fig. 1). The largest and best preserved collections come generally from the more complete exposures and from glades.

Qualitatively, the ostracode fauna is similar throughout the area in which the Birdsong is exposed; the principal variation is in abundance. Geographically restricted species are generally those species that are poorly represented and, therefore, their geographic distribution cannot be properly evaluated.

Stratigraphic Distribution

Text-figures 3 and 4 summarize the stratigraphic distribution of ostracodes in the Rockhouse and Birdsong Formations, respectively. Lundin and Petersen (1974) discussed the kinds of data available on the stratigraphic distribution of Rockhouse Formation ostracodes and concluded that there is no sound evidence, based on ostracodes, for a biostratigraphic subdivision of the unit in its outcrop area.

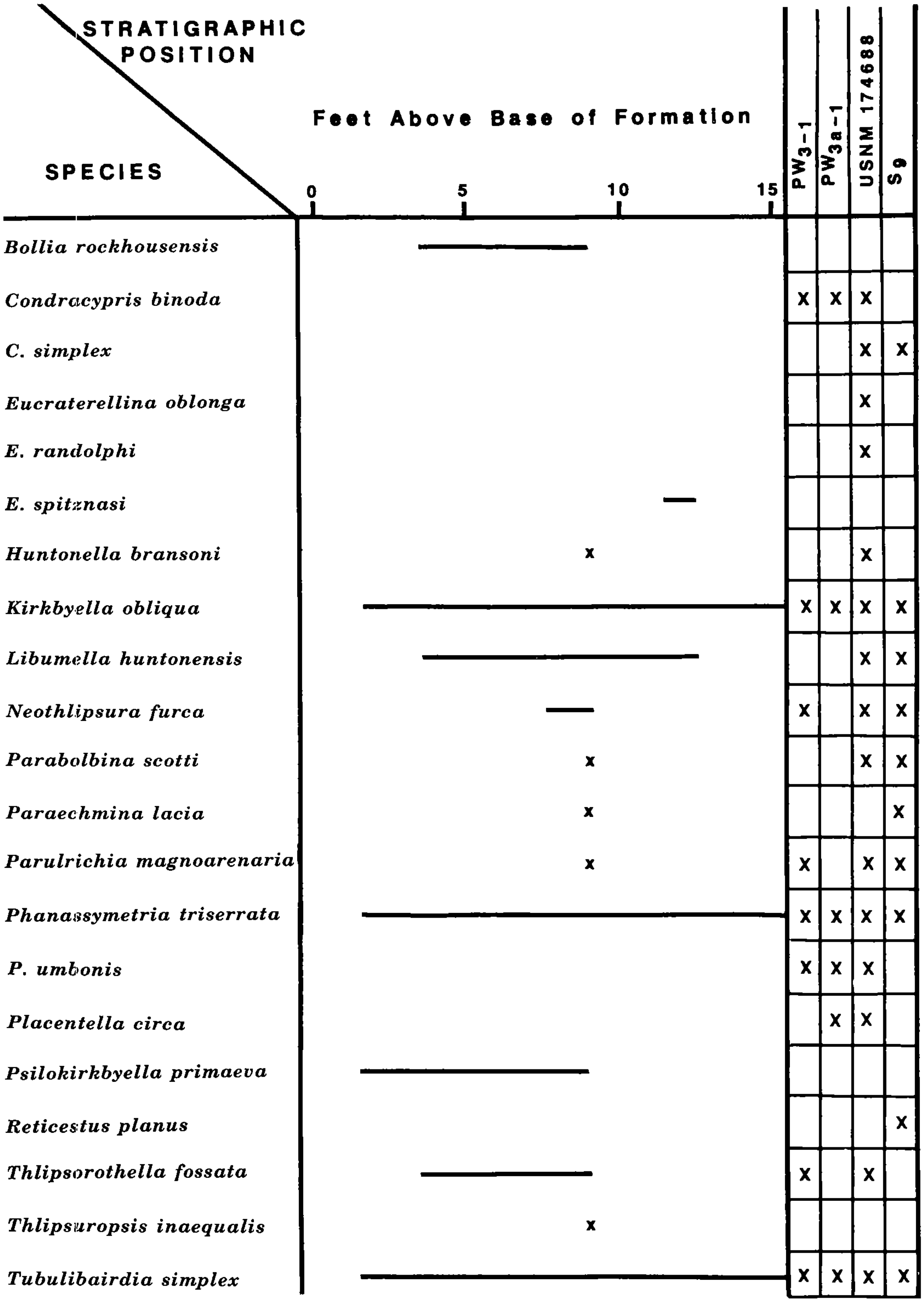
Several comments on the construction of the chart summarizing the stratigraphic distribution of Birdsong Formation ostracodes (Text-fig. 4) are necessary. Wherever possible, the species distributions were plotted from sections in which contacts were well defined. However, in most instances, the top contact of the Birdsong is poorly defined or covered. Dunbar (1919), Wilson (1949), and Broadhead and others (1988) have presented evidence that beds rich in bryozoans occur in the upper Birdsong. In the most complete sections used in this study, the bryozoan beds vary from 33 to 46 ft above the base of the formation, thus substantiating Dunbar's (1919), Wilson's (1949), and Broadhead and others' (1988) observations. Some sections have neither contact exposed, but due to the presence of the bryozoan beds are considered to be in the upper portion of the Birdsong. Where incomplete sections are used to define the distribution of a species, the bryozoan beds are considered to range between 33 and 46 ft above the base of the formation. Occurrences of ostracodes in samples from this interval (and in other samples) for which precise stratigraphic position is uncertain are shown on Text-figure 4 by dashed lines. Where a species is known from only one sample, its occurrence is shown by an "x."

Examination of the distribution of the Birdsong species (Text-fig. 4) clearly shows that most of the common elements of the fauna range throughout or nearly throughout the formation. With a few exceptions, those species that have restricted stratigraphic distributions are poorly represented in the fauna and the significance of their stratigraphic distribution is problematical.

Age and Correlation

Table 2 shows the occurrence of the Tennessee Lower Devonian species in other formations. Berdan (1983,1990) stressed the importance of comparing faunas from similar environmentally controlled associations for the purpose of time correlation and zonation by ostracodes. Berdan's work on North American lower Paleozoic ostracode provinicialism together with the studies of Lundin (1971), Polenova (1971), Berdan (1972), and Copeland and Berdan (1977) provide the basis for many of our conclusions on the age and correlation of the Lower Devonian of western Tennessee.

Dunbar (1919), Amsden (1958), and Boucot and Johnson (1967) have correlated the Birdsong Formation with the Haragan Formation of Oklahoma and the Kalkberg/New Scotland Formations of New York on the basis of brachiopods. More recently, Lundin (1968) substantiated these correlations with his study of the Haragan ostracodes. Our study confirms age correlations which have been made previously. Of the 38 previously reported species present in the Birdsong, 23 occur in the Haragan and 12 are present in the Kalkberg Limestone of New York. Species and family abundance are also similar to those of the Haragan and the Kalkberg. There is little species-level similarity (one or



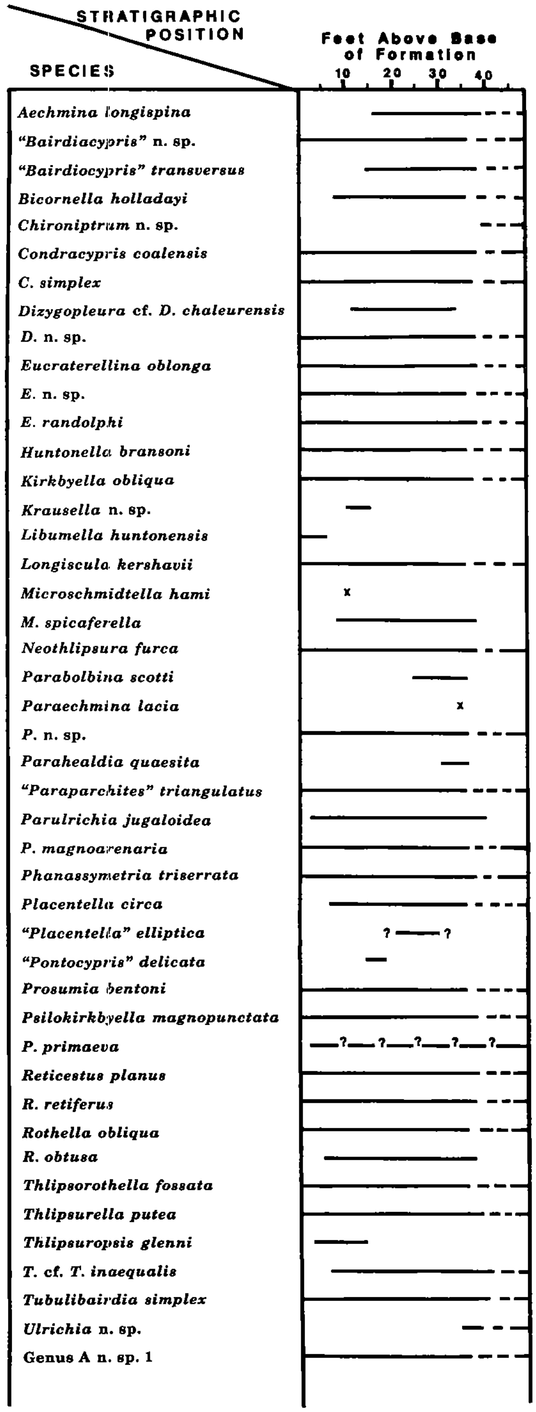
SPECIES	PW_{3}-1	PW_{3a}-1	USNM 174688	S_9
Bollia rockhousensis				
Condracypris binoda	X	X	X	
C. simplex			X	X
Eucraterellina oblonga			X	
E. randolphi			X	
E. spitznasi				
Huntonella bransoni			X	
Kirkbyella obliqua	X	X	X	X
Libumella huntonensis			X	X
Neothlipsura furca	X		X	X
Parabolbina scotti			X	X
Paraechmina lacia				X
Parulrichia magnoarenaria	X		X	X
Phanassymetria triserrata	X	X	X	X
P. umbonis	X	X	X	
Placentella circa		X	X	
Psilokirkbyella primaeva				
Reticestus planus				X
Thlipsorothella fossata	X		X	
Thlipsuropsis inaequalis				
Tubulibairdia simplex	X	X	X	X

Text-figure 3. Chart showing stratigraphic distribution of ostracodes in the Rockhouse Formation. Samples PW_{3-1} and PW_{3a-1} are from the upper half of the Rockhouse Formation. The stratigraphic position of samples USNM 174688 and S_9 within the Rockhouse Formation is not known. Small x's represent stratigraphic occurrence of species known from only one precisely located sample.

TABLE 2. — CHART SHOWING OCCURRENCE OF TENNESSEE LOWER DEVONIAN OSTRACODE SPECIES IN OTHER STRATIGRAPHIC UNITS

	Midcontinent Region							Northeastern North America Region			
Ostracode Species	Henryhouse	Helderberg NW Alabama	Rockhouse Formation	"Rockhouse" Limestone	Ross Limestone	Birdsong Formation	Haragan Bois d'Arc	Keyser Decker Cobleskill	Dalhousie	Kalkberg	Shriver Oriskany
Aechmina longispina Coryell and Cuskley, 1934						X	X			X	
"*Bairdiacypris*" n. sp.						X					
"*Bairdiocypris*" *transversus* (Roth, 1929)						X	X				
Bicornella holladayi (Wilson, 1935)				X		X					
Bollia rockhousensis Lundin and Petersen, 1974			X								
Chironiptrum n. sp.						X					
Condracypris binoda Roth, 1929			X	X	X		X				
C. coalensis Lundin, 1968						X	X				
C. simplex Roth, 1929			X	X	X	X	X				
Dizygopleura chaleurensis Copeland, 1962						X	X		X		
D. n. sp.						X					
Eucraterellina oblonga (Ulrich and Bassler, 1913)			X	X		X	X		X	X	X
E. n. sp.						X				X	
E. randolphi Wilson, 1935			X	X	X	X	X				
E. spitznasi Lundin, 1968			X				X				
Huntonella bransoni Lundin, 1968			X			X	X				
Kirkbyella obliqua (Coryell and Cuskley, 1934)			X	X	X	X	X				
Krausella n. sp.						X					
Libumella huntonensis (Roth, 1929)	X		X	X		X					
Longiscula kershavii (Wilson, 1935)						X	X				
Microschmidtella hami Lundin, 1968						X	X				
M. spicaferella (Wilson, 1935)						X					
Neothlipsura furca (Roth, 1929)		X	X	X	X	X	X				
Parabolbina scotti Lundin, 1968			X			X	X			X?	
Paraechmina lacia Wilson, 1935			X			X	X				
P. n. sp.						X					
Parahealdia quaesita (Roth, 1929)						X	X				
"*Paraparchites*" *triangulatus* Wilson, 1935						X					
Parulrichia jugaloidea (Wilson, 1935)						X					
P. magnoarenaria (Wilson, 1935)			X	X	X	X				X?	
Phanassymetria triserrata Roth, 1929		X	X	X	X	X	X				
P. umbonis Lundin and Petersen, 1974			X								
Placentella circa (Coryell and Cuskley, 1934)			X	X		X	X			X	
"*Placentella*" *elliptica* Wilson, 1935						X				X	
"*Pontocypris*" *delicata* Wilson, 1935						X					
Prosumia bentoni (Wilson, 1935)						X					
Psilokirkbyella magnopunctata (Wilson, 1935)				X		X	X				
P. primaeva Lundin and Petersen, 1974			X	X		X					
Reticestus planus (Wilson, 1935)			X	X		X					
R. retiferus (Roth, 1929)				X	X	X	X			X	
Rothella obliqua (Roth, 1929)				X	X	X	X				
R. obtusa Wilson, 1935						X					
Thlipsorothella fossata (Roth, 1929)			X	X	X	X	X			X	
T. murrayensis (Lundin, 1968)					X		X				
Thlipsurella putea Coryell and Cuskley, 1934						X	X			X	
Thlipsuropsis glenni (Wilson, 1935)						X				X?	
T. inaequalis (Ulrich and Bassler, 1913)	X	X	X					X			
T. cf. *T. inaequalis* (Ulrich and Bassler, 1913)						X					
Tubulibairdia simplex (Roth, 1929)		X	X	X	X	X	X			X?	
Ulrichia n. sp.						X					
Genus A n. sp. 1						X					

two species) between the Birdsong and New Scotland Formation faunas. This statement, however, is based upon analysis of only small New Scotland collections. A facies relationship between the Kalkberg and the New Scotland has been substantiated by Rickard (1962) and Epstein and others (1967), indicating that the differences between the New Scotland fauna and the faunas of the Birdsong and Kalkberg are more environmental than temporal.



Text-figure 4. Chart showing stratigraphic distribution of ostracodes in the Birdsong Formation.

Lundin and Petersen (1974) have presented evidence which leads us to reject the conclusions of Cooper and others (1942), Berry and Boucot (1970), and Broadhead and others (1988) that the Rockhouse Formation is Silurian and of Boucot and Johnson (1967) that the Silurian–Devonian boundary lies within the Rockhouse Formation. Of the 21 species reported from the Rockhouse, 19 are known from the Haragan and/or Birdsong Formations. Only two of the 21 species in the Rockhouse fauna have been reported from Silurian rocks elsewhere.

Boucot and Johnson (1967) and Broadhead and others (1988) concluded that the Rockhouse Formation is entirely older than the Birdsong Formation. Lundin and Petersen (1974) presented paleontologic and lithostratigraphic evidence suggesting that the lower beds of the Rockhouse Formation may be somewhat older than the oldest Birdsong beds. Nevertheless, the ostracode evidence demonstrates that the Rockhouse Formation is closely related in age to the Birdsong (Table 2).

Although we do not have large collections of ostracodes from the "Rockhouse" Limestone and Ross Limestone and the stratigraphic distribution of the ostracodes in these units is incompletely known, the units are most likely the same age as the Rockhouse and Birdsong Formations (see Table 2). Boucot and Johnson (1967) suggested that the Ross is time-equivalent with the Coeymans Limestone. On the basis of the first stratigraphic appearance of *Icriodus woschmidti*, Broadhead and others (1988) concluded that the lower part of the "Rockhouse" Limestone is Late Silurian in age at its southernmost exposures. *Icriodus woschmidti* is the index to the *woschmidti* zone of latest Silurian to earliest Devonian age (Klapper and Johnson, 1980). Its reliability in marking the base of the Devonian is limited by the fact that the direct ancestor to *Icriodus woschmidti* is unclear (Klapper and others, 1971; Broadhead and McComb, 1983). Ostracode evidence presented here (Table 2) and lithostratigraphic evidence lead us to reject Boucot and Johnson's (1967) chronocorrelation of the Ross Limestone with the Coeymans Limestone of New York as well as Broadhead and others' (1988) Late Silurian age assignment of the lower portion of the "Rockhouse" Limestone at its southernmost exposures.

The data presented in Table 2 overwhelmingly favor chronocorrelation of the Tennessee Lower Devonian units with the Haragan/Bois d'Arc Formations of Oklahoma and the Kalkberg/New Scotland Formations of New York. Further work on the ostracode faunas of the Appalachian area should strengthen the chronocorrelations that have been made between these units.

SUMMARY

Detailed field investigations and analysis of a large and diversified ostracode fauna indicate the Birdsong Formation, Rockhouse Formation, "Rockhouse" Limestone, and Ross Limestone represent facies of a single depositional episode.

The Lower Devonian ostracode fauna consists of 42 previously reported species representing 34 genera, plus nine new species and one new genus. The Metacopina and Podocopina dominate the fauna in number of individuals and the Beyrichicopina contribute the most taxa. The most important family in terms of number of individuals is the Pachydomellidae and, in terms of species diversity, the Thlipsuridae. Comparison of the fauna with the ostracode fauna of the Haragan Formation of Oklahoma substantiates Lundin's (1968) conclusion on the chronocorrelation of these units. Likewise, comparison with a large ostracode fauna from the Kalkberg Limestone of New York permits chronocorrelation of those two sequences.

Stratigraphic distribution of species in the Rockhouse and Birdsong Formations shows that no recognizable faunal zonation exists. Species that are abundant in the fauna range throughout or nearly throughout the formations. Species with a restricted stratigraphic distribution are generally poorly represented in the fauna. There appears to be no definite geographic restriction of the Birdsong faunal elements within the outcrop area. Variation in abundance, however, does occur.

ACKNOWLEDGMENTS

We wish to express our gratitude to A. J. Boucot and J. G. Johnson of Oregon State University and T. W. Amsden of the Oklahoma Geological Survey for their observations on the brachiopods and their age implications. Jean Berdan of the U.S. Geological Survey provided collections of Kalkberg Limestone and New Scotland Formation ostracodes, and R. H. Benson of the U.S. National Museum of Natural History arranged for us to use the Rockhouse Formation collections at that institution. L. G. Walker provided samples of the Birdsong Formation from one of the sections (PC 1) used in the study. Velma Birks graciously typed the manuscript and Pat Zeiger drafted several of the illustrations. Acknowledgment is made to the donors of the Petroleum Research Fund (grant no. 1663-A2,5), administered by the American Chemical Society, and to NATO (grant no. 0445/87) for support of this research.

REFERENCES CITED

Amsden, T. W., 1958, Haragan articulate brachiopods, *part 2 of* Amsden, T. W.; and Boucot, A. J., Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 9–144.

Berdan, J. M., 1972, Brachiopoda and Ostracoda of the Cobleskill Limestone (Upper Silurian) of central New York: U.S. Geological Survey Professional Paper 730, 44 p.

______1983, Biostratigraphy of Upper Silurian and Lower Devonian ostracodes in the United States, *in* Maddocks, R. F. (ed.), Applications of Ostracoda to economic and scientific problems: University of Houston, p. 313–337.

______1986, New ostracode genera from the Lower Devonian McMonnigal Limestone of central Nevada: Journal of Paleontology, v. 60, p. 361–378.

______1990, The Silurian and Early Devonian biogeography of ostracodes in North America, *in* McKerrow, W. S.; and Scotese, C. R. (eds.), Paleozoic palaeogeography and biogeography: Geological Society of London Memoir 12, p. 223–231.

Berry, W. B. N.; and Boucot, A. J. (eds.), 1970, Correlation of North American Silurian rocks: Geological Society of America Special Paper 102, 289 p.

Boucot, A. J.; and Johnson, J. G., 1967, Paleogeography and correlation of Appalachian Province Lower Devonian sedimentary rocks, *in* Toomey, D. F. (ed.), Symposium on Silurian–Devonian rocks of Oklahoma and environs: Tulsa Geological Society Digest, v. 35, p. 35–87.

Broadhead, T. W.; and McComb, R., 1983, Paedomorphosis in the conodont family Icriodontidae and the evolution of *Icriodus:* Fossils and Strata 15, p. 149–154.

Broadhead, T. W.; Capaccioli, D. A.; McComb, R.; Reid, S. R.; and Walker, K. R., 1988, Late Silurian and Early Devonian marine sedimentation near the southern margin of the North American craton, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world; proceedings of the second international symposium on the Devonian system: Canadian Society of Petroleum Geologists Memoir 14, v. 2, p. 197–208.

Cooper, G. A.; and others, 1942, Correlation of the Devonian sedimentary formations of North America: Geological Society of America Bulletin, v. 53, p. 1729–1793.

Copeland, M. J., 1962, Canadian fossil Ostracoda, Conchostraca, Eurypterida, and Phyllocarida: Geological Survey of Canada Bulletin 91, 57 p.

______1977, Early Paleozoic Ostracoda from Southwestern District of MacKenzie and Yukon Territory: Geological Survey of Canada Bulletin 275, 88 p.

Copeland, M. J.; and Berdan, J. M., 1977, Silurian and Early Devonian beyrichiacean ostracode provincialism in northeastern North America: Geological Survey of Canada Paper 77-1B, p. 15–24.

Coryell, H. N.; and Cuskley, V. A., 1934, Some new ostracodes from the "White Mound" section of the Haragan Shale, Murray County, Oklahoma: American Museum of Natural History 41st Novitates, v. 748, 12 p.

Dunbar, C. O., 1917, Devonian and black shale succession of western Tennessee [abstract]: Geological Society of America Bulletin, v. 28, p. 208.

______1918, Stratigraphy and correlation of the Devonian of western Tennessee: American Journal of Science, 4th series, v. 46, p. 732–756.

______1919, Stratigraphy and correlation of the Devonian of Tennessee: Tennessee Geological Survey Bulletin 21, 127 p.

______1920, New species of Devonian fossils from western Tennessee: Connecticut Academy of Arts and Sciences Transactions, v. 23, p. 109–158.

Epstein, A. G.; Epstein, J. B.; Spink, W. J.; and Jennings, D. S., 1967, Upper Silurian and Lower Devonian stratigraphy of northeastern Pennsylvania, New Jersey, and southeasternmost New York: U.S. Geological Survey Bulletin 1243, 74 p.

Foerste, A. F., 1903, Silurian and Devonian limestones of western Tennessee: Journal of Geology, v. 11, p. 679–719.

Gibson, M. A.; Clement, C. R.; and Broadhead, T. W., 1988, Bryozoan-dominated carbonate mudmounds in a cratonic setting from the basal Devonian of the southeastern United States, *in* McMillan, N. J.; Embry, A. F.; and Glass, D. J. (eds.), Devonian of the world; proceedings of the second international symposium on the Devonian system: Canadian Society of Petroleum Geologists Memoir 14, v. 2, p. 541–552.

Klapper, Gilbert; and Johnson, J. G., 1980, Endemism and dispersal of Devonian conodonts: Journal of Paleontology, v. 54, p. 400–455.

Klapper, Gilbert; and others, 1971, North American Devonian conodont biostratigraphy, *in* Sweet, W. C.; and Bergström, S. M. (eds.), Symposium on conodont biostratigraphy: Geological Society of America Memoir 127, p. 285–316.

Lundin, R. F., 1965, Ostracodes of the Henryhouse Formation (Silurian) in Oklahoma: Oklahoma Geological Survey Bulletin 108, 104 p.

______1968, Ostracodes of the Haragan Formation (Devonian) in Oklahoma: Oklahoma Geological Survey Bulletin 116, 121 p.

______1971, Possible paleoecological significance of Silurian and Early Devonian ostracode faunas from Midcontinental and northeastern North America, *in* Oertli, H. J. (ed.), Paleoecologie des Ostracodes, Colloque Pau (1970): Bulletin de Centre de Recherches Pau-SNPA, supplement to v. 5, p. 853–868.

Lundin, R. F.; and Newton, G. D., 1970, Ostracoda and Silurian stratigraphy of northwestern Alabama: Alabama Geological Survey Bulletin 95, 64 p.

Lundin, R. F.; and Petersen, L. E., 1974, Ostracoda from the Rockhouse Formation (Devonian) of western Tennessee: Journal of Paleontology, v. 48, p. 236–255.

McComb, R.; and Broadhead, T. W., 1981, Silurian–Devonian correlation in eastern United States [abstract]: Oklahoma Geology Notes, v. 41, p. 39.

Polenova, E. N., 1971, Biogeographical types of early Devonian ostracodes, *in* Oertli, H. J. (ed.), Paleoecologie des Ostracodes, Colloque Pau (1970): Bulletin de Centre de Recherches Pau-SNPA, supplement to v. 5, p. 843–852.

Rickard, L. V., 1962, Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) stratigraphy in New York: New York State Museum Bulletin 386, 157 p.

Roth, R. I., 1929, Some ostracodes from the Haragan Marl, Devonian of Oklahoma: Journal of Paleontology, v. 3, p. 327–372.

Safford, J. M., 1851, The Silurian basin of middle Tennessee; with notices of the strata surrounding it: American Journal of Science and Arts, 2nd series, v. 12, p. 352–361.

______1856, On the parallelism of the lower Silurian groups of middle Tennessee with those of New York: American Association for the Advancement of Science Proceedings 7, p. 153–156.

______1869, Geology of Tennessee: S. C. Mercer, Nashville, p. i–xi, 1–550.

Safford, J. M.; and Killebrew, J. B., 1876, The elementary geology of Tennessee: S. C. Mercer, Nashville, p. i–vi, 1–253.

______1900, The elements of the geology of Tennessee: S. C. Mercer, Nashville, 264 p.

Sohn, I. G., 1960, Paleozoic species of *Bairdia* and related genera: U.S. Geological Survey Professional Paper 330-A, 105 p.

______1961, *Aechminella*, *Amphissites*, *Kirkbyella* and related genera: U.S. Geological Survey Professional Paper 330-B, p. 106–160.

Ulrich, E. O.; and Bassler, R. S., 1913, Ostracoda, *in* Swartz, C. K.; and others, Systematic paleontology of the Lower Devonian deposits of Maryland: Maryland Geological Survey, p. 513–542.

Walker, L. G.; and Pruitt, G. N., 1975, Devonian and Silurian at the Vulcan Materials Company, Parsons Quarry, *in* Stearns, R. G. (ed.), Field trips in West Tennessee: Tennessee Geological Survey Reports of Investigations, v. 36, p. 8–13.

Wilson, C. W., Jr., 1935, The ostracode fauna of the Birdsong Shale, Helderberg, of western Tennessee: Journal of Paleontology, v. 9, p. 627–646.

______1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Division Geology Bulletin 56, 347 p.

PLATE 1

All illustrated specimens are adults and, unless indicated otherwise, are from the Birdsong Formation. All illustrated specimens are in the type collections of the Department of Geology, Arizona State University (ASU), Tempe, Arizona.

Figure 1.—*Huntonella bransoni* Lundin. Lateral view of female right valve (×27) (ASU X-155).

Figure 2.—*Aechmina longispina* Coryell and Cuskley. Lateral view of left valve (×45) (ASU X-191).

Figure 3.—*Placentella circa* (Coryell and Cuskley). Lateral view of left valve (×81) (ASU X-151).

Figure 4.—*Paraechmina* n. sp. Lateral view of left valve (×39) (ASU X-154).

Figure 5.—*Paraechmina lacia* Wilson. Lateral view of right valve (×45) (ASU X-152).

Figure 6.—*"Placentella" elliptica* Wilson. Lateral view of left valve (×68) (ASU X-153).

Figure 7.—*Bicornella holladayi* (Wilson). Lateral view of left valve (×109) (ASU X-150).

Figure 8.—*Ulrichia* n. sp. Lateral view of left valve (×81) (ASU X-156).

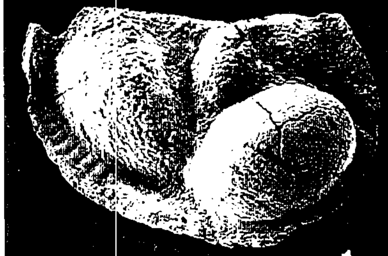
Figure 9.—*Chironiptrum* n. sp. Lateral view of right valve (×59) (ASU X-164).

Figure 10.—*Bollia rockhousensis* Lundin and Petersen. Lateral view of left valve from the Rockhouse Formation (×81) (ASU X-32).

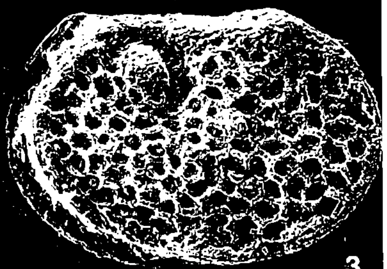
Figure 11.—*Parabolbina scotti* Lundin. Lateral view of female? right valve (×56) (ASU X-163).

Figure 12.—*Parulrichia jugaloidea* (Wilson). Lateral view of right valve (×45) (ASU X-158).

Figure 13.—*Parulrichia magnoarenaria* (Wilson). Lateral view of right valve (×35) (ASU X-161).

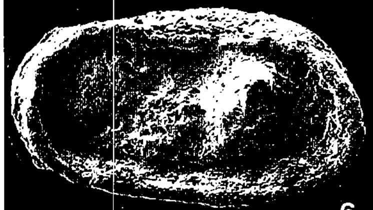

1

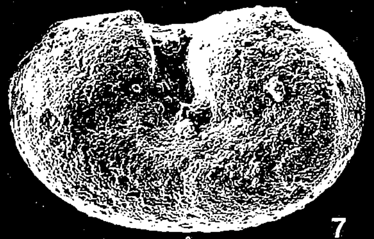

2

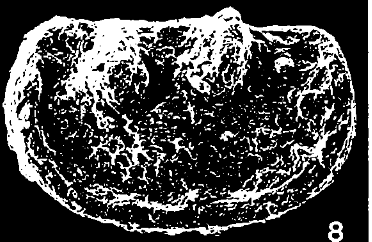

3

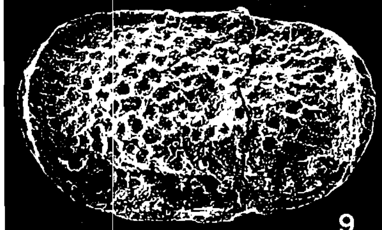

4

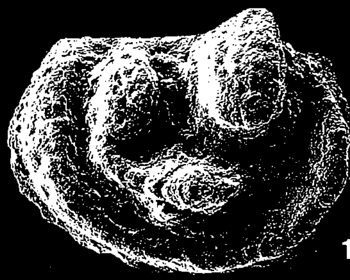

5

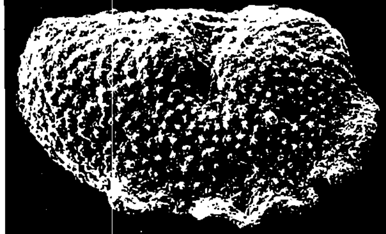

6

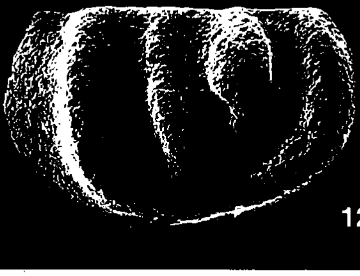

7


8


9


10


11


12


13

PLATE 2

All illustrated specimens are adults and, unless indicated otherwise, are from the Birdsong Formation. All illustrated specimens are in the type collections of the Department of Geology, Arizona State University (ASU), Tempe, Arizona.

Figure 1.—*Parahealdia quaesita* (Roth). Lateral view of female right valve (×43) (ASU X-176).

Figures 2,3.—Genus A n. sp. 1. **2**, posterior view of carapace (×63) (ASU X-193); **3**, left lateral view of carapace (×64) (ASU X-192).

Figure 4.—*Dizygopleura* n. sp. Right lateral view of carapace (×40) (ASU X-170).

Figure 5.—*Dizygopleura* cf. *D. chaleurensis* Copeland. Left lateral view of carapace (×46) (ASU X-162).

Figure 6.—*Krausella* n. sp. Right lateral view of carapace (×30) (ASU X-181).

Figure 7.—*"Paraparchites" triangulatus* Wilson. Left lateral view of carapace (×86) (ASU X-160).

Figure 8.—*Bairdiacypris* n. sp. Right lateral view of carapace (×58) (ASU X-177).

Figure 9.—*Psilokirkbyella magnopunctata* (Wilson). Lateral view of right valve (×73) (ASU X-159).

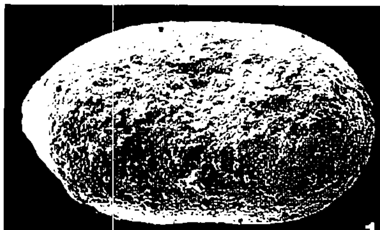
Figure 10.—*Psilokirkbyella primaeva* Lundin and Petersen. Lateral view of left valve from the Rockhouse Formation (×83) (ASU X-42).

Figure 11.—*Kirkbyella (Berdanella) obliqua* (Coryell and Cuskley). Lateral view of right valve (×71) (ASU X-157).

Figure 12.—*Libumella huntonesis* (Roth). Lateral view of left valve (×43) (ASU X-167).

Figure 13.—*Resticestus planus* (Wilson). Left lateral view of carapace (×50) (ASU X-165).

Figure 14.—*Resticestus retiferus* (Roth). Left lateral view of carapace (×51) (ASU X-166).


1

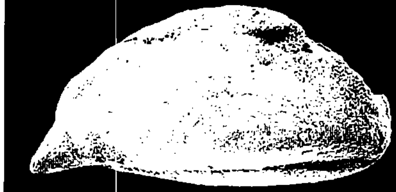

2

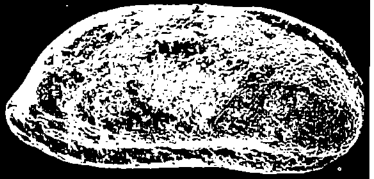

3


4

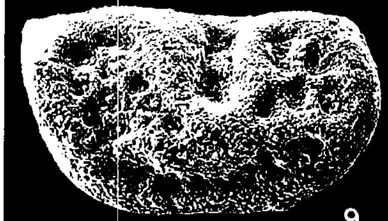

5

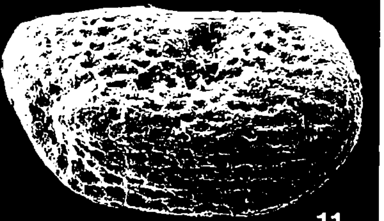

7

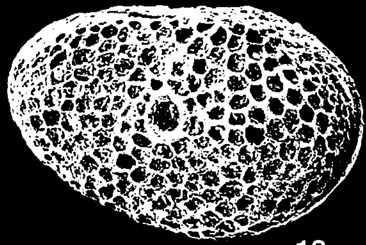

6

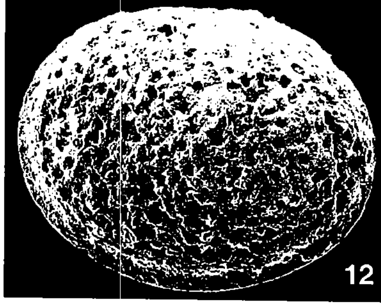

8


10


9


11


13


12

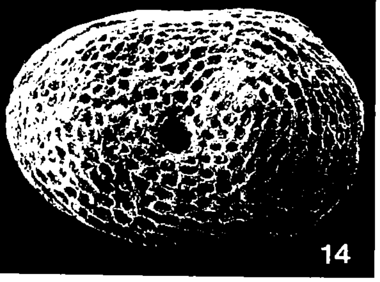

14

PLATE 3

All illustrated specimens are adults and, unless indicated otherwise, are from the Birdsong Formation. All illustrated specimens are in the type collections of the Department of Geology, Arizona State University (ASU), Tempe, Arizona.

Figure 1.—*Microschmidtella hami* Lundin. Lateral view of left valve (×125) (ASU X-168).

Figure 2.—*Microschmidtella spicaferella* (Wilson). Lateral view of left valve (×98) (ASU X-169).

Figure 3.—*"Bairdiocypris" transversus* (Roth). Right lateral view of carapace (×44) (ASU X-172).

Figure 4.—*"Pontocypris" delicata* Wilson. Right lateral view of carapace (×60) (ASU X-171).

Figure 5.—*Prosumia bentoni* (Wilson). Lateral view of left valve (×58) (ASU X-180).

Figure 6.—*Condracypris simplex* Roth. Right lateral view of carapace (×27) (ASU X-178).

Figures 7,8.—*Longiscula kershavii* (Wilson). **7**, right lateral view of carapace (×31) (ASU X-173); **8**, left lateral view of carapace (×35) (ASU X-174).

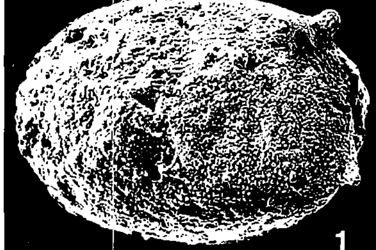
Figure 9.—*Tubulibairdia simplex* (Roth). Right lateral view of carapace (×32) (ASU X-179).

Figure 10.—*Condracypris coalensis* Lundin. Lateral view of right valve (×34) (ASU X-194).

Figure 11.—*Condracypris binoda* Roth. Lateral view of right valve from the Rockhouse Formation (×29) (ASU X-60).

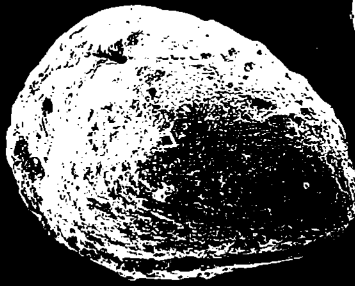
Figures 12,13.—*Phanassymetria umbonis* Lundin and Petersen. **12**, lateral view of left valve from the Rockhouse Formation (×35) (ASU X-51); **13**, lateral view of right valve from the Rockhouse Formation (×34) (ASU X-50).

Figure 14.—*Phanassymetria trisserrata* Roth. Left lateral view of carapace from the Rockhouse Formation (×41) (ASU X-47).

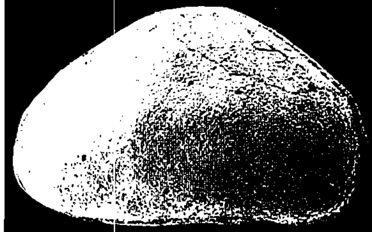

1


2


3

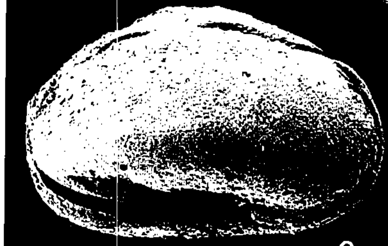

4


5

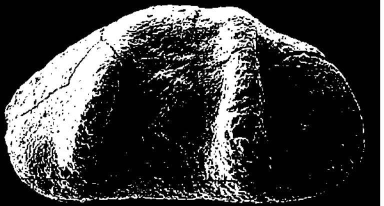

6

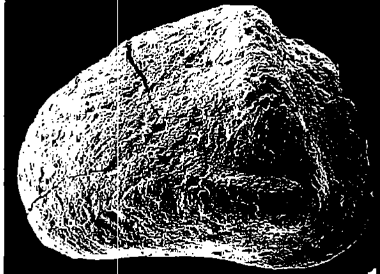

7


8


9


10


11


12


13


14

PLATE 4

All illustrated specimens are adults and, unless indicated otherwise, are from the Birdsong Formation. All illustrated specimens are in the type collections of the Department of Geology, Arizona State University (ASU), Tempe, Arizona.

Figure 1.—*Eucraterellina* n. sp. Lateral view of right valve (×68) (ASU X-175).

Figure 2.—*Eucraterellina spitznasi* Lundin. Lateral view of right valve from the Rockhouse Formation (×74) (ASU X-45).

Figure 3.—*Eucraterellina randolphi* Wilson. Right lateral view of carapace (×52) (ASU X-187).

Figure 4.—*Thlipsorothella fossata*. (Roth). Lateral view of right valve from the Rockhouse Formation (×31) (ASU X-49).

Figure 5.—*Eucraterellina oblonga* (Ulrich and Bassler). Right lateral view of carapace (×64) (ASU X-186).

Figure 6.—*Thlipsurella putea* Coryell and Cuskley. Lateral view of left valve (×73) (ASU X-182).

Figures 7,8.—*Thlipsuropsis* cf. *T. inaequalis* (Ulrich and Bassler). **7**, right lateral view of carapace (×68) (ASU X-185); **8**, lateral view of left valve (×64) (ASU X-184).

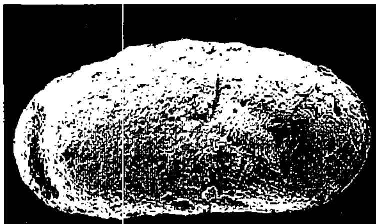
Figure 9.—*Neothlipsura furca* (Roth). Lateral view of right valve (×53) (ASU X-188).

Figure 10.—*Thlipsuropsis glenni* (Wilson). Left lateral view of carapace (×55) (ASU X-183).

Figure 11.—*Thlipsuropsis inaequalis* (Ulrich and Bassler). Lateral view of left valve from the Rockhouse Formation (×49) (ASU X-54).

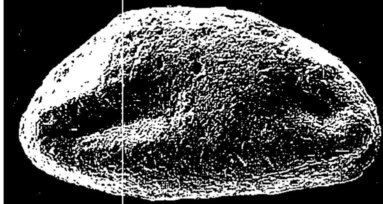
Figure 12.—*Rothella obliqua* (Roth). Left lateral view of carapace (×28) (ASU X-190).

Figure 13.—*Rothella obtusa* Wilson. Left lateral view of carapace (×30) (ASU X-189).


1

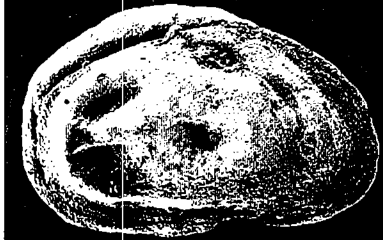

2


3


4


5


6


7

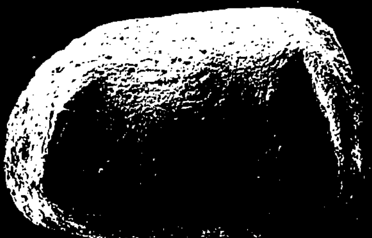

9


8


10


11


12


13

Oklahoma Geological Survey Bulletin 145, 1992

Middle and Late Ordovician Conodonts from Southwestern Kansas and Their Biostratigraphic Significance

Walter C. Sweet
The Ohio State University

ABSTRACT.—Distribution of conodonts in Middle and Upper Ordovician rocks at 17 Kansas subsurface localities enables recognition and correlation of three informal stratigraphic units. Subsurface unit A, the lowest, correlates with the late Whiterockian (Chazyan) McLish Formation of the Arbuckles in southern Oklahoma. Subsurface unit B yields the conodont fauna of the Glenwood, Platteville, and lower Decorah Formations of southeastern Minnesota. Subsurface unit C, an unnamed member of the Viola Group of late Edenian and early Maysvillian age, is part of a widespread carbonate body best known at localities west of the Transcontinental Arch. A fourth unit, identified as Maquoketa, occurs above unit C at one locality studied, but its age is not controlled by conodonts. Temporal relations between units A, B, and C, are determined graphically, and a continuous core through subsurface unit C in Stanton County, Kansas, is regarded as a local reference section.

INTRODUCTION

Rocks of Middle and Late Ordovician age are the most widely distributed Paleozoic deposits in North America. In vast areas of the Midcontinent, however, no Ordovician strata crop out at the surface and our knowledge of their lithic features, fossil content, and geographic distribution depends entirely upon information from well cuttings, borehole cores, and various types of geophysical logs. Because it is difficult to obtain large, well-controlled collections of microfossils from well cuttings and impossible to effect detailed biostratigraphic studies from either well cuttings or geophysical logs, it has not been possible thus far to fit collections from subsurface samples into high-resolution Ordovician chronostratigraphic networks with the same precision routinely obtained from studies of surface exposures. It is thus of considerable interest to have been able to sample and collect conodonts from two long, continuous borehole cores from southwestern Kansas, which include complete sections of Upper Ordovician strata referable to the Viola Group. Stratigraphic information from these closely sampled subsurface sections enables establishment of well-controlled local reference sections in southwestern Kansas for a part of the Upper Ordovician and thereby facilitates reasonable correlations of Middle and Upper Ordovician rocks sampled at several additional sites in Kansas.

MATERIALS AND METHODS

The first part of this report is based on samples taken from two long cores drilled in Stanton and Haskell Counties, southwestern Kansas (Fig. 1, localities M and N). These cores include 62 m to at least 76 m of cherty, vuggy, dark gray dolomite herein referred to an unnamed subsurface unit C of the Viola Group.

The McPherson and Citizens State Bank core—referred to as the "McPherson core"—(Fig. 1, locality M) is a continuous record of Paleozoic strata in this part of Kansas. It was completed by Amoco Petroleum Co. in January 1984, in Stanton County, Kansas. In addition to 62 m of Viola Group strata, the McPherson core includes a continuous, 214-m section of carbonate strata referred tentatively to the Arbuckle Group. In May 1984, Mark A. Frye and I sampled, at intervals of ~2 m, Arbuckle Group and Viola Group strata penetrated by the McPherson core. The samples were processed in acid and heavy liquid in the Amoco laboratories in Tulsa, Oklahoma, under the supervision of H. Richard Lane. I searched acid-insoluble residues from Viola Group strata and collected from them the 3,710 Upper Ordovician conodont elements identified in this report. Conodonts from Arbuckle Group samples are under study and will be described elsewhere.

The Ray Brian No. 1 core—referred to as the "Brian core"—(Fig. 1, locality N), drilled by Amoco in Haskell County, Kansas, penetrates at least 76 m of Upper Ordovician rock referred here to subsurface unit C of the Viola Group. The core was sampled by personnel in the Amoco research facility in Tulsa, who also processed the samples in acid and collected conodont elements from the resulting residues. I have little information on lithology from this core. My principal function has been to identify the species represented in the 19 Upper Ordovician

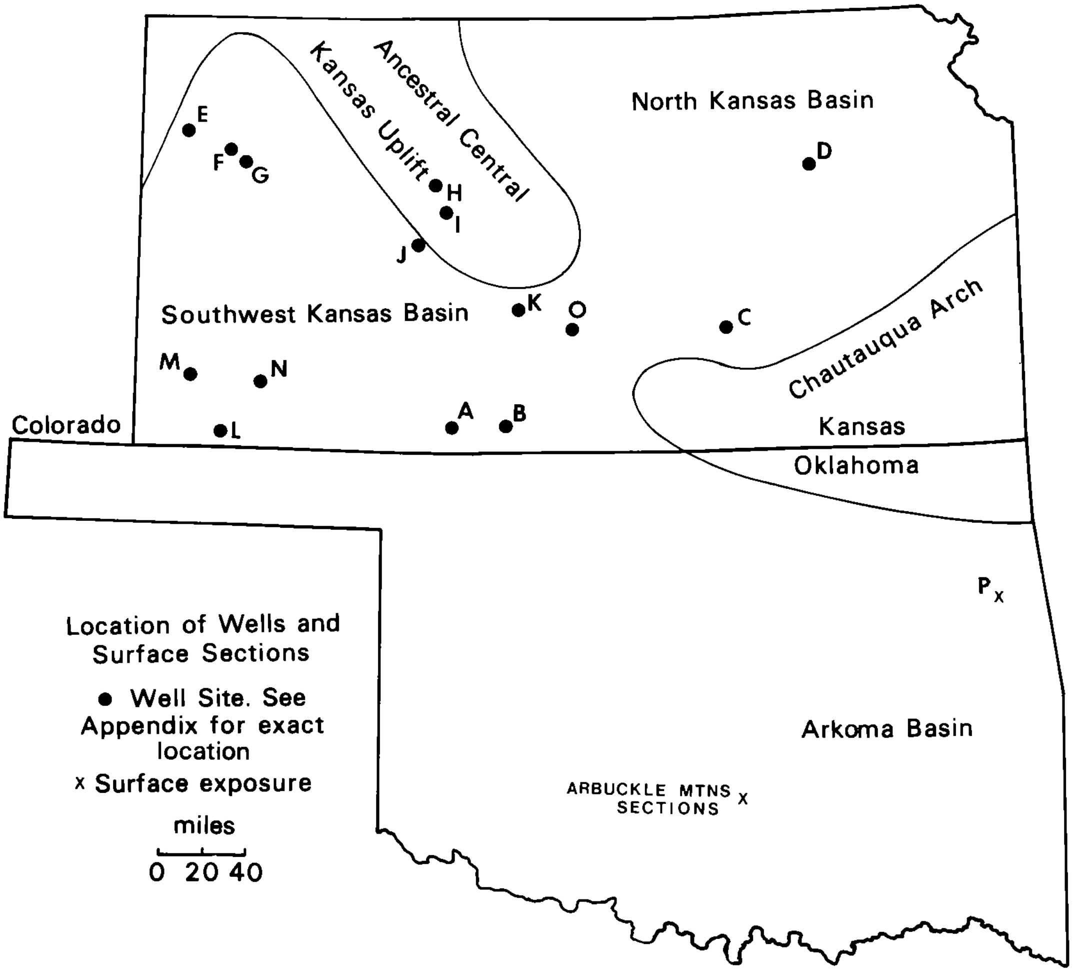


Figure 1. Location of sampled sections and other localities mentioned in the text. Localities identified by letter in the Appendix.

samples collected from the Brian core and to provide a biostratigraphic assessment of the interval studied.

The second part of this report is a general biostratigraphic interpretation of Simpson Group strata, which intervene between Viola Group and Arbuckle Group rocks at localities A–D and L of Figure 1. Samples that provide the basis for this part of the present report were collected in 1968 and processed in acid by personnel of the State Geological Survey of Kansas, under the supervision of Senior Geologist Edwin D. Goebel. In 1971, I began a study of the conodont elements recovered from these samples, but a report was shelved because a majority of the species were then undescribed and unnamed. Materials from the Kansas subsurface are abundant and mostly well-enough preserved to serve as primary type specimens; however, I feel that such types should be derived, if possible, from surface exposures that are accessible for recollecting by others. In recent years, all the conodont species represented in Simpson Group strata in the Kansas subsurface have been described from surface materials (Sweet, 1979b,1982; Amsden and Sweet, 1983; Bauer, 1987a,b,1989), so it is now appropriate to summarize their biostratigraphic distribution.

In relating sections to one another biostratigraphically, I have for some years utilized graphic correlation (Shaw, 1964), and that procedure is followed here. Sweet (1979b) first attempted to build a network of Upper Ordovician sections through graphic correlation; later Sweet (1984) outlined a more elaborate biostratigraphic framework for the Middle and Upper Ordovician of North America assembled through study of the distribution of conodonts at some 61 localities. Unpublished studies since 1984 have increased the number of localities represented, pointed out errors in the initial study, and increased overall resolution of the graphically collated network. A comprehensive report is now being assembled, and materials from Kansas subsurface localities are important components.

UPPER ORDOVICIAN BIOSTRATIGRAPHY

McPherson Core

In the McPherson and Citizens State Bank core (Fig. 1, locality M), Upper Ordovician rocks between 6,496 and 6,698 ft are herein referred informally to subsurface unit "C" of the Viola Group, which is divided into two parts. The lower part consists of 25 m of gray, mottled, vuggy, largely chert-free dolomite, with a 1.2-m interval of fissile grayish-brown siltstone at the top. The upper, thicker, part is composed of 37 m of tan and light gray, cherty dolomite, with burrowed, vuggy beds at the base and, at the top, a highly fractured, deeply weathered interval capped by a well-developed terra rosa of sandy, cherty red clay some 6 m thick. From Viola Group strata between 6,516 and 6,698 ft, 26 ~1,000-g samples were collected at 2.1-m intervals. Acid-insoluble residues of these samples yielded 3,710 conodont elements, which represent the 25 species indicated in Table 1 (McP column). All the species listed in Table 1, save those listed in open nomenclature, have been described and illustrated in the recent literature; hence, they are not illustrated or described further here.

Distribution of the 25 conodont species represented in Viola Group strata in the McPherson core is summarized in the column of Table 1 headed "McP." For convenience of comparison with surface sections, ranges are given in meters above the base of the Arbuckle Group, which is at the 7,400-ft depth in the core.

In Figure 2, first and highest occurrences in the McPherson core of the conodont species identified in Table 1 are plotted against ranges of the same species in a composite standard section (column headed "CS," Table 1). The CS is a synthesis of maximized distributional information for 186 conodont species represented in sections at 80 localities in North America obtained through graphic correlation and recorrelation of those sections and stated in terms of a standard reference section (SRS) in the Cincinnati Region of Ohio, Kentucky, and Indiana (Sweet, 1984).

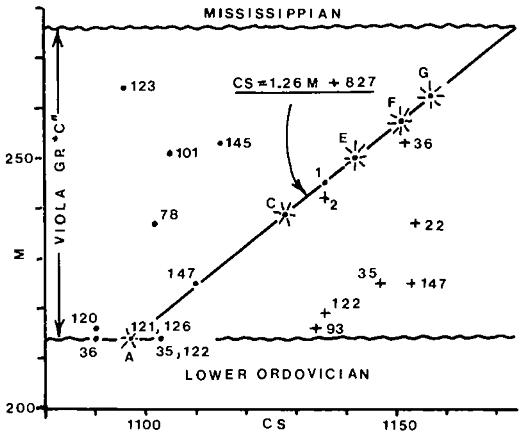


Figure 2. Graphic correlation of Viola Group (subsurface unit C) strata in the McPherson and Citizens State Bank core (M) and the composite standard (CS). First occurrences are plotted as dots; highest occurrences as crosses. Numbers by dots and crosses identify species named in Table 1. Stars are relative-abundance inflection points identified by the same capital letters in Figure 3. Scale on both axes is in meters.

Note in Figure 2 that dots marking the first occurrences in M (the McPherson core) and the CS of conodont species 121 *(Pseudobelodina kirki)*, 126 *(Pseudobelodina vulgaris vulgaris)*, 147 *(Staufferella lindstroemi)* and 1 *(Amorphognathus ordovicicus)* define a line that separates all but two (35, 122) of the plotted first occurrences (dots) from all of the highest occurrences, which are plotted as crosses. The line connecting these first occurrences is, in Shaw's (1964) terms, a "line of correlation" (or LOC), and its equation (CS = 1.26 M + 827) may be interpreted to mean not only that a meter of Viola Group rock in the McPherson core records the same interval of time recorded by 1.26 m of rock in the SRS, but also that the base of the Arbuckle Group in the McPherson core (the "0" level for conodont ranges) projects to the 82-m level in the SRS. However, because no information from the Arbuckle Group is plotted, it is safe to conclude only that the base of the Viola Group (214 m above the base of the Arbuckle Group) projects to a level 1,097 m above the base of the SRS, a value obtained by multiplying 214 m by 1.26 and adding 827 m. In fact, the base of the Viola in the McPherson core projects to a level only 297 m above the base of the SRS because, as Sweet (1984) notes, 800 m were added to the base of the SRS to accommodate graphic collation of sections that include rocks older than those in the SRS.

The LOC in the graph of Figure 2 also intersects (or nearly intersects) five additional points, plotted as asterisks and indexed by capital letters A, C, E, F, and G. These points, which are identified in Figure 3, were not used in fitting the LOC, but they may be regarded as evidence supporting the fit. Positions of the lettered points along the LOC of Figure 2 were determined by comparing a relative-abundance log for the Viola Group of the McPherson core with a log for that part of the standard reference section (SRS) shown by graphic correlation to be correlative. The McPherson log was, of course, enlarged vertically by 1.26, the coefficient of the LOC equation that expresses the relative rate of

TABLE 1. — RANGES[a] OF CONODONT SPECIES IN COMPOSITE SECTION (CS) AND IN SIX KANSAS SUBSURFACE SECTIONS

		Section[b]						
Species		DAVIS (D)	WATTS (C)	GENTRY (B)	EXB (A)	McP (M)	BRIAN (N)	CS
1[c]	*Amorphognathus ordovicicus*	55	—	—	86	245	—	1136–1243
2	*Amorphognathus superbus*	39–53	—	—	—	234–242	74–89	995–1136
3	*Amorphognathus tvaerensis*	—	—	—	46–52	—	—	959–1025
12	*Aphelognathus pyramidalis*	—	—	—	—	—	?128	1227–1267
	Aphelognathus spp.	—	—	—	—	264–266	125–128	—
21	*Belodina compressa*	26–29	35	25–34	—	—	—	938–1015
22	*Belodina confluens*	31–46	36–38	40–44	67–72	214–237	63–79	1019–1154
23	*Belodina monitorensis*	—	23	—	34	—	—	773–924
30	*Cahabagnathus friendsvillensis*	5	21–23	15	30–36	—	—	730–849
32	*Chirognathus duodactylus*	—	26–32	25–33	—	—	—	957–976
	Coleodus simplex	—	26–29	—	—	—	—	—
35	*Culumbodina occidentalis*	39–58	—	40	—	214–225	89–96	1103–1147
36	*Culumbodina penna*	39–46	36	40–42	—	214–253	63–114	1090–1151
46	*Drepanoistodus suberectus*	5–60	31–38	9–78	25–88	214–270	63–128	750–1270
52	*Erraticodon* sp. cf. *E. balticus*	—	21–24	—	—	—	—	750–850
59	*Icriodella superba*	—	—	—	46–47	—	—	962–1198
71	*"Oistodus" venustus*	55–58	—	—	—	228–261	63–79	860–1245
73	*Oneotodus? ovatus*	13	24–31	25–34	38–45	—	—	854–971
76	*Oulodus serratus*	24–32	26–35	25–26	44–45	—	—	957–994
78	*Oulodus ulrichi*	33–45	—	43–44	87	237–270	83–125	1102–1270
84	*Panderodus feulneri*	31–60	36–38	33–74	44–88	214–270	79–105	968–1261
85	*Panderodus gracilis*	23–32	32–35	—	—	—	63–128	822–1263
86	*Panderodus panderi*	38–60	—	40–70	55–87	219–264	—	822–1261
93	*Periodon grandis*	38–39	—	40–41	38–39	214–216	—	833–1134
94	*Phragmodus cognitus*	23–31	26?	—	—	—	—	960–986
95	*Phragmodus flexuosus* morph. B	5–13	21–24	9–15	25–36	—	—	734–785
98	*Phragmodus undatus*	44–58	—	39–74	46–88	225–270	63–128	959–1259
99	*Plectodina aculeata* s.l.	13–32	31–35	—	34–52	—	—	807–1009
100	*Plectodina aculeatoides*	35	—	—	—	—	—	1115–1221
100A	*Plectodina dakota*	—	24–27	25–35	38–46	—	—	957–976
101	*Plectodina florida*	55–58	—	68–70	—	251–270	83–128	1105–1247
102	*Plectodina tenuis*	35–60	36–38	39–78	55–88	214–266	63–128	979–1268
107	*Polyplacognathus ramosus*	26–28	35	25–33	—	—	—	957–1024
119	*Pseudobelodina? dispansa*	43–58	—	41–70	86	216–257	79–125	975–1249
120	*Pseudobelodina inclinata*	47–60	—	68–74	86–88	216–262	—	1090–1261
121	*Pseudobelodina kirki*	38–44	—	41–44	68	214–266	63–128	1098–1231
122	*Pseudobelodina? obtusa*	39–47	—	—	—	214–219	—	1103–1136
123	*Pseudobelodina quadrata*	—	—	—	—	264	—	1096–1243
126	*P. vulgaris vulgaris*	44–55	—	43–44	—	214–264	79–128	1097–1267
	Pseudooneotodus? sp.	—	—	—	—	237–260	—	—
130	*Pteracontiodus alatus*	—	21–24	—	—	—	—	750–910
144	*Scyphiodus primus*	—	—	25–33	38–45	—	—	957–976
145	*Staufferella brevispinata*	—	—	—	—	253	104	1115–1244
146	*Staufferella falcata*	28–60	23	25–70	25–45	—	—	858–1152
147	*Staufferella lindstroemi*	—	—	—	—	225	—	1110–1153
148	*Stereoconus gracilis*	—	35	—	—	—	—	957–976
	Walliserodus sp.	—	—	—	—	237–266	67–118	—
157	*Yaoxianognathus abruptus*	—	—	—	47–56	—	—	972–1114

[a] Ranges in meters above base of section

[b] Letters refer to sites shown on Figure 1 and described in the Appendix.

[c] Numbers are from an unpublished catalog of Ordovician conodont species used in graphic correlation. No numbers are assigned to *Coleodus simplex* or to species listed in open nomenclature.

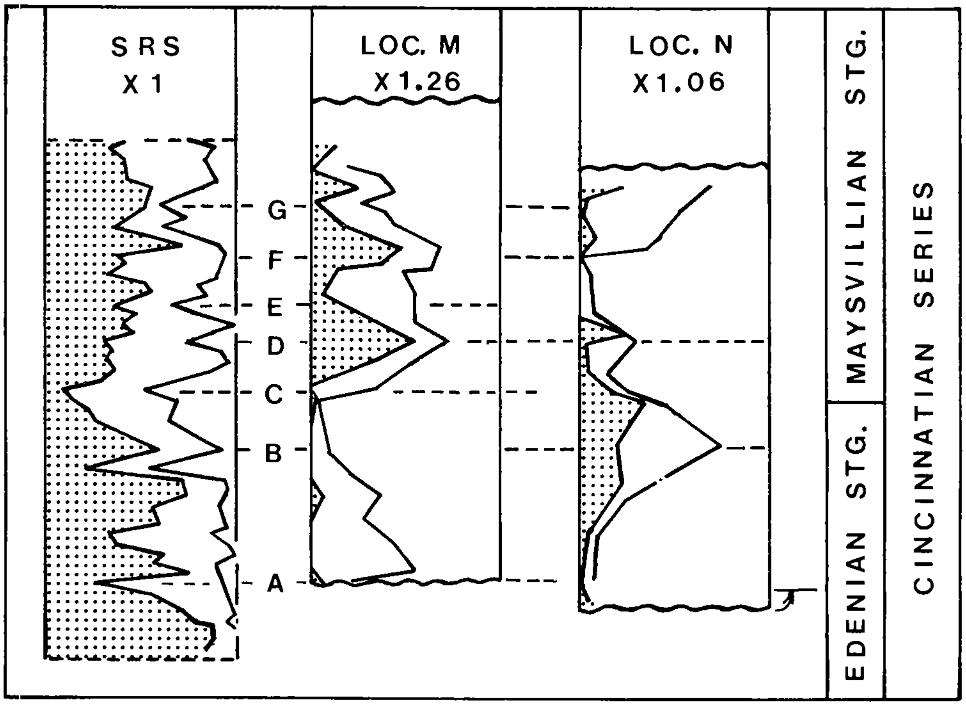


Figure 3. Relative-abundance logs for Viola Group (subsurface unit C) strata in the McPherson (locality M) and Brian (locality N) cores compared with a log for part of the standard reference section (SRS) in Kentucky. Stippled segments of logs represent *Phragmodus undatus;* the next log segment to the right represents species of *Plectodina;* the remainder of the log indicates relative abundance of all other conodonts, primarily species of *Aphelognathus* and *Oulodus* in the SRS, but a combination of *Aphelognathus, Oulodus,* and *Panderodus* in the McPherson and Brian cores. Capital letters A–G identify major inflection points in relative-abundance logs. These are plotted in Figures 2 and 4. Width of logs is 100%, with 0 on left; vertical scale of McPherson and Brian logs expanded by amount indicated by graphic correlation; SRS from Sweet and others (1974) with addition of detail.

rock accumulation between the McPherson core and the SRS. In at least the upper half of the logs compared in Figure 3, there is considerable congruity between relative-abundance maxima and minima, and the more pronounced of these are the ones identified by capital letters.

In studies summarized elsewhere (Sweet, 1979a,b,1988) fluctuations in relative abundance of the conodont species logged in Figure 3 are taken to represent fluctuations in water depth or in depth-dependent environmental features. Major inflections on relative-abundance logs may identify eustatic events that were widespread and essentially coeval because their plotted positions join arrays formed by plotting well-controlled first and last occurrences of species, which have long been accorded time significance.

In the graphically assembled CS, the projected base of the stratotype of the Maysvillian Stage is at almost exactly the same level as the inflection point labeled "C" in Figure 3. In the southeastern part of the Cincinnati Region, in Kentucky, inflection point C occurs stratigraphically at the top of the late Edenian Garrard Siltstone. In the McPherson core, inflection point C is at the top of a thin siltstone unit that caps the top of the lower carbonate unit of the Viola. Thus, in both sections, a pronounced drop in relative abundance of a relatively deeper-water conodont species (*Phragmodus undatus*) coincides with an incursion of silt.

Ray Brian Core

In the Ray Brian No. 1 borehole (Fig. 1, locality N), drilled by Amoco Production Co. in Haskell County, Kansas, rocks above 6,392 ft are Mississippian and those below 6,661 ft are Lower Ordovician (Ibexian). Between these limits are 71.6 m to as much as 82 m of Upper Ordovician carbonate rock, referred here informally to subsurface unit "C" of the Viola Group. Twenty samples, averaging 680 g in weight and collected at ~3.4-m intervals between 6,408 and 6,622 ft, yielded 2,527 conodont elements. The 19 species represented by these specimens are indicated in Table 1 and their ranges are given in meters above the 6,828-ft level in the core in the column of Table 1 headed "BRIAN." Personnel in the Amoco Research Laboratory in Tulsa collected and processed the samples and sorted the conodont elements from acid-insoluble residues. Note that bulk samples were only half as large as those from the McPherson core and were spaced about twice as far apart. In addition, configuration of the relative-abundance log for Viola strata penetrated by the Brian borehole (Fig. 3) and the fact that the aggregate Brian collection includes far fewer specimens than from the McPherson core suggest either that all conodonts were not picked from the Brian residues or that the operator picked more of some types of elements than of others.

In Figure 4, range data for conodont species represented in Viola Group strata in the Brian borehole are plotted against maximized range data for the same species in the composite standard section. The array of plotted points is diffuse; however, a line connecting the plotted first occurrence of species 121 *(Pseudobelodina kirki)* and the highest occurrence of species 36 *(Culumbodina penna)* clearly separates that area of the graph that includes first occurrences from the sector that includes all the highest occurrences. That line, although weakly controlled, is nevertheless fitted to first and highest occurrence events that are recognized at about the same level in a number of the sections that have contributed to the composite standard section and, thus, may be regarded as well established. Note, however, that the dashed line through the first occurrence of species 36 *(Culumbodina penna)*, and closely parallel to the solid line just described, intersects (or nearly intersects) the four starred points labeled A, B, D, and F. As with the McPherson core, the latter points were determined through comparison of relative-abundance logs. Those comparisons are admittedly rather weak, probably as a result of biased picking of conodonts from Brian borehole samples.

For correlation purposes, we have chosen to use the solid LOC of Figure 4, the equation for which is: CS = 1.06 B + 1030. Regardless of which of the two lines in Figure 4 is chosen as LOC, however, it is clear that the base of the Viola Group in the Brian borehole projects to a position 1,086–1,094 m above the base of the composite standard section and that essentially equivalent thicknesses of rock represent the same intervals of time in the SRS and the Brian section. It is equally clear that greater spacing of much smaller samples and probable bias in the separation of conodonts from those samples have resulted in a record that resolves biostratigraphically at a somewhat lower level than does that from the McPherson core.

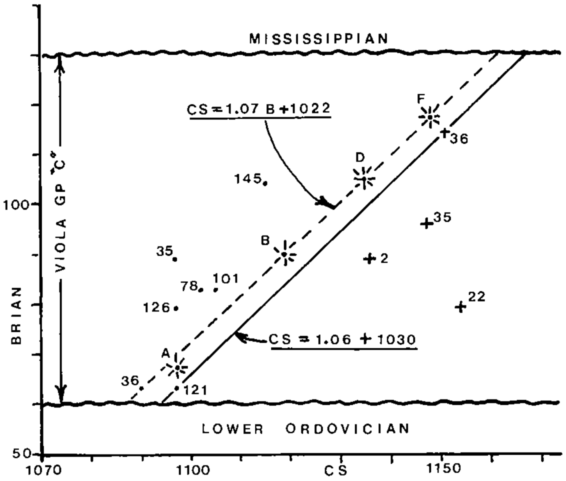


Figure 4. Graphic correlation of Viola Group (subsurface unit C) strata in the Ray Brian No. 1 well (BRIAN) and the composite standard section (CS). See caption to Figure 2 for further explanation. Significance of dashed LOC and solid LOC explained in text.

CORRELATION OF SUBSURFACE VIOLA AND SIMPSON STRATA

Figure 5 indicates correlation of Viola Group strata penetrated in the McPherson and Brian boreholes with Viola Group rocks exposed in the Arbuckle Mountains of south-central Oklahoma and with strata assigned informally in this report to a subsurface facies "C" of the Viola Group at four additional localities in Kansas. Oberg (1966b), Amsden and Sweet (1983), Bauer (1987a,b), and Dresbach (1983) are responsible for the data on which correlation of southern Oklahoma sections are based, and Sweet (1979b) determined correlation of Upper Ordovician rocks in the Davis borehole. Correlations of Middle and Upper Ordovician rocks in the Exchange Bank, Gentry, and Watts boreholes, and of Middle Ordovician strata in the Davis borehole, however, are presented for the first time here.

In the McPherson and Brian boreholes (Fig. 1, localities M and N, respectively), Viola Group strata (informal subsurface unit "C" of Fig. 5) rest unconformably on carbonate rocks that yield representatives of Early Ordovician (Ibexian) conodont species and are assigned to the Arbuckle Group. This situation also obtains in wells at localities G and J of Figure 1. At localities A–D, L, and O, however, Viola Group and Arbuckle Group carbonates are separated by a few meters to as much as 45 m of sandstone, shale, and fine-grained carbonate rock, assigned collectively to the Simpson Group. At localities E, F, H, and I, Mississippian rocks rest directly on Arbuckle carbonates.

In 1968, the State Geological Survey of Kansas provided me with acid-insoluble residues of 383 samples from Viola Group, Simpson Group, and Arbuckle Group strata penetrated in boreholes at localities A–L of Figure 1. At many sites, the short cores (mostly drill-stem tests) from which samples were obtained were too erratically spaced to provide the continuous record required by graphic correlation. At a few sites, however, longer cores

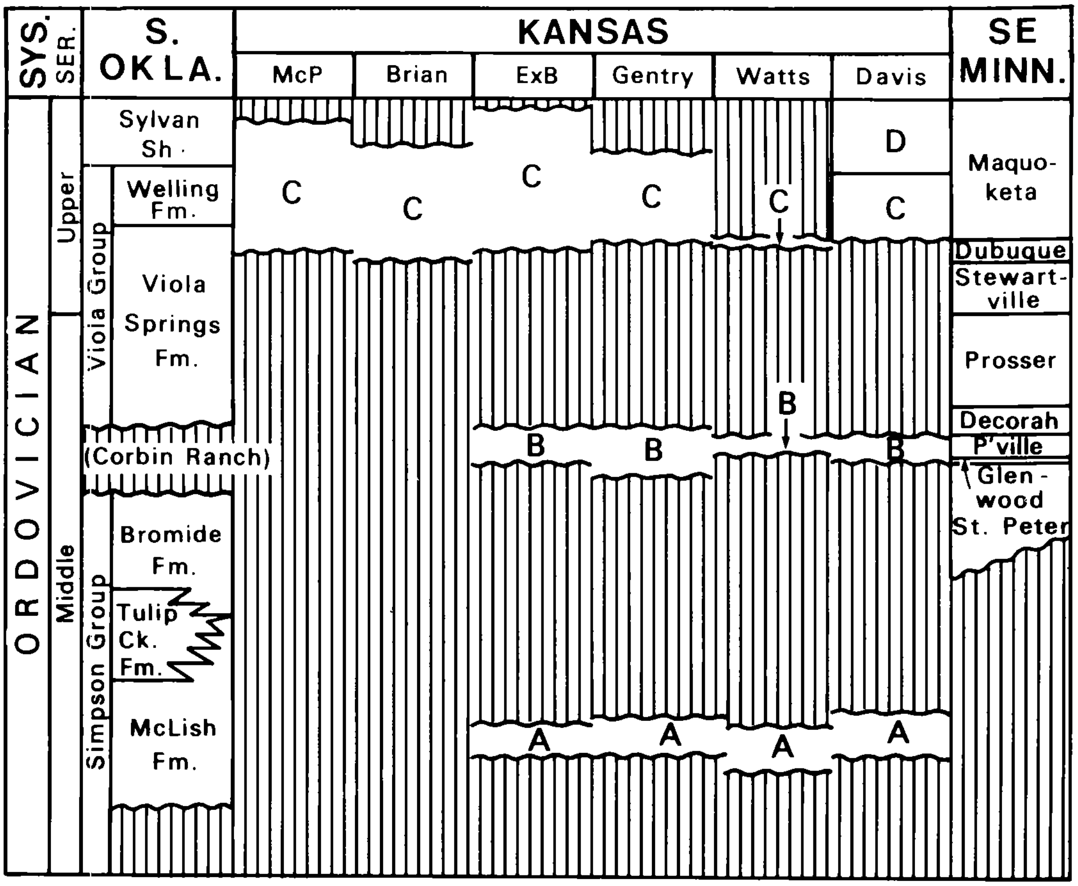


Figure 5. Correlation of Simpson Group and Viola Group strata at six Kansas subsurface localities with southern Oklahoma and southeastern Minnesota. The southern Oklahoma column is a composite of information from three sections (Amsden and Sweet, 1983; Dresbach, 1983; Bauer, 1987a), as is the southeastern Minnesota column (Webers, 1966). Vertical scale is in composite-standard units, hence vertical extent of stratigraphic units and hiatuses in each column are proportional to time, as indicated by graphic correlation. Nature of informal subsurface stratigraphic units A–D explained in text.

were available, samples were more closely spaced, and ranges of conodonts could be determined with greater precision. Data from samples at these sites are suitable for graphic correlation. Thus, I have used conodont range-data from Middle and Upper Ordovician rocks at localities A (No. 1 Exchange Bank well), B (No. 1 Alice Gentry well), C (No. 11 Mary D. Watts well), and D (No. 2A Davis Ranch well) of Figure 1 to establish correlations between the strata involved and coeval parts of the standard reference section in the Cincinnati Region.

As noted previously, composite standard ranges in Table 1 are from a more extensive composite standard section that is a synthesis of maximized ranges for 186 conodont species assembled by graphic correlation of sections at some 80 localities in North America. Conodont range-data from the subsurface sections considered here will eventually be important components of the composite standard. However, before a stable CS can be defended, data from each of these subsurface localities must be allowed to perturb the entire network of sections, and that has not yet been done. Therefore, even though the positions and temporal relations of subsurface units A–D of Figure 5 have been determined graphically, and are probably in essentially their final form, the results must be regarded as tentative until the effect of each on the entire network has been considered. For this reason, only ranges and conclusions with respect to correlation are presented here (in Table 1 and Fig. 5, respectively). A full discussion of the graphic assembly is deferred.

Subsurface Unit A

In boreholes considered in this study, subsurface unit A is 3–19 m of fine-grained sandstone, siltstone, and minor shale. Samples yield conodonts referable to:

Belodina monitorensis Ethington and Schumacher, 1969
Cahabagnathus friendsvillensis (Bergström, 1971)
Erraticodon sp. cf. *E. balticus* Dzik, 1978
Oneotodus? ovatus (Stauffer, 1935)
Phragmodus flexuosus Moskalenko, 1973, morphotype B of Bauer, 1987
Pteracontiodus alatus (Dzik, 1976).

In southern Oklahoma (Bauer, 1987a), this association of conodont species is confined to the lower part of the late Whiterockian (Chazyan) McLish Formation, although individual species of the association range somewhat above to well above the McLish. I suspect, but do not know, that Schramm (1964) also regarded unit A as a component of the McLish, for the McLish and Bromide are the only formations of the Simpson Group he shows to have any significant extension into Kansas. Therefore, it seems reasonable to conclude that Kansas subsurface unit A is equivalent in age to some part of the lower McLish Formation of Arbuckle Mountain localities; that it is late Whiterockian (Chazyan) in age; and that it is an extension into Kansas of the unit mapped as McLish by Schramm (1964).

Subsurface Unit B

In the subsurface sections considered here, subsurface unit B is 10–16 m of fine-grained carbonates and shale. Samples from this unit yield representatives of a distinctive conodont fauna, which includes:

Amorphognathus tvaerensis Bergström, 1962
Belodina compressa (Branson and Mehl, 1933)
Chirognathus duodactylus Branson and Mehl, 1933
Coleodus simplex Branson and Mehl, 1933
Drepanoistodus suberectus (Branson and Mehl, 1933)
Icriodella superba Rhodes, 1953
Oneotodus? ovatus (Stauffer, 1935)
Oulodus serratus (Stauffer, 1930)
Panderodus feulneri (Glenister, 1957)
Panderodus gracilis (Branson and Mehl, 1933)
Panderodus panderi (Stauffer, 1940)
Periodon grandis (Ethington, 1959)
Phragmodus cognitus Stauffer, 1935
Phragmodus undatus Branson and Mehl, 1933
Plectodina aculeata (Stauffer, 1930) s.l.
Plectodina dakota Sweet, 1982
Polyplacognathus ramosus Stauffer, 1935
Scyphiodus primus Stauffer, 1935
Staufferella falcata (Stauffer, 1935)
Stereoconus gracilis Branson and Mehl, 1933
Yaoxianognathus abruptus (Branson and Mehl, 1933).

In central and western Colorado, components of this group of species (but not the entire association) have been reported from the Harding Sandstone (Branson and Mehl, 1933; Sweet, 1955), and Amsden and Miller (1942) collected representatives of several species from Harding equivalents in the northern Bighorn Mountains of Wyoming. Virtually the entire association is known from the Icebox and Roughlock Members of the Winnipeg Formation of the Dakotas (Furnish and others, 1936; Carlson, 1960; Sweet, 1982), and elements of it have been recovered from the Deer Island Member of the Winnipeg in southern Manitoba (Oberg, 1966a). The species association characteristic of Kansas subsurface unit B is probably best known from the Glenwood, Platteville, and Decorah Formations of Upper Mississippi Valley sections in southeastern Minnesota and nearby parts of Iowa (Stauffer, 1930,1935a,b; Webers, 1966), and elements of it are clearly represented among the numerous conodonts described by Stauffer (1932) from the "Decorah Shale" in the subsurface of Reno County, Kansas (Fig. 1, locality O).

In light of the preceding discussion, it is not surprising that graphic correlation of rocks penetrated in the Exchange Bank, Gentry, Watts, and Davis boreholes (Fig. 1, localities A–D) indicates that subsurface unit B is equivalent in age to the Glenwood, Platteville, and lower Decorah Formations of southeastern Minnesota. It is also interesting to note that subsurface unit B, logged appropriately as Platteville in northeastern Kansas (Merriam, 1963), was apparently deposited during the interval of time represented in southern Oklahoma by the unconformity separating the Simpson and Viola Groups. In Figure 5, it is suggested that the Corbin Ranch Submember of the Poolville Member of the Bromide Formation may, in at least its type section, include rocks equivalent to subsurface unit B. In Figure 5, these rocks are included in the basal part of the Viola Group; however, Amsden (in Amsden and Sweet, 1983) notes that Corbin Ranch strata exposed along Interstate 35, on the south flank of the Arbuckle Anticline, belong in the uppermost part of the Bromide Formation, which there yields stratigraphically undiagnostic conodonts. Thus, it may be that, from place to place, the Corbin Ranch Submember includes rocks both below and above the unconformity between the Simpson and Viola Groups.

Conodonts reported by Sweet (in Amsden and Sweet, 1983) and Bauer (1989) from the Upper Tyner and Fite Formations in Cherokee County, eastern Oklahoma (Fig. 1, locality P) are clearly much younger than those in subjacent beds of the Lower Tyner and Burgen Formations. Sweet (in Amsden and Sweet, 1983) concluded that the largely generalized conodont fauna of the Fite Formation indicated a Rocklandian or Kirkfieldian age, and Bauer (1989) reached a similar conclusion for the Upper Tyner–Fite unit. Except for *Plectodina aculeata* s.l., a long-ranging Middle Ordovician species, and a specifically indeterminate *Oulodus* (which might be *O. serratus*), the Upper Tyner–Fite of eastern Oklahoma has little in common with subsurface unit B. However, both appear to occupy the same general stratigraphic position and, thus, they may be of comparable age.

Subsurface Unit D

In the Davis core of Wabaunsee County, Kansas (Fig. 1, locality D) silty, shaly dolomitic rocks above subsurface unit C have been logged as "Maquoketa." Merriam (1963) notes that this unit is widespread in the Kansas subsurface and reports it as far west as the southeastern part of the Southwest Kansas Basin. However, I have no conodonts from this unit and cannot comment further on its age. It is not recognized in any of the cores from southwestern Kansas studied here, in which rocks of subsurface unit C are unconformably overlain by Mississippian strata. Thus, largely for the sake of completeness, this uncontrolled unit is identified only as subsurface unit D and recognized only in the Davis borehole (Fig. 5).

CONCLUSIONS

Graphic correlation of subsurface sections at six localities in Kansas results in recognition of three distinct stratigraphic units, which may be overlain by a fourth at some localities in northeastern Kansas. The lower of the three units, subsurface unit A, is clearly equivalent to strata in the lower half of the McLish Formation of the Simpson Group of the Arbuckle Mountains in southern Oklahoma and of late Whiterockian (Chazyan) age. Subsurface unit A is overlain unconformably by subsurface unit B, which yields conodonts that indicate a correlation with the Harding Sandstone of Colorado, the Winnipeg Formation of the Dakotas, the Glenwood, Platteville, and lower Decorah Formations of southeastern Minnesota, and probably the Upper Tyner–Fite unit of Cherokee County, eastern Oklahoma. Subsurface unit C, here regarded as an unnamed member of the Viola Group, yields Ordovician conodonts characteristic of rocks of late Edenian and early Maysvillian age and widely distributed in North America west of the Transcontinental Arch (Sweet, 1979b; Mitchell and Sweet, 1989; Leatham, 1987; Nowlan and others, 1988). The McPherson core, from Stanton County in southwestern Kansas, provides an almost continuous record of subsurface unit C and may be regarded as a local reference section for this part of the Ordovician sequence in Kansas.

ACKNOWLEDGMENTS

Publication of data on Ordovician conodonts from the McPherson and Citizens State Bank core and the Ray Brian No. 1 core has been authorized by officials of the Amoco Production Co., to whom I express my thanks. Samples from Ordovician strata at localities A–L (Fig. 1), were collected and prepared by personnel of the State Geological Survey of Kansas, whose help and patience is gratefully acknowledged. Figures 1 and 4 were drafted by Karen Tyler, Geological Sciences draftsperson, The Ohio State University.

REFERENCES CITED

Amsden, T. W.; and Miller, A. K., 1942, Ordovician conodonts from the Bighorn Mountains of Wyoming: Journal of Paleontology, v. 16, p. 301–306.

Amsden, T. W.; and Sweet, W. C., 1983, Upper Bromide Formation and Viola Group (Middle and Upper Ordovician) in eastern Oklahoma: Oklahoma Geological Survey Bulletin 132, 76 p.

Bauer, J. A., 1987a, Conodonts and conodont biostratigraphy of the McLish and Tulip Creek Formations (Middle Ordovician) of south-central Oklahoma: Oklahoma Geological Survey Bulletin 141, 58 p.

______ 1987b, Conodont biostratigraphy, correlation, and depositional environments of Middle Ordovician rocks in Oklahoma: The Ohio State University unpublished Ph.D. dissertation, 346 p.

______ 1989, Conodont biostratigraphy and paleoecology of Middle Ordovician rocks in eastern Oklahoma: Journal of Paleontology, v. 63, p. 92–107.

Branson, E. B.; and Mehl, M. G., 1933, Conodont studies: University of Missouri Studies, v. 8, 349 p.

Carlson, C. C., 1960, Stratigraphy of the Winnipeg and Deadwood Formations in North Dakota: North Dakota Geological Survey Bulletin 35, 149 p.

Dresbach, R. I., 1983, Conodont biostratigraphy of the Middle and Upper Ordovician Viola Group of the south-central Oklahoma Arbuckle anticline: The Ohio State University unpublished M.S. thesis, 101 p.

Furnish, W. M.; Barragy, E. J.; and Miller, A. K., 1936, Ordovician fossils from the upper part of the type section of the Deadwood Formation, South Dakota: American Association of Petroleum Geologists Bulletin, v. 45, p. 1334–1363.

Leatham, W. B., 1987, Conodont-based chronostratigraphy and conodont distribution across the Upper Ordovician western North American carbonate platform in the eastern Great Basin and a model for Ordovician–Silurian genesis of the platform margin based on interpretation of the Silurian Diana Limestone, central Nevada: The Ohio State University unpublished Ph.D. dissertation, 258 p.

Merriam, D. F., 1963, The geologic history of Kansas: State Geological Survey of Kansas Bulletin 162, 317 p.

Mitchell, C. E.; and Sweet, W. C., 1989, Upper Ordovician conodonts, brachiopods, and chronostratigraphy of the Whittaker Formation, southwestern District of Mackenzie, N.W.T., Canada: Canadian Journal of Earth Sciences, v. 26, p. 74–87.

Nowlan, G. S.; McCracken, A. D.; and Chatterton, B. D. E., 1988, Conodonts from Ordovician–Silurian boundary strata, Whittaker Formation, Mackenzie Mountains, Northwest Territories: Geological Survey of Canada Bulletin 373, 99 p.

Oberg, R., 1966a, Winnipeg conodonts from Manitoba: Journal of Paleontology, v. 40, p. 130–137.

______ 1966b, The conodont fauna of the Viola Formation: University of Iowa unpublished Ph.D. dissertation, 186 p.

Schramm, M. W., Jr., 1964, Paleogeologic and quantitative lithofacies analysis, Simpson Group, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 48, p. 1164–1195.

Shaw, A. B., 1964, Time in stratigraphy: McGraw-Hill, New York, 365 p.

Stauffer, C. R., 1930, Conodonts from the Decorah Shale: Journal of Paleontology, v. 4, p. 121–128.

______1932, Decorah Shale conodonts from Kansas: Journal of Paleontology, v. 6, p. 257–264.

______1935a, Conodonts of the Glenwood beds: Geological Society of America Bulletin, v. 46, p. 125–168.

______1935b, The conodont fauna of the Decorah Shale (Ordovician): Journal of Paleontology, v. 9, p. 596–620.

Sweet, C., 1955, Conodonts from the Harding Formation (Middle Ordovician) of Colorado: Journal of Paleontology, v. 29, p. 226–262.

______1979a, Conodonts and conodont biostratigraphy of post-Tyrone Ordovician rocks of the Cincinnati Region: U.S. Geological Survey Professional Paper 1066-G, 26 p.

______1979b, Late Ordovician conodonts and biostratigraphy of the western Midcontinent Province: Brigham Young University Geology Studies, v. 26, p. 45–85.

______1982, Conodonts from the Winnipeg Formation (Middle Ordovician) of the northern Black Hills, South Dakota: Journal of Paleontology, v. 56, p. 1029–1049.

______1984, Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, U.S.A., *in* Bruton, D. L. (ed.), Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo 295, Universitetsforlaget, p. 23–35.

______1988, The Conodonta; morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum: Oxford University Press (Clarendon Press), 212 p.

Sweet, W. C.; Harper, Howard, Jr.; and Zlatkin, Dennis, 1974, The American Upper Ordovician Standard. 19.—A Middle and Upper Ordovician reference standard for the eastern Cincinnati Region: The Ohio Journal of Science, v. 74, p. 47–54.

Webers, G. F., 1966, The Middle and Upper Ordovician conodont faunas of Minnesota: Minnesota Geological Survey Special Publication 4, 123 p.

APPENDIX:

Register of Subsurface and Surface Localities

Letters preceding the following locality descriptions refer to sites identified in Figure 1. Boundaries of subsurface units A–D are included for cores in which they are recognized; boundaries are given in feet below well curb.

A — No. 1 Exchange Bank well, Sinclair–Prairie Oil Co., sec. 27, T. 33 S., R. 19 W., Comanche County, Kansas (41 samples studied; 3,347 conodont elements collected). Unit A, 6,391–6,428 ft; Unit B, 6,289–6,391 ft; Unit C, 6,102–6,289 ft.

B — No. 1 Alice Gentry well, Sinclair–Prairie Oil Co., sec. 1, T. 33 S., R. 15 W., Barber County, Kansas (29 samples studied; 1,358 conodont elements collected). Unit A, 5,297?–5,342 ft; Unit B, 5,236–5,297 ft; Unit C, 5,106–5,236 ft.

C — No. 11 Mary D. Watts well, Sinclair Oil and Gas Co., sec. 13, T. 26 S., R. 4 E., Butler County, Kansas (25 samples studied; 576 conodont elements collected). Unit A, 2,616–2,696 ft; Unit B, 2,580–2,616 ft; Unit C, 2,567–2,580 ft.

D — No. 2A Davis Ranch well, Carter Oil Co., sec. 33, T. 13 S., R. 10 E., Wabaunsee County, Kansas (84 samples studied; 3,180 conodont elements collected). Distribution of Viola Group conodonts in this well given in Sweet (1979b). Unit A, 3,330–3,390 ft; Unit B, 3298–3,330 ft; Unit C, 3,208–3,298 ft; Unit D, 3,127–3,208 ft.

E — No. 2 Goodland well, Phillips Petroleum Co., sec. 10, T. 10 S., R. 39 W., Sherman County, Kansas (93 samples studied; 1,196 conodont elements collected). All Ordovician samples from this well yield Lower Ordovician (Ibexian) conodonts, which await identification and description. Ibexian strata are overlain directly by Mississippian rocks.

F — No. 1 F. L. Smith well, Texas Co., sec. 30, T. 11 S., R. 36 W., Logan County, Kansas (7 samples studied; 60 Lower Ordovician conodont elements collected).

G — No. 1 Monument Prospect well, Phillips Petroleum Co., sec. 8, T. 12 S., R. 34 W., Logan County, Kansas (42 samples; 988 conodont elements collected). Strata between 5,318 and 5,342 ft are subsurface unit C of Viola Group; rocks above are Mississippian; rocks below are Arbuckle Group. Unit C strata too thin to be treated graphically.

H — No. 2 Gottschalk well, Mack Oil Co., sec. 4, T. 14 S., R. 20 W., Ellis County, Kansas (11 samples studied; 14 conodont elements collected). Conodonts are all Lower Ordovician (Ibexian) forms.

I — No. 1 Littler well, Rock Island Oil and Refining Co., sec. 31, T. 16 S., R. 19 W., Rush County, Kansas (16 samples studied; 211 conodont elements collected). Conodont elements all represent Lower Ordovician species.

J — No. 1 Wilhelm well, Sinclair–Prairie Oil Co., sec. 16, T. 19 S., R. 21 W., Ness County, Kansas (5 samples; 39 conodont elements collected). Conodonts, from rocks between 4,640 and 4,646 ft, are all Upper Ordovician forms and probably indicate presence of subsurface unit C.

K — No. 1 Brown "A" well, Western Petroleum Co., sec. 30, T. 24 S., R. 14 W., Stafford County, Kansas (10 samples studied; 84 conodont elements collected). Specimens from 4,132- to 4,161-ft interval represent long-ranging Middle and Upper Ordovician species.

L — No. 1 Cunningham Estate well, Mobil Oil Co., sec. 13, T. 34 S., R. 37 W., Stevens County, Kansas (24 samples studied; 2,730 conodont elements collected). Identity and distribution of Ordovician conodonts reported by Sweet (1979b). Samples between 7,838 and 7,859 ft yield representatives of the conodont fauna of Kansas subsurface unit C and of younger Devonian and Mississippian faunas. The latter may be indigenous or they may have leaked into Upper Ordovician rocks.

M — McPherson and Citizens State Bank No. 1 well, Amoco Petroleum Co., sec. 28, T. 29 S., R. 39 W., Stanton County, Kansas (26 samples studied for this report; 3,710 conodont elements collected from Viola Group strata). Unit C, 6,496–6,698 ft.

N — Ray Brian No. 1 well, Amoco Petroleum Co., sec. 7, T. 30 S., R. 33 W., Haskell County, Kansas (19 samples studied; 2,527 conodont elements collected). Unit C, 6,408–6,622 ft.

O — Hudson No. 1 well, Gypsy Oil Co., sec. 27, T. 24 S., R. 10 W., Reno County, Kansas. Stauffer (1932) studied, identified, and illustrated conodonts collected from an unreported number of shale samples taken between the 4,154- and 4,300-ft levels in this well. The whereabouts of Stauffer's collections, which include the types of 21 conodont species, are not known. A majority, possibly all, of Stauffer's specimens appear to represent the fauna of subsurface unit B.

P — Ohio State University surface localities 78SA, 78SB, 78SC, 78SE, 83JA, 83JB, 83JC, and 84JA, Cherokee County, Oklahoma. Conodont elements from samples taken at the first four localities are identified, tabulated, and illustrated in Amsden and Sweet (1983); those from the latter four sites are described and illustrated in Bauer (1989).

- 78SA — West bank Horseshoe Bend, NE¼ sec. 36, T. 16 N., R. 22 E.
- 78SB — Qualls area, NE¼SE¼ sec. 35, T. 15 N., R. 21 E.
- 78SC — Deep Hollow, NE¼ sec. 19, T. 16 N., R. 23 E.
- 78SE — East bank Horseshoe Bend, SE¼ sec. 31, T. 16 N., R. 23 E.
- 83JA — No Head Hollow, SE¼ sec. 12, T. 17 N., R. 22 E.
- 83JB — NE¼ sec. 35, T. 18 N., R. 22 E.
- 83JC — Eagles Bluff section, SW¼ sec. 13, T. 18 N., R. 22 E.
- 84JA — Combs Bridge section, SE¼ sec. 13, T. 18 N., R. 22 E.

Oklahoma Geological Survey Bulletin 145, 1992

Microfacies Correlation of the Early Permian Barneston Limestone, Conoco Test Facility to Vap's Pass, Kay County, Northern Oklahoma

Donald Francis Toomey
Conoco Inc. (retired)*
Ponca City, Oklahoma

ABSTRACT.—A petrographic study of stacked carbonates of the Early Permian Barneston Limestone, Kay County, northern Oklahoma, in core and outcrop, allows subdivision of this interval into seven microfacies. Those microfacies suggest relatively shallow-water paleodepositional settings for the entire interval. The coated-grain packstone to grainstone microfacies represents the shallowest paleodepositional setting. Biotic and petrologic parameters indicate an overall shifting of paleodepositional settings ranging from very shallow marine waters to somewhat deeper, less agitated waters. Depth ranges are interpreted to have been from 5 to 50 ft.

Fusulinids occur only sparingly, but one form, *Oketaella*, appears to be a reliable regional Early Permian (Wolfcampian) biostratigraphic marker.

Dissolution is the most apparent diagenetic feature and appears to be an ongoing event. Open-grain packing and sparse isopachous fringe cements on skeletal grains suggest early submarine cementation that has been modified by subsequent dissolution.

INTRODUCTION

In the early 1980s, Conoco's Exploration and Research management purchased a section of land in Kay County, Oklahoma, to be utilized as a permanent test facility (Text-fig. 1). Once preliminaries were completed, work commenced on drilling two deep boreholes and, most importantly, coring the entire interval. A primary purpose of the test facility was to have a site near Conoco's headquarters where a wide variety of geophysical and logging instruments could be tested, giving Conoco reliable test performance records that could be exploited for future research. Various studies could also be performed on the cores, including structural stress tests, petrography, and geochemical analyses of the rocks. In 1989, a study was initiated on fracturing within the Early Permian Barneston Limestone, and additional shallow cores were taken through this interval. It was decided that a nearby outcrop reference section in the Barneston Limestone was needed in order that reliable comparison could be made to the shallow cores taken at the test facility. A detailed petrographic and paleodepositional study of both the core and outcrop section are fully documented in this paper.

REGIONAL STRATIGRAPHY

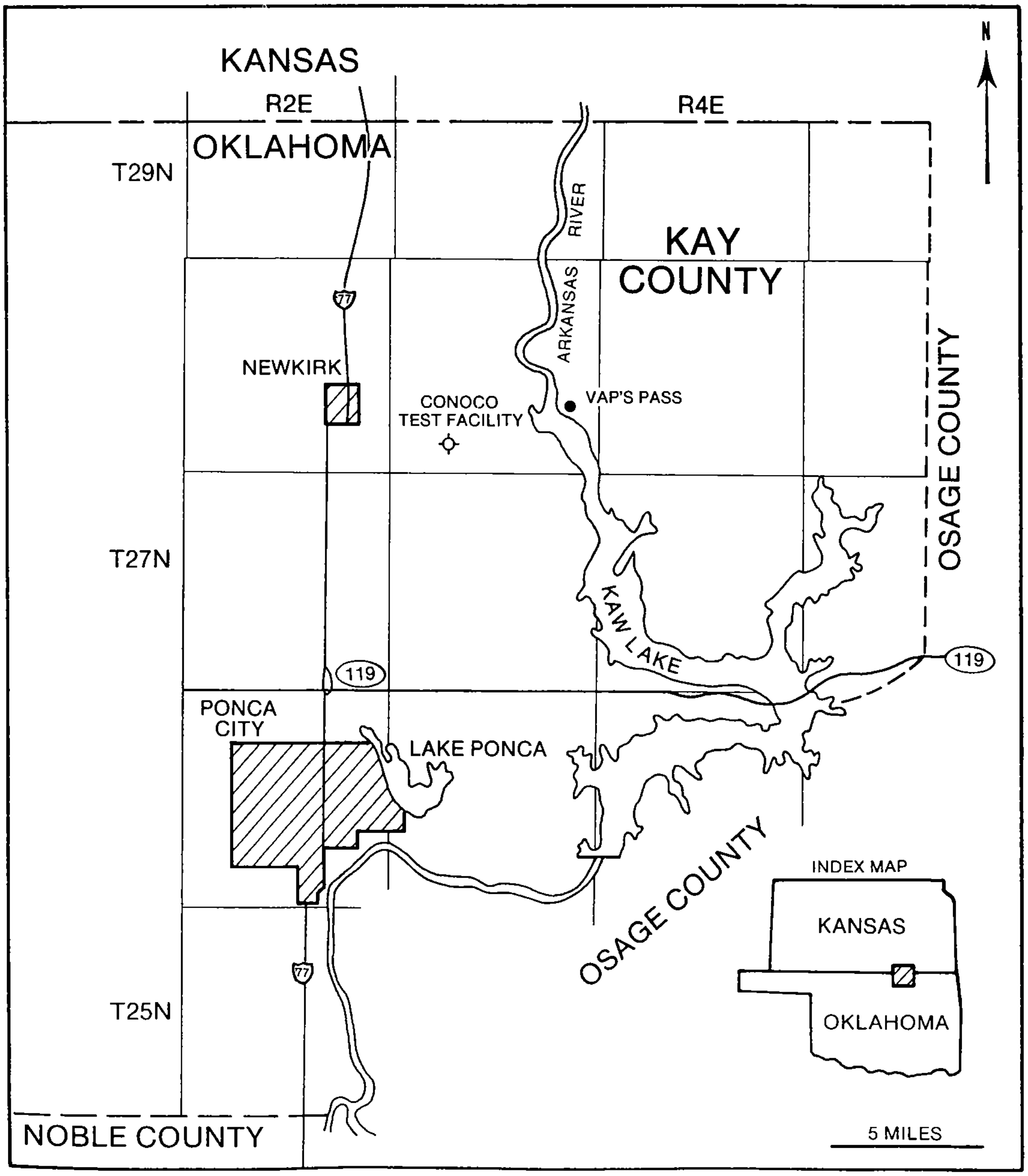
The rock units in this study are of Early Permian (Wolfcampian) age and comprise the Barneston Limestone, currently assigned to the middle Chase Group (Text-fig. 2). The Barneston Limestone consists of a lower member, termed the Florence Limestone, and an upper member, the Fort Riley Limestone (Text-fig. 2). The locations of the outcrop section at Vap's Pass and the GW-3 core at the Conoco test facility are shown in Text-figure 1, and descriptions are given in the Appendices.

Rocks of the Chase Group exposed in northeastern Kay County, northern Oklahoma, vary in thickness from 300 to 334 ft and include all the beds from the base of the Wreford Limestone to the top of the Nolans Limestone (Text-fig. 2). Those rocks are primarily repetitive sequences of limestones, shales, and sandstones. Limestones within the Chase Group average 25 ft thick, are generally fossiliferous, some can be cherty, and a few are partially dolomitized. Shales average 30–40 ft thick and are represented by marine and nonmarine types, some of which are quite fossiliferous. Sandstone units are highly variable in thickness, generally from 15 to 25 ft, with limited lateral extent; most sandstones are lenticular (Chaplin, 1988).

The Barneston Limestone was named by Condra and Upp (1931) for exposures in the bluffs west and southwest of the town of Barneston, Gage County, Nebraska. This lithic unit comprises two limestone members: (1) a lower Florence Limestone originally named by Prosser (1902) for exposures in quarries near Florence, Marion County, Kansas; and (2) the overlying Fort Riley Limestone, also named by Prosser (1902), for exposures near the town of Fort Riley, Geary County, Kansas. A thin shale member,

---

*Present address: 25 Tierra Madre Court, Placitas, New Mexico 87043.



Text-figure 1. Location of measured section at Vap's Pass and the GW-3 core at the Conoco test facility.

the Oketo Shale, separates the two limestones in northern Kansas, but is absent, or very poorly represented, farther south. The Barneston Limestone crops out in an almost continuous band from southeastern Nebraska, through central Kansas, and into north-central Oklahoma.

The two limestone members comprising this formation form bold east-facing cuestas. Generally, the lower Florence Limestone Member consists of a 10- to 20-ft-thick interval of thin- to medium-bedded micritic limestones, which sometimes carry relatively large, ellipsoidal chert nodules near the top of the unit. In the past, the top of the chert-bearing unit was regarded as the top of the Florence Limestone Member. However, since chert occurrence is not consistent over the outcrop belt, this criterion has not been followed in this study. Instead, the underlying Florence Limestone Member is delineated from the overlying Fort Riley Limestone Member on the basis of differences in carbonate sedimentology and microfacies sequence (discussed below). Conformably overlying the Florence

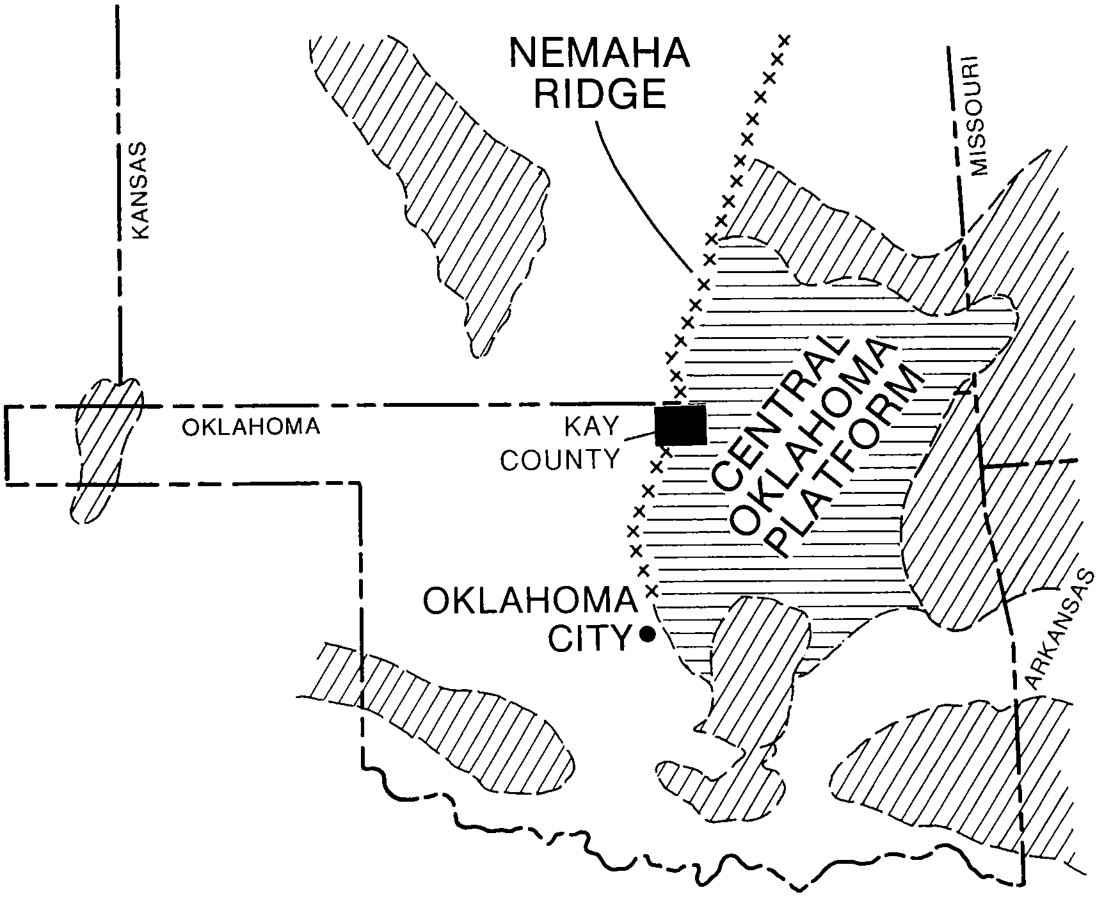
	MIDCONTINENT STRATIGRAPHIC NOMENCLATURE			OUTCROPPING LITHIC UNITS RECOGNIZED IN NORTHERN KAY COUNTY, OKLAHOMA	
AGE	GROUP	FORMATION	MEMBER		
EARLY PERMIAN (WOLFCAMPIAN)	CHASE	NOLANS LIMESTONE	HERINGTON LS.	?	
			PADDOCK SH.	?	
			KRIDER LS. =’s	HERINGTON LS.	
		ODELL SHALE		ODELL/ENTERPRISE/LUTA	
		WINFIELD LIMESTONE	CRESSWELL LS.	CRESSWELL LS.	
			GRANT SH.	▨	
			STOVALL LS.	▨	
		DOYLE SHALE	GAGE SH.	GAGE SH.	
			TOWANDA LS.	TOWANDA LS.	
			HOLMESVILLE SH.	HOLMESVILLE SH.	
		BARNESTON LIMESTONE	FT. RILEY LS.	FT. RILEY LS.	STUDIED INTERVAL
			OKETO SH.	▨	
			FLORENCE LS.	FLORENCE LS.	
		MATFIELD SHALE	BLUE SPRINGS SH.	BLUE SPRINGS SH.	
			KINNEY LS.	KINNEY LS.	
			WYMORE SH.	WYMORE SH.	
		WREFORD LIMESTONE	SCHROYER LS.	SCHROYER LS.	
			HAVENSVILLE SH.	HAVENSVILLE SH.	
			THREEMILE LS.	THREEMILE LS.	

Text-figure 2. Comparison of Midcontinent stratigraphic nomenclature to outcropping Early Permian units in northern Kay County, northern Oklahoma. Diagonal-line pattern indicates units are absent. Modified from Chaplin (1988).

Limestone Member is as much as 45 ft of the Fort Riley Limestone. This member is characterized by a lower sequence of thick- to massive-bedded "algal" limestones and an upper sequence of interbedded molluscan-rich, micritic limestones and marine shales. The measured section of the Barneston Limestone at Vap's Pass consists of 17.1 ft of Florence Limestone and 24 ft of Fort Riley Limestone, for a total of 41.1 ft. The GW-3 core, taken at the Conoco test facility 3.2 mi east of Vap's Pass, retrieved 57.9 ft of the Barneston Limestone, comprising 16 ft of the Florence Limestone and 41.9 ft of the Fort Riley Limestone (see Appendices for detailed descriptions).

PALEOTECTONIC SETTING

Text-figure 3 presents a generalized Late Paleozoic tectonic map of Oklahoma and portions of adjoining states. Regionally, most of Kay County is situated on the western margin of the Central Oklahoma Platform. The major structural elements in north-central Oklahoma are the Nemaha Ridge and associated anticlines (e.g., Blackwell, Ponca City,



Text-figure 3. Generalized Late Paleozoic paleotectonic map of Oklahoma and portions of adjacent states. This map shows the location of Kay County, north-central Oklahoma (black square), extent of the Central Oklahoma Platform (horizontal lines), trace of the Nemaha Ridge (X's), positive structural elements (slanted lines), and negative (embayments and basins) structures (light areas).

Mervine, and Dexter), which trend to the northeast across the western one-third of Kay County. The Nemaha Ridge extends nearly 900 mi northward from central Oklahoma, into eastern Kansas, southeastern Nebraska, and continues into Iowa, Wisconsin, and Minnesota. In northern Kay County, this structural zone (Nemaha Ridge and associated anticlines) is as much as 30 mi wide, but it narrows southwestward to 6 mi wide in central Oklahoma (Chaplin, 1988). According to Luza and Lawson (1981), the Nemaha Ridge also comprises a number of relatively small fault blocks that were uplifted and eroded during Late Missississian–Early Pennsylvanian time.

The Central Oklahoma Platform extends northward into south-central Kansas and abuts the Bourbon Arch. The eastern boundary is the Ozark Uplift. The Central Oklahoma Platform is blanketed with thin, repetitive, shallow-water carbonates and clastics of Pennsylvanian and Permian age. West of the platform basinal sediments predominate.

VAP'S PASS OUTCROP SECTION

The Barneston Limestone exposed at Vap's Pass in northeastern Kay County was measured, described, and sampled in August 1988 (see Appendix 1). A total of 60 large (2- × 3-in.) thin sections were prepared from this outcrop exposure and form the basis for the petrology/microfacies study of this measured section. Data from 27 of the total 60 prepared thin sections are documented on a summary sheet (Text-fig. 4).

A total of 41.1 ft of the Barneston Limestone is present at this location. The lower member of this formation, the Florence Limestone, is 17.1 ft thick and consists of thin- to medium-bedded skeletal wackestones. The Florence is conformably overlain by the younger Fort Riley Limestone Member comprising 24 ft of varied limestones and shales. The lower portion of the Fort Riley consists of massive, thick-bedded, coated-grain packstones to grainstones, followed by medium- to massive-bedded skeletal wackestones, capped by a thin bed of marine shale, and overlain by a thin, wavy-bedded molluscan wackestone. The top of the Barneston Limestone is eroded.

Microfacies Subdivision

This outcrop section was vertically subdivided into carbonate microfacies that reflect both biological and physical parameters associated with changing paleodepositional settings. The data are documented on the summary sheet (Text-fig. 4), which, in addition, contains a relative-depth curve that attempts to show shallowing and deepening of the paleoenvironmental sequence.

The Florence Limestone Member is subdivided into three microfacies (from bottom to top):

SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES is 1.3 ft thick; a typical example is shown in Plate 1, Figure 1. This microfacies is represented by rock unit 1. The coated grains are of irregular shape, comprising various molluscans and fenestrate bryozoan skeletal fragments circumscribed by algal/foraminiferal coatings. Other noteworthy skeletal grains consist of the smaller foraminifers *Globivalvulina* and *Tetrataxis* in association with the diagnostic fusulinid foraminifer *Oketaella*. Of interest is the occurrence throughout this unit of reworked mud clasts. The clasts are relatively well rounded and have distinctive corrosion rims. The lithology and microfauna suggest that this unit was deposited in slightly agitated, moderately shallow water.

DOLOMITIZED BRYOZAN/SKELETAL WACKESTONE WITH INTERBEDDED SHALE MICROFACIES is represented by rock unit 2 and consists of 3.8 ft of interbedded skeletal wackestone and gray marine shale. The microfauna is dominated by unbroken fronds of fenestrate bryozoans along with scattered crinoidal debris, within a finely dolomitized matrix. Some crinoid columnals have syntaxial calcite overgrowths and appear to be partially leached. Megafossils identified on outcrop are the clam *Myalina* and the brachiopod *Derbyia*. The lithology and biota indicate that this unit was deposited in quiet, somewhat deeper water than the underlying microfacies.

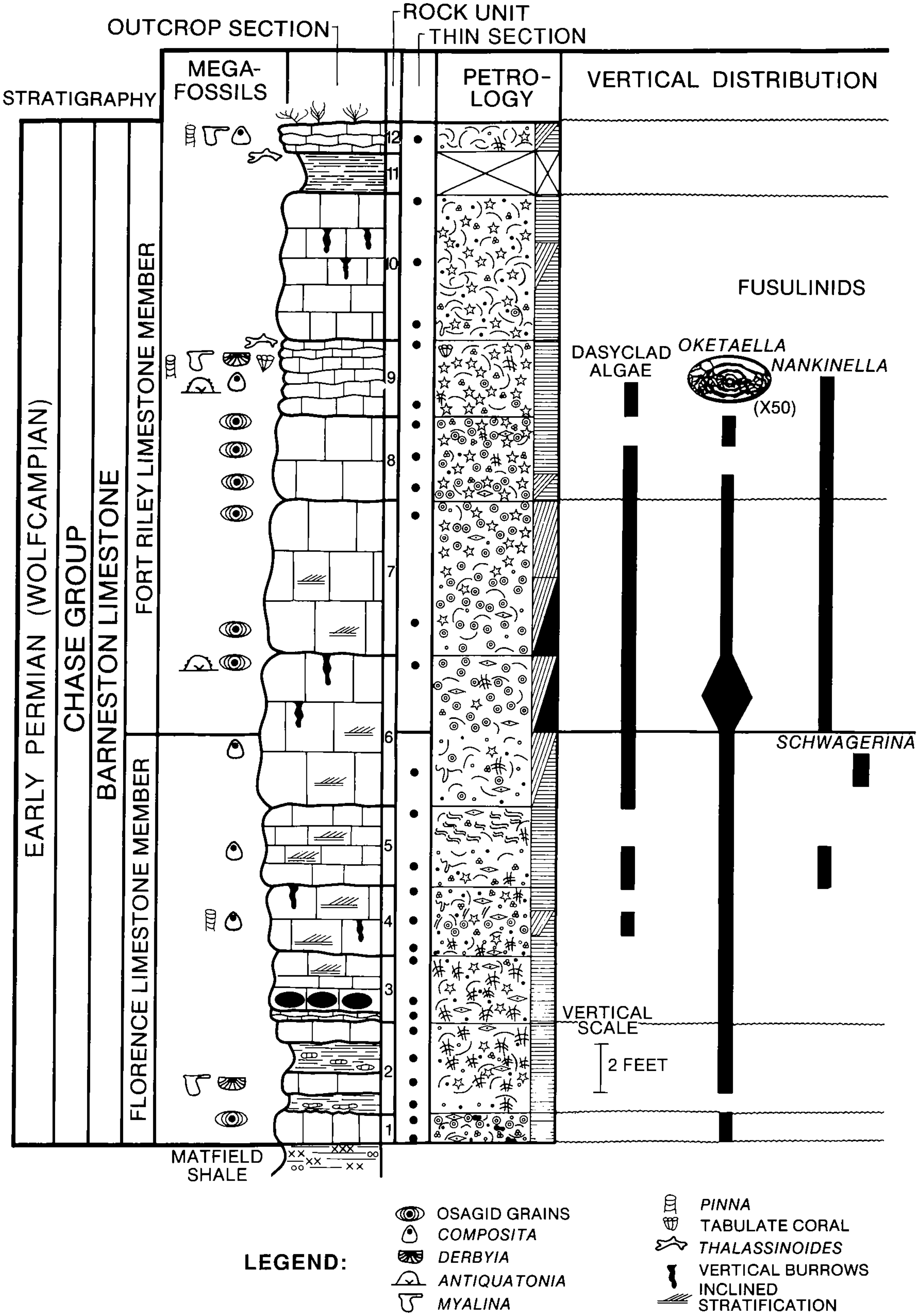
LEACHED FORAM WACKESTONE MICROFACIES is 12 ft thick and comprises rock units 3, 4, 5, and the lower portion of 6. These units are skeletal wackestones to packstones. The microfauna is characterized by a diverse assemblage of leached foraminifers. Those include *Globivalvulina, Endothyra, Tetrataxis*, palaeotextularids, and the nodosarids *Nodosinella* and *Geinitzina*, all associated with the fusulinids *Oketaella, Nankinella*, and *Schwagerina*. Rare occurrences of the dasyclad alga *Epimastopora* have also been observed. On outcrop, some horizons contain the brachiopod *Composita* and the burrowing clam *Pinna*. A few bedding-plane surfaces contain mud-filled borings, and a few horizons display low-angle cross-stratification. Some brachiopod fragments are partially silicified. The lithology and microfauna of this microfacies suggest an overall shallowing-upward sequence.

The overlying Fort Riley Limestone Member can be subdivided into three microfacies (from bottom to top):

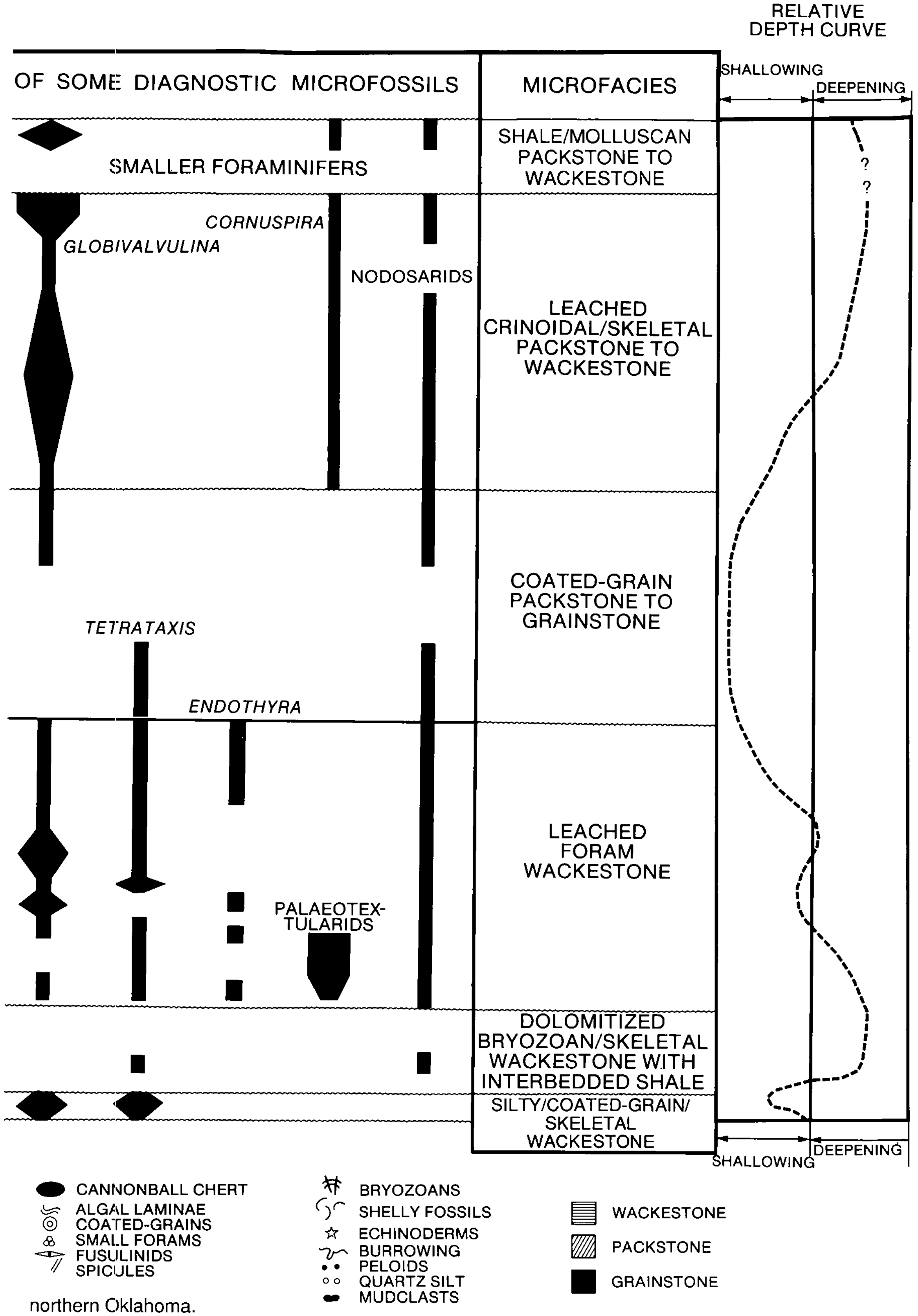
COATED-GRAIN PACKSTONE TO GRAINSTONE MICROFACIES comprises the upper portion of rock unit 6 and all of rock unit 7; it is 9.3 ft thick. The rocks are massive packstones to grainstones composed principally of well-sorted coated grains (Pl. 1, Fig. 2). These grains are what Toomey and others (1988) described as "osagid grains." Fusulinids are relatively common in this microfacies with *Oketaella* occurring as loose, uncoated skeletal grains, whereas *Nankinella* consistently serves as coated-grain nuclei. Fenestrate bryozoan fragments and echinoid spines also serve as coated-grain nuclei. Fragments of the dasyclad alga *Epimastopora* occur, along with a rather patchy distribution of smaller foraminifers (*Globivalvulina, Tetrataxis*, and nodosarids). A few relatively large productid brachiopods (*Antiquatonia*) have been noted on bedding plane surfaces, in addition to mud-filled borings and low-angle cross-stratification. The lithology and microfauna of this microfacies suggest deposition in well-agitated, very shallow water.

LEACHED CRINOIDAL/SKELETAL PACKSTONE TO WACKESTONE MICROFACIES is 11.9 ft thick and comprises rock units 8, 9, and 10. These units are medium-bedded skeletal wackestones to packstones with crinoidal debris as the dominant biotic component. The dasyclad alga *Epimastopora* disappears within unit 8, and the fusulinid *Oketaella* disappears in unit 9. The fusulinid *Nankinella* continues to serve as a coated-grain nucleus, but disappears in the middle of unit 9. Smaller foraminifers, especially *Globivalvulina*, along with *Cornuspira* and nodosarids characterize this microfacies. On outcrop, unit 9 contains a variety of megafossils including an unidentified tabulate coral, the brachiopods *Composita, Derbyia*, and *Antiquatonia*, and the clams *Pinna* and *Myalina*. Brachiopod shell fragments can sometimes serve as coated-grain nuclei. Some bedding-plane surfaces display the trace fossil *Thalassinoides*. Unit 10 contains abundant molluscan (mainly clams) skeletal debris, some of which are whole (articulated) and mud-filled. The lithology and microfauna of this microfacies suggest paleodeposition in relatively quiet, gradually deepening water.

SHALE/MOLLUSCAN PACKSTONE TO WACKESTONE MICROFACIES caps the Vap's Pass measured section, and the top is marked by an erosional surface. This microfacies is 2.8 ft thick and consists of rock units 11 and 12. Unit 11 consists of 1.8 ft of gray-green shale. No fossils were retrieved from this unit. Unit 12, the youngest bed in the section, is a 1-ft-thick unit of wavy-bedded molluscan wackestone to packstone. This bed contains abundant molluscan



Text-figure 4. Summary diagram of the measured section at Vap's Pass, northeastern Kay County,



northern Oklahoma.

shell debris made up of the clams *Myalina* and *Pinna*, in addition to rare brachiopods (*Composita*). The base of unit 12 is covered with *Thalassinoides* burrows. The lithology and microfauna of this interval suggest deposition beginning in relatively deep, quiet water and ending in a swing toward overall shallowing.

Paleodepositional Summary

Examination of the summary sheet (Text-fig. 4) for the outcrop section of the Barneston Limestone at Vap's Pass shows the section to be a series of stacked carbonates, with only minor shale intervals at two units. The units are repetitive, and the overall lithologic sequence and biota reflect a continual shifting of paleodepositional settings ranging from very shallow waters to relatively deeper waters. Depth ranges were probably from 5 to 50 ft. The shallowest units consist of coated-grain grainstone/packstone microfacies. There is no evidence of subaerial exposure surfaces within this interval.

CONOCO GW-3 CORE SECTION

The Barneston Limestone cored at Conoco's test facility site (GW-3 core) consists of 57.9 ft of stacked limestones with some interbedded shales. A total of 54 large (2- × 3-in.) thin sections were prepared, and these form the data base for the petrology/microfacies study of the core. All pertinent data are documented on a summary sheet (Text-fig. 5), which also includes a relative depth curve.

The Florence Limestone Member is 16 ft thick (95.3–79.3 ft) and consists principally of skeletal packstones to wackestones. Chert nodules are present at 89.1 ft. The Florence Member is conformably overlain by 41.9 ft (79.3–37.4 ft) of the Fort Riley Limestone Member. That interval comprises a series of coated-grain wackestones to grainstones, overlain by skeletal wackestones to packstones, followed by interbedded shales and molluscan wackestone to packstones. It is capped by a thin interval of silty/coated-grain/skeletal wackestone to grainstone, not present in the Vap's Pass outcrop section. The top of the Barneston Limestone is conformably overlain by the Doyle Shale, and the base of the formation is conformably underlain by the Matfield Shale (see Text-fig. 2).

Microfacies Subdivision

The Barneston Limestone of the GW-3 core has been vertically subdivided into seven distinctive carbonate microfacies. These microfacies reflect changing paleodepositional settings. The data are documented on the summary sheet (Text-fig. 5).

The lower Florence Limestone Member is subdivided (from bottom to top) into three microfacies:

SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES (base) is 1.2 ft thick and consists primarily of irregular-shaped coated grains and skeletal debris in a silty micritic matrix. The coated grains generally have skeletal nuclei consisting of mud-filled snails (Pl. 2, Fig. 9) or fragments of fenestrate bryozoans. Some coated-grain laminae contain encrusting foraminifers and tubules of the blue-green alga *Girvanella*. The fusulinid *Oketaella* and various smaller foraminifers are rare components. The lithology and microfauna of this microfacies suggest deposition in moderately agitated, shallow water.

DOLOMITIZED BRYOZOAN/SKELETAL WACKESTONE TO PACKSTONE MICROFACIES is 2.7 ft thick (93.3–90.6 ft) and consists of finely dolomitized skeletal rock with common, generally unbroken, fenestrate and ramose bryozoan fronds and crinoid columnals (Pl. 2, Figs. 7,8). Some crinoidal columnals are partially silicified and have syntaxial calcite overgrowths. The upper portion of this microfacies is slightly shaly. The lithology and microfauna suggest deposition of this microfacies in somewhat deeper, quiet water.

LEACHED FORAM WACKESTONE MICROFACIES is 10.1 ft thick (89.4–79.3 ft) and consists dominantly of porous (leached), recrystallized, foraminiferal wackestone to packstone. The microfauna is characterized by a relatively abundant and diverse foraminiferal assemblage comprising the diagnostic fusulinid *Oketaella* (Pl. 2, Fig. 4), rare occurrence of the fusulinid *Schwagerina*, whose chambers can be plugged with baroque dolomite (Pl. 2, Fig. 3), *Endothyra*, *Globivalvulina*, *Tetrataxis*, palaeotextularids (Pl. 2, Fig. 5), and the nodosarids *Geinitzina* and *Nodosinella*. Chert nodules occur at 89.1 ft and contain common monaxon sponge spicules (Pl. 2, Fig. 6). The blue-green alga *Girvanella* occurs only rarely as coatings on skeletal fragments. Some skeletal grains are partially silicified, and some crinoid columnals have syntaxial calcite overgrowths. A few horizons in the core appear to be burrowed, and microstylolites are relatively common within this interval. The lithology and microfauna suggest that this interval was deposited during a phase of overall upward shoaling.

The overlying Fort Riley Limestone Member can be subdivided (from bottom to top) into the following four microfacies:

COATED-GRAIN PACKSTONE/WACKESTONE/GRAINSTONE MICROFACIES is 12.9 ft thick (78.4–65.5 ft) and consists of relatively well-sorted coated grains (Pl. 2, Fig. 1). Many of these coated grains have the fusulinid *Nankinella* and fenestrate bryozoan fragments as nuclei. Uncoated *Oketaella* reach their greatest abundance within this microfacies. Smaller foraminifers such as *Globivalvulina* and the nodosarids occur in most intervals, and there are sporadic occurrences of fragments of the dasyclad alga *Epimastopora*. In addition, some well-developed microstylolites (Pl. 2, Fig. 2), along with partially silicified skeletal grains and scattered patches of dolomite rhombs, occur within this microfacies.

The lithology and microfauna indicate that this microfacies was deposited in very shallow, generally well-agitated waters. This microfacies represents the shallowest paleodepositional phase within the Barneston Limestone.

LEACHED CRINOIDAL/SKELETAL PACKSTONE TO WACKESTONE MICROFACIES is 14.4 ft thick (64.6–50.2 ft) and consists of leached skeletal wackestones to packstones containing much crinoidal debris. This microfacies contains two thin shale intervals. Scattered patches of micritic rock with floating dolomite rhombs occur within a few horizons, as do well-sorted coated grains. The lower two-thirds of this microfacies interval carries a representative microfauna consisting of fragments of the dasyclad alga *Epimastopora*, the fusulinids *Oketaella* and *Nankinella*, and the smaller foraminifers *Tetrataxis*, *Nodosinella*, and *Geinitzina*. Interestingly, *Oketaella*, *Nankinella*, and *Tetrataxis* do not occur above the 55-ft interval. This abrupt cutoff point was also observed in the Vap's Pass outcrop section (see Text-fig. 4). From 60.5 ft down to the base of this microfacies, abundant, very small, planispirally coiled foraminifers (*Cornuspira*) make their appearance, whereas *Globivalvulina* consistently occurs throughout this microfacies. Some intervals within this microfacies contain silty crinoidal wackestones. Microstylolites are also common within this microfacies, and some crinoid columnals have syntaxial calcite overgrowths. Close to the top of this microfacies there are a few horizons that contain small voids plugged with baroque dolomite. The lithology and microfauna suggest deposition of this microfacies in relatively shallow, moderately agitated waters that appear to have deepened near the top of this unit when an influx of bryozoans entered the biota.

INTERBEDDED SILTY SHALE AND MOLLUSCAN PACKSTONE TO WACKESTONE MICROFACIES is 7.4 ft thick (48.1–40.7 ft) and consists of thin-bedded skeletal (dominantly molluscan) packstones to wackestones, separated by gray-green shales. Some horizons carry bored molluscan shells serving as nuclei of coated grains. Some borings are distinctive and are attributed to barnacles (Toomey and others, 1988). Commonly, whole specimens of small claims and snails are either mud-filled or filled with peloids. No skeletal algae or fusulinid foraminifers were identified from this microfacies, but smaller foraminifers are represented by patchy occurrences of common to abundant *Globivalvulina*, *Cornuspira*, and nodosarids. The lithology and microfauna of this microfacies suggest deposition in relatively deeper, less agitated water. Common coated grains toward the top of the interval suggest a shift to deposition in shallower, more agitated water.

SILTY/COATED-GRAIN/SKELETAL WACKESTONE TO GRAINSTONE MICROFACIES, at the top of the Barneston Limestone Formation, is 2.2 ft thick (39.6–37.4 ft). This unit consists of silty/coated-grain/skeletal wackestones to grainstones. A single coated-grain horizon (37.8 ft) contains skeletal grains with poorly developed fringes of isopachous early submarine cements. Mud clasts occur in a few horizons; at 39.6 ft they contain distinctive mud-filled barnacle borings. At one interval (38.8 ft), the micritic matrix contains small voids plugged, in part, with baroque dolomite. Smaller foraminifers are represented by rare to abundant occurrences of *Globivalvulina* and *Nodosinella*. A few dasyclad algal (*Epimastopora*) fragments occur at 38.3 ft. Lithology and microfauna indicate that this microfacies represents the culmination of the overall upward shoaling of the Barneston Limestone. This microfacies is conformably overlain by gray-green shale of the younger Doyle Shale.

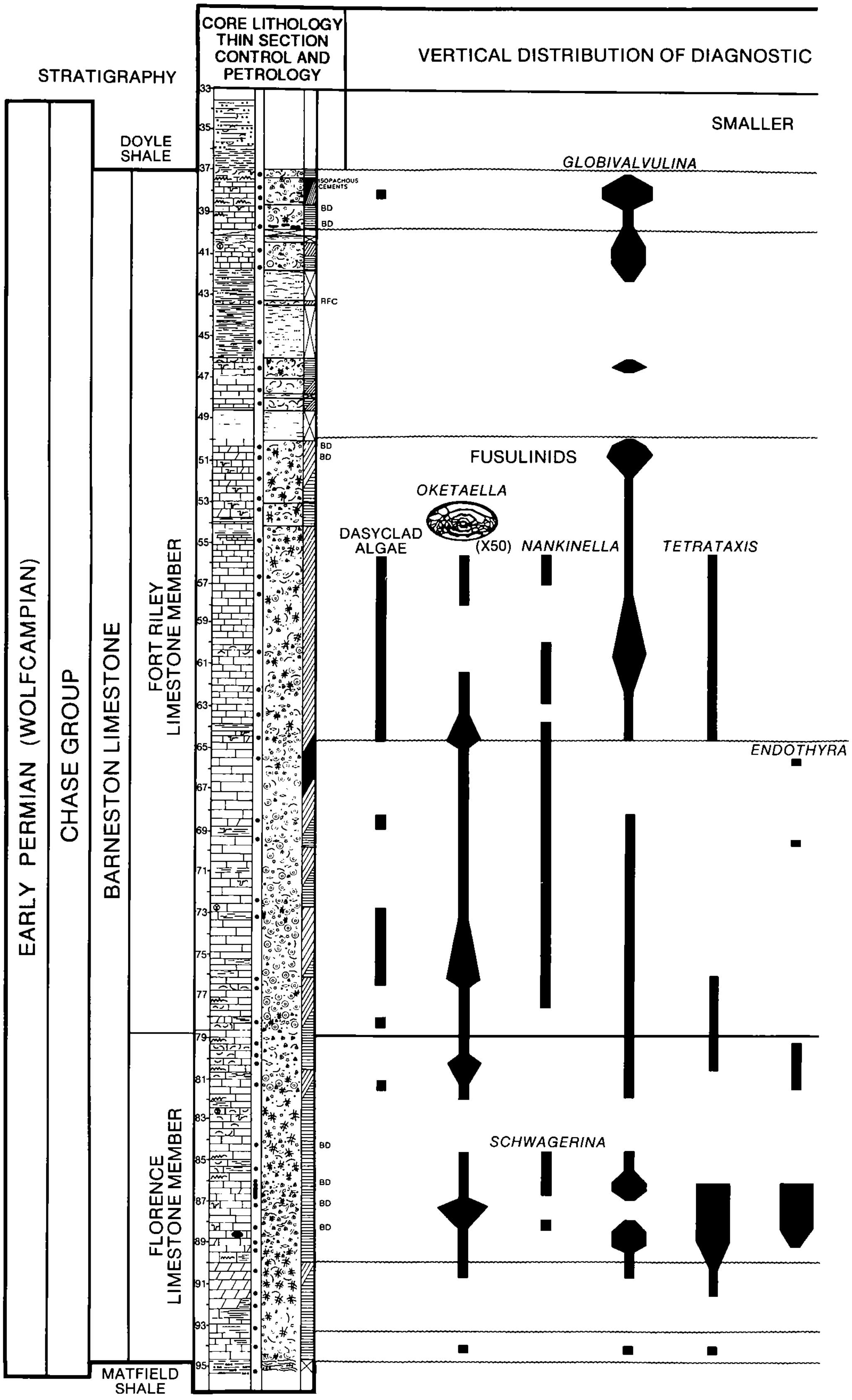
Paleodepositional Summary

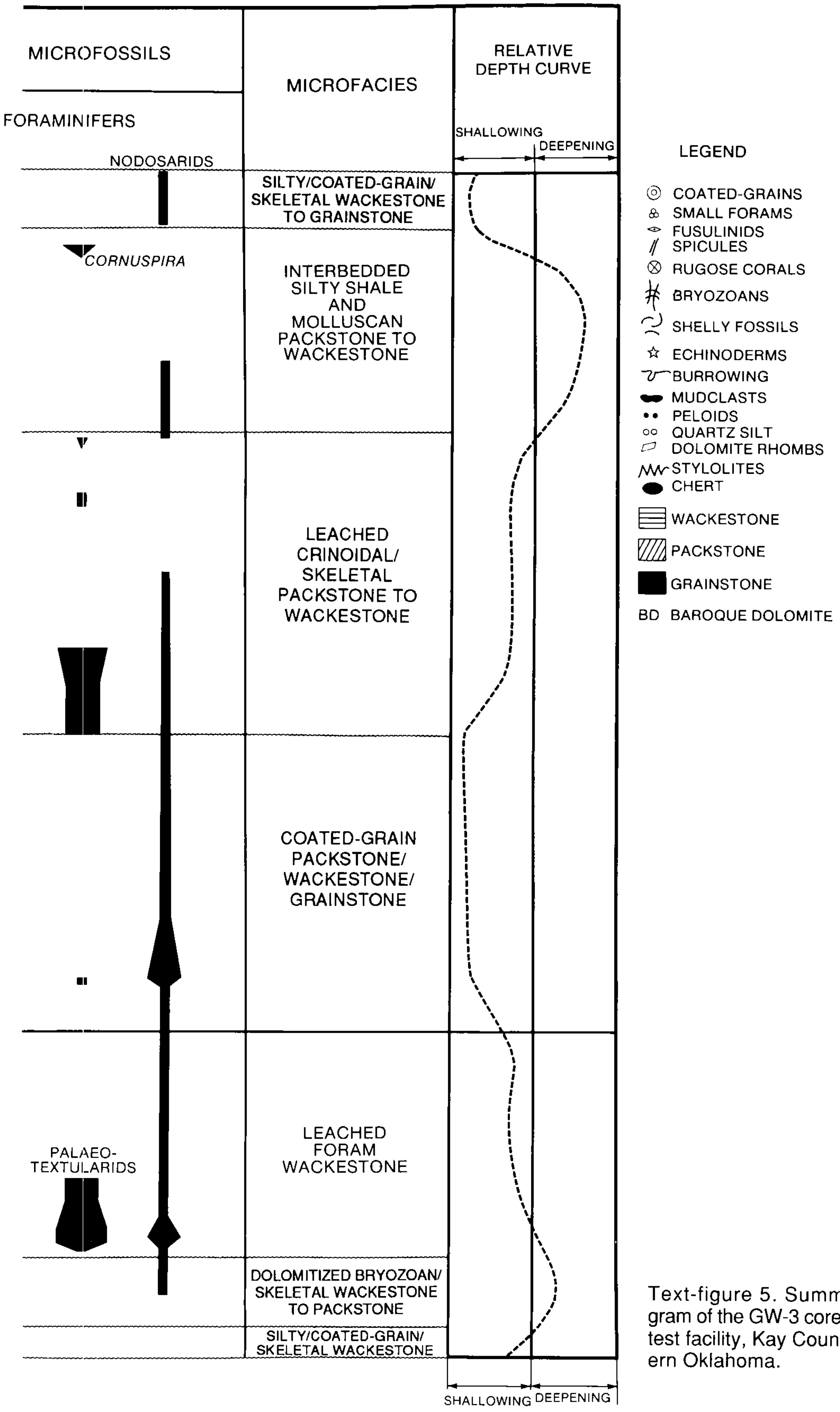
Examination of the summary sheet (Text-fig. 5) for the GW-3 core of the Barneston Limestone, taken at the Conoco test facility, shows the limestone to be composed principally of stacked carbonates, with the exception of the uppermost 13 ft. That interval is characterized by thin limestones with interbedded shales. When the GW-3 core is compared to the Vap's Pass outcrop section (Text-fig. 6), nearly identical microfacies can be seen in both intervals. The cored section is slightly thicker and appears not to have suffered the erosion seen in the outcrop measured section. Accordingly, the interbedded silty shale/molluscan wackestone to packstone microfacies is more fully developed in the core, and it is capped with the silty/coated-grain/skeletal wackestone to grainstone microfacies, a microfacies seen at the base of the formation. The sedimentary units are repetitive and indicate a continual shifting of paleodepositional settings ranging from very shallow-marine waters to somewhat deeper, less agitated waters. Depth ranges appear to have been from 5 to 50 ft. The shallowest intervals are represented by the coated-grain wackestone to grainstone microfacies. There is no evidence that the Barneston Limestone interval ever experienced subaerial exposure during overall deposition.

OCCURRENCE AND SIGNIFICANCE OF FUSULINIDS IN THE BARNESTON LIMESTONE

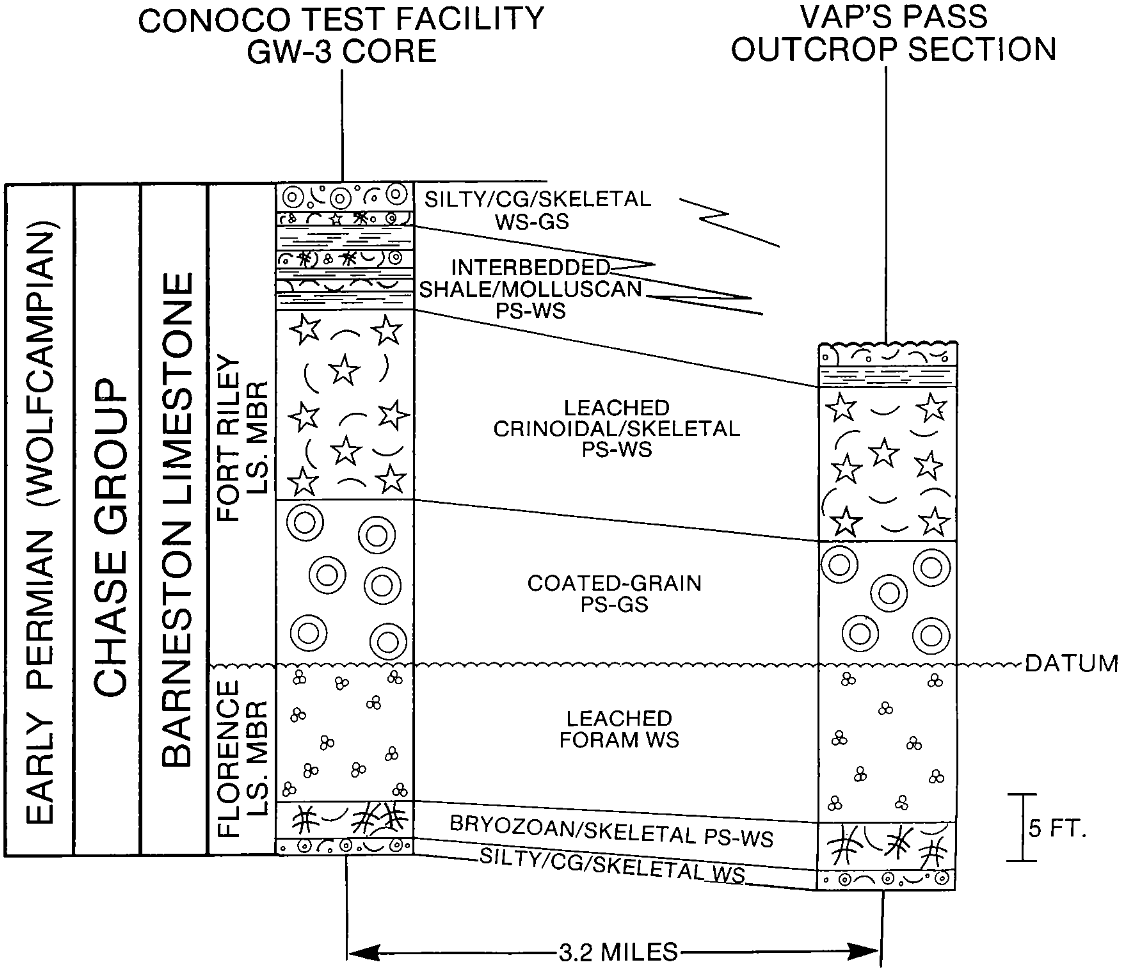
Fusulinid foraminifers occur in the Barneston Limestone, and their occurrence does offer some insight regarding time-stratigraphic relationships and paleoecologic observations.

The relatively small fusulinid *Oketaella* has both a restricted vertical time-stratigraphic range and a rather limited geographic range, as it has been reported previously only from rocks of Early Permian age in Kansas and north-central Texas. In Kansas, this form is common in the Oketo Shale (Thompson, 1954, p. 35), a thin shale that generally separates the Fort Riley Limestone Member from the


STRATIGRAPHY
CORE LITHOLOGY THIN SECTION CONTROL AND PETROLOGY
VERTICAL DISTRIBUTION OF DIAGNOSTIC
SMALLER
EARLY PERMIAN (WOLFCAMPIAN)
CHASE GROUP
BARNESTON LIMESTONE
FORT RILEY LIMESTONE MEMBER
FLORENCE LIMESTONE MEMBER
DOYLE SHALE
MATFIELD SHALE
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
ISOPACHOUS CEMENTS
BD
BD
RFC
BD
BD
BD
BD
BD
BD
GLOBIVALVULINA
FUSULINIDS
OKETAELLA
DASYCLAD ALGAE
(X50)
NANKINELLA
TETRATAXIS
ENDOTHYRA
SCHWAGERINA



Text-figure 5. Summary diagram of the GW-3 core, Conoco test facility, Kay County, northern Oklahoma.



Text-figure 6. Microfacies correlation of the Barneston Limestone from the core taken at the Conoco test facility with the outcrop section at Vap's Pass.

underlying Florence Limestone Member. Southward, into northern Oklahoma, the Oketo Shale is either very thin or absent. Hence, in this region the two limestones lie in conformable contact. Although there has obviously been a lateral facies change into northern Oklahoma, the fusulinid biofacies remains constant. In vertical sequence, *Oketaella* does not range above or below the Barneston Limestone. In fact, as we have seen, there is a distinct cutoff point for *Oketaella* that occurs two-thirds of the way up into the Fort Riley Limestone Member. Accordingly, *Oketaella* can be regarded as a good regional biostratigraphic marker.

The uniquely shaped, planispirally coiled fusulinid *Nankinella* is not a restricted biostratigraphic marker. Its vertical stratigraphic range is from low in the Pennsylvanian to near the close of Permian time, and its geographic distribution is cosmopolitan. However this form does have unique morphological attributes that have paleoecological importance. Being planispirally coiled, it has a shell (test) architecture similar to coiled nautiloid cephalopods, and it possesses a relatively thick, heavy test, not a streamlined fusiform test that is common to most fusulinids. Accordingly, *Nankinella* was probably a restricted benthic form, active on, or close to, the substrate in a position most susceptible to algal/foraminiferal coatings. Indeed, most occurrences of *Nankinella* are as skeletal-grain nuclei for osagid (algal/foraminiferal) coated grains. Generally, *Nankinella* only occurs in microfacies in which coated grains are common.

Only a few uncoated fragments of the relatively large fusiform fusulinid *Schwagerina* were observed. *Schwagerina* ranges from latest Pennsylvanian time through the Early Permian and has a cosmopolitan geographic distribution. Within the Barneston Limestone, *Schwagerina* only occurs in the leached foram microfacies of the Florence Limestone Member.

DIAGENESIS

As is usual in carbonates, diagenesis appears to be a rather complicated ongoing process. Unequivocal petrographic evidence for early submarine cementation, manifesting itself in the form of marine isopachous cements on skeletal grains, is only apparent in the uppermost microfacies (silty/coated-grain/skeletal wackestone to grainstone) present in the GW-3 core. However, grain packing and overall grain morphology of the coated-grain wackestone to grainstone microfacies suggests early cementation for this microfacies. Probably, original isopachous cements were removed during later dissolution and replaced with epigenetic spar calcite cements. Random partial skeletal-grain silicification, syntaxial calcite overgrowths, and the presence of scattered dolomite rhombs in patches of micrite were also relatively early diagenetic phenomena. Dissolution is the most obvious and perhaps the most consistent diagenetic process to affect the Barneston Limestone. This is especially apparent in the leached foram wackestone and leached crinoidal/skeletal packstone to wackestone microfacies, and probably was initiated late in the paragenetic sequence. The occurrence of microstylolites, resultant compaction, and the plugging of matrix and skeletal voids with baroque dolomite appears to be a very late diagenetic event. The occurrence of minor baroque dolomite would suggest the presence of open pathways that carried hydrothermal solutions, perhaps in a deeper burial environment.

CONCLUSIONS

Microfacies correlation of units of the Early Permian Barneston Limestone, present in outcrop and core over a distance of 3.2 mi, show the interval to comprise seven microfacies. Microfacies, from bottom to top, include: (1) silty/coated-grain/skeletal wackestone, (2) bryozoan/skeletal packstone to wackestone, (3) leached foram wackestone, (4) coated-grain packstone to grainstone, (5) leached crinoidal/skeletal packstone to wackestone, (6) interbedded shale/molluscan packstone to wackestone, and (7) silty/coated-grain/skeletal wackestone to grainstone. The microfacies reflect various biological and physical parameters associated with changing paleodepositional settings on the Central Oklahoma Platform. Shifting paleodepositional settings range from very shallow marine waters to somewhat deeper, less agitated waters. Depth ranges are interpreted to have been from 5 to 50 ft. The microfacies deposited within the shallowest paleodepositional setting is the coated-grain packstone to grainstone microfacies. The top of the Vap's Pass outcrop section has been eroded, hence two microfacies present in the GW-3 core (interbedded shale/molluscan packstone to wackestone and silty/coated-grain/skeletal wackestone to grainstone) are not present on outcrop.

Fusulinids are relatively rare biotic components within the Barneston Limestone, but *Oketaella* has a limited geographic distribution and restricted vertical time-stratigraphic range and may be regarded as a good regional biostratigraphic marker.

Diagenesis has altered this rock sequence, but petrographic evidence suggests rather early submarine cementation for some microfacies. Dissolution of skeletal grains and early cements, and subsequent replacement with epigenetic spar calcite cements, appears to be common throughout and is the most obvious diagenetic process to affect the Barneston Limestone.

ACKNOWLEDGMENTS

This paper has profited greatly by the cooperation, support, and help of Bill Rizer and Peter D'Onfro, especially their assistance in measuring and collecting the Vap's Pass outcrop section. Bill Rizer and Larry Cagle were also most helpful in overall preparation and assistance with the GW-3 core. Rock slabbing and preparation of thin sections were capably carried out by Ron Stimson. Preparation of photographs by Garth Hannum and drafting by Diana Beall is gratefully appreciated. Thanks are also due Conoco Inc. for allowing me time and facilities to prepare this paper.

REFERENCES CITED

Chaplin, J. R., 1988, Lithostratigraphy of Lower Permian rocks in Kay County, north-central Oklahoma, and their stratigraphic relationships to lithic correlatives in Kansas and Nebraska, *in* Morgan, W. A.; and Babcock, J. A. (eds.), Permian rocks of the Midcontinent: Society of Economic Paleontologists and Mineralogists, Midcontinent Section, Special Publication 1, p. 79–111.

Condra, J. R.; and Upp, J. E., 1931, Correlation of the Big Blue Series in Nebraska: Nebraska Geological Survey Bulletin 67, 2nd series, 74 p.

Luza, K. V.; and Lawson, J. E., Jr., 1981, Seismicity and tectonic relationship of the Nemaha Uplift in Oklahoma—Part 3: Oklahoma Geological Survey Special Publication 81-3, 70 p.

Prosser, C. S., 1902, Revised classification of the Upper Paleozoic formations of central Kansas: Journal of Geology, v. 10, p. 703–737.

Thompson, M. L., 1954, American Wolfcampian fusulinids: University of Kansas Paleontological Contributions, Protozoa-5, 226 p.

Toomey, D. F.; Mitchell, R. W.; and Lowenstein, T. K., 1988, "Algal biscuits" from the Lower Permian Herington/Krider Limestones of southern Kansas–northern Oklahoma: paleoecology and paleodepositional setting: Palaios, v. 3, p. 285–297.

APPENDIX 1:

Measured Section of the Barneston Limestone (Early Permian, Wolfcampian), Vap's Pass, Northeastern Kay County, Northern Oklahoma

This outcrop is located in northeastern Kay County, northern Oklahoma, and can be reached by proceeding east for ~6 mi from the town of Newkirk, on the Newkirk Road, and crossing the bridge over the Arkansas River. Outcrops of the Barneston Limestone are well exposed on the hill, in a road cut situated on the east bank of the river, in what is locally called Vap's Pass.

This measured section of the Barneston Limestone comprises the Florence Limestone and overlying Fort Riley Limestone Members. The Barneston Limestone is conformably underlain by the Matfield Shale. This section was measured and collected by Toomey, D'Onfro, and Rizer on May 17, 1988.

BARNESTON LIMESTONE (41.1 ft)

Florence Limestone Member (17.1 ft).—The Florence Limestone (Thin Sections 1A–6A) consists of thin- to massive-bedded limestones (with one distinctive chert interval) and interbedded shales.

ROCK UNIT 1 is a single bed of gray fossiliferous limestone 1.3 ft thick.

SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES

Thin Sections 1A–1C (1.3 ft):

1A (base of bed)—A recrystallized, slightly porous, silty/slightly peloidal/coated-grain skeletal (molluscan/foram) wackestone (recrystallized to microspar) with scattered mud clasts and coated grains with algal/foram coatings; skeletal debris is of two distinct sizes: (1) abundant, small, well-sorted skeletal grains consisting of many *Globivalvulina* and *Tetrataxis*, less abundant *Syzrania* and *Oketaella*, along with rare *Tuberitina*, fenestrate bryozoan fragments, ostracodes, crinoid columnals, and *Girvanella* fragments; and (2) less abundant, relatively large, broken molluscan fragments (clams and mud-filled snails), and brachiopod fragments, some of these grains having mud-filled borings and most having algal/foram coatings, along with a few partially silicified grains.

1C (top of bed)—A slightly silty/peloidal/coated-grain wackestone; coated-grain nuclei consist of mud clasts, molluscan fragments (including *Pinna*, with mud-filled borings), brachiopod fragments (mainly *Derbyia*, a few with mud-filled borings), echinoid spines and crinoid columnals; most coated grains have well-developed algal/foram coatings with well-preserved *Girvanella* tubules; other matrix skeletal debris, generally uncoated, consists primarily of molluscan fragments (clams and mud-filled snails), in addition to *Tetrataxis*, rare, small *Globivalvulina*, *Tuberitina*, *Cornuspira*, *Oketaella*, *Girvanella* tubules, fenestrate bryozoan fragments, *Tabulipora*, *Spirorbis*, a *Myalina* fragment (partially silicified), ostracodes, and echinoid spines (a few partially silicified).

ROCK UNIT 2 is a thin-bedded, dark-gray, argillaceous limestone interbedded with gray-green shales 3.8 ft thick. Two prominent limestone beds are present in this unit: (1) the lower limestone is 2.5 ft thick and contains *Myalina* and *Derbyia*, and (2) the upper limestone consists of thin interbeds of limestones and shales 0.9 ft thick.

DOLOMITIZED BRYOZOAN/SKELETAL WACKESTONE WITH INTERBEDDED SHALE MICROFACIES

Thin Sections 2A–2B (3.8 ft):

2A (base of bed)—A recrystallized, dolomitized, silty/peloidal/skeletal wackestone with scattered molluscan and brachiopod fragments (a few of which are bored and partially silicified); molluscan fragments include *Pinna*, indeterminate whole, spar-filled clams (some with mud-filled borings) and mud-filled snails; brachiopod fragments appear to be *Derbyia* (partially silicified); other matrix skeletal grains include a single *Syzrania*, fenestrate bryozoan fragments, rare ostracodes, crinoid columnals, and fish teeth; a few of the molluscan fragments have poor algal/foram coatings; rock with common pyrite.

2B (middle of bed)—A partially dolomitized, porous (leached), silty/skeletal wackestone consisting of a jumbled mass of finely broken shell debris comprising abundant fenestrate bryozoans, less common crinoid columnals and echinoid spines (some with syntaxial calcite overgrowths, and a few partially silicified); scattered molluscan (*Pinna*) fragments, some of which are partially silicified, crushed and distorted, rare trilobite fragments, ostracodes, brachiopod fragments, *Spirorbis*, and fish teeth fragments, along with a few *Oketaella*, scattered *Nodosinella* and *Syzrania*, and rare *Tetrataxis* and *Tuberitina*; rock with scattered pyrite.

Subunit 2B,a (thin limestone at bottom of bed)—A burrowed, dolomitized, leached, silty/peloidal/skeletal wackestone with much finely broken skeletal debris including common *Syzrania*, rare *Tetrataxis*, fenestrate bryozoan fragments, ?*Tabulipora*, *Pinna* fragments, brachiopod fragments (some partially silicified and bored), ostracodes, crinoid columnals and echinoid spines, and rare fish remains; rock with scattered pyrite and a single calcite-plugged microfracture.

Subunit 2B,c (thin limestone on top of bed)—A porous (leached), dolomitized, slightly silty/peloidal/skeletal wackestone with abundant finely broken skeletal debris consisting of abundant fenestrate bryozoans, scattered brachiopod fragments, crinoid columnals and echinoid spines (some partially silicified), few *Oketaella*, *Syzrania*, ostracodes, and rare fish remains; scattered pyrite.

ROCK UNIT 3 is a recrystallized limestone 2.8 ft thick, flaggy at the base, with some cross- and parallel stratification. This unit contains a distinctive layer of "cannonball" chert nodules. Chert may have filled and replaced large horizontal burrows.

LEACHED FORAM WACKESTONE MICROFACIES

Thin Sections 3A–6A (12 ft):

3A (base of bed)—A porous (leached), slightly dolomitized, peloidal/skeletal (foraminiferal/bryozoan) wackestone with much finely broken skeletal debris including abundant fenestrate bryozoan fragments, scattered crinoid columnals (some partially silicified and with poorly developed syntaxial calcite overgrowths), scattered *Nodosinella*, rare *Tetrataxis*, *Geinitzina*, and *Globivalvulina*, single *Syzrania*, *Tuberitina*, ?*Endothyra*, and palaeotextularid, few *Oketaella*, rare brachiopod fragments, ostracodes, echinoid spines, and fish teeth; rare pyrite.

3C (top of bed)—A porous (leached), cherty, peloidal/skeletal (foram/bryozoan) wackestone with much finely broken skeletal debris consisting of abundant fenestrate bryozoans, brachiopod fragments, lesser crinoid columnals (some partially silicified), common palaeotextularids, *Globivalvulina*, *Nodosinella*, *Tuberitina*, *Endothyra*, *Oketaella*, *Tetrataxis*, *Geinitzina*, sponge spicules, ostracodes, echinoid spines and fish teeth; includes chert fragments with ghost images of skeletal debris, especially *Tetrataxis*; few algally? coated fragments, small whole brachiopod and fragments.

ROCK UNIT 4 is a single bed of light-gray limestone 2.9 ft thick, with low-angle sediment cross-stratification, burrows, *Pinna* clams in growth position, and scattered *Composita*.

4A (base of bed)—A silty/peloidal/skeletal wackestone with many finely broken skeletal grains consisting of abundant fenestrate bryozoan fragments, and lesser crinoid columnals and echinoid spines, ostracodes, and forams (*Syzrania*, *Tuberitina*, *Geinitzina*, *Tetrataxis*, *Nodosinella*, *Globivalvulina*, *Oketaella*), brachiopod and trilobite fragments; few skeletal grains with poor algal/foram coatings; few fish remains; scattered pyrite.

4B (middle of bed)—A slightly porous, peloidal/silty/skeletal/coated-grain wackestone to packstone with much broken skeletal debris among patches of sparry matrix; skeletal debris contains a single *Epimastopora* fragment, common small *Globivalvulina* and *Nodosinella*, lesser *Syzrania*, *Endothyra*, *Tuberitina*, *Geinitzina*, *Oketaella*, rare *Girvanella* tubules, sponge spicules, fenestrate bryozoan fragments, rare fistuliporid bryozoan fragments, molluscan fragments including *Pinna*, ostracodes, echinoid spines, crinoid columnals, trilobite fragments, and a single fish tooth; some coated grains with heavily micritized coatings; scattered pyrite.

4C (top of bed)—A slightly silty, burrowed, peloidal/skeletal wackestone with broken skeletal debris including common *Tuberitina* and *Tetrataxis*, rare *Globivalvulina*, *Geinitzina*, *Syzrania*, and *Oketaella*, scattered fenestrate bryozoan fragments, few small, whole brachiopods and one large partially silicified *Derbyia* fragment with algal/foram coatings, molluscan fragments, sponge spicules, and rare crinoid columnals (one partially silicified); scattered pyrite.

ROCK UNIT 5 is a gray limestone 3.3 ft thick with low-angle cross-stratification containing abundant *Composita* on the surface.

5A (base of bed)—A burrowed, silty/peloidal/skeletal wackestone with much broken shell debris including a few fragments of *Epimastopora*, common small *Globivalvulina*, less common *Tetrataxis*, *Tuberitina*, *Syzrania*, *Geinitzina*, *Nodosinella*, *Oketaella*, *Nankinella*, scattered coated grains with algal/foram coatings, fenestrate bryozoan fragments, single fistuliporid bryozoan fragment, molluscan fragments including *Pinna* and mud-filled snails, brachiopod fragments including *Derbyia*, ostracodes, trilobite fragments, echinoid spines (few partially silicified), and crinoid columnals, rare fish remains; rock with few sparry patches and scattered pyrite.

5C (top of bed)—A recrystallized leached foraminiferal wackestone with laminar coatings of algae/forams encrusted by *Tubiphytes;* greatest percentage of coatings seems to be diagenetically altered *Girvanella* tubules, giving the rock an almost boundstone fabric; scattered skeletal debris includes *Syzrania, Tetrataxis, Tuberitina, Globivalvulina, Nodosinella, ?Endothyra, Oketaella,* fenestrate bryozoan fragments, brachiopods including whole specimens and fragments of *Composita,* ostracodes, and rare crinoid columnals.

ROCK UNIT 6 is a gray limestone 6.1 ft thick characterized by low-angle cross-stratification, the brachiopods *Antiquatonia* and *Composita,* and filled burrows.

6A (base of bed)—A porous (leached), burrowed, silty/peloidal/skeletal (foraminiferal)/wackestone with scattered coated grains and much broken skeletal debris including rare *Epimastopora* and *Girvanella* fragments, possible *Tubiphytes* fragments, coated grains with heavily micritized coatings, scattered foraminifers including *Tetrataxis, Tuberitina, Globivalvulina, Syzrania, Endothyra, Nodosinella, Geinitzina, Oketaella,* and mud-filled *Schwagerina,* fenestrate bryozoan fragments, molluscan fragments including *Pinna* and snails, brachiopod fragments, ostracodes, echinoid spines and crinoid columnals (in part silicified); rock with sparry patches, poorly developed microstylolites, and scattered pyrite.

Fort Riley Limestone Member.—The Fort Riley Limestone (Thin Sections 6C–12) consists of 24 ft of more massive limestones, forming distinctive ledges, and grading upward into thinner-bedded limestones and interbedded shale.

COATED-GRAIN PACKSTONE TO GRAINSTONE MICROFACIES

Thin Sections 6C–7C (9.3 ft):

6C (top of bed)—A coated grain packstone to grainstone, with variable coated-grain nuclei comprising *Nankinella,* mud-filled snails, fenestrate, and fistuliporid bryozoans, molluscan fragments (some bored), echinoid spines, and crinoid columnals (some bored), *Epimastopora,* mud clasts, fistuliporid bryozoans, brachiopod fragments, and *Tetrataxis;* loose, generally uncoated skeletal grains consist of common *Oketaella,* less common *Geinitzina,* snails, brachiopod fragments (some partially silicified and bored), ostracodes, and echinoid spines; some fine quartz silt incorporated in coated grains.

ROCK UNIT 7 is a gray limestone 6.2 ft thick with low-angle cross-stratification.

7A (base of bed)—A leached silty/coated-grain packstone to grainstone with variable coated-grain nuclei consisting of fenestrate and fistuliporid bryozoans, molluscan fragments, including mud-filled snails, *Nankinella, Oketaella, Epimastopora,* brachiopod fragments, ostracodes, and crinoid columnals; loose, generally uncoated grains consisting of *Oketaella,* mud-filled snails, ostracodes, trilobite fragments, echinoid spines and crinoid columnals (some partially silicified); some fine quartz silt incorporated in coated grains; incipient microstylolites with concentrations of quartz silt.

7C (top of bed)—A porous, slightly silty, skeletal/coated-grain packstone to wackestone, with abundant crinoid columnals and echinoid spines; coated grains less abundant than below, with nuclei of *Epimastopora, Nankinella,* fenestrate bryozoans, molluscan fragments, echinoid spines, crinoid columnals, and mud-filled snails; loose, uncoated skeletal grains include the foraminifers *Nodosinella, Globivalvulina, Geinitzina,* and *Oketaella,* along with molluscan fragments, ostracodes, trilobite fragments, echinoid spines and crinoid columnals; scattered pyrite.

ROCK UNIT 8 is a gray muddy skeletal limestone 3.5 ft thick.

LEACHED CRINOIDAL/SKELETAL PACKSTONE TO WACKESTONE MICROFACIES

Thin Sections 8A–10C (11.9 ft):

8A (base of bed)—A skeletal/coated-grain wackestone to packstone with abundant crinoid columnals and echinoid spines; coated-grain nuclei include *Spirorbis,* brachiopod fragments, molluscan fragments including mud-filled snails, fenestrate bryozoans, rare *Nankinella,* echinoid spines and crinoid columnals; loose, uncoated skeletal grains comprise rare *Epimastopora, Globivalvulina, Geinitzina, Nodosinella, Cornuspira,* mud-filled *Oketaella,* brachiopod fragments, fenestrate bryozoans, ostracodes, trilobite fragments, crinoid columnals and echinoid spines (some with mud-filled borings), and a single fish remain; incipient microstylolites and scattered pyrite.

8B (middle of the bed)—A slightly porous, recrystallized, peloidal/skeletal wackestone with scattered coated grains; coated-grain nuclei are molluscan fragments, fenestrate bryozoans, and rare *Nankinella;* loose skeletal grains consist of common to abundant crinoid columnals and echinoid spines (some with mud-filled borings), common *Globivalvulina,* lesser *Nodosinella,* rare

Geinitzina, Cornuspira, Tuberitina, single large *Epimastopora* fragment, fenestrate bryozoans, molluscan fragments including *Pinna* and mud-filled snails, brachiopod fragments including one whole spar-filled specimen, ostracodes, trilobite fragments, and a fish tooth; some poorly developed microstylolites, and scattered pyrite.

8C (top of bed)—A porous, recrystallized (dolomitized) skeletal/wackestone with scattered coated grains; coated-grain nuclei include *Nankinella,* molluscan fragments, fenestrate bryozoans, brachiopod fragments, and crinoid columnals; loose uncoated skeletal grains are common *Globivalvulina,* less common *Calcivertella, Geinitzina, Nodosinella, Tuberitina, Cornuspira,* fenestrate bryozoan fragments, molluscan fragments including mud-filled snails, brachiopod fragments, ostracodes, trilobite fragments, common crinoid columnals and echinoid spines; incipient microstylolites, and scattered pyrite.

ROCK UNIT 9 is a gray, slabby limestone 2.5 ft thick with *Antiquatonia, Derbyia, Composita, Myalina, Pinna, Straparolus,* a scaphopod, and a tabulate coral colony; surface of unit with *Thalassinoides* burrows.

9A (base of bed)—A recrystallized, slightly dolomitized, leached skeletal wackestone with a large *Epimastopora* fragment and common to abundant crinoid columnals and echinoid spines, with scattered skeletal grains including common *Globivalvulina,* less common *Nodosinella,* rare *Nankinella, Tuberitina, Cornuspira,* and *Nankinella,* fenestrate bryozoan fragments, ?*Tabulipora,* molluscan fragments including a whole clam and mud-filled snails, brachiopod fragments, ostracodes, trilobite fragments, a fish tooth, and scattered coated grains with nuclei of molluscan fragments, fenestrate bryozoans, and echinodermal debris (some with mud-filled borings); rock with incipient microstylolites and scattered pyrite.

9C (top of bed)—A recrystallized, dolomitized skeletal wackestone with an entire tabulate coral colony (corallites with *Spirorbis* encrustations), common crinoid columnals and echinoid spines (few with mud-filled borings), common *Globivalvulina,* less common *Nodosinella,* rare *Syzrania, Tuberitina,* and *Cornuspira,* a few scattered coated grains, fenestrate bryozoan fragments and *Tabulipora,* whole mud-filled clams and molluscan fragments including *Pinna* and mud-filled snails, ostracodes, trilobite fragments, and a fish tooth; rock with incipient microstylolites and scattered pyrite.

ROCK UNIT 10 is a single bed of gray limestone 5.9 ft thick with vertical burrows 6 in. long, ~2 ft below the top of the unit.

10A (base of bed)—A burrowed, recrystallized, skeletal wackestone with broken skeletal grains consisting of abundant molluscan fragments (including *Pinna* and *Myalina* and mud-filled snails, and a few small, whole, cement-filled clams), with common crinoid columnals and *Globivalvulina,* rare *Nodosinella, Geinitzina, Calcivertella, Syzrania, Tuberitina,* and *Cornuspira,* few, scattered coated grains, fenestrate bryozoan fragments, *Spirorbis,* brachiopod fragments (*Derbyia*), trilobite fragments, ostracodes, and echinoid spines; rock with microstylolites and scattered pyrite.

10B (middle of bed)—A partially recrystallized, skeletal (molluscan) wackestone to packstone with abundant molluscan fragments (including a few small, whole clams, abundant clam fragments, and abundant mud-filled snails), along with common crinoid columnals; other skeletal grains include scattered *Globivalvulina,* rare *Syzrania, Tuberitina, Calcivertella, Cornuspira,* fenestrate bryozoan fragments, brachiopod fragments, ostracodes, and echinoid spines; incipient microstylolites and scattered pyrite.

10C (top of bed)—A recrystallized, slightly leached, skeletal wackestone with abundant *Globivalvulina* and crinoid columnals (some with syntaxial calcite overgrowths), broken molluscan fragments including mud-filled snails, fenestrate bryozoan fragments, rare brachiopod fragments, *Nodosinella, Cornuspira, Calcivertella,* ostracodes, trilobite fragments, and echinoid spines; rock with microstylolites and scattered pyrite.

SHALE/MOLLUSCAN PACKSTONE TO WACKESTONE MICROFACIES

Thin Sections 11–12 (2.8 ft):

ROCK UNIT 11 consists of 1.8 ft of gray-green shale.

ROCK UNIT 12 is the youngest bed exposed at this section and consists of 1 ft of gray, wavy-bedded, fossiliferous limestone with abundant *Myalina, Pinna,* and lesser *Composita;* bottom of bed is covered with *Thalassinoides* burrows.

12—A recrystallized, slightly silty, and peloidal/molluscan wackestone to packstone with abundant broken molluscan debris including mud-filled snails, scattered crinoid columnals and *Globivalvulina,* rare brachiopod fragments, fenestrate bryozoan fragments, *Calcivertella, Cornuspira, Nodosinella, Tuberitina, Earlandia, Spirorbis,* a few small whole brachiopods (mud-filled), rare echinoid spines; few coated shell fragments.

APPENDIX 2:

Thin-Section Descriptions of the GW-3 Core, Conoco Test Facility, Kay County, Northern Oklahoma

Primary coring objective: Fort Riley Limestone Member of the Barneston Limestone; described cored interval 33.5–95.5 ft; core taken August 1988.

Top of Fort Riley Limestone Member of the Barneston Limestone:

SILTY/COATED-GRAIN/SKELETAL WACKESTONE TO GRAINSTONE MICROFACIES (37.4–39.6 ft):

Footage	Description
37.4	A burrowed, silty coated-grain/skeletal (molluscan) wackestone; coated grains with algal/foram coatings including *Girvanella*, and with nuclei composed of crinoid columnals and molluscan fragments; loose skeletal debris comprises rare *Tuberitina*, *Calcivertella*, *Globivalvulina*, *Derbyia* fragment, molluscan fragments, mud-filled snails, and crinoid columnals; scattered pyrite.
37.8	A coated-grain/skeletal grainstone to packstone with poorly developed fringes of isopachous cements on some grains; coated grains with obvious foraminiferal component, and nuclei of molluscan fragments (a few with borings), snails, fenestrate bryozoans, *Spirorbis*, echinoid spines, and crinoid columnals; loose skeletal debris consists of: common to abundant *Globivalvulina*, less abundant *Calcivertella*, *Tuberitina*, *Nodosinella*, *Spirorbis*, molluscan fragments (some bored), mud-filled snails, crinoid columnals, a few small mud clasts, and echinoid spines; some tests of *Globivalvulina* are mud-filled.
38.3	Description as above, but with a few more mud clasts; rare *Epimastopora* fragments, *Earlandia*, molluscan fragments with mud-filled borings, mud-filled clams and ostracodes.
38.8	A burrowed, slightly silty/skeletal wackestone with scattered coated grains; skeletal debris finely broken and consisting of *Calcivertella*, *Nodosinella*, *Globivalvulina*, fenestrate bryozoans, brachiopod fragments, molluscan fragments, ostracodes (some mud-filled), crinoid columnals and echinoid spines; rare mud clasts; few voids plugged with calcite and baroque dolomite; some dissolution of skeletal grains.
39.6	A slightly silty/skeletal wackestone with some relatively large flat clasts with prominent mud-filled barnacle borings and encrustations of *Spirorbis* (some truncated) and *Calcivertella*; clasts are peloidal/skeletal wackestone; finely broken loose skeletal debris comprises *Calcivertella*, *Nodosinella*, *Globivalvulina*, brachiopod fragments, *Spirorbis*, molluscan fragments (few with algal/foram coatings), ostracodes and crinoid columnals; rare baroque dolomite rhombs in microfractures in clasts, and in burrows.

INTERBEDDED SILTY SHALE/MOLLUSCAN PACKSTONE TO WACKESTONE MICROFACIES (40.7–48.1 ft):

40.7	A slightly silty, recrystallized, somewhat leached skeletal (dominantly molluscan)/coated-grain packstone with common crinoid columnals (some with syntaxial calcite overgrowths); coated-grain nuclei are molluscan fragments (some with mud-filled borings) and fenestrate bryozoans; loose skeletal debris composed of common *Cornuspira* and *Globivalvulina*, less common fenestrate bryozoans, molluscan fragments, mud-filled snails and ostracodes, crinoid columnals (some with mud-filled borings), and rare fish remains; few patches of mud with scattered dolomite rhombs and fine pyrite.
41.7	A recrystallized, slightly leached, silty/skeletal (dominantly finely broken molluscan fragments and crinoid columnals) wackestone; loose skeletal debris consists of common *Cornuspira* and *Globivalvulina*, lesser *Calcivertella*, *Tuberitina*, fenestrate bryozoans, *Spirorbis*, brachiopod fragments, mud-filled snails, a few whole clams, ostracodes, echinoid spines, rare fish remains, and a few skeletal grains with algal/foram coatings; few muddy patches with scattered dolomite rhombs.
43.3	A silty/pyritic/laminar/skeletal (clams) packstone; some shells with silt and pyrite-filled borings, and what appear to be fans of submarine cements clustered under and between clam shells; other skeletal components include common fish remains, a single mud-filled snail and a few ostracodes; scattered pyrite.
45.1	A laminated quartz siltstone with scattered pyrite.
46.2	A burrowed, slightly silty, slightly peloidal/skeletal wackestone, recrystallized in part to microspar, with common *Globivalvulina*, lesser *Nodosinella*, *Calcivertella*, finely broken fenestrate bryozoans and molluscan frag-

ments, brachiopod fragments, few grains with algal/foram coatings, snails, ostracodes, crinoid columnals and echinoid spines; some molluscan fragments with mud-filled borings; incipient microstylolites.

47.4 A recrystallized skeletal (dominantly molluscan)/coated-grain wackestone to packstone; coated-grain nuclei are molluscan fragments, some with mud-filled borings; *Girvanella* present in some coated grains; loose skeletal debris comprises *Nodosinella*, fenestrate and ramose bryozoan fragments, brachiopod fragments, *Spirorbis*, clams and snails (some mud-filled), ostracodes, crinoid columnals, and fish remains; scattered pyrite.

48.1 A laminar, slightly silty/skeletal wackestone to packstone with layers of ostracodes and recrystallized, bored molluscan fragments, along with rare thin-shelled molluscan fragments and a few *Spirorbis*.

LEACHED CRINOIDAL/SKELETAL PACKSTONE TO WACKESTONE MICROFACIES (50.2–64.6 ft):

50.2 A recrystallized crinoidal/skeletal packstone with finely broken fenestrate bryozoan fragments, common *Globivalvulina* (a few with baroque dolomite rhombs plugging some chambers), rare *Cornuspira* and *Geinitzina*, ramose bryozoans, brachiopod fragments, molluscan fragments, mud-filled snails, ostracodes, ?trilobite fragments, echinoid spines, and fish remains; a few coated grains with algal/foram coatings are also present; there are also abundant microstylolites, scattered pyrite, and muddy patches with dolomite rhombs.

50.7 A recrystallized slightly leached, skeletal (mainly crinoid columnals)/packstone with muddy patches containing dolomite rhombs (some baroque dolomite); many crinoid columnals with syntaxial calcite overgrowths; other skeletal debris includes common to abundant *Globivalvulina*, lesser *Calcivertella*, a few coated grains, relatively large fenestrate bryozoan fragments, molluscan fragments, mud-filled snails and clams, brachiopod fragments, ostracodes, and fish remains; incipient microstylolites, and rare pyrite.

51.6 A recrystallized slightly leached, skeletal (mainly crinoid columnals)/packstone with abundant incipient microstylolites; some crinoid columnals with syntaxial calcite overgrowths and in microstylolitic (sutured) contact; other skeletal grains consist of *Globivalvulina, Calcivertella, Cornuspira*, fenestrate and ramose bryozoan fragments, *Spirorbis*, brachiopod fragments, mud-filled snails, echinoid spines, and fish remains; scattered muddy patches with dolomite rhombs.

52.7 A recrystallized slightly leached, slightly silty/crinoidal packstone to wackestone with abundant microstylolites; some crinoid columnals with syntaxial calcite overgrowths and in sutured contact; other skeletal debris consists of *Globivalvulina, Cornuspira, Tuberitina, Calcivertella*, fenestrate bryozoans, mud-filled snails, ostracodes, echinoid spines, and fish remains; scattered pyrite.

53.3 A recrystallized, slightly leached, slightly silty/crinoidal wackestone to packstone with abundant microstylolites and patches with dolomite rhombs; skeletal debris consists of *Globivalvulina, Cornuspira, Tuberitina, Calcivertella*, fenestrate and ramose bryozoans, molluscan fragments (some coated), mud-filled snails, ostracodes, echinoid spines, and fish remains, some crinoid columnals with syntaxial calcite overgrowths.

54.8 A silty/crinoidal wackestone with common pyrite and incipient microstylolites; other skeletal debris consists of scattered *Globivalvulina, Tuberitina*, a single whole brachiopod and fragments, fenestrate bryozoans, molluscan fragments, mud-filled snails, ostracodes, trilobite fragments, echinoid spines, and fish remains; crinoid columnals relatively large, and some in microstylolitic contact.

56.4 A porous (leached), finely broken, skeletal (crinoid columnals and fenestrate bryozoans)/packstone with *Epimastopora, Tuberitina, Tetrataxis, Nodosinella, Calcivertella, Globivalvulina, Nankinella, Oketaella*, a few coated grains, brachiopod fragments, molluscan fragments (some coated), mud-filled snails and ostracodes, trilobite fragments, echinoid spines and fish remains; scattered pyrite; crinoid columnals relatively small and some with syntaxial calcite overgrowths.

57.5 Description as above, but better sorted and with incipient microstylolites; skeletal debris with *Epimastopora*, a few coated grains, *Nodosinella, Cornuspira, Geinitzina, Oketaella*, and molluscan fragments (one with mud-filled borings); some syntaxial calcite overgrowths on crinoid columnals.

60.5 A recrystallized, porous (leached), slightly silty/skeletal (crinoids/fenestrate bryozoans/forams) packstone, with common to abundant *Cornuspira*, lesser *Globivalvulina*, rare *Nodosinella, Tuberitina, Tetrataxis, Nankinella, Epimastopora*, few coated grains, fenestrate bryozoans, mud-filled snails, ostracodes, trilobite fragments, echinoid spines, and fish remains; rare patches of dolomite rhombs, incipient microstylolites, and scattered pyrite.

62.3 A recrystallized, slightly silty/crinoidal/coated-grain packstone with scattered muddy patches with dolomite rhombs; coated-grain nuclei consist of *Nankinella*, fenestrate bryozoans, brachiopod fragments, molluscan fragments, mud-filled snails, echinoid spines, and crinoid columnals; loose skeletal material comprises common *Cornuspira*, lesser *Globivalvulina, Tuberitina, Tetrataxis, Geinitzina, Nodosinella*, mud-filled *Oketaella, Epimastopora*, fenestrate bryozoan and brachiopod fragments, mud-filled snails, ostracodes, and fish remains; scattered pyrite and incipient microstylolites.

63.5 Description as above, but somewhat more porous (leached), and with *Oketaella*, and a trilobite fragment.

64.6 Description as above, with common *Oketaella* and *Nankinella*, and a few trilobite fragments; conspicuous patches of dolomite rhombs.

COATED-GRAIN PACKSTONE/WACKESTONE/GRAINSTONE MICROFACIES **(65.5–78.4 ft):**

65.5 A recrystallized, slightly porous (leached), silty/coated-grain/skeletal (crinoid columnals)/packstone to grainstone; coated-grain nuclei include *Nankinella*, fenestrate and ramose bryozoans, molluscan fragments, mud-filled snails, echinoid spines, and crinoid columnals; other skeletal components are *Girvanella, Nodosinella, Endothyra, Oketaella*, mud-filled ostracodes, echinoid spines, crinoid columnals (some with syntaxial calcite overgrowths); much of the quartz silt is entrapped within the coated grains; scattered pyrite and incipient microstylolites.

68.6 A recrystallized, slightly porous (leached), silty/coated-grain/skeletal packstone; coated-grain nuclei include *Epimastopora, Nankinella*, fenestrate bryozoans, molluscan fragments, mud-filled snails, trilobite fragments, echinoid spines, crinoid columnals (some with mud-filled borings), other skeletal components include *Nodosinella, Geinitzina, Globivalvulina, Oketaella*, mud-filled snails, ostracodes, trilobite fragments, crinoid columnals and echinoid spines; rare pyrite and common incipient microstylolites; some scattered dolomite rhombs.

69.8 A recrystallized, porous (leached), silty/coated-grain/crinoidal packstone to wackestone; coated-grain nuclei are *Nankinella, Oketaella*, fenestrate bryozoans, molluscan fragments, mud-filled snails, echinoid spines, and crinoid columnals (some partially silicified); additional skeletal components include *Globivalvulina, Endothyra, Geinitzina, Earlandia, Nodosinella, Nankinella, Oketaella*, partially silicified brachiopod fragments, mud-filled snails, ostracodes (some mud-filled), trilobite fragments, echinoid spines, and crinoid columnals; incipient microstylolites, and rare pyrite.

72.8 A recrystallized, porous (leached), very silty/coated-grain/skeletal packstone to wackestone; coated-grain nuclei include *Nankinella*, fenestrate and ramose bryozoans, mud-filled snails, molluscan fragments, echinoid spines and crinoid columnals; other skeletal debris include *Epimastopora, Geinitzina, Globivalvulina, Nankinella, Oketaella*, fenestrate bryozoans, brachiopod fragments (some partially silicified), mud-filled snails, ostracodes, trilobite fragments, echinoid spines and crinoid columnals; incipient microstylolites and scattered clumps of pyrite; much of skeletal debris is finely broken.

73.1 A recrystallized, porous (leached), very silty/coated-grain/skeletal packstone with abundant finely broken crinoid columnals and fenestrate bryozoans; coated-grain nuclei include *Nankinella, Epimastopora*, fenestrate bryozoans, brachiopod and molluscan fragments, mud-filled snails, echinoid spines, and crinoid columnals (partially silicified); loose skeletal debris consists of *Girvanella, Globivalvulina, Nodosinella, Tuberitina, Oketaella*, brachiopod fragments (partially silicified), molluscan fragments, mud-filled snails, ostracodes, trilobite fragments, and echinoid spines; abundant incipient microstylolites, some plugged with quartz silt; some grains in sutured contact.

76.2 A recrystallized, porous (leached), silty/peloidal/skeletal/coated-grain packstone to wackestone; coated-grain nuclei include *Epimastopora, Tuberitina, Nankinella*, brachiopod fragments, (partially silicified), molluscan fragments, mud-filled snails, trilobite fragments, crinoid columnals (some partially silicified), and echinoid spines (some with mud-filled borings); loose skeletal debris consists of common *Nodosinella* and *Oketaella*, less common *Globivalvulina, Tuberitina, Geinitzina, Tetrataxis*, molluscan fragments, ostracodes, crinoid columnals (some partially silicified), echinoid spines, and fish remains; skeletal material finely broken.

76.6 A recrystallized, porous (leached), slightly silty/peloidal/skeletal/coated-grain packstone with finely broken skeletal debris in addition to a few relatively large brachiopod shells (partially silicified); coated-grain nuclei include *Nankinella*, and molluscan fragments; loose skeletal grains consist of *Cornuspira, Globivalvulina, Nodosinella, Tetrataxis,* *Nankinella, Oketaella,* brachiopod fragments, fenestrate bryozoans, molluscan fragments, ostracodes, crinoid columnals (partially silicified), and echinoid spines.

78.4 A recrystallized, porous (leached), silty/peloidal/skeletal/coated-grain packstone to wackestone with finely broken skeletal debris; coated-grain nuclei comprise *Epimastopora,* brachiopod fragments (partially silicified), fenestrate bryozoan and molluscan fragments, and echinoid spines; loose skeletal debris consists of *Tetrataxis, Globivalvulina, Geinitzina, Nodosinella, Oketaella,* fenestrate bryozoans, brachiopod fragments (partially silicified), molluscan fragments, mud-filled snails, ostracodes, trilobite fragments, crinoid columnals, and echinoid spines; scattered pyrite, and abundant incipient microstylolites, some with patches of dolomite rhombs.

Top of Florence Limestone Member of the Barneston Limestone:

LEACHED FORAM WACKESTONE MICROFACIES (79.3–89.4 ft):

79.3 A recrystallized, porous (leached), slightly silty/peloidal/skeletal (foraminiferal) wackestone, with skeletal material finely broken and comprising common *Tuberitina,* less common *Globivalvulina, Geinitzina, Nodosinella, Endothyra, Tetrataxis, Oketaella, Spirorbis,* fenestrate bryozoans, few relatively large brachiopod shells (partially silicified) with diagenetically altered *Girvanella* coatings, molluscan fragments, ostracodes, and crinoid columnals; abundant incipient microstylolites, and scattered pyrite; thin section cuts burrow with fecal pellets.

79.9 Description as above, but rock more recrystallized and *Girvanella* coatings on shell fragments, and partially silicified crinoid columnals; few questionable *Tubiphytes* fragments; fish remains.

80.2 A recrystallized, porous (leached), slightly silty/skeletal (foraminiferal) wackestone with finely broken skeletal debris comprising common *Tuberitina* and *Oketaella,* less common *Globivalvulina, Tetrataxis, Nodosinella, Endothyra, Geinitzina,* possible *Tubiphytes* with *Girvanella* coatings, fenestrate bryozoans, brachiopod fragments and a few partially silicified whole brachiopod shells, molluscan fragments, ostracodes, crinoid columnals, echinoid spines (partially silicified), and fish remains; incipient microstylolites.

81.3 A recrystallized, porous (leached), silty/peloidal/coated-grain packstone to wackestone with finely broken skeletal debris; coated-grain nuclei comprise *Girvanella,* fenestrate bryozoans, brachiopod fragments (partially silicified), molluscan fragments, trilobite fragments, partially silicified echinoid spines (some with mud-filled borings), and partially silicified crinoid columnals; loose skeletal debris consists of *Epimastopora, ?Tubiphytes, Tuberitina, ?Earlandia, Endothyra, Globivalvulina, Tetrataxis, Nodosinella, Oketaella,* fenestrate bryozoans, molluscan fragments, ostracodes, crinoid columnals, and echinoid spines; common pyrite, finely scattered and in patches.

84.5 A slightly porous (leached), silty/fenestrate bryozoan wackestone with common crinoid columnals, and with all skeletal debris finely broken; some syntaxial calcite overgrowths on crinoid columnals; loose fossil components consist of *Nodosinella, ?Syzrania, Geinitzina,* a few coated grains, brachiopod fragments, molluscan fragments (partially silicified), ostracodes (single whole one plugged with baroque dolomite), trilobite fragments, and fish remains; scattered pyrite, and poorly developed incipient microstylolites.

85.6 A slightly porous (leached), silty/peloidal/fenestrate bryozoan wackestone with finely broken skeletal components consisting of *Nodosinella, Geinitzina, Syzrania, Globivalvulina, Oketaella,* molluscan fragments, partially silicified brachiopod fragments, crinoid columnals, echinoid spines, and fish remains; scattered fine pyrite and poorly developed incipient microstylolites.

86.1 A porous (leached), slightly peloidal/silty/skeletal (foraminiferal) wackestone with finely broken skeletal material consisting of *Girvanella* fragments, *Tuberitina, Globivalvulina, Nodosinella, Syzrania,* palaeotextularids, *Oketaella, Schwagerina,* fenestrate bryozoans, sponge spicules, molluscan fragments (some partially silicified), ostracodes, and crinoid columnals and echinoid spines (some partially silicified); rare baroque dolomite rhombs plugging some palaeotextularid and *Schwagerina* chambers; well-developed, silt-plugged microstylolites, and rare pyrite.

86.15 A porous (leached), silty/peloidal/skeletal (foraminiferal) wackestone with finely broken skeletal debris comprising *Endothyra, Tuberitina, Syzrania, Globivalvulina, Geinitzina,* palaeotextularids, *Oketaella, Schwagerina,* sponge spicules, a few coated grains, fenestrate bryozoans, brachiopod fragments, ostracodes, crinoid columnals (partially silicified and with syntaxial calcite overgrowths), and fish remains; rare baroque dolomite rhombs in a few *Schwagerina* test chambers; rare pyrite, and incipient microstylolites; few schwagerinids with algal? coatings.

86.3 A slightly porous (leached), silty/peloidal/skeletal (foraminiferal) wackestone with finely broken skeletal debris comprising *Syzrania, Tuberitina, Nodosinella, Globivalvulina, Endothyra, Geinitzina, Tetrataxis,* palaeotextularids, *Oketaella, Schwagerina,* ?*Tubiphytes* fragment, few coated grains, sponge spicules, fenestrate bryozoans, molluscan fragments, ostracodes, crinoid columnals (partially silicified and with syntaxial calcite overgrowths), and fish remains; rare pyrite, poorly developed incipient microstylolites, and patches of scattered dolomite rhombs.

86.4 A porous (leached), silty/slightly peloidal/skeletal (foraminiferal) wackestone with finely broken skeletal debris consisting of *Globivalvulina, Nodosinella, Tuberitina, Endothyra, Syzrania, Geinitzina,* palaeotextularids, *Tetrataxis, Schwagerina, Oketaella,* sponge spicules, fenestrate bryozoans, molluscan fragments, and partially silicified crinoid columnals; rare baroque dolomite rhombs in a few palaeotextularid test chambers; rare pyrite, and incipient microstylolites with scattered dolomite rhombs.

86.5 A porous, slightly peloidal/silty/skeletal (foraminiferal) wackestone with finely broken skeletal debris consisting of *Tuberitina, Endothyra, Syzrania, Globivalvulina, Nodosinella, Tetrataxis,* palaeotextularids, *Oketaella, Schwagerina,* sponge spicules, fenestrate bryozoans, *Spirorbis,* molluscan fragments, ostracodes, crinoid columnals and echinoid spines (some with syntaxial calcite overgrowths), a few coated grains; rare baroque dolomite rhombs in ostracodes, and in palaeotextularid and *Schwagerina* test chambers; rare pyrite, scattered dolomite rhombs, and incipient microstylolites.

86.7 A porous (leached), slightly peloidal/skeletal (foraminiferal) wackestone with finely broken skeletal debris comprising common *Tuberitina, Nodosinella,* and palaeotextularids, less common *Endothyra, Syzrania, Geinitzina, Tetrataxis, Oketaella, Schwagerina, Globivalvulina,* few coated grains with *Girvanella,* fenestrate bryozoans, molluscan fragments (some partially silicified), ostracodes, echinoid spines, crinoid columnals (some partially silicified and with syntaxial calcite overgrowths), and fish remains; rare pyrite.

87.4 A porous (leached), recrystallized, peloidal/skeletal (foraminiferal) wackestone with finely broken skeletal debris consisting of abundant palaeotextularids, *Oketaella,* and *Tuberitina,* less common *Globivalvulina, Nodosinella, Syzrania, Endothyra, Tetrataxis, Geinitzina,* fenestrate bryozoans, molluscan fragments, *Spirorbis,* ostracodes, crinoid columnals, partially silicified echinoid spines; rare baroque dolomite rhombs plugging some palaeotextularid test chambers; few crinoid columnals with syntaxial calcite overgrowths; small portion of thin section with a pocket of quartz silt; rare pyrite, and poorly developed incipient microstylolites.

88.7 A porous (leached), dolomitized, slightly peloidal/silty/skeletal (foraminiferal) wackestone with finely broken skeletal debris and scattered patches with dolomite rhombs; skeletal material consists of *Endothyra, Nodosinella, Globivalvulina, Syzrania, Tuberitina, Tetrataxis,* palaeotextularids, *Oketaella,* ?*Schwagerina,* fenestrate bryozoans, *Spirorbis,* common sponge spicules, whole brachiopods and fragments (some partially silicified), molluscan fragments, ostracodes, echinoid spines, and crinoids (some with syntaxial calcite overgrowths and partially silicified), and fish remains; rare baroque dolomite rhombs plugging a few palaeotextularid test chambers; incipient microstylolites, and patches of pyrite.

89.1 A porous (leached), slightly silty/skeletal wackestone with finely broken skeletal debris; part of thin section cuts through a chert nodule with abundant silicified microfossils including sponge spicules, *Geinitzina, Oketaella,* palaeotextularids, ostracodes, fenestrate bryozoans, *Spirorbis,* and molluscan fragments; loose skeletal debris in wackestone portion of thin section consists of *Endothyra, Tetrataxis, Globivalvulina, Nodosinella, Tuberitina, Oketaella,* palaeotextularids, a single coated grain, sponge spicules, fenestrate bryozoans, molluscan fragments, ostracodes, echinoid spines, crinoid columnals (some with syntaxial calcite overgrowths and partially silicified), and fish remains; rare pyrite, scattered patches of dolomite rhombs, and incipient microstylolites; few ostracodes plugged with baroque dolomite rhombs.

89.4 A porous (leached), silty, fenestrate bryozoan wackestone with finely broken skeletal debris including rare forams (*Tuberitina, Syzrania, Nodosinella, Globivalvulina* and palaeotextularids), sponge spicules, ostracodes, and crinoid columnals (some with syntaxial calcite overgrowths and partially silicified); rare pyrite, and scattered patches with dolomite rhombs.

DOLOMITIZED BRYOZOAN/SKELETAL WACKESTONE TO PACKSTONE MICROFACIES (90.6–93.3 ft):

90.6 A dolomitized fenestrate bryozoan packstone with rare skeletal debris consisting of *Globivalvulina, Tetrataxis, Oketaella,* sponge spicules, molluscan fragments, *Spirorbis,* ostracodes, echinoid spines, crinoid columnals (some with syntaxial calcite overgrowths and partially silicified), and fish remains; rare pyrite and incipient microstylolites.

91.7 A dolomitized fenestrate bryozoan wackestone to packstone with *Nodosinella, Tetrataxis,* ramose and fenestrate bryozoans, brachiopod fragments (some partially silicified), molluscan fragments, echinoid spines and crinoid columnals (some with syntaxial calcite overgrowths and partially silicified), and fish remains; rare pyrite and incipient microstylolites; lower portion of thin section with quartz silt, ramose and fenestrate bryozoans, trilobite fragments, and brachiopod fragments (some with borings), and crinoid columnals.

92.2 Description as above, but quite shaly and silty, and much less broken skeletal debris which includes bored brachiopod fragments and ramose bryozoans (partially silicified), in addition to scattered pyrite and rare fish remains.

93.3 A slightly laminated shaly/silty/skeletal wackestone; skeletal fragments partially silicified and consisting of ?*Syzrania,* fenestrate and ramose bryozoans, a few coated grains, brachiopod and molluscan fragments, mud-filled snails, and crinoid columnals and echinoid spines and fish remains; common pyrite and a few mud clasts.

SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES (94.1 ft):

94.1 A silty/coated-grain/skeletal wackestone (in part recrystallized to microspar); coated grains (with *Girvanella*), and nuclei include fenestrate bryozoans, molluscan fragments (some with mud-filled borings), mud-filled snails, ostracodes, echinoid spines, crinoid columnals (some partially silicified), and mud clasts; loose skeletal debris comprises *Tetrataxis, Cornuspira, Globivalvulina, Oketaella,* brachiopod fragments (some with borings); and crinoid columnals (partially silicified).

Matfield Shale at 95.3 ft

95.3 A silty laminated shale with scattered limy mud clasts (some peloidal), and scattered pyrite.

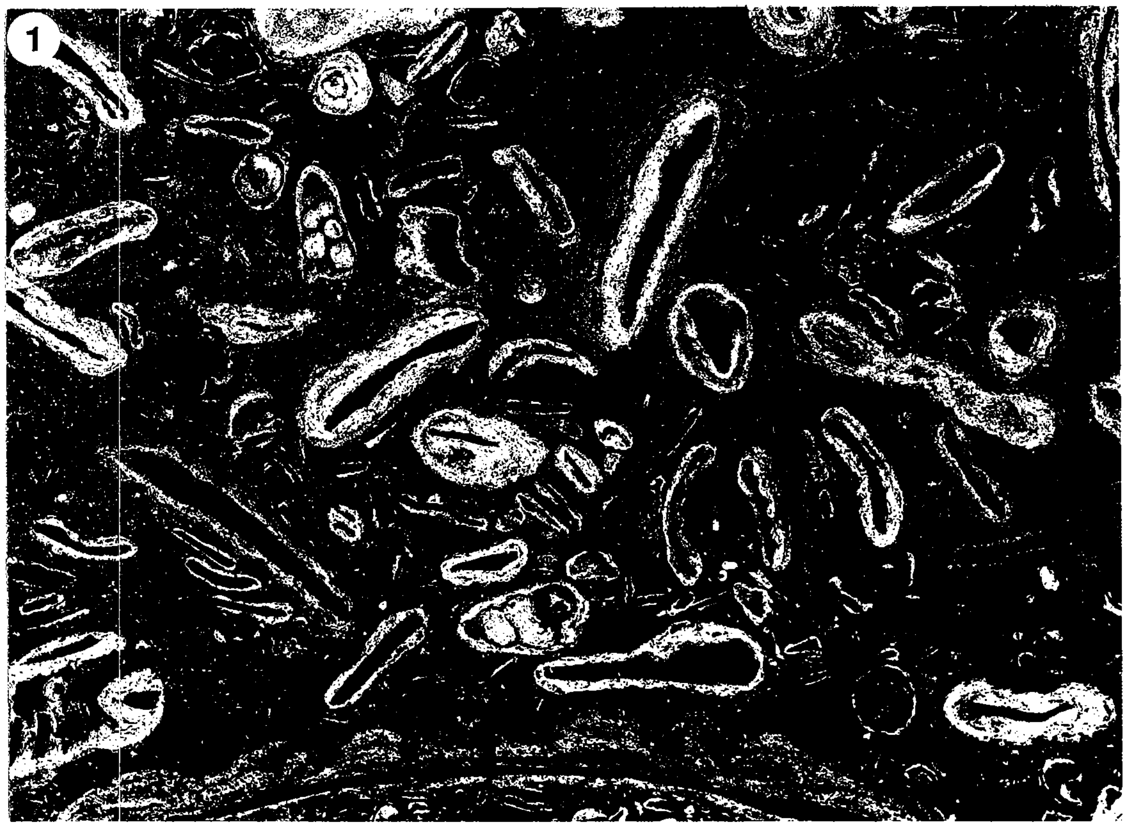
PLATE 1

Negative print thin section photomicrographs (×6) of the Florence and Fort Riley Limestone Members of the Barneston Limestone at the Vap's Pass measured outcrop section, Kay County, Oklahoma.

Figure 1.—A coated-grain/skeletal wackestone; note that skeletal fragments (mainly molluscan fragments) are coated with concentric laminations of algae and forams (not seen at this magnification); VP-Unit 1C, SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES.

Figure 2.—A coated-grain packstone to grainstone; VP-Unit 7A, COATED-GRAIN PACKSTONE TO GRAINSTONE MICROFACIES.

1



2

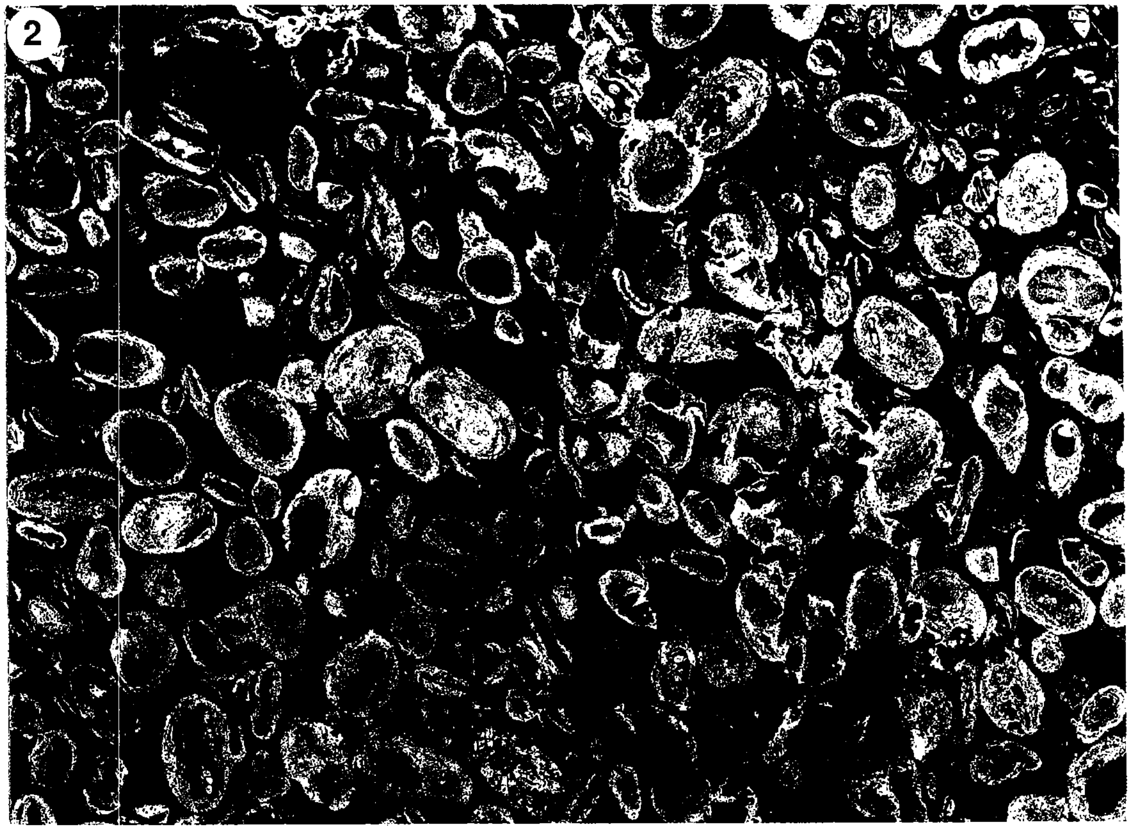


PLATE 2

Thin section photomicrographs of fossils and other components of the Fort Riley and Florence Limestone Members of the Barneston Limestone from the GW-3 core taken at the Conoco test facility, Kay County, Oklahoma.

Figure 1.—Well-sorted coated grain with a fenestrate bryozoan fragment as the grain nucleus; depth 72.8 ft in the COATED-GRAIN PACKSTONE/WACKESTONE/GRAINSTONE MICROFACIES.

Figure 2.—Microstylolite (arrows) with concentrations of fine quartz silt in a silty/peloidal/skeletal wackestone; depth 78.4 ft in the COATED-GRAIN PACKSTONE/WACKESTONE/GRAINSTONE MICROFACIES.

Figure 3.—Thin section cut through a portion of the fusulinid *Schwagerina* with some of the chambers plugged with baroque dolomite (arrows); depth 86.4 ft in the LEACHED FORAM WACKESTONE MICROFACIES.

Figure 4.—Random thin section cuts through two specimens of the fusulinid *Oketaella;* depth 86.7 ft in the LEACHED FORAM WACKESTONE MICROFACIES.

Figure 5.—An oblique longitudinal thin section cut through a palaeotextularid foraminifer in a silty/peloidal/foraminiferal wackestone; depth 87.4 ft in the LEACHED FORAM WACKESTONE MICROFACIES.

Figure 6.—Thin section cut through a chert nodule (lighter colored right side) showing well-preserved microfossils, especially sponge spicules (arrows) in the chert; depth 89.1 ft in the LEACHED FORAM WACKESTONE MICROFACIES.

Figure 7.—Fenestrate bryozoan fragments in a dolomitized skeletal packstone; depth 90.6 ft in the DOLOMITIZED BRYOZOAN/SKELETAL WACKESTONE TO PACKSTONE MICROFACIES.

Figure 8.—Longitudinal thin section cut through a ramose bryozoan in a dolomitized wackestone; depth 91.7 ft in the DOLOMITIZED BRYOZOAN/SKELETAL WACKESTONE TO PACKSTONE MICROFACIES.

Figure 9.—A coated, mud-filled snail in a skeletal wackestone; depth 94.1 ft in the SILTY/COATED-GRAIN/SKELETAL WACKESTONE MICROFACIES.


1
0.5 mm

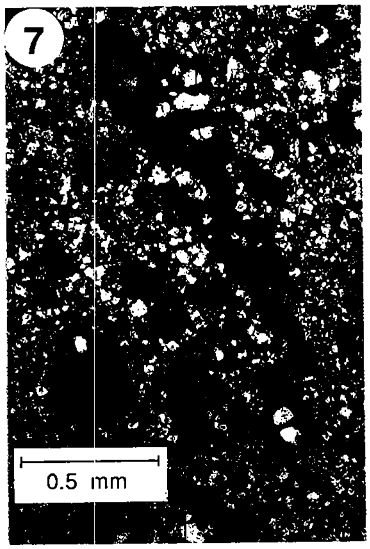

2
0.5 mm


3
0.5 mm


4
0.5 mm


5
0.5 mm


6
0.5 mm


7
0.5 mm


8
0.5 mm


9
0.5 mm

Letters from Friends and Colleagues

James E. Barrick

Texas Tech University

My closest contact with Tom Amsden occurred when I spent a year (1978–79) at the University of Oklahoma. It was my first position after graduate school, and I was coping with full-time teaching, seeking direction for my research, and my wife and I were expecting our first child. As time permitted, I would walk to the Oklahoma Geological Survey, and if Tom were there, we would spend a while talking. Conversations covered a variety of topics on paleontology and stratigraphy, but often focused on the Hunton Group and the use of brachiopods and conodonts. Regardless of the topic, I always left invigorated and filled with new determination and enthusiasm for research. I learned many things from Tom, in particular to use a large degree of skepticism about geological interpretations, to consider all the alternatives before making conclusions, and to keep one's sense of humor about the whole business. These discussions continued after I left Norman, and led to several collaborative projects, mostly at Tom's gentle insistence. Tom's productivity, professionalism, and personal integrity have always impressed me, and I have been honored by, and certainly have enjoyed, being able to work with him.

James R. Chaplin

Oklahoma Geological Survey

I first met Tom Amsden while interviewing for a position with the Oklahoma Geological Survey in 1983. We had a common interest in fishing and conodont studies, but what I recall most vividly was Tom's perspective of a state geological survey. Tom related to me that a state geological survey was far more than just a state agency that collected and disseminated information, though he recognized and appreciated the importance of that role. Tom said a Survey needs to go beyond that task, to analyze and synthesize data regarding the science of geology and then to use that data in making practical applications to the fuel and non-fuel industries of the state and its citizens. Thanks, Tom, for your genuine and honest perspective that contributed, in part, to my accepting a position with the Oklahoma Geological Survey.

G. A. Cooper

Raleigh, North Carolina

At my age recollection of old events, humorous or otherwise, is indistinct and unreliable. I do, however, recollect with pleasure my dealings, as curator at the National Museum, with Tom Amsden. Tom described some of the USNM collections, especially the Henryhouse brachiopods of Oklahoma and St. Clair brachiopods mostly from Arkansas. These excellent works established him as as expert in knowledge of Silurian Brachiopoda. He extended his brachiopod studies to the Lower Devonian of Oklahoma, much needed works. Through his work, Tom proved himself to be a leading student of the Brachiopoda and can look with pride on his works.

I endorse his excellence as a paleontologist and cherish him as a friend.

J. Thomas Dutro, Jr.

U.S. Geological Survey
Washington, D.C.

I've always felt close to Tom Amsden though we never have worked together professionally. Part of this feeling must be due to shared experiences: both graduate students at Yale, learning paleontology and brachiopods from Carl Dunbar; both with jobs in practical biostratigraphy for government surveys (Tom at Oklahoma and I at the USGS); both involved in the tribute to G. A. Cooper on his retirement in 1971; both subject to by-pass surgery for heart problems in the past five years; and, finally, both on the podium at the 1989 Paleontological Society meeting in St. Louis when Tom received the Paleontological Society Medal and I was his citationist.

I especially like the way Tom has cast his brachiopod systematic studies in the context of solving general geologic problems. Detailed biostratigraphic analyses of the Silurian–Devonian of the Midcontinent are landmark studies that will stand for decades. His depositional syntheses of the Anadarko and Arkoma Basins are models of eclectic stratigraphy. And his careful analyses of brachiopod biochronology added basic evidence for international decisions on the Silurian–Devonian and Ordovician–Silurian boundaries.

Congratulations on your retirement, Tom. You've had a fine and fulsome career.

Bill Furnish
University of Iowa

I have never had an opportunity to spend time with Tom or know him well on a personal basis. At the same time, I talked with Tom various times over a period of fifty years and do feel a strong kindred spirit. We have walked in each other's steps, but mostly I am impressed by his accomplishments and insights into the field of biostratigraphy.

Tom's first effort involved a master's thesis on Harding equivalents in Wyoming. This happened to be the same area, in general, where I started. His career at Yale and Hopkins was followed with interest. When he signed up with the Oklahoma Survey it seemed to be a natural association to me.

I can speak concerning his professional competency, for the work that he did on the Haragan, etc., should be regarded as one of the most significant studies ever presented. His synthesis picked up every "loose end" and explored all aspects. It will be a classic for future generations to utilize.

Betty Awbrey Ham
Oklahoma Geological Survey (retired)

What can one say about Tom Amsden?

Tom Amsden *is.*

That's all.

Tom Amsden is a great person, a truly outstanding paleontologist, a fine gentleman, a wonderful friend.

What can you say about a man who has been such a good friend through all those years? We have known Tom and Virginia Amsden ever since they came here, and I have never thought about them without pleasure. And now Bill Ham is gone, but the friendship continues.

I think of Tom at parties, at our house, at their house, at the homes of others. I think of all the meetings, conventions, all over the country, the world, the presentations he has given on the results of his investigations, the articles, books he has written—

What do you say about Tom Amsden?

Tom Amsden *is.*

Jess Johnson
Oregon State University

My first contact with Tom Amsden was in correspondence when I was still a graduate student at UCLA. I had been making an attempt to learn the world literature of Lower Devonian brachiopods and Tom's two monographs on the Haragan and Bois d'Arc brachiopods, published in 1958, were inspirational.

I never had the opportunity to go into the field with Tom, but coauthored a paper on *Conchidium* with him and Art Boucot in 1967. We met when Tom visited Cal Tech and again later when he visited Corvallis. Always, it has been a genuine pleasure to "talk brachiopods" with Tom at these meetings and in correspondence.

Kenneth S. Johnson

Oklahoma Geological Survey

Tom has been a valued colleague during the long association we have had at the Oklahoma Geological Survey. He was well entrenched in the basement of Gould Hall when I started with the Survey in 1962, and he has now worked his way up to the second floor in the new Sarkeys Energy Center. (I, on the other hand, went from the third floor down to the basement!) I, and other staff members, have used Tom's biostratigraphic and map data extensively in dealing with regional synthesis of Oklahoma's geologic history, and also in dealing with site-specific geologic problems. His work always is meticulous and thorough, and he conveys his ideas and interpretations in a clear and concise manner.

Tom has continued to contibute, even in his years of partial retirement. Inquiries to the Survey on Late Ordovician through Devonian geology are still dealt with by Tom, or by others through reference to his prior publications, and he is still working on a major project in the Anadarko Basin.

His work is an excellent standard that others should strive to meet.

Markes E. Johnson

Williams College

Gudveig Baarli was a recent graduate of the University of Oslo and employed by the Oslo Paleontologisk Museum when she met Tom Amsden during the 1982 Field Meeting of the Subcommission on Silurian Stratigraphy. The field meeting was held in conjunction with the 4th International Symposium on the Ordovician System, in Norway. Prior to the meeting, she had worked very hard to incorporate some of the results from her cand. real. thesis into the guidebook being produced on behalf of the Silurian Subcommission, which was to consider the Oslo region as a possible type district for the Lower Silurian. Her lasting impression of Tom is that he was the only participant from among the established leaders of the Silurian syndicate who took the time to talk with her and discuss her work. She also recalls that Tom made a beeline to collect from the lowest available horizon with the brachiopod *Stricklandia* at Spirodden, where she was conserving the material for collection *after* the conference. She came to the abrupt realization that someone from the wide, open spaces of Oklahoma might not understand the limitations of urban geology. She and her future husband, Markes Johnson, later sent Tom a representative set of *Stricklandia* from the Oslo region for comparison with the North American forms Tom had earlier described.

Markes became familiar with Tom's ground-breaking work on the Silurian, while a graduate student at the University of Chicago. He has carried on a long and productive correspondence with Tom over the years.

Gilbert Klapper

University of Iowa

I have known Tom Amsden since 1963, when I joined the Amoco Research Center in Tulsa and was assigned as my initial task the conodont biostratigraphy of the Hunton Group. During the following years Tom guided me to all of the important Hunton localities in the Arbuckles, as well as to the Silurian–Devonian outcrop in northeastern Oklahoma, and we shared a number of memorable field excursions. I recall him saying on one field trip that what has plagued North American stratigraphy from the beginning is the fact that many paleontologists had failed to locate the precise stratigraphic position of their collections and had often used fossils from float.

Tom was eager to have conodont data integrated into the massive network of lithostratigraphic and biostratigraphic information on the Hunton that he had developed. He was extremely flexible in accepting all of the results from the conodont research, even in the few instances which differed in some respects from previous results. I know of no one more tolerant of other views, more soft-spoken, more gentlemanly, nor a greater pleasure to be with in the field.

Alfred Lenz

University of Western Ontario

I first met Tom in 1968 during an extensive field trip to Siberia, Ukraine, and Czechoslovakia, looking at Silurian and Devonian rocks. We subsequently participated in several other international field trips, the most recent being in China, and have always enjoyed his presence as well as his scientific input. He is a thoroughly pleasant person, and is one whom I immensely respect both personally and scientifically. As a, sometime, fellow-worker on lower Paleozoic brachiopods, I have always had the highest regard for his studies. His numerous, comprehensive, and excellently illustrated publications have always been among the first I reached for when studying Silurian and Early Devonian brachiopods of Arctic Canada. I wish him many more years of scientific contributions.

Bob Lundin

Arizona State University

Tom always calls it the way he sees it! After being informed by Carl Branson that he (Carl) had hired a person, whose name shall be withheld, to describe some Hunton fossil group, Tom said, "Carl, why did you do that?" To which Carl answered, "Tom, it's difficult to find people to describe these fossils!" To which Tom responded, "Carl, you can go out on the street corner and find a dozen people who can describe them as well as the person you hired."

Tom is an avid bird hunter. Perhaps feeling a little squeamish about his truancy during the previous hunting season, before which he had gotten his first bird dog, Tom explained, "I had my dog out five of the first six days of the quail season, and there isn't any way you can work that into a weekend!!"

Tom was the most important influence on me as I started into the world of paleontology and stratigraphy in the 1960s. For that I will be forever grateful. Tom helped me to understand Hunton stratigraphy and to understand the importance of meticulous work. He even helped me collect rocks. At the end of the half-mile walk to the car from White Mound, Tom said, "Don't ever ask me to do this again." I didn't! It was 103 degrees with humidity to match, and each of us was loaded down with 100 pounds or so of the Haragan Formation. I still have some of that rock.

Thanks for all of the help and guidance you gave me, Tom.

Javelina hunt in Arizona, ca. 1967. Front row: Tom Amsden, Bob Lundin, and Bill Bellis. Back row: local guides. *Photo courtesy of Bob Lundin.*

Robert B. Neuman

Smithsonian Institution

I was one of the lucky ones who was a graduate student under Tom's supervision at The Johns Hopkins University, then and thereafter to be guided by his commitment to the primacy of fact above fancy. Through these decades he has served as a model of self-discipline, diligence, and thoroughness in observation and analysis from which are derived well-supported and sound interpretations in his many publications. Perhaps he wonders what went wrong with those of his former students who occasionally have taken to flights of fancy. For these offenses I proffer apologies; for our more soundly based accomplishments I am glad to have this opportunity to join others in our expressions of gratitude.

William J. Sando

U.S. Geological Survey
Washington, D.C.

It gives me great pleasure to share some memories of my association with Tom Amsden in this honorary volume because I am deeply indebted to him for helping me get started on the path to a happy and rewarding career in geology. Tom was my teacher and mentor at The Johns Hopkins University, where I studied as an undergraduate in 1947–50 and received a Ph.D. in 1953. His courses in Invertebrate Paleontology and Stratigraphic Paleontology were inspiring models of organization, content, and clarity, and they formed the knowledge base for my later work in biostratigraphy. I disappointed him by not choosing a thesis on the Keyser Limestone brachiopods, but he shrugged this off and served as principal advisor on my thesis on the Lower Ordovician of Maryland (Ernst Cloos charmed me into that one). Although he demanded excellence from his students, his friendly disposition, unselfish availability for consultation, and willingness to defend me when I bumped up against less sympathetic faculty members made my birth as a scientist much less traumatic than it might have been without his help.

Patrick K. Sutherland

University of Oklahoma

Tom has been a good friend for more than 35 years. I have been in the field with him many times looking at various aspects of his beloved Hunton Group. As a part of his initial detailed studies of the Hunton brachiopod faunas in the Arbuckle Mountains, he worked out the carbonate lithostratigraphy and the complex depositional history. He initiated studies by others on all major Hunton fossil groups. At his invitation I studied the Henryhouse corals. But, a subsequent development has set Tom's research career apart from virtually all others. By the 1960s, the Hunton Group had become an important oil producing interval in Oklahoma. Tom took many oil company groups to see the surface exposures of the Hunton in the Arbuckle Mountains. But, many of those geologists concluded that those numerous unconformities seen in the outcrop could not be recognized on electric logs and thus could not be used to decipher the complex regional stratigraphic relationships.

Although I never heard Tom comment on the above, I had the impression at the time that he was miffed by such comments. In any case, Tom embarked gradually on a study of the Hunton Group in the subsurface of Oklahoma. The difference was that he searched out cores taken from the Hunton, dissected those cores for megafossils as well as microfossils and used brachiopods as the primary basis for correlation. Almost immediately he discovered that all Hunton oil and gas was not from the Devonian Frisco Formation, as previously thought, but much of it was from the Upper Silurian. As the subsurface facies changed northwestward from the Arbuckle Mountains into the Anadarko Basin he used brachiopods to establish the age of the strata and the location of the Silurian–Devonian boundary. He astonished the petroleum industry by showing that half of the Anadarko Basin could be written off as a possible Upper Silurian hydrocarbon target because it lacked the right facies. His subsurface investigations, based primarily on brachiopods and on detailed studies of the carbonate lithostratigraphy as seen primarily in cores, has now been extended over the entire state for the entire Hunton Group.

The above comments are given to support the following conclusions: Tom Amsden is first and foremost a research scientist who has above all else achieved a skill and reputation matched by few in his chosen field of biostratigraphy. We next see a perfect union of fundamental research on brachiopods and the reconstruction in the subsurface of a truly complex depositional history. The results that he has achieved have been truly extraordinary.

Oklahoma Geological Survey Bulletin 145, 1992

Publications of Thomas W. Amsden

Amsden, T. W., 1941, Ordovician conodonts from the Bighorn Mountains of Wyoming: The University of Iowa unpublished M.S. thesis, 17 p.

_____1947, Stratigraphy and paleontology of the Brownsport Formation (Silurian) of western Tennessee: Yale University unpublished Ph.D. dissertation, 285 p.

_____1949a, Two new genera of brachiopods from the Henryhouse Formation (Silurian) of Oklahoma: Washington Academy of Sciences Journal, v. 39, p. 202–203.

_____1949b, Stratigraphy and paleontology of the Brownsport Formation (Silurian) of western Tennessee: Yale University, Peabody Museum of Natural History Bulletin 5, 138 p., 34 pls.

_____1951a, Paleontology, *in* The physical features of Washington County: Maryland Department of Geology, Mines, and Water Resources, Washington County (Report 14), p. 98–123, 6 pls.

_____1951b, On Dr. Elizabeth Alexander's proposal for the use by the International Commission on Zoological Nomenclature of its plenary powers to validate current usage of the generic name *'Pentamerus'* Sowerby, 1813 (Class Brachiopoda): Bulletin of Zoological Nomenclature, v. 2, p. 96.

_____1951c, Brachiopods of the Henryhouse Formation (Silurian) of Oklahoma: Journal of Paleontology, v. 25, p. 69–96, 6 pls.

_____1952, Request for a ruling that the alleged name, *'Antirhynchonella'* Quenstedt 1871, is a 'nomen nudum' (Phylum Brachiopoda, Class Articulata): Bulletin of Zoological Nomenclature, v. 6, p. 242–244.

_____1953, Some notes on the Pentameracea, including a description of one new genus and one new superfamily: Washington Academy of Sciences Journal, v. 43, p. 137–147.

_____1954, Geology of Garrett County: Maryland Department of Geology, Mines, and Water Resources, Bulletin 13, p. 1–107, 7 pls.

_____1955, Lithofacies map of Lower Silurian deposits in central and eastern United States and Canada: American Association of Petroleum Geologists Bulletin, v. 39, p. 60–74.

_____1956a, Catalog of fossils from the Hunton Group, Oklahoma: Oklahoma Geological Survey Circular 38, 63 p.

_____1956b, Classification of the Pentameracea [abstract]: Geological Society of America Abstracts with Programs, v. 67, p. 1665.

_____1956c, Notes on *Parmorthis brownsportensis* and *Isorthis arcuaria* from the Henryhouse and Brownsport Formations: Oklahoma Geology Notes, v. 16, p. 78–85.

_____1957a, Catalog of fossils from the Middle and Upper Ordovician of Oklahoma: Oklahoma Geological Survey Circular 43, 41 p.

_____1957b, Introduction to stratigraphy, *pt. 1 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Circular 44, 57 p., 3 pls.

_____1958a, Geologic range of *Dictyonella* in the Hunton Group: Oklahoma Geology Notes, v. 18, p. 31–32.

_____1958b, Haragan articulate brachiopods, *pt. 2 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 9–144, 14 pls.

_____1958c, Supplement to the Henryhouse brachiopods, *pt. 3 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 145–157.

_____1958d, Bois d'Arc articulate brachiopods, *pt. 5 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 82, 110 p., 5 pls.

_____1958e, White Mound: Oklahoma Geology Notes, v. 18, p. 131–135.

_____1959a, A remarkable specimen of the trilobite *Isotelus* from the Viola Limestone: Oklahoma Geology Notes, v. 19, p. 18–19.

_____1959b, *Chilidiopsis* Boucot: a recently described brachiopod genus, with some remarks on the Hunton orthotetacea: Oklahoma Geology Notes, v. 19, p. 74–77, 1 pl.

_____1960a, *Lissatrypoidea concentrica* (Hall), emend Boucot and Amsden: illustrations of the lectotype: Oklahoma Geology Notes, v. 20, p. 138–139.

_____1960b, Hunton stratigraphy, *pt. 6 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 84, 311 p., 17 pls.

_____1960c, Silurian and Devonian strata in the Marble City area, Sequoyah County, Oklahoma: Kansas Geological Society 25th Field Conference, Guidebook, p. 110–112.

_____1961, Stratigraphy of the Frisco and Sallisaw Formations (Devonian) of Oklahoma: Oklahoma Geological Survey Bulletin 90, 121 p., 13 pls.

_____1962a, Additional fossils from the Bois d'Arc Formation in the southeastern part of the Arbuckle Mountains region: Oklahoma Geology Notes, v. 22, p. 212–216.

_____1962b, Silurian and Early Devonian carbonate rocks of Oklahoma: American Association of Petroleum Geologists Bulletin, v. 46, p. 1502–1519.

_____1963a, Articulate brachiopods of the Sallisaw Formation (Devonian), *pt. 2 of* Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, p. 141–192, 8 pls.

_____1963b, Supplement to the Haragan (Devonian) brachiopods, *pt. 3 of* Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, p. 193–205.

_____1963c, Silurian stratigraphic relations in the central part of the Arbuckle Mountains, Oklahoma: Geological Society of America Bulletin, v. 74, p. 631–636, 2 pls.

_____1964, Brachial plate structure in the brachiopod family Pentameridae: Palaeontology, v. 7, pt. 2, p. 220–239, 3 pls.

_____1966, *Microcardinalia protriplesiana* Amsden, a new species of stricklandiid brachiopod, with a discussion on its phylogenetic position: Journal of Paleontology, v. 40, p. 1009–1016, 3 pls.

_____1967a, Chimneyhill Limestone sequence (Silurian), Hunton Group, Oklahoma, revised: American Association of Petroleum Geologists Bulletin, v. 51, p. 942–945.

_____1967b, Silurian and Early Devonian strata in Oklahoma, *in* Toomey, D. F. (ed.), Symposium on Silurian–Devonian rocks of Oklahoma and environs: Tulsa Geological Society Digest, v. 35, p. 25–34.

_____1968a, Upper Silurian (Wenlockian and Ludlovian) and Lower Devonian brachiopod faunas in the central United States [abstract]: Symposium on the Silurian–Devonian boundary and stratigraphy of the Lower and Middle Devonian, Third International, Leningrad, p. 12–13.

_____1968b, Articulate brachiopods of the St. Clair Limestone (Silurian), Arkansas, and the Clarita Formation (Silurian), Oklahoma: Journal of Paleontology, v. 42, no. 3, supplement [Paleontological Society Memoir 1], 117 p., 20 pls.

_____1968c, Lower Devonian brachiopod faunas in Oklahoma [abstract]: American Association of Petroleum Geologists, v. 52, p. 517.

_____1968d, Widespread zone of pentamerid brachiopods in subsurface Silurian strata of north-central Oklahoma [abstract]: Geological Society of America Special Paper 115, p. 363.

_____1968e, Silurian and Early Devonian representatives of *Dicoelosia* [abstract]: Geological Society of America Special Paper 101, p. 4.

_____1969, A widespread zone of pentamerid brachiopods in subsurface Silurian strata of Oklahoma and the Texas Panhandle: Journal of Paleontology, v. 43, p. 960–975, 3 pls.

_____1970a, A late Ashgillian (Ordovician) brachiopod fauna from the Edgewood Formation, Illinois and Missouri [abstract]: Geological Society of America Abstracts with Programs, v. 2, p. 482–483.

_____1970b, The genus; a basic concept in paleontology: North American Paleontological Convention Proceedings, part C, p. 156.

_____1971a, *Triplesia alata* Ulrich and Cooper, *in* Dutro, J. T., Jr. (ed.), Paleozoic perspectives: a paleontological tribute to G. Arthur Cooper: Smithsonian Contributions to Paleobiology, no. 3, p. 143–154, 2 pls.

_____1971b, Upper Silurian (Wenlockian and Ludlovian) and Lower Devonian brachiopod faunas in the central United States, *in* Granitsa Silura I Devona I biostratigrafiia Silura, Leningrad, Nauka, v. 1, p. 21–34.

_____1971c, Late Ordovician–Early Silurian brachiopods from the central United States: Bureau de Recherches Géologiques et Minieres, Mémoire 73, p. 19–25, 2 pls.

_____1973a, Stop 3: Late Ordovician, Silurian, and Early Devonian strata, *in* Ham, W. E., Regional geology of the Arbuckle Mountains, Oklahoma: Oklahoma Geological Survey Special Publication 73-3, p. 39–43.

_____1973b, The pseudodeltidium in *Triplesia* and *Placotriplesia:* Lethaia, v. 6, p. 253–274.

_____1973c, Porosity and permeability in Silurian carbonate rocks of Anadarko Basin, Oklahoma [abstract]: American Association of Petroleum Geologists Bulletin, v. 57, p. 766–767.

_____1974, Late Ordovician and Early Silurian articulate brachiopods from Oklahoma, southwestern Illinois, and eastern Missouri: Oklahoma Geological Survey Bulletin 119, 154 p., 28 pls.

_____1975a, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko Basin of Oklahoma: Oklahoma Geological Survey Bulletin 121, 214 p., 15 pls.

_____1975b, Early late Silurian biofacies in south-central Oklahoma as determined by point counting [abstract]: Geological Society of America Abstracts with Programs, v. 7, p. 974–975.

_____1976, Early late Silurian biofacies and lithofacies in central United States [abstract]: 25th International Geologic Congress, v. 1, section 7, p. 299.

_____1977, Middle Paleozoic history of Anadarko and Arkoma Basins, Oklahoma [abstract]: American Association of Petroleum Geologists Bulletin, v. 61, p. 760–761.

_____1978, Articulate brachiopods of the Quarry Mountain Formation (Silurian), eastern Oklahoma: Oklahoma Geological Survey Bulletin 125, 75 p., 13 pls.

_____1979a, Welling Formation, new name for Upper Ordovician unit in eastern Oklahoma (formerly called "Fernvale"): American Association of Petroleum Geologists Bulletin, v. 63, p. 1135–1138.

_____1979b, Late Ordovician–Early Silurian strata in Mid-Continent area [abstract]: American Association of Petroleum Geologists Bulletin, v. 63, p. 410.

_____1980a, *Kirkidium* biofacies of Henryhouse Formation (Silurian), central Oklahoma subsurface: Oklahoma Geology Notes, v. 40, p. 217–218.

_____1980b, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Arkoma Basin of Oklahoma: Oklahoma Geological Survey Bulletin 129, 136 p., 12 pls.

_____1981a, Biostratigraphic and paleoenvironmental relations: a Late Silurian example, *in* Broadhead, T. W. (ed.), Lophophorates, notes for a short course organized by J. T. Dutro, Jr., and R. S. Boardman: University of Tennessee, Department of Geological Sciences, Studies in Geology 5, p. 154–169.

_____1981b, Arkoma Basin model: Middle Ordovician through Early Devonian [abstract]: American Association of Petroleum Geologists Bulletin, v. 65, p. 1495. [Reprinted in Oklahoma Geology Notes, v. 42, p. 30].

_____1982a, Late Ordovician–Silurian brachiopod biostratigraphy, southern Midcontinent region, *in* Bruton, D. L.; and Williams, S. H. (eds.), Fourth International Symposium on the Ordovician System: University of Oslo, p. 4.

_____1982b, Early and middle Paleozoic history of the Anadarko Basin [abstract]: Geological Society of America Abstracts with Programs, v. 14, p. 105.

_____1983a, Welling–Fite–Corbin Ranch strata, *part 1 of* Upper Bromide Formation and Viola Group (Middle and Upper Ordovician) in eastern Oklahoma: Oklahoma Geological Survey Bulletin 132, p. 1–23.

_____1983b, The Late Ordovician brachiopod genera *Lepidocyclus* and *Hiscobeccus, part 3 of* Upper Bromide Formation and Viola Group (Middle and Upper Ordovician) in eastern Oklahoma: Oklahoma Geological Survey Bulletin 132, p. 36–44, 7 pls.

_____1983c, *Coelospira concava* (Hall) from the Pinetop Chert (Early Devonian), Ouachita Mountains, Oklahoma: Journal of Paleontology, v. 57, p. 1244–1260, 9 pls.

_____1983d, Oolitic strata of the Keel Formation and Edgewood Group (Late Ordovician and Early Silurian), Texas Panhandle to the Mississippi Valley [abstract]: Geological Society of America Abstracts with Programs, v. 15, p. 222–223.

_____1984a, Arkoma Basin model: Middle Ordovician through Early Devonian, *in* Borger, J. G., II (ed.), Technical proceedings of the 1981 American Association of Petroleum Geologists Mid-Continent Regional Meeting: Oklahoma City Geological Society, p. 116–118.

_____1984b, Correction of a Pinetop (Lower Devonian) collecting locality: Journal of Paleontology, v. 58, p. 1135.

_____1985, Brachiopods from the Turkey Creek Limestone (Early Devonian), Marshall County, southern Oklahoma: Oklahoma Geological Survey Bulletin 138, 20 p.

_____1989, Depositional and post-depositional history of middle Paleozoic (Late Ordovician through Early Devonian) strata in the ancestral Anadarko Basin, *in* Johnson, K. S. (ed.), Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 143–146.

Amsden, T. W.; and Barrick, J. E., 1986, Late Ordovician–Early Silurian strata in the central United States and the Hirnantian Stage: Oklahoma Geological Survey Bulletin 139, 95 p., 7 pls.

_____1988, Late Ordovician through Early Devonian annotated correlation chart and brachiopod range charts for the southern Midcontinent region, U.S.A., with a discussion of Silurian and Devonian conodont faunas: Oklahoma Geological Survey Bulletin 143, 66 p., 7 pls.

Amsden, T. W.; and Biernat, Gertruda, 1965, Pentameridina, *in* Moore, R. C. (ed.), *pt. H of* Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press, p. H523–H552.

Amsden, T. W.; and Huffman, G. G., 1958, Frisco brachiopod from a Hunton core, Pottawatomie County: Oklahoma Geology Notes, v. 18, p. 73–76.

Amsden, T. W.; and Klapper, Gilbert, 1972, Misener Sandstone (Middle–Upper Devonian), north-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 56, p. 2323–2334.

Amsden, T. W.; and Miller, A. K., 1942, Ordovician conodonts from the Bighorn Mountains of Wyoming: Journal of Paleontology, v. 16, p. 301–306.

Amsden, T. W.; and Rowland, T. L., 1965, Silurian stratigraphy of northeastern Oklahoma: Oklahoma Geological Survey Bulletin 105, 174 p., 18 pls.

_____1967a, Geologic maps and stratigraphic cross sections of Silurian strata and Lower Devonian formations in Oklahoma: Oklahoma Geological Survey Map GM-14, scale 1:750,000.

_____1967b, Résumé of Silurian and Devonian strata in the subsurface of Oklahoma, *in* Toomey, D. F. (ed.), Symposium on Silurian–Devonian rocks of Oklahoma and environs: Tulsa Geological Society Digest, v. 35, p. 22–24.

_____1967c, Silurian–Devonian relationship in Oklahoma, *in* Oswald, D. H. (ed.), International symposium on the Devonian System: Alberta Society of Petroleum Geologists, v. 2, p. 949–959.

_____1971, Silurian and Lower Devonian (Hunton) oil- and gas-producing formations: American Association of Petroleum Geologists Bulletin, v. 55, p. 104–109.

Amsden, T. W.; and Sweet, W. C., 1983, Upper Bromide Formation and Viola Group (Middle and Upper Ordovician) in eastern Oklahoma: Oklahoma Geological Survey Bulletin 132, 76 p., 14 pls.

Amsden, T. W.; and Ventress, W. P. S., 1963, Articulate brachiopods of the Frisco Formation (Devonian), *pt. 1 of* Early Devonian brachiopods of Oklahoma: Oklahoma Geological Survey Bulletin 94, p. 9–140, 12 pls.

Amsden, T. W.; Boucot, A. J.; and Johnson, J. G., 1967a, *Conchidium* and its separation from the subfamily pentamerinae: Journal of Paleontology, v. 41, p. 861–867, 3 pls.

Amsden, T. W.; Caplan, W. M.; Hilpman, P. L.; McGlasson, E. H.; Rowland, T. L.; and Wise, O. A., Jr., 1967b, Devonian of the southern Midcontinent area, United States, *in* Oswald, D. H. (ed.), International symposium on the Devonian System: Alberta Society of Petroleum Geologists, v. 1, p. 913–932.

Amsden, T. W.; Klapper, Gilbert; and Ormiston, A. R., 1968, Lower Devonian limestone of post-Hunton age, Turkey Creek Inlier, Marshall County, south-central Oklahoma: American Association of Petroleum Geologists Bulletin, v. 52, p. 162–166.

Amsden, T. W.; Toomey, D. F.; and Barrick, J. E., 1980, Paleoenvironment of Fitzhugh Member of Clarita Formation (Silurian, Wenlockian), southern Oklahoma: Oklahoma Geological Survey Circular 83, 54 p., 7 pls.

Barrick, J. E.; Klapper, Gilbert; and Amsden, T. W., 1990a, Stop 1: Hunton Group (Late Ordovician–Early Devonian), *in* Ritter, S. M. (ed.), Early to middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 5–9.

_____1990b, Late Ordovician–Early Devonian conodont succession in the Hunton Group, Arbuckle Mountains and Anadarko Basin, Oklahoma, *in* Ritter, S. M. (ed.), Early to middle Paleozoic conodont biostratigraphy of the Arbuckle Mountains, southern Oklahoma: Oklahoma Geological Survey Guidebook 27, p. 55–62.

Boucot, A. J.; and Amsden, T. W., 1958, New genera of brachiopods, *pt. 4 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 78, p. 159–170, 1 pl.

_____1963, Virgianidae, a new family of pentameracean brachiopods: Journal of Paleontology, v. 37, p. 296.

_____1964, *Chonostrophiella*, a new genus of chonostrophid brachiopod: Journal of Paleontology, v. 38, p. 881–884.

Branson, C. C.; and Amsden, T. W., 1958, *Conocardium* from the Hunton Group: Oklahoma Geology Notes, v. 18, p. 147–151, 1 pl.

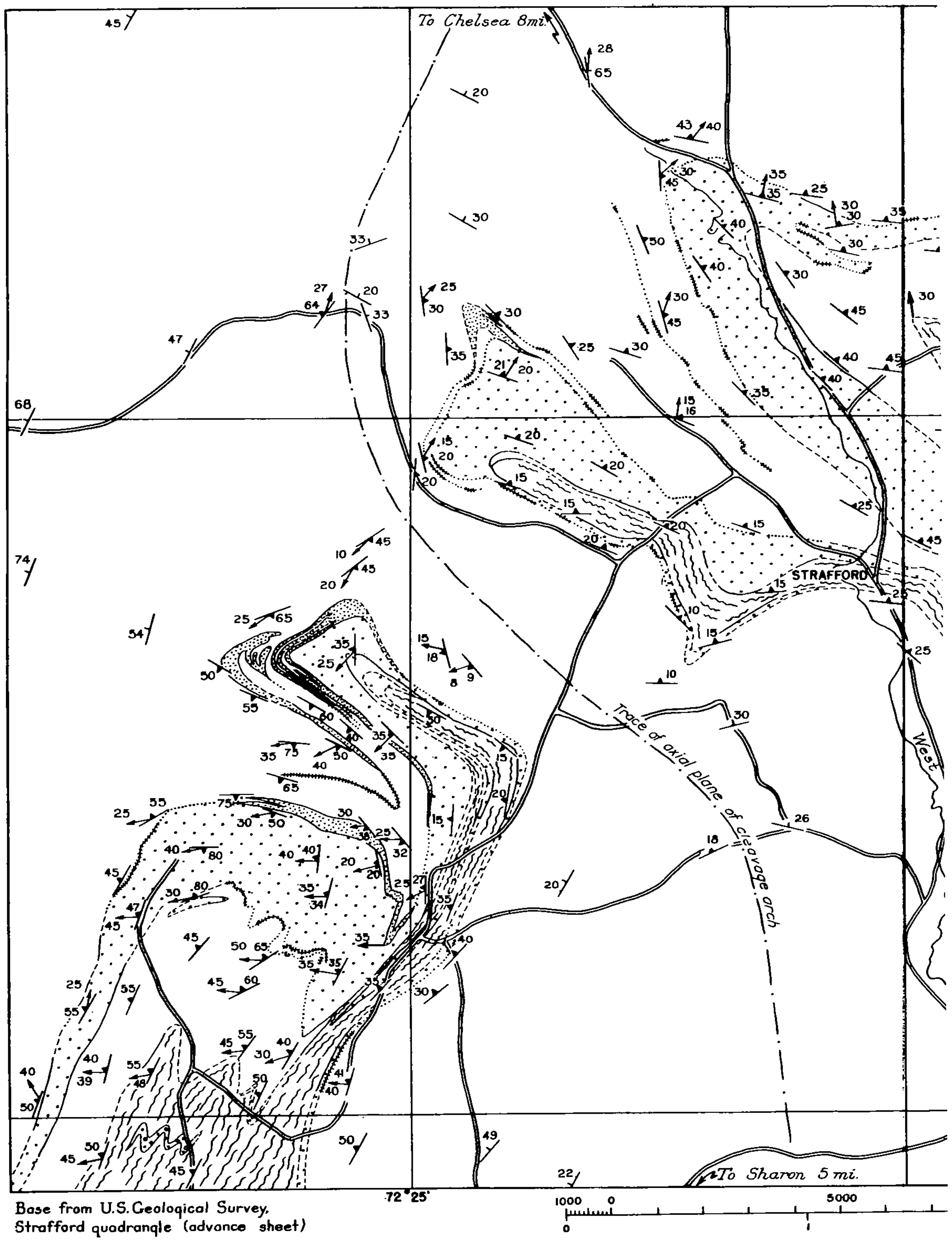
Branson, C. C.; Elias, M. K.; and Amsden, T. W., 1959, Type of *Goniatites choctawensis:* Oklahoma Geology Notes, v. 19, p. 157–164.

Kirk, E.; and Amsden, T. W., 1952, Upper Silurian brachiopods from southeastern Alaska: descriptions and illustrations of a fauna from the islands of Kosciusko and Heceta: U.S. Geological Survey Professional Paper 233-C, p. 53–66, 4 pls.

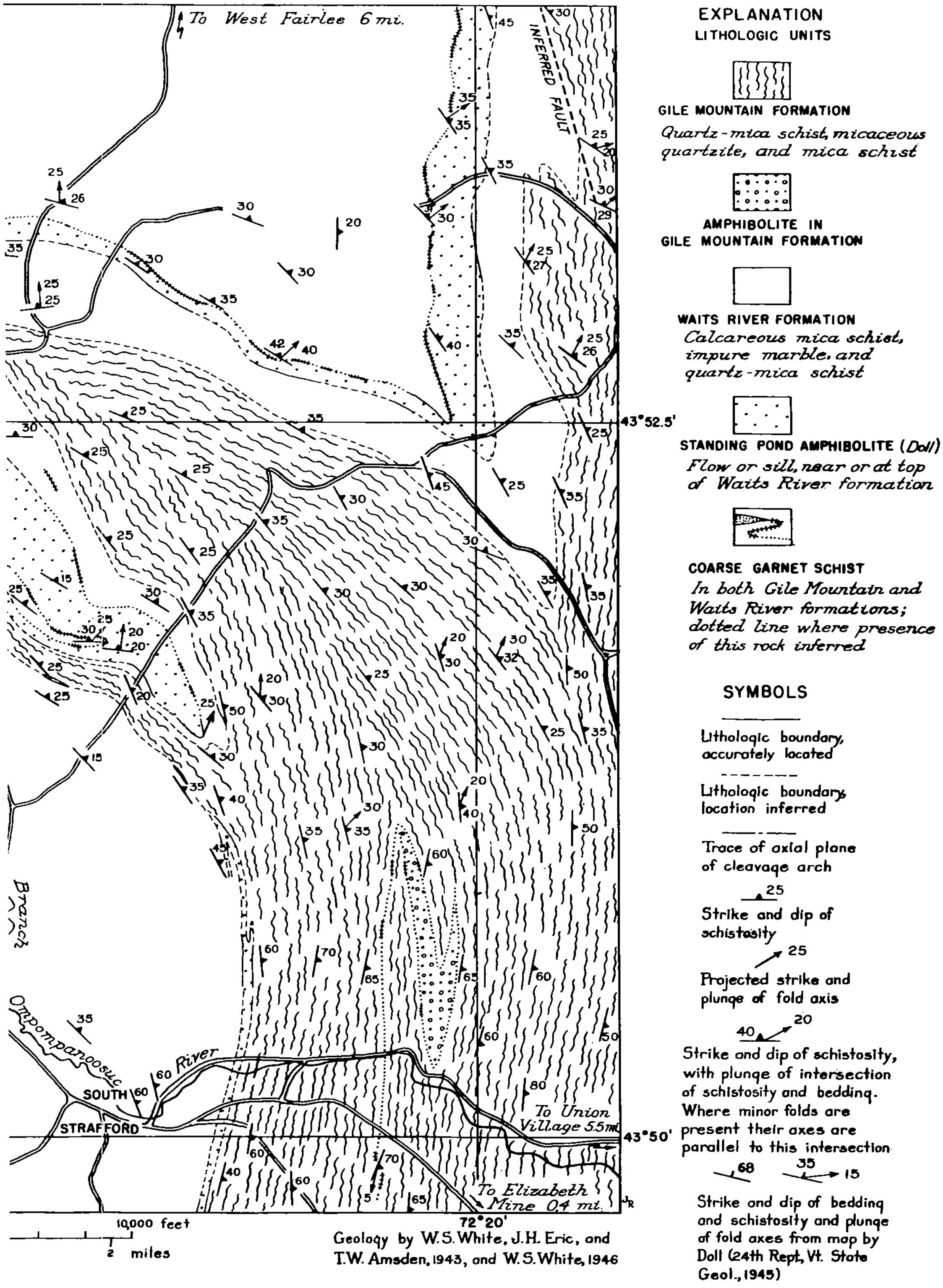
Johnson, K. S.; Amsden, T. W.; Denison, R. E.; Dutton, S. P.; Goldstein, A. G.; Rascoe, Bailey, Jr.; Sutherland, P. K.; and Thompson, D. M., 1988, Southern Midcontinent region, *in* Sloss, L. L. (ed.), Sedimentary cover—North American Craton, U.S.: Geological Society of America, The Geology of North America, v. D-2, p. 307–359, 2 pls. [Reprinted as Geology of the southern Midcontinent: Oklahoma Geological Survey Special Publication 89-2, 53 p., 2 pls.]

Sutherland, P. K.; and Amsden, T. W., 1959, A re-illustration of the trilobite *Lonchodomas mcgeheei* Decker from the Bromide Formation (Ordovician) of southern Oklahoma: Oklahoma Geology Notes, v. 19, p. 212–219, 2 pls.

White, W. S.; Eric, J. H.; and Amsden, T. W., 1979, Preliminary report on Orange and Gove copper mines, Strafford, Vermont: U.S. Geological Survey Open-File Report 79-0352, 6 p.



Geologic map of the slate belt of Vermont, compiled by a field party of the Strategic Minerals Section of the



U.S. Geological Survey for whom Tom Amsden worked from 1943–45.