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# THE ATOKAN SERIES (PENNSYLVANIAN) AND ITS BOUNDARIES—A SYMPOSIUM

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**Title Page Illustration**

*Fusulinella barnettensis* Douglass and Nestell, n. sp.; axial section of paratype, ×30. This specimen was collected from the Atoka Formation northwest of Clarita, Coal County, south-central Oklahoma. (See plate 3, figure 2, of Douglass and Nestell's paper, pages 34 and 35.)

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## PREFACE

A symposium on "The Atokan Series and Its Boundaries" was held in Norman, Oklahoma, on March 29, 1982, at the annual meeting of the Geological Society of America, South-Central Section. Prior to the symposium, a two-day field trip visited the type area for the Atokan Series in southern Oklahoma, an area not previously visited on a formal field trip (see OGS Guidebook 20). Fourteen invited papers were presented at the symposium by speakers from both the United States and Canada, and these papers, after revision by the authors, form the volume here published.

By the late 1940's the main divisions of the Midcontinent Pennsylvanian System had emerged as the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian Series. In this system, only the usage of the term Atokan has been controversial. Thus, one of the purposes of the Norman symposium and the field trip was to examine both the biostratigraphic and lithostratigraphic bases of the Atokan Series in its type region in Oklahoma. In addition, the symposium provided the occasion for the presentation of papers on important sequences of the same age in various parts of North America and for discussions of Early and Middle Pennsylvanian chronostratigraphic terminology as used throughout the continent.

At the conclusion of the symposium, participants and members of the audience were invited to make statements regarding the papers presented and the Atokan Series in general. These comments and those that they generated were tape recorded and are published at the end of this volume.

A general conclusion of the symposium, apparently agreed upon by all, is that the next step in stabilizing Pennsylvanian chronostratigraphic nomenclature and stratigraphic procedure on a continent-wide basis is to work toward the selection of boundary stratotypes both for the Pennsylvanian System and for its various series. It is hoped that the publication of this symposium on the Atokan Series will provide an impetus for the description by many investigators across the continent of detailed Pennsylvanian faunal sequences based, where possible, on several fossil groups. Such faunal sequences, in stratigraphic intervals where deposition may have been nearly continuous, would provide the best basis for eventual and careful selection of boundary stratotypes in the Pennsylvanian System.

This symposium was an outgrowth of our work on upper Morrowan–lower Atokan biostratigraphy over the past few years. We acknowledge major funding of that research by the National Science Foundation (Grant EAR-7926336). We thank John Lance, Program Director, Stratigraphy and Paleontology Division, for his support and encouragement of our research efforts. We also thank Charles J. Mankin, Director of the Oklahoma Geological Survey, for his interest in our work and his willingness to publish this volume. The high quality of this publication is a tribute to the efforts of William D. Rose, editor for the Oklahoma Geological Survey.

Patrick K. Sutherland
Walter L. Manger

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# THE ATOKAN SERIES: AN INTERVAL IN SEARCH OF A NAME

PATRICK K. SUTHERLAND[1] and WALTER L. MANGER[2]

**Abstract**—Earlier refinement of Pennsylvanian fusulinid zonation equated the Midcontinent Morrowan Series with the Zone of *Millerella* and the Desmoinesian Series with the Zone of *Fusulina*. The intervening interval, representing the Zones of *Profusulinella* and *Fusulinella*, had been variously termed Bendian, Lampasan, or Derryan, but confusion and inaccuracy surrounded application of these names and recognition of their boundaries. Thus, the Midcontinent name Atokan was proposed as a subdivision of the fusulinid zonation, with only incidental concern given to relations in the type region. Further study and development of biostratigraphic zonations based on other taxa have identified inadequacies with the Atokan Series as originally proposed. A gap exists at the base of the series in its type area owing to an unconformable relationship between the Atoka Formation and the underlying Wapanucka Limestone, which was specifically excluded from the Atokan Series. The top of the Atokan Series in its type area apparently overlaps the Desmoinesian Series, based on the occurrence of the fusulinid *Beedeina*. We propose as working definitions that the appearance of the conodont *Diplognathodus* and the foraminifer *Eoschubertella* be taken to mark the base of the Atokan Series, and the appearance of *Beedeina* be taken to mark the base of the Desmoinesian Series. Abandonment of the term Atokan in favor of some new name is unlikely as well as undesirable. Boundary stratotypes are needed, however, to resolve the several remaining problems affecting recognition and correlation of the Atokan.

## INTRODUCTION

The two-decade period from 1930 to 1950 witnessed an intensive effort to synthesize existing knowledge pertaining to the whole of North American Phanerozoic stratigraphy. Coordination of the project was the responsibility of the Committee on Stratigraphy, formed in 1932 by the National Research Council of the National Academy of Science. The committee was charged with producing a series of correlation charts for all geologic periods, to replace the U.S. Geological Survey Correlation Papers that were then nearly 50 years old. Synthesis of stratigraphic data gained further impetus about this time from a codification of stratigraphic principles and practices (Ashley and others, 1933). Rising recognition of the success of regional and intercontinental correlations based on biostratigraphic zones and narrowly defined marker species led quickly to establishment of a formal chronostratigraphic hierarchy to serve as the framework for each correlation chart.

Studies of the Carboniferous System figured prominently in the lithostratigraphic and chronostratigraphic synthesis of the mid-20th century. Subcommittees for the Mississippian and Pennsylvanian were organized by the Committee on Stratigraphy, and in 1939 the American Association of Petroleum Geologists formed its own Carboniferous Subcommittee of the Committee on Geologic Names and Correlations. Reports on the Pennsylvanian System resulting from the deliberations of these subcommittees were published by Moore and others (1944) and Cheney and others (1945). In addition, many papers dealing with classification and subdivision of the Pennsylvanian appeared during the same period (for example, Harlton, 1934, 1938; Cheney, 1940; Thompson, 1942; Spivey and Roberts, 1946). Together, these studies led to the chronostratigraphic framework for the Pennsylvanian System that exists today.

## A MIDCONTINENT STANDARD

Traditionally, the type Pennsylvanian has been regarded as those strata exposed in the coal fields of central and western Pennsylvania, although the first appearance of the name was in a report on the geology of northern Arkansas (Williams, 1891). The main divisions of the Appalachian Pennsylvanian (ascending order) are the Pottsville, Allegheny, Conemaugh, and Monongahela Series. However, these units were used principally in a lithostratigraphic sense, as groups or supergroups with boundaries placed at arbitrarily designated coals or limestones traceable presumably throughout most or all of the Appalachian Basin. Terrigenous strata, much of it of continental ori-

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gin, punctuated by unconformities, dominate the Pennsylvanian section in its type region. Biostratigraphic control, where available, was and is based almost entirely on megaflora. The inability to effect widespread correlation of the Appalachian-based standard focused attention, particularly during the second quarter of this century, on the Midcontinent Pennsylvanian record. There, the better development of fossiliferous marine zones, in addition to some floras, plus extensive stratigraphic and biostratigraphic study, provided a firm basis for continental and intercontinental correlations. In addition, Pennsylvanian strata of the Midcontinent serve as important reservoirs for petroleum, and thus these strata received the detailed attention of many geologists during that period. Publications on lithostratigraphy, surface/subsurface correlations, and chronostratigraphic subdivisions appeared almost monthly in journals, guidebooks, and charts published during the 1930's and 1940's. The amount of this literature, and the success in correlating Midcontinent subdivisions on a regional basis, mandated the replacement of an Appalachian-based, standard chronostratigraphic framework with one from the Midcontinent. At first, the Pennsylvanian in the Midcontinent was divided into four series, and there was some experimentation in the use of different names. For example, Moore (1933) proposed the use of Bend, Des Moines, Pottawatomie, and Virgil. In later papers, however, he and other authors most commonly used Morrowan, Desmoinesian, Missourian, and Virgilian (that is, Moore, 1937). In these usages, the Atoka Formation was included in the lower part of the Desmoinesian Series. The first use of five series was proposed by Cheney (1940), and by the late 1940's the main divisions of the Midcontinent Pennsylvanian had emerged as the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian Series. In this system, only the usage of Atokan has been controversial and unsettled.

## HISTORICAL DEVELOPMENT OF THE ATOKAN SERIES

At least four names have been applied to the post-Morrowan and pre-Desmoinesian interval of the Pennsylvanian System: Bendian, Lampasan, Derryan, and Atokan.

### Bendian Series

The name Bend Series was originally proposed by the Texas Geological Survey (Dumble, 1890) for a lithostratigraphic unit that comprises beds now referred to the Barnett Shale ( = lower Bend Shale), Marble Falls Limestone, and Smithwick Shale (ascending order). Inclusion of the Barnett Shale, now known to represent a Meramecian–early Chesterian age, in the Bendian confused correlation of the interval. Attempts to restrict the Bendian to the Marble Falls and Smithwick, and thus to the Pennsylvanian System, were ignored. Subsequently, Harlton (1934), in a study of the Carboniferous strata in southeastern and southern Oklahoma, proposed the Bendian as a separate system between the Mississippian and a restricted Pennsylvanian. It included the entire Stanley–Jackfork–Johns Valley sequence in the Ouachitas and the Springer–Lester sequence in the Ardmore Basin. The Bendian was said to include all post-Chesterian and pre-Desmoinesian strata, but Harlton placed the Atoka Formation in the Desmoinesian Series. Later, Harlton (1938) subdivided this Bendian system into two series, the Pushmataha (below) and the Morrowan, and maintained his placement of the Atoka Formation in the Desmoinesian Series. Harlton's proposals did not receive support. Plummer (1945) and Moore and Jeffords (1945), in papers completed in 1942 (R. M. Jeffords, written communication, 1983), used Morrowan for the Lower Marble Falls Limestone and Bendian for the Upper Marble Falls Limestone and Smithwick Formation. Yet no more than a year later, Moore supported the use of Lampasan in place of Bendian on the Pennsylvanian correlation chart (Moore and others, 1944). The term Bend has been used subsequently as a group name for the Marble Falls Limestone and Smithwick Shale in the Llano region of central Texas (Cheney, 1947; Cheney and Goss, 1952), and it is still widely used in that manner in the Texas subsurface.

### Lampasan Series

Cheney (1940) proposed the name Lampasan for the interval younger than the type Marble Falls ( = Morrowan in his usage) and older than the type Strawn ( = Desmoinesian), based on fusulinid correlations. Although no specific type section was proposed, the best outcrops were said to be those near the village of Bend, central Texas, which had been designated as type Bend by Dumble (1890). The Lampasan Series was accepted for the Pennsylvanian correlation chart by Moore and others (1944), where it was defined as being equivalent to the Zone of *Fusulinella*.[3] Unfortunately, regional correlations by Cheney (1940, 1947) and Cheney and others (1945) confounded the interpretation of the Lampasan in its type region. The details of this confusion were reviewed by Turner (1957). Basically, the controversy revolved around Cheney's subsurface lithostratigraphic correlations. The upper portion of the Lampasan in the subsurface, as correlated by Cheney, included beds that are clearly of Desmoinesian age, based on the occurrence of both *Fusulina* and *Wedekindellina* (Thompson, 1942; Spivey and Roberts, 1946). The lower Lampasan Series had been specifically defined to exclude all of the type Marble Falls, yet Spivey and Roberts (1946) reported a significant interval of post-Morrowan strata at the type section of the Marble Falls that produced fusulinids more advanced than *Millerella*. Those strata would have been unassigned with further use of Lampasan as originally defined. Cheney tried to resolve these problems by dividing the Lampasan into the Atoka and succeeding Kickapoo Creek Stages (Cheney and Goss, 1952), but there was little enthusiasm for the name after the proposal of the Atokan Series.

## Derryan Series

Thompson (1942) proposed the Derryan Series for all rocks in extreme south-central New Mexico that occur between the base of the Pennsylvanian System and the Desmoinesian Series. There, Pennsylvanian strata rest on the Devonian Percha Shale, although Thompson stated further that the series could be recognized by unspecified species of *Eoschubertella* and *Profusulinella* and that the Zone of *Fusulinella* was included in the upper part. Thompson did not discuss the relationship of the base of the Derryan to the Morrowan Series. Moore and Thompson (1949) utilized the names Derryan and Atokan interchangeably to designate the lowest stage of their proposed Oklan Series, but the latter chronostratigraphic unit has been ignored. Subsequently, the Derryan Series has come to be equated with the Zones of *Profusulinella* and *Fusulinella* and as a synonym of Atokan (Douglass, 1977). The use of Derryan has been sporadic, and confined essentially to the southwestern United States (for example, Webster, 1969; Lane and Straka, 1974). Recent study of the type Derryan by Lane and others (1972) shows that *Profusulinella* does not occur through the basal 15 feet. Instead, that interval is characterized by *Pseudostaffella*, and the lowest occurrence of *Eoschubertella* is no more than 2 or 3 feet above the base of the type section.[4] It should be noted that neither the name Derryan nor any of the formations proposed to define that series by Thompson (1942) are utilized presently by the New Mexico Bureau of Mines and Mineral Resources (Armstrong and others, 1979; Frank E. Kottlowski, personal communication to Robert H. Shaver, 1982).

## Atokan Series

Spivey and Roberts (1946), in studying the Lower Pennsylvanian fusulinid sequence in central Texas, proposed the name Atokan specifically to include a post-Morrowan and pre-Desmoinesian series represented by the post-*Millerella* and pre-*Fusulina–Wedekindellina* portions of the fusulinid zonation. This interval was characterized by foraminifers more advanced than *Millerella*, and included such forms as *Pseudostaffella*, *Ozawainella*, *Profusulinella*, and *Fusulinella* (Spivey and Roberts, 1946, table 1). The authors suppressed Lampasan as a series name for two reasons. First, they reported fusiform fusulinids in the type Marble Falls Limestone, which was thought to be totally Morrowan and thus excluded from the Lampasan (Cheney, 1940). Second, subsurface correlation of the Lampasan by Cheney (1940) included the Caddo Pool and Parks Groups, both of which contain *Wedekindellina*, according to Spivey and Roberts, and were thus Desmoinesian. The older term Bendian was rejected by them for the same reason: problems with subsurface correlations of the Caddo Pool and Park Groups. The term Derryanwasrejected because at its type locality it "is only about 130 feet thick, whereas the Atoka beds reach 7,000 feet in thickness" (Spivey and Roberts, 1946, p. 186).

Alternatively, the Atokan was used as a stage name by Moore and Thompson (1949) and by Cheney and Goss (1952), but those proposals never received widespread acceptance. We find it remarkable that, with the proposal of the name Atokan, use of the name Lampasan, selected for the Pennsylvanian correlation chart and published only 2 years earlier, ended without a single paper being published in its defense.

[3] Russell M. Jeffords, who was R. C. Moore's research assistant from 1940 to 1942, has kindly read this paper and has made many helpful suggestions for clarification, giving us the benefit of his historical perspective. He was present during many of the deliberations surrounding preparation of the Pennsylvanian correlation chart (Moore and others, 1944). He states that the correlation chart, as published, was based on a variety of criteria. These particularly included regional unconformities, significant faunal "breaks," and fossil occurrences used most commonly as "marker species," such as *Mesolobus striatus*. He contends that the fusulinid "zonation," which at the time was only at an early stage of development, was adapted to and did not precede recognition of the various series boundaries.

[4] Subsequent to the completion of this paper, Sutherland and Manger (1984) had occasion to visit a new road-cut exposure at the type Derryan on Interstate Highway 25, east of Derry, New Mexico. This new cut exposes the unconformity between Pennsylvanian rocks and the Devonian Percha Shale and a 2.5-foot exposure of a previously covered shale lying below the described base of the type Derryan. This Pennsylvanian shale has produced a well-preserved late Morrowan brachiopod fauna that includes *Zia novamexicana* Sutherland and Harlow, *Neochonetes*? *platynotus* (White), and *Plicochonetes*? cf. *P. arkansanus* (Mather). This fauna occurs also in the La Pasada Formation in northern New Mexico and in part in the Kessler Limestone Member of the Bloyd Formation in the type Morrowan of northwestern Arkansas. Thus, the lower type Derryan of New Mexico overlaps the type Morrowan of Arkansas and cannot be regarded as the precise equivalent of the Atokan Series.

### Conclusions

With increasing refinement of the fusulinid zonation, and reliance on the Midcontinent Pennsylvanian standard, the Morrowan Series became regarded as equivalent to the Zone of *Millerella*, and the Desmoinesian Series was equated with the Zone of *Wedekindellina* and *Fusulina* (=*Beedeina*, after Douglass, 1977). Those restrictions left the interval of the Zones of *Profusulinella* and *Fusulinella* without a name. Confusion and controversy surrounding the previously proposed terms Bendian, Lampasan, and Derryan encouraged proposal of a new name, particularly one from the Midcontinent region. The name Atokan was proposed as a subdivision of the fusulinid zonation, with only incidental reference given to relations in its type region. The rise of detailed zonations that were based on taxa such as conodonts, ammonoids, and brachiopods from other geologic provinces focused attention on the inadequacies of the Atokan Formation in its type area as a chronostratigraphic standard. Yet the name survived, and it becomes further ingrained in the literature with each published study of the Lower–Middle Pennsylvanian interval. It seems pointless now to propose yet another term for the interval. Instead, the challenge is to develop an understanding of the Atokan as a series, to resolve the controversy surrounding its recognition.

## ATOKAN SERIES—PRESENT UNDERSTANDING

Zachry and Sutherland (this volume) describe the regional lithostratigraphic relationships of the Atoka Formation in the Arkoma Basin. As a consequence of advocating retention of the name Atokan as a chronostratigraphic unit, some attention must be given to the biostratigraphic relations in the type region, regardless of how meager those data may be. Much of the Atokan controversy revolves around the designation of that type area. Spivey and Roberts (1946, p. 185), in proposing the Atokan Series, stated that "the Atoka formation be elevated to Atoka series and defined to include all the beds from the top of the Wapanucka limestone, Morrowan series, to the base of the Hartshorne sandstone, Des Moines series." Although transfer of lithostratigraphic units to chronostratigraphic use is repudiated by modern stratigraphic practice, it has characterized procedure in the past. In this case, that procedure is complicated further because no type section was designated in the original description of the Atoka Formation by Taff and Adams (1900).

### Atokan Type Area

That portion of the Arkoma Basin lying in southeastern Oklahoma coincides precisely with the area called the Choctaw Coal Field by Taff and Adams (1900). This area extends from the town of Atoka and the Arbuckle Mountains on the southwest, to the Arkansas state line on the east. It is bounded on the south by the front margin of the Ouachita Mountains and on the north by the Ozark Uplift and the Central Oklahoma Platform. Taff described the geology and coal resources of the southwestern and western part of this area (McAlester–Lehigh Coal Field or Western Choctaw Coal Field) in 1899. The following year, Taff and Adams (1900) described the eastern half of the area (Eastern Choctaw Coal Field). In the first paper, Taff named the coal-bearing formations, including the Hartshorne Sandstone and higher units. In the second paper, he and Adams named the underlying Atoka Formation. The name was based unquestionably on the town of Atoka, because Atoka County was not designated until Oklahoma statehood in 1907. It is clear that, although the Atoka Formation was named in a report on the Eastern Choctaw Coal Field, Taff had already studied and published on the area around the town of Atoka. We therefore conclude that one must start with the area that includes the town of Atoka in evaluating the Atoka Formation and the Atokan Series.

The town of Atoka is near the Choctaw Fault, which marks the frontal Ouachita thrust belt. It is obvious from the papers by both Taff (1899) and Taff and Adams (1900) that they studied only the geology of the Choctaw Coal Field. They made no mention of rocks with the character of the Ouachita fold belt, and Taff did not describe any turbidite formations in the central Ouachitas (south of the Ti Valley Fault). Those formations were not described until many years later, by other authors. There is, also, no evidence that Atoka strata at or near the town of Atoka include flysch sedimentation, as suggested by Shaver and Smith (1974).

The town of Atoka rests on that formation, but few exposures occur near the town. Branson (1962) stated that the area "in and near the northwestern corner of Atoka County . . . must serve as type for the formation and series." He added, however, that "the area has not been studied, the section has not been measured and no fossils have been found there." The area mentioned by Branson, about 12 miles west of the town of Atoka, serves no useful purpose as a reference, because the rocks there are poorly exposed and cannot be evaluated.

Most published biostratigraphic data from the Atoka Formation in this region have come from fossiliferous exposures in Coal and Pontotoc Counties, particularly in T. 1 S. and T. 1 N., R. 7 E. and R. 8 E. This area extends northwestward from Clarita for 6 to 12 miles, and begins about 18 miles northwest of the town of Atoka (see Sutherland and others, 1982, fig. 7). The part of this area that lies just northwest of Clarita and includes the

Goose Creek Valley was proposed by Strimple and Watkins (1969) as the type for their Atokan Stage. Sutherland and Manger (1983), in a review of problems concerning the Morrowan–Atokan boundary, supported the designation of this area as type for the Atokan Series, but included for reference the exposures 2 to 4 miles farther west in Pontotoc County, on Coal and Canyon Creeks (Sutherland and others, 1982, fig. 7). The area northwest of Clarita is considered the most significant reference for the series because it contains the only sequence of multiple fossil zones in the Atoka Formation in the entire region.

## Base of the Atokan Series

### *Northeastern Arbuckle Mountains*

In the original description of the Atokan Series, Spivey and Roberts (1946) specifically stated that the series excluded the Wapanucka Limestone of presumed Morrowan age. The Wapanucka–Atoka contact is exposed in only two areas in the Arkoma Basin, one on the eastern and northeastern flank of the Arbuckle Mountains and one along the frontal margin of the Ouachita Mountains. Unfortunately, Spivey and Roberts (1946) made no reference as to which of those areas would serve to establish Wapanucka age relations. The Wapanucka Formation was named by Taff (1901) for the town of Wapanucka, located in the first area at the eastern margin of the Arbuckle Mountains. The Wapanucka Formation underlies a regional unconformity at the base of the Atoka Formation throughout this area and along the northeastern flank of the Arbuckle Mountains. The regional decrease in thickness of the Atoka, from the Atoka town area northwestward to Clarita and beyond, supports the interpretation of regional westward transgression during early Atokan time. The Wapanucka in the Wapanucka–Clarita area consists of various fossiliferous, shallow-shelf carbonates that Grayson (this volume) places in the *Idiognathoides convexus* Zone, except for the localities where the highest strata contain his *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage. The *I. convexus* Zone occurs throughout the Kessler Limestone Member of the Bloyd Formation at the top of the type Morrowan Series in northwestern Arkansas (Lane and Straka, 1974). The *N.* n. sp. A–*I. ouachitensis* assemblage is missing in northwestern Arkansas, where it is believed to fall in the hiatus at the regional unconformity that overlies the Kessler and separates strata of Morrowan and Atokan age in that area (Grayson, 1979).

The Atoka Formation on the northeastern flank of the Arbuckle Mountains consists of interbedded shales and sandstones, with rare thin limestones. The total thickness of the formation north of Clarita is about 3,000 feet (Archinal, 1979). Thompson (1935a, 1935b) described *Pseudostaffella atokensis* and *Profusulinella fittsi* as occurring 100 feet above the base of the Atoka Formation on a tributary of Goose Creek, northwest of Clarita. An intensive search of the Goose Creek area (Sutherland and others, 1982) failed to locate the *P. fittsi* zone, or any other fusulinids, within the lowest few hundred feet of the formation. The lowest fusulinids found in this search in the type Atoka Formation are a group of closely related species of *Fusulinella* that include *F. prolifica* Thompson and *F. devexa* Thompson (Douglass and Nestell, this volume). This group occurs at several localities in this region and can be used as a basis for correlation within the area. These forms occur in the area north of Clarita and are about 400 feet above the base of the formation; they indicate a middle Atokan age.

Conodonts from the Atoka Formation north and northwest of Clarita have been studied by Grayson (this volume). Occurring in the lower part of the formation and at the base in one locality is an *Idiognathoides marginodosus* assemblage overlain by a *Neognathodus atokaensis* assemblage. In the area north of Clarita, the base of the *N. atokaensis* assemblage coincides approximately with the occurrences of the fusulinid species of the *Fusulinella prolifica–F. devexa* group just mentioned (Grayson, this volume). Grayson considers the *I. marginodosus* assemblage to indicate a middle Atokan age for the lower part of the formation in this area. It is Grayson's interpretation that, in the area northwest of Clarita, the unconformity between the Wapanucka and Atoka Formations spans the upper part of the Morrowan *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* interval and the whole of an Atokan *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage, as preserved in the frontal Ouachitas (Grayson, this volume).

### *Frontal Ouachita Mountains*

It is impossible to evaluate Wapanucka–Atoka relationships at the town of Atoka, because the Wapanucka Limestone is cut out by faulting there and for a distance of about 10 miles to the north (for map, see Hendricks and others, 1947). Farther to the northeast, beginning at Stringtown and extending almost continuously eastward to the Red Oak area, the Wapanucka Limestone forms the rather prominent "Limestone Ridge," the first prominent, steeply dipping fault ridge southeast and south of the Choctaw Fault. Virtually all of the descriptions in the literature of the Wapanucka in the frontal Ouachitas refer to exposures on some part of Limestone Ridge. However, Hendricks and others (1947) mapped as many as four additional thrust-faulted ridges, labeled as either Wapanucka Limestone or Chickachoc Chert, within 2 to 3 miles south of Limestone Ridge. The latter unit is a basinward facies of the Wapanucka. Each successive ridge to the south exposes a progressively deeper water facies, and depositional environments southward are considered to range from those of outer-shelf (Limestone Ridge) to slope deposits (Sutherland and Manger, 1979).

Grayson (1979) was the first to describe in detail the stratigraphic sequences exposed on these sequential ridges, and he used conodonts as a basis for correlating the diverse lithologic types. Morrowan–Atokan deposition was apparently continuous in this area. The top of the Wapanucka in the frontal Ouachitas has been placed, in some localities, at the top of the main Wapanucka Limestone (Grayson's member 2, 1979), as on Bandy Creek, south of Wilburton, Oklahoma (Bowsher and Johnson, 1968). In other localities, it has been placed at the top of a higher sandstone–limestone sequence (Grayson's member 4, 1979) that occurs above a middle shale of varying thickness. The confusion results from lateral variations in the upper member, from mostly limestone to all sandstone. Grayson (1980, p. 57) recorded that the middle shale ranges in thickness from 11 to 288 feet, and can be characterized as a basinward-thickening wedge. The upper sandstone–limestone member varies from 5 to 160 feet, and "the member is a basinward-thickening wedge that thickens mostly owing to an increased importance of quartz sandstone" (Grayson, 1980, p. 70). It seems likely that the lithostratigraphic relationships would be better understood if the name Wapanucka were restricted to main ridge-forming limestone (Grayson's member 2, 1979). New names should be given to both the middle shale member and the upper sandstone–limestone member, the latter believed to be a lateral facies of the basal Atoka "Spiro sand" in the subsurface of the Arkoma Basin (Bowsher and Johnson, 1968). We regard both intervals in the frontal Ouachitas as representing portions of the Atoka Formation.

It is interesting to note that the most recent biostratigraphic evidence indicates that the main Wapanucka Limestone in the frontal Ouachitas is Morrowan in age and that most or all of the upper sandstone–limestone member is Atokan in age, with the boundary most probably falling somewhere within the unfossiliferous middle shale member. The main Wapanucka Limestone (Grayson's member 2, 1979) carries the *Idiognathoides convexus* conodont fauna and, in its upper part, the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage of Grayson (this volume). Identical relations exist in the type Wapanucka in the eastern Arbuckle Mountains, although the higher assemblage has been found at only a few localities.

An arbitrary Atokan age is suggested for all or most of the upper sandstone–limestone member, based on the lowest occurrence of the foraminifer *Eoschubertella* (Groves and Grayson, this volume) and the occurrence of Grayson's (this volume) *Idiognathodus* n. sp.–*Diplognathodus* spp. conodont assemblage.

## Top of the Atokan Series

Biostratigraphic information is extremely limited for the upper part of the Atoka Formation throughout the Arkoma Basin. A prolific foraminiferal fauna, including *Fusulinella euthusepta* Henbest, was described by Galloway and Ryniker (1930) from 500 feet below the base of the Hartshorne Sandstone, at a single locality near the southern margin of the Arkoma Basin, 2.8 miles southwest of Red Oak, Latimer County, Oklahoma. In this area, the thickness of the Atoka Formation exceeds 6,000 feet.

In the type Atoka area north of Clarita in the northeastern Arbuckle Mountains, a single fossil locality is known from the "Griley" limestone in the upper part of the formation (Archinal, 1977, 1979; Archinal and others, 1982, Stop 4). This locality yields *Beedeina* (Douglass and Nestell, this volume). The occurrence of *Beedeina* indicates overlap by some portion of the upper part of the Atoka Formation, and consequently the Atokan Series, with the Desmoinesian Series (see Shaver and Smith, 1974; see Shaver, this volume, for discussion).

## Conclusions

Exposures in the vicinity of Clarita, Oklahoma, provide the only biostratigraphic data available for the Atoka Formation in what can reasonably be regarded as its type area. There, the Atoka Formation rests unconformably on the Wapanucka Limestone, which was specifically excluded from the Atokan Series by Spivey and Roberts (1946). The top of the Wapanucka Limestone contains a *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage. This conodont assemblage succeeds an *Idiognathoides convexus* assemblage that is found also in the Kessler Limestone of the type Morrowan Series. Both assemblages are accorded a Morrowan age, but a gap at the Morrowan–Atokan boundary exists as a result of the Wapanucka–Atoka unconformity. The basal type-Atoka strata yield an *Idiognathoides marginodosus* assemblage that would be considered of middle Atokan age elsewhere. The *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage is succeeded by an *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage that occurs with the foraminifer *Eoschubertella* in beds that we regard as representing the Atoka Formation in the frontal Ouachita Mountains. We propose as a working definition that the appearance of this assemblage and *Eoschubertella* marks the base of the Atokan Series, until a boundary stratotype is chosen to resolve the problem more precisely. It should be noted that the traditional placement of the Morrowan–Atokan boundary at the first appearance of the fusiform fusulinid *Profusulinella* is not supported by relations in the type area, and excludes a significant post-Morrowan section from the Atokan Series.

The upper Atokan Series apparently overlaps the Desmoinesian Series, based on the occurrence of the fusulinid *Beedeina* in the "Griley" limestone, but little refinement of relationships is available from the type Atoka Formation.

## REFERENCES CITED


**Archinal, B. E.,** 1977, The lithostratigraphy of the Atoka Formation (Lower Pennsylvanian) along the southwestern margin of the Arkoma Basin, Oklahoma: University of Oklahoma unpublished M.S. thesis, 172 p.

———1979, Atoka Formation (Pennsylvanian) deposition and contemporaneous structural movement, southwestern Arkoma Basin, Oklahoma, *in* Hyne, N. J., editor, Pennsylvanian sandstones of the Mid-Continent: Tulsa Geological Society Special Publication 1, p. 259–267.

**Archinal, B. E., Sutherland, P. K., Grayson, R. C., Jr., Douglass, R. C.,** and **Nestell, M. K.,** 1982, Stop descriptions—northeastern Arbuckle Mountains, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey, Guidebook 20, p. 19–29.

**Armstrong, A. K., Kottlowski, F. E., Stewart, W. J., Mamet, B. L., Baltz, E. H., Siemers, W. T.,** and **Thompson, S.,** 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—New Mexico, *in* The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-M–DD, p. W1–W27.

**Ashley, G. H.,** and others, 1933, Classification and nomenclature of rock units: Geological Society of America Bulletin, v. 40, p. 423–459.

**Bowsher, A. L.,** and **Johnson, N. L.,** 1968, Road log for second day of field trip, *in* Cline, L. M., editor, A guidebook to the Geology of the Western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geological Society Guidebook, p. 24–61.

**Branson, C. C.,** 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C., editor, Pennsylvanian System in the United States, a symposium: American Association of Petroleum Geologists, p. 431–460.

**Cheney, M. G.,** 1940, Geology of north-central Texas: American Association of Petroleum Geologists Bulletin, v. 24, p. 65–118.

———1947, Pennsylvanian classification and correlation problems in north-central Texas: Journal of Geology, v. 55, p. 202–219.

**Cheney, M. G.,** and **Goss, L. F.,** 1952, Tectonics of central Texas: American Association of Petroleum Geologists Bulletin, v. 36, p. 2237–2265.

**Cheney, M. G., Dott, R. H., Hake, B. F., Moore, R. C., Newell, N. D., Thomas, H. D.,** and **Tomlinson, C. W.,** 1945, Classification of Mississippian and Pennsylvanian rocks of North America: American Association of Petroleum Geologists Bulletin, v. 29, p. 125–169.

**Douglass, R. C.,** 1977, The development of fusulinid biostratigraphy, *in* Kauffman, E. G., and Hazel, J. E., editors, Concepts and methods of biostratigraphy: Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, p. 463–481.

**Dumble, E. T.,** 1890, Report of the state geologist for 1889: Texas Geological Survey Annual Report 1, p. xvii–lxxv.

**Galloway, J. J.,** and **Ryniker, C.,** 1930, Foraminifera from the Atoka formation of Oklahoma: Oklahoma Geological Survey Circular 21, 37 p.

**Grayson, R. C., Jr.,** 1979, Stop descriptions—fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

———1980, The stratigraphy of the Wapanucka Formation (lower Pennsylvanian) along the frontal margin of the Ouachita Mountains, Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 320 p.

**Harlton, B. H.,** 1934, Carboniferous stratigraphy of the Ouachitas with special study of the Bendian: American Association of Petroleum Geologists Bulletin, v. 18, p. 1018–1049.

———1938, Stratigraphy of the Bendian of the Oklahoma salient of the Ouachita Mountains: American Association of Petroleum Geologists Bulletin, v. 22, p. 852–914.

**Hendricks, T. A., Gardner, L. S., Knechtel, M. M.,** and **Averitt, Paul,** 1947, Geology of the western part of the Ouachita Mountains of Oklahoma: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 66, scale 1:42,240, 3 sheets.

**Lane, H. R., Sanderson, G. A.,** and **Verville, G. J.,** 1972, Uppermost Mississippian–basal Middle Pennsylvanian conodonts and fusulinids from several exposures in the south-central and southwestern United States: International Geological Congress, 24th, Montreal, 1972, sec. 7, Palaeontology, p. 549–555.

**Lane, H. R.,** and **Straka, J. J.,** 1974, Late Mississippian and early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

**Moore, R. C.,** 1933, Proposed new type section of the Pennsylvanian system [abstract]: Geological Society of America Bulletin, v. 43, p. 279.

———1937, Upper Carboniferous rocks of southeastern Kansas and northeastern Oklahoma: Kansas Geological Society, 11th Annual Field Conference, p. 9–16.

**Moore, R. C.,** and **Jeffords, R. M.,** 1945, Description of Lower Pennsylvanian corals from Texas and adjacent states: University of Texas Publication 4401, p. 77–209.

**Moore, R. C.,** and **Thompson, M. L.,** 1949, Main divisions of Pennsylvanian period and system: American Association of Petroleum Geologists Bulletin, v. 33, p. 275–301.

**Moore, R. C.,** and others, 1944, Correlation of Pennsylvanian formations of North America: Geological Society of America Bulletin, v. 55, p. 657–706.

**Plummer, F. B.,** 1945, Stratigraphy of the Lower Pennsylvanian coral-bearing strata of Texas: University of Texas Publication 4401, p. 63–76.

**Shaver, R. H.,** and **Smith, S. G.,** 1974, Some Pennsylvanian kirkbyacean ostracods of Indiana and Midcontinent series terminology: Indiana Geological Survey Bulletin 31, 59 p.

**Spivey, R. C.**, and **Roberts, T. G.**, 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Strimple, H. L.**, and **Watkins, W. T.**, 1969, Carboniferous crinoids of Texas with stratigraphic implications: Palaeontographica Americana, v. 6, p. 141–275.

**Sutherland, P. K.**, **Archinal, B. E.**, and **Grubbs, R. K.**, 1982, Morrowan and Atokan (Pennsylvanian) stratigraphy in the Arbuckle Mountains area, Oklahoma, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 1–17.

**Sutherland, P. K.**, and **Manger, W. L.**, editors, 1979, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, 81 p.

**Sutherland, P. K.**, and **Manger, W. L.**, 1983, The Morrowan–Atokan (Pennsylvanian) boundary problem: Geological Society of America Bulletin, v. 94, p. 543–548.

———1984, Morrowan brachiopods in the type "Derryan" Series (Pennsylvanian), New Mexico [abstract]: Geological Society of America Abstracts with Programs, v. 16, p. 115.

**Taff, J. A.**, 1899, Geology of the McAlester–Lehigh coal field, Indian Territory: U.S. Geological Survey Annual Report 19, part 3, p. 425–456.

———1901, Description of the Coalgate quadrangle [Indian Territory]: U.S. Geological Survey Geologic Atlas, Folio 74, 6 p.

**Taff, J. A.**, and **Adams, G. I.**, 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 257–311.

**Thompson, M. L.**, 1935a, The fusulinid genus *Staffella* in America: Journal of Paleontology, v. 9, p. 111–120.

———1935b, Fusulinids from the lower Pennsylvanian Atoka and Boggy formations of Oklahoma: Journal of Paleontology, v. 9, p. 291–306.

———1942, Pennsylvanian system in New Mexico: New Mexico School of Mines Bulletin 17, 90 p.

**Turner, G. L.**, 1957, The Lampasas series, *in* Conselman, F. B., editor, Abilene and Fort Worth Geological Societies 1957 joint field trip guidebook: Abilene Geological Society and Fort Worth Geological Society, p. 85–90.

**Webster, G. D.**, 1969, Chester through Derry conodonts and stratigraphy of northern Clark and southern Lincoln Counties, Nevada: University of California Publications in Geological Sciences, v. 79, 121 p.

**Williams, H. S.**, 1891, The formations of Washington County, *in* Branner, J. C., Annual report of the Geological Survey of Arkansas for 1888: v. 4, p. xiii.

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# STRATIGRAPHY AND DEPOSITIONAL FRAMEWORK OF THE ATOKA FORMATION (PENNSYLVANIAN) ARKOMA BASIN OF ARKANSAS AND OKLAHOMA

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**Abstract**—The Atokan Series is represented by strata assigned to the Atoka Formation in the Arkoma Basin of Arkansas and Oklahoma. The Arkoma Basin is a peripheral foreland basin, bounded on the south by the Ouachita Fold Belt and on the north by the Ozark Uplift and the Central Oklahoma Platform.

The Atoka Formation crops out in a broad belt on the northern margin of the basin in the Ozark region of Oklahoma and Arkansas, where it unconformably overlies Morrowan strata of the McCully (Oklahoma) and Bloyd (Arkansas) Formations. Atoka strata are also exposed along the southern margin of the basin north of the Choctaw Fault, in Oklahoma, and in the frontal Ouachitas south of this fault. In the southwestern part of the Arkoma Basin, west of the town of Atoka, the underlying Wapanucka Limestone is truncated by pre-Atoka erosion against a depositional high known as the Hunton Arch. Subsequent westward transgression on this surface positioned successively younger Atokan strata unconformably above the Wapanucka Limestone and older beds. This unconformity extends throughout the northern and central parts of the Arkoma Basin, separating Atoka strata from the Wapanucka Limestone in Oklahoma and the Bloyd Formation in Arkansas.

The Atoka Formation is overlain throughout the axial part of the Arkoma Basin by the Hartshorne Sandstone and the McAlester Formation of Desmoinesian age. A pre-Desmoinesian unconformity truncates Atoka strata adjacent to the Arbuckle Mountains, in the west, and along the western margin of the Ozark Mountains, in northeastern Oklahoma.

The Atoka Formation ranges in thickness from a feather edge around the northern and western margins of the basin, to more than 15,000 feet adjacent to the Ouachita Fold Belt. Cyclic progradation of deltas from the north and northeast formed a succession of sandstone and shale units in Arkansas. Westward, in Oklahoma, the succession is dominated by shale.

The present-day Arkoma structural basin was, during Morrowan and early Atokan time, a shallow shelf that lay immediately north of the deep Ouachita Trough. The area became a depositional basin, beginning with deposition of the middle part of the Atoka Formation, by the development of down-to-the-south growth faults.

## INTRODUCTION

The Arkoma Basin is an elongate structural trough that extends as a surface feature from the Gulf Coastal Plain in central Arkansas westward for 250 miles to the Arbuckle Mountains in south-central Oklahoma (fig. 1). This structural basin ranges from 20 to 50 miles in width. It is bounded to the north and northwest by the Ozark Uplift and the Central Oklahoma Platform, respectively, and to the south by the intensely deformed Ouachita Fold Belt. The Arkoma Basin was depositionally part of the shelf that lay north of the Ouachita Trough during Cambrian to Early Pennsylvanian time. This broad shelf also included the southern part of the present-day Ozark Uplift. Shallow-shelf conditions persisted during Morrowan and early Atokan time, and the area did not become a depositional basin until the beginning of deposition of the middle part of the Atoka Formation, by the development of down-to-the-south growth faults. The pre-Atoka Cambrian to Lower Pennsylvanian strata in the Arkoma Basin are approximately 5,000 feet thick and show little southward thickening across the area.

The Atoka Formation, dominated by terrigenous clastic beds, ranges in thickness from 300 to 500 feet along the northern margin of the basin, adjacent to the Central Oklahoma Platform and the Ozark Uplift. The formation thickens to the south toward the frontal Ouachita Mountains in Arkansas and Oklahoma, attaining a thickness approaching 15,000 feet at the southern margin of the basin (Berry and Trumbly, 1968).

The Atoka Formation is composed dominantly of shale in Oklahoma. Thin, discontinuous units of sandstone occur in the succession above a more continuous basal sandstone unit. To the east, in Arkansas, sandstone units are more prominent. Many individual sandstone units are continuous and can be traced across substantial parts of the basin.

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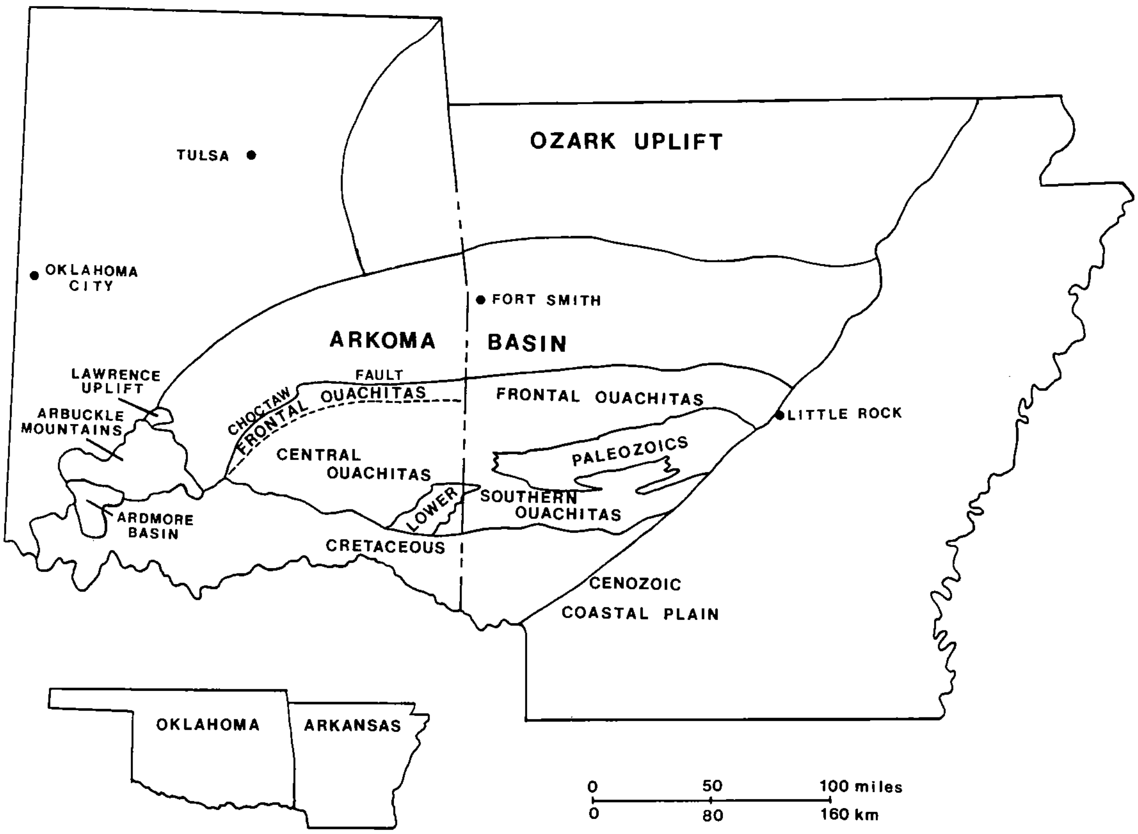


Figure 1. Arkoma Basin of Arkansas and Oklahoma, and surrounding geologic provinces.

In Oklahoma, Atoka strata are exposed along the northern margin of the basin adjacent to the Ozark Uplift, and in a thin belt immediately north of the frontal Ouachitas along the southern margin of the basin (fig. 2). In the central part of the basin, exposures occur in the core of several large anticlinal structures. The Atoka outcrop belt is more extensive in Arkansas. Exposures occur in broad belts adjacent to the Ozark Uplift at the northern margin of the basin and adjacent to the frontal Ouachitas at the southern margin. The outcrop belt is less continuous throughout the central part of the basin, where Atoka beds are concealed by belts of Desmoinesian strata.

The Atoka Formation was named by Taff and Adams (1900) for a succession of shale with lenticular sandstone units that underlies the Hartshorne Sandstone. They designated no type section or area, but the name comes from the town of Atoka (fig. 2). Owen (1858) and Simonds (1891) applied the name Millstone Grit Formation to an interval of sandstone and shale widely exposed in the Boston Mountains of Washington County, Arkansas, north of the Arkoma Basin (fig. 2). Ulrich (1904) replaced the name Millstone Grit with Winslow Formation, and Purdue (1907) definitively mapped the Winslow Formation in the Winslow Quadrangle of southern Washington County. Croneis (1930) suggested that the Winslow Formation of northern Arkansas is continuous with the earlier named Atoka Formation of south-central Oklahoma, and proposed that the name Atoka be applied to the succession in Arkansas.

# STRATIGRAPHY

## Relationships with Bounding Units

The Atoka Formation throughout most of the Arkoma Basin is bounded below by rocks of Morrowan age. Surface exposures of the boundary occur on the southern margin of the Ozark Uplift immediately north of the basin margin, and in the frontal Ouachitas of Oklahoma immediately south of the basin (fig. 2). In the Arkoma Basin, the boundary is exposed along a narrow belt through western Atoka and Coal Counties and eastern Pontotoc County, adjacent to the Arbuckle Mountains. On the Ozark Uplift, Atoka strata overlie the Bloyd Formation of Arkansas and the McCully Formation of eastern Oklahoma (fig. 3). The Atoka Formation is underlain by the Wapanucka Limestone in the frontal Ouachitas and in the southwestern part of the Arkoma Basin.

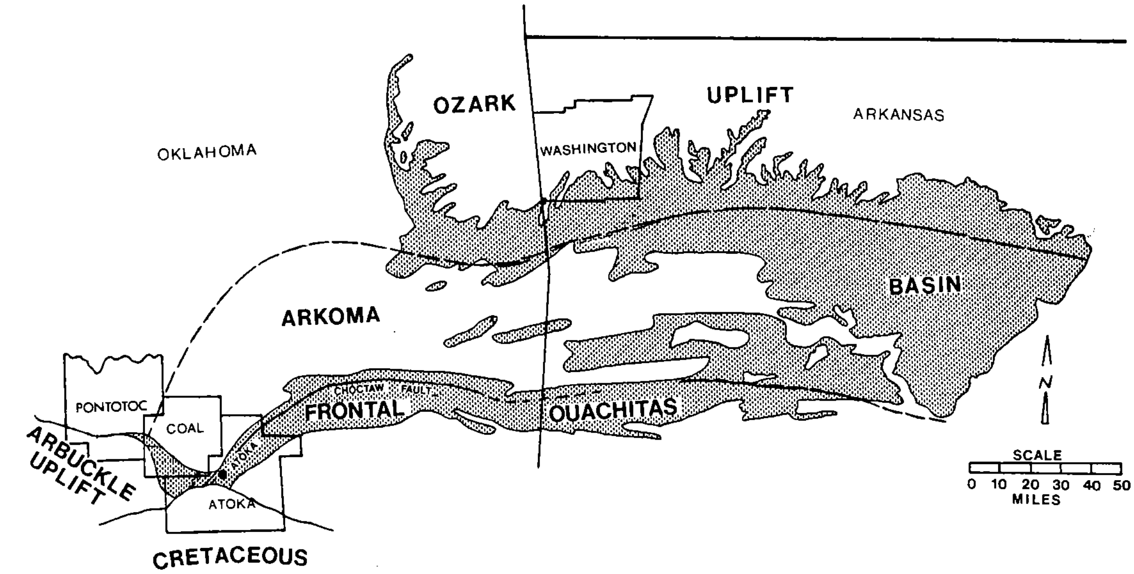


Figure 2. Stippled area depicts distribution of Atoka Formation outcrop belts in Arkoma Basin and in adjacent geologic provinces.

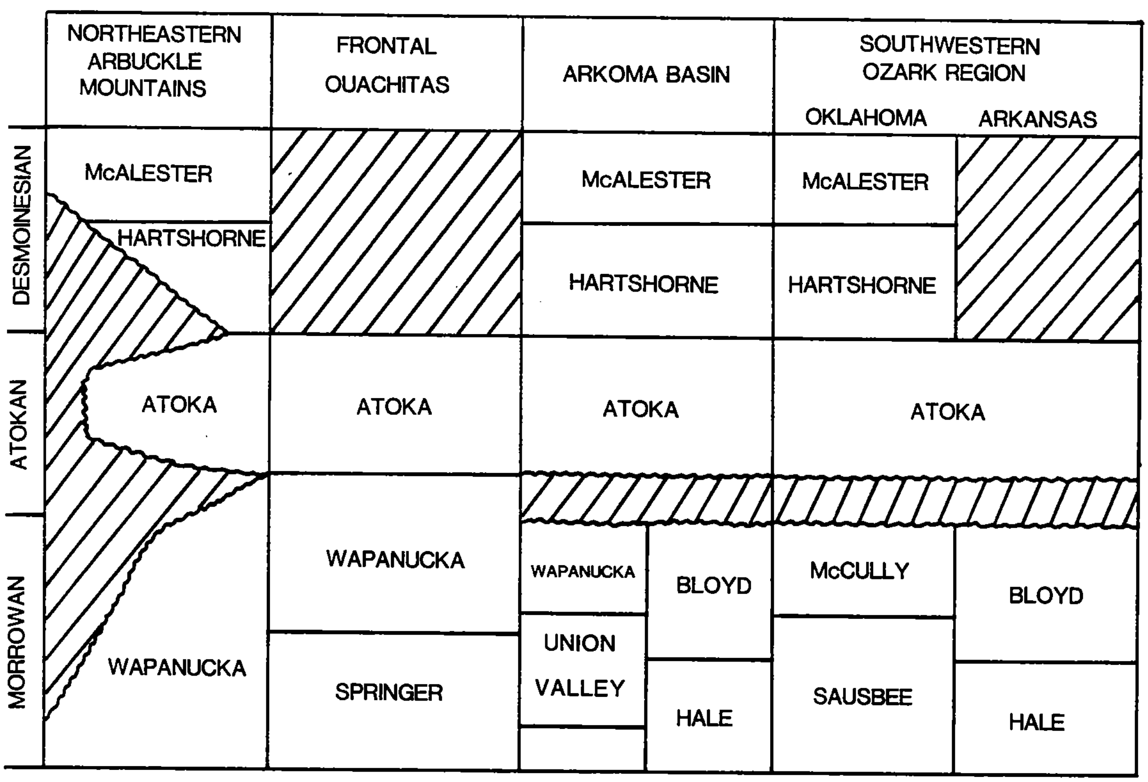


Figure 3. Stratigraphic relationships between Atoka Formation and bounding units above and below it in Arkoma Basin and adjacent areas.

The Hartshorne Sandstone of Desmoinesian age overlies the Atoka Formation throughout the central and southern parts of the basin (fig. 3). The Hartshorne is absent along the northern margin of the basin, along the flank of the Ozarks in Mayes County, Oklahoma (fig. 4), and adjacent to the Arbuckle Mountains in south-central Oklahoma, where strata of the overlying McAlester Formation rest directly on the Atoka. In Arkansas, Hartshorne strata are restricted to the central part of the basin, and the Atoka to the north and south is bounded above by the modern erosion surface.

## *Northwestern Arkansas*

The Atoka Formation overlies strata of the Bloyd Formation (Morrowan) throughout the northern part of the Arkoma Basin and on the Ozark Uplift in places where the boundary is exposed (fig. 4). The Bloyd Formation is composed dominantly of shale, with an interval of interbedded limestone and shale at its base, the Brentwood Member, and a persistent limestone unit at its top, the Kessler Limestone Member. Purdue (1907) investigated this succession while mapping the Winslow Quadrangle in extreme western Arkansas. He named the Bloyd Formation, and defined the base of the Winslow Formation (Atoka) as the base of the first persistent sandstone unit approximately 75 feet above the top of the Kessler Limestone (fig. 4). The interval between the Kessler Limestone and the base of the Winslow (Atoka) is composed of shale with a thin, discontinuous sandstone unit near the base. Purdue (1907) assigned this interval to the Bloyd Formation, and Henbest (1962) named it the Trace Creek Shale Member. However, the boundary between the Trace Creek Shale and the overlying Atoka sandstone is gradational. Moreover, Grayson and Sutherland (1977) provided biostratigraphic evidence that indicates an Atokan age for the Trace Creek Shale, and Sutherland and others (1978) reported physical evidence of a regional unconformity at the base of the member in western Arkansas and extreme eastern Oklahoma. Zimbrick (1978) demonstrated that the Trace Creek is a lateral facies of the lower part of the Atoka Formation in Oklahoma. Sutherland and Grayson (1978) proposed that the Trace Creek Shale be assigned to the Atoka Formation.

The Kessler Limestone Member of the Bloyd Formation is persistent throughout Washington and western Madison Counties in western Arkansas. East of central Madison County, the member has not been recognized in the outcrop belt. In most exposures, the Kessler ranges from 5 to 30 feet in thickness. Shale-pebble conglomerates are

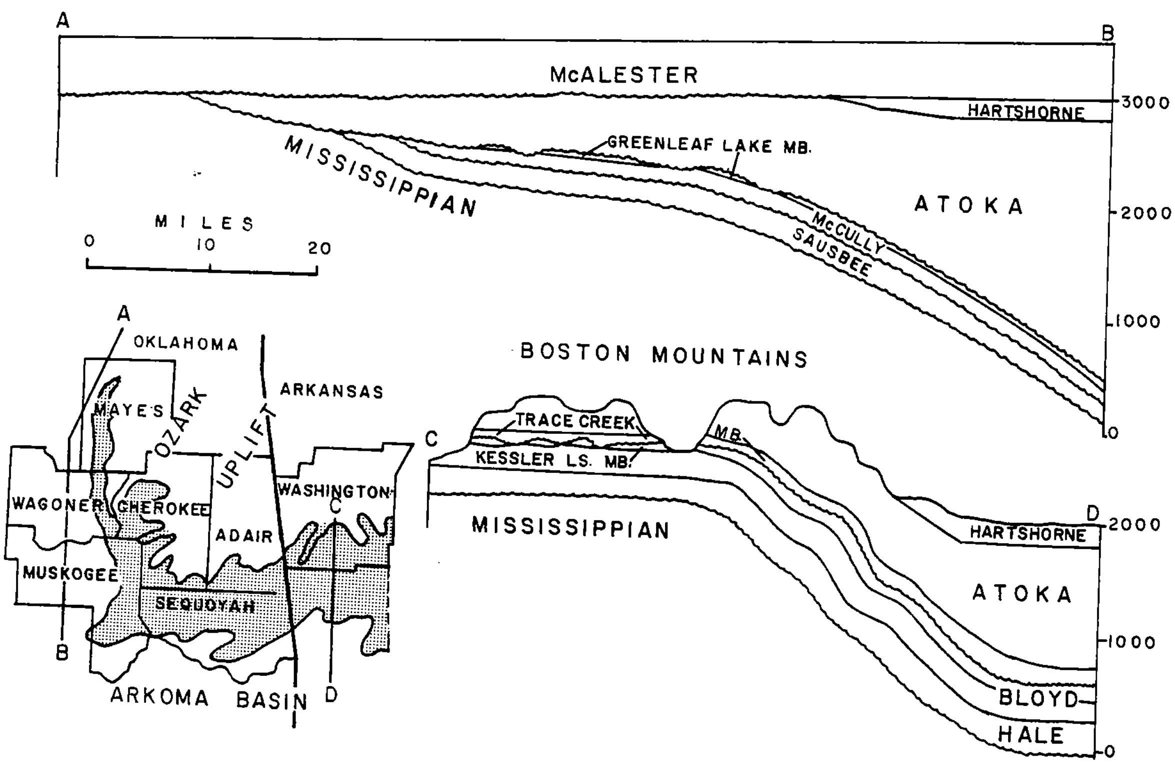


Figure 4. Cross sections *A–B* and *C–D* showing distribution of Atoka Formation and bounding units in Ozark region of Arkansas and Oklahoma. Stippled area on map depicts outcrop pattern of Atoka Formation.

common at the top of the unit. Southward toward the Arkoma Basin, the unit thickens, is less conglomeratic, and is more persistent (Zachry, 1977). The erratic thickness of the Kessler, and its composition in the Ozark region, support the placement of a regional unconformity at the top of the member.

The Kessler Limestone Member is recognized in wells throughout the northern part of the Arkoma Basin of western Arkansas. Strata directly overlying the Kessler Limestone, and equivalent to the Trace Creek Shale, have long been assigned to the Atoka Formation by petroleum geologists. The Kessler Limestone becomes sandy to the east and southeast, and is difficult to recognize east of Pope County, Arkansas. In this area, the Bloyd–Atoka boundary cannot be readily differentiated. The Kessler Limestone Member persists southward to central Sebastian County in the central part of the Arkoma Basin of western Arkansas (Haley and Frezon, 1965). Its distribution in the southern part of the basin is largely unknown.

Strata of the Atoka Formation are truncated above by the modern erosion surface throughout the Ozark region of northwestern Arkansas. The formation is conformably overlain by the Desmoinesian Hartshorne Sandstone to the south in the Arkoma Basin.

### *Northeastern Oklahoma*

The outcrop belt of the Atoka Formation extends westward from Arkansas into Adair and Sequoyah Counties, Oklahoma, on the northern margin of the Arkoma Basin, and thence northward through Muskogee, Cherokee, Wagoner, and Mayes Counties, along the western periphery of the Ozark Uplift (fig. 4). The Atoka Formation unconformably overlies the Morrowan McCully Formation in Sequoyah and Muskogee Counties. The erosion surface is irregular, incising and in places truncating the uppermost Greenleaf Lake Limestone Member ( = Kessler Limestone Member) of the McCully (Sutherland and Manger, 1979). Northward along the western border of the Ozark Uplift, the unconformity regionally truncates the Morrowan succession, and in central Mayes County (T. 20 N.) the Atoka strata rest on beds that are Mississippian in age.

The Atoka Formation at the northern margin of the Arkoma Basin is overlain by strata of the Desmoinesian Hartshorne Sandstone (fig. 4). North of the basin margin adjacent to the Ozark Uplift, the McAlester Formation directly overlies the Atoka. A regional unconformity at the base of the McAlester truncates the Atoka in northern Mayes County (Sutherland and Manger, 1979).

### *Northeastern Arbuckle Mountains*

The Arkoma Basin is terminated to the west and southwest at the northeastern margin of the Arbuckle Mountains (fig. 1). Atoka strata crop out in a narrow belt that extends northwestward from the frontal Ouachitas in Atoka County, along the northeastern flank of the Arbuckle Mountains (fig. 5).

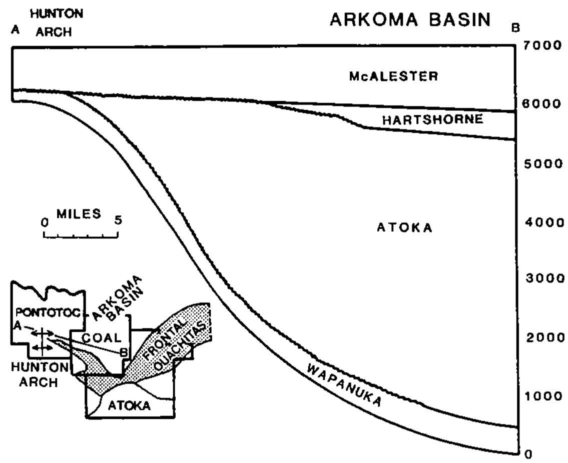


Figure 5. Cross section *A–B* showing distribution and stratigraphic relationships between Atoka Formation and bounding units in northeastern Arbuckle Mountains sector of Arkoma Basin. Stippled area on map depicts Atoka outcrop belt in frontal Ouachitas and in Arkoma Basin adjacent to Hunton Arch.

The Atoka Formation is confined mostly to the subsurface of the Arkoma Basin in northern Atoka County. In this area, the formation is approximately 8,000 feet thick (Bellis, 1961) and overlies strata of the Wapanucka Formation. Desmoinesian-age strata of the Hartshorne Sandstone overlie the Atoka. From northern Atoka County westward and northwestward toward the terminus of the Arkoma Basin adjacent to the Arbuckle Mountains, the Atoka thins markedly (fig. 5). North of Clarita in Coal County, at a distance of approximately 20 miles, the formation is 3,000 feet thick (Bellis, 1961). Thinning continues to the northwest, and the Atoka is truncated within a further 10 miles.

The contact between the Atoka and the underlying Wapanucka Formation is gradational throughout the extreme southern part of the Arkoma Basin and in the frontal Ouachitas (Lumsden and others, 1971; Berry and Trumbly, 1968). Westward toward the Arbuckle Mountains, the boundary becomes an unconformity partially truncating Wapanucka strata. Part of the westward thinning of the Atoka Formation is attributed to onlap onto the erosional surface of the Hunton Arch, a north-south positive feature during Early and Middle Pennsylvanian time that predated the main folding of the Arbuckle Mountains (Sutherland and others, 1982).

The Hartshorne Sandstone conformably overlies the Atoka throughout most of the Arkoma Basin. However, in the western part of the basin adjacent to the Arbuckles, the boundary is an unconformity, and the Hartshorne thins and becomes absent owing to onlap onto the Hunton Arch. Hartshorne strata have been mapped as far west as western Coal County (Archinal, 1977). Westward from the terminus of the Hartshorne, the Atoka is overlain by beds of the McAlester Formation, and an unconformity at the base of the McAlester regionally truncates the Atoka Formation in central Pontotoc County (fig. 5).

### *Frontal Ouachitas*

The Arkoma Basin is bounded to the south by the frontal Ouachita province of the Ouachita Fold Belt (fig. 1). The boundary between the basin and the frontal zone is normally defined as the trace of the Choctaw Fault in Oklahoma and its eastward projection into Arkansas. The Choctaw Fault is a high-angle thrust fault with a south-dipping fault plane that developed from compressive stress related to the Ouachita Orogeny. The sedimentary succession that crops out on the southern, upthrown side of the fault is similar stratigraphically to the succession found at depth on the northern, downthrown side.

The Atoka Formation in the frontal zone overlies strata of the Wapanucka Formation in Oklahoma. The boundary is gradational, and carbonate units at the top of the Wapanucka are interbedded with a sandstone unit that is assigned to the base of the Atoka Formation (Spiro Sandstone) north of the fault in the Arkoma Basin (Grayson, 1979, 1980). The Wapanucka Formation in the eastern Arbuckle area is entirely of Morrowan age and is separated from the Atoka Formation by an unconformity. Biostratigraphic studies by Grayson (1979, 1980) indicate that the upper part of the Wapanucka in the frontal zone is Atokan in age, but Sutherland and Manger (this volume) consider this highest unit (Grayson's upper sandstone–limestone member, 1979) to be part of the Atoka Formation.

North of the Choctaw Fault in Oklahoma, the base of the Atoka Formation has been penetrated at depths exceeding 12,000 feet. The boundary is conventionally chosen below a basal Atoka sandstone unit and above limestone units of the Wapanucka Formation. In the Wilburton Field of Latimer County, immediately north of the Choctaw Fault, the boundary between the basal Atoka sandstone and the underlying Wapanucka is gradational (Berry and Trumbly, 1968). Lumsden and others (1971), in their study of the Spiro or basal Atoka sandstone in the Arkoma Basin, concluded that the Wapanucka–Atoka boundary in the southern part of the basin is gradational. These investigators suggested that sedimentation during Morrowan through Atokan time was continuous in the southernmost part of the Arkoma Basin of Oklahoma, in contrast to the central and northern parts of the basin and adjacent shelves where sedimentation was interrupted and the Morrowan–Atokan boundary is characterized by an unconformity.

The Atoka Formation in the frontal Ouachita Mountains of Arkansas overlies strata of the deep-water Johns Valley Formation. Few wells have penetrated the formation in the Arkoma Basin adjacent to the frontal zone, and the pre-Atoka succession in this area is largely unknown. In southern Sebastian County, adjacent to the Oklahoma border (T. 5 N.), the Atoka Formation overlies strata believed to correlate with the Bloyd Formation. The boundary appears to be consistent with the conformable nature of the boundary in the southern part of the basin in Oklahoma.

The Atoka Formation is the highest unit stratigraphically in the frontal zone of Arkansas and Oklahoma. The Desmoinesian Hartshorne Sandstone conformably overlies the Atoka in the Arkoma Basin.

## Stratigraphic Framework

The Atoka Formation of the Arkoma Basin is a complex terrigenous deposit that accumulated prior to and during the development of a peripheral foreland basin associated with the Ouachita Fold Belt. The distribution and character of the various detrital rocks were controlled by the volume of sediments supplied to the region, the geographic positions where sediment entered the area, and the tectonic activity that accompanied sedimentation.

Morrowan strata in the region are composed of limestone, shale, and sandstone units that accumulated in various shallow-shelf environments, adjacent to the deep Ouachita Trough immediately to the south. Shelf conditions persisted to the southern margin of the present-day structural basin in Oklahoma, and to positions near the margin in Arkansas. The thickness of the Morrowan succession ranges to several hundred feet and is essentially constant throughout the basin.

The Atoka Formation within the basin is informally divided into lower, middle, and upper intervals for discussion purposes (fig. 6). The intervals conform closely to the lower, middle, and upper intervals described by Buchanan and Johnson (1968).

The lower unit ranges in thickness from 900 feet adjacent to the northern margin of the basin, to approximately 2,000 feet near the southern margin. In Arkansas and extreme eastern Oklahoma, the interval is composed of multiple sandstone units separated by shale units. Individual sandstone units range from 20 to 200 feet in thickness, and are continuous throughout the northern and

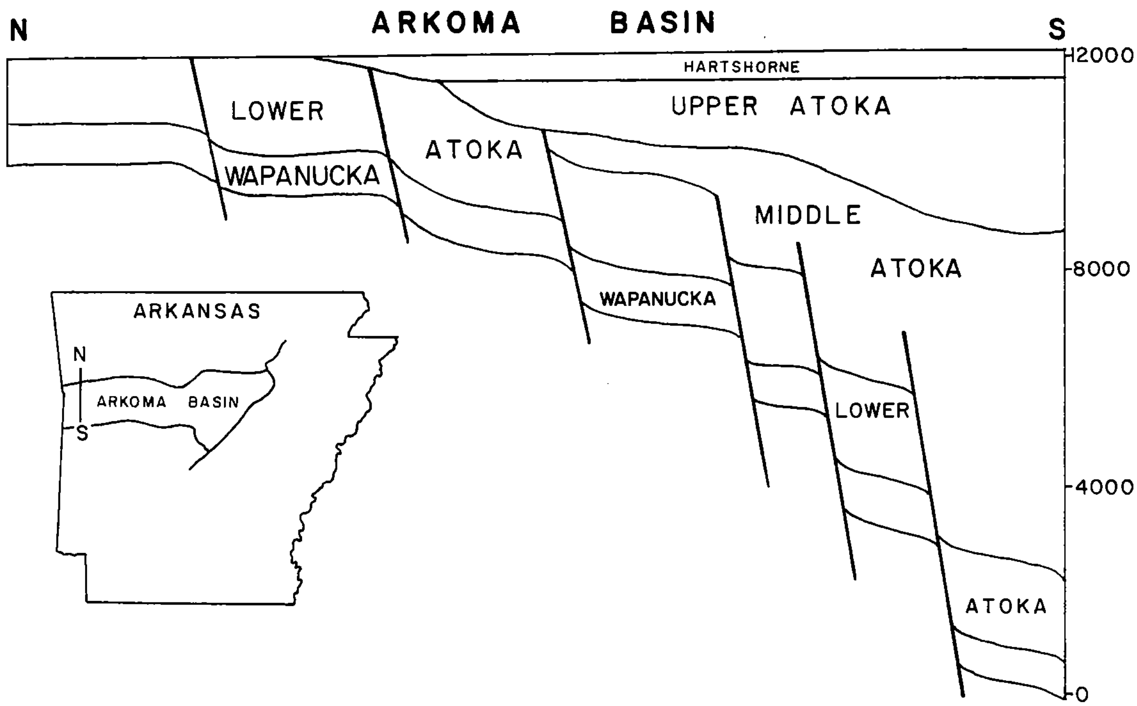


Figure 6. North–south section across Arkoma Basin of Arkansas depicting pattern of growth faulting that controlled sedimentation during accumulation of middle part of Atoka Formation in southern part of basin.

central parts of the basin. A general increase in unit thickness occurs to the east in Arkansas, and shale intervals are thinner. Sandstones of the lower interval thin in the southern part of the basin and except for the basal unit, pass into shale.

The lower Atoka of Oklahoma is characterized by a widespread basal sand, the Spiro Sandstone, overlain by shale. The multiple sand succession of Arkansas is absent in Oklahoma. Pre-Spiro channel systems (Foster sand trends) are cut into the underlying Morrowan succession and contain elongate sand bodies that trend southeastward across the northern and central parts of the basin (Lumsden and others, 1971). These elongate sand bodies are vertically continuous with the overlying Spiro blanket sand. In the absence of correlatable sand units above the Spiro in Oklahoma, the upper boundary of the lower Atoka interval occurs within a shale succession and is poorly defined.

The middle Atoka unit of Arkansas and Oklahoma is confined to the southern part of the basin. It is composed of laterally discontinuous sandstone units, ranging to 100 feet in thickness, that are separated by thick intervals of shale in western Arkansas. The unit thickens from approximately 1,200 feet in T. 7 N. to more than 10,000 feet in T. 4 N. (Buchanan and Johnson, 1968). Increments of thickening occur successively on the downthrown sides of large, east- and northeast-trending normal faults, in a stepwise fashion from north to south (fig. 6). The relationship of the faults to southward thickening within the terrigenous clastic deposit indicates that faulting was contemporaneous with sedimentation. Buchanan and Johnson (1968) suggested that faulting began in the south, focusing the site of earliest middle Atoka deposition. Later development of east-trending faults successively to the north controlled the accumulation of younger sediments within the middle Atoka wedge. Middle Atoka strata are very thin to the north of T. 7 N. in Arkansas.

The middle Atoka interval in Arkansas is composed dominantly of shale, but many sandstone units occur within the succession. South of T. 7 N. in western Arkansas, sandstone units in the lower part of the middle Atoka interval range to 15 feet in thickness and occur in groups of four to eight sandstone units. The units are separated by thick intervals of shale. In the middle and upper part of the interval, individual sandstone units range to 50 feet in thickness and also occur in discrete groups of several units. The continuity of the units or the groups in which they occur is difficult to evaluate because well control is poor. However, they do not appear to have the continuity shown by units within the lower Atoka interval. The thickness, lack of continuity, and inferred grain-size profiles suggest that the middle Atoka sands initially were deposited at the distal margin of active submarine-fan systems. Thicker sands higher in the section may reflect sedimentation in more proximal positions on the fan surface.

The middle Atoka interval in Oklahoma is composed dominantly of shale, with few major sandstone units. The interval conforms to the middle Atoka pattern in Arkansas, being confined to the southern part of the basin and displaying thickening trends related to east-trending normal faults. A major sand unit within this interval, the Red Oak sandstone, is a significant producer of natural gas. The Red Oak is confined to the south side of the San Bois Fault. Vedros and Visher (1979) suggested, from an analysis of sedimentary structures and sand unit geometry, that the Red Oak accumulated in a submarine-fan environment supplied with sediment from submarine canyons cut into the scarp of an active growth fault to the north. The Fanshawe sandstone, a unit that occurs higher in the middle Atoka interval, was also interpreted as a submarine-fan deposit.

The upper Atoka interval in the Arkoma Basin of Arkansas is composed of sandstone units alternating with thick intervals of shale. The unit displays a pattern of gradual thickening to the south, and is present from the northern margin of the basin southward. Individual sandstone units are among the units of greatest continuity in the basin. Large normal faults that cut the middle Atoka interval are buried by upper Atoka strata, indicating a cessation of fault activity (Buchanan and Johnson, 1968).

The upper Atoka interval of Oklahoma is composed of shale with thin, discontinuous sands, and conforms to the pattern of thickening displayed by the upper Atoka unit in Arkansas.

## DEPOSITIONAL HISTORY

Lower Atoka strata in the Arkoma Basin accumulated in a shallow-shelf setting not unlike the setting of earlier Morrowan sedimentation. Deposition was continuous from Morrowan to Atokan time on the southern part of the shelf in Oklahoma and probably in Arkansas. Widespread Atoka sedimentation was initiated by northward transgression of Atokan seas across an erosion surface cut on Morrowan strata. The basal Spiro Sandstone (including the Foster sands) accumulated in pre-transgression channel systems and in widespread coastal sand complexes to form a blanket-sand unit at the base of the formation. Multiple sand units above the basal sand thicken eastward in Arkansas and are absent in Oklahoma, suggesting that the dominant sediment supply entered the basin from the northeast and north in Arkansas. High, destructive cratonic deltas that prograded southward across a shelf characterized by little subsidence formed widespread but thin sand units in delta and delta-related environments. Progradation was interrupted by periodic northward transgressions, bringing open-shelf environments to the Arkoma Basin area and forming shale units. Distal to the major sediment source, the shelf in Oklahoma was a site of shale accumulation. Thin, calcareous sand units were deposited in shoreface environments in the western part of the area adjacent to the Arbuckle Mountains.

The lower Atoka shelf was subjected to tensional stress during the deposition of the middle Atoka, and large, east- and northeast-trending normal faults developed in a stepwise fashion from south to north. Large volumes of sediment bypassed the northern shelf areas and accumulated on the downthrown sides of active faults, forming the middle Atoka clastic wedge.

In Arkansas, proximal to the northeastern source, submarine-fan systems delivered sand to deep-water environments. Distal to the source, in Oklahoma, rates of sedimentation were lower, and submarine scarps developed along the faults. Submarine canyons transferred sand, brought westward by littoral drift, to the base of the fault scarps, constructing submarine fans.

Upper Atoka strata were deposited after the cessation of normal faulting that produced the great structural relief and thick sediment fill characteristic of the southern Arkoma Basin. Sandstone units within the upper Atoka of Arkansas are related to the progradation of deltaic systems southward across a muddy, open shelf. Periodic regional transgressions interrupted deltation and spread open-shelf conditions across the basin, forming the shale units. Sediment supply remained high, but subsidence slowed, allowing deltaic sands to be moved laterally into strand-plain and coastal sand environments. This redistribution of sand allowed for the development of sandstone units with great lateral continuity during progradation.

## REFERENCES CITED

**Archinal, B. E.**, 1977, The lithostratigraphy of the Atoka Formation (Lower Pennsylvanian) along the southwestern margin of the Arkoma Basin, Oklahoma: University of Oklahoma unpublished M.S. thesis, 172 p.

**Bellis, W. H.**, 1961, Distribution and thickness of pre-Desmoinesian rock units in south-central Oklahoma: University of Oklahoma unpublished M.S. thesis, 30 p.

**Berry, R. M.**, and **Trumbly, W. D.**, 1968, Wilburton gas field, Arkoma Basin, Oklahoma, *in* Cline, L. M., editor, A guidebook to the geology of the western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geological Society Guidebook for AAPG–SEPM Annual Meeting, p. 86–103.

**Buchanan, R. S.**, and **Johnson, F. K.**, 1968, Bonanza gas field—a model for Arkoma Basin growth faulting, *in* Cline, L. M., editor, A guidebook to the geology of the western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geological Society Guidebook for AAPG–SEPM Annual Meeting, p. 75–85.

**Croneis, C. G.**, 1930, Geology of the Arkansas Paleozoic area with especial reference to oil and gas possibilities: Arkansas Geological Survey Bulletin 3, 457 p.

**Grayson, R. C., Jr.**, 1979, Stop descriptions—fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

———1980, The stratigraphy of the Wapanucka Formation (Lower Pennsylvanian) along the frontal margin of the Ouachita Mountains, Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 317 p.

**Grayson, R. C., Jr.**, and **Sutherland, P. K.**, 1977, Conodont evidence for unconformity within Trace Creek Shale Member of Bloyd Formation (Lower Pennsylvanian) in northwestern Arkansas and northeastern Oklahoma, *in* Sutherland, P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 181–185.

**Haley, B. R.**, and **Frezon, S. E.**, 1965, Geologic formations penetrated by the Shell Oil Company No. 1 Western Coal and Mining Company well on the Backbone anticline, Sebastian County, Arkansas: Arkansas Geological Commission Information Circular 20D, 17 p.

**Henbest, L. G.**, 1962, New members of the Bloyd Formation of Pennsylvanian age, Washington County, Arkansas: U.S. Geological Survey Professional Paper 450-D, p. D42–D44.

**Lumsden, D. N.**, **Pittman, E. D.**, and **Buchanan, R. S.**, 1971, Sedimentation and petrology of Spiro and Foster sands (Pennsylvanian), McAlester basin, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 55, p. 254–266.

**Owen, D. D.**, 1858, First report of a geological reconnaissance of the northern counties of Arkansas made during the years 1857 to 1858: Arkansas Geological Survey, 256 p.

**Purdue, A. H.**, 1907, Description of the Winslow quadrangle [Arkansas–Indian Territory]: U.S. Geological Survey Geologic Atlas, Folio 154, 6 p.

**Simonds, F. W.**, 1891, The geology of Washington County: Arkansas Geological Survey Annual Report for 1888, v. 4, pt. 1, p. 1–148.

**Sutherland, P. K.**, **Archinal, B. E.**, and **Grubbs, R. K.**, 1982, Morrowan and Atokan (Pennsylvanian) stratigraphy in the Arbuckle Mountains area, Oklahoma, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 1–17.

**Sutherland, P. K.**, and **Grayson, R. C., Jr.**, 1978, Redefinition of the Morrowan Series (Lower Pennsylvanian) in its type area, northwestern Arkansas [abstract]: Geological Society of America Abstracts with Programs, v. 10, p. 501.

**Sutherland, P. K.**, **Grayson, R. C., Jr.**, and **Zimbrick, G. D.**, 1978, Reevaluation of Morrowan–Atokan Series boundary in northwestern Arkansas and northeastern Oklahoma [abstract]: American Association of Petroleum Geologists Bulletin, v. 62, p. 566.

**Sutherland, P. K.**, and **Manger, W. L.**, editors, 1979, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, 81 p.

**Taff, J. A.**, and **Adams, G. I.**, 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 257–311.

**Ulrich, E. O.**, 1904, Determination and correlation of formations, *in* Adams, G. I. (assisted by Purdue, A. H., and Burchard, E. F.), Zinc and lead deposits of northern Arkansas: U.S. Geological Survey Professional Paper 24, p. 90–113.

**Vedros, S. G.**, and **Visher, G. S.**, 1979, The Red Oak Sandstone: A hydrocarbon-producing submarine fan deposit, *in* Stanley, D. J., and Kelling, Gilbert, editors, Sedimentation in submarine canyons, fans, and trenches: Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, p. 292–308.

**Zachry, D. L., Jr.**, 1977, Stratigraphy of middle and upper Bloyd strata (Pennsylvanian, Morrowan), northwestern Arkansas, *in* Sutherland. P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 61–66.

**Zimbrick, G. D.**, 1978, The lithostratigraphy of the Morrowan Bloyd and McCully Formations (Lower Pennsylvanian) in southern Adair and parts of Cherokee and Sequoyah Counties, Oklahoma: University of Oklahoma unpublished M.S. thesis, 182 p.

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# FUSULINIDS OF THE ATOKA FORMATION LOWER–MIDDLE PENNSYLVANIAN SOUTH-CENTRAL OKLAHOMA

RAYMOND C. DOUGLASS[1] and MERLYND K. NESTELL[2]

**Abstract**—Fusulinids are found in several zones in rocks of early Middle Pennsylvanian age in the Atoka Formation in the northeastern Arbuckle Mountains, west and northwest of Clarita, Oklahoma. Outcrops are poor, and generally the calcareous beds that yield fusulinids are thin and discontinuous. The limestones are mostly detrital and contain a high percentage of organic clasts; the fusulinids tend to be abraded or broken. Both the *Profusulinella* and the *Fusulinella* Assemblage Zones of the Atokan Provincial Series are present, including forms from early *Profusulinella* through advanced *Fusulinella*. *Millerella* and other small Foraminifera also are present. The fauna appears to be related more to faunas of the Illinois and Appalachian Basins than to those of the southwestern United States. New species described herein include *Eostaffella clarita*, *Profusulinella millcreekensis*, and *Fusulinella barnettensis* from Atokan beds, and *Beedeina lewisi*, *Beedeina grileyi*, and *Wedekindellina praematura* from the Desmoinesian beds.

## INTRODUCTION

Early Middle Pennsylvanian (Atokan) fusulinids were first described by Thompson (1935b) from Coal County in southern Oklahoma. He described three species of *Fusulinella*. Two species, *F. prolifica* and *F. oliviformis*, are primitive forms of *Fusulinella*. The third, *F. fittsi*, was later referred to *Profusulinella* Rauser-Chernoussova and Beljaev (Thompson, 1948) and is the first species of this genus to be so referred from North America. These taxa were reported to have been recovered from shales of the Atoka Formation in the Clarita Anticline of the northeastern Arbuckle Mountains (fig. 1), northwest of Clarita in Coal County. Waddell (1966a, 1966b) described two species of *Fusulinella* of Atokan age from the nearby Ardmore Basin in southern Oklahoma.

In this paper, we describe fusulinid faunas from six measured sections of the Atoka Formation in the northeastern Arbuckle Mountains. Two of the six sections are in the Mill Creek Syncline southeast of Sulphur, and the remaining sections are in the area northwest of Clarita (see Sutherland, 1982). We also include the descriptions of Desmoinesian forms from the Deese Formation and from the so-called "Griley" limestone in the same area. The exact stratigraphic position of the "Griley" limestone has been the subject of some controversy (Strimple and Watkins, 1969, p. 150).

### Acknowledgments

We thank Dr. P. K. Sutherland of the University of Oklahoma for suggesting the problem. Two of his graduate students, R. Kent Grubbs and Bruce E. Archinal, did master's theses in the area; we have used their measured sections. P. K. Sutherland and R. Kent Grubbs aided in the collection of the samples. Richard Margerum of the U.S. Geological Survey, Washington, D.C., did an exceptional job of preparing thin sections from very difficult material. Marilyn Ryder patiently typed several drafts of the manuscript. We also thank the property owners of the area for their kindness in granting us access.

## STRATIGRAPHIC SETTING AND BIOSTRATIGRAPHY

The Atoka Formation was named by Taff and Adams (1900, p. 273). No type locality was designated. The Atoka Series was defined by Spivey and Roberts (1946, p. 185) as "all the beds from the top of the Wapanucka limestone, Morrow series, to the base of the Hartshorne sandstone, Des Moines series." There has been some controversy regarding the validity of the Atokan Series because there seems to be no clear agreement on the base or top of the Atoka Formation. Branson (1962, p. 439) stated that, in the type area, provincial series and formation boundaries are identical. Similar difficulties exist regarding the exact definition of the overlying Desmoinesian Provincial Series (Sanderson, 1981).

Insofar as fusulinid evidence is concerned, the lower part of the Atokan Provincial Series is assigned to the *Profusulinella* Assemblage Zone, and the upper part is assigned to the *Fusulinella* Assemblage Zone. The Atokan–Desmoinesian boundary generally has been drawn beneath the first appearance of *Wedekindellina*, *Fusulina* (or

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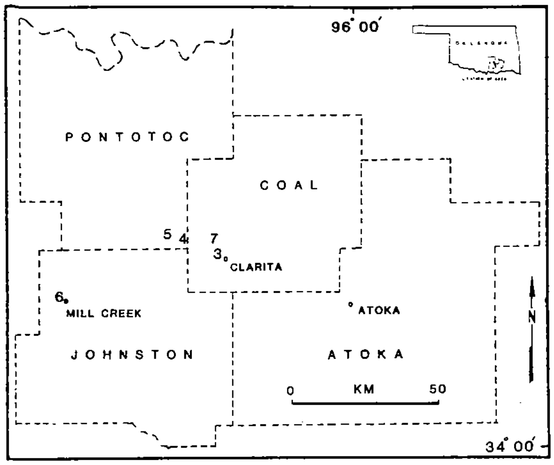



Figure 1. Map showing locations of figures 3–7.

*Beedeina*), and advanced *Fusulinella* (Douglass, 1977).

Fusulinid faunas of Atokan age are described or known from numerous areas in North America (Ross and Sabins, 1965; Thompson, 1936, 1947, 1948, 1953, 1966; Thompson and Zeller, 1956; Thompson and others, 1959).

In Coal County, Oklahoma, Thompson (1935a, 1935b) described *Profusulinella fittsi* and *Pseudostaffella atokensis* from approximately 100 feet above the base of the Atoka Formation, and *Fusulinella prolifica* and *F. oliviformis* from approximately 200 feet above the base. The exact localities from which the specimens of *Profusulinella fittsi*, described by Thompson, were obtained have not been relocated, despite intensive searches (P. K. Sutherland, personal communication, 1982).

Waddell (1966b) described *Fusulinella vacua* and *F. dakotensis* from the Bostwick Conglomerate Member of the Lake Murray Formation in the Ardmore Basin, Oklahoma. He assigned an Atokan age to his Fusulinid Zone I, which included the Bostwick and part of the overlying shale. He placed the base of the Desmoinesian Provincial Series at the base of the overlying Lester Member of the Lake Murray Formation, on the basis of the lowest occurrence of the genera *Fusulina* (*Beedeina* of current usage) and *Wedekindellina*. Waddell (1966b, p. 21) considered *Fusulinella vacua* Waddell and *F. dakotensis* Thompson to be more advanced than *F. prolifica*.

In our collections, the fusulinids from two measured sections (MS), the Lewis Ranch and the Pipeline Trench, appear to span the Atokan interval (fig. 2). The oldest species, *Profusulinella millcreekensis* n. sp., a primitive form of the genus, occurs 4 m above the Wapanucka Limestone in the Pipeline Trench section, from unit 283-13 (Grubbs and others, 1982). This zone is correlated with unit 284-24 of Grubbs (1981), in the Lewis Ranch section. The first fusiform fusulinid found in the Lewis Ranch section was *Fusulinella* sp. aff. *F. devexa* Thompson. This form is in units 284-27,

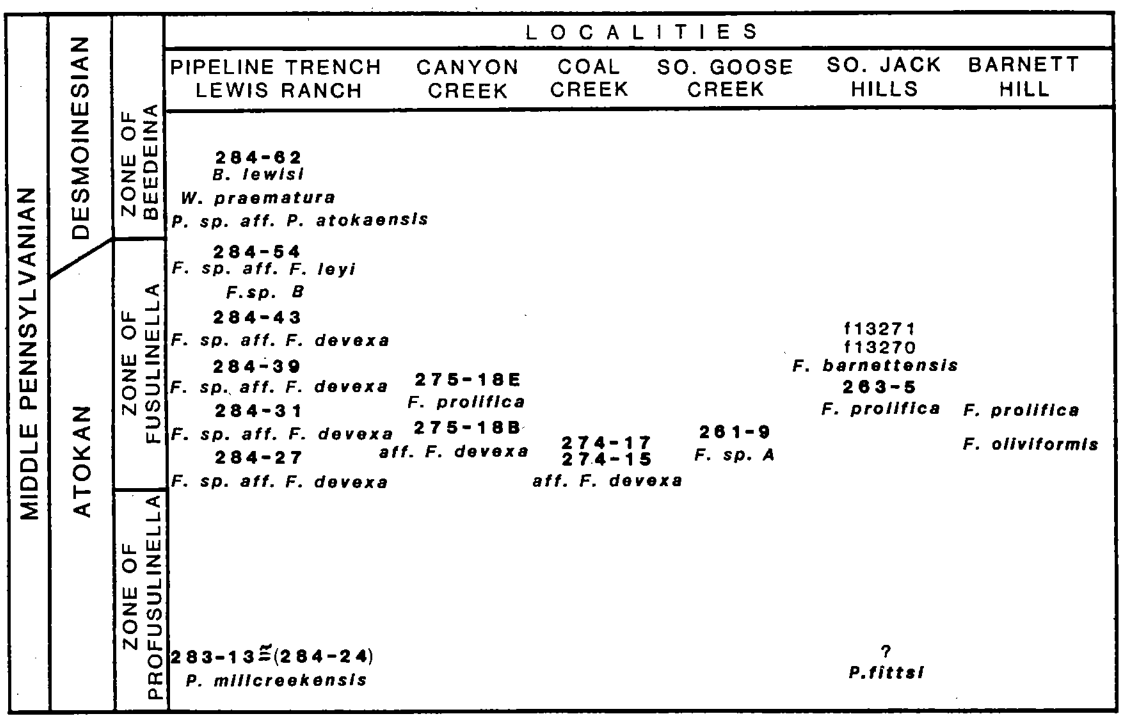



Figure 2. Distribution of fusulinids in Clarita–Mill Creek area of south-central Oklahoma.

284-31, 284-39, and 284-43. *Fusulinella* sp. aff. *F. leyi* Thompson occurs in unit 284-54. These forms occur in thin, sandy limestones, which are crinoidal packstones and wackestones. The fusulinids are commonly abraded and broken.

Grubbs (1981) took unit 284-61, a limestone-cobble conglomerate approximately 159 m above the top of the Wapanucka Limestone, to mark the Atokan–Desmoinesian boundary. We agree with this conclusion because primitive forms of *Beedeina* and *Wedekindellina* occur in unit 284-62, a thin limestone immediately overlying this conglomerate. We have described these forms as *Beedeina lewisi* n. sp. and *Wedekindellina praematura* n. sp. *Pseudostaffella* sp. aff. *P. atokensis* (Thompson) also occurs in this fauna.

Species of *Fusulinella* found in the Canyon Creek, Coal Creek, South Goose Creek, and South Jack Hills Syncline sections are shown in figure 2 in their relative stratigraphic positions with respect to the Lewis Ranch and Pipeline Trench sections.

Age of the invertebrate fauna from the so-called "Griley" limestone locality (Archinal, 1981; Archinal and others, 1982, p. 28) has been the subject of some controversy. Strimple and Watkins (1969, p. 150) considered the crinoids to be early Desmoinesian. However, fusulinid material sent by them to Thompson and to Wilde for identification was referred to *Profusulinella*. The washed residues of the shales at this locality have abundant small fusulinids and rare larger forms. We are describing the larger form as *Beedeina grileyi*. The smaller forms appear to be juvenile forms of *Beedeina* and, in the absence of the larger form, could easily be mistaken for *Profusulinella*. On the basis of the presence of *Beedeina*, we consider these shales to be Desmoinesian. Additional fusulinids were found in collections made after the first reviews of this paper. The top of the exposed shale unit, and loose limestone pieces lying on the shale, contain rare fusulinids. Both *Beedeina* and *Fusulinella* are present.

Correlation of the Lewis Ranch section with the Eastern Interior Basin of Illinois, Indiana, and western Kentucky shows some interesting differences and similarities. Through most of the basin, the older beds either are not present or contain no fusulinids. Beds that contain *Profusulinella* are known from Kentucky and Indiana, and beds with *Fusulinella* are more widespread. *Profusulinella kentuckyensis* was described from the Lead Creek Limestone Member of the Tradewater Formation in western Kentucky by Thompson and others (1959), and was reported from the Mansfield Formation in southern Indiana by Thompson and Shaver (1964). The genus is recognized through several meters of section in some wells in western Kentucky (Douglass, 1979, p. 15). This interval correlates with unit 24 of the Lewis Ranch section.

Faunas equivalent to those reported herein from units 27 through 43 of the Lewis Ranch section are not known from the Eastern Interior Basin. The rocks between the Lead Creek Limestone and Curlew Limestone Members of the Tradewater Formation probably span the same interval of time. Unit 284-54 of the Lewis Ranch section correlates approximately with the type Curlew in western Kentucky, with the Seville Limestone Member of the Spoon Formation in western Illinois, and with the Perth Limestone Member of the Brazil Formation in northern Indiana.

Unit 284-62 of the Deese Formation in the Lewis Ranch section contains a fusulinid fauna intermediate in age between that of the type Curlew Limestone and Yeargins Limestone Members of the Tradewater Formation in western Kentucky. No equivalent fauna is known from Illinois, but it would fall between the Seville Limestone and "Curlew" Limestone Members of the Spoon Formation.

## LOCALITIES

South Jack Hills Syncline offset, MS 263 (fig. 3). E½NW¼NW¼ sec. 10, T. 1 S., R. 8 E. The base of the section is approximately 30 m north of a dirt road near the base of the hill; the top is approximately 15 m due north of the base. The section is approximately 11 m thick. Illustrated fusulinids are from unit 263-5, the limestone that forms the top of the section. U.S. Geological Survey Foraminifera collection numbers are also shown in our figures. See Archinal and others (1982, p. 26). The map is from the north-center edge of the Wapanucka North, Oklahoma, 7.5-minute topographic-quadrangle map, 1969 edition.

South Goose Creek, MS 261 (fig. 4). SW¼SW¼NE¼ sec. 19, T. 1 N., R. 8 E. The base of the section is at the top of the Wapanucka Lime-

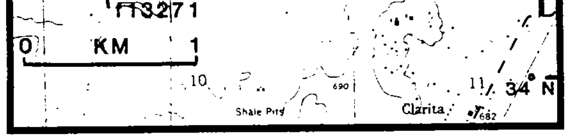



Figure 3. Locality map of South Jack Hills Syncline section.

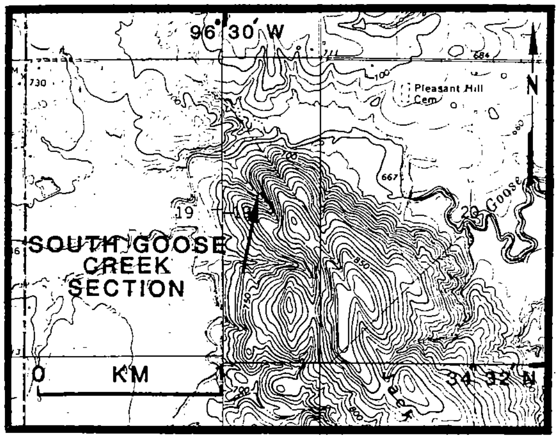



Figure 4. Locality map of South Goose Creek section.

stone on the southeast side of Goose Creek, approximately 122 m south of where the Wapanucka is cut by the creek; the top is on the crest of the second prominent northwest-trending ridge in the Jack Hills, due east of the base of the section. The section is approximately 155 m thick. Illustrated fusulinids are from unit 261-9, a limestone 0.5 m thick and 17 m below the top of the section. See Archinal (1977, p. 88). Figure 4 is a composite from the southeast edge of the Harden City, Oklahoma, and the southwest edge of the Tupelo, Oklahoma, 7.5-minute topographic-quadrangle maps, 1966 editions.

Coal Creek, MS 274 (fig. 5). NW¼SE¼SE¼ sec. 15, T. 1 N., R. 7 E. The base of the section is on the east side of Coal Creek, approximately 90 m south of a sharp bend in the creek, on a small, rounded northwest-trending ridge of the Wapanucka Limestone; the top is on the north side of the large ridge cut by Coal Creek. The section is approximately 144 m thick. Fusulinids were recovered from units 274-15 and 274-17, located 98 and 100 m, respectively, above the base of the formation. See Archinal and others (1982, p. 22).

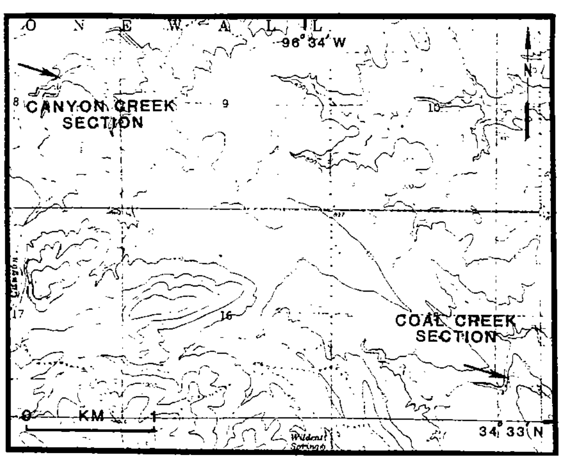



Figure 5. Locality map of Canyon Creek section and Coal Creek section.

Canyon Creek, MS 275 (fig. 5). SE¼SW¼NE¼ sec. 8, T. 1 N., R. 7 E. The base of the section is at the top of the Wapanucka Limestone, on the creek; the top is at the crest of a sandstone ridge at the southwest end of the flood-control lake to the northeast. The section is approximately 188 m thick. Illustrated fusulinids were recovered from units 275-18B and 275-18E, located 67 and 70 m, respectively, above the base of the formation. See Archinal and others (1982, p. 19). Figure 5 is from the center of the Harden City, Oklahoma, 7.5-minute topographic-quadrangle map, 1966 edition.

Pipeline Trench, MS 283 (fig. 6). SW¼NW¼NW¼ sec. 7, T. 2 S., R. 5 E. This section was exposed briefly while a sewer line was being constructed. It was located one block west and on the east side of the third block south of the intersection of State Highway 12 and Main Street in Mill Creek. Fusulinids were collected from unit 283-13, a thin limestone lens approximately 4 m above the base of the formation. See Grubbs and others (1982, p. 32).

Lewis Ranch, MS 284 (fig. 6). CN½S½ sec. 2, T. 2 S., R. 4 E. The base of the section is in the creek bed at the base of the Wapanucka Limestone approximately 0.6 km north of the east–west section-line road and 2.7 km west of Mill Creek, Oklahoma. The Atoka part of the section is approximately 157 m thick, starting with unit 24. Samples 284-27, 284-31, 284-39, 284-43, and 284-54 are from thin limestones approximately 27, 38, 54, 69, and 123 m, respectively, above the base of the Atoka Formation. The base of the Desmoinesian Deese Formation is unit 284-61, a limestone-cobble conglomerate approximately 158 m above the base of the Atoka Formation. Unit 284-62 contains a Desmoinesian fusulinid fauna. See Grubbs and others (1982, p. 33). Figure 6 is from the southwest corner of the Mill Creek, Oklahoma, 7.5-minute topographic-quadrangle map, 1978 edition.

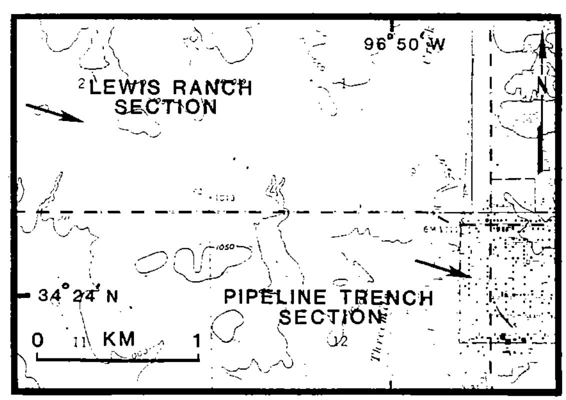



Figure 6. Locality map of Lewis Ranch section and Pipeline Trench section.

"Griley" limestone locality, unit 264-3 (fig. 7). NE¼NE¼NW¼ sec. 28, T. 1 N., R. 8 E. The "Griley" limestone is in a series of natural ravines exposing about 2 m of calcareous clay shale, about 50 m south of the east–west section-line road. See Archinal and others (1982, p. 28). Figure 7 is from the west–center of the Tupelo, Oklahoma, 7.5-minute topographic-quadrangle map, 1966 edition.

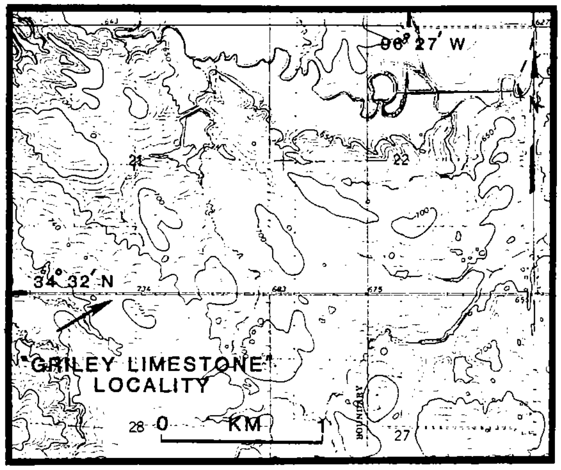



Figure 7. Map showing "Griley" limestone locality.

The U.S. Geological Survey collections were made by Lloyd Henbest and Mackenzie Gordon on April 12, 1968, and were verified during the present study.

USGS locality f13269. Thin, nodular limestone of the Wapanucka Formation. The locality is adjacent to the north side of the ranch road and a few meters west of the gate from the section-line road between secs. 2 and 3, T. 1 S., R. 8 E. See figure 3.

USGS locality f13270. Steeply dipping limestone in a sandstone sequence. The locality is a few meters north of the section-line road, one-third of the way up the hill, and 50 m east of the north–south power line crossing the road. This limestone is probably equivalent to unit 263-5 of the South Jack Hills Syncline section. See figure 3.

USGS locality f13271. Same location as f13270, but from float beside the road.

## SYSTEMATIC PALEONTOLOGY

Illustrated specimens are deposited in the paleontological collections of the U.S. National Museum (USNM), The University of Oklahoma (OU), and the University of Iowa (SUI). Measurements are given in tables 1 and 2.

Genus **Pseudostaffella** Thompson, 1942

**Pseudostaffella** sp. aff. **P. atokensis** (Thompson), 1935

Pl. 1, figs. 1–7

*Discussion.*—Several specimens of *Pseudostaffella* sp. were recognized in collection 284-62 from the top of the Lewis Ranch section. They are all more tightly coiled than *P. needhami* Thompson, which is commonly found lower in many rocks of early Middle Pennsylvanian age. The inner volutions are at varying angles to the outer volutions, and the axis may rotate throughout growth on many of the specimens. They closely resemble *P. atokensis* (Thompson). These forms were described by Thompson (1935a) from several localities 100 and 200 feet above the base of the Atoka Formation in the area north and northwest of Clarita, Coal County, Oklahoma.

Unit 284-62 is considered to be Desmoinesian in age, based on the occurrence of *Beedeina lewisi* n. sp. and *Wedekindellina praematura* n. sp.

Genus **Eostaffella** Rauser-Chernoussova, 1948

**Eostaffella clarita** Douglass and Nestell, n. sp.

Pl. 1, figs. 8–15

*Description.*—Test minute, discoidal and planispiral in most specimens, but the early chambers may be coiled at a small to great angle to the adult test. Tests attain a diameter of about 0.9 mm in six and one-half volutions but commonly develop only five to five and one-half volutions with a diameter of 0.65 to 0.8 mm and an axial length of 0.4 to 0.45 mm. The first volutions are lenticular and slightly umbilicate. Later volutions tend to develop a diamond shape, with subangular periphery and nearly straight lateral slopes that may be either slightly convex or slightly concave.

The proloculus is minute, measuring 32 microns or less in the specimens seen. The spirotheca is composed of a tectum with a thin, granular-appearing layer on the inner surface and a thicker, similar layer on the outer surface. The wall is unusually well preserved, for a staffellid; it does not appear to be replaced or recrystallized (pl. 1, fig. 12). The septa are numerous and closely spaced, with 22 to 25 septa in the fifth volution. They are straight across the middle of the test (pl. 1, fig. 14). The tunnel is typically straight and narrow, occupying the peripheral area in each volution. It is low, extending less than one-third the chamber height, and is bordered by chomata that tend to extend a short distance along the lateral slopes.

*Discussion.*—*Eostaffella clarita* is an unusual form, bearing little resemblance to previously described species. It is a little like *Nankinella plummeri* Thompson (1947) in shape, but it has a much smaller proloculus, is more tightly coiled, has more pronounced chomata, and may have a differ-

## TABLE 1.—MEASUREMENTS FOR *Eostaffella clarita, Profusulinella millcreekensis,* AND *Fusulinella barnettensis*

TABLE 1

[Measurements in millimeters]

| | | Eostaffella clarita Plate 1, figures | | | | | | Profusulinella millcreekensis Plate 1, figures | | | | Fusulinella barnettensis Plate 3, figures | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volution | 8 | 9 | 10 | 11 | 12 | 15 | 16 | 18 | 20 | 22 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Diameter of proloculus | | .025 | .025 | .032 | .019 | .020 | | .130 | .020 | .080 | .110 | .10 | .065 | .10 | .09 | .07 | .06 | .065 |
| Radius vector | 1 | .02 | .03 | .04 | .03 | .04 | .04 | .11 | .05 | .08 | .10 | .04 | .07 | .09 | .08 | .07 | .04 | .06 |
| | 2 | .08 | .07 | .07 | .06 | .07 | .08 | .17 | .10 | .14 | .17 | .11 | .10 | .14 | .11 | .11 | .08 | .10 |
| | 3 | .12 | .12 | .12 | .10 | .13 | .11 | .26 | .15 | .23 | .26 | .18 | .17 | .22 | .20 | .17 | .14 | .16 |
| | 4 | .18 | .17 | .19 | .18 | .23 | .18 | .39 | .21 | .33 | .37 | .26 | .26 | .33 | .30 | .25 | .21 | .24 |
| | 5 | .32 | .29 | | .27 | .36 | .29 | | .29 | .43 | | .37 | .36 | .47 | .42 | .37 | .30 | .35 |
| | 6 | | | | | | .42 | | .40 | | | .52 | .50 | .60 | .56 | .50 | .42 | .48 |
| | 7 | | | | | | | | | | | .68 | | | | | .58 | .62 |
| Half length | 1 | .03 | .02 | .02 | .02 | .02 | | .14 | | .13 | .12 | .14 | .09 | .16 | .14 | | | .11 |
| | 2 | .05 | .05 | .05 | .04 | .06 | | .27 | | .27 | .26 | .25 | .18 | .34 | .23 | | | .17 |
| | 3 | .10 | .08 | .10 | .08 | .11 | | .30 | | .46 | .50 | .53 | .38 | .54 | .34 | | | .30 |
| | 4 | .15 | .14 | .17 | .12 | .17 | | .73 | | .68 | .84 | .75 | .54 | .78 | .62 | | | .64 |
| | 5 | .26 | .21 | | .19 | .22 | | | | .90 | | 1.04 | .72 | 1.10 | 1.00 | | | .98 |
| | 6 | | | | | | | | | | | 1.66 | 1.10 | 1.40 | 1.40 | | | 1.45 |
| | 7 | | | | | | | | | | | 1.86 | | 1.75 | | | | 1.90 |
| Tunnel width (axials) or septal count | 1 | .15 | | | | | | .05 | 12 | .03 | .03 | .03 | .03 | .04 | .02 | 9 | 9 | .02 |
| | 2 | .20 | .15 | .20 | .20 | .20 | | .08 | 17 | .04 | .07 | .06 | .05 | .07 | .03 | 13 | 12 | .04 |
| | 3 | .30 | .20 | .30 | .40 | .30 | 13 | .14 | 20 | .07 | .14 | .10 | .09 | .12 | .07 | 18 | 13 | .07 |
| | 4 | .60 | .60 | | .70 | .40 | 16 | | | .18 | | .18 | .12 | .17 | .18 | 18 | 14 | .12 |
| | 5 | | | | | .50 | 20 | | | | | .36 | .20 | .32 | .32 | 23 | 20 | .20 |
| | 6 | | | | | | 27 | | | | | .58 | .38 | .48 | | | 23 | .40 |
| | 7 | | | | | | | | | | | | | | | | 25 | |

## TABLE 2.—MEASUREMENTS FOR *Wedekindellina praematura, Fusulinella* SP. A AND B, *Beedeina lewisi,* AND *B. grileyi*

TABLE 2

[Measurements in millimeters]

| | | Wedekindellina praematura Plate 4, figures | | | | Fusulinella sp. A Plate 4, figs. | | Fusulinella sp. B Plate 4, figs. | | Beedeina lewisi Plate 5, figures | | | | | | | | Beedeina grileyi Plate 5, figures | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volution | 13 | 14 | 18 | 22 | 7 | 9 | 11 | 12 | 1 | 2 | 4 | 5 | 6 | 9 | 10 | 12 | 13 | 14 | 17 | 18 | 19 |
| Diameter of proloculus | | .05 | .065 | .07 | .07 | .10 | .07 | .045 | .05 | .045 | .06 | .06 | .07 | .06 | .09 | .07 | .09 | .09 | .09 | | .05 | |
| Radius vector | 1 | .05 | .06 | .06 | .07 | .12 | .09 | .05 | .09 | .05 | .06 | .06 | .08 | .05 | .08 | .07 | .10 | .09 | .08 | .06 | .04 | .04 |
| | 2 | .09 | .10 | .11 | .11 | .20 | .14 | .08 | .14 | .08 | .11 | .09 | .14 | .08 | .13 | .12 | .15 | .16 | .13 | .13 | .07 | .10 |
| | 3 | .12 | .15 | .16 | .15 | .32 | .22 | .12 | .22 | .13 | .16 | .14 | .20 | .13 | .18 | .19 | .22 | .25 | .21 | .22 | .12 | .17 |
| | 4 | .20 | .21 | .22 | .20 | .49 | .35 | .20 | .35 | .20 | .21 | .21 | .31 | .20 | .27 | .29 | .31 | .36 | .27 | .33 | .18 | .26 |
| | 5 | .27 | .28 | .34 | .27 | | | .29 | | .28 | .32 | .30 | .45 | .28 | .42 | .42 | .42 | .46 | .38 | .47 | .27 | .39 |
| | 6 | .35 | .37 | .45 | .34 | | | .40 | | .38 | .47 | .42 | .62 | .38 | | .56 | | | .51 | .62 | .38 | |
| | 7 | .45 | | | | | | | | .52 | .58 | .55 | | .52 | | | | | .64 | | .49 | |
| Half length | 1 | .09 | .09 | | | .15 | .11 | .06 | | .06 | .06 | .07 | .08 | .07 | | | | | .12 | .14 | .05 | |
| | 2 | .18 | .22 | | | .32 | .20 | .11 | | .11 | .11 | .14 | .16 | .13 | | | | | .25 | .28 | .12 | |
| | 3 | .31 | .33 | | | .54 | .39 | .23 | | .22 | .21 | .21 | .28 | .19 | | | | | .47 | .44 | .24 | |
| | 4 | .47 | .48 | | | .92 | .62 | .42 | | .36 | .32 | .31 | .49 | .28 | | | | | .61 | .84 | .46 | |
| | 5 | .66 | .68 | | | | | .63 | | .55 | .51 | .45 | .72 | .43 | | | | | 1.14 | 1.30 | .69 | |
| | 6 | .93 | .85 | | | | | .94 | | .74 | .97 | .58 | | .74 | | | | | 1.35 | 1.80 | 1.07 | |
| | 7 | 1.18 | | | | | | | | 1.12 | 1.18 | .80 | | | | | | | 1.72 | | 1.48 | |
| Tunnel width (axials) or septal count | 1 | .025 | .02 | 8 | 10 | .05 | .04 | .01 | 7 | .015 | .014 | .02 | .02 | .02 | 9 | 10 | 11 | 6 | .02 | .02 | | |
| | 2 | .030 | .03 | 14 | 14 | .10 | .06 | .03 | 13 | .02 | .021 | .02 | .04 | .02 | 16 | 16 | 19 | 13 | .05 | .03 | .02 | 12 |
| | 3 | .045 | .06 | 16 | | .19 | .11 | .04 | 16 | | .040 | .03 | .07 | .04 | 20 | 19 | 21 | 14 | .07 | .08 | .03 | 13 |
| | 4 | .06 | .08 | 19 | | .26 | | .07 | 18 | .07 | .080 | .05 | .10 | .08 | 22 | 24 | 23 | 16 | .14 | .10 | .07 | 19 |
| | 5 | .11 | .12 | 23 | 22 | | | .11 | | .08 | .114 | .06 | .14 | .10 | 21 | 26 | | | .17 | .16 | .16 | 22 |
| | 6 | .12 | | | | | | .18 | | .11 | .120 | .09 | | .18 | | 30 | | | | .21 | .22 | |

ent wall structure. It also bears some resemblance to *Eostaffella ikensis* Vissarionova (1948), but the proloculus is consistently smaller and the chomata better developed. The wall structure may be about the same.

*Occurrence.*—*Eostaffella clarita* is common in sample f13269 from northwest of Clarita, Oklahoma, where it is associated with fragments of bryozoans, ostracodes, echinoderms, and other shell debris, in a grainstone with many fragments coated with algae. Other foraminifers include endothyrids, *Tetrataxis* sp. and *Millerella* sp. The specimen figured on plate 1, figure 8, is designated the holotype. The locality is considered by Archinal (personal communication, 1982) to be part of the Wapanucka Limestone.

Genus **Profusulinella** Rauser-Chernoussova and Beljaev, 1936

**Profusulinella millcreekensis** Douglass and Nestell, n. sp.

Pl. 1, figs. 16–23

*Description.*—Small, thickly fusiform to ovoid tests of as many as six volutions, attaining lengths of 2 mm and diameters of 0.9 mm. The proloculi seen are nearly 110 microns in outer diameter. The first volution is at a large angle to the rest of the test in some, but not all, specimens. The test expands regularly and relatively rapidly, with convex lateral slopes and broadly rounded poles. Septa are closely spaced and are irregularly fluted to planar across the middle of the test. The tunnel extends a little more than one-half the chamber height, and is bordered by well-developed chomata that tend to spread laterally along the adjacent septa. The spirotheca is thin, composed of tectum and diaphanotheca with a well-developed outer tectorium in the inner volutions. Only hints of mural pores are visible in the diaphanotheca of some specimens.

*Discussion.*—Among most similar species, *Profusulinella millcreekensis* is more loosely coiled, has closely spaced and slightly more fluted septa, and has a larger proloculus than *P. kentuckyensis* Thompson and Riggs. It is less-regularly shaped, has a consistently larger proloculus, and has more closely spaced and slightly more fluted septa than *P. whitetailensis* Ross and Sabins.

*Occurrence.*—Lowermost sandstone of the Atoka Formation above the Wapanucka Limestone in the Pipeline Trench section of Grubbs (1981) in Mill Creek, Johnston County, Oklahoma. The sandstone has a calcareous cement and includes various rounded, calcareous elements, including fusulinids, crinoidal debris, and ooids, some containing smaller foraminifers as a nucleus. R. Kent Grubbs collection 283-13, January 1980. The specimen illustrated on plate 1, figures 16 and 17, is designated the holotype.

**Profusulinella fittsi** (Thompson), 1935

Pl. 2, figs. 1–8

*Fusulinella fittsi* Thompson, 1935b, p. 300, pl. 26, figs. 1–6.

*Profusulinella fittsi* (Thompson), 1953, pl. 41, figs. 13–20.

*Discussion.*—Thompson's original description of this form was accompanied by illustrations of whole specimens and of thick thin sections that did not clearly show the nature of the spirotheca. Thompson discussed a diaphanotheca and inner tectorium that, combined, were slightly thicker than the outer tectorium. Later, Thompson (1953) had better thin sections from topotypes that clearly reveal the typical three-layered wall characteristic of *Profusulinella*. All his specimens are smaller than *P. millcreekensis* at the same number of volutions, and the chomata are consistently broader in *P. fittsi*.

*Occurrence.*—*P. fittsi* was described originally as coming from two localities in Coal County, Oklahoma, each approximately 100 feet above the base of the Atoka Formation. The primary locality, from which all but one of Thompson's figured specimens came, is confused in that, as given (exact center of NW¼ sec. 10, T. 1 N., R. 8 E.), it is located in the Desmoinesian about 3 miles northeast of the base of the Atoka Formation. The locality is also recorded as being "on the south bank of a small tributary of Goose Creek" (Thompson, 1935, p. 301). A possible location on a tributary of Goose Creek and in the lower part of the Atoka Formation would be achieved if the location read "NW¼ sec. 19, T. 1 N., R. 8 E." Alternatively, a location in the lower part of the Atoka Formation would also be possible if the locality read "NW¼ sec. 10, T. 1 S., R. 8 E.," but such a location would not be on a tributary of Goose Creek. In any case, intense searching in these and other exposures in the lower part of the Atoka Formation in the region by P. K. Sutherland (personal communication, 1982) and his students has produced nooccurrences of *P. fittsi*.

Thompson (1953) figured topotypes from the first locality. The specimen illustrated by Thompson (1935b) on his plate 26 as figure 3, SUI 810, is here designated the lectotype and is shown herein on plate 2 as figures 1 and 2.

Genus **Fusulinella** Möller, 1877

**Fusulinella prolifica** Thompson, 1935

Pl. 2, figs. 9–20

*Fusulinella prolifica* Thompson, 1935b, p. 302, pl. 26, figs. 23–29.

*Description.*—Small, elongate fusiform with straight to convex lateral slopes and bluntly pointed to rounded poles. Mature specimens attain five to seven volutions and are as much as

2.7 mm long and 1.1 mm wide. Inner volutions tend to be ovate, and the outer volutions elongate rapidly, giving a subcylindrical shape in some specimens. The proloculus ranges in outer diameter from nearly 50 microns to 160 microns, but is commonly about 100 microns. The spirotheca of tectum and diaphanotheca is relatively thin where it can be seen, but a thick outer tectorium is common along the lateral slopes extending from the chomata toward the poles. This gives the appearance of a thick wall, except in the immediate area of the tunnel. The specimens studied by Thompson do not have the pore staining that is common in many of the samples found in the immediate area. The septa are nearly straight across the middle of the test in all volutions, but are irregularly fluted in the outer volutions and near the poles. The septa tend to be evenly spaced; as many as about 20 septa are in the outer volutions. The tunnel is nearly straight and extends only about one-third the chamber height; its width increases gradually through the inner three to four volutions, but commonly increases rapidly in the outermost volutions. The tunnel is bordered by asymmetrical chomata that commonly blend imperceptibly with the outer tectorium on the lateral slopes.

*Discussion.*—The description above is based solely on the specimens that were available to Thompson when he first described the species. These specimens were studied for comparison with subsequent collections made by L. G. Henbest, M. K. Nestell, and P. K. Sutherland and students. Among these collections, specimens from unit 263-5 are similar (pl. 2, figs. 16–20), and those from unit 275-18E (pl. 2, figs. 13–15) also are similar.

*Occurrence.*—*Fusulinella prolifica* was described as coming from two localities north of Clarita in Coal County, Oklahoma. The primary locality, from which most of the specimens were collected and from which our selected lectotype came, was located, according to Thompson (1935b, p. 303), "about 200 feet above the base of the Atoka Formation in the center of the section line between secs. 2 and 3, T. 1 S., R. 8 E." Thus, the locality must have been in one of the section-line-road ditches, but the distance north of the section corner was not given. In 1960, C. C. Branson took P. K. Sutherland (personal communication, 1982) to the east ditch on this road, immediately in front of the Stutte farmhouse (indicated by arrow marked *Z* on fig. 3). They collected rare, loose fusulinids from a thin, calcareous shale layer in an otherwise unfossiliferous interval of thin sandstones and shales. Branson pronounced this to be the type locality of *Fusulinella prolifica*, but the specimens they collected there were not permanently preserved. This ditch is now covered, and thus the type locality of *F. prolifica* cannot now be reestablished with certainty.

The other specimens assigned to this species were found at localities 263-5 (South Jack Hills Syncline section) and 275-18E (Canyon Creek section). The specimen numbered SUI 1004, and illustrated by Thompson (1935b) as figure 28 on his plate 26, is here designated the lectotype and is reillustrated as figure 9 on our plate 2.

**Fusulinella barnettensis** Douglass and Nestell, n. sp.

Pl. 3, figs. 1–9

*Description.*—Test relatively large for the genus, attaining lengths of 4 mm and diameters of 1.5 mm in seven volutions. The shape starts out as ovoidal, and remains fusiform to ovoid throughout growth. The length increases regularly and a little more rapidly than the diameter, giving an unusually regular appearance in axial section. The proloculus in most specimens is 60 to 100 microns in outside diameter, but microspheric forms are present in which the proloculus is less than 20 microns in outer diameter.

Spirotheca is thin, composed of tectum and diaphanotheca with variable additions of inner and outer tectoria. Tectoria are missing in places but are thick in other areas of the same volution, the outer tectorium exceeding the inner layers in combined thickness. Preservation of some specimens shows the porous nature of the wall structure in the outer volutions (pl. 3, fig. 9). Septa are numerous and evenly spaced. The outer whorls commonly contain 25 to 28 chambers per volution. Septa are irregularly fluted to straight throughout most of the test. The tunnel is straight to irregular and widens rapidly. It extends one-third to one-half the volution height, and may be four to six times as wide as it is high in the outer volutions. Chomata are high and asymmetrical, tapering rapidly toward the poles.

*Discussion.*—*Fusulinella barnettensis* differs from *F. prolifica* in being larger and more ovoid at all volutions, in having more chambers per volution, especially in the adult whorls, and in having greater regularity of form.

*Occurrence.*—This species was collected by L. G. Henbest from two localities, f13270 and f13271, west of Barnett Hill, north of Clarita, Oklahoma. Specimens are abundant in a calcarenite that is rich in echinodermal debris and fragments of bryozoans, brachiopods, and foraminifers. Abundant millerellids also are present. The specimen illustrated on plate 3, figure 1, is designated the holotype.

**Fusulinella** sp. aff. **F. devexa** Thompson, 1948

Pl. 3, figs. 10–19

*Fusulinella devexa* Thompson, 1948, p. 94, pl. 32, figs. 6, 10; pl. 35, figs. 1–15; pl. 36, figs. 7–10, 12–17; Ross and Sabins, 1965, p. 186, pl. 24, figs. 13–22; Stewart, 1970, p. 43, pl. 4, figs. 1–3.

*Description.*—Elongate fusiform, with nearly straight axis of coiling and with lateral slopes that are nearly straight, slightly concave, or slightly convex. The inner volutions tend to be ovoid, but the test elongates rapidly to the fusiform shape of adult specimens. Adult specimens having six to seven volutions are nearly 4 mm in length and 1.5 mm in diameter. The proloculus is small but quite variable, ranging from about 60 to more than 130 microns in outer diameter. The spirotheca is composed of tectum and diaphanotheca and has thin inner and outer tectoria, except in the vicinity of the septa. A fine, porous structure can be seen in the diaphanotheca of the outer volutions of some specimens. The septa are closely spaced and irregularly fluted, forming only irregular chamberlets toward the poles in some specimens. A few small septal pores are apparent in the outer volutions. The tunnel is nearly straight and widens regularly. It extends one-third to one-half the chamber height, and is two to three times as wide as it is high. Chomata are relatively small and asymmetrical, commonly two to three times as wide as they are high.

*Discussion.*—*F. devexa* is a variable species. The original group of specimens described by Thompson shows some of the range of variation, from very regularly coiled forms that have almost no apparent septal fluting to less regular forms that have considerable but irregular septal fluting. The fusulinids from several beds within the Atoka Formation fall within these limits, including those in units 284-27 through 284-43 of the Lewis Ranch section, 274-15 and 274-17 in the Coal Creek section, and 275-18B in the Canyon Creek section.

*Occurrence.*—This species was described from beds 24 and 26 of the "Cuchillo Negro Formation" in southern New Mexico by Thompson (1948), from the Horquilla Limestone in southeastern Arizona by Ross and Sabins (1965), and from the Joyita Hills in central New Mexico by Stewart (1970). In Oklahoma, it is recognized in the collections mentioned in the discussion above.

### **Fusulinella** sp. aff. **F. leyi** Thompson, 1945
Pl. 4, figs. 1–6

*Fusulinella iowensis* var. *leyi* Thompson, 1945, p. 50, pl. 2, figs. 15–25; pl. 3, figs. 16–21; pl. 5, fig. 6.

*Description.*—Small, inflated fusiform to subglobose, and especially globose in the microspheric form. The inner volutions are round to ovate; the lateral slopes remain convex throughout on most specimens, but do straighten or even become concave on a few specimens. Specimens with six volutions attain lengths of 2 mm and diameters of 1 mm. The proloculus of megalospheric forms ranges from less than 60 to 100 microns in outer diameter. The spirotheca is composed of tectum, diaphanotheca, and variable amounts of tectoria. Tectoria are quite thin between septa and may be absent in places. Near the top and bottom of the septa, the deposits may be thicker than the tectum and diaphanotheca combined. Septa are closely spaced and irregularly fluted throughout their length. Megalospheric forms have more tightly fluted septa than their microspheric counterparts. The tunnel is not straight but is narrow and meanders irregularly around the equatorial zone. It extends about one-half the chamber height. Chomata are well developed throughout and are asymmetrical. In microspheric forms, the chomata tend to be extended along the lateral slopes more than they are in the megalospheric forms.

*Discussion.*—This form resembles the group of species that includes *Fusulinella leyi, F. famula, F. insolita,* and *F. iowensis.* The specimens described herein are smaller than those of any of these species. Septa may be more fluted in these specimens than in typical *F. leyi*, but they remain irregular and relatively simple across the middle of the test. Fluting is less intense than in *Beedeina lewisi* n. sp., which occurs in the overlying Deese Formation.

*Occurrence.*—These specimens are from unit 284-54 of the Lewis Ranch section and are from a partly recrystallized crinoidal limestone containing some *Komia*, bryozoans, and small foraminifers, including textularids, endothyrids, and *Tetrataxis* sp.

### **Fusulinella** sp. A
Pl. 4, figs. 7–10

*Discussion.*—Small, robust form with a form ratio of 2 in four to four and one-half volutions showing a rapid expansion in diameter similar to that of *Profusulinella primaeva* (Skinner) (1931), but possessing a distinct inner tectorium, indicating a more advanced stage of evolution. The inner volutions of these species still have the profusulinellid wall, but the inner tectorium is present in the outer two to three volutions. The more elongate specimens in the sample show some similarity to the more robust specimens of *F. prolifica*, but the chomata are more discrete than in the robust specimens of *F. prolifica* mentioned by Thompson (1935b).

*Occurrence.*—The specimens illustrated are from unit 261-9B, South Goose Creek section.

### **Fusulinella** sp. B
Pl. 4, figs. 11, 12

*Discussion.*—Some specimens from unit 284-54, near the top of the Lewis Ranch section, cannot be assigned to *Fusulinella* sp. aff. *F. leyi* Thompson, because they are more loosely coiled and have widely spaced septa. They bear considerable resemblance to *F. lounsberyi* Thompson, but the material available is not sufficent to make a significant comparison.

*Occurrence.*—These specimens are associated with *F.* sp. aff. *F. leyi* in unit 284-54, near the top of the Lewis Ranch section.

Genus **Wedekindellina** Dunbar and Henbest, 1933

**Wedekindellina praematura** Douglass and Nestell, n. sp.
Pl. 4, figs. 13–22

*Description.*—Small, fusiform test, elongating regularly with each volution from the ovoid inner whorl. The slopes are straight to slightly convex. Proloculus is minute, measuring less than 80 microns in outer diameter. Spirotheca is thin, with a tectum, diaphanotheca, and thin inner tectorium. The outer tectorium is very thin in the tunnel area, and on the slopes it is indistinguishable from the polar extensions of the chomata. The septa are closely spaced and essentially straight throughout their length, having only minor undulations toward the poles; they are thickened at the base by secondary deposits. The tunnel is nearly straight and narrow, and extends through most of the height of the chambers. The chomata are asymmetrical, rising sharply at the tunnel but tapering gradually toward the poles.

*Discussion.*—*W. praematura* n. sp. is small for the genus. It resembles *W. prolifica* Kanmera (1954) in general shape but is only one-half its size at the same number of volutions. It is smaller, more fusiform, and has chomata that extend more toward the poles than they do on most other species of the genus, including *W. euthysepta* and *W. henbesti*. It is about the same length as *W. matura*, but is more fusiform and has chomata that are more extended.

*Occurrence.*—*W. praematura* n. sp. was recognized only in unit 284-62, from the top of the Lewis Ranch section, where it is rare. The sample contains abundant *Beedeina lewisi* n. sp. and rare *Pseudostaffella* sp. aff. *P. atokensis* (Thompson). The specimen illustrated on plate 4, figure 13, is designated the holotype.

Genus **Beedeina** Galloway, 1933

**Beedeina lewisi** Douglass and Nestell, n. sp.
Pl. 5, figs. 1–12

*Description.*—Small, inflated fusiform, with roundly pointed poles. The early volutions are subrounded, but additional chambers are increasingly elongate and the lateral slopes tend to flatten out and become concave in some volutions. Mature specimens with six to seven volutions rarely exceed 2.5 mm in length and 1.25 mm in diameter. Proloculus is small and round, attaining 90 microns in outer diameter in some specimens. The spirotheca is variable. Tectum and diaphanotheca are thin and well defined, but the epithecal deposits range from almost no inner tectorium to a thick deposit, and from a thin outer tectorium to deposits thicker than the tectum and diaphanotheca combined. The septa are closely spaced and fluted; intense fluting in the outer volutions forms regular chamberlets extending to the tunnel area. The tunnel is commonly straight and narrow, but meanders a bit in many specimens; it extends about one-half the height of the chambers. Chomata are well developed, high, and asymmetrical, with nearly straight inner slopes and rounded to slightly elongated outer slopes, especially in the inner volutions.

*Discussion.*—*B. lewisi* n. sp. is comparable to *Fusulina insolita* Thompson (1948) and *Fusulinella leyi* Thompson (1945), especially in its inner volutions, but *B. lewisi* n. sp. has regularly and intensely fluted septa, more discrete chomata, and more concave lateral slopes, in the adult whorls. It is also consistently smaller at the same number of volutions. *F. insolita* also has a much larger proloculus.

*Occurrence..*—*Beedeina lewisi*, from unit 284-62 in the Lewis Ranch section, is associated with rare *Wedekindellina praematura* n. sp. and *Pseudostaffella* sp. aff. *P. atokensis* (Thompson). The inner volutions of many of the specimens are altered through replacement, and the specimens in the samples available are abraded. The specimen illustrated on plate 5, figure 1, is designated the holotype.

**Beedeina grileyi** Douglass and Nestell, n. sp.
Pl. 5, figs. 13–21

*Description.*—Small, elongate fusiform species that expand regularly with little change in shape from the inner to the outer volutions. Specimens with six to six and one-half volutions attain lengths of 3.5 mm and diameters of 1.2 mm. Proloculus is small, averaging just less than 100 microns in outer diameter. Spirotheca is composed of tectum, diaphanotheca, a thick outer tectorium, and a thinner inner tectorium. Preservation in this sample, however, reveals the porous nature of the entire wall through iron-staining of the pore infillings (pl. 5, figs. 15, 21). Septa are nearly straight across the middle of the test in the early volutions, but are irregularly fluted toward the poles. They are irregularly and commonly intensely fluted in the outer volutions, forming chamberlets to the tunnel area. The tunnel is nearly straight and quite narrow, bordered by chomata that extend one-half the chamber height and taper gradually to two to three times their height along the lateral slopes.

*Discussion.*—*B. grileyi* n. sp. bears some resemblance to *B. mutabilis* (Waddell) (1966) but is smaller, less inflated, and maintains a more regular shape throughout the ontogeny. It is about the same size as *B. plattensis* (Thompson) (1936) and *B.* sp. of Thompson (1936), but the chomata are less elongate and the septal fluting is more regular in Thompson's forms. The striking preservation of the porous wall in this sample is similar to that illustrated by Skinner and Wilde (1954) from the Mingus Shale Member of the Garner Formation in Parker County, Texas. Specimens from the Atoka Formation in Coal County, Oklahoma, show similar preservation.

*Occurrence.—B. grileyi* n. sp. is found in the shale of the "Griley" limestone at locality 264-3C, in Coal County, Oklahoma. Associated with the fusulinids are many other small fossils, including a variety of smaller foraminifers, the ostracodes *Amphissites centronotus* and *Bairdia* sp., and rare conodonts. The specimen figured on plate 5, figure 14, is the holotype.

## REFERENCES CITED


**Archinal, B. E.,** 1977, The lithostratigraphy of the Atoka Formation (Lower Pennsylvanian) along the southwestern margin of the Arkoma Basin, Oklahoma: University of Oklahoma unpublished M.S. thesis, 172 p.

———1981, Pennsylvanian sandstones of the Mid-Continent: Tulsa Geological Society Special Publication 1, p. 259–267.

**Archinal, B. E., Sutherland, P. K., Grayson, R. C., Jr., Douglass, R. C.,** and **Nestell, M. K.,** 1982, Stop descriptions—northeastern Arbuckle Mountains, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 19–29.

**Branson, C. C.,** 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C., editor, Pennsylvanian System in the United States, a symposium: American Association of Petroleum Geologists, p. 431–460.

**Douglass, R. C.,** 1977, The development of fusulinid biostratigraphy, *in* Kauffman, E. G., and Hazel, J. E., editors, Concepts and methods of biostratigraphy: Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, p. 463–481.

———1979, The distribution of fusulinids and their correlation between the Illinois Basin and the Appalachian Basin, *in* Palmer, J. E., and Dutcher, R. R., editors, Depositional and structural history of the Pennsylvanian System of the Illinois Basin: Illinois Geological Survey Guidebook Series 15, pt. 2, p. 15–20.

**Galloway, J. J.,** 1933, A manual of Foraminifera: Principia Press, Bloomington, Indiana, 483 p.

**Grubbs, R. K.,** 1981, Pennsylvanian stratigraphy and conodont biostratigraphy of the Mill Creek Syncline, central Arbuckle Mountains, Oklahoma: University of Oklahoma unpublished M.S. thesis, 227 p.

**Grubbs, R. K., Sutherland, P. K., Douglass, R. C.,** and **Nestell, M. K.,** 1982, Stop descriptions—Mill Creek Syncline, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 30–37.

**Kanmera, K.,** 1954, Fusulinids from the Yayamadake limestone of the Hikawa Valley, Kumamoto Prefecture, Kyushu, Japan, Part I, Fusulinids of the upper Middle Carboniferous: Japanese Journal of Geology and Geography, Transactions, v. 25, p. 117–144.

**Rauser-Chernoussova, D. M.,** 1948, Data on a fauna of Carboniferous Foraminifera of deposits of central Kazakhstan [in Russian]: Akademia Nauk SSSR, Institut Geologicheskikh Nauk (Trudy), vyp. 66, (Geol. ser. 21), p. 1–27.

**Rauser-Chernoussova, D. M., Beljaev, G.,** and **Reitlinger, E.,** 1936, Upper Paleozoic Foraminifera from the Pechora Region [in Russian]: Akademia Nauk SSSR, Trudy polyarnoi komissii, vyp. 28, p. 159–232. (German summary, p. 219–228.)

**Ross, C. A.,** and **Sabins, F. F., Jr.,** 1965, Early and Middle Pennsylvanian fusulinids from southeast Arizona: Journal of Paleontology, v. 39, p. 173–209.

**Sanderson, G. A.,** 1981, Fusulinids from the Desmoinesian type area [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 545.

**Skinner, J. W.,** 1931, Primitive fusulinids of the mid-continent region: Journal of Paleontology, v. 5, p. 253–259.

**Skinner, J. W.,** and **Wilde, G. L.,** 1954, Fusulinid wall structure: Journal of Paleontology, v. 28, p. 445–451.

**Spivey, R. C.,** and **Roberts, T. G.,** 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Stewart, W. J.,** 1970, Fusulinids of the Joyita Hills, Socorro County, central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 23, pt. 2, p. 32–80.

**Strimple, H. L.,** and **Watkins, W. T.,** 1969, Carboniferous crinoids of Texas with stratigraphic implications: Palaeontographica Americana, v. 6, p. 141–275.

**Sutherland, P. K.,** editor, 1982, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, 44 p.

**Taff, J. A.,** and **Adams, G. I.,** 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 257–311.

**Thompson, M. L.,** 1935a, The fusulinid genus *Staffella* in America: Journal of Paleontology, v. 9, p. 111–120.

———1935b, Fusulinids from the lower Pennsylvanian Atoka and Boggy formations of Oklahoma: Journal of Paleontology, v. 9, p. 291–306.

———1936, Fusulinids from the Black Hills and adjacent areas in Wyoming: Journal of Paleontology, v. 10, p. 95–113.

———1942, New genera of Pennsylvanian fusulinids: American Journal of Science, v. 240, p. 403–420.

———1945, Pennsylvanian rocks and fusulinids of east Utah and northwest Colorado correlated with the Kansas section: Kansas Geological Survey Bulletin 60, pt. 2, 84 p.

———1947, Stratigraphy and fusulinids of pre-Desmoinesian Pennsylvanian rocks, Llano uplift, Texas: Journal of Paleontology, v. 21, p. 147–164.

———1948, Studies of American fusulinids: University of Kansas Paleontological Contributions, Protozoa, Article 1, 184 p.

———1953, Primitive *Fusulinella* from southern Missouri: Journal of Paleontology, v. 27, p. 321–327.

———1966, Distribution of *Profusulinella* in North America [in Russian]: Akademia Nauk SSSR, Voprosy Mikropaleontologii, v. 10, p. 126–133.

**Thompson, M. L.,** and **Shaver, R. H.,** 1964, Early Pennsylvanian microfaunas of the Illinois Basin: Transactions of the Illinois State Academy of Science, v. 57, p. 3–23.

**Thompson, M. L., Shaver, R. H.,** and **Riggs, E. A.,** 1959, Early Pennsylvanian fusulinids and ostracods of the Illinois Basin: Journal of Paleontology, v. 33, p. 770–792.

**Thompson, M. L.,** and **Zeller, D. N.,** 1956, *Profusulinella* in western Utah: Journal of Paleontology, v. 30, p. 333–337.

**Vissarionova, A. Ya.,** 1948, Primitive fusulinids from the Lower Carboniferous of the European part of the USSR [in Russian]: Akademia Nauk SSSR, Institut Geologicheskikh Nauk (Trudy), v. 62, no. 19, p. 216–226.

**Waddell, D. E.,** 1966a, Pennsylvanian fusulinid biozones in southern Oklahoma: Oklahoma Geology Notes, v. 26, p. 123–133.

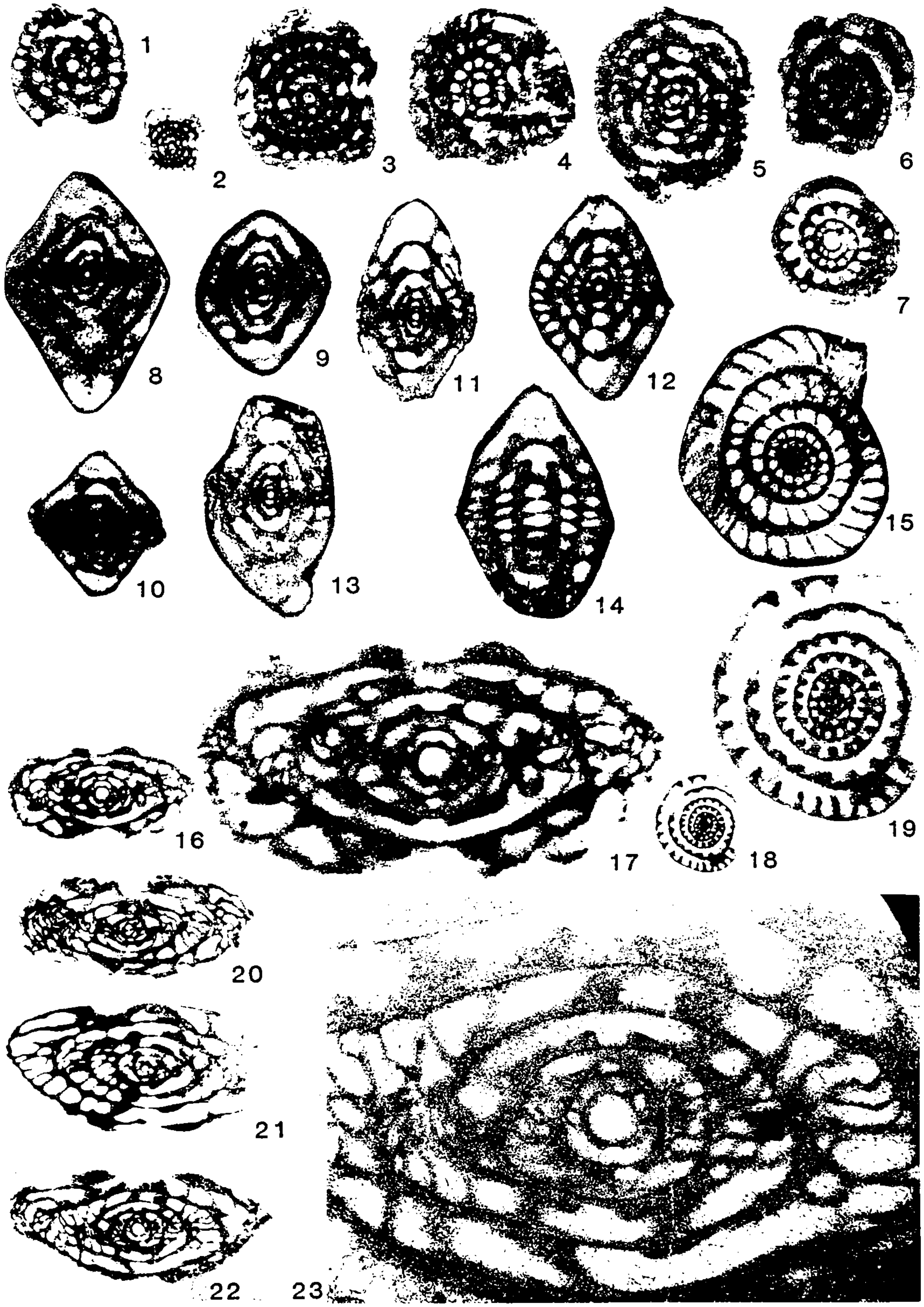
———1966b, Pennsylvanian fusulinids in the Ardmore basin, Love and Carter Counties, Oklahoma: Oklahoma Geological Survey Bulletin 113, 128 p.

## Plate 1

Figs. 1–7.—*Pseudostaffella* sp. aff. *P. atokensis* (Thompson). Unit 284-62, top of Lewis Ranch section of Grubbs (1981), ×50, except fig. 2, ×20 (OU 9947–OU 9952).

Figs. 8–15.—*Eostaffella clarita* n. sp. *8*, axial section of holotype, ×50 (USNM 337412); *9–13*, axial section of paratypes, ×50 (USNM 337413–USNM 337417); *14*, horizontal section of paratype showing nature of chomata and straight septa, ×50 (USNM 337418); *15*, subequatorial section of paratype showing low tunnel and closely spaced septa, ×50 (USNM 337419). Locality f13269, Coal County, Oklahoma.

Figs. 16–23.—*Profusulinella millcreekensis* n. sp. *16, 17*, axial section of holotype, ×20 and ×50 (OU 9953); *18, 19*, equatorial section of paratype, ×20 and ×50 (OU 9954); *20, 21*, axial sections of paratypes, ×20 (OU 9955, OU 9956); *22, 23*, axial section of paratype showing detail of profusulinellid wall, ×20 and ×80 (OU 9957). Unit 283–13, Pipeline Trench section of Grubbs (1981).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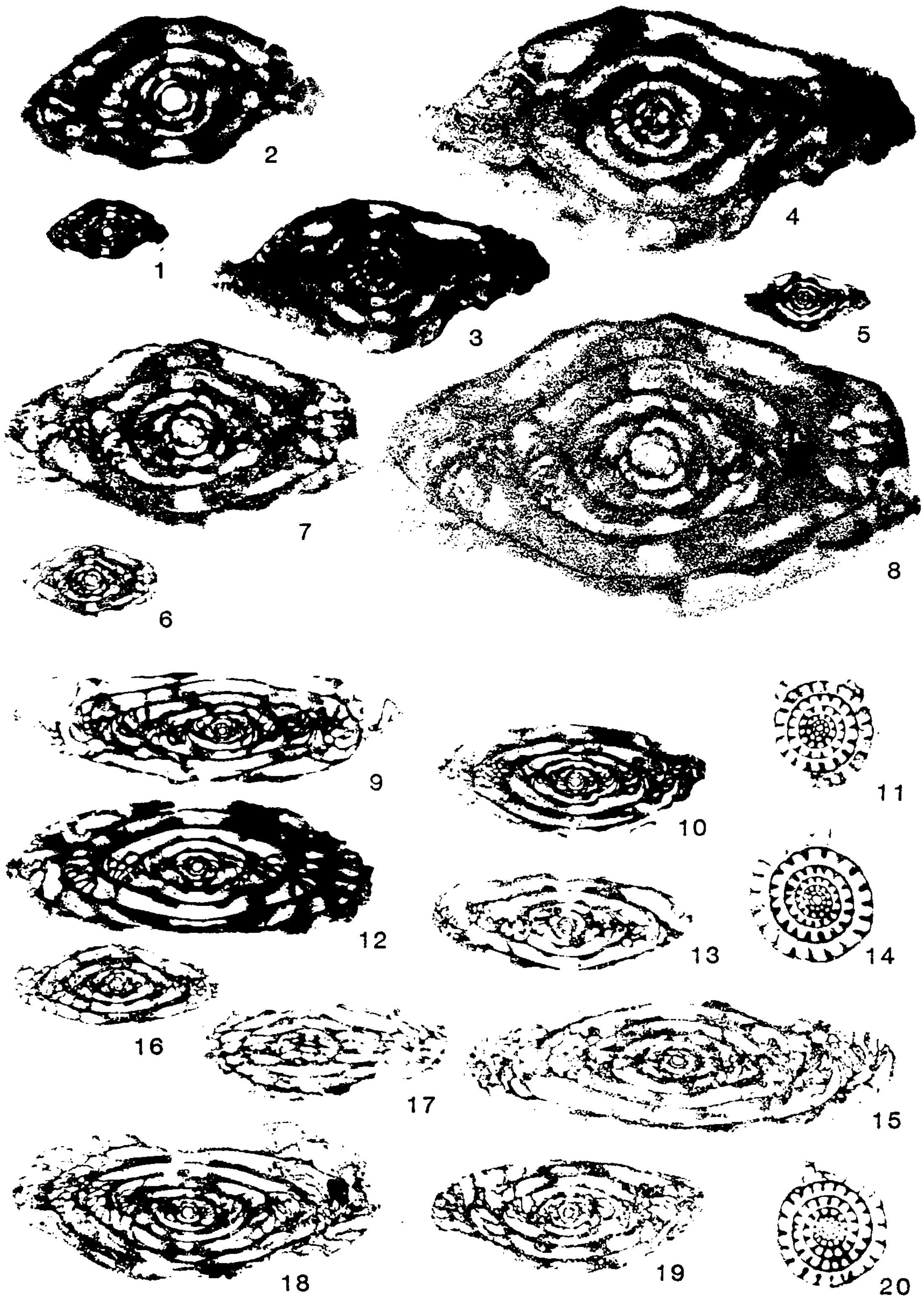
## Plate 2

Figs. 1–8.—*Profusulinella fittsi* (Thompson). *1, 2*, axial section of lectotype, ×20 and ×50 (SUI 810); *3–5*, axial section of paralectotype showing typical profusulinellid wall, ×50, ×80, and ×20 (SUI 806E); *6–8*, axial section of topotype illustrated by Thompson (1953) showing typical profusulinellid wall, ×20, ×50, and ×80 (SUI 11210).

Figs. 9–20.—*Fusulinella prolifica* Thompson. *9*, axial section of lectotype, ×20 (SUI 1004); *10*, axial section of paralectotype, ×20 (SUI 1003); *11*, equatorial section of paralectotype, ×20 (SUI 1001); *12*, axial section of paralectotype, ×20 (SUI 1009); *13–15*, specimens from sample 275-18E, Canyon Creek section, ×20 (OU 9958–OU 9960); *16–20*, unit 263-5, South Jack Hills Syncline section, ×20 (OU 9961–OU 9965).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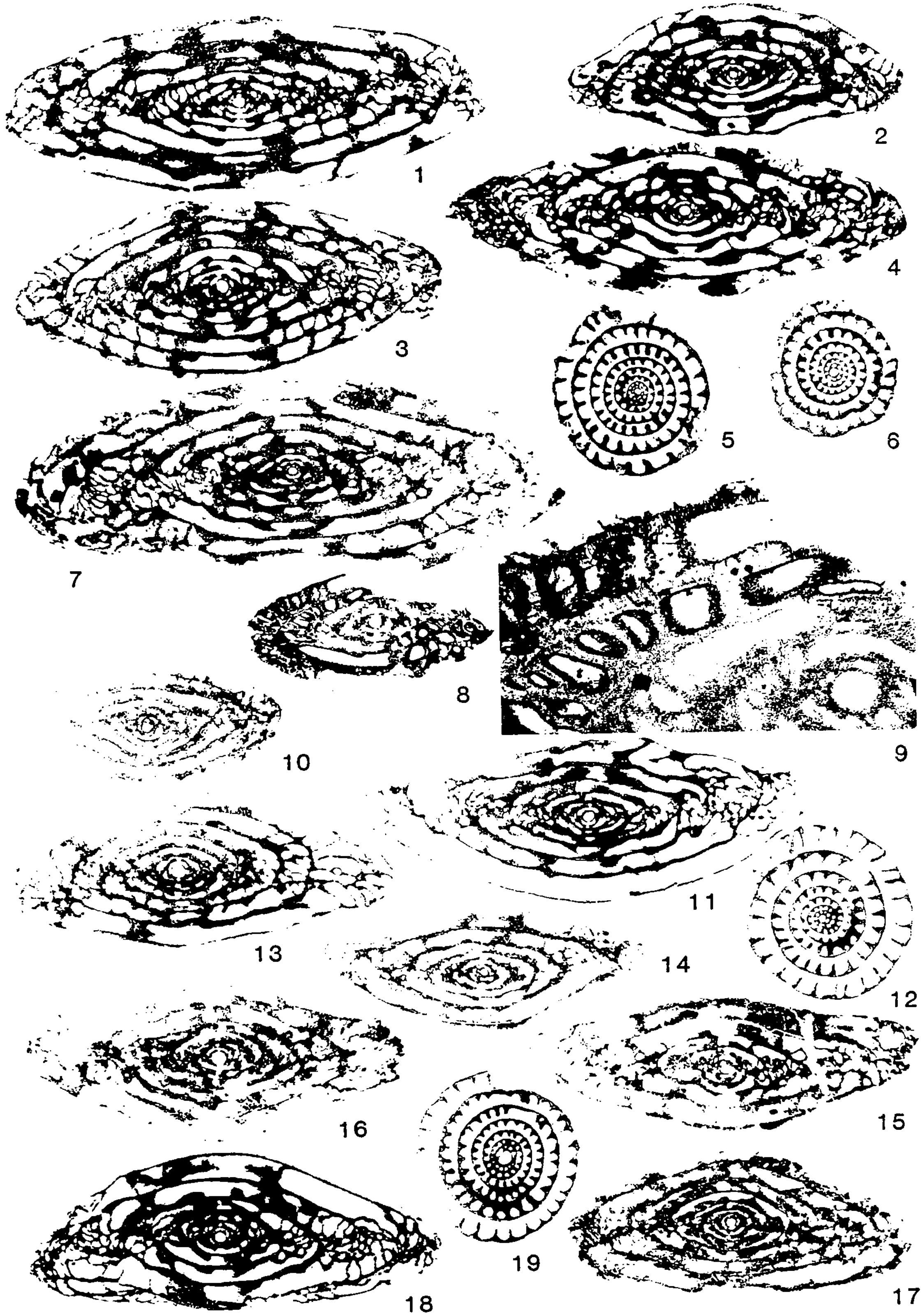
## Plate 3

Figs. 1–9.—*Fusulinella barnettensis* n. sp. *1,* axial section of holotype, ×20 (USNM 337420); *2–4,* axial sections of paratypes, ×20 (USNM 337421–USNM 337423); *5, 6,* equatorial sections of paratypes, ×20 (USNM 337424, USNM 337425); *1–6* from locality f13270. *7,* axial section of paratype, ×20 (USNM 337426); *8, 9,* partial axial section of paratype showing unusual preservation of porous wall structure, ×20 and ×80 (USNM 337427); *7–9* from locality f13271.

Figs. 10–19.—*Fusulinella* sp. aff. *F. devexa* Thompson. *10,* axial section of specimen from unit 274-17, Coal Creek section, ×20 (OU 9966); *11, 12,* axial and equatorial sections of specimens from unit 274-15, Coal Creek section, ×20 (OU 9967, OU 9968); *13,* axial section from unit 284-43C, ×20 (OU 9969); *14, 15,* axial sections from unit 284-39, ×20 (OU 9970, OU 9971); *16, 17,* axial section from unit 284-31, ×20 (OU 9972, OU 9973); *18, 19,* axial and equatorial sections from unit 284-27, ×20 (OU 9974, OU 9975). MS 284 = Lewis Ranch section; compare with fig. 2.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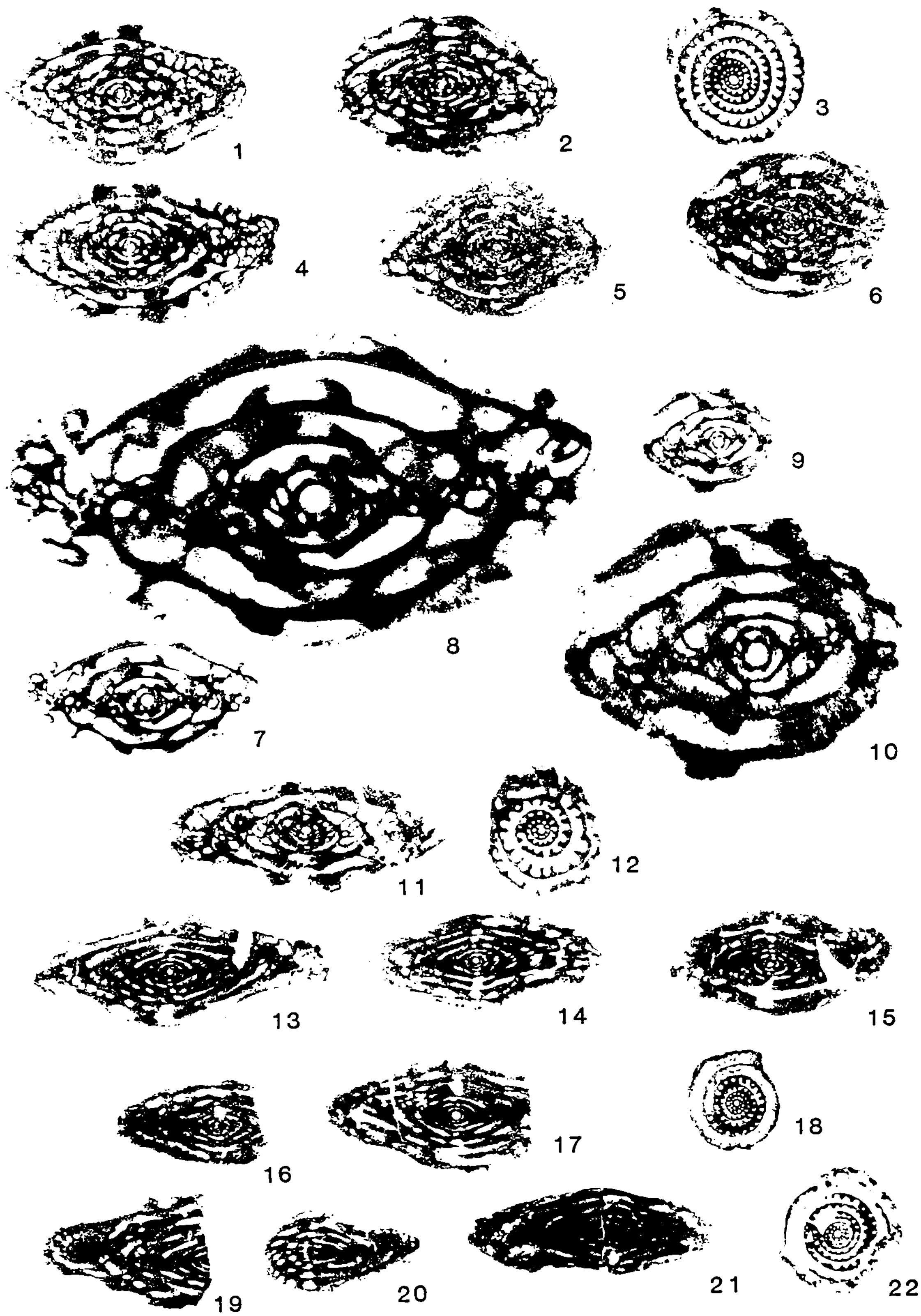
## Plate 4

Figs. 1–6.—*Fusulinella* sp. aff. *F. leyi* Thompson. *1–4,* megalospheric specimens, × 20 (OU 9976–OU 9979); *5, 6,* microspheric axial sections, × 20 (OU 9980, OU 9981). Unit 284-54, near top of Lewis Ranch section.

Figs. 7–10.—*Fusulinella* sp. A. *7, 8,* axial section, × 20 and × 50 (OU 9982); *9, 10,* axial section, × 20 and × 50 (OU 9983). Unit 261-9, top of South Goose Creek section.

Figs. 11, 12.—*Fusulinella* sp. B. *11, 12,* axial and equatorial sections, × 20 (OU 9984, OU 9985). Unit 284-54, near top of Lewis Ranch section.

Figs. 13–22.—*Wedekindellina praematura* n. sp. *13,* axial section of the holotype, × 20 (OU 9986); *14–17,* axial sections of paratypes, × 20 (OU 9987–OU 9990); *18,* equatorial section of paratype, × 20 (OU 9991); *19,* half of an axial section of paratype, × 20 (OU 9992); *20, 21,* tangential sections of paratypes, × 20 (OU 9993, OU 9994); *22,* equatorial section of paratype, × 20 (OU 9995). Unit 284-62, top of Lewis Ranch section.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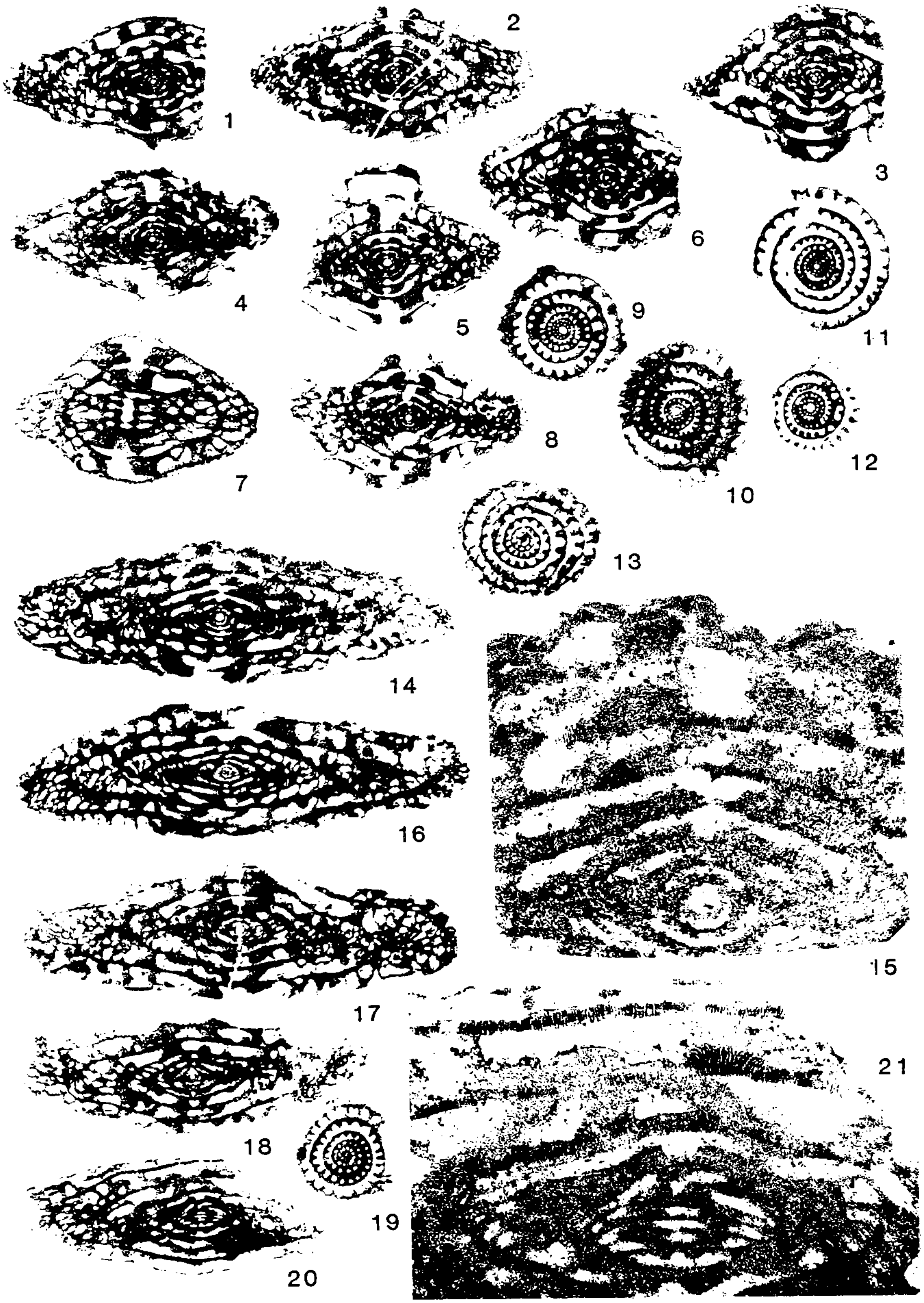
## Plate 5

Figs. 1–12.—*Beedeina lewisi* n. sp. *1,* partial axial section of the holotype, × 20 (OU 9996); *2–6,* axial sections of paratypes, × 20 (OU 9997–OU 10002); *7,* tangential section of paratype showing closed chamberlets near middle of test, × 20 (OU 10003); *8,* axial section of paratype, × 20 (OU 10004); *9–12,* equatorial sections of paratypes, × 20 (OU 10005–OU 10008). Unit 284-62, top of Lewis Ranch section.

Figs. 13–21.—*Beedeina grileyi* n. sp. *13,* near equatorial section of paratype, × 20 (OU 10009); *14, 15,* axial section of holotype showing unusual preservation of porous wall, × 20 and × 80 (OU 10010); *16–18,* axial sections of paratypes, × 20 (OU 10011–OU 10013); *19,* near equatorial section of a paratype, × 20 (OU 10014); *20, 21,* tangential section of paratype showing unusual preservation of porous wall, × 20 and × 80 (OU 10015). "Griley" limestone locality, unit 264-3.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*Oklahoma Geological Survey Bulletin 136, 1984*

# MORROWAN AND ATOKAN (PENNSYLVANIAN) CONODONTS FROM THE NORTHEASTERN MARGIN OF THE ARBUCKLE MOUNTAINS SOUTHERN OKLAHOMA

ROBERT C. GRAYSON, JR.[1]

**Abstract**—Two conodont assemblages, possibly biofacies, occur in the Wapanucka Formation. The *Idiognathoides convexus* assemblage suggests correlation of the lower, major portion of the Wapanucka Formation with the Kessler Limestone Member (latest Morrowan) of the type Morrowan Bloyd Formation. The age significance of the succeeding *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage is a problem. Based on the present definition of the Atokan series (Spivey and Roberts, 1946), occurrences of this assemblage in the Arbuckle Wapanucka Formation are latest Morrowan in age.

The Atoka Formation conodont succession is similarly divided into two assemblages. The lower *Idiognathoides marginodosus* n. sp. assemblage is marked by low abundances and diversity. The succeeding *Neognathodus atokaensis* assemblage is distinguished by *Neognathodus* spp. and relatively higher diversity and abundances of conodonts. Both assemblages are thought to be middle Atokan in age and may possibly represent nearly synchronous biofacies.

Three autochthonous species of *Neognathodus* occur in the Atoka Formation: *N.* n. sp. B, *N. atokaensis* n. sp., and *N. bothrops* Merrill. These closely related species and *Neognathodus* n. sp. A are older representatives of the *Neognathodus* lineage documented by Merrill (1972, 1975) for the late Atokan and Desmoinesian. Seemingly, *N. atokaensis* n. sp. and not *N. bassleri* is the ancestral species to *N. bothrops*.

## INTRODUCTION

Conodont zonations have been proposed for Lower and (or) Middle Pennsylvanian rocks by several authors, including Lane (1967), Koike (1967), Webster (1969), Dunn (1970b, 1976), Lane and others (1971), Merrill (1972, 1975), Lane and Straka (1974), Lane (1977), and Grayson (1979). These zonation schemes differ in substantial details owing partly to varying species concepts, but some significant differences are also due to differing faunal constituents and local ranges of taxa (biofacies). These discrepancies, particularly for coeval strata, reflect the local environmental controls on the presence or absence of particular taxa, diversity of taxa, and probably morphologic variation within taxa. Because these factors cannot currently be evaluated on a regional basis, and because a limited number of samples were examined for this study, no formal zones are proposed. In addition, the usage of assemblages does not mean that they will be retained, except perhaps for local correlation, as understanding of Pennsylvanian conodont phylogenies, ranges, biofacies, and species concepts stabilizes.

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## Acknowledgments

Bruce E. Archinal determined the basic stratigraphic framework of the Atoka Formation and assisted in the collection of samples. Patrick K. Sutherland also aided in sample collection and provided facilities at The University of Oklahoma for extracting the conodonts. Walter L. Manger and Patrick K. Sutherland critiqued the initial manuscript. John F. Baesemann and Gary D. Webster critically evaluated the manuscript and offered helpful suggestions.

This project was initiated at The University of Oklahoma and completed during a sabbatical leave from Baylor University.

## WAPANUCKA FORMATION

### Stratigraphy

The Wapanucka Formation is exposed in three geographically separate areas in Oklahoma: the frontal Ouachita Mountains, the northeastern flank of the Arbuckle Mountains, and the Mill Creek Syncline in the central Arbuckle Mountains. The formation ranges from 200 to 700 feet in thickness and consists of a diversity of lithofacies that are commonly repetitive both vertically and laterally. The major carbonate facies include spiculiferous packstone, bioclastic and oolitic grainstone or packstone, and algal carbonate mudstone. Shale is an important constituent near the base of the formation and in the middle portion of the Ouachita Wapanucka. In the frontal Ouachitas, a prominent marine sandstone facies occurs in the upper part of the formation. In the Ouachitas, Grayson (1979) subdivided the Wapanucka into three informal lithologic members (fig. 1); these are, in ascending order: lower limestone, middle shale, and upper sandstone–limestone. A fourth unit, the Chickachoc Chert Member, is the basinward facies of the lower Wapanucka. The Arbuckle Wapanucka, including the Mill Creek exposures, correlates biostratigraphically with only the lower limestone member of the formation in the frontal Ouachitas (fig. 1). The lithologies of the formation in the Arbuckles are also rather similar to those found in the lower limestone of the frontal Ouachitas (Grayson, 1979). Both represent shallowing-upward sequences punctuated by reversals, but lithologic types in the Arbuckle Wapanucka represent mostly nearer shore and shallower water deposits. Seemingly, shallowing conditions led to subaerial exposure and erosion in the Arbuckle Mountain area in latest Morrowan and earliest Atokan time, while more continuous sedimentation occurred in the Ouachitas.

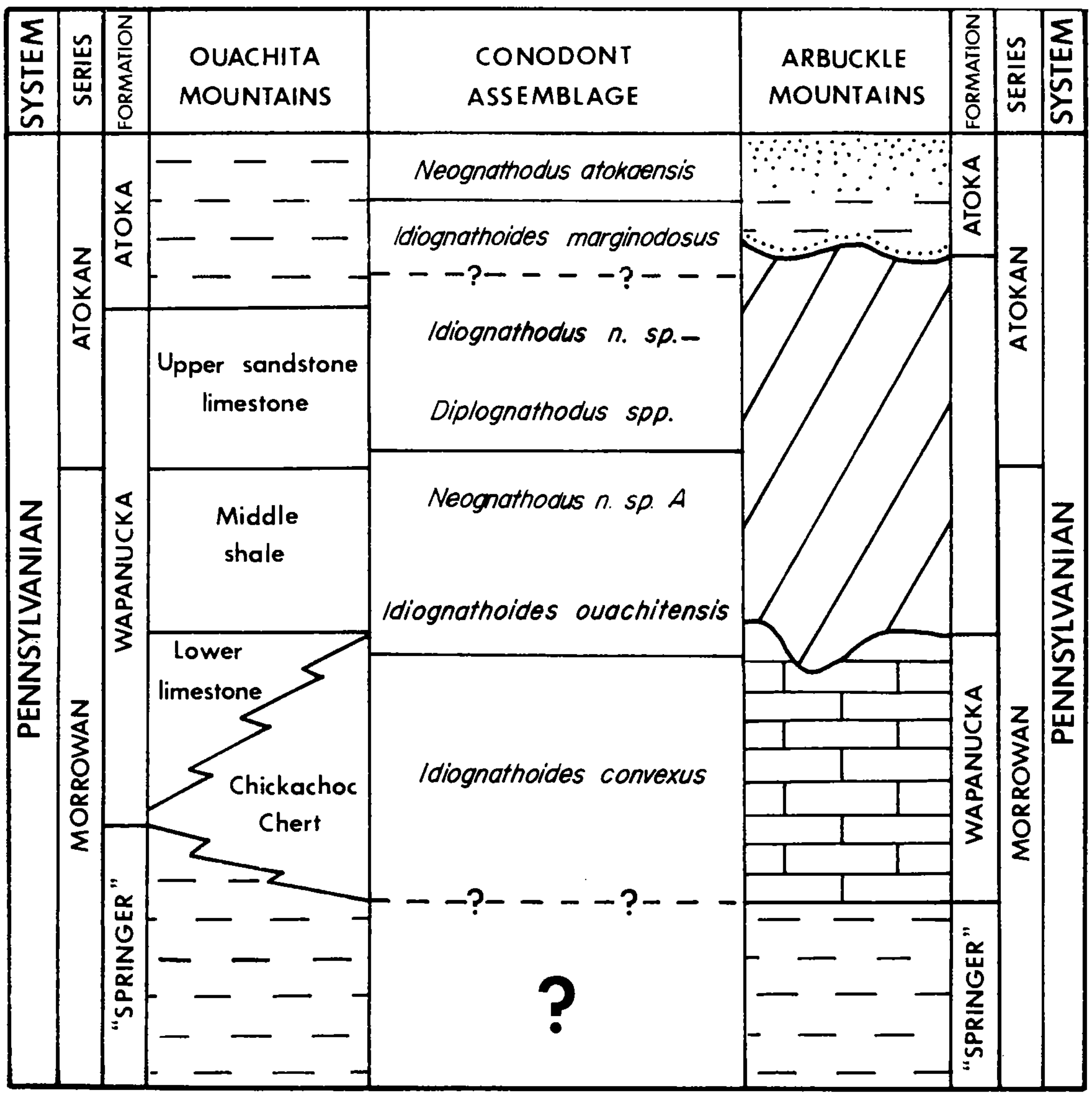


Figure 1. Correlation of Wapanucka Formation in Ouachita Mountains with same formation in its type area on northeastern and eastern flanks of Arbuckle Mountains, based on conodonts (modified from Grayson, 1979).

## Conodont Fauna

The Wapanucka conodont fauna obtained for this study is based on 21 samples (table 1) from four of Bruce E. Archinal's measured sections (MS) on the northeastern and eastern flanks of the Arbuckles (fig. 2). Two of the exposures (MS 260 and 262) represent only the upper part of the formation at or near the contact with the overlying Atoka Formation. The other two sequences (MS 275 and 159) are nearly complete. MS 159 is a primary reference sequence for the Wapanucka because it is in the type area of the formation near the town of Wapanucka, Oklahoma. Sampled zones and conodont correlations of the four exposures are shown in figure 3. The conodont sequence in the Arbuckle Wapanucka is incomplete relative to that of the Ouachita Wapanucka (fig. 1). At least one of Grayson's conodont assemblages and part or locally all of a second are missing in the Arbuckles owing presumably to pre-Atoka erosion.

The platform-conodont fauna of the Wapanucka Formation from the Arbuckles exhibits relatively low diversity, consisting of only nine form-species assigned to five form-genera (table 1). The fauna is numerically dominated by three platform species: *Idiognathoides corrugatus, Adetognathus lautus,* and *Idiognathodus delicatus. Anchignathodus minutus, Idiognathodus expansus,* and *Neognathodus bassleri* constitute a small but significant component of the fauna. Two additional species, *Idiognathoides convexus* and *Idiognathoides ouachitensis,* appear to be useful for local and regional correlation. All but the uppermost 3 to 20 feet of the Wapanucka produces the *Idiognathoides convexus* assemblage. *Idiognathoides convexus* indicates correlation of the lower, major portion of the Wapanucka with the Kessler Limestone Member of the type Morrowan Bloyd Formation. The assemblage occurs also in the Jolliff Limestone and unnamed unit 1 of the Golf Course Formation.

The topmost portion of the Wapanucka Formation yields the succeeding *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage (fig. 3). Although *Neognathodus* n. sp. A is not present in the limited collections from the northeastern Arbuckle Mountains, the occurrence of *Idiognathoides ouachitensis* (Harlton) is diagnostic of the assemblage (Grayson, 1979). The age significance of this assemblage is a problem, although occurrences of the assemblage in the Arbuckle Wapanucka are Morrowan by definition (Spivey and Roberts, 1946). Lane's (1977) *Neognathodus* n. sp. Zone is thought to be essentially equivalent to the present assemblage. He shows his zone (Lane, 1977, fig. 2) as spanning the Morrowan–Atokan boundary but succeeding his *Idiognathoides convexus* Zone. A similar sequential relationship is present in the Wapanucka except for Mill Creek, where the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage occurs at the base of the formation (Grubbs, 1982; Grubbs, this volume). Either the Mill Creek exposures are younger than the other sequences or the two Wapanucka assemblages represent conodont biofacies. The latter explanation is probably more

TABLE 1.—PLATFORM-CONODONT FAUNA OF WAPANUCKA FORMATION

(See figure 3 for stratigraphic distribution of samples. Lithologic symbols: 1 = carbonate mudstone/packstone, 2 = bioclastic packstone, 3 = bioclastic grainstone, 4 = oolitic–bioclastic grainstone, 5 = coated-grain grainstone, 6 = oolitic grainstone, 7 = oolitic packstone.)

| SECTION | 275 | | | | | | | | | 260 | | 262 | | 277 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LITHOLOGY | 7 | 7 | 2 | 4 | 4 | 1 | | 1 | 3 | 2 | 2 | 6 | 2 | 2 | 2 | 5 | 2 | 2 | 2 | 4 | 3 |
| SPECIES / SAMPLE | 4A | 4B | 4C | 6A | 6B | 8A | 8B | 8C | 9 | A | B | A | B | 2A | 2B | 2C | 6 | 10 | 12A | 12B | 13 |
| *Adetognathus lautus* | 2 | 2 | 5 | 47 | 64 | 1 | 1 | 1 | 54 | 12 | 7 | 20 | | 21 | 21 | 8 | 8 | 2 | 39 | 5 | 24 |
| *Anchignathodus minutus* | 2 | | | | 2 | | | | | | 1 | 1 | | 4 | | | 1 | 1 | 3 | 1 | 9 |
| *Idiognathodus delicatus* | | | 1 | 4 | 3 | | 1 | | 25 | | 18 | 2 | 2 | 27 | 30 | 8 | 99 | 1 | 2 | | 26 |
| *I. expansus* | | | | | 1 | | | | 3 | | 1 | | | | | | | | | | |
| *Idiognathoides convexus* | | 1 | | 2 | 2 | | | | 17 | 1 | 2 | | | 7 | 1 | 2 | 8 | | | | 2 |
| *I. corrugatus* | | | | 51 | 75 | | | | 78 | 7 | 10 | | 3 | 26 | 13 | 2 | | | | | 16 |
| *I. ouachitensis* | | | | | | | | | 4 | 1 | 1 | | | | | | | | | | 57 |
| *I. sinuatus* | | | | 47 | 53 | | | | 57 | 10 | 9 | | | 6 | 15 | 7 | 13 | 1 | | | 59 |
| *Neognathodus bassleri* | | | | | | | | | | | | | | | | | | | | | 2 |

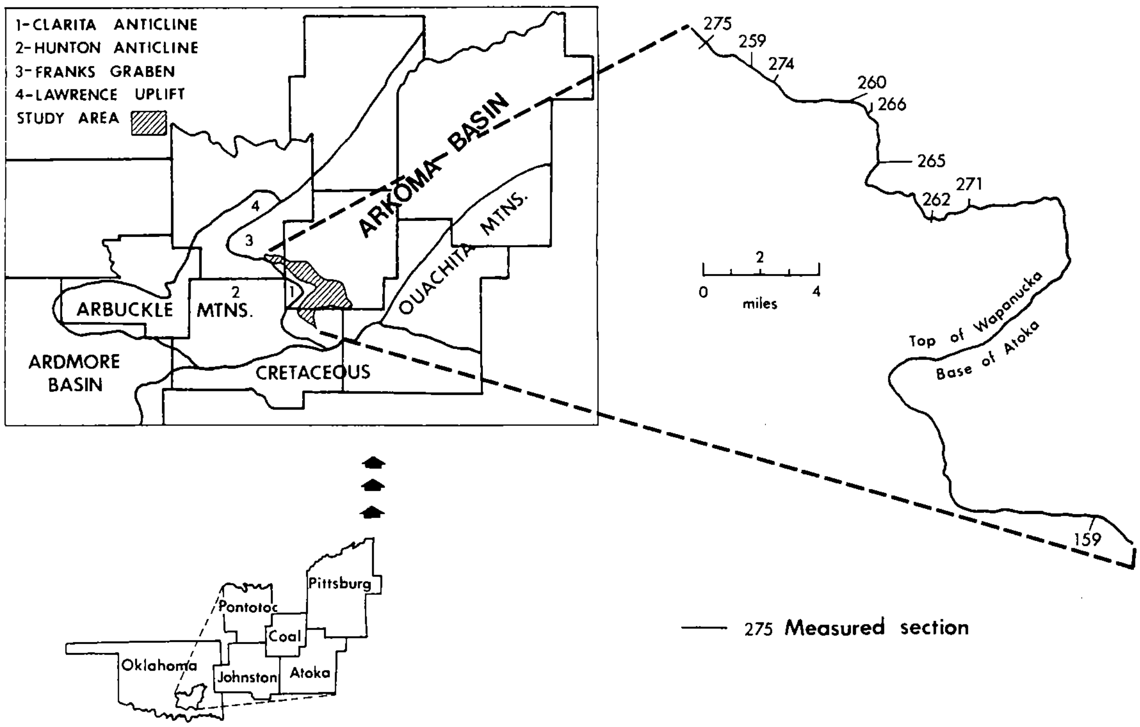


Figure 2. Generalized tectonic map and locality map for sections measured by Bruce E. Archinal, and collected for conodonts by Robert C. Grayson, Jr., and Patrick K. Sutherland (modified from Archinal, 1977).

nearly correct. Dunn's (1970a) data suggest that *Neognathodus* n. sp. A may range as low as the middle Morrowan and possibly could overlap some of Lane's (1977) uppermost type Morrowan conodont zones. In the Ouachita Mountains, *Neognathodus* n. sp. A ranges upward from the Morrowan into the early Atokan, based on associated conodonts (Grayson, 1979) and foraminifers (Groves and Grayson, this volume).

## ATOKA FORMATION

### Stratigraphy

Taff and Adams (1900) and Taff (1899, 1901, 1902) named, mapped and described the Atoka Formation in the Choctaw Coal Field ( = Oklahoma part of Arkoma Basin). Everything between the Wapanucka Limestone marker and the Hartshorne coal bed was mapped as a formation regardless of lithology. In the Ouachita Mountains, the Atoka Formation is an unfossiliferous shale and sandstone unit interpreted to represent deep-marine pelagic shale and turbidites (Cline, 1956a, 1956b). Along the southwestern margin of the Arkoma Basin adjacent to the Arbuckle Mountains, the Atoka Formation comprises an onlapping, transgressive wedge of sediment composed predominantly of shale, mudstone, and sandstone (Archinal, 1977, 1979). A few thin, variable limestone and calcareous-sandstone layers are also present. Archinal suggested that the sandstone and limestone units accumulated as shoreface to foreshore barrier beaches and longshore bars during stillstands or minor regressions. Sutherland and Manger (1983) discussed correlation problems for both the Atoka Formation and the Atokan Series.

### Conodont Fauna

Twenty-four bulk samples collected from eight measured sections (fig. 2) provide a basis for preliminary evaluation of middle Atokan conodonts. Measured sections (MS 275 and MS 274) contain abundant calcareous sandstone and limestone layers and thus provide the most significant information regarding the conodont succession (fig. 3; table 2).

The conodont fauna of the Atoka Formation contains both autochthonous and allochthonous platform elements. The allochthonous fauna consists of reworked Pennsylvanian, Mississippian, and Devonian forms that pertain to the deformational history of the southern Oklahoma region during Pennsylvanian time (Grayson, 1981). Onlap of an uplifted surface sufficiently eroded to expose pre-Atoka units down to the Woodford Formation is required to account for the allochthonous conodont species.

The autochthonous Atoka conodont fauna is relatively diverse and consists of 14 form-species

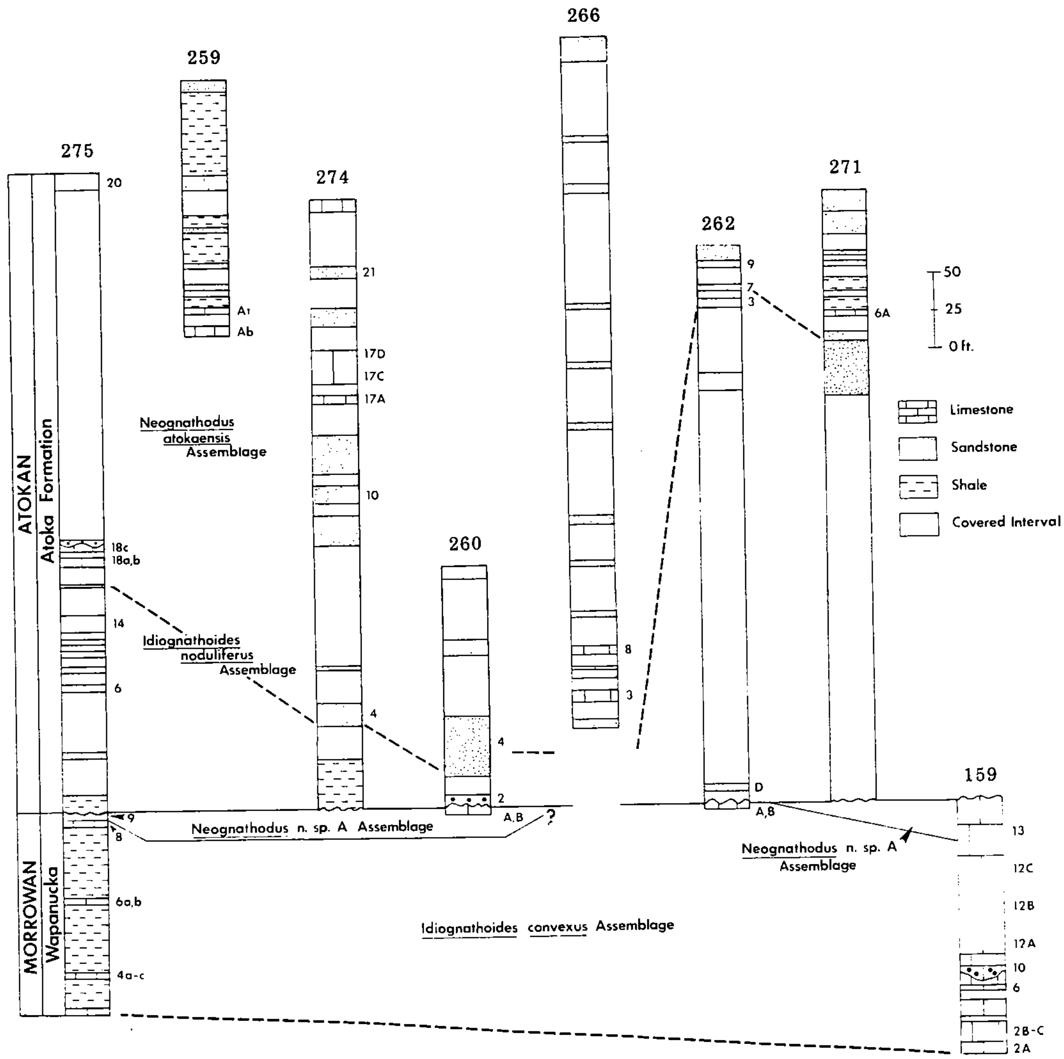


Figure 3. Correlation of measured sections of Wapanucka and Atoka Formations on northeastern and eastern flanks of Arbuckle Mountains, based on conodonts. Numbered zones show locations of productive samples. Platform-conodont faunas from these samples are listed in tables 1 and 2.

assigned to 6 form-genera (table 2). Several form-species, particularly those assigned to *Idiognathoides,* generally have been regarded as characteristic of Morrowan faunas but are now known to range into the Atokan (Landing and Wardlaw, 1981). Two platform-conodont assemblages can be recognized in the Atoka conodont succession (fig. 3). The limited number of samples and incomplete knowledge of evolutionary relationships preclude formal zonation at this time. Each of the assemblages is discussed, and their significance assessed.

## *Idiognathoides marginodosus* Assemblage

This assemblage extends from the base of the Atoka Formation upward to the appearance of one of three autochthonous species of *Neognathodus* (fig. 3; table 2). The assemblage is dominantly an *Idiognathodus delicatus* fauna. *I. marginodosus, Adetognathus lautus, Idiognathoides* spp., and *Idiognathodus* n. sp. are less common constituents. Based on my collections, the assemblage occurs in the Atoka Formation in northeastern Oklahoma, the Bostwick Conglomerate of southern Oklahoma, and the upper Marble Falls Limestone of Texas. Based on Mendez and Menendez-Alvarez's (1981) data, the assemblage may be present in the lower Valdeteja Formation. Although the assemblage can be widely recognized, its biostratigraphic potential has yet to be fully tested and it could prove to have more paleoecologic than biostratigraphic significance.

TABLE 2.—AUTOCHTHONOUS PLATFORM-CONODONT FAUNA OF ATOKA FORMATION

(See figure 3 for approximate stratigraphic distribution of samples. Lithologic symbols: 1 = calcareous sandstone, 2 = bioclastic sandstone, 3 = carbonate mudstone, 4 = bioclastic grainstone, 5 = coated-grain grainstone, 6 = sandy bioclastic packstone, 7 = conglomeratic packstone.)

| FORMATION | ATOKA | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LITHOLOGY | 1 | 2 | 2 | 2 | 3 | 2 | 5 | 5 | 1 | 1 | 4 | 4 | 4 | 6 | 7 | 1 | 3 | 3 | 4 | 1 | 6 | 3 | 1 | 6 |
| SPECIES / SAMPLE | 275-6 | 275-14 | 275-18A | 275-18B | 275-18C | 275-20 | 259-Ab | 259-At | 274-4 | 274-10 | 274-17A | 274-17C | 274-17D | 274-21 | 260-2 | 260-4 | 266-3 | 266-8 | 265-13 | 262-1 | 262-3 | 262-7 | 262-9 | 271-6A |
| *Adetognathus lautus* | | 2 | | | 1 | 2 | 3 | 2 | 3 | | 1 | 2 | 1 | 2 | 17 | | 2 | 18 | | | | 2 | 10 | 1 |
| *Anchignathodus minutus* | | | 4 | | 4 | | 12 | 10 | | 2 | 13 | 10 | 6 | | | | 1 | 6 | | | | | 3 | 7 |
| *Diplognathodus orphanus* | | | | | | | 1 | | | | 12 | 4 | 1 | 2 | | | | | | | | | | 1 |
| *Idiognathodus delicatus* | 3 | 152 | 171 | 33 | 273 | 2 | 535 | 264 | 87 | 92 | 336 | 261 | 191 | 311 | 25 | 103 | 97 | 69 | | | 35 | 20 | 38 | 22 |
| *I. elegantulus* | | | | | | | | | 3 | | | | | | | | | | | | | | | |
| *Idiognathoides convexus* | | | | 2 | | | | 2 | | | 1 | | | 1 | 20 | | 1 | | | | | 1 | | 2 |
| *I. corrugatus* | 1 | | 1 | 7 | | | 4 | 1 | | 7 | 2 | 4 | 2 | | 6 | 9 | 6 | | | | | | | |
| *I. marginodosus morphotype A* | 1 | 1 | 1 | | | | | | 1 | 3 | | | | | | 1 | | | | | | | | |
| *I. marginodosus morphotype B* | 1 | 12 | 10 | | | | 1 | | 6 | 8 | 3 | 3 | 3 | | 1 | 6 | 1 | | 1 | | 2 | | 4 | 3 |
| *I. marginodosus morphotype C* | | | 5 | | | | 135 | 36 | | 2 | 133 | 54 | 35 | | | 10 | | 2 | | 1 | 2 | | 2 | 39 |
| *I. ouachitensis* | | | 1 | 2 | | | 1 | | | | | | | | 2 | 1 | 10 | 3 | | | | 3 | | |
| *I. sinuatus* | | 1 | 1 | 10 | | | 1 | 4 | 4 | | 2 | | | | 2 | 7 | 11 | 3 | | 1 | | 2 | | 1 |
| *Neognathodus n. sp. B* | | | | | | | | | | 1 | | | | | | | | | | | | | | |
| *N. atokaensis* | | | | 2 | 6 | | 1 | 2 | 1 | 3 | 7 | 3 | 4 | | | | | | | | | | | 2 |
| *N. bothrops* | | | 3 | 1 | 5 | | 6 | 5 | | 6 | 4 | 3 | 4 | | | 3 | 3 | | | | | 1 | | 7 |

### *Neognathodus atokaensis* Assemblage

This assemblage is distinguished at its base by the initial, probably ecological appearance of *Neognathodus* n. sp. B, *N. atokaensis*, or *N. bothrops*. *I. delicatus* persists as the most abundant taxa, but with the incoming of neognathodids, a general increase in abundance and diversity of conodont taxa is obvious (table 2). Rare taxa such as *Diplognathodus orphanus* have their only occurrences within the limits of this assemblage. *I. marginodosus* also occurs but shows significant reduction in morphotypes A and B and a general increase in numeric abundance and relative dominance of morphotype C. The reasons for these nonbiostratigraphic changes have not been exhaustively analyzed, but environmental changes during transgression are a possibility.

The initial occurrences of *Diplognathodus* spp. are apparently Atokan in age (Lane, 1977; Dunn, 1976), but some species range through the whole of the Atokan and possibly into the Desmoinesian. The range of *I. marginodosus* is not conclusively known, so it cannot currently be regarded as an exclusively middle Atokan index. Possibly *Neognathodus* will permit the development of a refined biostratigraphy of equal value to that provided by species of the genus in the late Atokan and Desmoinesian.

I interpret occurrences of *Neognathodus* n. sp. A, *N.* n. sp. B, and *N. atokaensis* to represent an older segment of the *Neognathodus* lineage described by Merrill. This portion of the lineage begins with *Neognathodus* n. sp. A and is followed successively by *N.* n. sp. B, *N. atokaensis,* and *N. bothrops*. The most significant evolutionary trend seen in this part of the lineage is the development of an inner parapet that progressively extends from an initial relatively posterior position to the anterior tip. Undoubtedly *Neognathodus* will provide a basis for refined biostratigraphy of Early–Middle Pennsylvanian rocks in a manner similar to that employed by Merrill (1972, 1975) where present in sufficient abundance. No zonation is attempted, owing to the limited part of the presumed phylogeny in the Atoka Formation.

Based on my collections, the *Neognathodus atokaensis* assemblage occurs at the top of the Bostwick Conglomerate in southern Oklahoma and the Smithwick Shale in Texas. The assemblage also may be present in the upper part of the Valdeteja Formation and the lower Picos Formation, based on Mendez and Menendez-Alvarez's (1981) data. The fauna described by Landing and Wardlaw (1981) from the Pennsylvanian outlier of the Michigan Basin also has similarities to the *N. atokaensis* assemblage. Landing and Wardlaw's specimens of *Neognathodus* are immature and consequently difficult to evaluate phylogenetically and taxonomically. Their fauna is probably younger than the Atoka assemblages, based on associated fusulinids. Merrill's data (*in* Lane and others, 1971) suggest that the assemblage may be present in the Pottsville Group (Boggs) of the central Appalachians. The relationship of Merrill's *N. bassleri bassleri* Zone to the *N. atokaensis* assemblage is uncertain, although Merrill's zone is most likely younger. Specimens that Merrill identified as *N. bassleri bassleri* I interpret as belonging to *N. bothrops* Merrill or *N. atokaensis* n. sp. Thus his *N. bassleri bassleri* Zone consequently is thought to be misnamed and is distinguished by the abundant occurrence of *N. bothrops* and not *N. bassleri bassleri*.

## SYSTEMATIC PALEONTOLOGY

Stratigraphically important conodont form-species are discussed in this section. Figured specimens are deposited at The University of Oklahoma.

Specimens of all taxa listed in tables 1 and 2 are illustrated in plates 1–4. Only the most significant taxa are treated systematically.

Genus **Declinognathodus** Dunn, 1966

*Type Species.—Cavusgnathus nodulifera* Ellison and Graves, 1941.

**Declinognathodus noduliferus** (Ellison and Graves)

Pl. 3, fig. 20

*Cavusgnathus nodulifera* Ellison and Graves, 1941, p. 4, pl. 3, figs. 4, 6.

*Idiognathodus* cf. *magnificus* Stauffer and Plummer; Clarke, 1960, p. 28, pl. 5, fig. 2 only.

*Streptognathodus parallelus* Clarke, 1960, p. 29, pl. 5, figs. 6–8, 14, 15.

*Declinognathodus nevadensis* Dunn, 1966, p. 1300, pl. 158, figs. 4, 8.

*Idiognathoides* aff. *I. noduliferus* (Ellison and Graves); Lane, 1967, p. 938, pl. 123, figs. 9–11, 13, 17 only.

*Gnathodus japonicus* (Igo and Koike); Higgins and Bouckaert, 1968, p. 35, pl. 4, figs. 1, 2, 4.

*Gnathodus nodulifera* (Ellison and Graves); Koike, 1967, p. 297, pl. 3, fig. 10 only.

*Gnathodus noduliferus* (Ellison and Graves); Higgins and Bouckaert, 1968, p. 33, pl. 2, figs. 6, 12.

*Gnathodus japonicus* (Igo and Koike); Higgins and Bouckaert, 1968, p. 35, pl. 4, figs. 1, 2, 4.

*Streptognathodus lateralis* Higgins and Bouckaert, 1968, p. 45, pl. 5, figs. 1–4, 7; Higgins, 1975, p. 73, pl. 12, fig. 9; pl. 17, figs. 10, 11, 13, 14; Metcalf, 1981, p. 309, pl. 38, figs. 19–22.

*Streptognathodus noduliferus* (Ellison and Graves); Webster, 1969, p. 48, pl. 4, figs. 7, 8; Webster *in* Lane and others, 1971, pl. 1, fig. 24.

*Declinognathodus lateralis* (Higgins and Bouckaert); Dunn, 1970a, p. 330, pl. 62, figs. 5–7.

*Declinognathodus–Neognathodus* transition; Dunn, 1970a, p. 330, pl. 62, fig. 8.

*Idiognathoides noduliferus* (Ellison and Graves); Lane and Straka *in* Lane and others, 1971, pl. 1, fig. 11; Lane and Straka, 1974, p. 85, fig. 35:1–5; fig. 41:15–17.

*Idiognathoides noduliferus inaequalis* HIGGINS, 1975, p. 53, pl. 12, figs. 1–7, 12; pl. 14, figs. 11–13; pl. 15, figs. 10–14; METCALF, 1981, p. 306, pl. 38, figs. 10–12, 15.
*Idiognathoides noduliferus japonicus* (Igo and Koike); METCALF, 1981, p. 306, pl. 38, figs. 14, 17.
*Idiognathoides noduliferus noduliferus* (Ellison and Graves); HIGGINS, 1975, p. 54, pl. 14, figs. 15, 16; METCALF, 1981, p. 306, pl. 38, figs. 16, 18.

*Diagnosis.*—A symmetrically paired (Class 11 symmetry of Lane, 1968) species distinguished by a median carina terminating posteriorly against the outer margin or curving laterally to merge with outer margin.

*Remarks.*—*D. noduliferus* (Ellison and Graves) is a pre-Morrowan through early Morrowan species, based on its distribution in Europe (Higgins, 1975), Malaysia (Metcalf, 1981), Japan (Koike, 1967), and Arkansas, U.S.A. (Lane, 1967). Higgins and Bouckaert (1968) separated *Streptognathodus lateralis* from *D. noduliferus* because of the presence of a median carina to nearly the posterior tip in the former taxa. My concept of *D. noduliferus* (Ellison and Graves) includes *S. lateralis* because of its apparent intergradation with Higgins' subspecies of *Declinognathodus noduliferus*.

In my opinion, Ellison and Graves' (1941) holotype of *D. noduliferus* represents an ontogenetic or ecophenotypic juvenile stage of their presumably more mature paratype of the same species. The type specimens are from the Dimple Limestone of the Marathon region, Texas, a unit mostly of early–middle Atokan age, based on fusulinids reported by Sanderson and King (1964) and my analysis of Ellison and Graves' conodont fauna.

Higgins (1975) recognized the problem that in Europe occurrences of *D. noduliferus* are substantially older than those in the Dimple Limestone. The question is, are Atokan occurrences of *D. noduliferus* due to stratigraphic admixture or homeomorphy? My analysis of the literature and personal collections suggests the former explanation.

Several worn and discolored specimens of *D. noduliferus* are present in the Atoka Formation conodont fauna (pl. 3, fig. 20). The Atoka Formation is slightly younger or possibly equivalent to the Dimple Limestone. Occurrences of *D. noduliferus* in both of these units is attributed to reworking from an older zone. This stratigraphic admixture in the Atoka Formation is due to onlap of the formation across an uplifted and eroded surface that has exposed the Rhoda Creek Formation, a Mississippian–Pennsylvanian unit in the northeastern Arbuckle Mountains area. A report documenting the occurrence of *D. noduliferus* and *Gnathodus* n. sp. succeeding the *Adetognathus unicornis* Zone in the Rhoda Creek is now in progress.

Genus **Diplognathodus** Kozur and Merrill *in* Kozur, 1975

*Type Species.*—*Spathognathodus coloradoensis* Murray and Chronic.

*Diagnosis.*—See Merrill (1975).

**Diplognathodus orphanus** (Merrill), 1973

Pl. 1, fig. 6; pl. 2, figs. 24, 25

*Spathognathodus orphanus* MERRILL, 1973, p. 309, pl. 3, figs. 45, 46.
*Diplognathodus coloradoensis* (Murray and Chronic); LANDING AND WARDLAW, 1981, p. 1257, pl. 1, fig. 7 only.

*Diagnosis.*—A diplognathodid characterized by a coarsely denticulate carina that is convex in lateral view.

*Description.*—See Merrill (1973).

*Remarks.*—Grayson (1979) recognized a *Diplognathodus orphanus* Zone in the upper part of the Wapanucka Formation in the frontal Ouachita Mountains of southeastern Oklahoma. The zone was recognized by the initial appearance of the name-bearer or *D. coloradoensis* above the first occurrence of *Neognathodus* n. sp. A and (or) *Idiognathoides ouachitensis* and below the initial appearance of *Idiognathodus* n. sp. (=*Streptognathodus elegantulus* of Grayson, 1979). Subsequent study has resulted in the downward extension of the range of *Idiognathodus* n. sp. to coincide with the initial appearance of diplognathodids in the Ouachita Mountains. This invalidates Grayson's (1979) original concept of two zones, an older *D. orphanus* Zone and the younger *Idiognathodus* n. sp. Zone, and has led to the present recognition of a single *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage (fig. 1).

**Gnathodus** n. sp.

Pl. 2, fig. 22

*Gnathodus wapanuckensis* (Harlton); ELLISON AND GRAVES, 1941, pl. 2, figs. 15, 16 only; KOIKE, 1967, p. 300, pl. 1, fig. 23 only.
*Gnathodus* cf. *girtyi* HASS; HIGGINS AND BOUCKAERT, 1968, p. 32, pl. 2, fig. 9; pl. 5, figs. 5, 6.
*Neognathodus bassleri* (Harris and Hollingsworth); HIGGINS, 1975, p. 64, pl. 12, figs. 8, 10, 11; pl. 17, figs. 12, 15.

*Gnathodus* n. sp. is a pre-Morrowan earliest Pennsylvanian species, based on its range in Europe (Higgins and Bouckaert, 1968; Higgins, 1975) and Japan (Koike, 1967). Occurrences of this species in Atokan strata (Atoka Formation and Dimple Limestone) are due to reworking from an older zone. Those specimens recovered from the Atoka Formation are known to have been derived from uplift and erosion of the Rhoda Creek Formation, a unit in the northeastern Arbuckle Mountains that spans the Mississippian–Pennsylvanian boundary. A report detailing the significance of this important species and associated fauna from the Rhoda Creek is currently in progress.

Genus **Idiognathodus** Gunnell, 1931

*Type Species.—Idiognathodus claviformis* Gunnell, 1931.

*Diagnosis.*—Free blade intersects platform in a median position and continues a short distance as a carina. The oral surface of the platform is flat or grooved and is ornamented by transverse ridges. Nodes may be developed on the inner or outer platform margin, and prominent sulci may occur on either side of the carina.

*Remarks.—Idiognathodus* has been distinguished from *Streptognathodus* by the lack of a median oral trough. Von Bitter (1972) and Baesemann (1973) recognized an intergradational relationship between the two genera. Baesemann (1973) synonymized the genus *Streptognathodus* with *Idiognathodus* owing to this relationship. This treatment is followed herein, since it is phylogenetically acceptable because species of *Streptognathodus* sensu stricto appear to have evolved iteratively from *Idiognathodus*. Their close evolutionary relationship is also indicated by the fact that coeval populations are nearly indistinguishable on the basis of many morphologic characteristics. Their ontogenetic sequences are also remarkably similar and equally complex. Numerous species could be, and seemingly have been, proliferated, based on stage of growth.

**Idiognathodus delicatus** Gunnell, 1931

Pl. 1, figs. 1, 2, 12; pl. 3, figs. 2, 3, 5, 6, 21, 23, 25; pl. 4, figs. 1, 6–8, 17, 24

*Remarks.*—Webster (1969) and Merrill (1975) recognized two Atokan species of *Idiognathodus: I. claviformis* and *I. delicatus*. Webster (1969) suggested that *I. claviformis* could represent gerontic specimens of *I. delicatus*. My observations are consistent with this possibility, but additional work is needed to clarify taxonomic relationships in this highly variable group (Merrill, 1975). Consequently, no synonymy is attempted, and most of the specimens of *Idiognathodus* are assigned to a broad concept of *I. delicatus*.

At least three general morphotypes can be distinguished from the central point of the variability exhibited by "*I. delicatus*"; these are (1) individuals with a broad, shallowly concave oral-platform surface); (2) those that exhibit a narrow, groove-like trough that completely bisects the transverse ornamentation on the oral-platform surface; and (3) specimens characterized by discontinuous, nodose-like disorganized or organized transverse ornamentation on the oral-platform surface. Similar morphotypes occur in most large populations of Pennsylvanian "*I. delicatus*" that I have examined. The evolutionary and biofacies significance of these forms is a major problem.

It appears possible that some middle Atokan individuals of *I. delicatus* in Oklahoma can be distinguished from Morrowan populations. A significant number of middle Atokan representatives of *I. delicatus* exhibit an anterior tapering of their distinctive transverse ornamentation and the development of prominent sulci (compare pl. 4, figs. 8 and 17, with pl. 4, figs. 1 and 24).

**Idiognathodus** n. sp.

Pl. 1, fig. 15

*Streptognathodus elegantulus* Stauffer and Plummer; Grayson, 1979, p. 69, fig. 105.

*Streptognathodus* sp. cf. *S. elegantulus* Stauffer and Plummer; Grayson and Sutherland, 1977, p. 183, fig. 3.

*Idiognathodus delicatus* Gunnell; Landing and Wardlaw, 1981, p. 1260, pl. 2, figs. 8–14.

*Diagnosis.*—Idiognathodid with deep, prominent sub-central trough; steep platform flanks, and accessory lobes typically on inner side but in some mature and gerontic specimens on outer side, as well.

*Remarks.—Streptognathodus elegantulus* (=*Idiognathodus* n. sp.) was the namebearer for the youngest zone recognized by Grayson (1979) in the Wapanucka Formation in the frontal Ouachita Mountains of southeastern Oklahoma. The initial appearance of *Idiognathodus* n. sp. has been found to be lower than that originally determined, and essentially to coincide with the first occurrence of *Diplognathodus* spp. The resulting *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage is thought to be absent in the present study area, owing to pre-Atoka erosion (fig. 1). One specimen of this species occurs in one sample (MS 274-4) from the basal Atoka Formation; its significance is uncertain.

Genus **Idiognathoides** Harris and Hollingsworth, 1933

*Type Species.—Idiognathoides sinuata* Harris and Hollingsworth, 1933.

*Diagnosis.*—A platform-conodont genus derived from *Declinognathodus* and consisting of symmetrically or asymmetrically paired (Class 11 or 111b symmetry of Lane, 1968) polymorphic elements. In oral view the platform exhibits a median trough of variable length. Prominent transverse ridges may be developed in some species. The outer margin passes with flexure into a short carina, then into a free blade; where little or no flexure is present, the outer margin passes directly into a free blade.

*Remarks.—Idiognathoides sinuatus* was recognized by Lane (1967) and Lane and Straka (1974) as a single form-species that consists of paired asymmetric left- and-right-handed platform elements. Lane and Straka stated that the left element displayed features characteristic of the holotype of the form species *I. sinuatus* Harris and Hollingsworth and that the right element displayed characteristics of the lectotype of the form-species *I. corrugatus* (Harris and Hollingsworth). Although this is probably correct, definitive evidence is lacking (Higgins, 1981).

Austin (1972) noted that the ranges of the form-species *I. sinuatus* and *I. corrugatus* are dissimilar. This may be due to the fact that the left and right elements in *Idiognathoides* exhibit mosaic evolution. Consequently, it is currently difficult consistently to associate lefts and rights. In the absence of detailed analyses, I have placed all asymmetrically paired left-sided specimens of *Idiognathoides* in a broadly interpreted form-species, *I. sinuatus*, and the asymmetrically paired right-sided elements in the form-species *I. corrugatus, I. convexus*, or *I. ouachitensis*.

### **Idiognathoides convexus** (Ellison and Graves), 1941

Pl. 4, figs. 9, 15

*Polygnathodella convexa* Ellison and Graves, 1941, p. 9, pl. 3, figs. 10, 12, non fig. 16 (=*I. corrugatus*).
*Polygnathodella* cf. *convexa* Ellison and Graves; Koike, 1967, p. 308, pl. 3, figs. 1, 2.
*Idiognathoides convexus* (Ellison and Graves); Higgins and Bouckaert, 1068, p. 39, non pl. 4, fig. 3 (=*I. corrugatus*); Webster, 1969, p. 37, pl. 5, figs. 17(?), 18; Dunn, 1970a, p. 334, pl. 63, fig. 20(?), text-fig. 11F; Lane and others, 1971, pl. 1, figs. 17, 18; Lane and Straka, 1974, p. 84.
(?)*Idiognathoides convexus* (Ellison and Graves); Dunn, 1970a, p. 334, pl. 63, fig. 20.
(?)*Idiognathoides corrugatus* (Harris and Hollingsworth); Dunn, 1970a, p. 335, pl. 63, fig. 16 (non figs. 17, 18, 25).

*Diagnosis.*—An exclusively right-sided form-species that is narrow and commonly convex in lateral view. The oral surface is ornamented by prominent arcuate, transverse ridges that are convex anteriorly.

*Remarks.*—*Idiognathoides convexus* is the name bearer for a conodont zone defined by Lane and Straka (1974) from the Kessler Limestone (type Morrowan) in northwestern Arkansas. The range of the species in other areas of the contiguous United States may include strata older than those encompassed by its local range in northwestern Arkansas (Webster, 1969; Dunn, 1970a, 1976). In the author's Oklahoma collections, the species occurs only in late Morrowan or Atokan rocks.

### **Idiognathoides marginodosus** n. sp.

Pl. 1, figs. 3, 4, 7, 9–11, 13, 14, 16, 18; pl. 2, figs. 4, 8, 9, 17, 19; pl. 3, figs. 4, 10, 12, 14, 19; pl. 4, figs. 11, 12, 16, 21–23

*Declinognathodus noduliferus inaequalis* (Higgins); Mendez and Menendez-Alvarez, 1981, fig. 3:1.
*Declinognathodus noduliferus noduliferus* (Ellison and Graves); Mendez and Menendez-Alvarez, 1981, fig. 3:2.
*Idiognathoides sulcatus sulcatus* Higgins and Bouckaert; Mendez and Menendez-Alvarez, 1981, fig. 3:7.

*Diagnosis.*—A symmetrically paired (Class 11 symmetry of Lane, 1968) species distinguished by its characteristic platform margins. The margins of this variable species are rather constant in morphology and are readily divisible into anterior and posterior portions. The anterior platform margins are ornamented with delicate transverse ridges or nodes that commonly fuse to form a single continuous ridge or series of closely spaced arcuate ridges. In contrast, the posterior margins are ornamented by more distinct nodes that are relatively more widely spaced and exhibit little or no tendency to fuse with adjacent nodes on the same margin. Transverse ridges may be developed between nodes on opposite margins near the posterior tip. The tip is generally bulbous or strikingly nodose in appearance. A short carina may be present, but typically the blade passes into the outer margin with little or no deflection. Three intergradational morphotypes are recognized by the character and (or) the absence of accessory nodes. A row of nodes lateral to the anterior platform margin is diagnostic of Morphotype A. Morphotype B exhibits only a single cleanly separated node located lateral to the outer anterior platform margin. The total lack of development of accessory nodes characterizes Morphotype C.

*Remarks.*—*I. marginodosus* is distinguished from *D. noduliferus* (Ellison and Graves) by its distinctive nodose margins and simplified range of variability. Some Morrowan to early Atokan specimens assigned by workers to *D. noduliferus, Idiognathoides sulcatus sulcatus* Higgins and Bouckaert or *I. sulcatus parvus* Higgins and Bouckaert significantly overlap the range of variability of *I. marginodosus*. Some representatives of these "species" can be discriminated from *I. marginodosus* only by differences in their posterior platform margins. In *I. marginodosus* the posterior margins are ornamented by relatively widely spaced nodes that commonly exhibit a bulbous appearance. The older specimens, in contrast, exhibit more closely spaced nodes that typically have a ridge-like character.

*Name.*—The specific name refers to the diagnostic ornamentation of the margins, particularly the posterior margins.

*Type Material.*—Owing to the variability exhibited by this species, equal weight is given to the paratypes in distinguishing *I. marginodosus*. Holotype, OU 7151; paratypes: morphotype A–OU 7157; morphotype B–OU 10,167; morphotype C–OU 10,030.

### **Idiognathoides ouachitensis** (Harlton), 1933

Pl. 3, figs. 8, 13, 15; pl. 4, figs. 2, 5

*Polygnathodella ouachitensis* Harlton, 1933, p. 15, pl. 4, figs. 14a–14c; Ellison and Graves, 1941, pl. 3, figs. 8, 9; (non Koike, 1967, p. 309, pl. 3, figs. 3–5—=*I. corrugatus?*); *Polygnathodella fossata* Branson and Mehl, 1941, p. 103, pl. 19, figs. 27, 28.

*Idiognathoides corrugatus* (Harris and Hollingsworth); Dunn, 1970a, p. 335, pl. 63, figs. 18, 25 only, non figs. 16, 17 (=*I. corrugatus*); Mendez and Menendez-Alvarez, 1981, fig. 3:5.
*Idiognathoides sinuatus* Harris and Hollingsworth; Landing and Wardlaw, 1981, p. 1262, pl. 2, figs. 15–20 only.

*Diagnosis.*—An idiognathoidid distinguished by an oral surface bearing a prominent trough on the entire right-sided element. The trough may or may not be completely traversed by ridges.

*Remarks.*—*I. ouachitensis* is the youngest species of an evolutionay sequence that is characterized by development of an oral trough that eventually extends the full length of the platform. The oldest (early Morrowan) representatives of this phylogeny (*I. corrugatus*) lack a significant trough in mature specimens. Middle Morrowan representatives of *I. corrugatus* possess a trough that generally extends about three-fourths the length of the platform. This progressive increase in length of the oral trough culminated in *I. ouachitensis* by late Morrowan time, a species which has a trough that extends the full length of the platform. All the presently recognized variants in this lineage occur in the Atoka Formation. The relative abundance of each, after its initial evolution, appears to be environmentally controlled. The nature of these controls needs to be studied.

Some middle Morrowan representatives of *I. corrugatus* possess an oral trough that extends completely to the posterior tip of the platform. These can usually be differentiated morphologically from *I. ouachitensis*. The trough in *I. corrugatus* is commonly narrow and generally completely bisects the transverse ridges on the oral platform surface. In *I. ouachitensis* the oral trough is generally broad, deep, and symmetrical. Commonly the transverse ornamentation continues uninterrupted across the broad trough.

### Genus **Neognathodus** Dunn, 1970a

*Type Species.*—*Polygnathus bassleri* Harris and Hollingsworth, 1933.

### **Neognathodus symmetricus** Lane, 1967
Pl. 2, fig. 7

*Gnathodus wapanuckensis* (Harlton); Ellison and Graves, 1941, pl. 2, fig. 13 only.
*Gnathodus bassleri symmetricus* Lane, 1967, p. 935, pl. 120, figs. 2, 13, 14, 17; pl. 121, figs. 6, 9.
*Gnathodus bassleri* (Harris and Hollingsworth); Webster, 1969, p. 29, pl. 5, fig. 14 only.
*Neognathodus bassleri* (Harris and Hollingsworth); Dunn, 1970a, p. 336, pl. 64, figs. 1a–c, 12 only.
*Neognathodus bassleri symmetricus* (Lane); Lane and Straka, 1974, p. 96, fig. 37: 22, 31, 32, 37–39; fig. 39: 16–18, 21–24.

*Diagnosis.*—For diagnosis, see Lane (1967).

*Remarks.*—Occurrences of this species in the Atoka Formation are due to reworking from older strata. They are included for comparison with autochthonous Atoka neognathodids.

### **Neognathodus bassleri** (Harris and Hollingsworth), 1933
Pl. 1, figs. 5, 17

*Polygnathus bassleri* Harris and Hollingsworth, 1933, p. 198, pl. 1, figs. 13a–e.
*Gnathodus wapanuckensis* (Harlton); Ellison and Graves, 1941, pl. 2, fig. 15 only.
*Gnathodus bassleri bassleri* (Harris and Hollingsworth); Lane, 1967, p. 935, pl. 120, figs. 1, 3–5, 9–12, 15; pl. 123, figs. 1–6; Lane and Straka *in* Lane and others, 1971, pl. 1, figs. 9, 10.
*Neognathodus bassleri* (Harris and Hollingsworth); Dunn, 1970a, p. 336, pl. 64, fig. 13 only.
*Neognathodus bassleri bassleri* (Harris and Hollingsworth); Lane and Straka, 1974, p. 95, fig. 37:16, 17, 19; fig. 42: 17–24.

*Remarks.*—The two specimens assigned to *N. bassleri* from the Wapanucka Formation differ slightly from middle Morrowan representatives (Lane, 1967). The significance of these differences cannot be evaluated owing to the limited number of specimens.

### **Neognathodus** n. sp. A

*Gnathodus* cf. *roundyi* Gunnell; Koike, 1967, p. 229, pl. 1, figs. 27, 28.
*Neognathodus roundyi* (Gunnell); Dunn, 1970a, p. 336, pl. 64, figs. 2, 3.
*Neognathodus* n. sp. Lane and others, 1972, p. 551; Lane, 1977, p. 178.
*Neognathodus kanumai* Koike; Grayson and Sutherland, 1977, p. 183, fig. 3; Grayson, 1979, p. 69, fig. 105.
*Neognathodus dilatus* (Stauffer and Plummer); Mendez and Menendez-Alvarez, 1981, fig. 3:10.

*Diagnosis.*—Inner platform margin elevated and ornamented by prominent transverse ridges; outer platform margin distinctly lower than inner and semicircular in oral view. Ornamentation may be absent on the outer margin; where present, it consists of a row of nodes paralleling the outer margins or transverse ridges that are subperpendicular to the carina.

*Remarks.*—*Neognathodus* n. sp. A does not occur in the Wapanucka Formation in its exposures along the northeastern flank of the Arbuckle Mountains. However, the *Neognathodus* n. sp. A—*Idiognathoides ouachitensis* assemblage can be recognized by occurrences of *I. ouachitensis* in the Wapanucka Formation. *Neognathodus* n. sp. A is locally abundant in the Ouachita Wapanucka, which generally represents a more offshore, deeper water regime compared to the Arbuckle Wapanucka.

Lane (1977) defined a conodont zone based on the range of *Neognathodus* n. sp. A. His zone is not utilized in the present study because of inadequate knowledge regarding its range and thus its relationship to upper type-Morrowan conodont zones.

*Neognathodus* n. sp. A and younger representatives of its lineage are distinguished from the mostly older species *N. symmetricus* (Lane) and *N. bassleri* (Harris and Hollingsworth) by the character of the anterior portion of the platform. In *N. symmetricus* and *N. bassleri,* the anterior termination of the platform is generally abrupt and precipitous. In contrast, that portion of the platform in *N.* n. sp. A and younger related species is beveled and slopes more gently anteriorly to merge with the blade. The phylogenetic relationship of *N. bassleri* to *Neognathodus* n. sp. A is unknown. However, it seems probable that *Neognathodus* n. sp. A and not *N. bassleri,* as suggested by Merrill (1972), gave rise to middle Atokan and Desmoinesian neognathodids.

### **Neognathodus** n. sp. B

Pl. 2, fig. 13

*Neognathodus roundyi* (Gunnell); Mendez and Menendez-Alvarez, fig. 3:11.

*Diagnosis.*—Inner parapet typically extends to posterior tip and is ornamented by prominent transverse ridges. In transverse profile the outer parapet is distinctly lower or even with inner parapet. In oral view, the outer parapet is semicircular in outline and does not extend toward the posterior tip. Ornamentation on outer parapet consists of nodes that are developed upward sufficiently to form a shallow trough between outer margin and carina. The carina is subcentrally located.

*Remarks.*—*Neognathodus* n. sp. B is a rare constituent of the Atoka Formation conodont fauna. Only one specimen from a single locality (274-10) is presently available for study. Consequently, formal recognition of this species is precluded.

*Neognathodus* n. sp. B is thought to have evolved from *Neognathodus* n. sp. A by upward development of the outer margin into a parapet separated from the carina by a shallow trough.

### **Neognathodus atokaensis** n. sp.

Pl. 1, fig. 8; pl. 2, figs. 1, 5a, 5b, 10–12, 16, 23; pl. 3, figs. 1a, 1b, 7a, 7b, 11, 16, 18, 22

*Gnathodus wapanuckensis* (Harlton); Ellison and Graves, 1941, pl. 2, fig. 14 only.
*Streptognathodus colombiensis* Stibane, 1967, p. 336, pl. 36, figs. 3, 6–8 only.
*Gnathodus bassleri* (Harris and Hollingsworth); Webster, 1969, p. 29. pl. 5, figs. 15a, 15b only.
*Neognathodus bassleri* (Harris and Hollingsworth); Dunn, 1970a, p. 336, pl. 64, fig. 14 only.
*Gnathodus bassleri bassleri* (Harris and Hollingsworth); Merrill *in* Lane and others, 1971, pl. 1, fig. 30.
*Gnathodus bassleri symmetricus* Lane; Merrill *in* Lane and others, 1971, pl. 1, fig. 29.
*Gnathodus* n. sp. A Merrill *in* Lane and others, 1971, pl. 1, fig. 31.
*Neognathodus bassleri bassleri* (Harris and Hollingsworth); Merrill and King, 1971, p. 659, pl. 76, figs. 11, 12.
*Neognathodus bothrops* Merrill; Merrill, 1975, p. 69, pl. 17, fig. 65 only; Mendez and Menendez-Alavarez, 1981, fig. 3:9.
*Neognathodus medadultimus* Merrill; Merrill, 1975, p. 69, pl. 17, fig. 67 only.
?*Neognathodus medexultimus* Merrill; Landing and Wardlaw, 1981, p. 1265, pl. 2, figs. 6, 7.

*Diagnosis.*—Inner parapet typically extends to near posterior tip and is generally ornamented with prominent transverse ridges. In transverse profile the outer parapet is slightly lower or even with crest of inner parapet. In oral view, anterior portion of the inner margin is semicircular in outline and ornamented with weakly developed transverse ridges. It is separated from the subcentral carina by a trough. The posterior, newly developed portion of the outer parapet consists of distinct nodes either fused to the carina or separated from the carina by an incipient trough.

*Remarks.*—*Neognathodus atokaensis* n. sp. apparently represents a transitional stage between *Neognathodus* n. sp. B and *Neognathodus bothrops.*

*Name.*—The specific name is derived from the Atoka Formation.

*Type Specimens.*—Holotype (OU 10,051); paratypes (OU 10,039, OU 10,035, OU 10,149).

### **Neognathodus bothrops** Merrill, 1972

Pl. 2, figs. 2, 14a, 14b, 15, 18, 20; pl. 3, figs. 17, 24a, 24b

*Gnathodus roundyi* Gunnell; Murray and Chronic, 1965, p. 598, pl. 71, figs. 3, 4, only.
*Streptognathodus colombiensis* Stibane, 1967, p. 336, pl. 36, figs. 1, 2, 4, 5, 9, 10 only.
*Streptognathodus elegantulus* Stauffer and Plummer; Stibane, 1967, pl. 36, figs. 19–22.
*Gnathodus bassleri* (Harris and Hollingsworth); Webster, 1969, p. 29, pl. 5, figs. 9a–c only.
*Neognathodus roundyi* (Gunnell); Dunn, 1970a, p. 336, pl. 64, fig. 4 only.
*Neognathodus* n. sp. A Merrill and King, 1971, p. 659, pl. 76, figs. 7–10.
*Neognathodus bassleri bassleri* (Harris and Hollingsworth); Merrill and King, 1971, p. 659, pl. 76, fig. 11 only; Merrill, 1972, p. 822, pl. 1, figs. 16–19; Merrill, 1975, p. 117, pl. 17, fig. 68 only.
*Neognathodus bothrops* Merrill, 1972, p. 823, pl. 1, figs. 8–15; Merrill, 1975, p. 69, fig. 17: 63, 64, 66 only.

*Diagnosis.*—Inner and outer platform margins elevated to form parapets that typically extend and merge to form posterior tip. The parapets are ornamented with prominent transverse ridges and are separated from the carina by distinct troughs. The carina may or may not extend to the posterior tip. It varies from a central to clearly subcentral location.

*Remarks.*—My concept of this species is broader than that originally proposed by Merrill (1972, 1975). I include some specimens assigned by Merrill and King (1971) and Merrill (1972, 1975) to *N. bassleri bassleri* in *N. bothrops* or *N. atokaensis*. Merrill distinguished *N. bassleri bassleri* from *N. bothrops* by fusion of the carina to the posterior tip in the latter species. I believe the character of the carina (fused or nodose) may be ecologically controlled and should not be employed for taxonomic discrimination.

## REGISTER OF MEASURED STRATIGRAPHIC SECTIONS AND LOCALITIES

**MS 275—Canyon Creek.** This well-known exposure is in the bed and on the banks of Canyon Creek. The base of the Wapanucka Formation is in the NE¼NW¼ sec. 8, T. 1 N., R. 7 E., and the top of the Atoka section is at the crest of a sandstone ridge at the southwest end of a flood-control lake, NE¼SE¼NE¼ sec. 8, T. 1 N., R. 7 E., Pontotoc County, Oklahoma.

**MS 259—Southwest Stonewall.** The section begins at the crest of a hill in a drainage ditch on the west side of the north half of the east section-line road, sec. 16, T. 1 N., R. 7 E., Pontotoc County, and ends at the NW corner sec. 16, at the intersection of the section-line roads. The ledge at the crest of the hill on the section-line road is the base of the section.

**MS 274—Coal Creek.** The section begins on the east side of Coal Creek approximately 300 feet (91 m) south of a sharp bend in the creek on a small, rounded northwest-trending ridge of the Wapanucka Limestone, NW¼SE¼SE¼ sec. 15, T. 1 N., R. 7 E., and ends on the north side of the large ridge cut by Coal Creek.

**MS 260—North Goose Creek.** The base of this section is at the crest of the northwest-striking Wapanucka ridge where it is cut by a fence line; 150 feet north and 100 feet west of the mouth of an east-trending tributary of Goose Creek, SW¼NW¼SW¼NW¼ sec. 19, T. 1 N., R. 8 E. The top of the section is along a small trail that parallels Goose Creek in the NE¼NE¼SW¼NE¼ sec. 19.

**MS 266—North Jack Hills.** The base of this section is on the crest of the highest northwest-trending ridge of the Jack Hills, approximately 2,000 feet (610 m) north of the SE corner of the east section line, sec. 19, T. 1 N., R. 8 E.; the top of the section is approximately 1,800 feet (549 m) from the NE corner sec. 19, along the east section line at the base of the Jack Hills. The section line has recently been cleared by seismic crews, so it is easily accessible and the units fairly well exposed.

**MS 265—Central Jack Hills.** The section is along an east–west fence line, with the base at the top of a ridge of Wapanucka Limestone in the NW¼SW¼NW¼ sec. 32, T. 1 N., R. 8 E.; the top is at the crest of a sandstone cuesta along the fence line at the center of the north line of the SW¼NW¼ sec. 33, T. 1 N., R. 8 E.

**MS 262—South Jack Hills Syncline.** The base of this section is on top of a small, thin ridge of Wapanucka Limestone in the SE¼NE¼NE¼ sec. 9, T. 1 S., R. 8 E., and ends at a sandstone by the road in the NE¼NE¼NE¼ sec. 9

**MS 271—Stutte–Burr Valley.** The base of this section is at the top of a ridge of Wapanucka Limestone where it is cut by the old Clarita–Tupelo road, just north of an access gate on the Burr Valley Ranch and 960 feet (293 m) north of the SE corner sec. 3, T. 1 S., R. 8 E. The section ends 1,580 feet (525 m) north of the SE corner sec. 3, where a ridge of Atoka sandstone and shale abruptly ends.

**MS 159—Type Wapanucka.** Exposures of the Wapanucka Formation occur at this locality in bluffs facing the east side of a small reservoir formed by Sandy Creek, about 1.4 miles west of Wapanucka, Johnston County, Oklahoma. It extends from the edge of the spillway eastward to the crest of the ridge in the NE¼NW¼ sec. 22, T. 2 S., R. 8 E.

## REFERENCES CITED


**Archinal, B. E.**, 1977, The lithostratigraphy of the Atoka Formation (Lower Pennsylvanian) along the southwestern margin of the Arkoma Basin, Oklahoma: University of Oklahoma unpublished M.S. thesis, 172 p.

———1979, Atoka Formation (Pennsylvanian) deposition and contemporaneous structural movement, southwestern Arkoma Basin, Oklahoma, *in* Hyne, N. J., editor, Pennsylvanian sandstones of the Mid-Continent: Tulsa Geological Society Special Publication 1, p. 259–267.

**Austin, R. L.**, 1972, Problems of conodont taxonomy with special reference to Upper Carboniferous forms: Geologica et Paleontologica SB 1, p. 115–126.

**Baesemann, J. F.**, 1973, Missourian (Upper Pennsylvanian) conodonts of northeastern Kansas: Journal of Paleontology, v. 47, p. 689–710.

**Cline, L. M.**, 1956a, Regional stratigraphy and history of Ouachita Mountain area: American Association of Petroleum Geologists Bulletin, v. 40, p. 427–428.

———1956b, Mississippian–Pennsylvanian stratigraphy of central Ouachita Mountains, Oklahoma: Ardmore Geological Society Guidebook to Ouachita Mountains Field Conference, p. 47–63.

**Dunn, D. L.**, 1970a, Middle Carboniferous conodonts from western United States and phylogeny of the platform group: Journal of Paleontology, v. 44, p. 312–342.

———1970b, Conodont zonation near the Mississippian–Pennsylvanian boundary in western United States: Geological Society of America Bulletin, v. 81, p. 2959–2974.

———1976, Biostratigraphic problems of Morrowan and Derryan (Atokan) strata in the Pennsylvanian System of western United States: Geological Society of America Bulletin, v. 87, p. 641–645.

**Ellison, S.**, and **Graves, R. W., Jr.**, 1941, Lower Pennsylvanian (Dimple limestone) conodonts of the Marathon region, Texas: University of Missouri School of Mines and Metallurgy Bulletin, v. 15, no. 3, 21 p.

**Grayson, R. C., Jr.**, 1978, Depositional environments and conodont biostratigraphy of Wapanucka Formation (Pennsylvanian), frontal Ouachita Mountains, Oklahoma [abstract]: American Association of Petroleum Geologists Bulletin, v. 62, p. 518.

———1979, Stop descriptions–fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

———1981, Distribution and significance of allochthonous conodonts in Early Pennsylvanian rocks of eastern Oklahoma [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 279.

**Grubbs, R. K.**, 1982, Pennsylvanian stratigraphy and conodont biostratigraphy of Mill Creek Syncline, central Arbuckle Mountains, Oklahoma: University of Oklahoma unpublished M.S. thesis, 227 p.

**Higgins, A. C.**, 1975, Conodont zonation of the late Viséan–early Westphalian strata of the south and central Pennines of northern England: Geological Survey of Great Britain Bulletin 53, 90 p.

———1981, Coprolitic conodont assemblages from the Lower Westphalian of North Staffordshire: Palaeontology, v. 24, pt. 2, p. 437–441.

**Higgins, A. C.**, and **Bouckaert, J.**, 1968, Conodont stratigraphy and palaeontology of the Namurian of Belgium: Belgique service Geol. Mem. 10, 64 p.

**Koike, Toshio**, 1967, A Carboniferous succession of conodont faunas from the Atetsu Limestone in southwest Japan (studies of Asiatic conodonts, Pt. VI): Tokyo Kyoiku Daigaku Science Reports, Sec. C, Geology, Mineralogy, and Geography, v. 9, no. 93, p. 279–318.

**Landing, E.**, and **Wardlaw, B. R.**, 1981, Atokan conodonts from the Pennsylvanian outlier of the Michigan Basin: Journal of Paleontology, v. 55, p. 1251–1269.

**Lane, H. R.**, 1967, Uppermost Mississippian and Lower Pennsylvanian conodonts from the type Morrowan region, Arkansas: Journal of Paleontology, v. 41, p. 920–942.

———1968, Symmetry in conodont element-pairs: Journal of Paleontology, v. 42, p. 1258–1263.

———1977, Morrowan (Early Pennsylvanian) conodonts of northwestern Arkansas and northeastern Oklahoma, *in* Sutherland, P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 177–180.

**Lane, H. R., Merrill, G. K., Straka, J. J., II,** and **Webster, G. D.**, 1971, North American Pennsylvanian conodont biostratigraphy, *in* Sweet, W. C., and Bergström, S. M., editors, Symposium on conodont biostratigraphy: Geological Society of America Memoir 127, p. 395–414.

**Lane, H. R.**, and **Straka, J. J.**, 1974, Late Mississippian and Early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

**Mendez, C. A.**, and **Menendez-Alvarez, J. R.**, 1981, Conodontos del Bashkiriense Superior y Moscoviense Inferior en una seccion de la Cordillera Cantabrica (NW de Espana): Trabajos de Geologia, Univ. de Oviedo, 11, 129–134.

**Merrill, G. K.**, 1972, Taxonomy, phylogeny, and biostratigraphy of *Neognathodus* in Appalachian Pennsylvanian rocks: Journal of Paleontology, v. 46, p. 817–829.

———1973, Pennsylvanian nonplatform conodont genera, I. *Spathognathodus*: Journal of Paleontology, v. 47, p. 289–314.

———1975, Pennsylvanian conodont biostratigraphy and paleoecology of northwestern Illinois: Geological Society of America Microform Publication 3, 129 p.

**Merrill, G. K.**, and **King, C. W.**, 1971, Platform conodonts from the lowest Pennsylvanian rocks of northwestern Illinois: Journal of Paleontology, v. 45, p. 645–664.

**Metcalf, I.**, 1981, Upper Carboniferous conodont faunas of the Panching Limestone, Pahang, West Malaysia: Palaeontology, v. 23, pt. 2, p. 297–314.

**Sanderson, G. A.**, and **King, W. E.**, 1964, Paleontological evidence for the age of the Dimple Limestone, *in* The filling of the Marathon geosyncline—Symposium and guidebook, 1964 field trip: Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Publication 64-9, p. 31–34.

**Spivey, R. C.**, and **Roberts, T. G.**, 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Sutherland, P. K.**, and **Manger, W. L.**, 1983, The Morrowan–Atokan (Pennsylvanian) boundary problem: Geological Society of America Bulletin, v. 94, p. 543–548.

**Taff, J. A.**, 1899, Geology of the McAlester–Lehigh coal field, Indian Territory: U.S. Geological Survey 19th Annual Report, pt. 3, p. 423–456.

———1901, Description of the Coalgate quadrangle [Indian Territory]: U.S. Geological Survey Geologic Atlas, Folio 74, 6 p.

———1902, Description of the Atoka quadrangle [Indian Territory]: US. Geological Survey Geologic Atlas, Folio 79, 8 p.

**Taff, J. A.**, and **Adams, G. I.**, 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 257–311.

**von Bitter, P. H.**, 1972, Environmental control of conodont distribution in the Shawnee Group (Upper Pennsylvanian) of eastern Kansas: University of Kansas Paleontological Contributions, Article 59, 105 p.

**Webster, G. D.**, 1969, Chester through Derry conodonts and stratigraphy of northern Clark and southern Lincoln Counties, Nevada: University of California Publications in Geological Sciences, v. 79, 121 p.

## Plate 1

(Figured specimens 5 and 17 from Wapanucka Formation; all others from Atoka Formation)

Figs. 1, 2, 12.—*Idiognathoides delicatus* Gunnell. *1*, upper view of OU 10,017 (259-Ab), ×30; *2*, upper view of OU 10,018 (275-18c), ×60; *12*, upper oblique view of OU 10,019 (274-4), ×50.

Figs. 3, 4, 9, 10, 11, 13, 14.—*Idiognathoides marginodosus* n. sp. Morphotype B. *3*, upper view of OU 10,020 (275-18A), ×50; *4*, upper view of OU 10,021 (275-18A), ×50; *9*, upper view of OU 10,028 (275-18A), ×40; *10*, upper view of OU 10,024 (275-18A), ×40; *11*, upper view of OU 7150 (275-18A), ×40; *13*, upper view of OU 7151 (274-17C), ×40; *14*, upper view of OU 7152 (275-18A), ×40.

Figs. 5, 17.—*Neognathodus bassleri* (Harris and Hollingsworth). *5*, upper view of OU 10,023 (159-13), ×40; *13*, upper oblique view of OU 10,025 (159-13), ×40.

Fig. 6.—*Diplognathodus orphanus* (Merrill). Upper view of OU 10,026 (274-17A), ×50.

Fig. 7.—*Idiognathoides marginodosus* n. sp. Morphotype A; upper view of OU 10,022 (275-6), ×50.

Fig. 8—*Neognathodus atokaensis* n. sp. Upper view of holotype, OU 10,027 (259-Ab), ×30.

Fig. 15.—*Idiognathodus* n. sp. Upper view of OU 10,029 (274-4), ×90.

Figs. 16, 18.—*Idiognathoides marginodosus* n. sp. Morphotype C. *16*, upper view of OU 7153 (259-Ab), ×40; *18*, upper view of paratype, OU 10,030 (259-Ab), ×40.


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## Plate 2

(Figured specimens 6 and 26 from Wapanucka Formation; all others from Atoka Formation)

Figs. 1, 5a, 5b, 10, 11, 12, 16, 21, 23.—*Neognathodus atokaensis* n. sp. *1*, upper view of OU 10,031 (259-Ab), ×35; *5a*, aboral view of OU 10,045 (259-Ab), ×25; *5b*, oral view of same specimen; *10*, upper view of OU 10,038 (274-17d), ×25; *11*, upper view of OU 10,032 (275-18c), ×45; *12*, upper view of OU 10,033 (274-10), ×35; *16*, upper view of paratype, OU 10,039 (275-18c), ×40; *21*, upper view of paratype, OU 10,035 (259-Ab), ×25; *23*, upper view of OU 10,042 (259-Ab), ×25.

Figs. 2, 14a, 14b, 15, 18, 20.—*Neognathodus bothrops* Merrill. *2*, upper view of OU 10,036 (274-10), ×45; *14a*, upper view of OU 7154 (274-17c), ×25; *14b*, aboral view of same specimen; *15*, upper view of OU 10,046 (275-18c), ×45; *18*, upper view of OU 10,040 (274-10), ×60; *20*, upper view of OU 10,041 (274-10), ×60.

Figs. 3, 26.—*Anchignathodus minutus* (Ellison). *3*, lateral view of OU 10,043 (274-17A), ×60; *26*, lateral view of OU 10,044 (275-6b), ×35.

Figs. 4, 8.—*Idiognathoides marginodosus* n. sp. Morphotype B. *4*, upper view of a specimen transitional to morphotype C, OU 7155 (259-At), ×40; *8*, upper view of OU 10,299 (274-10), ×25.

Fig. 6.—*Adetognathus lautus* (Gunnell). Lateral view of OU 10,048 (159-2B), ×35.

Fig. 7.—*Neognathodus symmetricus* (Lane). Upper view of OU 10,037 (274-10), ×90.

Figs. 9, 17.—*Idiognathoides marginodosus* n. sp. Morphotype A. *9*, upper view of OU 10,300 (274-10), ×25; *17*, upper view of a specimen transitional to morphotype B, OU 10,301 (275-18A), ×40.

Fig. 13.—*Neognathodus* n. sp. B. Upper view of OU 10,034 (274-10), ×35.

Fig. 19.—*Idiognathoides marginodosus* n. sp. Morphotype C. Upper view of OU 10,298 (274-10), ×25.

Fig. 22.—*Gnathodus* n. sp. Upper view of OU 10,047 (275-18A), ×60.

Figs. 24, 25.—*Diplognathodus orphanus* (Merrill). *24*, lateral view of OU 10,049 (274-17A), ×90; *25*, lateral view of OU 10,050 (274-17A), ×90.


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## Plate 3

(Figured specimens 3, 5, 6, 13, 21, 25, 26, and 27 from Wapanucka Formation; all others from Atoka Formation)

Figs. 1a, 1b, 7a, 7b, 11, 16, 18, 22.—*Neognathodus atokaensis* n. sp. *1a,* upper view of holotype, OU 10,051 (274-17c), ×25; *1b,* aboral view of same specimen; *7a,* aboral view of OU 10,052 (259-Ab), ×25; *7b,* upper view of same specimen; *11,* upper view of OU 10,148 (275-18c), ×25; *16,* upper view of paratype, OU 10,149 (274-17d), ×25; *18,* upper view of OU 10,1135 (259-Ab), ×25; *22,* upper view of OU 7156 (275-18c), ×25.

Figs. 2, 3, 5, 6, 21, 23, 25.—*Idiognathodus delicatus* Gunnell. *2,* upper view of OU 10,047 (259-Ab), ×45; *3,* upper view of OU 10,053 (159-6), ×45; *5,* upper view of OU 10,054 (159-6), ×45; *6,* upper view of OU 10,132 (159-6), ×45; *21,* upper view of OU 10,133 (159-6), ×45; *23,* upper view of OU 10,134 (275-18C), ×45; *25,* upper view of OU 10,1365 (275-6B), ×45.

Figs. 4, 10, 12, 14.—*Idiognathoides marginodosus* n. sp. Morphotype C. *4,* upper view of OU 10,137 (259-At), ×45; *10,* upper view of OU 10,139 (274-17A), ×45; *12,* upper view of OU 10,140 (274-17A), ×60; *14,* upper view of OU 10,138 (259-Ab), ×45.

Figs. 13, 15.—*Idiognathoides ouachitensis* Harlton. *13,* upper view of OU 10,142 (277-13), ×45; *15,* upper view of OU 10,141 (266-3), ×45.

Figs. 8, 9, 26, 27.—*Adetognathus lautus* (Gunnell). *8,* lateral view of OU 10,143 (266-8), ×45; *9,* lateral view of OU 10,144 (266-8), ×45; *26,* lateral view of OU 10,145 (275-6B), ×90; *27,* lateral view of OU 10,146 (275-6B), ×90.

Figs. 17, 24a, 24b.—*Neognathodus bothrops* (Merrill). *17,* upper view of OU 7158 (274-17d), ×25; *24a,* upper view of OU 7159 (259-At), ×25; *24b,* aboral view of same specimen.

Fig. 19.—*I. marginodosus* n. sp. Morphotype A. Upper view of paratype, OU 7157 (275-18A), ×40.

Fig. 20.—*Declinognathodus noduliferus* (Ellison and Graves). Upper view of OU 10,296 (274-10), ×40.


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## Plate 4

(Figured specimens 1, 4, 9, 10, 14, 15, 18, 19, 20 and 24 from Wapanucka Formation; all others from Atoka Formation)

Figs. 1, 6, 7, 8, 17, 24.—*Idiognathodus delicatus* Gunnell. *1*, upper view of OU 10,150 (159-6), ×30; *6*, upper view of OU 10,151 (260-1A), ×30; *7*, upper view of OU 10,152 (275-18c), ×30; *8*, upper view of OU 10,153 (275-18c), ×30; *17*, upper view of OU 10,154 (275-18c), ×30; *24*, upper view of OU 10,155 (275-6B), ×30.

Figs. 2, 5.—*Idiognathoides ouachitensis* (Harlton). *2*, upper view of OU 10,156 (266-3), ×30; *5*, upper view of OU 10,157 (266-3), ×30.

Figs. 3, 13, 14, 19, 20.—*Idiognathoides sinuatus* Harris and Hollingsworth. *3*, upper view of OU 10,159 (266-3), ×30; *13*, upper view of OU 10,160 (266-3), ×30; *14*, upper view of OU 10,161 (275-9), ×30; *19*, upper view of OU 10,162 (275-9), ×30; *20*, upper view of OU 10,163 (275-9), ×30.

Figs. 4, 10.—*Idiognathoides corrugatus* (Harris and Hollingsworth). *4*, upper view of OU 10,158 (275-6B), ×30; *10*, upper view of OU 10,164 (275-9), ×30.

Figs. 9, 15.—*Idiognathoides convexus* (Ellison and Graves). *9*, upper view of OU 10,165 (275-9), ×30; *15*, upper view of OU 10,166 (159-6), ×30.

Figs. 11, 12, 22.—*Idiognathoides marginodosus* n. sp. Morphotype B. *11*, upper view of OU 10,167 (275-18A), ×30; *12*, upper view of OU 10,168 (275-14), ×30; *22*, upper view of OU 10,297 (275-18A), ×25.

Figs. 16, 21, 23.—*Idiognathoides marginodosus* n. sp. Morphotype C. *16*, upper view of OU 10,169 (274-17D), ×30; *21*, upper view of OU 10,170 (274-17D), ×30; *23*, specimen transitional to morphotype B, OU 10,171 (274-17D), ×25.

Fig. 18.—*Idiognathodus expansus* (Igo and Koike). Upper view of OU 10,172 (275-6B), ×30.


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*Oklahoma Geological Survey Bulletin 136, 1984*

# CONODONT PLATFORM ELEMENTS FROM THE WAPANUCKA AND ATOKA FORMATIONS (MORROWAN–ATOKAN) OF THE MILL CREEK SYNCLINE CENTRAL ARBUCKLE MOUNTAINS, OKLAHOMA

R. KENT GRUBBS[1]

**Abstract**—Conodont platform elements have been recovered from 56 to 62 intervals sampled in the Wapanucka, Atoka, and basal Deese Formations of the Mill Creek Syncline. The Wapanucka fauna is dominated by the genera *Idiognathoides* and *Adetognathus*; however, *Neognathodus* n. sp., *I. ouachitensis,* and the fusulinid *Millerella* were also recovered from the Wapanucka Formation. These species indicate a late Morrowan age for the formation in this area. No conodonts were recovered from the lower 75 feet of the Atoka Formation, but *Profusulinella millcreekensis,* a primitive species of the genus, occurs 12 feet above the base. A limited hiatus between the Wapanucka and Atoka Formations in the Mill Creek Syncline is suggested by the absence of *Eoschubertella* and *Pseudostaffella* in the lowest part of the Atoka Formation. Conodonts from the middle and upper parts of the Atoka Formation include *Neognathodus bothrops, N. medadultimus, Diplognathodus orphanus, D. coloradoensis,* and *Streptognathodus* sp. aff. *S. wabaunsensis.* Fusulinids recovered from the same interval have been identified as *Fusulinella* sp. aff. *F. devexa, F. prolifica,* and *F.* sp. aff. *F. leyi.* A middle to late Atokan age is indicated for this part of the Atoka Formation by both the conodonts and the fusulinids. Conodonts recovered from a single sample at the base of the overlying Deese Formation are indistinguishable from the Atoka fauna, but the presence of the fusulinid *Beedeina* indicates a Desmoinesian age for that interval. One new *Idiognathodus* morphotype, recovered from both the Wapanucka and Atoka Formations, is described and figured herein as *I.* sp. A.

## INTRODUCTION

The Mill Creek Syncline is an elongate northwest–trending structure in the central part of the Arbuckle Mountains of southern Oklahoma. Also known as the Mill Creek Graben, the syncline is preserved in a downthrown block between several larger structures. Because of its structural position, the Mill Creek Syncline contains a sequence of upper Morrowan and Atokan rocks (Wapanucka and Atoka Formations) that have been removed by erosion elsewhere in the Arbuckles. The nearest coeval strata are approximately 10 miles to the southwest, in the Ardmore Basin (Dornick Hills Group), and approximately 25 miles to the east and northeast, along the northeastern flank of the Arbuckle Mountains (Wapanucka and Atoka Formations). The regional stratigraphic relations were summarized by Sutherland and others (1982).

Sections of the Wapanucka and Atoka Formations in the Mill Creek Syncline were measured at five localities. Sixty-one 2-kg bulk samples were collected and processed for conodonts. An additional sample was collected from the base of the overlying Deese Formation at one locality (MS 284). Fifty-six of these samples produced 4,517 identifiable conodont platform elements that are assignable to 23 form-species. The distribution of these species is shown in figure 1. Both the Wapanucka and Atoka Formations produce relatively homogenous conodont faunas. However, there is a dramatic difference in compositional abundance between the two faunas, accompanied by the appearance of new taxa. Furthermore, this difference is apparent in the lowest conodont sample recovered from the Atoka Formation. This abrupt faunal change, which is also reflected in the fusulinids, suggests the presence of an unconformity between the Wapanucka and Atoka Formations in the Mill Creek Syncline.

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## Acknowledgments

This study is from my master's thesis, completed at The University of Oklahoma in 1981. Dr. Patrick K. Sutherland served as thesis advisor and contributed greatly to the successful completion of the project. Dr. Robert C. Grayson, Jr., Baylor University, and Dr. H. Richard Lane, Amoco Production Co., Tulsa, provided information and encouragement during the course of the study. Dr. Raymond C. Douglass, U.S. Geological

| FORMATION | Sample number \ Species | *Adetognathus lautus* | *Adetognathus spathus* | *Diplognathodus coloradoensis* | *Diplognathodus orphanus* | *Idiognathodus claviformis* | *Idiognathodus delicatus* | *Idiognathodus parvus* | *Idiognathodus* sp. A | *Idiognathoides convexus* | *Idiognathoides ouachitensis* | *Idiognathoides sinuatus* | *Idiognathoides sulcatus* | *Idiognathoides* sp. aff. *I. noduliferus* | *Neognathodus bothrops* | *Neognathodus medadultimus* | *Spathognathodus minutus* | *Streptognathodus anteeccentricus* | *Streptognathodus elegantulus* | *Streptognathodus expansus* | *Streptognathodus suberectus* | *Streptognathodus* sp. aff. *S. wabaunsensis* | *Streptognathodus* sp. |
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| DEESE | 284-62B | | | | | | 29 | | | | | | | | 3 | | | | | | | 72 | |
| | 284-54 | | | | | | 30 | | | | | | | | 2 | | | | 2 | | | 11 | |
| | 284-50 | 1 | | | | | 23 | | | | | | | | 3 | | | | | | | 7 | |
| | 282-14 | 1 | | 3 | 2 | | 65 | 6 | 20 | | 2 | | | | 20 | 5 | 26 | | | | | 4 | |
| | 284-43B | 12 | | 1 | | | 16 | | | 1 | | 3 | | | 45 | 2 | 2 | 1 | 3 | | | 70 | |
| ATOKA | 284-43A | 4 | | | | 2 | 23 | 1 | | 1 | 3 | 1 | | | 69 | 7 | | 4 | 4 | | | 77 | 1 |
| | 284-39 | 3 | | | | | 11 | 1 | | 2 | 4 | | | | | 1 | | 1 | | | | 2 | |
| | 284-35 | | | | | | 4 | 5 | | | 1 | | | | 2 | | | 1 | | | | 1 | |
| | 281-16B | 1 | | | 13 | | 636 | 14 | | 1 | 125 | 45 | | | 94 | 38 | | 1 | | | | 23 | 2 |
| | 284-290 | | | 1 | | | | | | | | | | | | | | | | | | | |
| | 284-27A | | | | 4 | 2 | 311 | 5 | 9 | | | | 59 | | 47 | 9 | 18 | | | | | 4 | |
| WAPANUCKA | 283-11B | 5 | | | | | | | | | | | | | | | | | | | | | |
| | 281-12 | | | | | | 1 | 1 | | | | | | | | | | | | | | | |
| | 282-8 | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 284-21B | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 281-10C | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 283-8F | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 281-10B | 13 | | | | 1 | 10 | | | 6 | 2 | 3 | | | | | 1 | 1 | | | | | |
| | 280-14D | 7 | | | | | 5 | | | 2 | | 1 | | | | | | | | | | | |
| | 283-8C | | | | | | | | | | | 1 | | | | | | | | | | | |
| | 284-21A | 2 | | | | | 2 | | | 2 | | | | | | | | 1 | | | | | |
| | 283-6F | 11 | | | | 1 | 5 | | | 7 | | | | | | | | 2 | | | | | |
| | 280-14C | 24 | | | | | 14 | | 1 | 14 | 3 | 9 | | | | | | 5 | | | | | 1 |
| | 283-6E | 3 | | | | 1 | 1 | | | 2 | | 4 | | | | | | | | | | | |
| | 284-19 | 11 | | | | | 6 | 1 | | 13 | | 3 | | | | | | | | | | | 2 |
| | 283-6D | 8 | | | | 1 | 10 | | | 9 | 1 | 6 | | | | | | | | | | | 2 |
| | 280-14B | 62 | 6 | | | 1 | 20 | 3 | 1 | 49 | 5 | 28 | | 1 | | | 1 | 6 | | | | | 2 |
| | 281-8A | 7 | | | | | | | | 6 | | | | | | | | | | | | | |
| | 283-6C | 24 | | | | | 13 | 2 | | 18 | 3 | 11 | | | | | | 5 | | | | | |
| | 280-14A | 10 | | | | 1 | 8 | | | 3 | | 4 | | | | | | | | | | | |
| | 283-6A | 9 | | | | | 5 | | | 2 | 1 | 4 | | | | | | | | | | | |
| | 280-12B | 16 | 2 | | | 1 | 29 | 4 | 1 | 11 | | 2 | | | | | | 9 | | | | | 2 |
| | 281-6C | 8 | | | | | | | | 4 | | 2 | | | | | 1 | | | | | | |
| | 283-4C | 9 | | | | | | | | 10 | 1 | 7 | | | | | | | | | | | |
| | 281-5 | 1 | | | | | | | | 1 | | | | | | | | | | | | | |
| | 282-4B | | | | | | | | | 3 | | 1 | | | | | | | | | | | |
| | 283-3 | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 282-3 | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 281-1 | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 282-2C | 9 | | | | | | | | 40 | | 8 | | | | | 1 | | | | | | |
| | 282-2B | 10 | | | | | | | | 50 | | 16 | | | | | 2 | | | | | | |
| | 284-16A | | | | | | | | | | | | | | | | 2 | | | | | | |
| | 282-1 | 1 | | | | | | 1 | | 18 | | 6 | | | | | 1 | | | | | | |
| | 280-7B | 18 | 2 | | | | 10 | 2 | | 114 | 3 | 82 | | | | | 1 | 1 | | | | | |
| | 280-5E | 2 | | | | | 2 | | | | | | | | | | | | | | | | |
| | 284-14B | 21 | | | | | 15 | 4 | | 140 | 6 | 58 | | | | | | 6 | | | | | |
| | 280-5D | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 280-5B | 6 | | | | | 2 | | | 1 | | 1 | | | | | | | | | | | |
| | 284-12A | 15 | 3 | | | | 10 | | | 67 | 3 | 36 | | | | | 1 | 1 | | | | | |
| | 284-8 | 27 | | | | 1 | 66 | 1 | | 83 | 4 | 26 | | | | | | 22 | | 1 | | | 6 |
| | 284-6A | 21 | 2 | | | | 12 | 6 | | 85 | 7 | 15 | | | | | | 3 | | | | | |
| | 280-1D | 7 | | | | | 4 | 1 | | 22 | | 21 | | | | | 1 | | | | | | |
| | 284-3A | 66 | 4 | | | | 13 | | | 136 | 6 | 61 | | | | | | 11 | | | 1 | | 1 |
| | 280-1C | 18 | | | | | 2 | | | 4 | 1 | 19 | | | | | | | | | | | |
| | 280-1B | 5 | 2 | | | | | | | 2 | 1 | 7 | | | | | | | | | | | |
| | 280-1A | 4 | | | | | 2 | | | | 1 | 2 | | | | | | | | | | | |

Figure 1. Distribution of conodont specimens recovered from Wapanucka, Atoka, and Deese Formations. Sample numbers are in proper stratigraphic sequence. For paired species, abundances of left and right elements are given in section on Systematic Paleontology.

Survey, Washington, D.C., Dr. Merlynd K. Nestell, University of Texas at Arlington, and John R. Groves, University of Iowa, examined numerous thin sections and identified fusulinids. Partial funding for this study was provided by a Grant-in-Aid from the American Association of Petroleum Geologists, in 1978, and by a grant to Dr. Sutherland from the Mobil Foundation. The manuscript was reviewed by Drs. R. C. Grayson, Jr., A. G. Harris, T. W. Henry, H. R. Lane, W. L. Manger, and P. K. Sutherland.

## LOCATION OF MEASURED SECTIONS

All measured sections (MS) are in Johnston County, Oklahoma. The sections are numbered 280 to 284, from east to west. The distance between the easternmost and westernmost sections is approximately 3½ miles. A geologic map of the area is given by Sutherland and others (1982, p. 12), and columnar sections of MS 282, MS 283, and MS 284 are given by Grubbs and others (1982). The names and locations of the sections are (1) MS 280 (Gray Ranch), W½NE¼ sec. 17, T. 2 S., R. 5 E.; (2) MS 281 (Howell Ranch), SW¼SE¼ sec. 7, T. 2 S., R. 5 E.; (3) MS 282 (Mill Creek Quarry), C W½SW¼ sec. 7, T. 2 S., R. 5 E.; (4) MS 283 (Pipeline Trench), SW¼NW¼NW¼ sec. 7, T. 2 S., R. 5 E.; and (5) MS 284 (Lewis Ranch), C N½S½ sec. 2, T. 2 S., R. 4 E.

## WAPANUCKA FORMATION

### Conodont Fauna

The Wapanucka Formation in the Mill Creek Syncline is about 400 feet thick. The formation is partially covered; in the best exposed measured section (MS 280), the exposed beds make up 48 percent of the total thickness. Wapanucka exposures in the Mill Creek Syncline are almost exclusively limestone. Skeletal and oolitic grainstone and packstones are the dominant lithologic types; outcrops of wackestones, mudstones, and shales are uncommon. A total of 2,326 identifiable platform elements were recovered from 45 Wapanucka limestone samples. *Idiognathoides* is the dominant genus, making up 61 percent of the Wapanucka fauna. *Idiognathoides convexus* is the most common species, but *Adetognathus lautus, Idiognathoides sinuatus,* and *Idiognathodus delicatus* also occur in large numbers. Although the Wapanucka Formation is about 400 feet thick, little compositional variation was observed in the fauna. This homogeneity suggests rapid deposition and is consistent with the interpretation by Sutherland and others (1982) that the Mill Creek area was on the northern flank of a rapidly subsiding basin (Southern Oklahoma Aulacogen) during the time of Wapanucka deposition.

### Regional Correlation

A sample from near the base of the Wapanucka Formation in the Mill Creek Syncline produced *Idiognathoides ouachitensis* and a single specimen of *Neognathodus* n. sp. Uncommon specimens of *I. ouachitensis* are scattered throughout the formation, in addition to common specimens of *I. convexus*. These conodonts indicate a late Morrowan age and a correlation with the *Neognathodus* n. sp.–*Idiognathoides ouachitensis* assemblage as defined in the Wapanucka of the frontal Ouachitas by Grayson (1979; this volume). Thus, the whole of the Wapanucka Formation exposed in the Mill Creek Syncline correlates with only the top few feet of the formation on the northeastern and eastern flanks of the Arbuckle Mountains (see Grayson, this volume). The covered interval below the Wapanucka in the Mill Creek Syncline, presumed to be shale, is believed to correlate with strata in the *Idiognathoides convexus* Zone in the lower and middle parts of the Wapanucka Formation in the northeastern Arbuckles. In the type Wapanucka section, at the town of Wapanucka, this interval is primarily limestone, but at Canyon Creek to the west it is mostly shale (see Sutherland and others, 1982, fig. 6).

In relation to the type Morrowan sequence in northwestern Arkansas, the Wapanucka Formation in the Mill Creek Syncline appears to be younger than the Kessler Limestone Member of the Bloyd Formation (*I. convexus* Zone of Lane and Straka, 1974, and Lane, 1977), based on a comparison of both areas with Grayson's (this volume) sequence of conodont assemblages in the frontal Ouachitas. The Wapanucka of the Mill Creek Syncline appears to have been deposited during the interval represented by the hiatus between the Kessler Limestone and overlying Trace Creek Shale units in northwestern Arkansas. The Trace Creek contains a definite Atokan conodont assemblage, thus precluding correlation of the Mill Creek Wapanucka with that unit.

Groves and Grayson (this volume) proposed an earliest Atokan age for the uppermost part of the *N.* n. sp.–*I. ouachitensis* assemblage in the frontal Ouachitas, based on the occurrence at that horizon of the fusulinid *Eoschubertella*. However, Grayson (this volume) places the major part of the interval characterized by the *N.* n. sp.–*I. ouachitensis* assemblage in the Morrowan. The whole of the Wapanucka Formation in the Mill Creek Syncline is considered to be late Morrowan in age. In addition to the conodont fauna, an examination of over 100 limestone thin sections by John R. Groves (University of Iowa) produced *Millerella* throughout the Wapanucka, but neither *Eoschubertella* nor *Pseudostaffella* nor *Profusulinella*.

# ATOKA FORMATION

## Conodont Fauna

The Atoka Formation in the Mill Creek Syncline consists of a lower sandstone member (75 to 100 feet thick) and an upper member containing limestone, sandstone, shale and chert-pebble conglomerate (about 440 feet thick). The limestones of the upper member fall into two general categories: coarse-grained, crinoidal grainstones/packstones, and finer grained, spiculiferous mudstones/wackestones. These limestones produced 2,087 identifiable platform elements from 10 samples. Most of the samples were taken from MS 284; elsewhere in the Mill Creek Syncline, the Atoka is poorly exposed. The conodont fauna from the Atoka Formation is fundamentally different from the Wapanucka fauna in several respects. In the Atoka Formation, the genera *Idiognathodus, Neognathodus,* and *Streptognathodus* make up 58 percent, 17 percent and 14 percent of the fauna, respectively. The genera *Idiognathoides* and *Adetognathus,* which dominate the Wapanucka fauna, represent only 12 percent and 1 percent of the Atoka fauna. Certainly the significant environmental differences between the two formations in the Mill Creek Syncline (see Sutherland and others, 1982) may be partially responsible for the large difference in faunal composition, especially in the case of *Adetognathus.* However, comparison of the Atoka fauna in the Mill Creek Syncline with other faunas of Atokan age indicates that the difference is primarily temporal rather than environmental. Furthermore, the faunal change is abrupt. Five species that do not occur in the Wapanucka in the Mill Creek Syncline appear in the lowest sample taken from the Atoka (unit 284-27A, about 78 feet above the base of the Atoka). These species are *Idiognathoides sulcatus, Neognathodus bothrops, Neognathodus medadultimus, Diplognathodus orphanus,* and *Streptognathodus* sp. aff. *S. wabaunsensis. Diplognathodus coloradoensis* appears in the next higher sample (unit 284-29D, about 117 feet above the base). This dramatic faunal change is also reflected in the fusulinids. As previously stated, the Wapanucka Formation in the Mill Creek Syncline produced only *Millerella.* However, a calcareous sandstone near the base of the Atoka Formation in MS 283 produced specimens described by Douglass and Nestell (this volume) as *Profusulinella millcreekensis* n. sp., a primitive form of the genus (Grubbs and others, 1982, p. 33). The interval that produced these specimens is only 11 feet stratigraphically higher than the highest Wapanucka limestone exposed in that section. In MS 284, the interval in which five new conodont species appeared (unit 284-27A) also contains specimens assignable to *Fusulinella* (Grubbs and others, 1982, p. 35). The change in both the conodont and the fusulinid faunas, and in particular the absence of *Eoschubertella* and *Pseudostaffella,* suggests a hiatus between the Wapanucka and Atoka Formations in the Mill Creek Syncline.

## Regional Correlation

No conodonts were collected from the sandstone interval in the lower 75 to 100 feet of Atoka Formation in the Mill Creek Syncline. Conodonts and fusulinids recovered from the formation above the sandstone indicate a middle to late Atokan age for that part of the sequence. In MS 284, the interval between units 27 and 43 inclusive (75 to 230 feet above the base) is characterized by the conodonts *N. bothrops, N. medadultimus* (in fewer numbers than *N. bothrops*), *D. orphanus,* and *D. coloradoensis,* and by fusulinids of the group that includes *Fusulinella prolifica* and *F.* sp. aff. *F. devexa* (Douglass and Nestell, this volume). These species suggest a middle Atokan age. At unit 54 in MS 284 (402 feet above the base of the Atoka), the conodont fauna is essentially the same; but the fusulinids recovered from this interval are more advanced (*F.* sp. aff. *F. leyi*), indicating a late Atokan age (Douglass and Nestell, this volume).

A general correlation can be made between exposures of the Atoka Formation in the Mill Creek Syncline and those in the northeastern Arbuckle Mountains. In both areas, the occurrence of *N. bothrops* and *N. medadultimus,* and fusulinids of the group that includes *F. prolifica* and *F. devexa,* suggests that the two sequences are approximately coeval.

# DEESE FORMATION

The Deese Formation overlies the Atoka Formation in the Mill Creek Syncline. It is composed primarily of limestone-cobble conglomerate and is estimated to be several thousand feet thick (Ham, 1969). One conodont sample was collected from a limestone interval in the lower part of the Deese, in MS 284. This sample produced only three species (*I. delicatus, N. bothrops,* and *S.* sp. aff. *S. wabaunsensis*) and is indistinguishable from samples recovered from the Atoka Formation. However, this limestone interval also contains fusulinids of Desmoinesian age, including *Beedeina lewisi* n. sp. and *Wedekindellina praematura* n. sp. (Douglass and Nestell, this volume). The Atoka–Deese contact is believed to be unconformable, based on regional stratigraphic evidence (Sutherland and others, 1982).

# SYSTEMATIC PALEONTOLOGY

Genus **Adetognathus** Lane, 1967

**Adetognathus lautus** (Gunnell, 1933)

*Description.*—See Lane and Straka, 1974.
*Material.*—Sinistral, 221; dextral, 278.

**Adetognathus spathus** (Dunn, 1966)

*Material.*—Sinistral, 13; dextral, 8.

Genus **Diplognathodus** Kozur and Merrill *in* Kozur, 1975

**Diplognathodus coloradoensis** (Murray and Chronic, 1965)

Pl. 1, figs. 1, 2

*Spathognathodus coloradoensis* Murray and Chronic, 1965, p. 606–607, pl. 72, figs. 11–13; Webster, 1969, p. 44, pl. 7, fig. 7; Lane and Straka *in* Lane and others, 1971, pl. 1, fig. 23; Merrill, 1973, p. 304, pl. 3, figs. 20–42 (*non Spathognathodus coloradoensis* Murray and Chronic; Koike, 1967, pl. 3, figs. 23, 24—*S. minutus*).

*Gnathodus atetsuensis* Koike, 1967, p. 295, pl. 1, figs. 6–8.

"*Spathognathodus*" *coloradoensis* Murray and Chronic; Merrill, 1974, pl. 1, figs. 23, 24; pl. 2, figs. 38, 39.

*Diplognathodus coloradoensis* (Murray and Chronic); Merrill, 1975, p. 48–50, figs. 16: 40, 17: 16; Landing and Wardlaw, 1981, p. 1257–1259, pl. 1, figs. 2?, 3?, 4, 5, 8 (*non Diplognathodus coloradoensis* (Murray and Chronic); Landing and Wardlaw, 1981, pl. 1, figs. 1, 6, 7, 9, 10—*D. orphanus*).

*Description.*—See Merrill, 1973.
*Material.*—Five specimens.

**Diplognathodus orphanus** (Merrill, 1973)

Pl. 1, figs. 3, 4

*Spathognathodus orphanus* Merrill, 1973, p. 309, pl. 3, figs. 45–56.

"*Spathognathodus*" *orphanus* Merrill; Merrill, 1974, pl. 1, figs. 25–27.

*Diplognathodus coloradoensis* (Murray and Chronic); Landing and Wardlaw, 1981, pl. 1, figs. 1, 6, 7, 9, 10.

*Description.*—See Merrill, 1973.
*Remarks.*—*D. orphanus* is distinguished from *D. coloradoensis* by the carina; it is coarsely denticulate in the former and a relatively nondenticulate smooth ridge ("spatula") in the latter. Both of these species are distinctive members of the Atoka fauna in the Mill Creek Syncline.
*Material.*—19 specimens.

Genus **Idiognathodus** Gunnell, 1931

*Remarks.*—Unfortunately, the present state of *Idiognathodus* taxonomy is extremely confusing. Therefore, following Webster (1969) and Merrill (1975), those specimens with relatively continuous transverse ridges that comprise the bulk of the fauna have been placed in one species, *I. delicatus*. One unique, previously undescribed morphotype was recovered in this study, and it is described herein as *I.* sp. A.

**Idiognathodus claviformis** Gunnell, 1931

*Material.*—Sinistral, 8; dextral, 6.

**Idiognathodus delicatus** Gunnell, 1931

Pl. 1, figs. 5–7

*Description.*—See Merrill, 1975.
*Material.*—Sinistral, 722; dextral, 693.

**Idiognathodus parvus** (Dunn, 1966)

*Material.*—58 specimens.

**Idiognathodus** sp. A

Pl. 1, figs. 12–15

*Description.*—In upper view, the platform is moderately narrow, strongly incurved, and sharply pointed posteriorly. The platform may be incurved from either the right or the left side, making this a paired species with Class II symmetry (Lane, 1968). The free blade joins the platform in a medial position and continues as a carina-like ridge for at least half the platform length. Widely spaced, oblique transverse ridges are well developed in the posterior two-thirds of the platform. The ridges continue across the "carina," giving it a nodose appearance. Nodose accessory lobes are common along the anterior inner margin and are well set off from the platform. Weaker lobes may be present along the outer anterior margin of larger specimens. In transverse view, the upper platform surface is flat to slightly convex and is bisected by the elevated "carina." In lateral view, the conodont is arched, with the point of flexure being in the anterior one-third of the platform. An intact free blade was not observed in this study, but these forms are assumed to have typical idiognathodid blade morphology. In lower view, these forms resemble *I. delicatus*.
*Remarks.*—This morphotype is distinguished from *I. delicatus* by its "carina." In the Mill Creek Syncline, *I.* sp. A appears in the upper part of the Wapanucka Formation and continues in greater abundance through the Atoka Formation.
*Material.*—Sinistral, 19; dextral, 13.

Genus **Idiognathoides** Harris and Hollingsworth, 1933

*Remarks.*—Several workers (Lane and Straka, 1974; Landing and Wardlaw, 1981) have suggested that the morphologically distinct sinistral and dextral elements formerly assigned to *I. sinuatus* and *I. corrugatus*, respectively, should be placed in a single paired species, *I. sinuatus* (Class IIIb symmetry of Lane, 1968; "parasymmetry pair" of Landing and Wardlaw, 1981), because they commonly occur together, in approximately equal numbers, and have similar ranges. The results of my study generally agree with this concept. In the Wapanucka and Atoka Formations in the Mill Creek Syncline, sinistral and dextral elements of this species occur in approximately equal numbers in the same samples, and they display similar ranges. The difficulty lies in determining how the elements were paired in the conodont apparatus (*I. sulcatus*, which was recovered from the Atoka Formation, is excluded from this discussion because it displays Class II symmetry of Lane, 1968). The dextral elements of *Idiognathoides* recovered in this study can be placed into three species with fairly distinct morphologies: *I. convexus, I. ouachitensis,* and *I. corrugatus*. The sinistral elements, however, are much more homogenous morphologically, and in general they resemble only one species, *I. sinuatus*. It is certainly possible that the sinistral elements that were paired with a particular dextral morphotype (for example, *I. convexus*) are indistinguishable from sinistral elements that were paired with a different dextral morphotype (for example, *I. corrugatus*), or that they were paired in a random fashion. Alternatively, there could be subtle morphologic traits among sinistral elements that allow them to be related to a particular dextral morphotype. For example, Lane and Straka (1974, p. 84) stated that "the left (=sinistral) element of *I. convexus* is much like the left element of *I. sinuatus,* except that the central trough is generally longer and deeper in *I. convexus*."

An attempt was made in this study to determine if subtle morphologic distinctions could be made among the sinistral elements and related to the dominance of a particular dextral morphotype in the same sample. Using this approach, the following observations can be made: (1) In samples where *I. corrugatus* dextral elements were dominant, the sinistral elements tended to have short median grooves, generally restricted to the anterior half of the platform (pl. 2, figs. 1, 2); (2) in samples where *I. convexus* dextral elements were dominant, the sinistral elements tended to have narrower platforms and longer median grooves (pl. 2, figs. 5, 6); (3) in samples where *I. ouachitensis* dextral elements were dominant, the sinistral elements tended to have median grooves that extended to, or nearly to, the posterior tip, bisecting the platform longitudinally into outer (higher) and inner (lower) platform margins (pl. 2, figs. 10, 11). Using the above criteria, the sinistral elements in this study were paired with their corresponding dextral elements, creating three "parasymmetrically" paired species, *I. convexus, I. ouachitensis,* and, following Lane and Straka (1974) and Landing and Wardlaw (1981), *I. sinuatus*.

### **Idiognathoides convexus** (Ellison and Graves, 1941)

Pl. 2, figs. 5–8

Dextral elements:

*Polygnathodella convexa* Ellison and Graves, 1941, p. 9, pl. 3, figs. 10, 12, 16.

*Polygnathodella* cf. *convexa* Ellison and Graves; Koike, 1967, p. 308–309, pl. 3, figs. 1, 2.

*Idiognathoides convexus* (Ellison and Graves); Webster, 1969, p. 37, pl. 5, figs. 17, 18; Dunn, 1970, p. 334–335, pl. 63, fig. 20; Lane and Straka *in* Lane and others, 1971, pl. 1, fig. 19; Webster *in* Lane and others, 1971, pl. 1, fig. 18.

*Description.*—Dextral elements, see Dunn, 1970.

*Material.*—Sinistral, 456; dextral, 476.

### **Idiognathoides ouachitensis** (Harlton, 1933)

Pl. 2, figs. 9–13

Sinistral elements:

*Polygnathodella ouachitensis* Harlton; Ellison, 1972, pl. 1, fig. 5.

?*Idiognathoides sinuatus* Harris and Hollingsworth; Landing and Wardlaw, 1981, pl. 2, figs. 8–10, 12, 14.

Dextral elements:

*Polygnathodella ouachitensis* Harlton, 1933, p. 15, pl. 4, fig. 14; Ellison and Graves, 1941, p. 10, pl. 3, figs. 8, 9; Ellison, 1972, pl. 1, figs. 6, 7 (*non Polygnathodella ouachitensis* Harlton; Koike, 1967, pl. 3, figs. 3–5—*I. sinuatus*).

?*Idiognathoides sinuatus* Harris and Hollingsworth; Landing and Wardlaw, 1981, pl. 2, figs. 20, 21.

*Description.*—Dextral elements, see Harlton, 1933.

*Remarks.*—Dextral elements of *I. ouachitensis* are distinguished from those of *I. sinuatus* by the presence of a median trough in the former. Although intergradation between the two morphotypes was observed in this study, many specimens of *I. ouachitensis* displayed very well developed troughs (pl. 2, figs. 9, 13).

*Material.*—Sinistral, 89; dextral, 92.

### **Idiognathoides sinuatus** Harris and Hollingsworth, 1933

Pl. 2, figs. 1–4

Sinistral elements:

*Idiognathoides sinuata* Harris and Hollingsworth, 1933, p. 201–202, pl. 1, fig. 14; Lane, 1967, p. 937–938, pl. 119, figs. 1–9, 12–15; pl. 123, figs. 7, 8, 12.

*Cavusgnathus sinuata* (Harris and Hollingsworth); Ellison and Graves, 1941, p. 5–6, pl. 3, figs. 1, 5, 7.

*Gnathodus opimus* Igo and Koike, 1964, pl. 28, fig. 18; Webster, 1969, pl. 5, fig. 20.

*Idiognathoides sinuatus* Harris and Hollingsworth; Dunn, 1970, p. 335, pl. 63, figs. 14, 15, 21–23; Lane and Straka *in* Lane and others, 1971, pl. 1, figs. 12, 14; Lane and Straka, 1974, p. 88–89, fig. 37: 18, 23–26, fig. 41: 20–27; Landing and Wardlaw, 1981, p. 1262–1263, pl. 2, figs. 11?, 13?.

Dextral elements:

*Idiognathodus corrugata* Harris and Hollingsworth, 1933, p. 202–203, pl. 1, figs. 7, 8.

*Polygnathodella attenuata* (Harris and Hollingsworth); Ellison and Graves, 1941, pl. 3, figs. 11, 13–15.

*Idiognathoides corrugata* (Harris and Hollingsworth); LANE, 1967, p. 939, pl. 122, figs. 1, 2, 4–7, 9–11.
*Polygnathodella ouachitensis* HARLTON; KOIKE, 1967, pl. 3, figs. 3–5.
*Idiognathoides corrugatus* (Harris and Hollingsworth); DUNN, 1970, p. 355, pl. 63, figs. 16, 17, 18?, 25; LANE AND STRAKA *in* Lane and others, 1971, pl. 1, fig. 13.
*Idiognathoides sinuatus* (Harris and Hollingsworth); LANE AND STRAKA, 1974, p. 88–89, fig. 37: 14, 15, 20, 36, fig. 41: 1–14; LANDING AND WARDLAW, 1981, p. 1262–1263, pl. 2, figs. 15–19.

*Description.*—Sinistral and dextral elements, see Lane, 1967.
*Material.*—Sinistral, 238; dextral, 255.

**Idiognathoides sulcatus** Higgins and Bouckaert, 1968

*Material.*—Sinistral, 30; dextral, 29.

**Idiognathoides** sp. aff. **I. noduliferus** (Ellison and Graves, 1941)

*Material.*—Sinistral, 1.

Genus **Neognathodus** Dunn, 1970

**Neognathodus bothrops** Merrill, 1972
Pl. 3, figs. 1, 2, 5–9

*Gnathodus roundyi* GUNNELL; MURRAY AND CHRONIC, 1965, pl. 71, figs. 3, 4.
*Streptognathodus colombiensis* STIBANE, 1967, p. 336, taf. 36, figs. 1–10.
*Streptognathodus elegantulus* STAUFFER AND PLUMMER; STIBANE, 1967, p. 336, taf. 36, figs. 19–22.
*Gnathodus bassleri* HARRIS AND HOLLINGSWORTH; WEBSTER, 1969, pl. 5, figs. 9, 14, 15; WEBSTER *in* Lane and others, 1971, pl. 1, fig. 26?
*Gnathodus* n. sp. A MERRILL *in* Lane and others, 1971, pl. 1, fig. 31.
*Neognathodus* n. sp. A MERRILL AND KING, 1971, p. 659–660, pl. 76, figs. 7–10.
*Neognathodus bothrops* MERRILL, 1972, p. 823–824, pl. 1., figs. 8–15; MERRILL, 1974, pl. 1, figs. 5, 11, 12; MERRILL, 1975, p. 69, fig. 17: 63–66.
*Neognathodus colombiensis* (Stibane); SUTHERLAND and others, 1982, p. 11, 13, 30, 36.

*Description.*—See Merrill, 1972.
*Remarks.*—*N. bothrops* is characterized by a carina that is fused for its entire length, and that continues to the posterior tip of the platform. However, a few specimens were recovered whose carina is fused but does not extend to the posterior tip (pl. 3, figs. 1, 2). These forms are considered to be variants of *N. bothrops* and are not considered to be conspecific with *N. bassleri,* whose carina is markedly nodose in its posterior half.
*Material.*—286 specimens.

**Neognathodus medadultimus** Merrill, 1972
Pl. 3, figs. 3, 4, 10–13

*Gnathodus roundyi* GUNNELL; MURRAY AND CHRONIC, 1965, pl. 71, figs. 1, 2.
*Streptognathodus asymmetricus* STIBANE, 1967, p. 335–336, taf. 36, figs. 11–18.
*Neognathodus medadultimus* MERRILL, 1972, p. 824–825, pl. 1, figs. 2–7; pl. 2, fig. 19; MERRILL, 1974, pl. 1, figs. 2–4, 10; MERRILL, 1975, p. 69, fig. 15: 44; fig. 16: 25: fig. 17: 8, 30, 67.

*Description.*—See Merrill, 1972.

*Remarks.*—*N. medadultimus* is the direct descendant of *N. bothrops* in the evolutionary lineage proposed by Merrill (1972). Whereas intergradation was observed between the two species in this study, there was no trend toward the development of *N. medadultimus* from *N. bothrops*, because both occur together (see fig. 1).
*Material.*—61 specimens.

Genus **Spathognathodus** Branson and Mehl, 1941

**Spathognathodus minutus** (Ellison, 1941)

*Material.*—58 specimens.

Genus **Streptognathodus** Stauffer and Plummer, 1932

**Streptognathodus anteeccentricus** Dunn, 1966

*Material.*—Sinistral, 29; dextral, 52.

**Streptognathodus elegantulus** Stauffer and Plummer, 1932

*Material.*—Sinistral, 4; dextral, 5.

**Streptognathodus expansus** Igo and Koike, 1964

*Material.*—Sinistral, 1.

**Streptognathodus suberectus** Dunn, 1966

*Material.*—Dextral, 1.

**Streptognathodus** sp. aff. **S. wabaunsensis** Gunnell, 1933
Pl. 1, figs. 8–11

*Idiognathodus delicatus* GUNNELL; LANDING AND WARDLAW, 1981, pl. 2, fig. 1.

*Description.*—The upper platform surface is shallowly concave, with a sharp medial crease. In all other respects, these forms are similar to *I. delicatus.*
*Remarks.*—These specimens are similar to those referred to as "streptognathodan" *I. delicatus* elements by Landing and Wardlaw (1981, p. 1260, 1262). While it is true that elements of *S.* sp. aff. *S. wabaunsensis* and *I. delicatus* intergraded morphologically in this study, the generic distinction was retained owing to their

differing ranges (the former was recovered from only the Atoka and basal Deese Formations; see fig. 1).

*Material.*—Sinistral, 122; dextral, 149.

**Streptognathodus** spp.

*Material.*—Sinistral, 10; dextral, 9.

## REFERENCES CITED

**Branson, E. B.**, and **Mehl, M. G.**, 1941, New and little known Carboniferous conodont genera: Journal of Paleontology, v. 15, p. 97–106.

**Dunn, D. L.**, 1966, New Pennsylvanian conodonts from southwestern United States: Journal of Paleontology, v. 40, p. 1294–1303.

———1970, Middle Carboniferous conodonts from western United States and phylogeny of the platform group: Journal of Paleontology, v. 44, p. 312–342.

**Ellison, Samuel**, 1941, Revision of the Pennsylvanian conodonts: Journal of Paleontology, v. 15, p. 107–143.

———1972, Conodont taxonomy in the Pennsylvanian: Geologica et Paleontologica, SB 1, p. 127–146.

**Ellison, Samuel**, and **Graves, R. W., Jr.**, 1941, Lower Pennsylvanian (Dimple limestone) conodonts of the Marathon region, Texas: University of Missouri, School of Mines and Metallurgy Bulletin, Technical Series, v. 14, no. 3, 21 p.

**Grayson, R. C., Jr.**, 1979, Stop descriptions—fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

**Grubbs, R. K.**, **Sutherland, P. K.**, **Douglass, R. C.**, and **Nestell, M. K.**, 1982, Stop descriptions—Mill Creek Syncline, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 30–37.

**Gunnell, F. H.**, 1931, Conodonts from the Fort Scott limestone of Missouri: Journal of Paleontology, v. 5, p. 244–252.

———1933, Conodonts and fish remains from the Cherokee, Kansas City, and Wabaunsee groups of Missouri and Kansas: Journal of Paleontology, v. 7, p. 261–297.

**Ham, W. E.**, 1969, Regional geology of the Arbuckle Mountains, Oklahoma: Oklahoma Geological Survey Guidebook 17, 52 p.

**Harlton, B. H.**, 1933, Micropaleontology of the Pennsylvanian Johns Valley shale of the Ouachita Mountains, Oklahoma, and its relationship to the Mississippian Caney shale: Journal of Paleontology, v. 7, p. 3–29.

**Harris, R. W.**, and **Hollingsworth, R. V.**, 1933, New Pennsylvanian conodonts from Oklahoma: American Journal of Science, series 5, v. 25, p. 193–204.

**Higgins, A. C.**, and **Bouckaert, J.**, 1968, Conodont stratigraphy and palaeontology of the Namurian of Belgium: Belgique service Geol. Mem. 10, 64 p.

**Igo, H.**, and **Koike, T.**, 1964, Carboniferous conodonts from the Omi Limestone, Niigata Prefecture, central Japan (studies of Asian conodonts, Pt. I): Paleont. Soc. Japan Trans. and Proc., N.S., no. 53, p. 179–193.

**Koike, T.**, 1967, A Carboniferous succession of conodont faunas from the Atetsu Limestone in southwest Japan (studies of Asiatic conodonts, Pt. VI): Tokyo Kyoiku Daigaku Science Reports, Sec. C, Geology, Mineralogy, and Geography, v. 9, no. 93, p. 279–318.

**Kozur, H.**, 1975, Beiträge zur Condontenfauna des Perm: Geol. Paläontol. Mitt. Innsbruck, v. 5, p. 1–44.

**Landing, E.**, and **Wardlaw, B. R.**, 1981, Atokan conodonts from the Pennsylvanian outlier of the Michigan Basin: Journal of Paleontology, v. 55, p. 1251–1269.

**Lane, H. R.**, 1967, Uppermost Mississippian and Lower Pennsylvanian conodonts from the type Morrowan region, Arkansas: Journal of Paleontology, v. 41, p. 920–942.

———1968, Symmetry in conodont element-pairs: Journal of Paleontology, v. 42, p. 1258–1263.

———1977, Morrowan (Early Pennsylvanian) conodonts of northwestern Arkansas and northeastern Oklahoma, *in* Sutherland, P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 177–180.

**Lane, H. R.**, **Merrill, G. K.**, **Straka, J. J., II**, and **Webster, G. D.**, 1971, North American Pennsylvanian conodont biostratigraphy, *in* Sweet, W. C., and Bergström, S. M., editors, Symposium on conodont biostratigraphy: Geological Society of America Memoir 127, p. 395–414.

**Lane, H. R.**, and **Straka, J. J.**, 1974, Late Mississippian and Early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

**Merrill, G. K.**, 1972, Taxonomy, phylogeny, and biostratigraphy of *Neognathodus* in Appalachian Pennsylvanian rocks: Journal of Paleontology, v. 46, p. 817–829.

———1973, Pennsylvanian nonplatform conodont genera, I. *Spathognathodus*: Journal of Paleontology, v. 47, p. 289–314.

———1974, Pennsylvanian conodont localities in northeastern Ohio: Ohio Division of Geological Survey Guidebook 3, 29 p.

———1975, Pennsylvanian conodont biostratigraphy and paleoecology of northwestern Illinois: Geological Society of America Microform Publication 3, 129 p.

**Merrill, G. K.**, and **King, C. W.**, 1971, Platform conodonts from the lowest Pennsylvanian rocks of northwestern Illinois: Journal of Paleontology, v. 45, p. 645–664.

**Murray, F. N.**, and **Chronic, J.**, 1965, Pennsylvanian conodonts and other fossils from insoluble residues of the Minturn Formation (Desmoinesian), Colorado: Journal of Paleontology, v. 39, p. 594–610.

**Stauffer, C. R.**, and **Plummer, H. J.**, 1932, Texas Pennsylvanian conodonts and their stratigraphic relations: University of Texas Bulletin 3201, Contributions to Geology, p. 13–50.

**Stibane, F. R.**, 1967, Conodonten des Karbons aus den nördlichen Anden südamerikas: Neues Jahrbuch für Geologie und Paleontologie, Abhandlungen, v. 128, p. 329–340.

**Sutherland, P. K.**, **Archinal, B. E.**, and **Grubbs, R. K.**, 1982, Morrowan and Atokan (Pennsylvanian) stratigraphy in the Arbuckle Mountains area, Oklahoma, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklaho-

ma: Oklahoma Geological Survey Guidebook 20, p. 1–17.
**Webster, G. D.**, 1969, Chester through Derry conodonts and stratigraphy of northern Clark and southern Lincoln Counties, Nevada: University of California Publications in Geological Sciences, v. 79, 121 p.

## Plate 1

(All specimens from Atoka Formation)

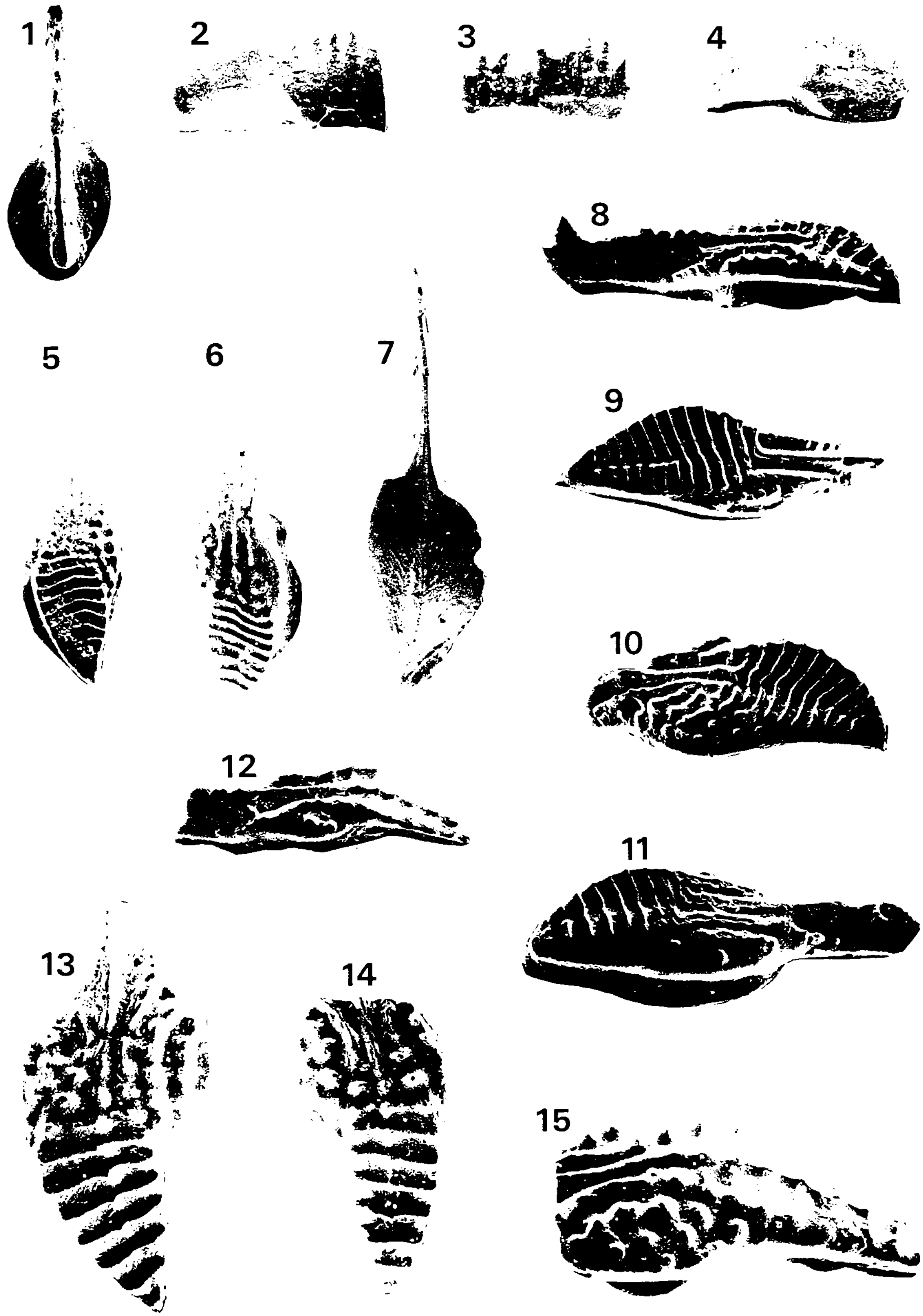
Figs. 1, 2.—*Diplognathodus coloradoensis* (Murray and Chronic). *1,* upper view, and *2,* lateral view, ×70 (OU 10174, unit 282-14).

Figs. 3, 4.—*Diplognathodus orphanus* (Merrill). *3,* lateral view, ×70 (OU 10175, 284-27A); *4,* lateral view, ×70 (OU 10176, 281-16B).

Figs. 5–7.—*Idiognathodus delicatus* Gunnell. *5,* upper view of sinistral element, ×50 (OU 10177, 284-27A); *6,* upper view of dextral element, ×50 (OU 10178, 284-27A); *7,* lower view of sinistral element, ×50 (OU 10179, 284-27A).

Figs. 8–11.—*Streptognathodus* sp. aff. *S. wabaunsensis* Gunnell. *8,* inner oblique-lateral view of dextral element, ×70 (OU 10180, 284-43B); *9,* upper view of sinistral element, ×70 (OU 10181, 284-43A); *10,* inner oblique-lateral view of dextral element, ×70 (OU 10182, 284-43A); *11,* inner oblique-lateral view of sinistral element, ×70 (OU 10183, 284-43B).

Figs. 12–15.—*Idiognathodus* sp. A. *12,* inner oblique-lateral view of dextral element, ×70 (OU 10184, 284-27A); *13,* upper view of sinistral element, ×70 (OU 10185, 284-27A); *14,* upper view of dextral element, ×70 (OU 10186, 282-14); *15,* inner oblique-lateral view of dextral element, ×100 (OU 10187, 282-14).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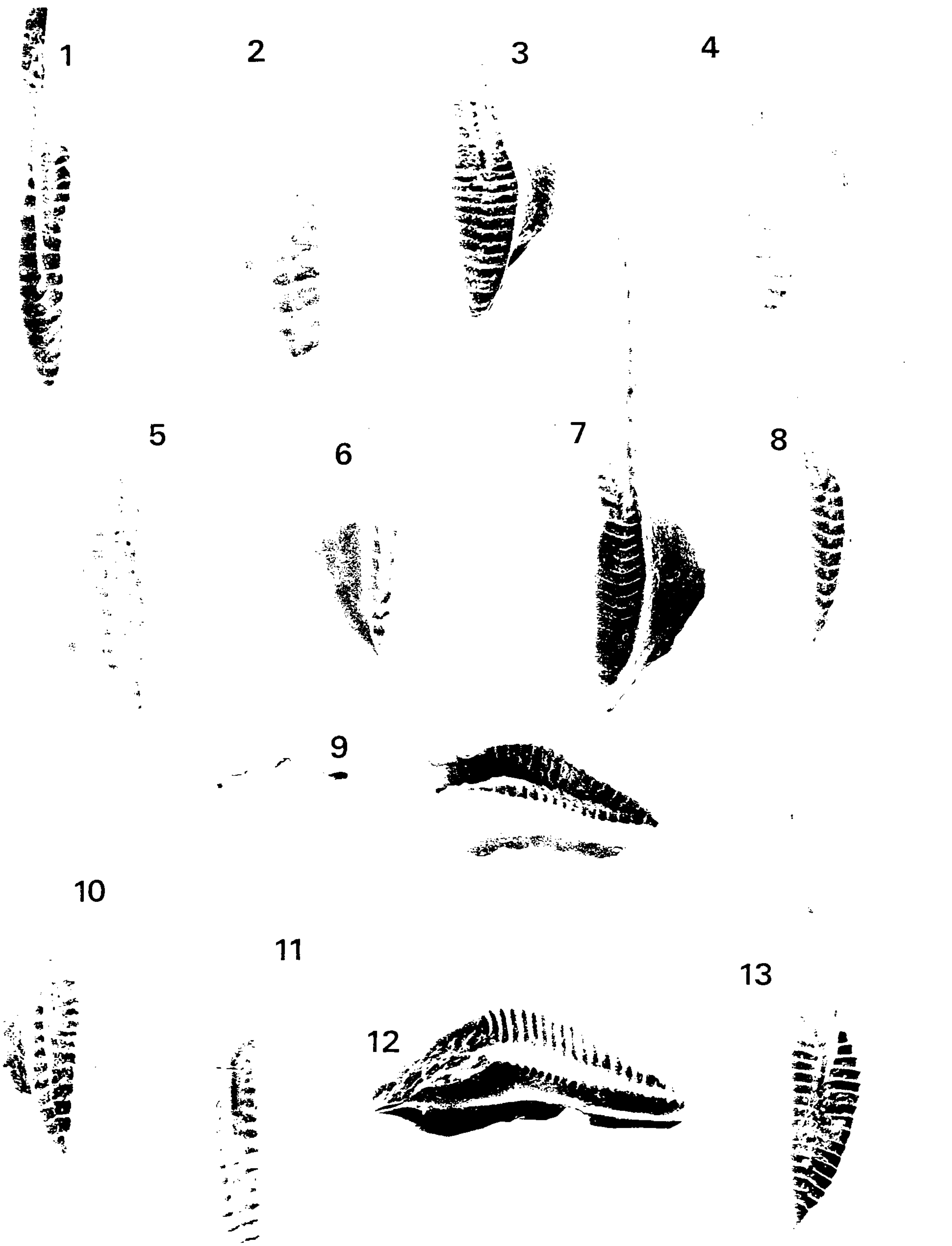
## Plate 2

(All specimens from Wapanucka Formation unless noted otherwise)

Figs. 1–4.—*Idiognathoides sinuatus* Harris and Hollingsworth. *1,* upper view of sinistral element, × 70 (OU 10188, unit 284-3A); *2,* upper view of sinistral element, × 70 (OU 10189, 284-8); *3,* upper view of dextral element, × 70 (OU 10190, 284-8); *4,* upper view of dextral element, × 70 (OU 10191, 284-3A).

Figs. 5–8.—*Idiognathoides convexus* (Ellison and Graves). *5,* upper view of sinistral element, × 70 (OU 10192, 284-8); *6,* upper view of sinistral element, × 70 (OU 10193, 284-6A); *7,* upper view of dextral element, × 70 (OU 10194, 284-8); *8,* upper view of dextral element, × 70 (OU 10195, 284-6A).

Figs. 9–13.—*Idiognathoides ouachitensis* (Harlton). *9,* inner oblique-lateral view, and *13,* upper view, × 70 (OU 10196, 281-16B); *10,* upper view of sinistral element, × 70 (OU 10197, 281-16B); *11,* upper view of sinistral element, × 70 (OU 10198, 281-16B); from Atoka Formation; *12,* inner oblique-lateral view of dextral element, × 70 (OU 10199, 284-3A).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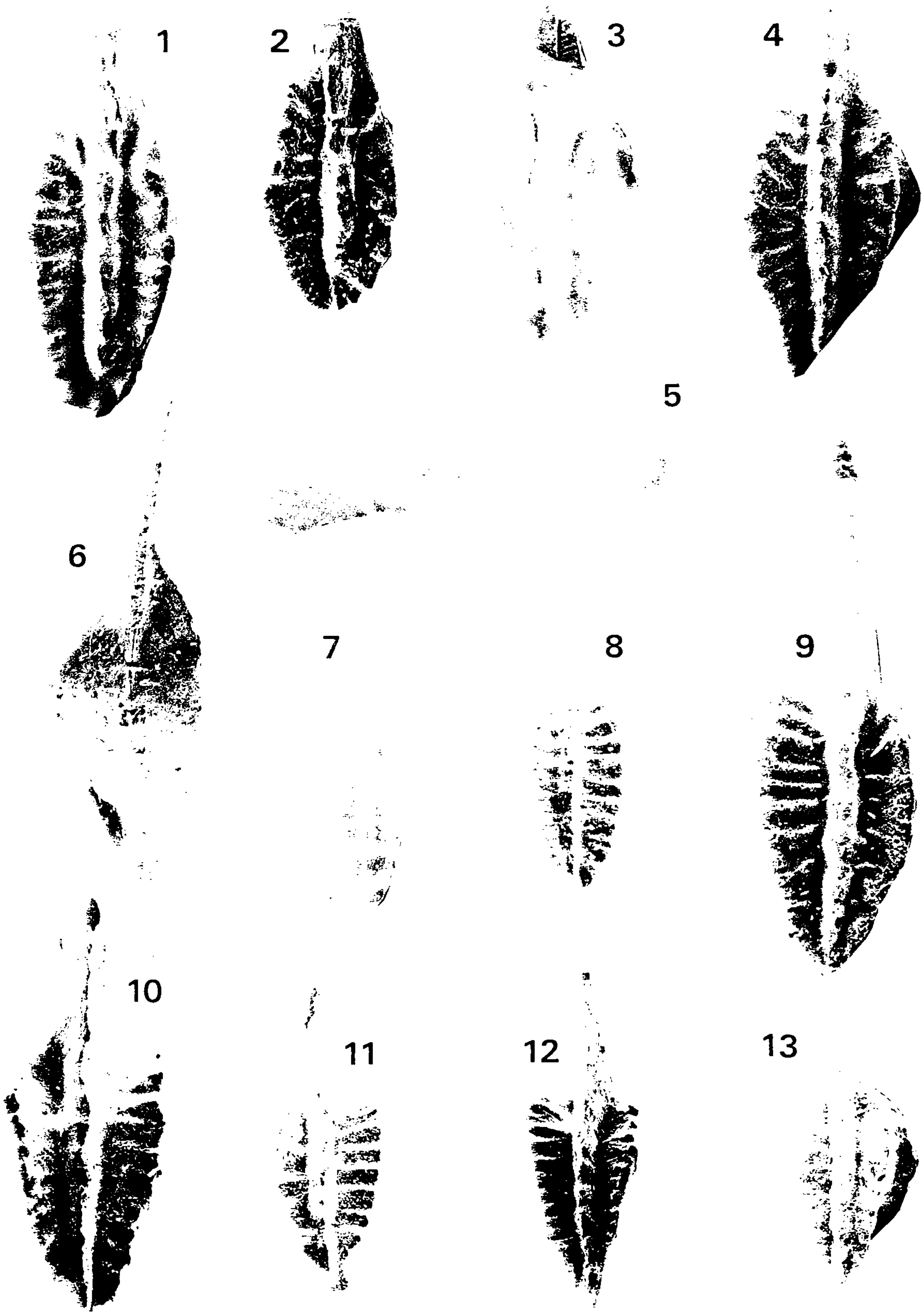
## Plate 3

(All specimens from Atoka Formation)

Figs. 1, 2, 5–9.—*Neognathodus bothrops* Merrill. *1,* upper view, × 70 (OU 10200, unit 284-43A); *2,* upper view, × 70 (OU 10201, 281-16B); *5,* lateral view, and *6,* lower view, × 50 (OU 10201, 284-27A); *7,* upper view, × 70 (OU 10203, 284-43B); *8,* upper view, × 70 (OU 10204, 281-16B); *9,* upper view, × 70 (OU 10205, 284-27A).

Figs. 3, 4, 10–13.—*Neognathodus medadultimus* Merrill. *3,* upper view, × 70 (OU 10206, 284-43A); *4,* upper view, × 70 (OU 10207, 281-16B); *10,* upper view, × 70 (OU 10208, 281-16B); *11,* upper view, × 70 (OU 10209, 281-16B); *12,* upper view, × 70 (OU 10210, 281-16B); *13,* upper view, × 70 (OU 10211, 281-16B).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# CALCAREOUS FORAMINIFERS AND CONODONTS FROM THE WAPANUCKA FORMATION (LOWER–MIDDLE PENNSYLVANIAN), FRONTAL OUACHITA MOUNTAINS SOUTHEASTERN OKLAHOMA

JOHN R. GROVES[1] and ROBERT C. GRAYSON, JR.[2]

**Abstract**—Three conodont assemblages are recognized locally in the Wapanucka Formation of the frontal Ouachita Mountains, southeastern Oklahoma. They are, in ascending order: (1) *Idiognathoides convexus–Idiognathodus delicatus* assemblage, (2) *Neognathodus* n. sp. A—*Idiognathoides ouachitensis* assemblage, and (3) *Idiognathodus* n. sp.—*Diplognathodus* spp. assemblage. Examination of coincident foraminiferal collections demonstrates that the appearances of the primitive fusulinids *Eoschubertella* and *Staffella*? are roughly parallel with the base of the *Idiognathodus* n. sp.—*Diplognathodus* spp. assemblage. We equate this level with the base of the Atokan Series, whereas the subjacent *Neognathodus* n. sp.—*Idiognathoides ouachitensis* assemblage is questionably Morrowan or Atokan, and the lowermost *Idiognathoides convexus—Idiognathodus delicatus* assemblage is confidently interpreted to be late Morrowan.

## INTRODUCTION

The question of the position of the lower boundary of the chronostratigraphic interval between the Morrowan and Desmoinesian Series (Pennsylvanian) has been addressed by numerous authors within the past decade (see references in Sutherland and Manger, 1983). Despite these efforts, little consensus exists as to its exact placement, or even the proper name for the interval it denotes. A major stumbling block to the resolution of these problems has been our limited understanding of the nature of the biota of this interval, and of chronostratigraphic relationships among key taxa of various fossil groups. Historically, fusulinid foraminifers have been used nearly exclusively to recognize the boundary, with only a few attempts made to integrate fusulinid biostratigraphic information with that of other groups (e.g., Lane and others, 1972).

The purpose of this paper is to report occurrences of calcareous foraminifers (fusulinids included) and conodonts from coincident samples of rocks that apparently span the boundary interval in question. We hope these findings will contribute toward a better understanding of the relationships between these groups at this level.

The Wapanucka Formation is exposed repeatedly in a series of thrust-fault blocks in the frontal Ouachita Mountains of southeastern Oklahoma (fig. 1) and recently was the subject of detailed lithostratigraphic and conodont biostratigraphic investigations by Grayson (1979, 1980). The conodont assemblages recognized here are based on collections from 33 measured sections (Grayson, 1979, fig. 104), whereas the foraminiferal data generated by Groves are derived from four localities (fig. 1; Appendix).

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### Acknowledgments

We gratefully acknowledge the efforts of P. K. Sutherland for assisting us with various aspects of this study, and Lu Willis for expertly preparing several hundred thin sections. R. C. Douglass, P. L. Brenckle, Gilbert Klapper, W. L. Manger, and P. K. Sutherland reviewed early drafts of this manuscript.

## CONODONT ASSEMBLAGES

Three conodont assemblages are recognized locally in the Wapanucka Formation of the frontal Ouachitas. They are, in ascending order: (1) *Idiognathoides convexus–Idiognathodus delicatus* assemblage, (2) *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage, and (3) *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage. Each assemblage, as we employ the term, represents a distinctive association of conodonts that provides the basis for local biostratigraphic correlations. The assemblages, however, are undoubtedly controlled environmentally, and their interregional chronostratigraphic integrity is largely untested. We therefore defer designation of them as formal zones. Figure 2 illustrates the relationships of the assemblages to lithostratigraphic subdivisions of the Wapanucka. Figures 3–6 illustrate occurrences of key conodonts and foraminifers.

### *Idiognathoides convexus–Idiognathodus delicatus* Assemblage

The *Idiognathoides convexus–Idiognathodus delicatus* assemblage is recognized as the interval

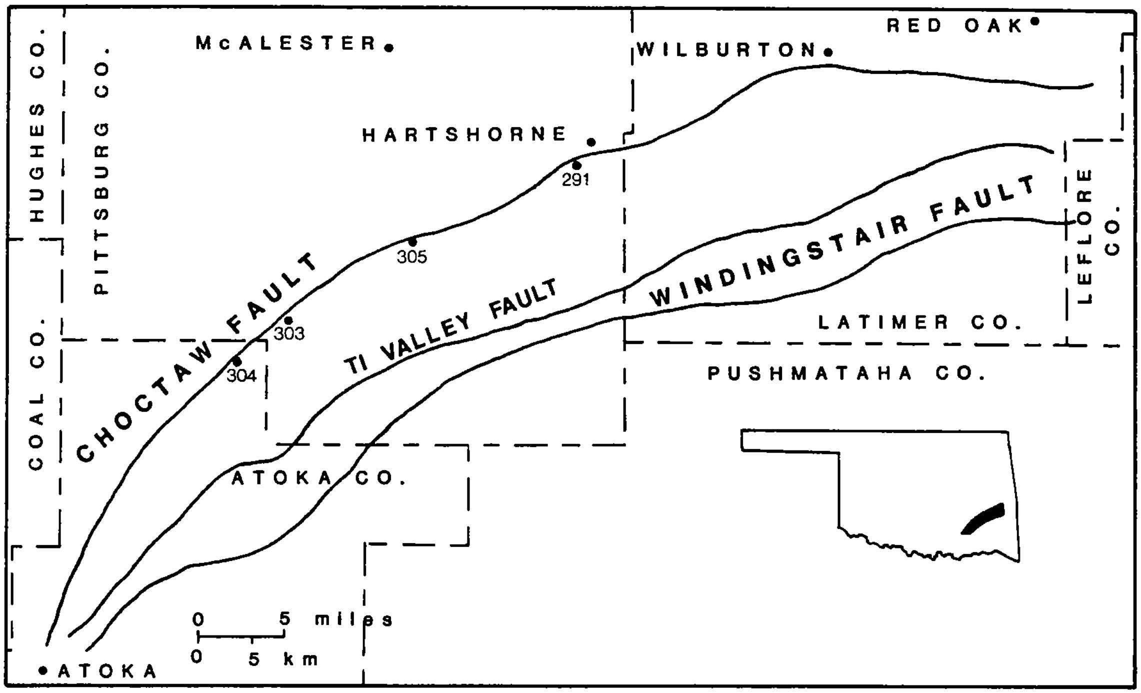


Figure 1. Index map of frontal Ouachita Mountains and locations of numbered measured sections from which microfossil-occurrence data are presented in figures 3–6. After Grayson (1979).

from the appearance of one or both of the name-bearers up to the appearances of *Neognathodus* n. sp. A and/or *Idiognathoides ouachitensis*. The assemblage occurs in approximately the lower one-third of the Wapanucka, including part or all of the Chickachoc Chert and the lower part of the lower limestone members (fig. 2). Associated species include *Adetognathus lautus* and *Anchignathodus minutus*.

## *Neognathodus* n. sp. A—*Idiognathoides ouachitensis* Assemblage

The *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage is defined as the interval from the appearance of one or both of the name-bearers up to the appearance of *Idiognathodus* n. sp. and (or) *Diplognathodus* spp. This assemblage occurs in approximately the middle one-third of the Wapanaucka, including the upper part of the lower limestone, all of the middle shale, and the lower part of the upper sandstone–limestone members (fig. 2). Associated species include those of the subjacent *Idiognathoides convexus–Idiognathodus delicatus* assemblage plus *Neogondolella clarki* and early gondolellids.

## *Idiognathodus* n. sp.—*Diplognathodus* spp. Assemblage

The base of the *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage is defined by the appearance of one or more of the name-bearers. It occurs in approximately the upper one-third of the Wapanucka, including the upper part of the upper sandstone-limestone member (fig. 2). The upper limit of this assemblage remains undefined in the frontal Ouachitas, owing to the generally unfavorable lithologies of the Atoka Formation, which overlies the Wapanucka. Associated species include those of the two subjacent assemblages plus *Gondolella gymna*.

## DISTRIBUTION OF FORAMINIFERS

Calcareous foraminifers of the Wapanucka (figs. 3–6) are generally rare and restricted in terms of generic diversity in comparison with Lower and Middle Pennsylvanian faunas described elsewhere in North America (e.g., Brenckle, 1973; Mamet, 1975; Armstrong and Mamet, 1977; Groves, 1983). The fauna is dominated by undiagnostic, long-ranging encrusting forms, palaeotextulariids, endothyrids, tetrataxids, and tuberitinids. Biostratigraphically useful eostaffellids (*Eostaffella, Millerella*) and primitive fusulinids (*Eoschubertella, Staffella*?) are particularly scarce and typically cannot be identified at the specific level.

The local appearances of *Eoschubertella* and *Staffella*? in the upper part of the Wapanucka are especially significant. Mamet (1975; *in* Mamet and Skipp, 1970) defined the base of his microfossil Zone 21 on the appearances of *Eoschubertella*

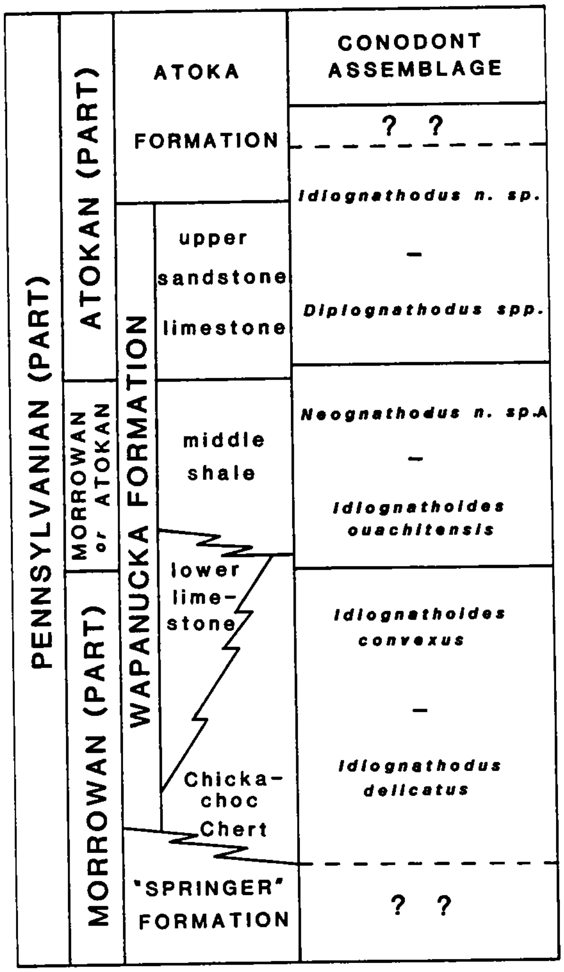


Figure 2. Relationships between lithostratigraphic subdivisions of the Wapanucka and conodont assemblages. After Grayson (1979).

and *Pseudostaffella,* and arbitrarily equated this level with the base of the Atokan Series. The utilization of these genera as indices of the lower Atokan similarly has been adopted by other workers (e.g., Lane and others, 1972; Webster and others, in press). *Eoschubertella* was recovered in the Wapanucka in two samples from measured section (MS) 304 (fig. 5), which are assigned to the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* and *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblages, respectively. It should be noted that the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage at this locality is represented stratigraphically by only two samples, and the possibility exists that part or nearly all of this assemblage remains unrecognized as a result of the thick covered interval directly below the upper sandstone–limestone. Accordingly, we equate the appearance of *Eoschubertella* approximately with the base of the *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage.

*Staffella*? occurs in the Wapanucka at locality MS 291 (fig. 3) in rocks assigned to the top of the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage, at MS 303 (fig. 4) in rocks assigned to the *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage, and at MS 304 (fig. 5), with *Eoschubertella,* in the lower sample questionably assigned to the *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage. The interregional chronostratigraphic significance of forms we are referring to *Staffella*? is unclear, owing to nomenclatural confusion and lack of documentation. Thompson (1935, p. 113, footnote) noted that "the small forms from the Lower Pennsylvanian of many parts of the world that are referred to *Staffella* may not be congeneric with the type of the genus *S. moellerana.*" Recent workers have referred "*Staffella*-like" forms from the Lower Pennsylvanian to *Pseudoendothyra* Mikhailov (e.g., Armstrong and Mamet, 1977; Ross and Bamber, 1978), which is known worldwide from Upper Mississippian equivalents and younger rocks. Our specimens are completely recrystallized (presumably originally aragonitic) with very broadly rounded peripheries and large numbers of chambers. Regardless of nomenclatural uncertainty, specimens similar to ours have not been reported from unequivocal Morrowan rocks of the Midcontinent but have been reported in association with *Eoschubertella* and younger forms from Texas and Oklahoma (Thompson, 1935, 1947).

## AGE OF THE WAPANUCKA

The lower part of the Wapanucka Formation assigned to the *Idiognathoides convexus–Idiognathodus delicatus* assemblage, and below the appearances of *Eoschubertella* and *Staffella*?, is interpreted to be late Morrowan on the basis of the presence of the *I. convexus* Zone in the Kessler Limestone Member of the Bloyd Formation at the top of the type Morrowan succession (Lane and Straka, 1974; Lane, 1977).

Rocks assigned to the superjacent *Neognathodus* n. sp. A–*Idiognathoides ouachitensis* assemblage, which, except for the uppermost samples, also lack primitive fusulinids, are questionably interpreted to be Morrowan or Atokan. A more precise interpretation is not possible, owing to the lack of depositionally continuous sections in the type areas of the Morrowan and Atokan Series against which faunal comparisons can be made (Sutherland and Manger, 1983). Foraminifers from this interval are typical of Morrowan faunas (cf. Groves, 1983), whereas the corresponding conodonts are typical of both Atokan and Morrowan rocks (cf. Lane, 1977).

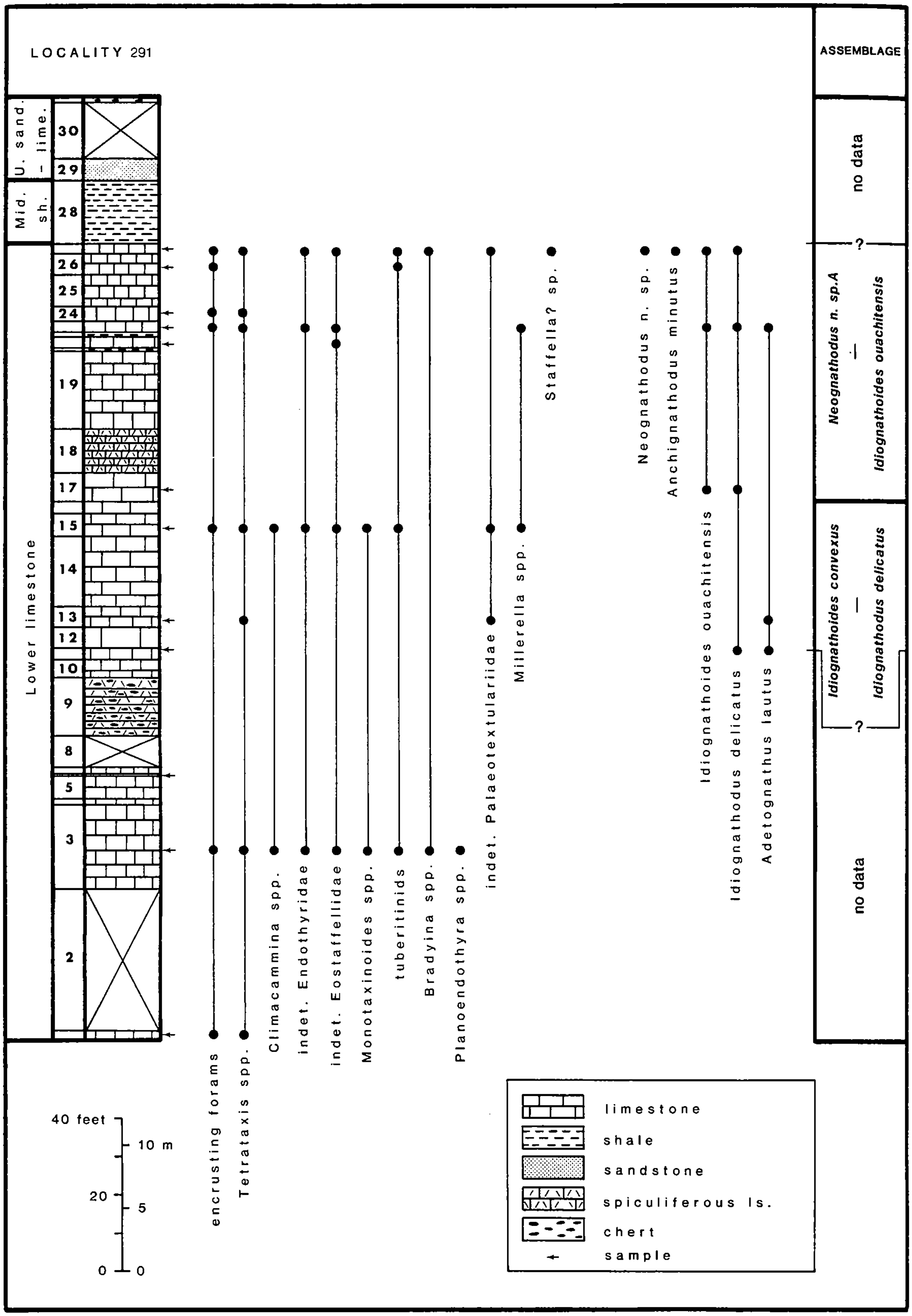


Figure 3. Columnar section, sampling intervals, and microfossil occurrences at MS 291.

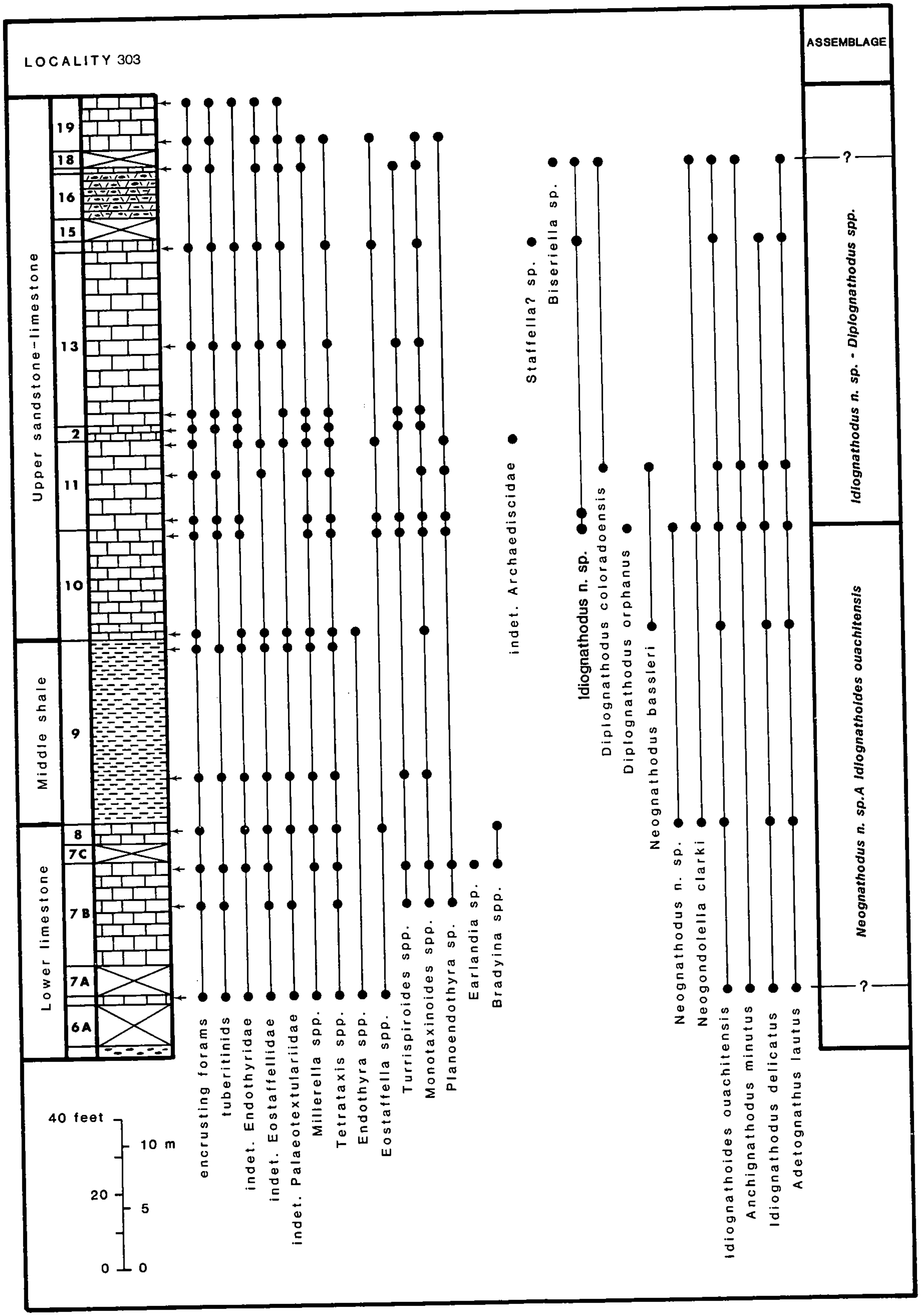


Figure 4. Columnar section, sampling intervals, and microfossil occurrences at MS 303. For explanation, see figure 3 (bottom).

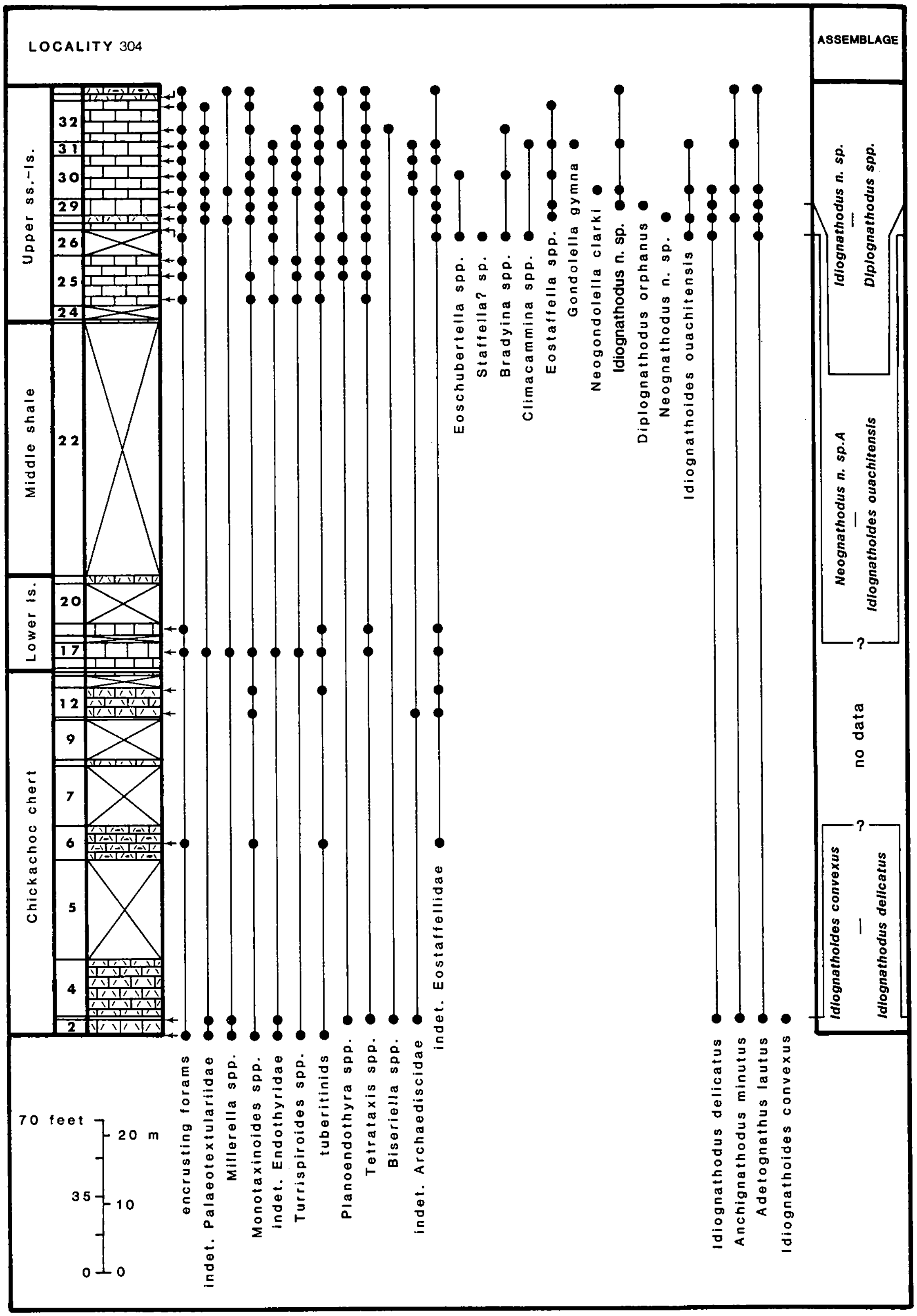


Figure 5. Columnar section, sampling intervals, and microfossil occurrences at MS 304. For explanation, see figure 3 (bottom).

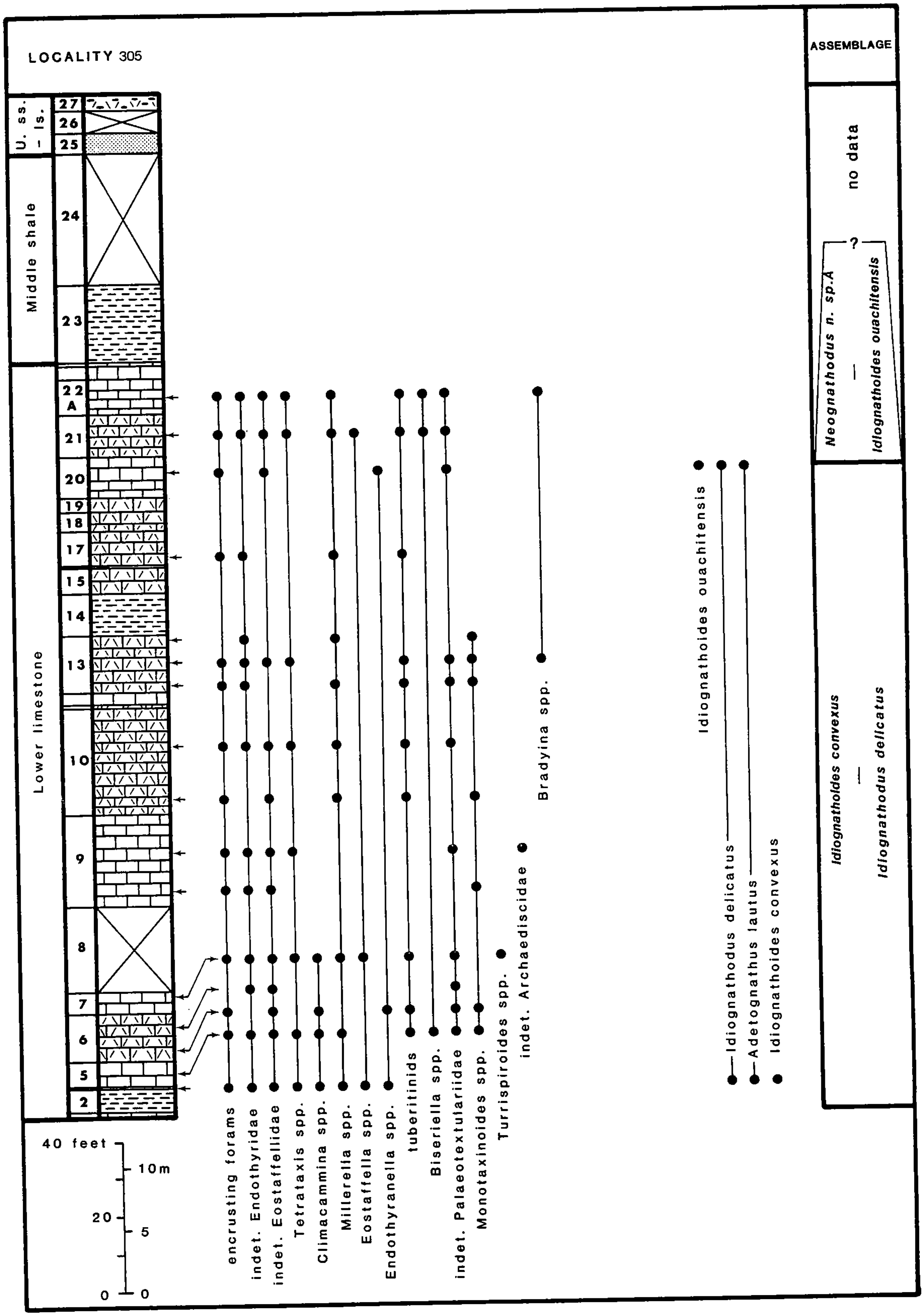


Figure 6. Columnar section, sampling intervals, and microfossil occurrences at MS 305. For explanation, see figure 3 (bottom).

The upper part of the Wapanucka assigned to the *Idiognathodus* n. sp.–*Diplognathodus* spp. assemblage is interpreted to be Atokan on the basis of the presence of *Eoschubertella, Idiognathodus* n. sp., *Diplognathodus orphanus,* and *D. coloradoensis,* all of which are demonstrably post-Morrowan (Lane and others, 1972; Lane, 1977; Webster and others, in press). We hasten to point out that this usage of Atokan is somewhat arbitrary, inasmuch as the interval containing the appearances of these taxa is clearly older than the oldest type Atokan rocks (Sutherland, 1982; Grayson, this volume).

## DISCUSSION

The Wapanucka Formation of the frontal Ouachitas represents a package of rocks deposited continuously across the Morrowan–Atokan boundary, which contains microfossils historically considered useful for biostratigraphic correlations at this level. We are unable, however, to identify positively the position of the boundary. This inability stems principally from the inadequacy of the type Morrowan and type Atokan Series as chronostratigraphic standards of reference; the type Morrowan is marred by unconformities at both its base and top, whereas the type Atokan is unsuitable because of an unconformity at its base followed by generally unfavorable lithologies. Consequently, precise faunal correlations to the type areas at the boundary level are rendered impossible.

## REFERENCES CITED

**Armstrong, A. K.**, and **Mamet, B. L.**, 1977, Carboniferous microfacies, microfossils, and corals, Lisburne Group, Arctic Alaska: U.S. Geological Survey Professional Paper 849, 144 p.

**Brenckle, P. L.**, 1973, Smaller Mississippian and Lower Pennsylvanian calcareous foraminifers from Nevada: Cushman Foundation for Foraminiferal Research Special Publication 11, 82 p.

**Grayson, R. C., Jr.**, 1979, Stop descriptions—fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

———1980, The stratigraphy of the Wapanucka Formation (Lower Pennsylvanian) along the frontal margin of the Ouachita Mountains, Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 317 p.

**Groves, J. R.**, 1983, Calcareous foraminifers and algae from the type Morrowan (Lower Pennsylvanian) region of northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Bulletin 133, 65 p.

**Lane, H. R.**, 1977, Morrowan (Early Pennsylvanian) conodonts of northwestern Arkansas and northeastern Oklahoma, *in* Sutherland, P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 177–180.

**Lane, H. R., Sanderson, G. A.**, and **Verville, G. J.**, 1972, Uppermost Mississippian–basal Middle Pennsylvanian conodonts and fusulinids from several exposures in the south-central and southwestern United States: International Geological Congress, 24th, Montreal, 1972, sec. 7, Palaeontology, p. 549–555.

**Lane, H. R.**, and **Straka, J. J.**, 1974, Late Mississippian and Early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

**Mamet, B. L.**, 1975, Carboniferous Foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey Professional Paper 848-B, 18 p.

**Mamet, B. L.**, and **Skipp, B. A.**, 1970, Preliminary foraminiferal correlations of early Carboniferous strata in the North American Cordillera, *in* Colloque sur la stratigraphie du Carbonifère: Congrès et Colloques de l'Université de Liège, v. 55, p. 327–348.

**Ross, C. A.**, and **Bamber, E. W.**, 1978, Middle Carboniferous and Early Permian fusulinaceans from the Monkman Pass area, northeastern British Columbia: Contributions to Canadian Paleontology, Geological Survey of Canada Bulletin 267, p. 25–44.

**Sutherland, P. K.**, editor, 1982, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, 44 p.

**Sutherland, P. K.**, and **Manger, W. L.**, 1983, the Morrowan–Atokan (Pennsylvanian) boundary problem: Geological Society of America Bulletin, v. 94, p. 543–548.

**Thompson, M. L.**, 1935, The fusulinid genus *Staffella* in America: Journal of Paleontology, v. 9, p. 111–120.

———1947, Stratigraphy and fusulinids of pre-Desmoinesian Pennsylvanian rocks, Llano uplift, Texas: Journal of Paleontology, v. 21, p. 147–164.

**Webster, G. D., Brenckle, P. L., Gordon, M., Jr., Lane, H. R., Langenheim, R. L., Jr., Sanderson, G. A.**, and **Tidwell, W. D.**, in press, the Mississippian–Pennsylvanian boundary in the western Great Basin: Compte Rendu 9e Congrès international de Stratigraphie et de Géologie du Carbonifère, Urbana–Champaign, 1979.

# APPENDIX

## Register of Localities

MS-291 (Hartshorne Quarry): NW¼NW¼ sec. 18, T. 4 N., R. 17 E., Hartshorne Quadrangle, Pittsburg County, Oklahoma.

MS 303 (Kiowa East): NE¼NE¼ sec. 36, T. 3 N., R. 13 E., Kiowa Quadrangle, Pittsburg County, Oklahoma.

MS 304 (Reynold's Lake): SE¼SE¼ and SW¼SE¼ sec. 10, T. 2 N., R. 13 E., Kiowa Quadrangle, Atoka County, Oklahoma.

MS 305 (Blanco East): SW¼SW¼SW¼ sec. 19, T. 3 N., R. 15 E., Pittsburg County, Oklahoma.

The reader is referred to Grayson (1980) for more detailed information on access to these localities.

*Oklahoma Geological Survey Bulletin 136, 1984*

# THE INADEQUACIES OF CARBONIFEROUS SERIAL NOMENCLATURE: NORTH AMERICAN EXAMPLES

H. RICHARD LANE[1] and R. R. WEST[2]

**Abstract**—Spivey and Roberts defined the Atokan Series to correspond to the Atoka Formation, a lithostratigraphic unit having no type section. The authors stated that its lower and upper boundaries corresponded to major faunal and stratigraphic breaks. Procedurally, they recognized the Atokan's lower boundary at the appearance of fusulinids (such as *Pseudostaffella)* that are more advanced than *Millerella* and included in it the "zones" of *Profusulinella* and *Fusulinella*. None of these fusulinids are known to occur in the vicinity of Atoka, Oklahoma, the town from which the name is derived. As with the four other widely used major subdivisions of the Pennsylvanian Subsystem, the Atokan's definition fits better that of a stage than a series.

Similar problems of inadequacy beset all other serial subdivisions of the Carboniferous, be they North American or otherwise. For example, none of the series stratotypes commonly used for the Mississippian Subsystem reflect precisely their generally employed limits. Moreover, geographically derived names, such as Atoka, invoke subjective loyalties by local geologists that impede progress toward a soundly defined and unified classification of the Mississippian and Pennsylvanian. Because of these reasons, we advocate the abandonment of geographically derived serial nomenclature for both subsystems in favor of the simpler and more objective subdivisions "Lower," "Middle," and "Upper" in conformance with earlier Paleozoic systems. If defined by boundary stratotypes, such serial subdivisions would transcend the labyrinthine regional Carboniferous nomenclature.

## INTRODUCTION

The original definition of the Atokan Series was made by Spivey and Roberts (1946, p. 185) with the following statement: "Because of important faunal (fusulinid) breaks from Morrow to Atoka and from Atoka to overlying beds, and because of important unconformities which correspond with these faunal breaks, and because these sediments comprise a thick complex sequence of beds, the writers propose that the Atoka formation be elevated to Atoka series and defined to include all beds from the top of the Wapanucka limestone, Morrow series, to the base of the Hartshorne sandstone, Des Moines series." Thus, in order to understand the original definition of the Atoka Series, one must first understand what the Atoka Formation represents. In their definition of the series, Spivey and Roberts did not refer to an original type section of the Atoka Formation nor did they propose one. In the absence of a designated type section for the Atoka Formation and Series, the interval that Spivey and Roberts suggested as representing the Atoka Series—from the top of the Wapanucka Limestone to the base of the Hartshorne Sandstone—represents a substantially different time-stratigraphic interval from place to place and certainly is not precise enough for the definition of a series. Thus, Spivey and Roberts' lithostratigraphic definition of the Atokan Series is inadequate by contemporary standards.

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## ATOKA FORMATION

Since Spivey and Roberts utilized the Atoka Formation in their definition, perhaps stability can be found in the original proposal of the formation. The Atoka Formation was named by Taff and Adams (1900, p. 273–275) from irregular exposures along the southern end of the Eastern Choctaw Coal Field (fig. 1). These exposures consisted of thin and slabby, brown and light-gray sandstone beds separated by recessive bluish clay shales containing ironstone concretions. The Eastern Choctaw Coal Field was defined by Taff and Adams (1900, p. 263) as extending eastward from the McAlester–Lehigh or Western Choctaw Coal Field to the Arkansas state line. The boundary between the two coal fields corresponds approximately to a position at 90°30′ W. longitude (fig. 1). Consequently, the town of Atoka, about 50 miles southwest of the western limit of the Eastern Choctaw Coal Field, is not even within the type area of the original definition of the Atoka Formation!

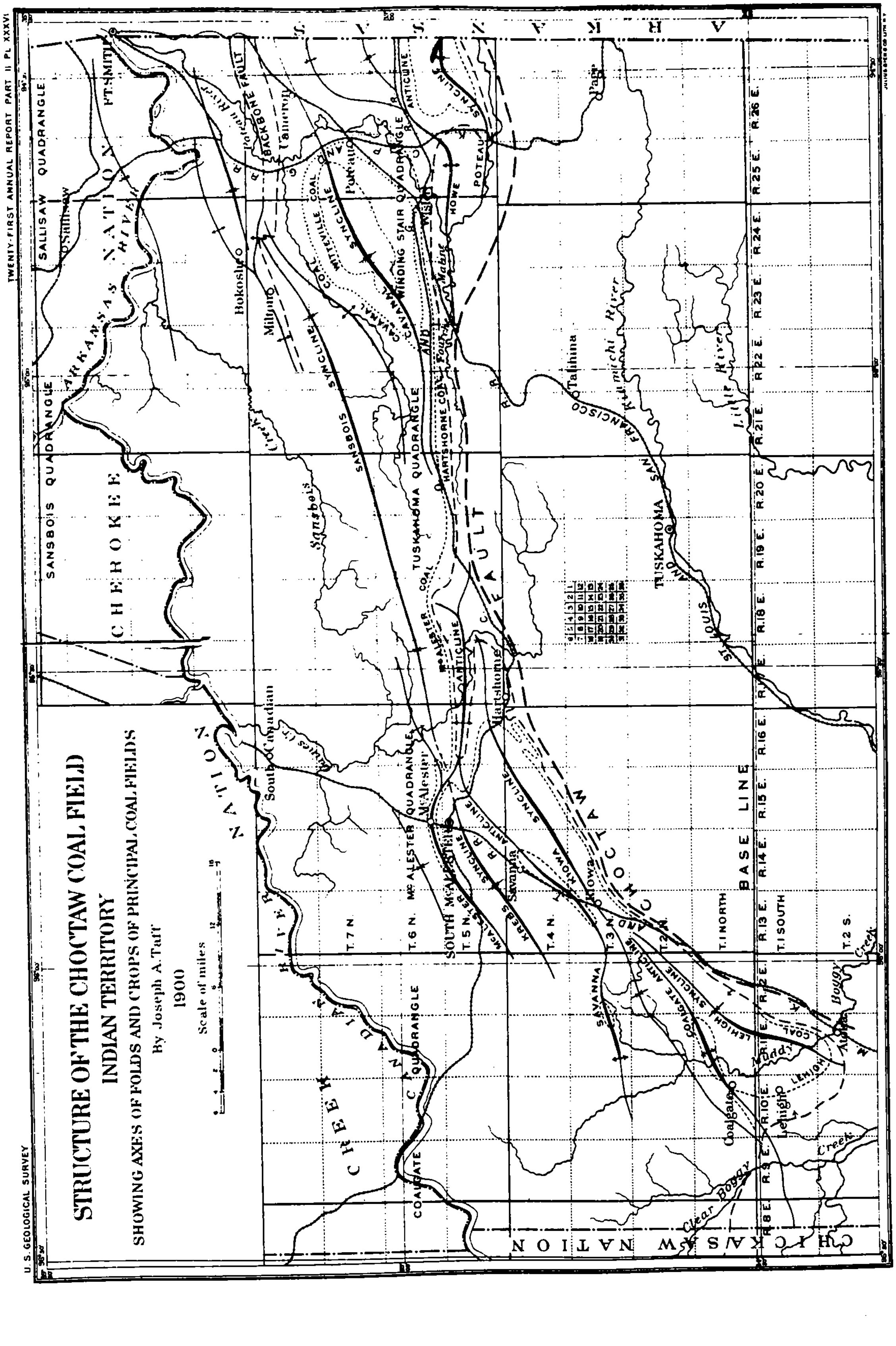


Figure 1. Map showing structure of Choctaw Coal Field, Indian Territory (photographic reduction from Taff and Adams, 1900, pl. 36).

Even though a type section for the Atoka Formation was not designated by its original authors, it was stated that the formation thinned from 6,000 to 7,000 feet near the Arkansas state line to 3,000 feet near the Boiling Springs Anticline to not more than 300 feet in the southwestern corner of the Eastern Choctaw Coal Field. According to Taff and Adams, four sandstones up to 100 feet thick, each separated by 1,200 feet of shale, are present in the formation near the Arkansas state line. Furthermore, it was their interpretation that the lower two sandstones are cut out by the Choctaw Fault as the formation is traced westward and that the highest sandstone is not present west of the central part of the coal field.

Branson's (1962, p. 439) assumption that the concept of the Atoka Formation was developed by Taff and Adams in the vicinity of the town of Atoka is clearly erroneous, and his selection of a type section for the formation in northwest Atoka County is not appropriate. Attempts to establish a type section for the formation in more highly fossiliferous marine sequences even farther north and west of Branson's type section (Strimple and Watkins, 1969, p. 147) would remove further Taff and Adams' concept of the Atoka Formation from its original area of definition.

## ATOKAN SERIES

The Atokan Series is defined much better paleontologically than the Atoka Formation is defined lithostratigraphically. Although for many years the base of the Atokan has been placed at the base of the Zone of *Profusulinella* (e.g., Moore and Thompson, 1949, fig. 2; Thompson, 1964, fig. 297; Douglas, 1977, text-fig. 5), it is clear from Spivey and Roberts (1946, table 1; = fig. 2 herein) that the base of the series originally was defined at the first appearance of fusulinids that are more advanced than *Millerella*. Numerous occurrences of *Pseudostaffella* and *Eoschubertella* below the first occurrence of *Profusulinella* represent the first appearance of fusulinids that are advanced over *Millerella*. It is at the first appearance of these genera that Spivey and Roberts defined the base of the Atokan Series. This occurrence corresponds to a position later included within the upper part of the Zone of *Millerella* (Thompson, 1948) and with the base of Zone 21 of the Mamet calcareous microfossil zonation (Mamet and Skipp, 1970, p. 337).

Confusion over the position of the paleontologic base of the Atokan probably stems from the work of Thompson (1948) and Moore and Thompson (1949). Thompson (1948, fig. 4) did not favor usage

| *Proposed Pennsylvanian Series* | *Beds Included in Series* | *Fusulinid Zones* |
|---|---|---|
| Virgil (Cisco) | Top of upper Crystal Falls limestone to base of Kisinger Channel sandstone | *Triticites*, various species<br>*Dunbarinella*<br>*Waeringella spiveyi* |
| Missouri (Canyon) | Top of Home Creek limestone to base of Lake Pinto sandstone | *Triticites*, various related species<br>*Triticites ohioensis*<br>*Triticites irregularis*<br>"*Wedekindellina*" *ultimata* |
| Des Moines (Strawn) | Top of Capps limestone to base of Caddo Pool limestone | *Fusulinella* (advanced type)<br>*Fusulina*<br>*Wedekindellina* |
| Atoka | Unnamed subsurface beds<br>Smithwick<br>Marble Falls | *Fusulinella* (restricted)<br>*Fusiella*<br>*Profusulinella?*<br>*Ozawainella*<br>*Pseudostaffella* |
| Morrow | Possibly not represented, unnamed if present | *Millerella;* with absence of all the more advanced forms previously listed |

Figure 2. Outline of proposed Pennsylvanian Series in central Texas (from Spivey and Roberts, 1946, table 1). Note paleontologic definition of Morrowan at bottom of right column and inclusion of *Pseudostaffella* in Atokan.

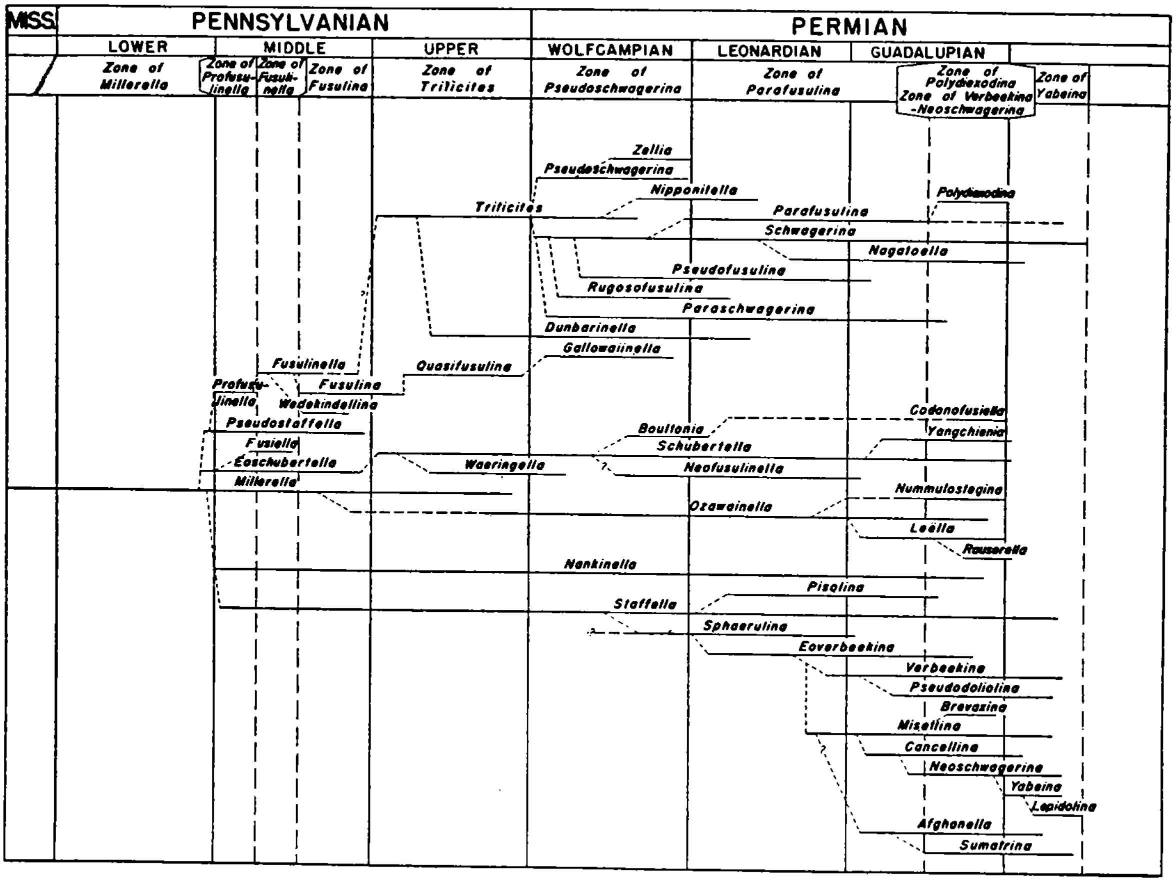


Figure 3. Phylogeny and stratigraphic zonation of Fusulinidae (from Thompson, 1948, fig. 4). Note range of *Eoschubertella* and *Pseudostaffella* below base of Middle Pennsylvanian.

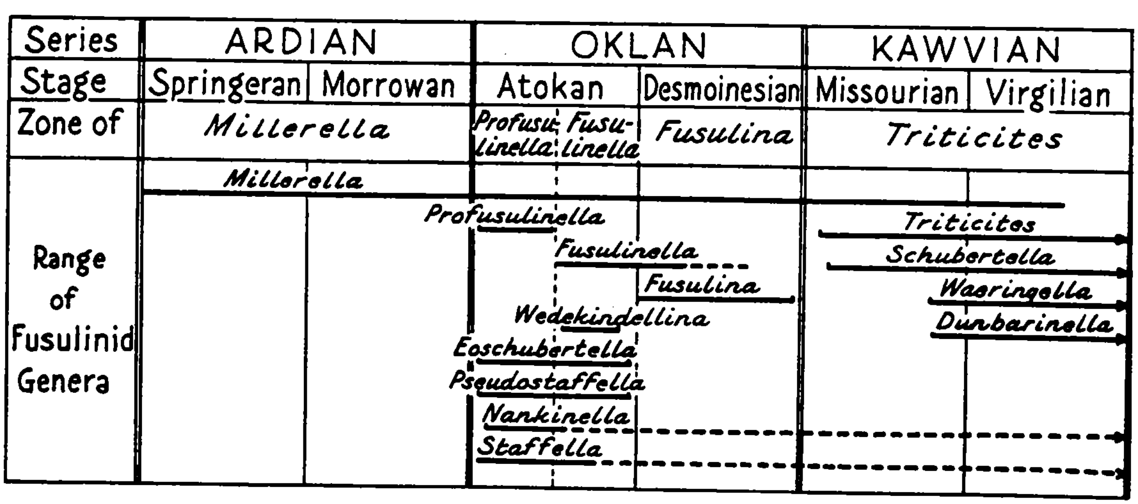


Figure 4. Fusulinid zones and range of fusulinid genera in Pennsylvanian rocks (from Moore and Thompson, 1949, fig. 2). Note that first appearances of *Pseudostaffella, Eoschubertella,* and *Profusulinella* are shown to be at same stratigraphic level, thus conflicting with Thompson (1948, fig. 4) as shown herein in figure 3.

of the term Atokan, since he had earlier proposed the term Derryan for the same time-stratigraphic interval. He drew the base of his Middle Pennsylvanian (this was the first application of the term Middle Pennsylvanian in North America) at the base of the Zone of *Profusulinella* and unequivocally placed the lower range of *Eoschubertella* and *Pseudostaffella* into the uppermost part of the Lower Pennsylvanian (fig. 3). Later, the lowest ranges of *Profusulinella, Eoschubertella,* and *Pseudostaffella* were shown to be coincident with the base of the Middle Pennsylvanian ( = Moore and Thompson's Oklan Series, 1949, fig. 2) and the base of the Atokan (fig. 4). Of course, this is inconsistent with Spivey and Roberts' original definition of the Atokan Series. Thus, the base of the Middle Pennsylvanian as originally used by Thompson for the North American Midcontinent did not correspond to the base of the Atokan Series as defined by Spivey and Roberts. Although the Atokan is well defined paleontologically, its stratigraphic definition is inadequate.

## OTHER PENNSYLVANIAN SUBDIVISIONS

Similar inadequacies can be illustrated for other Pennsylvanian subdivisions in the Midcontinent. A general summary of the status of each of the Midcontinent Pennsylvanian subdivisions is shown in figure 5.

### Morrowan

The Morrow Group was first named by Adams and Ulrich (1905, p. 4), and they designated the area around Hale Mountain, Washington County, Arkansas, as the type section. The Hale Mountain Morrowan exposure described by Giles and Brewster (1930) and regarded as the type section is now very poorly exposed. However, Henry (1973, p. 355–377) described a series of exposures on Hale Mountain that should now serve as the composite type section. Functionally, the Evansville Mountain exposure (Lane, 1967, p. 925–926; Lane and Straka, 1974, fig. 6 and Appendix) has served as the main reference section for the last 15 years. It was Harlton (1938) who first referred to the Morrow as a series. The difficulties with positioning the Morrowan–Atokan boundary are illustrated well by the papers of this symposium, not to mention the voluminous literature previously written on this subject. Thompson (1948, p. 23) noted the coincidence of his Zone of *Millerella* and the Morrowan. Spivey and Roberts (1946) further stabilized the upper limit of the Morrowan at the appearance of fusulinids more advanced than *Millerella.*

### Desmoinesian

Keyes (1893, p. 85) defined the Des Moinesian Stage. Considering the Desmoinesian, one finds that the type area along the Des Moines River in Iowa is partly inaccessible because of lake con-

| SERIES | MORROWAN | ATOKAN | DESMOINESIAN | MISSOURIAN | VIRGILIAN |
|---|---|---|---|---|---|
| AUTHORS | ADAMS & ULRICH, 1905 (MORROW GROUP) | TAFF & ADAMS, 1900, (ATOKA FM.) SPIVEY & ROBERTS, 1946 | KEYES, 1893 (DES MOINES GROUP) | KEYES, 1893 (MISSOURI GROUP) | MOORE, 1931 |
| TYPE SECTION DESIGNATED | YES | NO | NO | NO | NO |
| MAIN REF. SECTION | HALE MOUNTAIN (GILES & BREWSTER, 1930; HENRY, 1973) | NONE THAT ARE APPROPRIATE | NONE | NONE | NONE |
| CONDITION OF MAIN REF. SECTION | PARTIALLY COVERED | | | | |
| DOES TYPE OR REF. SECTION REPRESENT CURRENT CONCEPT OF THE SERIES? | NO | NO | NO | NO | NO |

Figure 5. Status of most commonly used Midcontinent Pennsylvanian series. Names of series are shown across top, and a list of major considerations concerning each series, along left column. These considerations consist of (1) author(s), (2) whether a type section was designated, (3) type or main reference section, (4) condition of these exposures, and (5) whether they represent current, most commonly employed concept of series. Please note that no type section or sections are proposed in this paper.

struction; even if it were accessible, as when defined by Keyes (1893), it would be a series of poor, discontinuous exposures that were deposited on a Late Mississippian (Meramecian?) erosion surface. No specific type section was designated by the original author. Moore and Thompson (1949, fig. 2) and subsequent authors have considered the Desmoinesian to be coincident with the Zone of *Fusulina*. It has been suggested (Moore and others, 1944) that the lower part of the Pennsylvanian sequence in the type Desmoinesian region in Iowa is Atokan. Fusulinids studied from outcrop and core collections in the Desmoinesian type area suggest that this may not be correct (Sanderson and West, 1981), but a recent reexamination of Kastler's (1958) conodont faunas indicates an Atokan age for the lower part of the Pennsylvanian sequence in the area. Furthermore, there is an apparent disconformity at the Desmoinesian–Missourian boundary. Thus, the Desmoinesian of Iowa is hardly a sequence appropriate as a type area.

### Missourian

Keyes (1893) also recognized and defined the Missouri Stage, based on exposures along the Missouri River in Iowa and in northwestern Missouri. No specific type section was designated by the original author. Again, the type area displays a stratigraphic sequence bounded above and below by apparent disconformities. It is interesting to note that Keyes (1893, p. 85) proposed the terms Missouri and Des Moines as stages. Subsequent work, primarily under the influence of Moore, elevated these to series rank (Moore and others, 1944) and later back to stage rank (Moore and Thompson, 1949). Moore and Thompson (1949, fig. 2) recognized the base of the Missourian at the base of the Zone of *Triticites,* and Spivey and Roberts (1946, table 1) included in it such species as *Triticites ohioensis, Triticites irregularis* and "*Wedekindellina*" (=*Eowaeringella* of modern literature) *ultimata.*

### Virgilian

Unlike the Missourian, the Virgilian was proposed on a correlation chart (Moore, 1931) and later was more clearly defined (Moore, 1932). It is named for a town in eastern Greenwood County, Kansas, an area where only the middle part (Shawnee Group) of the Virgil is exposed (Jewett, 1964). There are no Missourian rocks mapped in Greenwood County, and the Permian occurs only in the northwestern corner of the county (Jewett, 1964). Thus the necessary continuity with underlying and overlying strata is lacking in the Virgilian type area. Spivey and Roberts (1946, table 1) recognized the Virgilian at occurrences of *Dunbarinella, Waeringella spiveyi,* and various species of *Triticites*. According to G. A. Sanderson (personal communication, May 25, 1982), the appearance of such species as *Triticites secalicus* Say and *Triticites oryziformis* Newell is very important in the recognition of the base of the Virgilian in terms of a contemporary understanding of the fusulinid succession.

## SUGGESTIONS

All Midcontinent subdivisions of the Pennsylvanian share the same problem with the Atokan—that is, they have been defined paleontologically but lack type sections that reflect these paleontologic definitions.

For this reason, we advocate abandonment of the Morrowan through Virgilian as series of the Pennsylvanian Subsystem in favor of three series simply termed Lower, Middle, and Upper Pennsylvanian. The lower, middle, and upper subdivisions would be simpler to use, and they would cut through the maze of regional Pennsylvanian serial nomenclature. Alternatively, Morrowan through Virgilian could be maintained as stage names, fitting better their original definitions and recognizable as subdivisions of a Lower, Middle, and Upper Series of the Pennsylvanian in the same style of Moore and Thompson's (1949) proposed classification of the Pennsylvanian. Indeed, this is the way the Kansas Geological Survey treats the Pennsylvanian (Jewett, 1964; Zeller, 1968).

## MISSISSIPPIAN SUBDIVISIONS

The Mississippian Subsystem suffers from similar problems of definition as the Pennsylvanian with respect to definition and application of its subdivisions.

Currently, there are two competing approaches to subdivision of the Mississippian. The one most widely used, shown on the left of figure 6, is followed by the U.S. Geological Survey and most state geological surveys. It consists of Kinderhookian, Osagean, Meramecian, and Chesterian. The U.S. Geological Survey subdivides the Mississippian into Lower and Upper series and recognizes the latter four subdivisions as provincial series. The second usage shown on the right of Figure 6 consists of the Kinderhookian, Valmeyeran, and Chesterian series and is employed by the Illinois and Indiana geological surveys.

A general summary of the status of each of the Mississippian series is shown in figure 7.

### Kinderhookian

The Kinderhookian was described as a group by Meek and Worthen (1861). Although no type section was designated, it has been assumed that

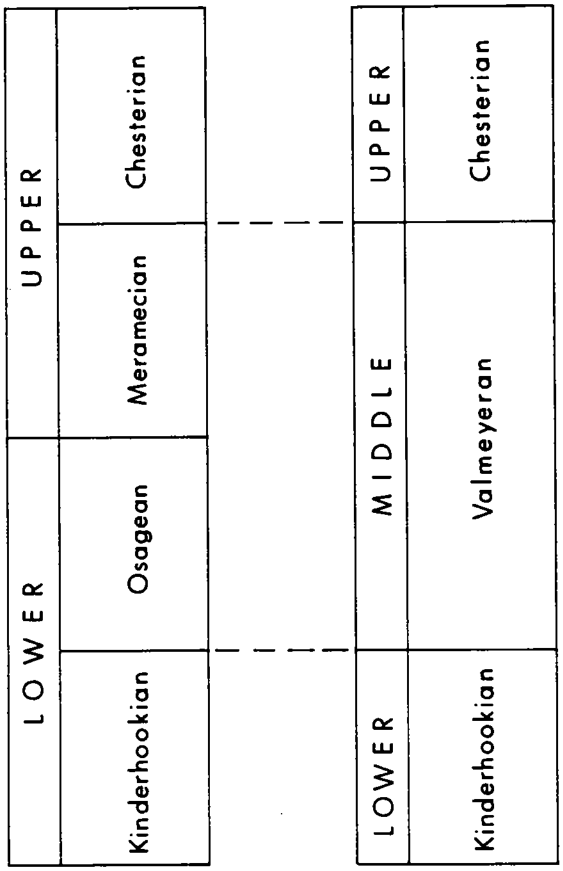


Figure 6. Interrelationship of dual serial classification of the Mississippian.

exposures around the town of Kinderhook, Illinois, constitute the type area. However, some workers feel that the section at Crapo Park in Burlington, Iowa, as designated by Keyes (1941) represents the type. We do not agree with this latter contention, which complicates definition of the series.

The McCraney section in the vicinity of the town of Kinderhook is now the main reference section for the Kinderhookian (Collinson, 1961, p. 51). It does not represent completely the current application of the Kinderhookian, because much of the upper half of what is considered Kinderhookian is not developed there. In fact, beds generally regarded as being of latest Kinderhookian age (=upper part of the *isosticha*–Upper *crenulata* Zone of Sandberg and others, 1978) are not even developed in the Mississippi Valley. Thus the term Kinderhookian is very poorly defined in its type area.

## Osagean

The term Osage group was first proposed in a chart published by H. S. Williams (1891, p. 172). No type section or type area was designated, but it has been assumed that the name derives from the Osage River in St. Clair County, Missouri, since he mentioned outcrops along the river in his study. Kaiser (1950) suggested that the best exposure in the area was the Bullard-Hunt Quarry, which has subsequently become the main reference section for the Osagean. Lane and Brenckle (1981) recently restudied this section. Unfortunately, the quarry is partially flooded by the Harry S. Truman Reservoir. In addition, the sequence is largely dolomitized, making fossil recovery and identification difficult. The section exposed in the area consists of only the Burlington Formation. The Keokuk Limestone, the other unit originally defined as comprising the Osagean, is not present along the Osage River. Currently, general usage of the term Osagean, irrespective of the nature of its main reference section, includes everything from the base of the Meppen or Fern Glen Limestone in the Mississippi Valley to the top of the Keokuk Limestone. Thus, the Osagean in its type area represents only a small part of the current concept of the series.

## Meramecian

The Meramec Group was defined by Ulrich (*in* Buckley and Buehler, 1904) for the St. Louis and Spergen (Salem) Limestones and the Warsaw Shale exposed at Meramec Highlands resort and quarry, southwest of St. Louis, Missouri (see Lane and Brenckle, 1977, fig. 8, for a recent section description). The original definition, and indeed Ulrich's type section, does not include the Ste. Genevieve Limestone. The lower limit of the series at the type section displays a gradational contact between the Keokuk Limestone (Osagean) and the Warsaw Shale. At this locality the upper part of the St. Louis Limestone has been removed by recent erosion. Weller (1920) included the Ste. Genevieve Limestone within the Meramecian, and this definition was adopted later by the U.S. Geological Survey (Wilmarth, 1938). Presently, the Meramecian includes all strata from the base of the Warsaw Shale to the top of the Ste. Genevieve Limestone. Therefore, the type section of the Meramecian does not completely represent the current usage of the series term.

## Valmeyeran

Moore (1933, p. 262–264) named the Valmeyeran Series to include the Osage and Meramec Groups (fig. 6). The name derives from Valmeyer, Illinois, but no type section was designated. The Dennis Hollow exposure just outside Valmeyer has become the major reference section (Collinson and others, 1981, p. 34). Exposures are fair to poor, being heavily vegetated. The basal 6 inches of the Fern Glen at this locality bears a Chouteau conodont fauna (Lane, 1978, p. 169), and the top of the

| SERIES | KINDERHOOKIAN | OSAGEAN | MERAMECIAN | VALMEYERAN | CHESTERIAN |
|---|---|---|---|---|---|
| AUTHOR(S) | MEEK & WORTHEN, 1861; WORTHEN, 1866 | WILLIAMS, 1891 | ULRICH, 1904 | MOORE, 1933 | WORTHEN, 1860 |
| TYPE SECT. DESIGNATED? | NO | NO | YES | NO | YES |
| MAIN REF. SECTION | McCRANEY NORTH AND McCRANEY SOUTH (COLLINSON et al, 1979) | ABANDONED, HUNT-BULLARD QUARRY, ST. CLAIR CO., MO. (KAISER, 1950) | MERAMEC RIVER MARSHALL ROAD MERAMEC HLDS. QUARRY, ST. LOUIS CO., MO. LANE & BRENCKLE, 1977 | DENNIS HOLLOW, WELLER, 1939 | MISSISSIPPI RIVER BLUFF, BELOW PRISON AT CHESTER, ILL. REXROAD, 1957 |
| CONDITION OF MAIN REF. SECTION | POOR | INCOMPLETE | FAIR, NEW ROADCUTS NEARBY ARE EXCELLENT | FAIR TO POOR | FAIR |
| DOES TYPE OR REF. SECTION REPRESENT CURRENT CONCEPT OF THE SERIES? | NO | NO | NO | NO | NO |

Figure 7. Status of most commonly used Mississippian series. Names of series are shown across top, and a list of major considerations concerning each of series along left column. These considerations consist of following: (1) author(s), (2) whether a type section was designated, (3) type or major reference section, (4) condition of these exposures, and (5) whether they represent current, most commonly employed concept of series. Please note that no type section or sections are proposed in this paper.

section ends within the Salem Limestone. Excellent but largely inaccessible exposures of the Salem and Ste. Genevieve are available nearby in the Mississippi River bluffs. Thus, the reference section for the Valmeyeran Series, originally defined as being composed of the Osage and Meramec Groups, does not completely represent this concept.

### Chesterian

The name Chester was applied originally by Worthen (1860) as the "upper *Archimedes* or Chester Limestone"; he soon afterward (1866) began referring to this rock sequence as a "group." The section in the bluffs directly below the state prison near the town of Chester, Illinois, is regarded as the type section, and Chesterian strata exposed in the vicinity of Chester include all beds from the base of the Aux Vases Sandstone to the top of the Kinkaid Limestone. However, the Chesterian today is regarded as representing everything from the base of the Aux Vases Sandstone to the top of the Grove Church Shale (Swann, 1963). The Grove Church Shale is not developed at the type section of the Chesterian and contains conodonts that are younger than any found in the Kinkaid. Thus, the type section of the series is not completely representative of the currently accepted concept of the series.

## SUMMARY

To summarize, serial nomenclature of the North American Mississippian and Pennsylvanian is very poorly defined. Part of the problem is usage of geographically derived names, such as Atoka. This approach has led to a proliferation of provincial names that obfuscate correlations of rock successions. These provincial names are maintained and defended by local geologists in the face of convincing scientific proof of their inadequacy. For this reason, we advocate abandonment of geographically derived serial nomenclature for both the Mississippian and Pennsylvanian in favor of the simpler and more objective subdivisions Lower, Middle, and Upper. If precisely defined by boundary stratotypes, such serial subdivisions would transcend the complex regional Carboniferous nomenclature. In the case of the Pennsylvanian, recognition of the Morrowan through Virgilian as stages would be appropriate and consistent with our suggestion.

## REFERENCES CITED


**Adams, G. I.**, and **Ulrich, E. O.**, 1905, Description of the Fayetteville quadrangle: U.S. Geological Survey Geologic Atlas, Folio 119, 6 p.

**Branson, C. C.**, 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C., editor, Pennsylvanian System in the United States, a symposium: American Association of Petroleum Geologists, p. 431–460.

**Buckley, E. R.**, and **Buehler, H. A.**, 1904, The quarrying industry of Missouri: Missouri Bureau of Geology and Mines, v. 2, 2d Series, 371 p.

**Collinson, C. W.**, 1961, Second day of field conference, *in* Koenig, J. W., Martin, J. A., and Collinson, C. W., Northeastern Missouri and west central Illinois: Kansas Geological Society Twenty-Sixth Annual Field Conference, 168 p.

**Collinson, C. W.**, **Baxter, J. W.**, **Norby, R. D.**, **Lane, H. R.**, and **Brenckle, P. D.** [*sic*], 1981, Mississippian stratotypes: International Union of Geological Sciences, Subcommission on Carboniferous Stratigraphy, and Illinois Geological Survey, Field Guidebook, 56 p.

**Collinson, C. W.**, **Norby, R. D.**, **Thompson, T. L.**, and **Baxter, J. W.**, 1979, Stratigraphy of the Mississippian stratotype—Upper Mississippi Valley, U.S.A.: Illinois Geological Survey, Field Trip 8, Ninth International Congress of Carboniferous Stratigraphy and Geology, 108 p.

**Douglass, R. C.**, 1977, The development of fusulinid biostratigraphy, *in* Kauffman, E. G., and Hazel, J. E., editors, Concepts and methods of biostratigraphy: Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, p. 463–481.

**Giles, A. W.**, and **Brewster, E. B.**, 1930, Hale Mountain section in northwest Arkansas: American Association of Petroleum Geologists Bulletin, v. 14, p. 121–138.

**Harlton, B. H.**, 1938, Stratigraphy of the Bendian of the Oklahoma salient of the Ouachita Mountains: American Association of Petroleum Geologists Bulletin, v. 22, p. 852–914.

**Henry, T. W.**, 1973, Brachiopod biostratigraphy and faunas of the Morrow Series (Lower Pennsylvanian) of northwestern Arkansas and northeastern Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 515 p.

**Jewett, J. M.**, 1964, Geologic map of Kansas: Kansas Geological Survey, scale 1:500,000.

**Kaiser, C. P.**, 1950, Stratigraphy of Lower Mississippian rocks in southwestern Missouri: American Association of Petroleum Geologists Bulletin, v. 34, p. 2133–2175.

**Kastler, N. B.**, 1958, Conodonts from the Middle Pennsylvanian of southeastern Iowa: University of Iowa unpublished M.S. thesis.

**Keyes, C. R.**, 1893, The geological formations of Iowa: Iowa Geological Survey Annual Report for 1892, v. 1, p. 13–161.

———1941, Type section of Kinderhook at Burlington, Iowa: Pan-American Geologist, v. 76, p. 233–236.

**Lane, H. R.**, 1967, Uppermost Mississippian and Lower Pennsylvanian conodonts from the type Morrowan region, Arkansas: Journal of Paleontology, v. 41, p. 920–942.

———1978, The Burlington Shelf (Mississippian, north-central United States): Geologica et Palaeontologica, v. 12, p. 165–176.

**Lane, H. R.**, and **Brenckle, P. L.**, 1977, The type section of the Meramecian Series: Guidebook for Field Trip, North-Central Section, Geological Society of America, Carbondale, Illinois, 1977, p. 1–34.

———1981, The type Osage, *in* Collinson, C. W., Baxter, J. W., Norby, R. D., Lane, H. R., and Brenckle, P. D. [*sic*], Mississippian stratotypes: International Union of Geological Sciences, Subcommission on Carboniferous Stratigraphy, and Illinois Geological Survey, Field Guidebook, p. 1–12.

**Lane, H. R.**, and **Straka, J. J., II**, 1974, Late Mississippian and Early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

**Mamet, B. L.**, and **Skipp, B. A.**, 1970, Preliminary foraminiferal correlations of early Carboniferous strata in the North American Cordillera, *in* Colloque sur la stratigraphie du Carbonifère: Congrès et Colloques de l'Université de Liège, v. 55, pp. 327–348.

**Meek, F. B.**, and **Worthen, A. H.**, 1861, Note to the paper of Messrs. Meek and Worthen on the age of the Goniatite limestone: American Journal of Science, 2d Series, v. 32, p. 288.

**Moore, R. C.**, 1931, Correlation chart: Kansas Geological Society, 5th Annual Field Conference Guidebook.

———1932, Proposed new type section of the Pennsylvanian system: Geological Society of America Bulletin, v. 43, p. 279–280.

———1933, Historical geology: McGraw-Hill, New York, 673 p.

**Moore, R. C.**, and others, 1944, Correlation of Pennsylvanian formations of North America: Geological Society of America Bulletin, v. 55, p. 657–706.

**Moore, R. C.**, and **Thompson, M. L.**, 1949, Main divisions of Pennsylvanian period and system: American Association of Petroleum Geologists Bulletin, v. 33, p. 275–302.

**Rexroad, C. B.**, 1957, Conodonts from the Chester series in the type area of southwestern Illinois: Illinois Geological Survey Report of Investigations 199, 43 p.

**Sandberg, C. A.**, **Ziegler, W.**, **Leuteritz, K.**, and **Brill, S. M.**, 1978, Phylogeny, speciation and zonation of *Siphonodella* (Conodonta, Upper Devonian and Lower Carboniferous): Newsletters on Stratigraphy, v. 7, p. 102–120.

**Sanderson, G. A.**, and **West, R. R.**, 1981, Fusulinids from the Desmoinesian type area [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 545.

**Spivey, R. C.**, and **Roberts, T. G.**, 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Strimple, H. L.**, and **Watkins, W. T.**, 1969, Carboniferous crinoids of Texas with stratigraphic implications: Palaeontographica Americana, v. 6, p. 141–275.

**Swann, D. H.**, 1963, Classification of Genevievian and Chesterian (Late Mississippian) rocks of Illinois: Illinois Geological Survey Report of Investigations 216, 91 p.

**Taff, J. A.**, and **Adams, G. I.**, 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 257–311.

**Thompson, M. L.**, 1948, Studies of American fusulinids: University of Kansas Paleontological Contributions, Protozoa, Article 1, 184 p.

———1964, Fusulinacea, *in* Loeblich, A. R., Jr., and Tappan, Helen, Sarcodina, chiefly "Thecamoebians" and Foraminiferida, *v. 1 of* Protista 2, *part C of* Moore, R. C., editor, Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press, p. C358–C436.

**Weller, J. M.,** 1939, Mississippian system, *in* Thirteenth annual field conference guidebook, southwestern Illinois and southeastern Missouri: Kansas Geological Society, p. 131–137.

**Weller, Stuart,** 1920, The geology of Hardin County and the adjoining part of Pope County [Illinois]: Illinois Geological Survey Bulletin 41, 416 p.

**Williams, H. S.,** 1891, Correlation papers, Devonian and Carboniferous: U.S. Geological Survey Bulletin 80, p. 1–279.

**Wilmarth, M. G.,** 1938, Lexicon of geologic names of the United States (including Alaska): U.S. Geological Survey Bulletin 896, 2396 p.

**Worthen, A. H.,** 1860, Remarks on the discovery of a terrestrial flora in the Mountain limestone of Illinois [abstract]: American Association for the Advancement of Science Proceedings, v. 13, p. 312–313.

———1866, Geology: Illinois Geological Survey, v. 1, 504 p.

**Zeller, D. E.,** editor, 1968, The stratigraphic succession in Kansas: Kansas Geological Survey Bulletin 189, 81 p.

*Oklahoma Geological Survey Bulletin 136, 1984*

# ATOKAN SERIES CONCEPTS WITH SPECIAL REFERENCE TO THE ILLINOIS BASIN AND IOWA

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**Abstract**—Despite gross ambiguities affecting determination of both lower and upper boundaries, the Atokan Series has been adopted for use in all 15 of the regional correlation charts that are being produced for the United States through the project called "Correlation of Stratigraphic Units of North America" (COSUNA). Accepting the need for such standardization, Middle Carboniferous stratigraphers should assign to a necessarily patched-up Atokan Series only those rocks that are not included in the more consistently definable Morrowan and Desmoinesian Series. At the same time, they should consider the correlative intent of the COSUNA global chronostratigraphic scale.

To achieve this dual objective, they should remove the authority for series boundaries from presumptive or real ranges of fusulinids and return it to type sections of rocks. Among the problems is belated recognition of the genus *Profusulinella* in rocks of possible Morrowan age. Also, many persons have overlooked the fact that part of the pre-*Fusulina* range of *Fusulinella* lies within type Desmoinesian rocks of Iowa.

In the Illinois Basin, rocks assignable to a consistently defined Atokan Series consist of shale and sandstone with thin coals and scattered thin lenses of limestone. These rocks are sparsely fossiliferous and range from about 15 m to as much as 100 m in thickness. This interval includes the lowest known stratigraphic level of *Fusulinella* but excludes higher rocks containing *Fusulinella iowaensis*. *Profusulinella* is unknown in these Atokan rocks as so defined.

## INTRODUCTION

The title of the symposium of which this paper is a part, "The Atokan Series and Its Boundaries," poses an ambiguity in the tacit assumption that a properly defined Atokan Series, complete with rock-defined top and bottom, already exists somewhere in the Midcontinent type area. One proposition of this paper is that such an entity does not exist, and one purpose of the symposium should be to devise a consistent concept of an Atokan Series that fits harmoniously with a subjacent Morrowan Series and a superjacent Desmoinesian Series. To realize this objective, ambiguity resulting from overlap in time values represented by the geographically separated type rocks of these three series must be eliminated.

Given the convictions noted above, how can an Atokan Series in the Illinois Basin and Iowa be adequately described? The plan of this paper is to present a series of propositions, which, if true or if held temporarily for testing, form a framework from which to proceed. At the same time, a scheme for series boundaries is proposed that recognizes new biozonal evidence as well as old, that returns authority to type sections, and that could end the ambiguity that presently attaches to traditional chronostratigraphic schemes for Middle Carboniferous rocks in North America.

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## PROPOSITIONS

The proposition stated above claims that no properly defined Atokan Series exists, that type rocks of the Atoka Formation in Oklahoma overlap in age definable upper Morrowan rocks and definable lower Desmoinesian rocks, and that the term Atokan Series as applied by most stratigraphers results in ambiguity. Such a proposition draws on related propositions:

1. Because type rocks of the Atoka Formation[2] of southeastern Oklahoma have not yielded the kinds of fossils commonly used for Pennsylvanian correlation, type sections secondarily defined as a basis for an Atokan Series (as summarized and extended by Sutherland, Archinal, and Grubbs, 1982, p. 7) make up a devised arrangement that has value only as judged in relation to the efficacy of the subjacent and superjacent series. Therefore, no automatically compelling reason exists to accord an Atokan definition priority over Morrowan and Desmoinesian definitions or to adopt a recent proposal to remove the Trace Creek Shale from the type Morrowan section in Arkansas and assign it to a thus newly incremented Atokan Series (see discussion on "Atokan Series—A Lower Boundary").

2. As commonly applied, the standard fusulinid zones are partly in error in relation to an Atokan Series and to the subjacent and superjacent series. The Zone of *Profusulinella* in North America may include rocks of Morrowan age, and the Zone of *Fusulinella,* beginning in post-Morrowan rocks, extends upward into type Desmoinesian rocks, whose base, therefore, should not be defined as the base of the Zone of *Fusulina.*

3. Misapplication of these zones has led to miscorrelations of rocks as distant as the far-western United States and Eurasia.

4. North American stratigraphers should subscribe to the Pennsylvanian chronostratigraphic scheme that has been adopted by the COSUNA[3] project.

## ATOKAN ROCKS IN THE ILLINOIS BASIN AND PART OF THE WESTERN INTERIOR BASIN

### Illinois Basin

The Atokan Series in the Illinois Basin consists of about 15 to 100 m of dominantly terrigenous clastic sediments that have been assigned to the Brazil Formation (Indiana), parts of the Abbott and Spoon Formations (Illinois), and part of the Tradewater Formation (Kentucky) (fig. 1). In parts of Illinois and in easternmost Iowa, the Atokan Series is absent by nondeposition or by pre-Desmoinesian erosion, or both.

The clastic sediments constitute shale, clay, mudstone, siltstone, sandstone, and mixtures thereof, so that the whole is best characterized as mixed fine and coarse clastics. The more widespread concentrations of single clastic lithologies, especially the sandstones, have been given member and bed names (fig. 2). Lateral discontinuity characterizes nearly all named members.

A small percentage of the Atokan rocks consists of thin (0.5± m) coals and marine limestones. Although discontinuous, they tend to be more persistent than the shale and sandstone bodies and therefore are key beds for correlative purposes. Some of the coals have been given member rank (figs. 1, 2), and they form the primary basis for defining the tops and bottoms of formations and groups. For example, in Indiana the Lower Block Coal Member defines the bottom of the Brazil Formation, and the Minshall Coal Member (Rock Island Coal Member in Illinois) defines the top. As the Atokan Series is defined here, moreover, these members and their equivalents in adjacent states form the bottom and top of the series in the Illinois Basin.

Normal-marine faunas are rare in these Atokan rocks. A notable exception is the occurrence of a species of *Fusulinella* in a limestone between the Lower and Upper Block Coal Members (fig. 2) in Clay County, Indiana (identified by M. L. Thompson; reported by Shaver and Smith, 1974, p. 17). The presence of the genus is compatible with an Atokan age assignment in Midcontinent terms. The limestone in which it occurs is only several meters stratigraphically above the highest known occurrence of *Profusulinella* and is a greater distance below the lowest occurrence of *Fusulinella iowaensis.*

This discussion points up the fact that these Atokan rocks lack most of the marine fossils that are normally used for interregional Carboniferous correlation. Plant fossils, including spores, however, are common in Atokan rocks. In Illinois (Abbott Formation), they have had some use in interregional correlation (Hopkins and Simon, 1975, p. 181).

### Pre-Atokan Ostracods and Fusulinids

Stratigraphically below the occurrence of *Fusulinella* sp. recorded above, along much of the eastern basin margin, and in upper Morrowan rocks as defined here, the genus *Profusulinella* occurs in fair abundance in both the Fulda and Ferdinand Beds of the Lead Creek Limestone Member of the Mansfield Formation in Indiana (Thompson and Shaver, 1964; fig. 2 here). In Kentucky, this occurrence is in essentially equivalent beds of the Lead Creek in the Tradewater Formation (Thompson and Shaver, 1964; Thompson, Shaver, and Riggs, 1959; fig. 1 here).

*Profusulinella* is associated in these occurrences with an abundant ostracod fauna in the Zone of *Amphissites rothi* as described by Shaver and

[2]Apparently, agreement cannot be reached even on what constitutes the original type area of the Atoka Formation. See the discussion under the heading "Question of a Type for an Atokan Series."

[3]COSUNA: "Correlation of Stratigraphic Units of North America," a project managed by the American Association of Petroleum Geologists, financed especially by the U.S. Geological Survey.

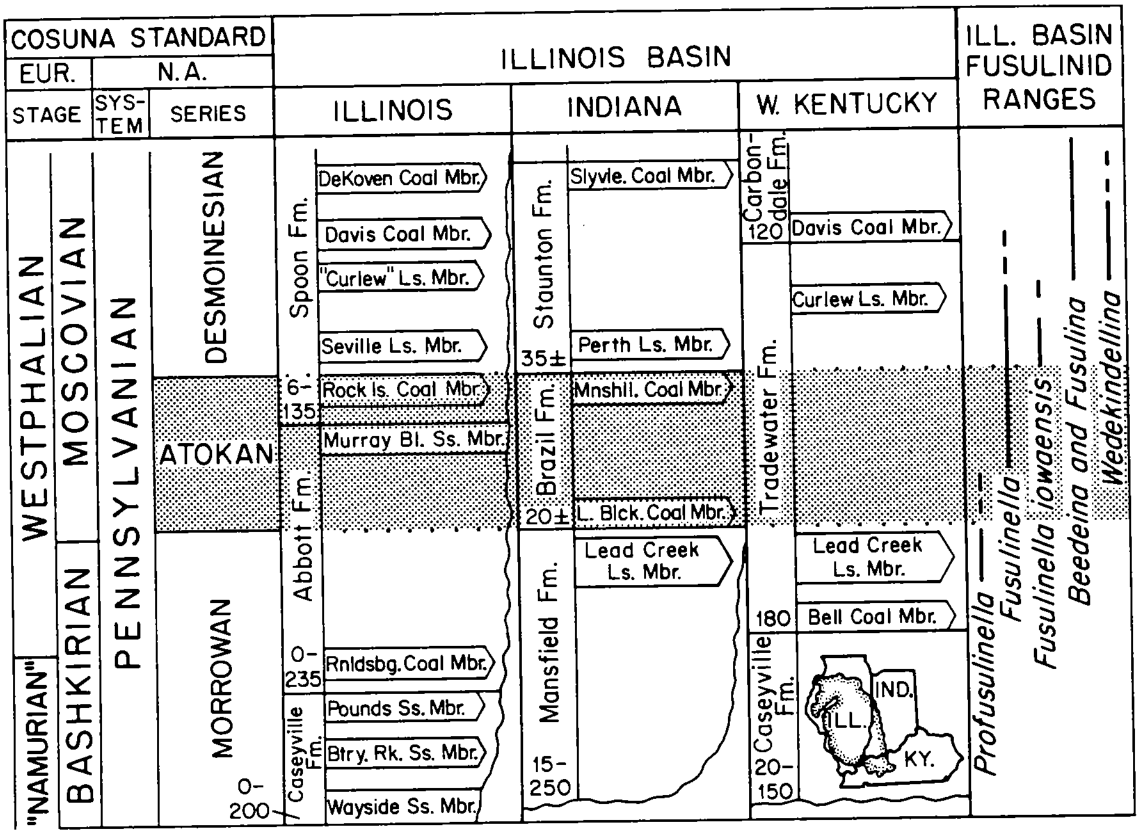


Figure 1. Correlation chart showing stratigraphic nomenclature and use of key members to define formation boundaries for Atokan and associated rocks of Illinois Basin. Thicknesses are stated in meters. Abbreviation: Bl., Bluff; other abbreviated words are spelled out in figure 2. From Shaver and others (in preparation).

Smith (1974; fig. 3 here). Much of this fauna also has been identified by others as wholly or partly Morrowan in age: Cooper (1946) for the Fulda of the Illinois Basin in southern Indiana, Bradfield (1935) for the Otterville and Joliff Members and associated rocks of the Golf Course Formation in the Ardmore Basin of southern Oklahoma; Harlton (1929, 1933) for parts of the Wapanucka Limestone and Johns Valley Shale in the frontal and central Ouachitas of Oklahoma, and Knox (1975) for rocks in the type Morrowan area of northwestern Arkansas and adjacent Oklahoma. Very few elements of this fauna are known anywhere in the Atoka Formation or in rocks known to be post-Morrowan in age. Neither these ostracods nor *Profusulinella,* however, have a precisely determined upper limit in the Illinois Basin because of the unfavorable environmental conditions represented by the critical section of rocks.

## Post-Atokan Ostracods and Fusulinids

In the first marine interval above Atokan rocks in Indiana, Illinois, and Iowa and in some higher marine zones, *Fusulinella iowaensis* is found together with unidentified species of *Fusulinella* (figs. 1, 2, 4). The fusulinid-bearing rocks are the Perth Limestone Member (Staunton Formation) in Indiana, the Seville Limestone Member (Spoon Formation) in Illinois, and Seville-equivalent rocks in Iowa, all of which lie close above Atokan rocks, and still higher members in Kentucky, Indiana, and Illinois. Associated with these fusulinids are abundant and distinctive ostracods of the zone characterized by *Amphissites centronotus* (Shaver and Smith, 1974; fig. 3 here). These rocks and faunas, which include those of the lower type Desmoinesian section itself, obviously should be assigned to the Desmoinesian Series as this series was originally understood, and still is, in Iowa and in the Illinois Basin proper. Most Midcontinent stratigraphers, however, would assign these *Fusulinella*-bearing rocks to their Atokan Series.

The next younger fusulinid zone, that of *Fusulina* and *Wedekindellina,* is found in the Holland and Silverwood Limestone Members and unnamed limestones of the Staunton Formation in Indiana, in the "Curlew" Limestone Member in Illinois, and in equivalent members in Kentucky and Iowa (Shaver and Smith, 1974; Hopkins and

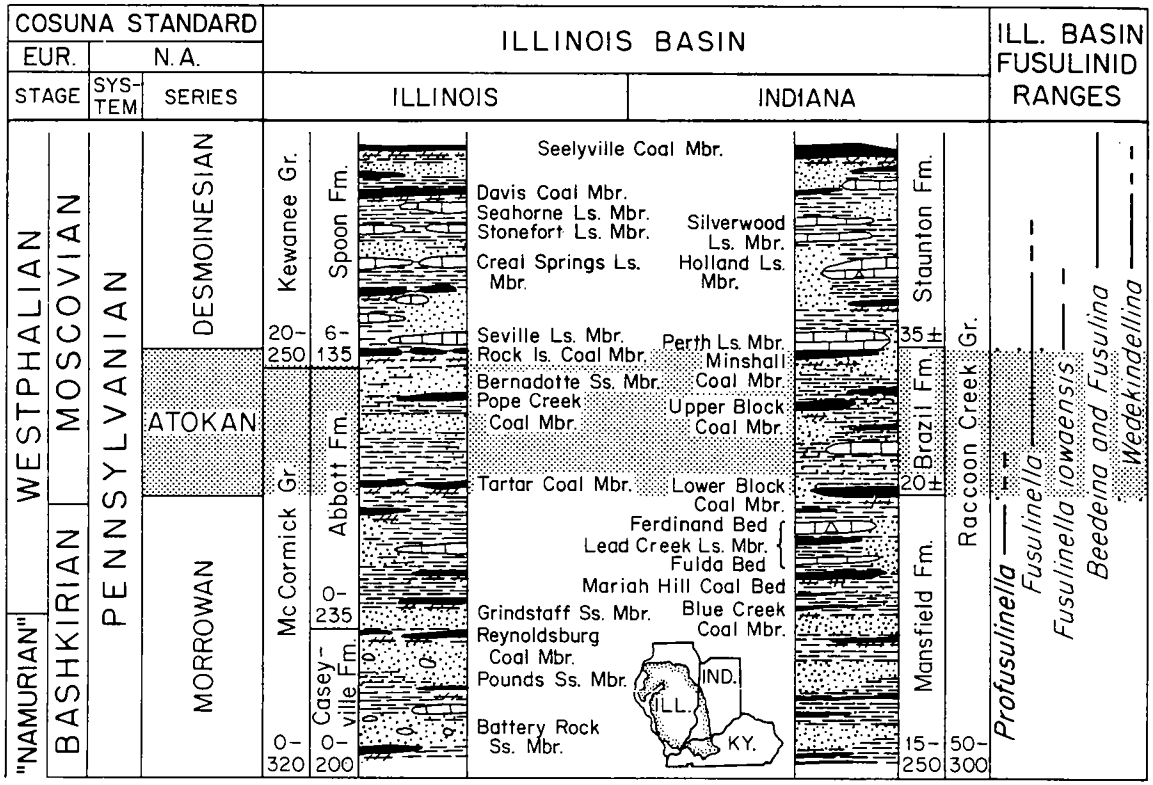


Figure 2. Correlation chart showing characteristic Atokan and associated lithologies and thicknesses (meters) and selected member and bed names in Illinois Basin. Not drawn to scale—horizontal lines are time synchronous. Mostly from Hopkins and Simon (1975), Shaver and others (1970), and selected coal maps of the Indiana Geological Survey.

Simon, 1975; Douglass, 1979; figs. 1, 2, and 4, here). It is the bottom of the Zone of *Fusulina* that most Midcontinent stratigraphers recognize as the bottom of their Desmoinesian Series, but this horizon is *within* the Desmoinesian Series that is recognized by most Midwestern stratigraphers.

## Conodonts

Conodonts have not been described from the Atokan rocks discussed here, but the group designated as *Neognathodus bassleri symmetricus* and *N. b. bassleri* has been identified by Taylor (1971, 1974) in both limestone beds of the Lead Creek Limestone Member (Mansfield Formation) and in the Perth Limestone Member (Staunton Formation) in Indiana, thus bracketing Atokan rocks (fig. 2). The named conodont species, as interpreted especially by Lane (1967) and Lane and Straka (1974), were considered to be Morrowan indices ranging from lower to upper type Morrowan rocks and found widely in other Morrowan rocks.

Several other conodont paleontologists have been unable to distinguish between *N. b. bassleri* and *N. b. symmetricus*, so that the precise age indications once attached to these subspecies are now questionable. Further, Taylor (1971, 1974) did not distinguish between the Lead Creek and Perth specimens but assigned a Morrowan age to both occurrences. Possibly the younger (Perth) occurrence belongs to Merrill and King's (1971) *Neognathodus* new sp. A or Lane and Straka's (1974) *N. colombiensis*, which would be compatible with at least a post-Morrowan age for the Perth.

The significance of the Lead Creek conodonts is yet to be fully assessed, but these possible Morrowan indicators in association with *Profusulinella* in the Illinois Basin have confirmed the need to reevaluate the Zone of *Profusulinella*. This association parallels that found in lower rocks of the so-called "Derryan Series" of the far-western United States (fig. 3) (see discussion farther on).

## Iowa

The Iowa part of the Western Interior Basin includes the type area of the Desmoinesian Series. Along the Des Moines River in the southeastern part of the state the lower part of the Cherokee Group rests on Mississippian rocks (fig. 4). In the Illinois Basin portion of east-central Iowa, Cherokee-equivalent rocks (Spoon Formation) rest un-

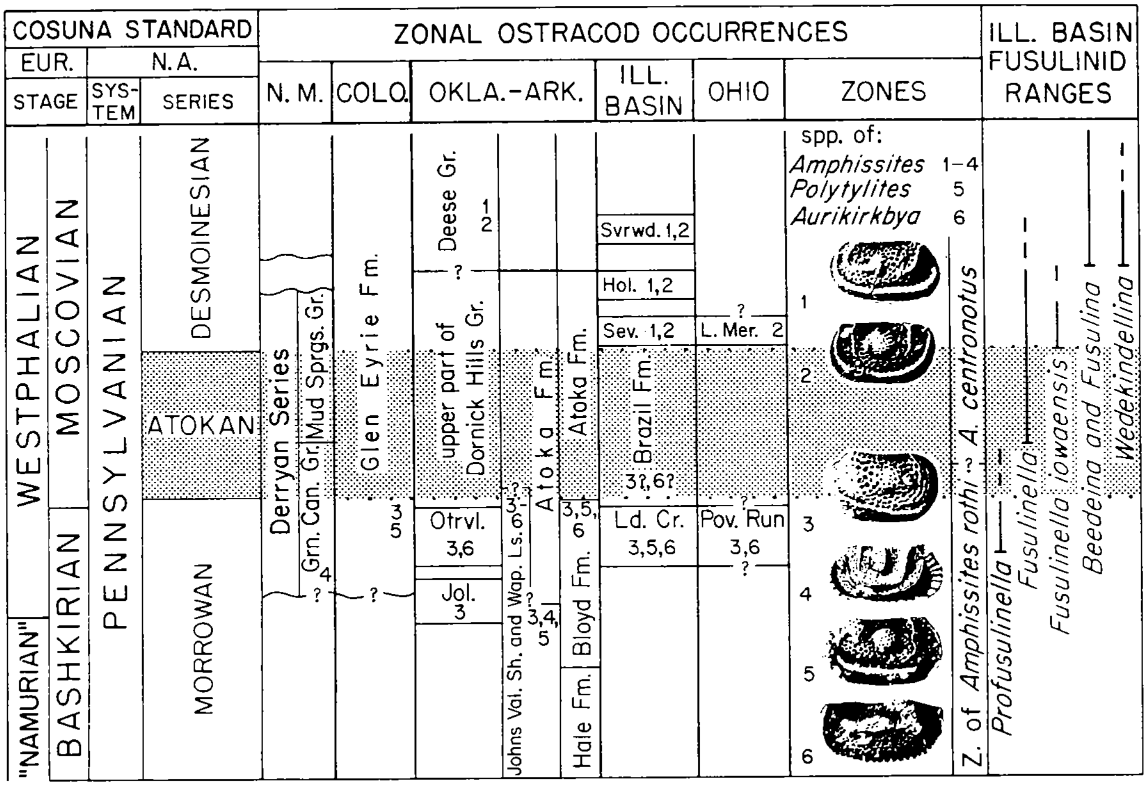


Figure 3. Chart showing approximate interregional correlations of selected rock units made on basis of two ostracod zones, the occurrences of individual species of which are noted by numbers. The several columns are both composited and incomplete as designated by states. For example, left side of Oklahoma–Arkansas column is for Ardmore Basin, middle part is composited for other parts of Oklahoma, and right side is for Morrowan type area. Abbreviations: Otrvl. and Jol., Otterville and Jolliff Members of Golf Course Formation; Slvrwd. and Hol., Silverwood and Holland Limestone Members of Staunton Formation; Sev., Seville Limestone Member of Spoon Formation; Ld. Cr., Lead Creek Limestone Member of Mansfield and Tradewater Formations; and L. Mer. and Pov. Run, Lower Mercer and Poverty Run Limestone Members of Pottsville Formation. From many sources, most being listed by Shaver and Smith (1974, includes species identities) and Knox (1975). In column headed "Zones," depicted species are separated by zones but are not intended to be shown in stratigraphic order in those zones. The New Mexico occurrence of ostracod no. 4, *Amphissites bushi* or a close relative, is first published here.

conformably on rocks identified by Fitzgerald (1977) as the Caseyville Formation. In southeastern Iowa the erosionally truncated Cherokee consists of 15 m to about 70 m of mostly unnamed beds of shale, sandstone, coal, and, near the eroded top, a bed of limestone that is equivalent to the Seville Limestone Member (Spoon Formation, Desmoinesian Series, Illinois) (Thompson, 1934; Landis and Van Eck, 1965; Adler and others, in preparation). This Seville equivalent in the Desmoinesian type area is the type stratum of the fusulinid species *Fusulinella iowaensis* (Thompson, 1934; see also Dunbar and Henbest, 1942, p. 93–95, and Sanderson and West, 1981). As in the Illinois Basin, *Fusulina* and *Wedekindellina* (with *Fusulinella* spp.) are found in higher marine zones in the Desmoinesian type area of Iowa (Thompson, 1934).

The entire Cherokee of central and southeastern Iowa belongs to the Desmoinesian Series by original definition of the series, but rocks defined by the Zone of *Fusulinella* (that is, lower Cherokee in Iowa) are assigned to the Atokan by most Mid-continent stratigraphers. Recently, geologists representing the Iowa Geological Survey and the COSUNA project have proposed a compromise between these two opposed practices, even though the type Desmoinesian sequence suggests little need for the Atokan Series. The lowest *Fusulinella*-bearing rocks remain in the redefined Desmoinesian Series, which extends down to the highest occurrence of the spore *Dictyotriletes bireticulatus* a short distance below the Seville equivalent (Ravn, 1979, 1981; Swade and others, 1981; Adler and others, in preparation; Brian W. Witzke, written communication, October 19, 1981; fig. 4 here). Therefore, in that usage, the Atokan Series, 15 to 70 m thick, has nearly the

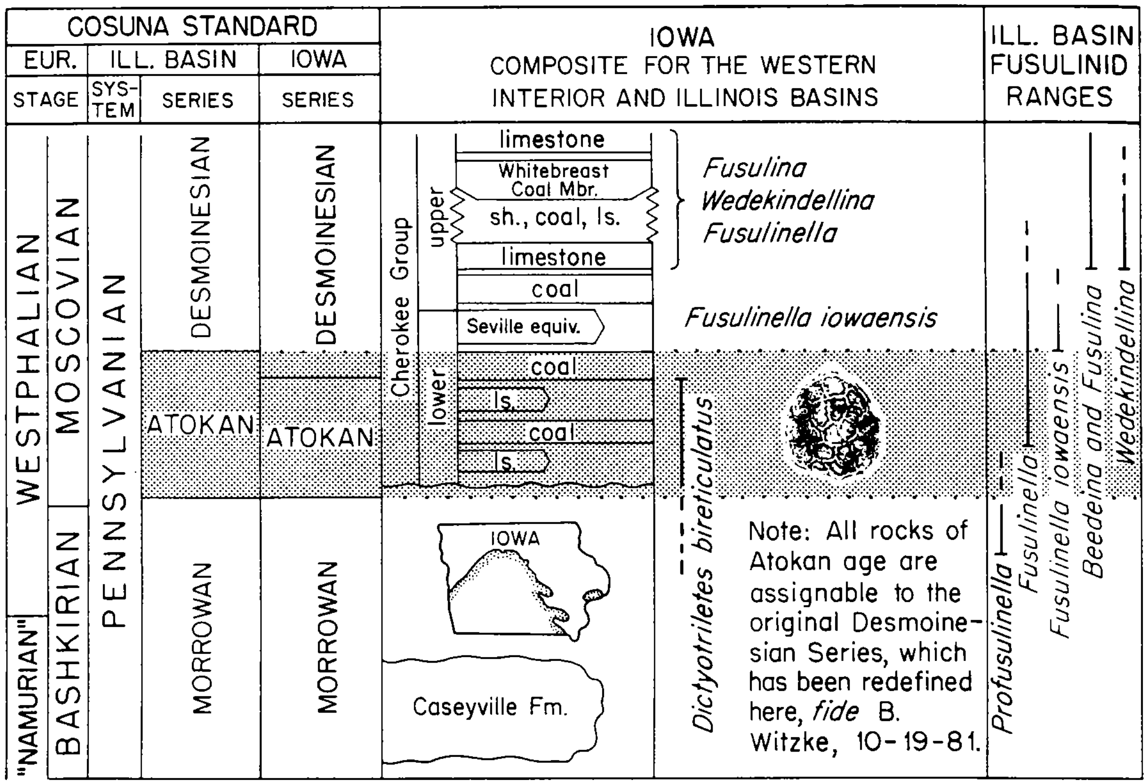


Figure 4. Correlation chart showing generalized sequence of Atokan and associated rocks in Iowa. Parts of information from Adler and others (in preparation), Fitzgerald (1977), Ravn (1981), Sanderson and West (1981), Swade and others (1981), and Thompson (1934). Note slight difference between Illinois Basin and Iowa recognitions of Atokan Series for purposes of two COSUNA correlation charts.

same top as the Atokan Series defined here for the Illinois Basin (fig. 4) but differs by one coal interval.

## Discussion

The Atokan Series as defined here for the Illinois Basin and Iowa follows the scheme shown on the COSUNA chart for this area (Shaver and others, in preparation). It has the approval of geologists representing the Illinois, Indiana, and Kentucky geological surveys and serving on the Tristate Committee on Correlation of Pennsylvanian Rocks in the Illinois Basin.

If generally adopted, this scheme would eliminate the modest differences between separately extant recognitions of the Atokan Series by the four central Midwestern state surveys (see Shaver and others, 1970; Hopkins and Simon, 1975, fig. P-2; and the new Iowa proposal cited above). The important fact here is that the more common Midwestern practice of drawing the upper Atokan boundary within the Zone of *Fusulinella* (that is, including the pre-*Fusulina* range of *Fusulinella iowaensis* within the Desmoinesian Series) remains in force today. The lower Atokan boundary recognized here may be considered as more arbitrary, as it involves the greater change in extant practices. It is based primarily on assignment of *Profusulinella*-bearing rocks (Lead Creek) to an upper Morrowan position and on detailed correlations within the Illinois Basin involving coals and made on the basis of spores.

Both of these proposed Atokan boundaries differ markedly from the commonly denoted Atokan boundaries in the Midcontinent. Something is wrong that requires further examination of the propositions listed at the beginning of this paper.

# QUESTION OF A TYPE FOR AN ATOKAN SERIES

## Type Atoka Formation

It is clear from Taff and Adams (1900, p. 273), who specified neither the town nor county of Atoka as the type area, that their original description of the Atoka Formation was for rocks on either side of the Choctaw Fault in southeastern Oklahoma. The pertinent area for their description thus extends into the frontal Ouachita Mountains, but it does not include the area outside the Ouachitas in which secondarily defined reference sections for an Atokan Series have been proposed (see Sutherland, Archinal, and Grubbs, 1982). In this understanding, the original Atoka type area includes places in the frontal Ouachitas that were influenced by flysch sedimentation (as described by such persons as Cline, 1970) and where the lower Atoka rocks have been considered by several persons to be Morrowan in age. Further, the town of Atoka itself is south of the mapped extent of the Choctaw Fault as shown by Miser (1954). P. K. Sutherland and W. L. Manger (written communication, July 26, 1982), however, believe that original type Atoka rocks should be considered as consisting only of deltaic and shallow-marine deposits of the Arkoma Basin.

Dealing with typical and (or) nontypical rocks and with flysch and (or) nonflysch rocks, several stratigraphers have depicted the overall Atoka Formation as onlapping northward the fossiliferous rocks assigned to the Morrowan Series (for example, Harlton, 1938; Cline, 1970; Briggs, 1974; Glick, 1975). The onlap has been interpreted to have taken place both through facies change (fig. 5) and unconformity. According to Lumsden, Pittman, and Buchanan (1971), the change from a facies relation to unconformity takes place within the Arkoma Basin, that is, probably north of most persons' interpretive type area for the Atoka Formation.

The underlying Wapanucka Limestone (assigned to the Morrowan Series by Lumsden, Pittman, and Buchanan, 1971, in the Arkoma Basin) also has been interpreted to have changing age relations (fig. 5). The scale of Morrowan–Atoka equivalency, as variously interpreted, ranges from inclusion of all or nearly all type Morrowan rocks within the time frame of Atoka deposition (for example, by Laudon, 1958, and Morris, 1974) to minimal overlapping age relations and to doubt of overlap (for example, by Sutherland and Manger, 1979). This Atoka problem extends to areas adjacent to the Oklahoma type area, for example, to Arkansas (fig. 5) and to Texas (Kier, Brown, and McBride, 1979). In Texas the Marble Falls Limestone and its *Profusulinella* occurrence (upper Marble Falls) are involved (is *Profusulinella* in the Marble Falls indeed only "Atokan" in age and not also late Morrowan?).

The question may be asked: "What part of the Atoka Formation should serve as the authority and represent the time value for an Atokan Series?" The section of rocks in northwestern Atoka County proposed to serve as type section for both the Atoka Formation and the Atokan Series (Branson, 1962, p. 439) has not yet yielded datable

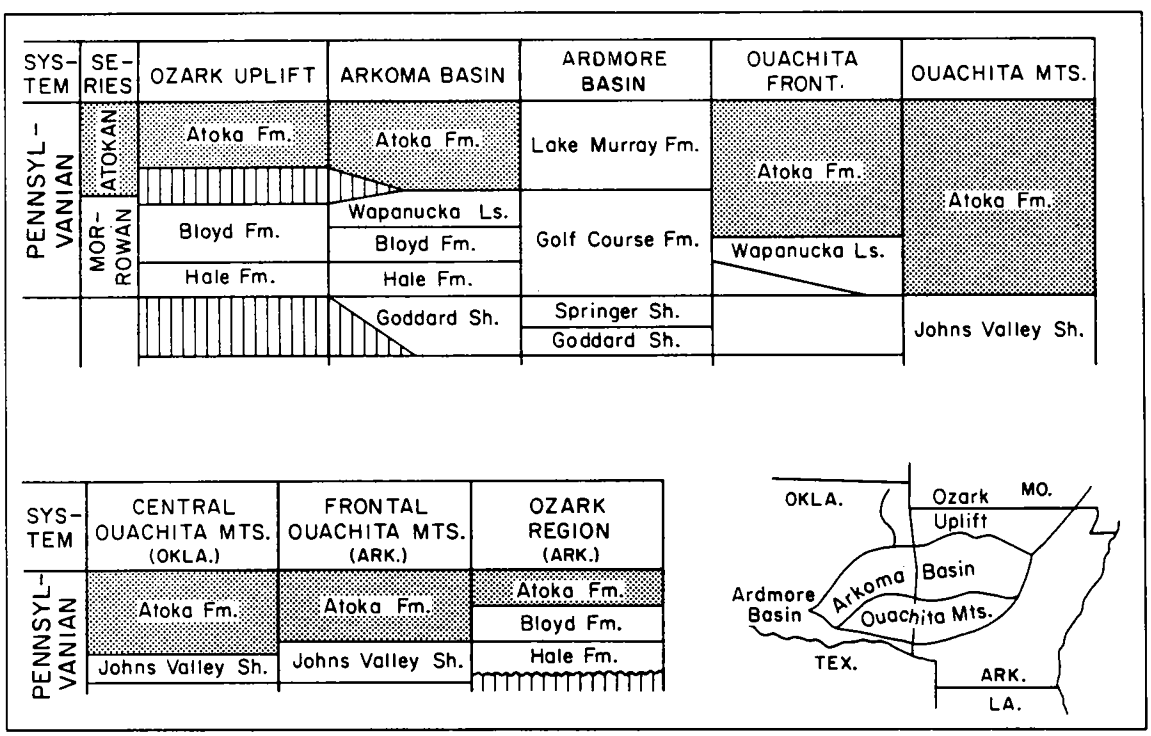


Figure 5. Parts of two correlation charts modified from Laudon (above, 1958) and Morris (below, 1974), representing views of geologists who have interpreted Atoka Formation as onlapping northward formations of Morrowan age, not all of which in themselves are isochronous. The question is raised: Which Atoka shall serve as type for an Atokan Series?

fossils. No doubt Strimple and Watkins' (1969, p. 147) view that the fossiliferous Atoka rocks near Clarita in Coal County, 20 miles and more northwest of Atoka, are useful in establishing a correlatable basis for a series has merit, as does Sutherland, Archinal, and Grubbs' (1982, p. 7) extension of this proposition to locales in Pontotoc County that are even more distant from Atoka. Nevertheless, the point is made that no compelling reason exists for according an Atokan definition priority over definitions of the subjacent and superjacent series in an attempt to establish a single unambiguous standard for correlating Middle Carboniferous rocks (for fuller discussions, see Strimple and Watkins, 1969, p. 147–151 and 157, and Shaver and Smith, 1974, p. 20–24, including consideration of the problem of faulting within the Atoka Formation).

### Atokan Series—A Lower Boundary

The preceding discussion highlights the problem in establishing a suitable concept in general of an Atokan Series. The instability of lower boundary definition is pointed up by the series of differing recognitions by Sutherland and Grayson (1978), Sutherland, Grayson, and Zimbrick (1978), and Sutherland and Manger (1979). The latter proposed to reassign the Trace Creek Member of the Bloyd Formation (type Morrowan Series of northwestern Arkansas) to their Atokan Series. Further, they reassigned the upper part of the Wapanucka Limestone in the frontal Ouachitas of southeastern Oklahoma from the Morrowan Series to their Atokan Series. The principal basis for these reassignments was that the reassigned rocks contain conodonts "thought to be of Atokan age" (see also Groves and Grayson, 1982).

By whose generally accepted definition of the Morrowan–Atokan boundary these rocks are known to be Atokan in age, and not also Morrowan, is not clear. It is not by Henbest's (1962a, 1962b) nor Sutherland and Grayson's (1977, p. 42) definitions by which "the Trace Creek Member is the highest unit in the type Morrowan sequence." It may be necessary to shorten the defined type Morrowan sequence as noted above before the upper Wapanucka rocks, also as noted above, can be thought to be Atokan in age. Nor could it be by Lumsden, Pittman, and Buchanan's (1971) and Glick's (1975) recognitions of the lower boundary, nor by Frezon and Dixon's (1975, p. 181) recognition, by which the top of the Morrowan Series in the frontal Ouachitas of Oklahoma coincides with the top of the Wapanucka Limestone.

Sutherland and Manger's (1979) proposal to place the Morrowan–Atokan boundary in the type Morrowan area at an unconformity (below the Trace Creek) raises a special question: Are gaps in the tangible record of time desirable places in which to place boundaries advocated for use in the North American standard? The same question plagues the secondarily defined Atokan type or reference area northwest and west of Clarita in Coal and Pontotoc Counties, Oklahoma (see the statement of unconformity by Sutherland, Archinal, and Grubbs, 1982, p. 7).

### Atokan Series—An Upper Boundary

The upper boundary problem for an Atokan Series seems to be more readily solvable than is the lower boundary problem. Most Midcontinent stratigraphers probably now restrict their identification of the upper part of their Atokan Series to rocks of the Zone of *Fusulinella* (for example, Waddell, 1966), but a part of this zone, as already noted, is also common to lower rocks of the type Desmoinesian Series (Sanderson and West, 1981, and several others at earlier dates). Furthermore, rocks as young as the Zone of *Fusulina* (includes *Wedekindellina*), commonly considered to be Desmoinesian in age, have been included in the Atoka Formation (for example, see Elias, 1963, p. 356, and 1966, p. 97; Hopkins and Simon, 1975, p. 181; Archinal and others, 1982, p. 29; Galloway and Ryniker, 1930, p. 25, *W. euthysepta*). Agreement on correlation is not the main problem in resolving this classificatory problem that has arisen because two series, as commonly recognized in geographically separated areas, have overlapping time values. What is needed is an arbitrary definition of a single upper Atokan (lower Desmoinesian) boundary that can be applied in both type areas and generally in North America.

## PROBLEMS WITH THE FUSULINID ZONES

### General Statement

For several decades, most American Carboniferous biostratigraphers have accepted definitions of the ranges of Middle Carboniferous fusulinid zones as they appear in the *Treatise on Invertebrate Paleontology* (Thompson, 1964; fig. 6 here). Fusulinid zones are highly useful, of course, in applying the authority of series type sections to the identification of ages of rocks beyond the type sections, but some ambiguity attaches to these zones as applied in America, the full extent of which is still to be assessed.

### Zone of *Profusulinella*

In its global distribution, the genus *Profusulinella* ranges into post-Bashkirian rocks, that is, into Moscovian rocks. This is to say that it ranges from Morrowan into indisputably post-Morrowan (i.e., Atokan) rocks (see fig. 7). Outside the United States the greater part of the Zone of *Profusulinella* (defined as the pre-*Fusulinella* part

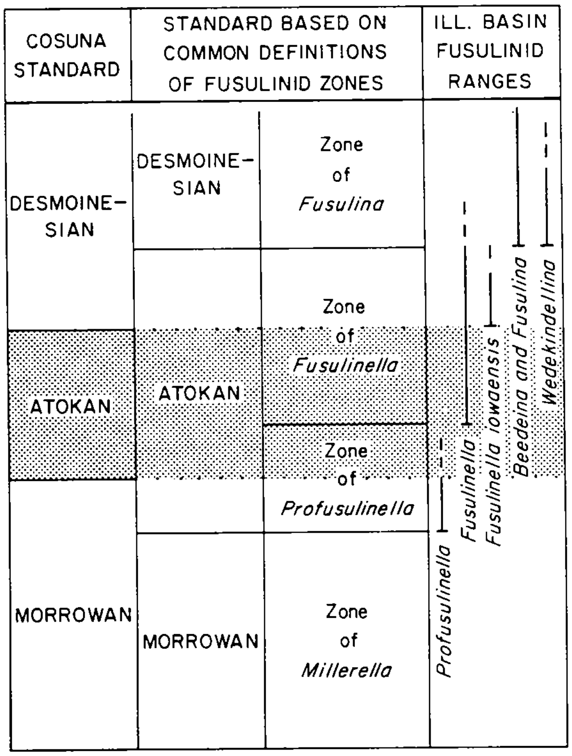


Figure 6. Chart showing comparison of COSUNA standard for Middle Carboniferous rocks in United States (Atokan fit by Shaver and others, in preparation) and standard based on common definitions of fusulinid zones as given by Thompson (1964), Douglass (1979), and others.

of the range of *Profusulinella*) is in the Bashkirian Series, meaning in rocks of Morrowan age, according to the COSUNA chronostratigraphic scale. In the U.S.S.R., *Profusulinella* is rare in lower and common in upper Bashkirian rocks; in Spitzbergen, Spain, and Algeria, it occurs in the upper Bashkirian; in China and Japan, it occurs in the lower and upper Bashkirian; and in Canada it occurs in rocks classified as Atokan in age by McGugan and Rapson (1979).

In the United States many Pennsylvanian stratigraphers have concluded that the Zone of *Profusulinella*, which is defined to exclude *Fusulinella*-bearing rocks, is supposed to identify lower Atokan rocks exclusively (fig. 6), that is, post-Bashkirian rocks only (fig. 7). Nevertheless, *Profusulinella* may occur nowhere in Oklahoma or Arkansas in rocks that are unequivocally Atokan in age and not also Morrowan, unless the occurrence newly published for purposes of the Atokan symposium (Sutherland, Archinal, and Grubbs, 1982, p. 13) qualifies. In possibly the only previously published occurrence of the genus in that area, *P. fittsi* was said (Thompson, 1935) to be found about 100 feet above the base of the Atoka Formation in the Goose Creek section a few miles north of Clarita, Coal County, Oklahoma (see discussion in Shaver and Smith, 1974, p. 20–29). These basal Atoka rocks, called the Barnett Hill Formation by Harlton (1938) and Barnett Hill Member of the Atoka Formation by Strimple and Watkins (1969, p. 147), were said to be well below the lowest unequivocally post-Morrowan cephalopod zone in that general area. Moreover, these rocks were considered by some persons to be Morrowan in age before the Zone of *Profusulinella* was generally accepted per se to denote the lower part of an Atokan Series (for example, by Harlton, 1938, and by R. C. Moore, *fide* Thompson, 1935, p. 292). Nevertheless, Sutherland, Archinal, and Grubbs (1982, p. 10) were unable to verify the Thompson-reported occurrence of *Profusulinella fittsi* in the Goose Creek area.

On such a single reported Oklahoma occurrence of *Profusulinella*, now disputed, has rested the decades-long and all-but-automatic assurance that the Zone of *Profusulinella* denotes rocks of Atokan age and never rocks of Morrowan age. Thinking seems backward in the transfer of authority for series recognition from the type rocks to the partial range of a fusulinid genus. The 1982 reported generic occurrence (see above) may be a beginning to better understanding.

*Profusulinella* appears to be erratic in its distribution, at least partly as response to critical sets of paleoecologic factors. For example, it is wholly absent from northwestern Europe even though marine zones exist in Westphalian A rocks of the same age as *Profusulinella*-bearing Westphalian rocks in Spain, and similar nonoccurrences apply to the U.S.S.R.

Two basins in the United States further illustrate its unpredictable distribution (or unavailability of host rocks for collection?). In the Ardmore Basin of south-central Oklahoma the Zone of *Fusulinella* begins near the base of the Bostwick Member of the Lake Murray Formation, which is Atokan in age, according to Waddell (1966, p. 8 and fig. 2). Directly below is the Golf Course Formation with its Jolliff and Otterville Limestone Members and associated rocks that contain an abundant ostracod fauna, which is Morrowan in age, according to Bradfield (1935), Shaver and Smith (1974), and Knox (1975) (see fig. 3 here). Where could there be room for the Zone of *Profusulinella* if the genus were present except in rocks that to this time have been assigned to the Morrowan Series?

In the Illinois Basin, the genus is associated with the same ostracod fauna (fig. 3) that is also common to the type Morrowan rocks in northwestern Arkansas. Its occurrences in the Illinois Basin have been detailed above (fig. 2) together with age notations.

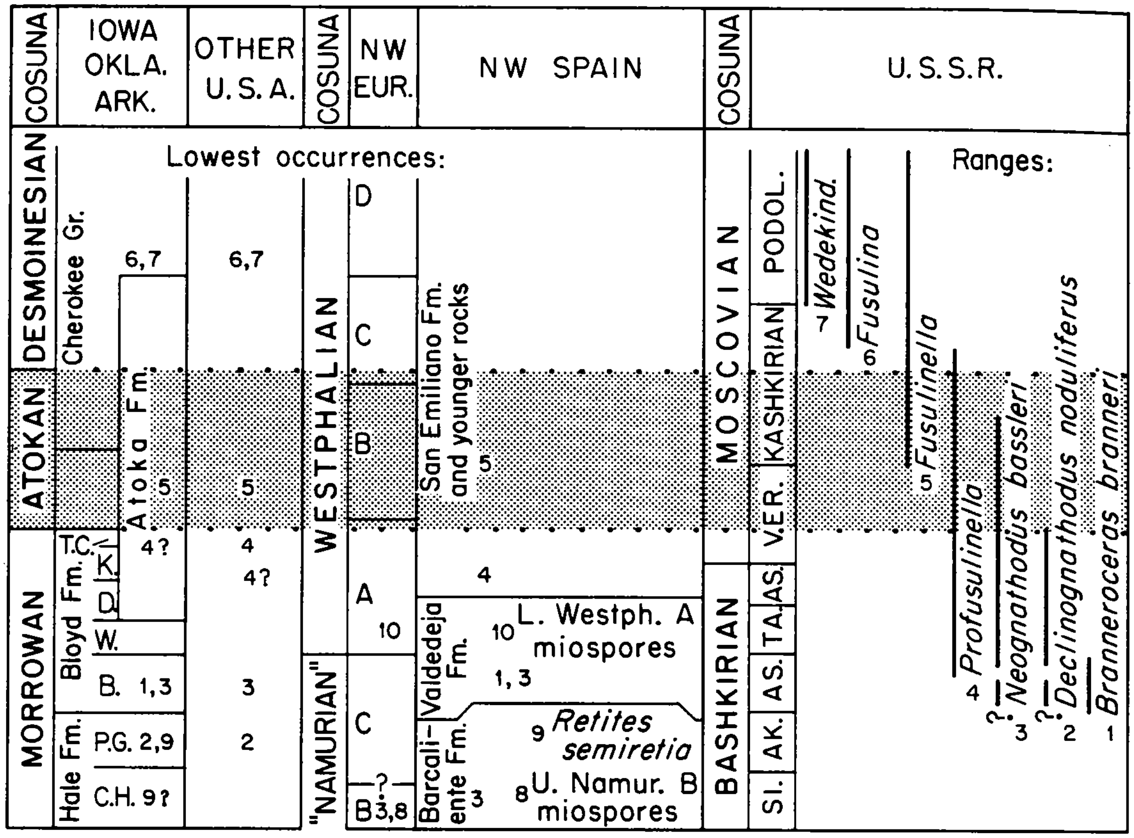


Figure 7. Chart showing biostratigraphic evidence leading to development of COSUNA chronostratigraphic scale in which Bashkirian–Moscovian boundary is placed within Morrowan time frame. Iowa–Oklahoma–Arkansas and other U.S.A. columns are composited. Lowest occurrences of fossils in non-U.S.S.R. columns are noted by numbers. Abbreviations in descending order: of members of Bloyd and Hale Formations—Trace Creek Shale, Kessler Limestone, Dye Shale, Woolsey, Brentwood Limestone, Prairie Grove, and Cane Hill Members; of substages of Moscovian and Bashkirian Stages—Podolian, Vereyan, Asatauan, Tashatinian, Askynbashian, Akavasian, and Siuranian Substages. Data especially from Barskov and Alexeyev (1975), Van Ginkel (1965), Ivanova and others (1979), Moore and others (1971), Cor Winkler Prins (written communication, October 1981), Requadt and others (1977), and Semichatova and others (1979).

## Zones of *Fusulinella* and *Fusulina*

Concerning an upper Atokan boundary, little needs to be said about the three-cornered ambiguity among (1) the Midcontinent stratigraphers' definition of an Atokan–Desmoinesian boundary, (2) the Midwestern stratigraphers' definition of an Atokan–Desmoinesian boundary, and (3) the fusulinid stratigraphers' definition of the Zone of *Fusulinella* as wholly excluding Desmoinesian rocks. Integrity of geologists' judgments is not at stake here so much as is the need for useful arbitrary agreement.

## THE COSUNA CHRONOSTRATIGRAPHIC SCALE

The standard scale coordinating Eurasian and North American time-rock units, shown on the left of figures 1–4, has been adopted for the COSUNA project for uniform use throughout the United States, but not all the regional coordinators will interpret Atokan rocks in the same manner as has this author. The scale evolved through consideration of the age relations among sections and biozones in the U.S.S.R., western Europe, including northwestern Spain, and mid-America (Amos Salvador, COSUNA project, and Cor F. Winkler Prins, Subcommission on Carboniferous Stratigraphy, written communications, June 12 and November 3, 1981; fig. 7 here). Some of the guiding reasoning may be found in Moore and others (1971), but the present arrangement is not wholly from that source.

Placement of the boundary between the Bashkirian and Moscovian Stages in the U.S.S.R. within the Westphalian A and Morrowan time frames is most significant. Key cephalopod, miospore, and fusulinid zones were instrumental. Considerable weight was given to geographic parallelisms in the cephalopod sequence represented by *Retites semiretia* and *Branneroceras branneri* in association with upper Namurian B miospores and lower Westphalian A miospores (fig. 7). n America, these cephalopods occur in the Hale Formation and in the Brentwood Limestone Member of the Bloyd Formation (lower and upper Morrowan, respectively; McCaleb, 1968).

Above this sequence in Spain begins the Zone of *Profusulinella* (Van Ginkel, 1965), although in the U.S.S.R. *Profusulinella* apparently arose as early as the time of *B. branneri* (fig. 7), which means as early as the time of deposition of the Brentwood Limestone Member (early late Morrowan) of Arkansas. *Profusulinella* may also occur in America in rocks of the same general age as in Spain, if not older rocks.

The placement of the Bashkirian–Moscovian boundary near the top of the Morrowan probably does not have official Russian sanction (for example, not of Einor and others, 1979, or of Semichatova and others, 1979). The Russian placement of this boundary within or at the top of an Atokan time frame apparently proceeds from conviction that the Zone of *Profusulinella* means precisely lower Atokan. Although the Russian argument appears to agree with that of those American fusulinid stratigraphers who equate their Zone of *Profusulinella* with lower Atokan rocks, they do not necessarily agree. The Russian position seems to put no stock in the idea that time in the magnitude of a stage was needed for migration of *Profusulinella* from Eurasia to America, and it seems to ignore conodont and cephalopod evidence that hardly supports assignment of much of an Atokan Series to a late Bashkirian time frame.

Conodont evidence from Spain and the Soviet Union has not been evaluated extensively. Nevertheless, two Russian conodont-assemblage zones identified in figure 7, and other conodonts described by Requadt and others (1977) in the western Pyrenees of Spain, suggest in relation to North American occurrences that, if further adjustment is to be made, the Bashkirian–Moscovian boundary of figure 7 should be lowered.

## IMPLICATIONS FOR FAR-WESTERN BOUNDARIES

The Atokan boundaries generally recognized in the far-western United States are unsatisfactory because of the Midcontinent-originated assumptions on which they are based. On the other hand, and by circular reasoning, the Derryan Series (originated by Thompson, 1942) in the Far West (fig. 8) has entered into the unsatisfactory Midcontinent Atokan concept. The term Derryan has not generally been adopted.[4] In the process of its abandonment, the literature has recorded many

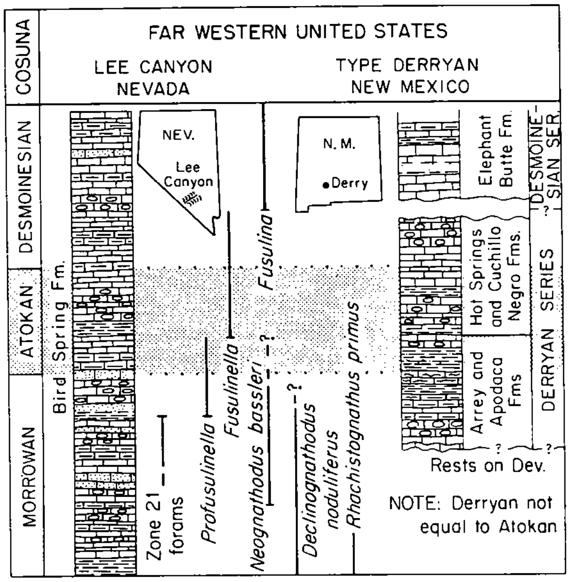


Figure 8. Chart showing revised placements of key sections and faunas in far-western United States in accord with COSUNA chronostratigraphic scale as interpreted here. Data especially from Dunn (1970, 1976), Lane and Straka (1974), Rich (1961), and Thompson (1942). See text footnote on obsolescence of New Mexico names.

instances of the western Derryan Series and the Midcontinent Atokan Series being precisely equated, a most unlikely circumstance! *Profusulinella*, occurring 5 m above the base of Pennsylvanian rocks at Derry, New Mexico, was one key, but type-Morrowan (disputed by some persons) conodont species have been identified with *Profusulinella* in the lower Derryan rocks of New Mexico (fig. 8), as they have elsewhere in this continent and in Eurasia. Therefore, a lower part of the so-called Derryan (or so-called Atokan) rocks in the Far West may be Morrowan in age. The same evidence suggests that critical far-western foraminifer zones of Mamet and Skipp (1970) need recalibration. For example, foraminifer Zone 21 is as likely to be Morrowan in age as it is unambiguously Atokan (fig. 8) (see especially Dunn, 1970, and 1976, p. 645; also, Shaver and Smith, 1974, p. 27).

Recognition of a far-western upper Atokan (upper Derryan) boundary on the basis of first occurrence of *Fusulina* (Thompson, 1942, and many others) poses the same problem that has been discussed for the Midcontinent and Midwest.

[4]F. E. Kottlowski (written communication, February 24, 1982), who is the COSUNA regional coordinator for the southwestern United States, has stated that neither the Derryan Series nor the rock-unit names proposed by Thompson (1942) and shown here in figures 3 and 8 will be recognized on the COSUNA chart for that area.

## SUMMARY AND A PROPOSAL

The propositions stated in the introduction also serve as part of this contributor's summary.

Considering all kinds of faunal evidence assembled here from many places, not all of which accords with common Midcontinent practices, Middle Carboniferous stratigraphers should, at least temporarily, put aside the traditional framework by which series boundaries within the lower half of the Pennsylvanian System most commonly have been recognized. And they should acknowledge validity in the often necessary practice of shortening (or lengthening) original type sections of named series of rocks to realize a single, unambiguous systemic standard.

To begin a somewhat arbitrary, yet logical, rearrangement of the series boundaries, stratigraphers should consider adoption of the COSUNA chronostratigraphic scale.[5] Usable, if not ideal, rock-based and fossil-coordinated concepts for the Morrowan and Desmoinesian Series already exist and are extendable to areas beyond the type areas. A setting of such priority should result in a residual logical base, coordinated by means of faunal zones, for an interregionally useful Atokan Series. One or more meaningful reference sections for the series could then be designated (or redesignated); anything more than a loose attachment of the thus-defined Atokan Series to a type Atoka Formation, which seems impossible to define to everyone's satisfaction, should be disclaimed.

Much of this summary appears to support establishment of a system of boundary stratotypes, but this account has been couched within the bounds of present conventions in time-rock classification.

## REFERENCES CITED

Readers are referred to the bibliographies in Shaver and Smith (1974) and in Sutherland and Manger (1979) for sources of all those references cited in the text and figures that are not given below.

**Adler, Frank,** and others, in preparation, Correlation of rocks in the central Midcontinent region: American Association of Petroleum Geologists Correlation of Stratigraphic Units of North America (COSUNA) Chart.

**Archinal, B. E., Sutherland, P. K., Grayson, R. C., Jr., Douglass, R. C.,** and **Nestell, M. K.,** 1982, Stop descriptions—northeastern Arbuckle Mountains, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 19–29.

[5]The question of whether the Mississippian–Pennsylvanian boundary has been placed too high in the COSUNA global chronostratigraphic scale, as suggested by C. B. Rexroad, H. R. Lane, and A. C. Higgins (Rexroad, written communication, January 1982), has not been considered here.

**Barskov, I. S.,** and **Alexeyev, A. S.,** 1975, Middle and Upper Carboniferous conodonts from the neighborhoods of Moscow: USSR Academy of Science Proceedings, Geologic series, no. 6, p. 84–99.

**Douglass, R. C.,** 1979, The distribution of fusulinids and their correlation between the Illinois Basin and the Appalachian Basin [preprint]: IX International Congress of Carboniferous Stratigraphy and Geology Proceedings, Urbana, Illinois, 14 p.

**Dunn, D. L.,** 1976, Biostratigraphic problems of Morrowan and Derryan (Atokan) strata in the Pennsylvanian System of western United States: Geological Society of America Bulletin, v. 87, p. 641–645.

**Einor, O. L.,** editor, and others, 1979, The Lower–Middle Carboniferous boundary [translation], *in* Wagner, R. H., Higgins, A. C., and Meyen, S. V., editors, The Carboniferous of the USSR: Yorkshire Geological Society Occasional Publication 4, p. 61–81.

**Fitzgerald, D. J.,** 1977, Petrology of the Pennsylvanian sandstones of Muscatine County, Iowa: University of Iowa unpublished M.S. thesis, 215 p.

**Frezon, S. E.,** and **Dixon, G. H.,** 1975, Texas Panhandle and Oklahoma, *in* McKee, E. D., and Crosby, E. J., coordinators, Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853, part 1, p. 177–195.

**Galloway, J. J.,** and **Ryniker, Charles,** 1930, Foraminifera from the Atoka formation of Oklahoma: Oklahoma Geological Survey Circular 21, 37 p.

**Groves, J. R.,** and **Grayson, R. C.,** 1982, Calcareous foraminifers and conodonts from the Morrowan–"Atokan" (Pennsylvanian) Wapanucka Formation, southeastern Oklahoma [abstract]: Geological Society of America Abstracts with Programs, v. 14, p. 112.

**Hopkins, M. E.,** and **Simon, J. A.,** 1975, Pennsylvanian System, *in* Willman, H. B., and others, Handbook of Illinois stratigraphy: Illinois Geological Survey Bulletin 95, p. 163–201.

**Ivanova, E. A., Solovieva, M. N.,** and **Shik, E. M.,** 1979, The Moscovian Stage in the USSR and throughout the world [translation], *in* Wagner, R. H., Higgins, A. C., and Meyen, S. V., editors, The Carboniferous of the USSR: Yorkshire Geological Society Occasional Publication 4, p. 117–146.

**Kier, R. S., Brown, L. F., Jr.,** and **McBride, E. F.,** 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Texas: U.S. Geological Survey Professional Paper 1110–S, 45 p.

**Knox, Larry,** 1975, Ostracods from the area of the type rocks of the Morrowan Series (Lower Pennsylvanian), Arkansas and Oklahoma: Indiana University unpublished Ph.D. thesis, 130 p.

**Landis, E. R.,** and **Van Eck, O. J.,** 1965, Coal resources of Iowa: Iowa Geological Survey Technical Paper 4, 141 p.

**McGugan, Alan,** and **Rapson, J. E.,** 1979, Pennsylvanian and Permian biostratigraphy, micropaleontology, petrography and diagenesis, Kananaskis Valley, Alberta: Bulletin of Canadian Petroleum Geology, v. 27, p. 405–417.

**Mamet, B. L.,** and **Skipp, B. A.,** 1970, Preliminary foraminiferal correlations of early Carboniferous strata in the North American Cordillera, *in* Colloque sur la stratigraphie du Carbonifère: Les Congrès et Colloques de l'Université de Liège, v. 55, p. 327–348.

**Merrill, G. K.**, and **King, C. W.**, 1971, Platform conodonts from the lowest Pennsylvanian rocks of northwestern Illinois: Journal of Paleontology, v. 45, p. 645–664.

**Moore, L. R., Neves, R., Wagner, R. H.**, and **Wagner-Gentis, C. H. T.**, 1971, The stratigraphy of Namurian and Westphalian rocks in the Villamanin area of northern Leon, northwest Spain, *in* Wagner, R. H., editor, The Carboniferous of northwest Spain: Universidad Oviedo Faculdad de Ciencias Trabajos de Geología, v. 3, p. 307–363.

**Ravn, R. L.**, 1979, An introduction to the stratigraphic palynology of the Cherokee Group (Pennsylvanian) coals of Iowa: Iowa Geological Survey Technical Paper 6, 117 p.

———1981, Palynostratigraphy of Lower and Middle Pennsylvanian coals of Iowa, with special reference to the Atokan–Desmoinesian boundary [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 314.

**Requadt, Hermann, Becker, Gerhard, Bless, M. J. M., Eickhoff, Günther**, and **Sánchez de Posada, L. C.**, 1977, Mikrofaunen aus dem Westfal der spanischen Westpyrenäen (Ostracoda, Conodonta, Foraminifera): Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 155, p. 65–107.

**Sanderson, G. A.**, and **West, R. R.**, 1981, Fusulinids from the Desmoinesian type area [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 545.

**Semichatova, S. V., Einor, O. L., Kireeva, G. D., Vassilynk, N. P., Gubareva, V. S.**, and **Potievskeya, P. D.**, 1979, The Bashkirian Stage as a global stratigraphic unit [translation], *in* Wagner, R. H., Higgins, A. C., and Meyen, S. V., editors, The Carboniferous of the USSR: Yorkshire Geological Society Occasional Publication 4, p. 99–116.

**Shaver, R. H.**, and others, in preparation, Correlation of rocks in the Midwestern arches and basins region: American Association of Petroleum Geologists Correlation of Stratigraphic Units of North America (COSUNA) Chart.

**Shaver, R. H.**, and **Smith, S. G.**, 1974, Some Pennsylvanian kirkbyacean ostracods of Indiana and Midcontinent series terminology: Indiana Geological Survey Report of Progress 31, 59 p.

**Sutherland, P. K., Archinal, B. E.**, and **Grubbs, R. K.**, 1982, Morrowan and Atokan (Pennsylvanian) stratigraphy in the Arbuckle Mountains area, Oklahoma, *in* Sutherland, P. K., editor, Lower and Middle Pennsylvanian stratigraphy in south-central Oklahoma: Oklahoma Geological Survey Guidebook 20, p. 1–17.

**Sutherland, P. K.**, and **Manger, W. L.**, 1979, Comparison of Ozark shelf and Ouachita basin facies for Upper Mississippian and Lower Pennsylvanian Series in eastern Oklahoma and western Arkansas, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 1–81.

**Swade, J. W., Ravn, R. L., Howes, M. R., Fitzgerald, D. J.**, and **Van Dorpe, P. E.**, 1981, Formational subdivision of the Cherokee Group and proposed revisions in Pennsylvanian stratigraphic nomenclature in Iowa [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 318.

**Taylor, G. D., Jr.**, 1971, Conodonts from the Mansfield and Brazil Formations (Morrowan) of the Illinois Basin: University of Illinois unpublished M.S. thesis, 70 p.

———1974, Morrowan conodont faunas from the Mansfield and Brazil formations, southeastern Illinois Basin [abstract]: Geological Society of America Abstracts with Programs, v. 6, p. 549.

**Thompson, M. L.**, 1942, Pennsylvanian system in New Mexico: New Mexico School of Mines Bulletin 17, 90 p.

———1964, Fusulinacea, *in* Loeblich, A. R., Jr., and Tappan, Helen, Sarcodina, chiefly "Thecamoebians" and Foraminiferida, *v. 1 of* Protista 2, *part C of* Moore, R. C., editor, Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press, p. C358–C436.

**Van Ginkel, A. C.**, 1965, Carboniferous fusulinids from the Cantabrian Mountains (Spain): Leidse Geologische Mededelingen, v. 34, p. 1–225.

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# PRELIMINARY CONODONT BIOSTRATIGRAPHY OF THE MORROWAN–ATOKAN BOUNDARY (PENNSYLVANIAN), EASTERN LLANO UPLIFT CENTRAL TEXAS

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**Abstract**—The Marble Falls Limestone in the eastern Llano region can be divided into informal lower and upper members. The lower member consists of thick successions of spiculite and high-energy carbonate grainstones but lacks significant shale. The upper member includes thinner alternations of low-energy carbonates and common shale intervals. The contact between the lower and upper members is a regional unconformity, but physical evidence for the hiatus is not obvious at most localities.

Conodonts recovered from the Marble Falls demonstrate that the unconformity at the lower–upper member contact corresponds to the Morrowan–Atokan boundary. In the northeastern uplift, the upper member produces a lower Atokan assemblage with *Diplognathodus coloradoensis, D. orphanus,* and *Neognathodus medadultimus* immediately overlying a middle Morrowan assemblage with *Idiognathodus delicatus* and *N. bassleri* at the top of the lower member. The bulk of the lower member falls in the older *N. symmetricus* zone.

At the type Marble Falls, southeastern Llano region, the entire lower member produces the same generalized upper Morrowan assemblage with *I. delicatus* and *Streptognathodus parvus* and appears to be younger than the equivalent interval in the northeast. The succeeding lower Atokan assemblage is identical to that found in the upper member in the northeastern uplift. Correlation of the Marble Falls assemblages suggests that most of the lower Atokan Series is missing at the lower–upper member contact in both areas.

## INTRODUCTION

Placement of the Morrowan–Atokan boundary has figured prominently, and controversially, in attempts to refine the lithostratigraphy of the Marble Falls Limestone in central Texas. Concurrently, studies of the Texas succession have played a significant role in development of formal chronostratigraphic subdivisions at the series level for the Pennsylvanian System as they are used in most of North America. In pursuit of these two objectives, the entire stratigraphic framework for the Pennsylvanian of central Texas was comprehensively reviewed by M. G. Cheney (1940). He restricted the name Marble Falls (Hill, 1889) as a group term to include its type section and equivalent strata of Morrowan age in the region. The Big Saline Group was proposed by Cheney (1940) for the section interpreted as unconformably succeeding the restricted Marble Falls Group and succeeded conformably by the Smithwick Group. The combined Big Saline and Smithwick Groups formed Cheney's Lampasas Series (1940) as a post-Morrowan and pre-Strawn ( = Desmoinesian) chronostratigraphic subdivision of the Pennsylvanian System. The fusulinid succession served as the basis for recognition of the Lampasas Series away from central Texas, and Cheney (1940) noted characteristic taxa and proposed some regional correlations.

Following Cheney's proposals, the lithostratigraphic classification of the Marble Falls–Big Saline section was revised repeatedly by Cheney (1947, 1950, 1951; Cheney and Goss, 1952) and F. B. Plummer (1945, 1947, 1950). At least a dozen names of various stratigraphic rank were proposed for the interval (Kier, 1980, fig. 4). No consensus was ever reached concerning these divisions, and subsequent work has ignored them for the most part (Turner, 1957; Bell, 1972; Kier, 1980). It should be noted, however, that each of these diverse classification schemes shares, in common, the utilization of the Morrowan–Lampasas (later Atokan) boundary as the fundamental basis for a bipartite (Marble Falls–Big Saline) lithostratigraphic subdivision (Kier, 1980, fig. 4). Although the Lampasas Series was included in the Pennsylvanian correlation chart (Moore and others, 1944), Spivey and Roberts (1946) suppressed it in favor of the name Atokan, which has become the ingrained series designation. Thus, little nomenclature remains in use

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from the Cheney–Plummer era, and the controversy is mostly of historical interest.

Recent review of the Morrowan–Atokan boundary (Sutherland and Manger, 1983) highlighted the problems resulting from unfavorable lithologies and an unconformity at the boundary in both type areas. A comprehensive study of the Marble Falls Limestone has been undertaken around the Llano Uplift to provide regional biostratigraphic data for more precise determination of upper Morrowan and Atokan relations in the southern Midcontinent. This paper presents preliminary analysis of conodonts from the Marble Falls Limestone at its type section and sections in the type Lampasas area in the eastern portion of the uplift (fig. 1).

## Acknowledgments

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## LITHOSTRATIGRAPHY

The most recent usage of the name Marble Falls has been as the designation of the entire carbonate sequence lying above the Barnett Shale or older units and below the Smithwick Shale or younger units (Kier, 1980). The Marble Falls consists of a variety of shelf and shelf-edge limestones with subordinate shales that are exposed discontinuously around the Llano Uplift (fig. 1). Two informal members can be recognized within the Marble Falls (Kier, 1980; fig. 1). A lower member consists of thick successions of spiculite and high-energy oolitic and bioclastic grainstones lacking shale for the most part (fig. 1). The upper member includes significant shale intervals, particularly in its lower part, and exhibits development of thin alternations of low-energy carbonate lithologies, especially algal mudstones (fig. 1). Chert formation is pervasive but favors the fine-grained lithologies, particularly spiculites (fig. 1). Diagrammatic representation of the succession of lithologies making up the sections under study in this paper is illustrated in figure 1. Further details of the Marble Falls lithologies and analysis of the depositional environments they represent can be found in Kier and others (1979) and Kier (1980).

Two important regional unconformities are associated with the Marble Falls succession. The Barnett–Marble Falls contact is a major hiatus corresponding to the Mississippian–Pennsylvanian boundary throughout the Llano Uplift. In the eastern half of the uplift, the lower member rests on the Barnett Shale. Both units exhibit interbedded shale and limestone across the boundary interval, and physical evidence for erosion is subtle at most exposures. This fact has led to interpretations by some that the boundary is conformable (Kier, 1980; Merrill, 1980), although biostratigraphic evidence for the hiatus has been reported by Liner and others (1979). The contact of the informal lower and upper members is indisputably unconformable, and Kier (1980) detailed erosional relationships found at a number of localities in the eastern Llano region. These relationships include irregularities and silicified burrow fills on the upper surface of the lower member, and local truncation of beds at the top of the lower member. Westward across the northern Llano region, local developments of limestone-pebble conglomerates (Sloan Conglomerate) mark this unconformity. However, physical evidence of erosion at the contact of the lower and upper members in the sections under study (fig. 1) is obscured at these places by poor exposures except for apparent irregularity and undulation on the upper surface of the lower member.

## CONODONT RECOVERY

A total of 205 samples were taken from the five measured sections as indicated by the solid areas next to the unit numbers in figure 1. From each sample, 2,000–3,000 grams were acidized in a 10-percent solution, by volume, of glacial acetic acid and sieved through either U.S. Standard 20/100 or 30/170 sieve combinations. All samples received at least five acidizings, and generally 80–90 percent of the sample was dissolved. The insoluble residue was concentrated using tetrabromoethane separation, and the conodonts were picked by the senior author.

Of the samples processed, 19 were barren, and the remaining 186 produced 6,446 discrete conodont elements, for an average yield of approximately 17 conodonts per kilogram. It should be noted that 28 samples produced 3,885 of the conodonts, for an average yield of approximately 69 conodonts per kilogram, reducing the average yield of the remaining 158 samples to just 8 conodonts per kilogram. In grain-dominated lithologies, platform elements exceed ramiform elements in abundance, and many samples lack ramiform elements entirely. The opposite relationship is true for mud-dominated lithologies, particularly the algal mudstones. Conodont occurrences have been tabulated for each sample; variation with lithology and its significance will be considered in a future paper.

# BIOSTRATIGRAPHY

The distribution of the principal platform conodont elements recovered from the Marble Falls section at each locality is recorded in figure 1. The appearances of the fusulinids *Eoschubertella* and *Profusulinella* are given as well. Plate 1 illustrates typical representatives of the various biostratigraphically significant platform elements.

## Morrowan Assemblages

As reported by Liner and others (1979), the base of the Marble Falls in the northeastern Llano region can be assigned to the *Neognathodus symmetricus* conodont zone of Lane (1977). In section A, that lower Morrowan element characterizes virtually the entire lower member (fig. 1). *Idiognathodus delicatus* and *N. bassleri* appear abruptly at the base of unit A-21 (fig. 1). In the type Morrowan region, the overlapping ranges of those two form-taxa define the *I. delicatus* ( = *I. sinuosis*) zone of Lane (1977). There, an intervening zone of *N. bassleri* was established for the range of the name bearer below the occurrence of *Idiognathodus*. That relationship does not seem to exist in the Llano region, since both taxa appear together, except possibly at the base of section B, where a single specimen of *N. bassleri* precedes the appearance of *I. delicatus*, also represented by a single specimen, by a few feet.

The upper type Morrowan succession, above the *Idiognathodus delicatus* zone, was divided into the *I. klapperi* and overlying *Idiognathoides convexus* zones by Lane (1977). A single, but unequivocal, specimen of *I. convexus* was recovered from unit A-17, which lies below the appearance of *Idiognathodus* (fig. 1). In addition, *I. convexus* is abundant in samples from unit A-21, in which both *I. delicatus* and *Neognathodus bassleri* appear for the first time. In the type Morrowan region, *I. convexus* does not overlap the range of *N. bassleri*, being confined instead to the Kessler Limestone Member of the Bloyd Formation at the top of the type succession. Recovery is very poor from unit A-25, but the top of the lower member is not thought to range above the *I. delicatus* zone in the northeastern Llano region. Furthermore, the entire lower member at section A is confined to zone 20 of the smaller calcareous foraminifer zonation of Mamet (1975).

At the type Marble Falls section (measured sections E and F, fig. 1), the entire lower member yields typically low-abundance, ramiform-dominated assemblages. Platform elements present are *Adetognathus lautus, Idiognathodus delicatus, Idiognathoides sinuatus*, and *Streptognathodus parvus*. Even in the few samples that produce abundant conodonts, such as from unit E-4, the composition of this assemblage does not change, except for a single specimen of *Neognathodus bassleri* recovered from the base of unit E-9. The Morrowan age of the lower member is not questioned, since the interval falls below the occurrence of *Eoschubertella* (fig. 1), and the assemblage lacks elements typical of the Atokan conodont assemblage here and in the northeastern Llano region. It seems likely, however, that the entire lower member at the type Marble Falls section is younger than the lithostratigraphically equivalent interval in the northeastern uplift. Only the upper 8 feet of the lower member at section A ranges as high as the *Idiognathodus delicatus* zone, while the entire lower member at the type section contains a generalized upper Morrowan assemblage.

## Atokan Assemblages

A formal, refined zonation for the Atokan Series based on conodonts is not available, but a general understanding of the succession has been developed by Merrill (1974, 1975) and Grayson (1979). By comparison, considerable further study will be required to raise the level of understanding of Atokan conodonts to that of the Morrowan. The fusulinids remain the most useful biostratigraphic index for correlation and subdivision of the Atokan Series at present.

The upper member of the Marble Falls in both the northeastern and type sections contains the appearances of an assemblage of typical post-Morrowan platform conodont form-taxa: *Diplognathodus coloradoensis, D. orphanus, Idiognathoides ouachitensis, Neognathodus medadultimus*, and *Neogondolella clarki*. In this preliminary examination, the upper member occurrences are treated as a single assemblage. Although the elements of the assemblage do not appear simultaneously (fig. 1), we have no confidence that the appearances indicated represent their true first occurrences. *Neogondolella clarki* seems consistently to follow the appearance of the other members of the assemblage, but the form is invariably rare. Taxa that appear in the Morrowan but continue into Atokan strata include *Idiognathodus delicatus, Idiognathoides convexus, I. sinuatus*, and *Streptognathodus parvus*. Unfortunately, those taxa of Morrowan aspect are common in all Marble Falls Atokan strata and may be the only forms recovered from samples of low abundance. The unequivocal Atokan elements are in no case abundant in these samples, and they are also sporadic in appearance. This relationship is particularly true of *N. medadultimus*, which is represented by only a total of 32 specimens recovered from 8 of 89 samples that potentially could have contained the element. Furthermore, 20 specimens were part of an assemblage of 506 conodonts recovered from a sample taken at the top of unit C-20, reducing the bulk of the remaining occurrences to single specimens. As a result of this poor recovery, many samples of Atokan age, based on their relationship to fusulinid occurrences, cannot be differentiated from upper Morrowan zones, based on the elements recovered.

It is clear from comparisons with Merrill (1974, 1975) and Grayson (1979) that the upper Marble Falls conodont assemblage does not represent the basal Atokan Series, substantiating the unconformable relationship with the lower member suggested by lithostratigraphic evidence. The middle Morrowan *Idiognathodus delicatus* zone (northeastern Llano region) or the upper Morrowan *I. delicatus–Streptognathodus parvus* assemblage (type Marble Falls) is succeeded immediately by Atokan elements at the lower–upper member boundary. Missing at that contact are representatives of the *Neognathodus* lineage (*N. bothrops* of Merrill, 1974, or *N. kanumai* of Grayson, 1979; =*N.* n. sp. A of Grayson, this volume) and the appearance of *Streptognathodus elegantulus* (Grayson, 1979; Grubbs, this volume). Although some of the zonal indices used by Grayson (1979), such as *Diplognathodus orphanus*, are found in the upper Marble Falls assemblage, all of his form-taxa range well above the zone they are said to characterize. Precise duration of the unconformity cannot be determined at present, but it must include a substantial part of the lower Atokan Series (references cited above; Grayson, this volume). This conclusion would seem to be at variance with the apparent fusulinid succession in the Marble Falls Limestone (fig. 1). There, the fusulinid *Eoschubertella*, whose appearance marks the base of the Atokan Series (Mamet, 1975; Sutherland and Manger, 1983), seems to be succeeded by *Profusulinella*, which characterizes the lower Atokan Series worldwide. Fusulinids are rare in the Marble Falls of this area, and the sporadic occurrences of both taxa do not represent their true first appearances. It should be noted that *Eoschubertella* ranges well into the Upper Pennsylvanian (Douglass, 1977), and the joint association of *Eoschubertella* and *Profusulinella* in a single, isolated sample could be as young as the top of the lower Atokan Series (Douglass, 1977).

## CONCLUSIONS

Conodonts recovered from the Marble Falls Limestone in the eastern Llano region confirm the historical interpretation of a lower interval of Morrowan age succeeded unconformably by an upper interval of Atokan age. Although Monroe Cheney erred in many of the lithostratigraphic details and correlations, his general framework was closer to the emerging synthesis for the Marble Falls than has been generally credited.

The oldest Marble Falls strata are found in the northeastern Llano region, where virtually the entire lower member belongs to the middle Morrowan *Neognathodus symmetricus* conodont zone. At the type section, the southeastern Llano Uplift, the lower member is still Morrowan but may be entirely younger than the equivalent lithostratigraphic interval in the northeast. In both areas, the upper member produces the same lower Atokan assemblage with *Diplognathodus coloradoensis*, *D. orphanus*, *Neognathodus medadultimus*, and *Neogondolella clarki*, although the latter occurs slightly above the other elements in all sections. It appears that a considerable amount of the lower Atokan Series is missing at the lower–upper member contact, based on comparison of the conodont assemblages, even though the upper member seems to contain the presumed lower Atokan fusulinid succession of *Eoschubertella* followed by *Profusulinella*. It should be noted that both taxa range higher than the chronostratigraphic intervals they characterize, and they occur sporadically and in low abundance in the Marble Falls sections. We do not believe that their appearances in these sections represent their chronostratigraphically significant occurrences, and we advise caution in age assignments for either isolated samples or beds based on either conodonts or fusulinids for this interval.

## REFERENCES CITED

**Bell, W. C.**, 1972, Carboniferous history, Llano region, *in* Barnes, V. E., Bell, W. C., Clabaugh, S. E., Cloud, P. E., Jr., McGehee, R. V., Rodda, P. U., and Young, Keith, Geology of the Llano region and Austin area: Texas Bureau of Economic Geology Guidebook 13, p. 38–40.

**Cheney, M. G.**, 1940, Geology of north-central Texas: American Association of Petroleum Geologists Bulletin, v. 24, p. 65–118.

———1947, Pennsylvanian classification and correlation problems in north-central Texas: Journal of Geology, v. 55, p. 202–219.

———1950, Strawn and older rocks of Pennsylvanian and Mississippian systems of Brown, San Saba, McCulloch, Mason, and Kimble Counties [Texas]: Abilene Geological Society Guidebook, 44 p.

———1951, Foreword, *in* Pennsylvanian of the Brazos River and Colorado River Valleys, north-central Texas: West Texas Geological Society Guidebook, p. 1–4.

**Cheney, M. G.**, and **Goss, L. F.**, 1952, Tectonics of central Texas: American Association of Petroleum Geologists Bulletin, v. 36, p. 2237–2265.

**Douglass, R. C.**, 1977, The development of fusulinid biostratigraphy, *in* Kauffman, E. G., and Hazel, J. E., editors, Concepts and methods of biostratigraphy: Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania, p. 463–481.

**Grayson, R. C., Jr.**, 1979, Stop descriptions—fifth day, *in* Sutherland, P. K., and Manger, W. L., editors, Mississippian–Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, p. 67–76.

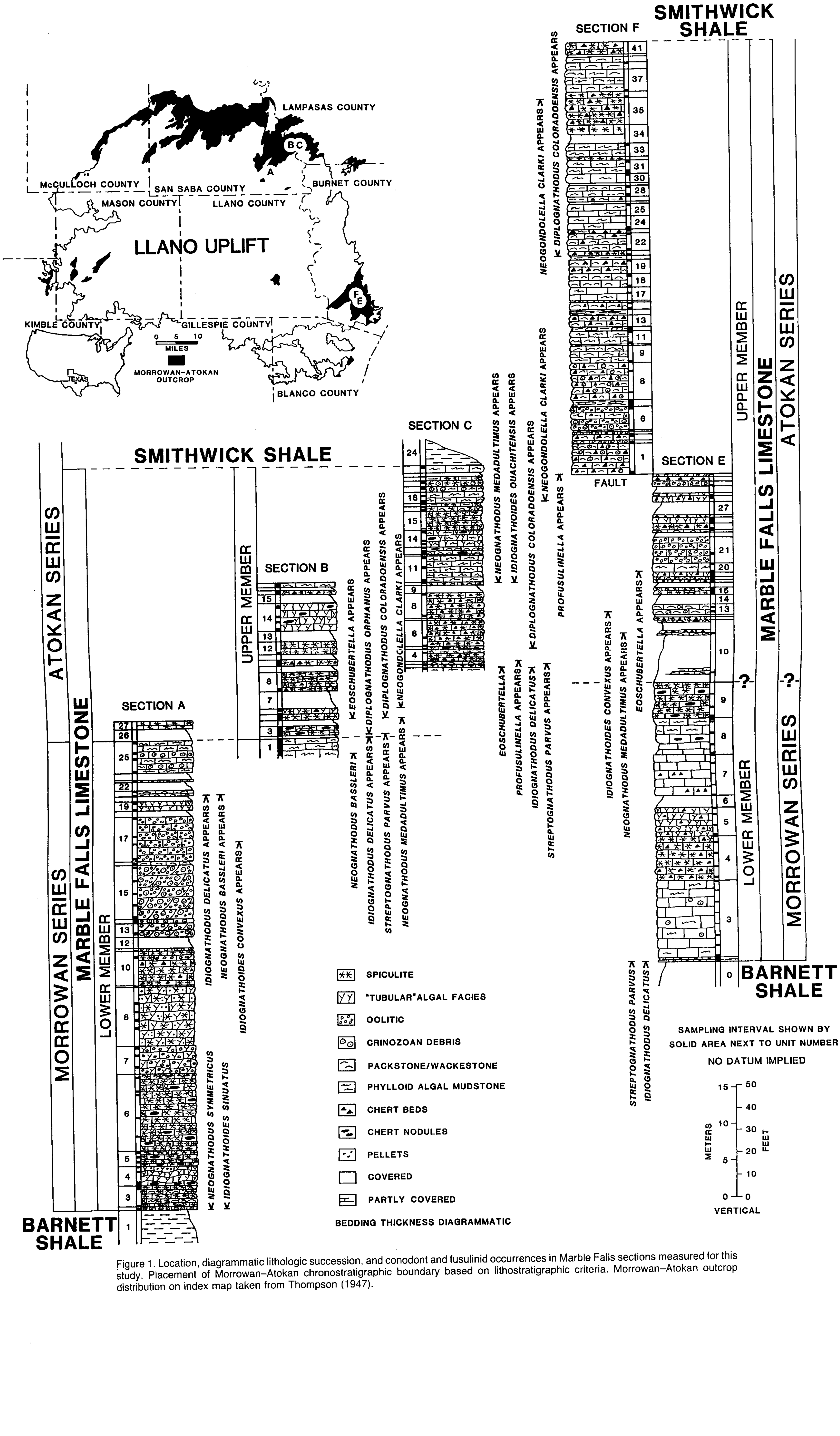


Figure 1. Location, diagrammatic lithologic succession, and conodont and fusulinid occurrences in Marble Falls sections measured for this study. Placement of Morrowan–Atokan chronostratigraphic boundary based on lithostratigraphic criteria. Morrowan–Atokan outcrop distribution on index map taken from Thompson (1947).

**Hill, R. T.**, 1889, A portion of the geologic story of the Colorado River of Texas: American Geologist, v. 3, p. 287–299.

**Kier, R. S.**, 1980, Depositional history of the Marble Falls Formation of the Llano region, central Texas, *in* Merrill, G. K., editor, Geology of the Llano region, Central Texas: West Texas Geological Society Guidebook 80-73, p. 59–75.

**Kier, R. S., Brown, L. F., Jr.**, and **McBride, E. F.**, 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Texas: U.S. Geological Survey Professional Paper 1110-S, p. S1–S45.

**Lane, H. R.**, 1977, Morrowan (Early Pennsylvanian) conodonts of northwestern Arkansas and northeastern Oklahoma, *in* Sutherland, P. K., and Manger, W. L., editors, Upper Chesterian–Morrowan stratigraphy and the Mississippian–Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 177–180.

**Liner, R. T., Manger, W. L.**, and **Zachry, D. L.**, 1979, Conodont evidence for the Mississippian–Pennsylvanian boundary, northeastern Llano region, central Texas: Texas Journal of Science, v. 31, p. 309–317.

**Mamet, B. L.**, 1975, Carboniferous Foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey Professional Paper 848-B, 18 p.

**Merrill, G. K.**, 1974, Pennsylvanian conodont localities in northwestern Ohio: Ohio Division of Geological Survey Guidebook 3, 29 p.

———1975, Pennsylvanian conodont biostratigraphy and paleoecology of northwestern Illinois: Geological Society of America Microform Publication 3, 129 p.

———editor, 1980, Geology of the Llano region, central Texas: West Texas Geological Society Guidebook 80-73, 246 p.

**Moore, R. C.**, and others, 1944, Correlation of Pennsylvanian formations of North America: Geological Society of America Bulletin, v. 55, p. 657–706.

**Plummer, F. B.**, 1945, Stratigraphy of the Lower Pennsylvanian coral-bearing strata of Texas: University of Texas Publication 4401, p. 1–79.

———1947, Lower Pennsylvanian strata of the Llano region—summary of classification: Journal of Paleontology, v. 21, p. 142–146.

———1950, The Carboniferous rocks of the Llano region of central Texas: University of Texas Publication 4329, 170 p.

**Spivey, R. C.**, and **Roberts, T. G.**, 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Sutherland, P. K.**, and **Manger, W. L.**, 1983, The Morrowan–Atokan (Pennsylvanian) boundary problem: Geological Society of America Bulletin, v. 94, p. 543–548.

**Thompson, M. L.**, 1947, Stratigraphy and fusulinids of pre-Desmoinesian Pennsylvanian rocks, Llano uplift, Texas: Journal of Paleontology, v. 21, p. 147–164.

**Turner, G. L.**, 1957, The Lampasas series, *in* Conselman, F. B., editor, Abilene and Fort Worth Geological Societies 1957 joint field trip guidebook: Abilene and Fort Worth Geological Societies, p. 85–90.

## Plate 1

(SEM photographs of gold-coated conodont elements from Marble Falls Limestone, Llano region, central Texas; section and sample zone given for each specimen and shown diagrammatically in figure 1)

Fig. 1.—*Streptognathodus parvus* Dunn, sample E-1, 75×.

Figs. 2, 3.—*Diplognathodus coloradoensis* (Murray and Chronic), sample B-6, 75×.

Fig. 4.—*Diplognathodus orphanus* (Merrill), sample B-3, 75×.

Figs. 5, 6.—*Neogondolella clarki* (Koike), sample C-17, 62×.

Figs. 7, 8.—*Neognathodus bassleri* (Harris and Hollingsworth), sample A-21, top 1 foot, 62×.

Figs. 9, 10.—*Neognathodus symmetricus* (Lane). *9*, sample A-2; *10*, sample A-17, 11–11.5 feet, 62×.

Figs. 11, 12.—*Idiognathoides convexus* (Ellison and Graves). *11*, sample A-21, top 1 foot; *12*, sample E-24; 62×.

Figs. 13, 14.—*Neognathodus medadultimus* Merrill. *13*, sample C-19; *14*, sample C-20; 45×.

Fig. 15.—*Idiognathoides ouachitensis* (Harlton), sample C-19, 62×.

Figs. 16, 17.—*Idiognathodus delicatus* Gunnell. *16*, sample E-1; *17*, sample A-21, top 1 foot; 62×.

Specimens reposited at the University Museum, University of Arkansas, by figure number on slides bearing the accession number 84-2.


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*Oklahoma Geological Survey Bulletin 136, 1984*

# ATOKAN STRATIGRAPHY OF THE SOUTHERN CORDILLERAN MIOGEOSYNCLINE AND ADJACENT SHELF PLATFORM, SOUTHEASTERN CALIFORNIA TO NORTHWESTERN ARIZONA

G. D. WEBSTER[1] and RALPH L. LANGENHEIM, JR.[2]

**Abstract**—Atokan strata in the southern part of the Cordilleran Miogeosyncline and adjacent shelf platform make up a thick sequence of fossiliferous shallow-marine carbonates with a few shale and sandstone interbeds. They can be divided into a western miogeosynclinal, a transitional shelf, and an eastern shelf–shoreline lithofacies. Unconformities are not recognized at the boundaries or within the eastern part of the miogeosynclinal lithofacies but may be present at the boundaries in the western part of the miogeosynclinal lithofacies. Unconformities are recognized at the base and within the eastern shelf–shoreline lithofacies. The sedimentary pattern is a reflection of nearly static tectonic elements of early Middle Pennsylvanian time in the southern part of the Cordilleran Miogeosyncline and adjacent shelf.

The excellent exposures, completeness of section, and rich fossil content of the western lithofacies support our proposal to consider a section in this area for boundary stratotypes and the stratotype for the lower Middle Pennsylvanian Series.

## INTRODUCTION

Atokan strata in the southern Cordilleran Miogeosyncline and adjacent shelf platform are known across northwestern Arizona, southern Nevada, and southeastern California (fig. 1). Except for a petrographic description of Atokan rocks in the southern Nevada area (Rich, 1969), the only discussions of these strata have been general descriptions of thick Carboniferous or Pennsylvanian–Permian sequences in papers describing local or regional geology (Hewett, 1931; Bissell, 1962; Brill, 1963; McKee and Crosby, 1975; among many others).

The objective of this paper is to summarize the regional stratigraphic and sedimentologic pattern for Atokan strata in the southern Cordilleran Miogeosyncline and adjacent shelf platform. The term Atokan is provisionally used herein, because we believe that problems exist in the type section in Oklahoma, and we question the continued use of the term for the lower Middle Pennsylvanian Series.

The base of the Atokan Series in this report is referred to the lowest occurrence of *Profusulinella* (Mamet foraminifer zone 22, Mamet and Skipp, 1970) and the top, to the lowest occurrence of *Wedekindellina* or *Fusulina*. It is recognized that a few modern workers have suggested that the base of the Atokan should be placed biostratigraphically lower as discussed in Langenheim and Webster (1979). Until boundary stratotypes have been established for the lower Middle Pennsylvanian, however, we prefer to follow the usage of most earlier workers, that is, the base of the *Profusulinella* Zone.

## LITHOSTRATIGRAPHY

From northwestern Arizona to southeastern California, Atokan rocks are assigned to numerous formations (fig. 2). However, they can be more logically divided into two major lithofacies, a western miogeosynclinal and an eastern shelf—shoreline lithofacies, which interfinger, forming a third or transitional lithofacies occupying a wide area in northwestern Arizona and southeastern Nevada approximately between the Grand Wash Cliffs to the east and the Muddy Mountains to the west (fig. 1). The area of interfingering coincides with the distribution of the Callville Limestone. McKee (1975b, p. 300), Wilson (1975, p. 317), and Welsh (1959, p. 58) stated that Atokan rocks are absent within the Callville Formation. This interpretation is incorrect, as shown by the presence of *Chaetetes* and *Fusulinella* within the Callville at several localities (see faunal discussion). In addition, preliminary conodont studies in progress by Webster clearly show that Atokan conodonts are present in the Callville Formation at Frenchman Mountain, Nevada.

The eastern facies is bounded below and above by erosional unconformities and was described by

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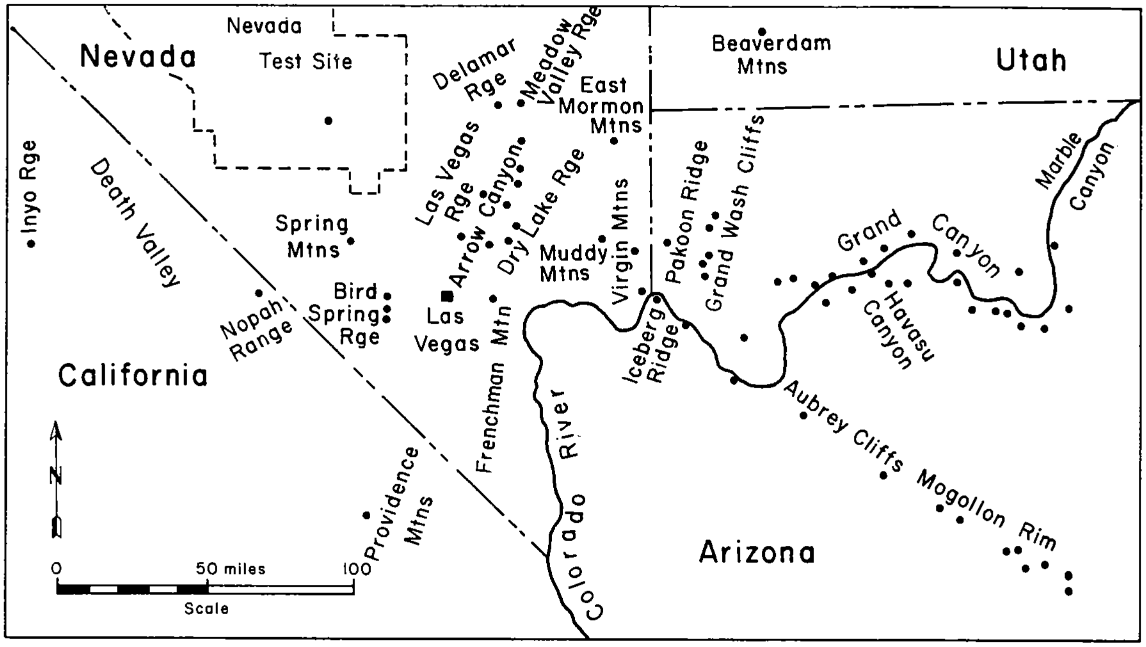


Figure 1. Map showing geographic features mentioned in text. Dots indicate measured sections with Atokan strata reported from various literature sources.

McKee (1975a, 1975b, 1979) and Blakey (1979, 1980). McKee (op. cit.) measured exposures along the Colorado River and its tributaries in Arizona. He reported an Atokan age for sandstones, siltstones, and a basal conglomerate in the Watahomigi Formation and for siltstones, limestones, and sandstones in the Manakacha Formation, based upon fusulinids. McKee (1975a) reported fusulinids present in Arizona throughout the Grand Canyon westward to Iceberg Ridge, but lacking faunal evidence he questioned the Atokan age of the upper part of the Manakacha Formation. Except for measured sections at Havasu Canyon (McKee, 1975a) and Iceberg Ridge (Lumsden and others, 1973; Beus, 1979), details of the other sections reported by McKee (1975b) along the Colorado River and its tributaries are unpublished. Blakey (1979, 1980) described and measured sections generally less than 300 feet thick along the Aubrey Cliffs and Mogollon Rim (fig. 1), demonstrating that lithostratigraphic units recognized by McKee in the Grand Canyon extend to the south, where they pinch out against the Sedona Arch in central Arizona. Blakey (op. cit.) interpreted the environment of deposition of the Watahomigi and Manakacha Formations as a sandy shoreline and shelf grading westward into a sandy carbonate shelf represented by the Callville Formation.

The Callville Formation was originally designated by Longwell (1921, 1928) for exposures in the Muddy Mountains, southern Nevada. Longwell and others (1965, pl. 1) mapped the Callville Formation in Clark County, Nevada, reporting it present at Frenchman Mountain, the Muddy Mountains and Virgin Mountains (fig. 1). Furthermore, Longwell and others (1965) noted that the section at Frenchman Mountain contains a number of sandstones and sandy limestones. Although a precise subdivision of the Callville was not presented, it was considered to include possibly Late Mississippian through Pennsylvanian into Early Permian strata.

McNair (1951) divided the Callville Formation at Pakoon Ridge and the Grand Wash Cliffs of Arizona into two members. He distinguished these members (p. 520) thus: "The lower member consists of thick-bedded, cliff-forming, commonly oolitic, limestones.... The upper member consists of silty, in many places cross-bedded, limestones that weather into subdued slopes." Lumsden and others (1973) also divided the Callville Formation at Frenchman Mountain, Azure Ridge, and Iceberg Ridge into a lower and an upper member; there the upper member contained a significantly higher percentage of quartz grains. In addition, Pierce (1979) divided the Callville Formation into a lower and an upper member at Lime Ridge and Pakoon Ridge but did not give reasons for this subdivision. He recognized the Supai Group and its formations rather than the Callville Formation at the Grand Wash Cliffs. Furthermore, Pierce (1979, fig. 111) showed an interfingering relationship of the upper member (of Atokan age) of the Watahomigi Formation and the upper part of the lower member of the Callville Formation. He

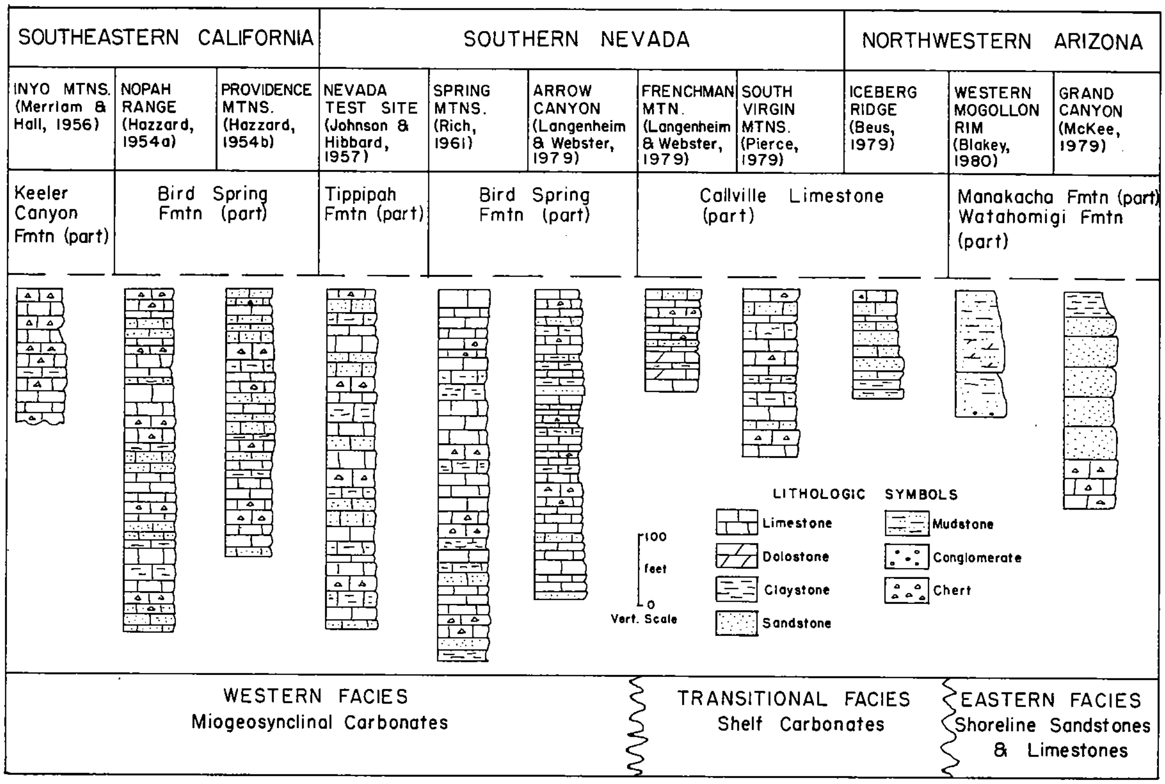


Figure 2. Correlation chart showing current lithostratigraphic terminology applied to Atokan strata in southern Nevada and adjacent states. Graphic columns are modified from indicated references above each column. Upper and lower limits for most columns are based on current paleontological data and may be modified with future work.

correlated the Manakacha Formation (containing *Fusulinella* in the lower part at Grand Wash Cliffs) with the basal part of the upper member of the Callville Formation. Pierce (1979) reported *Fusulina* and *Wedekindellina* approximately 35 feet above the base of the upper member of the Callville at Pakoon Ridge. This occurrence implies that the upper part of the Manakacha Formation, at least in its western extent, is of Desmoinesian age. To the east, at Iceberg Ridge and in the Grand Canyon region, it is thought to be only of Atokan age (Blakey, 1982, personal communication).

It is uncertain whether members of the Callville Formation recognized by McNair (1951), Lumsden and others (1973), and Pierce (1979) are directly correlatable with one another. However, reported fossil occurrences in the Callville Formation (see faunal discussion) suggest that Atokan strata are typically less arenaceous and correspond to the upper part of the lower member, and basal part of the upper member, of McNair (1951) and Pierce (1979) and the upper (but perhaps not uppermost) part of the lower member of Lumsden and others (1973).

The Atokan part of the Callville Formation is a sequence of shallow shelf carbonates of mixed facies. It contains abundant marine algae, oolites, and assorted, generally fragmentary marine invertebrates. There is an unconformity at the base of the Atokan in the eastern exposures of the Callville Formation, but the Atokan probably is conformable with underlying Morrowan strata to the west. The Atokan is believed to be conformable with the overlying Desmoinesian strata throughout its geographic distribution within the Callville Formation.

The western miogeosynclinal facies, a westward-thinning sequence of marine carbonates, is recognized in the Bird Spring, Tippipah, and Keeler Canyon Formations (fig. 2). Rich (1969) recognized nine major carbonate types of shallow-marine origin in the Atokan part of the Bird Spring Formation in southern and eastern Nevada and west-central Utah. Heath and others (1967) reported 11 carbonate microfacies in the Bird Spring Formation at Arrow Canyon, Nevada. In both studies, the facies relationships are shown to be complexly related and repeated. Webster (1969) found no individual Atokan beds or lithologic units that he could trace, with certainty, more than a few miles within the Meadow Valley, Arrow Canyon, and Las Vegas Ranges of Nevada. Still, his descriptions indicate vertical and lateral repetition of a few lithologic types. With additional study, some of the individual *Chaetetes*-bearing beds, as well as other lithologies, may prove to have considerable geographic extent within the area.

Rich (1969, p. 356) interpreted the Atokan western miogeosynclinal sequence as a "broad carbonate platform or carbonate shelf which was continuous eastward and northeastward with seaways covering the craton," having a "generally undulating bottom." In addition, Rich (1963) considered the *Komia*-bearing facies to represent warm, shallow-water deposition, less than 50 m deep, and suggested that the abundance of corals and algae in the Atokan beds indicate open, warm, shallow-water conditions. Heath and others (1967) considered the Atokan cyclic strata at Arrow Canyon to form the lower part of a major cycle of gradual regression. Furthermore, they believed the strata represented shallower water deposition (slightly below and above wave base), with less detrital quartz, than the rocks of the preceding Morrowan sequence.

Field observations by Webster suggest that the Bird Spring Formation contains a smaller percentage of detrital quartz of sand and silt size than the Tippipah and Keeler Canyon Formations. This difference in quartz content probably reflects the proximity of the latter two formations to the Antler Positive Area. Invertebrate fossils, commonly consisting of original shell material or silicified shells, are diverse and abundant in the western facies (Webster, 1969; Langenheim and Webster, 1979).

No unconformities are recognized at either boundary or within the Atokan strata in the eastern part of the miogeosynclinal lithofacies but may be present to the west.

Atokan strata in the southern Cordilleran Miogeosyncline are thickest (more than 1,000 feet) in the miogeosynclinal facies (fig. 3). They thin eastward and abut against the Sedona Arch

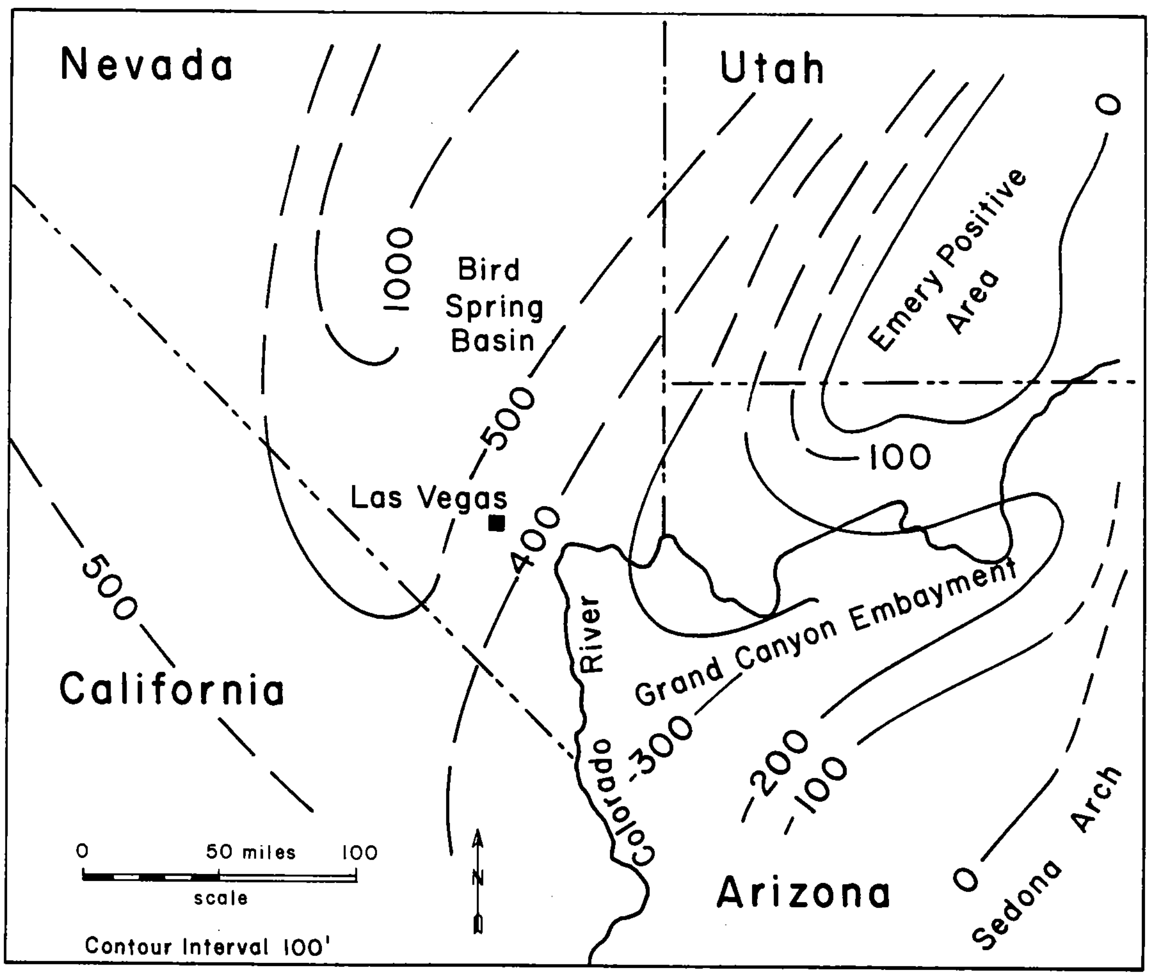


Figure 3. Isopach map of Atokan strata in southern Nevada and adjacent states. Modified from Blakey (1980) and McKee and Crosby (1975).

in central Arizona and the Emery Positive Area in south-central Utah. They thin and become more detritus bearing to the west approaching the Antler Positive Area. Divided into a western miogeosynclinal facies and an eastern shelf–shoreline facies separated by a transitional shelf facies, they reflect a sedimentation pattern developed by nearly static tectonic elements of the southern Cordilleran Miogeosyncline during Atokan time (fig. 4). The transitional facies, although containing most of the same major carbonate types and lithologically most similar to the western facies, is thinner and contains fewer well-preserved fossils. Atokan boundary unconformities present to the east in the shelf–shoreline facies are not recognized in the transitional facies or the eastern part of the miogeosynclinal facies but may be present to the west. Once the Atokan boundary has been determined on the basis of paleontologic evidence, lithologic differences corresponding to the boundary may be recognized. The lithologic differences may be used locally to trace the boundary for stratigraphic purposes, but they are not persistent throughout much of the region.

## TECTONIC FRAMEWORK

Atokan subsidence in the southern part of the Cordilleran Miogeosyncline is generally considered to be a continuation of, but less than, the subsidence of the preceding epoch (Coogan, 1964; Wilson, 1975; Rich, 1977). The area to the west was characterized during Atokan time by the Antler Positive Area (fig. 4), which shed some detrital clastics into the western part of the miogeosyncline (Bissell, 1962; Coogan, 1964; Rich, 1969; and others). The miogeosyncline trended northward and northeastward toward the Ely and Oquirrh Basins. It continued to subside as it filled with marine carbonates of the western facies. The western part of the cratonic shelf platform to the east was the deposition site of thinner arenaceous carbonates, which in turn graded into the clastic and

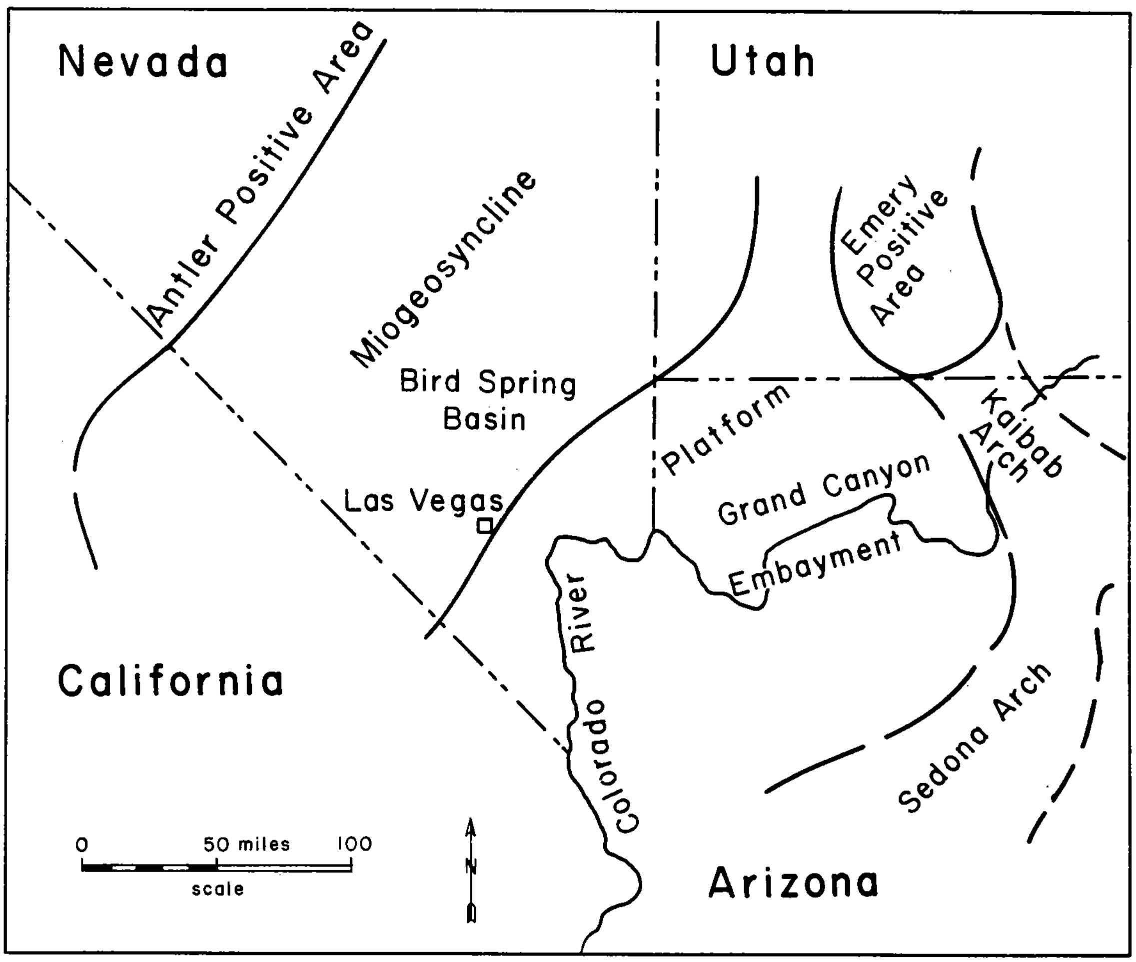


Figure 4. Tectonic elements of Atokan time in southern Nevada and adjacent states.

arenaceous carbonates of the eastern-facies shoreline sediments of the Grand Canyon Embayment (Blakey, 1979; McKee, 1979). Low-lying land areas of the Sedona Arch to the south, in central Arizona, and the Emery Positive Area to the north, in south-central Utah, formed the eastern margin of the Atokan seas. McKee (1975b) suggested that Atokan seas repeatedly extended across the Kaibab Arch in north-central Arizona to connect with the Paradox Basin of southeastern Utah and southwestern Colorado.

There is no evidence of any major tectonism within the area during Atokan time. This relative stability suggests that the repetitious lithologies discussed under the "Lithostratigraphy" section may have resulted from worldwide sea-level changes, perhaps as suggested for the late Paleozoic by Wanless and Shepard (1936). Periods of highest sea level would correspond with connections across the Kaibab Arch between the Grand Canyon Embayment and the Paradox Basin, extension of carbonate beds across the western part of the platform, and deposition of the deepest water carbonates in the miogeosyncline.

## CHARACTERISTIC FAUNA

Atokan strata in the western facies contain an abundant micro- and megafauna. Fossils are not common in the eastern facies. Except where specifically noted, the following discussions will be restricted to the western transitional facies and miogeosynclinal facies.

The Atokan can be subdivided on the basis of fusulinids into lower (Zone of *Profusulinella*) and upper (Zone of *Fusulinella*) parts. Mamet foraminiferal zone 22 corresponds to the Zone of *Profusulinella* (Mamet and Skipp, 1970). This small fusulinid has been reported at Lee Canyon (Rich, 1961), Las Vegas Range (Brill, 1963; Langenheim and others, 1977), Arrow Canyon Range (Coogan, 1964; Langenheim and Langenheim, 1965; Rich, 1969; Webster, 1969; Langenheim and others, 1977; Langenheim and Webster, 1979), Meadow Valley Range (Webster, 1969), Muddy Mountains (Welsh, 1959), and Dry Lake (Webster, 1969; Langenheim and others, 1977). *Profusulinella* is undoubtedly present elsewhere in southern Nevada and possibly occurs in southeastern California, but, if so, it has probably been overlooked because of its small size.

*Fusulinella* has been reported from the same sections as those of *Profusulinella* but in stratigraphically younger beds. In addition, it is reported from numerous other localities in southern Nevada (Brill, 1963; Webster, 1969); from the northern Nopah Range (Hazzard, 1954a, 1954b), southern Inyo Mountains (Merriam and Hall, 1957; Wilson, 1975), and northern Panamint Range (McAllister, 1952) in southeastern California; from the Beaverdam Mountains of southwestern Utah (Brill, 1963); and from Grand Gulch Ridge in northwestern Arizona (Pierce, 1979).

Perhaps the most diagnostic fossil for the Atokan in the southern Nevada area is the coral *Chaetetes* as discussed by Rich (1969). This tabulate coral forms colonies as much as 1 m high and 25 cm in diameter. It is commonly silicified and generally has associated syringoporids of the genus *Multithecopora* (Wilson, 1963; Coogan, 1964; Rich, 1969; Webster, 1969; Langenheim and Webster, 1979; Nelson and Langenheim, 1980). *Chaetetes* is easily recognized in the field. The genus ranges from Morrowan into Desmoinesian (Lane and Martin, 1966) but has been reported only from the late Atokan and earliest Desmoinesian in the area of this investigation. Clearly it is most common in the Atokan strata. Nelson and Langenheim (1980) restricted *Chaetetes favosus* to the later Atokan and *C. milleporaceous* to the earliest Desmoinesian, suggesting that they may be environmentally differentiated morphotypes of the same species.

*Chaetetes* is known from Atokan strata of the Bird Spring Range (Hewett, 1931; Welsh, 1959), Spring Mountains (Welsh, 1959; Rich, 1960, 1961; Brill, 1963), Las Vegas Range (Brill, 1963; Webster, 1969; Langenheim and others, 1977), Arrow Canyon Range (Welsh, 1959; Langenheim and others, 1962; Coogan, 1964; Langenheim and Langenheim, 1965; Rich, 1969; Webster, 1969; Langenheim and others, 1977; Langenheim and Webster, 1979), Meadow Valley Range (Webster, 1969), Frenchman Mountain (Brill, 1963; Webster and Langenheim, 1979), East Mormon Mountains (Rich, 1969), South Virgin Mountains (Pierce, 1979; Lumsden and others, 1973), Beaverdam Mountains in southwestern Utah (Brill, 1963), and Pakoon Ridge in northwestern Arizona (Pierce, 1979). Desmoinesian occurrences of *Chaetetes* are reported by Welsh (1959) from the Arrow Canyon Range, South Mormon Mountains, Muddy Mountains, Frenchman Mountain, and Bird Spring Range and by Nelson and Langenheim (1980) from Arrow Canyon and Dry Lake Ranges.

McKee (1979) and Blakey (1979), without naming the genera, referred to fossils, including fusulinids and corals, in the Watahomigi and Manakacha Formations of the eastern facies of the Atokan. Until the measured sections and fauna of Atokan age that McKee (1979) and Wilson (1975) reported in northwestern Arizona are published, it is uncertain how far the fusulinid and *Chaetetes* faunas may be extended eastward.

Rugose corals are commonly found in interbeds or in the same bed with *Chaetetes*. Webster (1969) recognized species of *Caninia, Lophophyllidium, Caninostrotion*?, and unidentified solitary and phaceloid rugose corals within Atokan strata in the Meadow Valley, Arrow Canyon, Las Vegas, and Dry Lake Ranges. Langenheim and Webster

(1979) reported *Pseudozaphrentoides* sp. and *Caninia* sp. from the Atokan at Arrow Canyon. Detailed studies of these corals are needed for more extensive stratigraphic correlation.

Conodonts are abundant in most Atokan carbonates in southern Nevada (Webster, 1969). Pierce (1979) reported conodonts of Morrowan or Atokan age from Pakoon Ridge directly below the occurrence of *Chaetetes* in the upper part of the lower Callville Formation. Dunn (1970) listed four conodont zones of Atokan age in the Spring Mountains at Lee Canyon.

Langenheim and Webster (1979) recognized two conodont zones, *Neognathodus* n. sp. and *Anchignathus coloradoensis*, in the lower Atokan at Arrow Canyon. These zones can be traced throughout the Arrow Canyon, Las Vegas, Meadow Valley, and Dry Lake Ranges. Rocks containing these zone fossils should also be present in the Spring Mountains. The *Anchignathus coloradoensis* Zone is present on Frenchman Mountain. Current conodont studies by Webster suggest that late Atokan conodont zones also are recognizable, based upon species of *Adetognathus, Neognathodus*, and *Idiognathodus*. Unfortunately these conodonts have not been studied in sufficient detail in the Atokan and younger strata of this region to determine fully their stratigraphic value.

Atokan brachiopods are abundant and diverse in southern Nevada but have not been studied in detail. Webster (1969) reported 21 species at Arrow Canyon. Productids and spiriferids dominate most faunas, with chonetids, athyrids, rhipidomellids, and orthotetids common. These forms are common throughout the Arrow Canyon, Meadow Valley, Las Vegas, and Dry Lake Ranges and in the Muddy and Virgin Mountains. With detailed study, it is highly probable that the Morrowan–Atokan and Atokan–Desmoinesian boundaries are definable on brachiopods in the Cordilleran Geosyncline.

Algal limestones are commonly interbedded with slightly deeper water shelf carbonates in southern Nevada. *Komia* was recognized as occurring in the *Fusulinella* Zone by Coogan (1964). *Donezella* is restricted to the Morrowan and Atokan, whereas *Dvinella* extends into the Desmoinesian in eastern and southern Nevada (Rich, 1967, 1969, 1971). *Osagia* was reported by Webster (1969) at Dry Lake and by Webster and Langenheim (1979) at Frenchman Mountain.

Molluscs are present but not abundant in southern Nevada. Webster (1969) reported a few genera of gastropods from the area. They do not appear to be of significant stratigraphic value. Gordon (1964) questionably identified a goniatite from the Providence Mountains of southeastern California as *Paralogoceras texanum* and assigned an Atokan age to it.

Other fossil groups, including arthropods (trilobites and ostracods), echinoderms (echinoids and crinoids), bryozoans, and fish remains, are recognized within the area (Webster, 1969). The fenestrate and ramose bryozoans and crinoid columnals occur in considerable abundance and diversity. They should be of stratigraphic value when investigated in detail.

## SUMMARY AND CONCLUSIONS

Lower Middle Pennsylvanian strata in the southern part of the Cordilleran Miogeosyncline, and adjacent shelf platform, constitute a thick sequence of fossiliferous shallow-marine carbonates with a few shale and sandstone interbeds. The sequence is well exposed at numerous localities and has been studied by several workers in the past few years.

Three laterally equivalent, major lithofacies are recognized across the area. The western miogeosynclinal lithofacies is formed of shallow-marine carbonates with minor sand and shale. It attains a maximum thickness greater than 1,000 feet and grades into the transition lithofacies eastward. It is best developed in the Bird Spring Formation in the Las Vegas and Arrow Canyon Ranges. The transitional lithofacies consists of shallow-water shelf carbonates with increasing sand and silt content eastward. It is 300 to 500 feet thick and corresponds to the Callville Formation. The eastern lithofacies is a complex of shelf–shoreline mudstones, siltstones, and limestones, generally less than 300 feet thick, that thin as they abut against positive areas to the east. This lithofacies is less complete than the western two lithofacies. It is recognized in the upper part of the Watahomigi and basal part of the Manakacha Formations of northwestern Arizona.

Unconformities are not recognized at the boundaries nor within the lower Middle Pennsylvanian strata in the central part of the miogeosynclinal or western facies, but an unconformity marks the base of the Atokan Series on the eastern shelf, and unconformities may be present at the base and top of the section in the western part of the miogeosynclinal facies.

The miogeosynclinal lithofacies should be given careful consideration as a stratotype, and as boundary stratotypes, for the lower Middle Pennsylvanian Series in United States stratigraphic nomenclature. It is recommended that the section at Arrow Canyon (Langenheim, Webster, and Weibel, this volume) be considered for designation as the stratotype, and boundary stratotypes, of the lower Middle Pennsylvanian Series.

## REFERENCES CITED

**Beus, S. S.**, 1979, Stop descriptions—fifth day, Arizona portion, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada:

Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 33–37.

**Bissell, H. J.**, 1962, Pennsylvanian and Permian rocks of Cordilleran area, *in* Branson, C. C., editor, Pennsylvanian System in the United States: American Association of Petroleum Geologists, p. 188–263.

**Blakey, R. C.**, 1979, Stratigraphy of the Supai Group (Pennsylvanian–Permian), Mogollon Rim, Arizona, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 89–104.

———1980, Pennsylvanian and Early Permian paleogeography, southern Colorado Plateau and vicinity, *in* Fouch, T. D., and Magathan, E. R., editors, Paleozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Paleogeography Symposium 1, p. 239–257.

**Brill, K. G., Jr.**, 1963, Permo-Pennsylvanian stratigraphy of western Colorado Plateau and eastern Great Basin regions: Geological Society of America Bulletin, v. 74, p. 307–330.

**Coogan, A. H.**, 1964, Early Pennsylvanian history of Ely Basin, Nevada: American Association of Petroleum Geologists Bulletin, v. 48, p. 487–495.

**Dunn, D. L.**, 1970, Conodont zonation near the Mississippian–Pennsylvanian boundary in western United States: Geological Society of America Bulletin, v. 81, p. 2959–2974.

**Gordon, Mackenzie, Jr.**, 1964, California Carboniferous cephalopods: U.S. Geological Survey Professional Paper 483-A, p. A1–A27.

**Hazzard, J. C.**, 1937, Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Journal of Mines and Geology, v. 33, p. 273–339.

———1954a, Revision of Devonian and Carboniferous sections, Nopah Range, Inyo County, California: American Association of Petroleum Geologists Bulletin, v. 38, p. 878–895.

———1954b, Rocks and structure of the northern Providence Mountains, San Bernardino County, California, *in* Jahns, R. H., editor, Geology of southern California: California Division of Mines Bulletin 170, p. 27–35.

**Heath, C. P., Lumsden, D. N.**, and **Carozzi, A. V.**, 1967, Petrography of a carbonate transgressive–regressive sequence; The Bird Spring Group (Pennsylvanian), Arrow Canyon Range, Clark County, Nevada: Journal of Sedimentary Petrology, v. 37, p. 377–400.

**Hewett, D. F.**, 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U.S. Geological Survey Professional Paper 162, 172 p.

**Johnson, M. S.**, and **Hibbard, D. E.**, 1957, Geology of the Atomic Energy Commission Nevada Proving Grounds area, Nevada: U.S. Geological Survey Bulletin 1021-K, p. 333–384.

**Lane, N. G.**, and **Martin, R. A.**, 1966, Redescription of *Chaetetes milleporaceus* Milne-Edwards and Haime, 1851: Journal of Paleontology, v. 40, p. 651–654.

**Langenheim, R. L., Jr., Carss, B. W., Kennerly, J. B., McCutcheon, V. A.**, and **Waines, R. H.**, 1962, Paleozoic section in Arrow Canyon Range, Clark County, Nevada: American Association of Petroleum Geologists Bulletin v. 46, p. 592–609.

**Langenheim, R. L., Jr., Nelson, W. J., Grove, K. A.**, and **McGovney, J. E.**, 1977, Fusulinids in carbonate microfacies of Bird Spring Group, Arrow Canyon quadrangle, Clark County, Nevada: Journal of Paleontology, v. 51, p. 1016–1022.

**Langenheim, R. L., Jr.**, and **Webster, G. D.**, 1979, Stop descriptions—sixth day, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 53–60.

**Langenheim, V. A. M.**, and **Langenheim, R. L., Jr.**, 1965, The Bird Spring Group, Chesterian through Wolfcampian, at Arrow Canyon, Arrow Canyon Range, Clark County, Nevada: Illinois Academy of Science Transactions, v. 57, p. 225–240.

**Longwell, C. R.**, 1921, Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs in western Arizona: American Journal of Science, 5th series, v. 1, p. 39–62.

———1928, Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U.S. Geological Survey Bulletin 798, 152 p.

**Longwell, C. R., Pampeyan, E. H., Bowyer, B.**, and **Roberts, R. J.**, 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines Bulletin 62, 218 p.

**Lumsden, D. N., Ledbetter, M. T.**, and **Smith, G. T.**, 1973, Lithostratigraphic analysis of the Birdspring–Callville Group and Pakoon Formation (Pennsylvanian–Lower Permian), southern Clark County, Nevada: Journal of Sedimentary Petrology, v. 43, p. 655–671.

**McAllister, J. F.**, 1952, Rocks and structure of the Quartz Spring area, northern Panamint Range, California: California Division of Mines Special Report 25, 38 p.

**McKee, E. D.**, 1975a, The Supai Group—subdivision and nomenclature: U.S. Geological Survey Bulletin 1395-J, p. J1–J11.

———1975b, Arizona, *in* Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853-P, p. 295–309.

———1979, Characteristics of the Supai Group in Grand Canyon, Arizona, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 105–113.

**McKee, E. D.**, and **Crosby, E. J.**, editors, 1975, Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853, parts 1–3.

**McNair, A. H.**, 1951, Paleozoic stratigraphy of part of northwestern Arizona: American Association of Petroleum Geologists Bulletin, v. 35, p. 503–541.

**Mamet, B. L.**, and **Skipp, B. A.**, 1970, Preliminary foraminiferal correlations of early Carboniferous strata in the North American Cordillera, *in* Colloque sur la stratigraphie du Carbonifère: Congrès et Colloques de l'Université de Liège, v. 55, p. 327–348.

**Merriam, C. W.**, and **Hall, W. E.**, 1957, Pennsylvanian and Permian rocks of the southern Inyo Mountains, California: U.S. Geological Survey Bulletin 1061-A, 13 p.

**Nelson, W. J.**, and **Langenheim, R. L., Jr.**, 1980, Ecological observations on *Chaetetes* in southern Nevada: Pacific Geology, v. 14, p. 1–22.

**Pierce, W. H.**, 1979, Biostratigraphy of the Upper Carboniferous (Pennsylvanian) in the Virgin Mountains of southern Nevada and northwestern Arizona, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 127–131.

**Rich, Mark**, 1960, *Chaetetes* in the Bird Spring formation near Lee Canyon, Clark County, Nevada: Journal of Paleontology, v. 34, p. 761–762.

———1961, Stratigraphic section and fusulinids of the Bird Spring formation near Lee Canyon, Clark County, Nevada: Journal of Paleontology, v. 35, p. 1159–1180.

———1963, Petrographic analysis of Bird Spring Group (Carboniferous–Permian) near Lee Canyon, Clark County, Nevada: American Association of Petroleum Geologists Bulletin, v. 47, p. 1657–1681.

———1967, *Donezella* and *Dvinella*, widespread algae in Lower and Middle Pennsylvanian rocks in east-central Nevada and west-central Utah: Journal of Paleontology, v. 41, p. 973–980.

———1969, Petrographic analysis of Atokan carbonate rocks in central and southern Great Basin: American Association of Petroleum Geologists Bulletin, v. 53, p. 340–366.

———1971, Middle Pennsylvanian rocks of eastern Great Basin: American Association of Petroleum Geologists Bulletin, v. 55, p. 432–453.

———1977, Pennsylvanian paleogeographic patterns in the western United States, *in* Stewart, J. H., Stevens, C. H., and Fritsche, A. E., editors, Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 87–111.

**Wanless, H. R.**, and **Shepard, F. P.**, 1936, Sea level and climatic changes related to late Paleozoic cycles: Geological Society of America Bulletin, v. 47, p. 1177–1206.

**Webster, G. D.**, 1969, Chester through Derry conodonts and stratigraphy of northern Clark and southern Lincoln counties, Nevada: University of California Publications in Geological Sciences, v. 79, 121 p.

**Webster, G. D.**, and **Langenheim, R. L., Jr.**, 1979, Stop descriptions—seventh day: Clark County, Nevada, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 73–78.

**Welsh, J. E.**, 1959, Biostratigraphy of the Pennsylvanian and Permian systems in southern Nevada: University of Utah unpublished Ph.D. dissertation, 321 p.

**Wilson, E. C.**, 1963, The tabulate coral *Multithecopora* Yoh from the *Chaetetes–Profusulinella* faunizone in eastern Nevada: Journal of Paleontology, v. 36, p. 157–163.

**Wilson, R. F.**, 1975, Nevada and southern California, *in* Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853-Q, p. 311–328.

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# ATOKAN ROCKS OF THE BIRD SPRING GROUP ARROW CANYON, CLARK COUNTY, NEVADA

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**Abstract**—Carbonate rocks of the late Morrowan through early Desmoinesian portion of the Arrow Canyon section of the Bird Spring Group are completely exposed in a section paralleled by a passable road within a few tens of feet of the outcrops. Atokan, or Derryan, rocks are reportedly 100 to 200 m thick, depending upon whose boundary determinations are accepted. Fusulinids and conodonts were described, and their ranges determined, by Cassity and Langenheim (1966) and by Webster (1969). In addition, Lane and others (1972) made an independent determination of the basal Atokan boundary, using fusulinids and conodonts. *Chaetetes* (Nelson and Langenheim, 1980) and the syringoporoids (Fritz and others, 1981) have been described and their ranges determined; also, many other invertebrate occurrences have been described, and their ranges determined, in theses and lists. Finally, stratigraphic and microfacies studies (Coogan, 1962; Langenheim and Langenheim, 1965; Heath and others, 1967) reinforce the biostratigraphy in demonstrating continuous deposition of the Atokan sequence.

We propose that the Arrow Canyon section be seriously considered as a western stratotype sequence for the Atokan. In support of such consideration, most of the significant published occurrences and ranges of fossils in the section have been related to a common, detailed section description. In addition, photographs of the entire section have been marked in the field with unit boundaries as described in the principal reports on the section.

## INTRODUCTION

The sequence of Pennsylvanian rocks exposed at Arrow Canyon is notably complete, well exposed, and readily accessible. It has been proposed as a stratotype section for both the Mississippian–Pennsylvanian and the Pennsylvanian–Permian boundaries for western North America. Rocks biostratigraphically equivalent to the Atokan, Derryan, or Lampasan Series occur in apparently uninterrupted succession with rocks of undoubted Morrowan and Desmoinesian age. Thus, the boundaries of these series, no matter where they may be placed, fall within a continuous sequence of carbonate rocks. Fusulinacean foraminifers, bryozoans, brachiopods, and conodonts are notably abundant throughout the sequence. Solitary corals, syringoporoids, *Chaetetes*, and echinoderms are moderately abundant. Molluscs, however, are poorly represented, and no ammonoid cephalopods have yet been noted. Thus, all of the more widely utilized zonal fossil groups of Atokan age, except for ammonoid cephalopods, occur throughout the sequence, and it should be possible to locate zone boundaries with reasonable precision. Therefore, this paper presents the Arrow Canyon section as a possible reference or stratotype section for post-Morrowan and pre-Desmoinesian rocks in the Cordilleran area.

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## LOCATION

The Arrow Canyon section is within a canyon cut by a superposed intermittent stream that crosses the northern end of the Arrow Canyon Range, in the northeast corner of the Arrow Canyon Quadrangle, Clark County, Nevada (fig. 1). The Arrow Canyon Quadrangle is bounded by lat. 36° 30′ N. and 36° 45′ N., and long. 114° 45′ W. and 115° 00′ W. The Arrow Canyon exposure is in the E½ sec. 11 and S½ sec. 12, T. 14 S., R. 64 E., and in the SW¼ sec. 7, T. 14 S., R. 65 E., about 50 miles northeast of Las Vegas.

To reach the canyon, take Interstate Highway 15 north to Glendale, Nevada, and proceed 14 miles northwest on State Highway 168. At the northwestern end of an extensive irrigated area, turn left on a secondary paved road and proceed about 200 yards south, crossing an unbridged dry wash. This wash debouches from Arrow Canyon. Near the south wall of the Arrow Canyon drainage, a jeep trail runs northwest from the paved road, through a rubbish dump. This trail crosses and recrosses the active wash, ultimately entering a narrow, rock-walled canyon. The top of the Pennsylvanian sequence is near the inflection point at which rocks dipping 30°–35° southeastward abruptly flatten. Missourian and Virgilian rocks crop out in a series of strike gullies and ridges, and Desmoinesian rocks largely form the narrow, cliffed portion of the canyon just northwest of the prominent iron-stained, cherty silt-

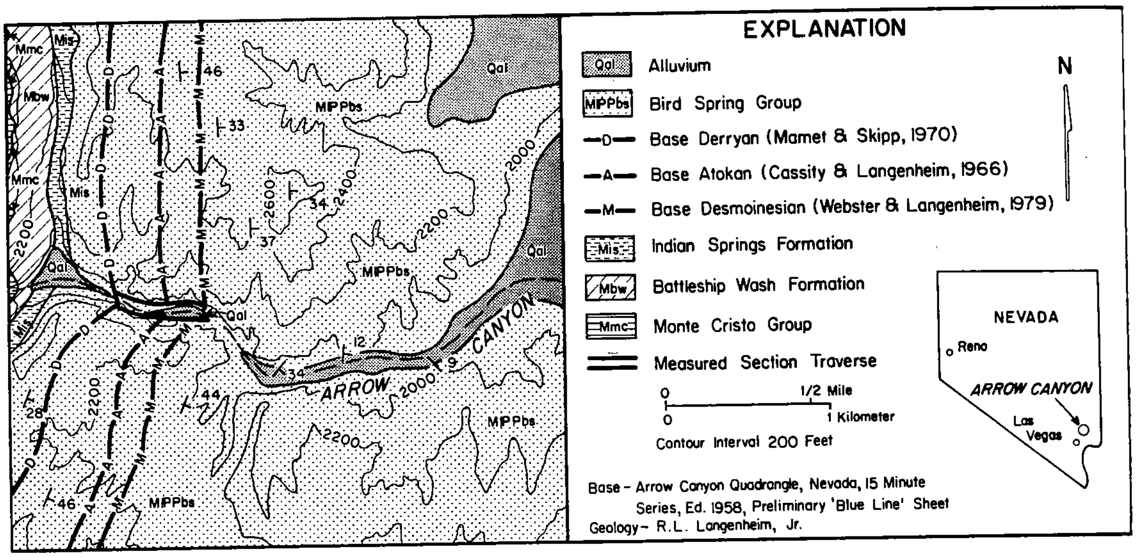


Figure 1. Geologic map of Arrow Canyon area, southeastern Nevada.

stone layer. Atokan rocks are exposed in the widened portion of the canyon upstream from the Desmoinesian cliffs, with the Morrowan sequence beginning in the narrower canyon above.

## PREVIOUS INVESTIGATIONS

Although Longwell (1928) mentioned 3,080 feet of well-exposed Carboniferous rocks at Arrow Canyon, serious study of the Pennsylvanian sequence, including the Atokan, began with Welsh's (1959) doctoral dissertation on the regional biostratigraphy of the Pennsylvanian and Permian in southern Nevada. This work describes the Arrow Canyon section in detail, including stratigraphically referenced faunal lists. It is the fundamental work on the section, and it is unfortunate that it remains unpublished.

Since Welsh's (1959) study, partial or complete measured sections of the Arrow Canyon section were published by Langenheim and others (1962), Brill (1963), Coogan (1964), Langenheim and Langenheim (1965), Cassity and Langenheim (1966), Webster (1969), Webster and Langenheim (1979), and Nelson and Langenheim (1980).

Heath and others (1967) petrographically studied most of the Pennsylvanian portion of the Arrow Canyon stratigraphic section, describing and illustrating the major carbonate-rock types (microfacies) and relating them to an inferred transgressive–regressive depositional pattern. Using their classification, any of the carbonate rocks in the sequence may be related to a presumed relative depth of deposition, as well as to other presumed environmental factors.

Cassity and Langenheim (1966) described fusulinids and reported their stratigraphic range in the Arrow Canyon section, and Webster (1969) described conodonts and their stratigraphic distribution in the Chesterian through Derryan sequence. Nelson and Langenheim (1980) described *Chaetetes* occurrences and reported their stratigraphic occurrence, and Wilson and others (1963) reported an occurrence of *Komia eganensis* in a systematic study introducing the species. In addition, Welsh (1959), Coogan (1964), Langenheim and Langenheim (1965), Webster (1969), Webster and Lane (1970), Lane and others (1972), Webster and Langenheim (1979), and Nelson and Langenheim (1980) listed fossil occurrences in the "Atokan" portion of the section.

Mamet and Skip (1970) and Lane and others (1972) cited occurrences of foraminifers and conodonts, and their relative stratigraphic range, from the base of the section through the base of the zone of *Profusulinella*. However, Dunn (1976) offered a different interpretation of these data.

## STRATIGRAPHIC SEQUENCE

Independent measurements and descriptions of the Arrow Canyon section are difficult to relate to one another. The sequence is thick, lithologic types are repetitive, measurements have been accomplished by different techniques, and the accuracy of the various workers was far from uniform. In addition, finding a specific described bed or unit from written descriptions or graphic columns is time consuming, and the results are seldom totally unambiguous. Therefore, we have photographically recorded the entire Pennsylvanian sequence, marking unit boundaries on the photographs so that any described unit can be located relatively quickly and accurately. Figures 2–12 are a series of photographs of the Atokan, Derryan, or Lampasan exposures in Arrow Canyon, marked to show the units described by Webster (1969), Langenheim (1964, as modified by Cassity and Langenheim, 1966) and subsequent workers in the University of Illinois group, and Nelson and Langenheim (1980).

The "standard" section for Arrow Canyon is related to measurements made by Amoco geologists, who placed brass markers and yellow lines at 1.5-m intervals throughout the canyon, from the top of the Chesterian–Meramecian Battleship Wash Formation through the entire Pennsylvanian and a few meters into the Permian. Utilizing written descriptions in Langenheim (1964), Webster (1969), and Nelson (1973), Langenheim and Weibel marked these authors' unit boundaries on photographs they carried in the field. In addition, Weibel subdivided some of the units described by Langenheim (1964), in the course of his own investigations of tabulate corals.

Figures 2 through 12 illustrate the sequence from the base of Webster's unit 54 (WEB 54), which is within Langenheim's unit 42 (VAL 42), through the base of Langenheim's unit 143 (VAL 143) and the top of Nelson's unit 48 (NEL 48). This sequence includes the base of the Derryan as identified by Mamet and Skipp (1970) and Lane and

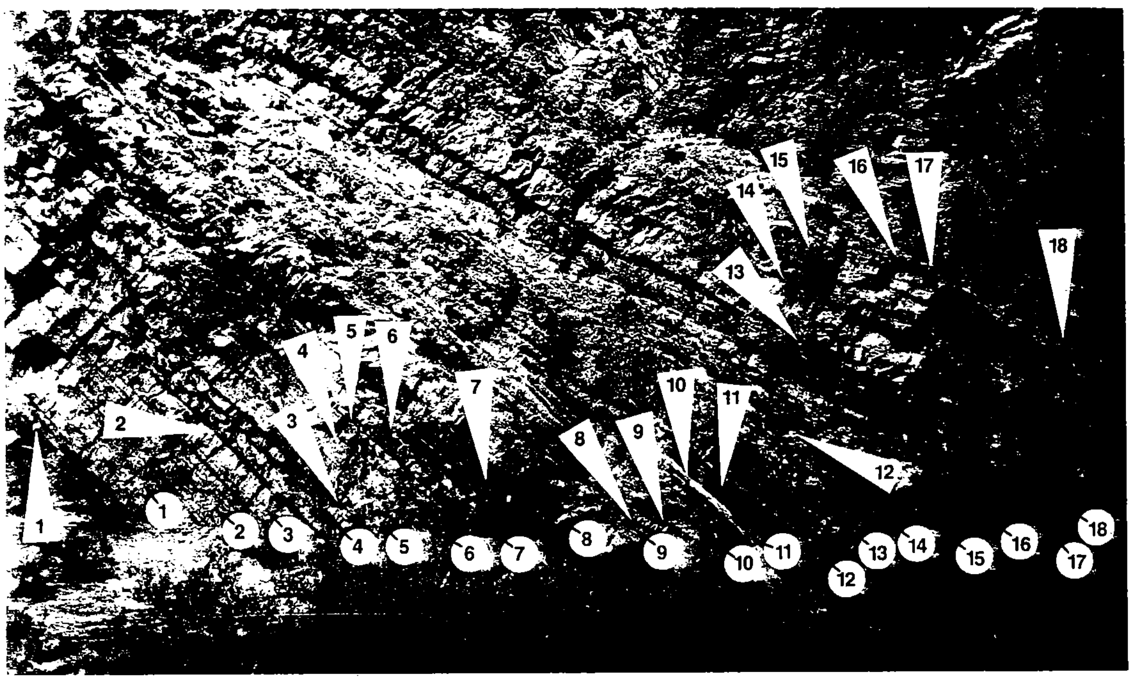


Figure 2. Middle Morrowan units as exposed on north wall at Arrow Canyon; VAL units 42A through 46; WEB units 53 through 59; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows.

| Unit boundaries | Stratigraphic measurement points |
|---|---|
| 1–WEB 53/54 | 1–A113 |
| 2–VAL 42A/42B | 2–A114 |
| 3–VAL 42B/43A, WEB 54/55 | 3–A115 |
| 4–VAL 43A/43B | 4–A116 |
| 5–VAL 43B/43C | 5–A117 |
| 6–VAL 43C/43D, WEB 55/56 | 6–A118 |
| 7–VAL 43D/43E | 7–A119 |
| 8–VAL 43E/43F | 8–A120 |
| 9–VAL 43F/43G, WEB 56/57 | 9–A121 |
| 10–VAL 43G/43H | 10–A122 |
| 11–VAL 43H/43I | 11–A123 |
| 12–VAL 43I/44 | 12–A124 |
| 13–VAL 44/45A, WEB 57/58 | 13–A125 |
| 14–VAL 45A/45B | 14–A126 |
| 15–VAL 45B/45C | 15–A127 |
| 16–VAL 45C/45D | 16–A128 |
| 17–WEB 58/59 | 17–A129 |
| 18–VAL 45D/46 | 18–A130 |

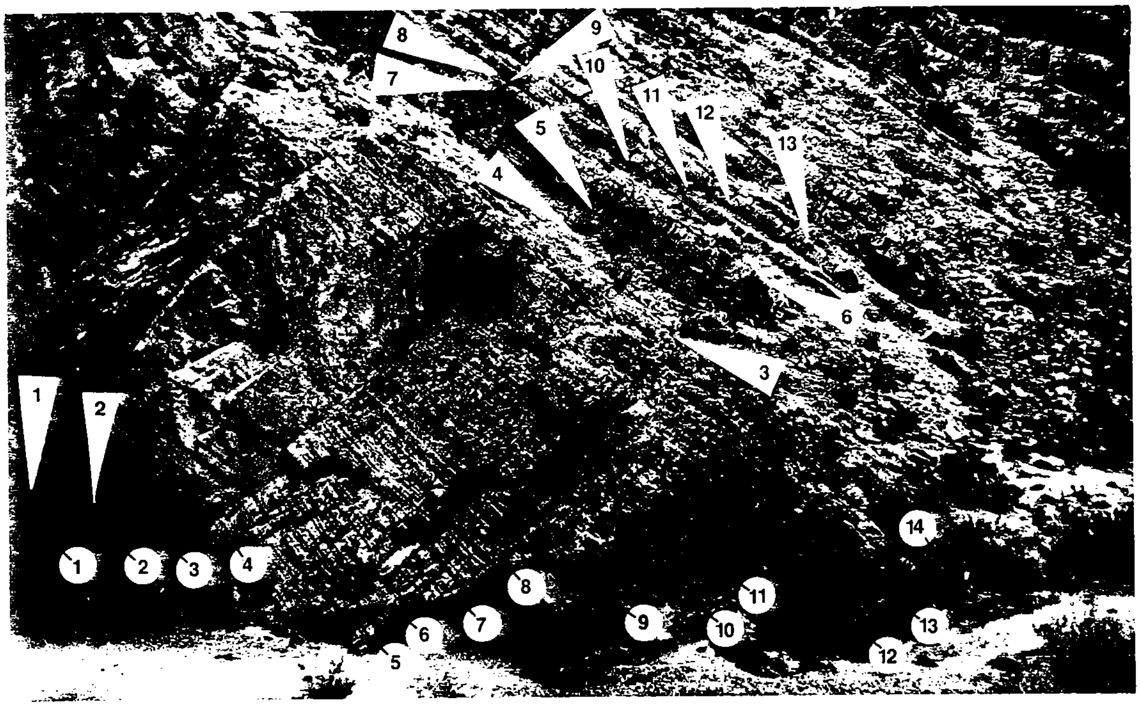

Figure 3. Middle Morrowan units as exposed on north wall at Arrow Canyon; VAL units 45D through 57; WEB units 58 through 61: boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows; VAL 49A/49B, 49B/49C, 54A/54B not shown.

Unit boundaries

1–VAL 45D/46, WEB 58/59
2–VAL 46/47
3–VAL 47/48
4–VAL 48/49A
5–VAL 49C/50
6–VAL 50/51
7–VAL 51/52
8–VAL 52/53, WEB 59/60
9–VAL 53/54A, WEB 60/61
10–VAL 54B/55
11–VAL 55/56
12–VAL 56/57

Stratigraphic measurement points

1–A133
2–A134
3–A135
4–A136
5–A137
6–A138
7–A139
8–A140
9–A141
10–A142
11–A143
12–A144
13–A145
14–A146


Figure 4. Middle Morrowan units as exposed on south wall at Arrow Canyon; VAL units 57 through 66A; WEB units 61 through 66: boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows; VAL units 62 and 63 are omitted because of section repetition caused by drag folding on north wall; VAL 60A/60B, WEB 63/64 stratigraphically in correct position, but indicated on slumped stratum.

Unit boundaries

1–VAL 57/58A, WEB 61/62
2–VAL 58A/58B
3–VAL 58B/59
4–VAL 59/60A, WEB 62/63
5–VAL 60A/60B, WEB 63/64
6–VAL 60B/60C, WEB 64/65
7–VAL 60C/61
8–VAL 61/64A
9–VAL 64A/64B
10–VAL 64B/65
11–VAL 65/66A, WEB 65/66

Stratigraphic measurement points

1–A161
2–A162
3–A163
4–A164
5–A165
6–A166
7–A167
8–A168
9–A169
10–A170
11–A171
12–A172
13–A173
14–A174
15–A175
16–A176
17–A177

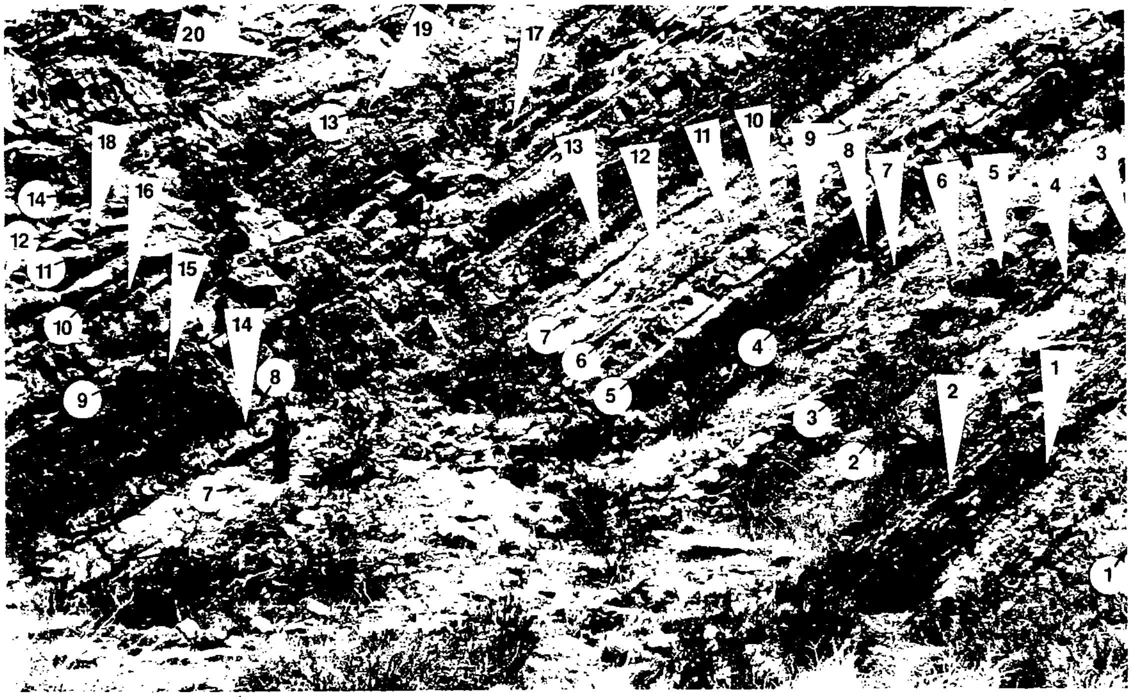


Figure 5. Upper Morrowan units as exposed on south wall at Arrow Canyon; VAL units 64B through 79; WEB units 65 through 72; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows.

Unit boundaries

1–VAL 64B/65
2–VAL 65/65A, WEB 65/66
3–VAL 66A/66B
4–VAL 66B/67
5–VAL 67/68
6–VAL 68/69
7–VAL 69/70
8–VAL 70/71
9–VAL 71/72
10–VAL 72/73A, WEB 66/67
11–VAL 73A/73B
12–VAL 73B/74
13–VAL 74/75A, WEB 67/68
14–VAL 75A/75B
15–VAL 75B/76A, WEB 68/69
16–VAL 76A/76B
17–VAL 76B/77A, WEB 69/70
18–VAL 77A/77B
19–VAL 77B/78, WEB 70/71
20–VAL 78/79, WEB 71/72

Stratigraphic measurement points

1–A170
2–A174
3–A175
4–A176
5–A177
6–A178
7–A179
8–A180
9–A181 projected along bedding
10–A182 projected along bedding
11–A183 projected along bedding
12–A184 projected along bedding
13–A185 projected along bedding
14–A186 projected along bedding


Figure 6. Upper Morrowan units as exposed on south wall at Arrow Canyon; VAL units 78 through 88A; WEB units 71 through 78; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows.

| Unit boundaries | Stratigraphic measurement points |
|---|---|
| 1–VAL 78/79, WEB 71/72 | 1–A186 |
| 2–VAL 79/80, WEB 72/73 | 2–A187 |
| 3–VAL 80/81 | 3–A188 |
| 4–VAL 81/82A | 4–A189 |
| 5–VAL 82A/82B | 5–A190 |
| 6–VAL 82B/83, WEB 73/74 | 6–A191 |
| 7–VAL 83/84, WEB 74/75 | 7–A192 |
| 8–VAL 84/85, WEB 75/76 | 8–A193 |
| 9–VAL 85/86 | 9–A194 |
| 10–VAL 86/87A, WEB 76/77 | 10–A195 projected along bedding |
| 11–VAL 87A/87B | 11–A196 |
| 12–VAL 87B/88A, WEB 77/78 | 12–A197 projected along bedding |
| | 13–A198 projected along bedding |


Figure 7. Upper Morrowan units as exposed on south wall at Arrow Canyon; VAL units 83 through 90D; WEB units 74 through 80; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows.

Unit boundaries

1–VAL 83/84, WEB 74/75
2–VAL 84/85, WEB 75/76
3–VAL 85/86
4–VAL 86/87A, WEB 76/77
5–VAL 87A/87B
6–VAL 87B/88A, WEB 77/78
7–VAL 88A/88B
8–VAL 88B/89, WEB 78/79
9–VAL 89/90A, WEB 79/80
10–VAL 90A/90B
11–VAL 90B/90C
12–VAL 90C/90D

Stratigraphic measurement points

1–A195
2–A196
3–A197
4–A198
5–A199
6–A200
7–A201
8–A202 projected along bedding
9–A203 projected along bedding
10–A204 projected along bedding

Figure 8. Upper Morrowan units as exposed on south wall at Arrow Canyon; VAL units 90C through 97; WEB units 80 through 85; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows.

Unit boundaries

1–VAL 90C/90D
2–VAL 90D/90E
3–VAL 90E/90F
4–VAL 90F/91, WEB 80/81
5–VAL 91/92, WEB 81/82
6–VAL 92/93A, WEB 82/83
7–VAL 93A/93B
8–VAL 93B/94
9–VAL 94/95, WEB 83/84
10–VAL 95/96A
11–VAL 96A/96B
12–VAL 96B/97, WEB 84/85

Stratigraphic measurement points

1–A203
2–A204
3–A205
4–A206
5–A207 projected along bedding
6–A208 projected along bedding
7–A209
8–A210
9–A211
10–A212
11–A213
12–A214 projected along bedding
13–A215 projected along bedding
14–A216 projected along bedding
15–A217 projected along bedding
16–A218 projected along bedding


Figure 9. Upper Morrowan–lower Atokan units as exposed on north wall at Arrow Canyon; VAL units 96C through 104; WEB units 85 through 90; NEL units 1 through 11; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) are marked on south wall. Arrow 4 is to be disregarded.

Unit boundaries

1–VAL 96B/97, WEB 84/85
2–VAL 97/98, WEB 85/86
3–VAL 98/99
5–Bottom of NEL 1
6–VAL 99/100, WEB 86/87, NEL 1/2
7–VAL 100/101A, NEL 2/3, Morrowan–Atokan boundary (Cassity and Langenheim, 1966; Webster, 1969)
8–VAL 101A/101B, NEL 3/4
9–VAL 101B/102, NEL 4/5
10–VAL 102/103A, WEB 87/88, NEL 5/6
11–VAL 103A/103B, NEL 6/7
12–VAL 103B/103C, WEB 88/89, NEL 7/8
13–VAL 103C/103D, NEL 8/9
14–VAL 103D/103E, NEL 9/10
15–VAL 103E/104, WEB 89/90, NEL 10/11

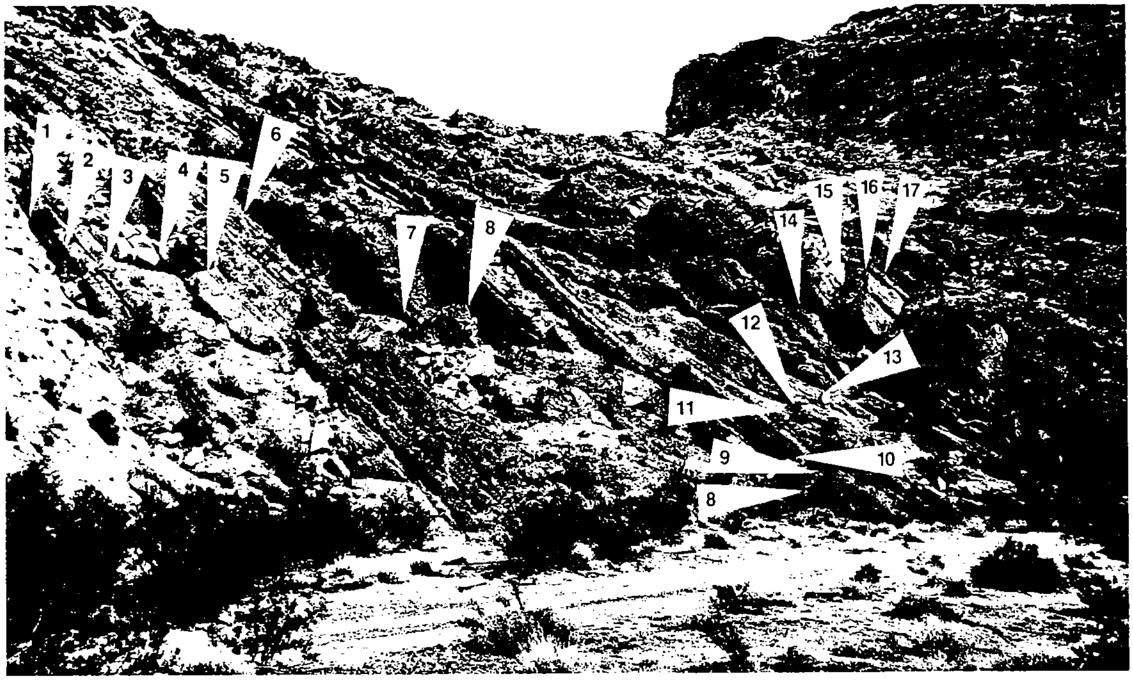


Figure 10. Lower and upper Atokan units as exposed on north wall at Arrow Canyon; VAL units 103E through 115E; WEB units 89 through 99; NEL units 10 through 25; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) are marked on south wall; WEB 92/93 not shown.

Unit boundaries

1–VAL 103E/104, WEB 89/90, NEL 10/11
2–NEL 11/12
3–VAL 104/105, NEL 12/13
4–VAL 105/106, WEB 90/91, NEL 13/14
5–VAL 106/107
6–VAL 107/108, WEB 91/92, NEL 14/15
7–VAL 108/109, WEB 93/94, NEL 15/16
8–VAL 109/110, WEB 94/95, NEL 16/17
9–VAL 110/111
10–VAL 111/112, NEL 17/18, lower Atokan–upper Atokan boundary (Langenheim and Webster, 1979)
11–VAL 112/113, WEB 95/96, NEL 18/19 (lower portion of NEL 19 is covered)
12–VAL 113/114, NEL 19/20
13–VAL 114/115A, WEB 96/97, NEL 20/21
14–VAL 115A/115B, WEB 97/98, NEL 21/22
15–VAL 115B/115C, WEB 98/99, NEL 22/23
16–VAL 115C/115D, NEL 23/24
17–VAL 115D/115E, NEL 24/25


Figure 11. Upper Atokan units as exposed on north wall at Arrow Canyon; VAL units 115C through 128; WEB units 99 through 107; NEL units 23 through 38; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) are marked on south wall; VAL 125/126, 126/127 not shown.

Unit boundaries

1–VAL 115C/115D, NEL 23/24
2–VAL 115D/115E, NEL 24/25
3–VAL 115E/116A, WEB 99/100, NEL 25/26
4–VAL 116A/116B, WEB 100/101, NEL 26/27
5–VAL 116B/117, WEB 101/102, NEL 27/28
6–VAL 117/118, NEL 28/29
7–VAL 118/119, NEL 29/30
8–VAL 119/120, WEB 102/103, NEL 30/31
9–VAL 120/121, WEB 103/104, NEL 31/32
10–VAL 121/122, WEB 104/105, NEL 32/33
11–VAL 122/123A, NEL 33/34
12–VAL 123A/123B, NEL 34/35
13–VAL 123B/124, WEB 105/106, NEL 35/36
14–VAL 124/125, WEB 106/107, NEL 36/37
15–VAL 127/128, NEL 37/38


Figure 12. Atokan(?)–Desmoinesian(?) units as exposed on north wall at Arrow Canyon; VAL units 124 through 143; WEB units 106 through 109; NEL units 36 through 48; boundaries between units marked by arrows; stratigraphic measurement points (Amoco numbers) marked by dots with black arrows; VAL 125/126, 126/127 not shown; VAL 139/140 hidden from view.

Unit boundaries

1–VAL 124/125, WEB 106/107, NEL 36/37
2–VAL 127/128, NEL 37/38
3–VAL 128/129
4–VAL 129/130, NEL 38/39
5–VAL 130/131, NEL 39/40
6–VAL 131/132, WEB 107/108, NEL 40/41 (on tilted bed)
7–VAL 132/133, WEB 108/109, NEL 41/42
8–VAL 133/134, NEL 42/43
9–VAL 134/135, Atokan–Desmoinesian boundary (Langenheim and Webster, 1979)
10–VAL 135/136A, top of WEB 109
11–VAL 136A/136B, NEL 43/44
12–VAL 136B/137, NEL 44/45
13–VAL 137/138, NEL 45/46
14–VAL 138/139, NEL 46/47
15–VAL 140/141
16–VAL 141/142, NEL 47/48
17–VAL 142/143, top of NEL 48

Stratigraphic measurement points

1–A276
2–A277
3–A278
4–A279
5–A280
6–A281
7–A283
8–A284
9–A285
10–A286 projected along bedding
11–A287 projected along bedding
12–A288 projected along bedding
13–A289 projected along bedding
14–A290 projected along bedding

others (1972), and the top of the Atokan as identified by Webster and Langenheim (1979). Cassity and Langenheim (1966), Nelson (1973), and Nelson and Langenheim (1980) located the base of the Desmoinesian at the base of unit VAL 152, about 160 feet above this contact. Thus, except for these uppermost rocks of questionable Atokan age, the photographs illustrate the entire sequence of presumed Atokan, Lampasan, or Derryan age. Also, the Amoco datum points, or their projected position, from A113, or 165.5 m above the base of their section, to A290, or 435 m above the base of their section, are located on the photographs. Figures 13–16 are columnar sections related to the Amoco datum points and the Webster (1969), Langenheim (1964), and Nelson (1973) units. Series boundaries are placed according to Langenheim and Webster (1979).

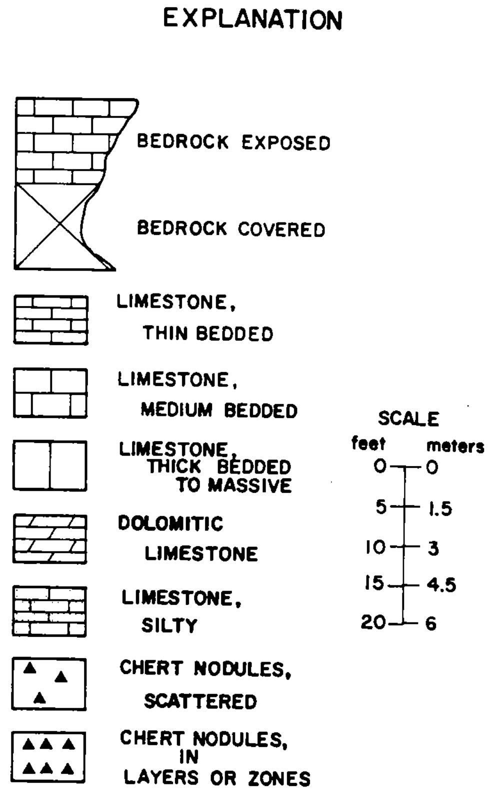


Figure 13. Explanation of columnar sections.

## BIOSTRATIGRAPHY

Algae, invertebrates, and fish fossils reported by Langenheim and Langenheim (1965), Cassity and Langenheim (1966), Webster (1969), Webster and Lane (1970), Lane and others (1972), Nelson (1973), Webster and Langenheim (1979), and Nelson and Langenheim (1980), along with syringoporoid occurrences tabulated by Weibel for this paper, clearly indicate that the Atokan, Derryan, or Lampasan rocks at Arrow Canyon are abundantly fossiliferous (figs. 17–22). Additional faunal lists in theses by Welsh (1959) and Coogan (1962) supplement the published material, but have not yet been incorporated in our comprehensive faunal list because Coogan's and Welsh's stratigraphic columns are difficult to compare with those of the other authors.

Lane and others (1972), working with fusulinids and conodonts, placed the base of foraminiferal zone 21, and the base of the Derryan, at the base of WEB unit 56. Dunn (1976), relying on conodont distribution, located the base of the series at about 60 to 90 m higher in the sequence. Webster and Langenheim (1979) accepted the base of the zone of *Profusulinella* as the bottom of the Atokan or Derryan, at the base of WEB 87. Lane and others (1972) also agreed that the base of the zone of *Profusulinella* occurs at the base of WEB 87, which means that differences in opinion regarding the series boundary here are philosophic rather than related to fossil occurrences in the section. In this work (fig. 15), the basal contact has been placed at the base of VAL 101, which is within the lower part of WEB 87. Also, without offering an opinion as to the merit of including zone 21 within the Atokan, we have elected to label the rocks in that zone as "Morrowan."

Langenheim and Webster (1979) concurred in locating the base of the zone of *Fusulinella* at the base of NEL 18 and WEB 95, which they correlated. Examination of the section, however, indicates that NEL 18 and VAL 112, which Cassity and Langenheim (1966) considered to contain the lowermost *Fusulinella*, probably compose only the uppermost portion of WEB 95. This usage is followed herein (fig. 16). This finding does not imply any differences in the field occurrences of the lowermost individuals of *Fusulinella*.

Webster and Langenheim (1979, fig. 62) and Langenheim and Webster (1979, fig. 48) reported *Fusulina* in WEB 109 and NEL 43. In this report, the bed in question is identified as VAL 135. Cassity and Langenheim (1966) earlier placed the base of the Desmoinesian at the base of VAL 152, on the basis of the occurrence of *Wedekindellina*. At this boundary, further collection and critical evaluation of fusulinid identifications probably are needed.

## CONCLUSION

Although questions remain as to the most appropriate location for the Morrowan–Atokan and Atokan–Desmoinesian boundaries in the Arrow Canyon section, abundant fossils, excellent exposures, and ready accessibility make this locality attractive for further work to determine these boundaries precisely in a useful stratotype section.

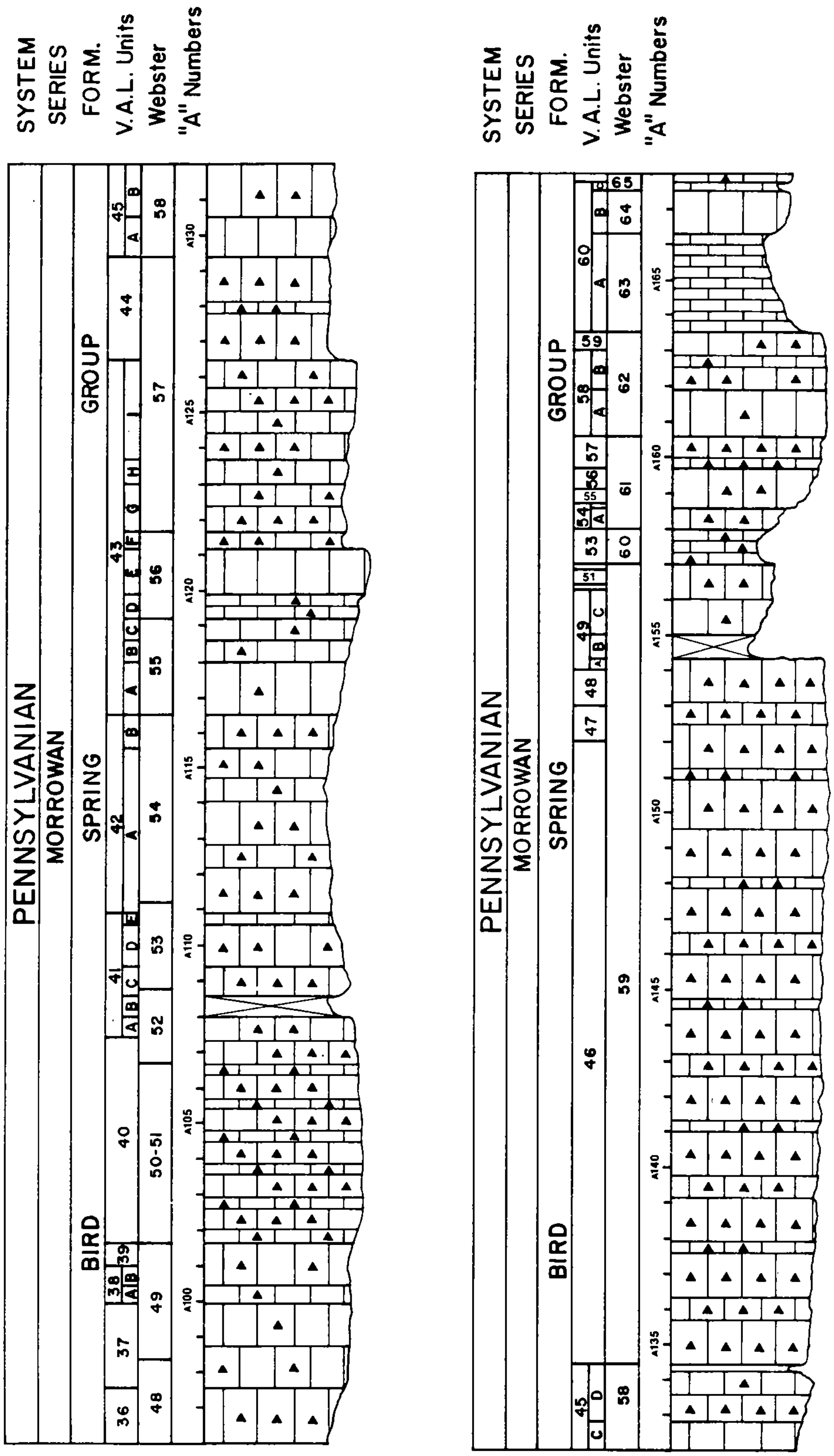


Figure 14. Columnar section, Morrowan, VAL 36–61.

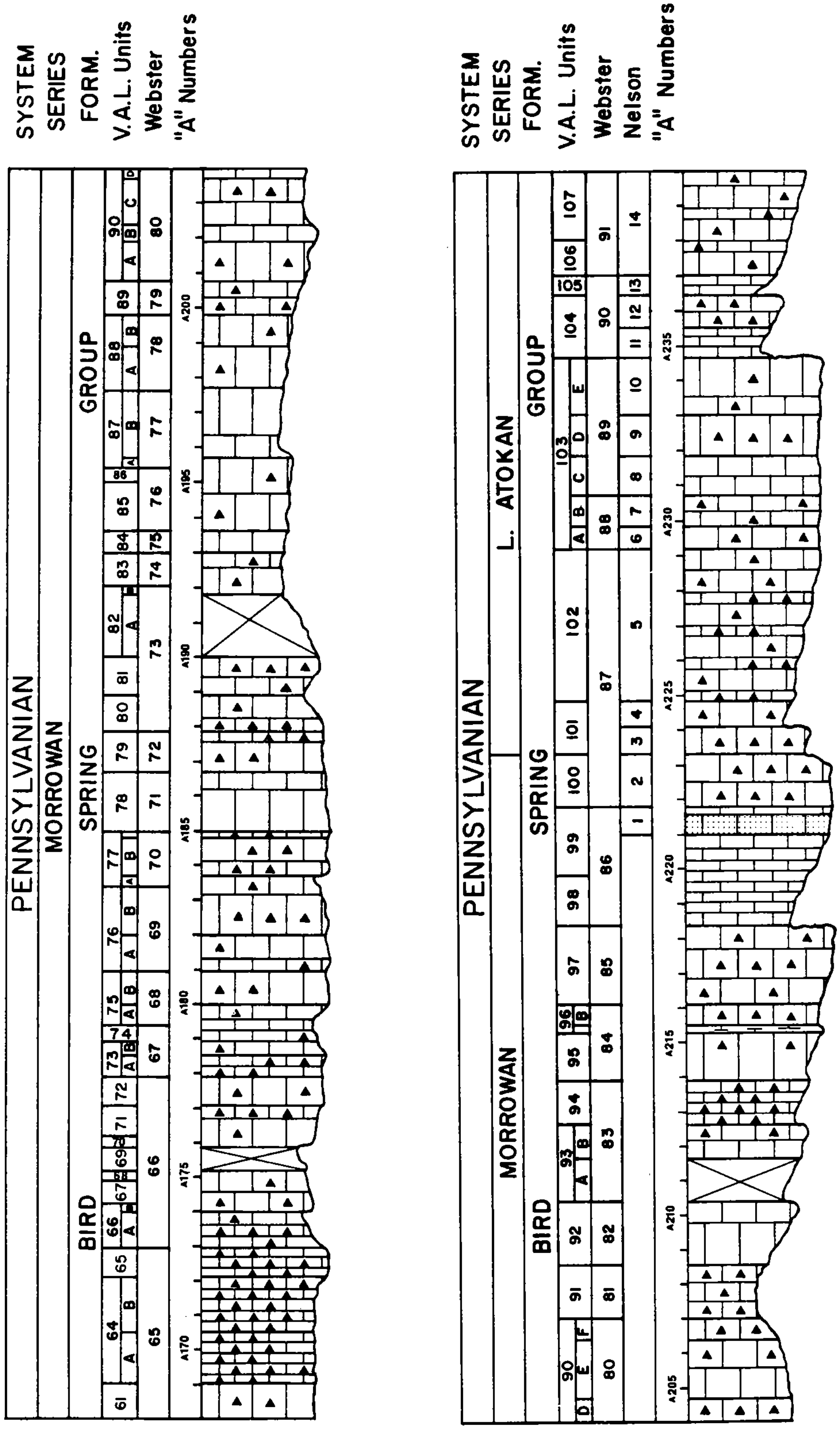


Figure 15. Columnar section, Morrowan and lower Atokan, VAL 61–107.

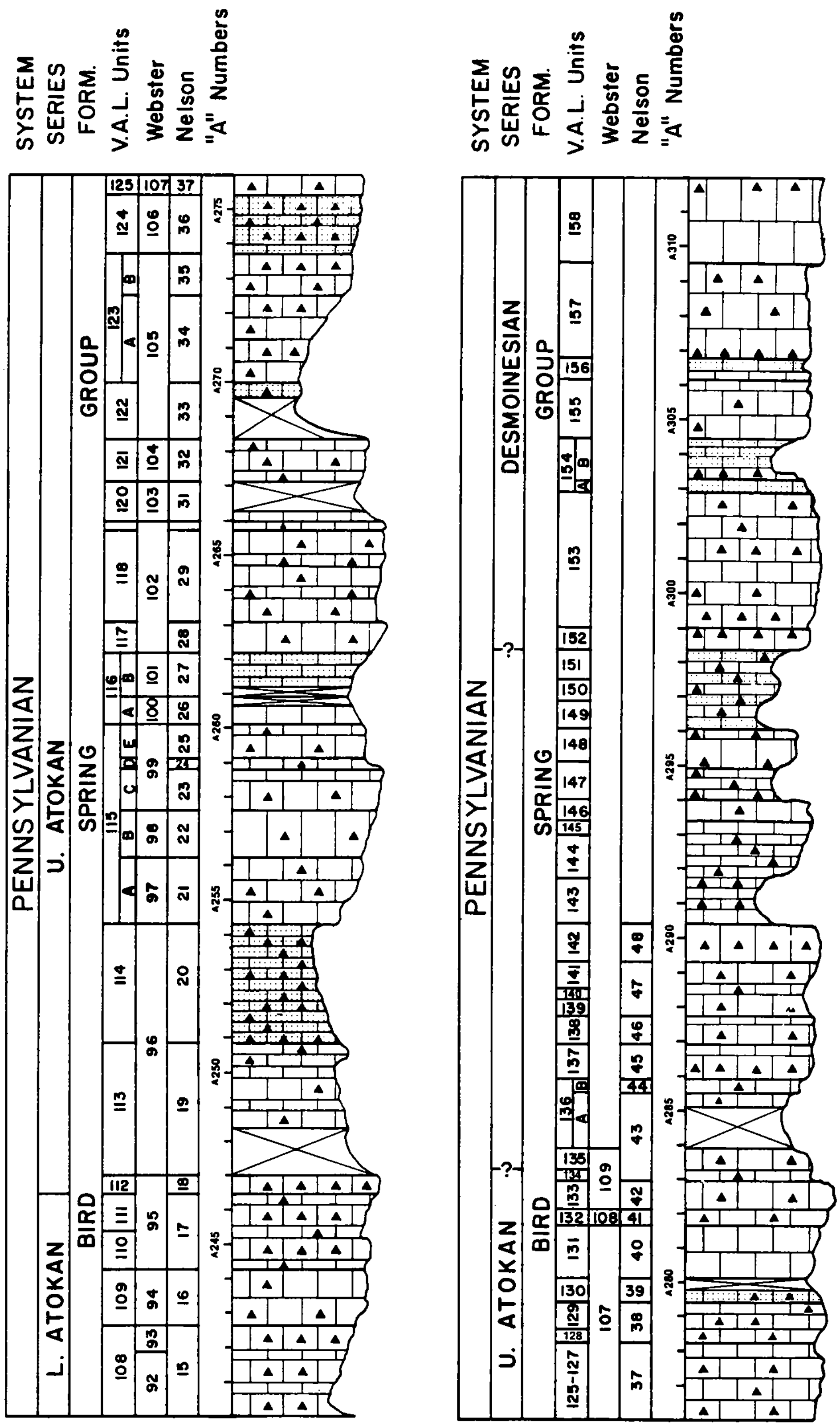


Figure 16. Columnar section, Atokan and Desmoinesian, VAL 108–158.

| V. A. Langenheim Units | V | 43 | | | | | 44 | 45 | | | | 46-52 | 53 | 54-7 | 56 | 58 | 59 | 60 | | 60C-65 | 66-72 | 73-5 | 76 | | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | | 89 | 90 | | | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subdivisions of V.A.L. Units | V' | D | E | F | G | H-I | | A | B | C | D | | | | | | | A | B | | | | A | B | | | | | | | | | | | | A | B | | A-C | D | E-F | | | | | | | | |
| Webster Units | W | 56 | | | 57 | | | 58 | | | | 59 | 60 | 61 | | 62 | | 63 | 64 | 65 | 66 | 67-8 | 69 | | 70 | 71 | 72 | 73 | | | 74 | 75 | 76 | | 77 | 78 | | 79 | 80 | | | 81 | 82 | 83 | | 84 | | 85 | 86 |
| Nelson Units | N | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ALGAE | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Donezella sp. | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Komia sp. | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FORAMINIFERA | F | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eoschubertella sp. | 3 | L | S | V | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fusulina sp. | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fusulinella sp. | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F. acuminata | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F. devexa | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F. fugax | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Millerella sp. | 9 | | | | | | C | | | C | C | | | | | | C | | | | | | C | | | | C | | C | | | C | C | | | C | | | | C | | | | | C | C | | C | |
| M. marblensis | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Paramillerella sp. | 11 | | | | | | C | | | C | | | | | | | C | | | | | | | | | | C | | | | | | C | | | C | C | | | C | | | | | | | | C | |
| P. ampla | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Profusulinella sp. | 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| P. regia | 14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| P. spicata | 15 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pseudostaffella sp. | 16 | | | | | | | | | C | | | | | | | C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Wedekindellina sp. | 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PORIFERA | P | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| sponge spicules | 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| COELENTERATA | C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Caninia sp. | 19 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. torquia | 20 | | | | ← | W→ | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | |
| Caninostrotion ? sp. | 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chaetetes sp. | 22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. favosus | 23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lophophyllidium sp. | 24 | | | | | | | ← | W | — | → | | | | | | | | | | | | | | | | W | | | | | | | | | | | W | | | | W | | W | → | | | | |
| Michelinia sp. | 25 | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Multithecopora sp. | 26 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M. hypatiae | 27 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pseudozaphrentoides sp. | 28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| solitary rugose coral | 29 | | | | | | | | | | | | | W | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stereostylus n. sp. | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Syringopora sp. | 31 | | | ● | | | | ←● | ● | W | → | | | | | | | | | | | | | | | | W● | | | | | | | | | | | ● | | | | | | | | | | | |
| BRYOZOA | B | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 17. Consolidated fossil list, part A.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| encrusting | 32 | | | | | | | | | | | | | | | | | | | | | | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | |
| fenestrate | 33 | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | |
| ramose | 34 | | | | | | | | | | | W | | | | W | | | | | | | W | | W | | ←W→ | | | | | | | | | | | | | | | W→ | | | | | | | |
| BRACHIOPODA | BR | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Antiquatonia sp. | 35 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A. coloradoensis | 36 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A. elyensis | 37 | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A. hermosana | 38 | | | | | | | | | | | | | | | | | | | | | | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | |
| A. morrowensis | 39 | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Anthracospirifer sp. | 40 | | | | | ←W→ | | | | | W | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A. birdspringensis | 41 | | | | | | | | | | | | W→ | | | W | | | | | | | W | | | | ←W→ | | | | | | | | | | | | | | | W→ | | | | | | | |
| A. opimus | 42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| buxtonid | 43 | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cleiothyridina orbicularia | 44 | | | | | | | | | | | | | | | W | | | | | | | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | |
| Composita sp. | 45 | | | | | | | | | | | W | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. ovata | 46 | | | | | | | | | | | | W→ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. subtilita | 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. trilobata | 48 | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dictyoclostus sp. | 49 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Echinaria sp. | 50 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eolissochonetes keyesi | 51 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | |
| Linoproductus sp. | 52 | | | | | | | | | | W | W | W→ | | | | | W | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | |
| L. prattenianus | 53 | | | | | | | | | | | | | L | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lissochonetes sp. | 54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Neospirifer sp. | 55 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | |
| N. cameratus | 56 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. triplicatus | 57 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | |
| orbiculoid | 58 | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Orbiculoidea capuliformis | 59 | | | | | ←W→ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W→ | | | | | | | |
| Orthotetes sp. | 60 | | | | | | | | | | | | | | | | | | | | | | | | W | | ←W→ | | | | | | | | | | | | | W | | W→ | | | | | | | |
| productid | 61 | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rhipidomella elyensis | 62 | | | | | | | | | | | | | | | | | | | | | | W | | W | | ←W→ | | | | | | | | | W | | | | W | | | | | | | | | |
| Rugosochonetes sp. | 63 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spirifer occiduus | 64 | | | | | | | | | | | | | L | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spiriferellina sp. | 65 | | | | | | | | | | | | | | | | | | | | | | W | | W | | | | | | | | | | | | | | | | | | | | | | | | |
| S. campestris | 66 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | W→ | | | | | | | |
| ECHINODERMATA | E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Archeocidaris sp. | 67 | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| crinoid columnals & fragments | | | | | | | | | | | W/ | W/ | | | | | | | | | | | W/ | | | | | | | | | | | | | | | | | | | | | | | | | | |
| echinoid spines & plates | 68 | | | | | | | | | | | // | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| V. A. Langenheim Units | V | 43 | | | | | 44 | 45 | | | | 46-52 | 53 | 54-7 | 56 | 58 | 59 | 60 | | 60C-65 | 66-72 | 73-5 | 76 | | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | | 89 | 90 | | | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subdivisions of V. A. L. Units | V' | D | E | F | G | H-I | | A | B | C | D | | | | | | | A | B | | | | A | B | | | | | | | | | | | | A | B | | A-C | D | E-F | | | | | | | | |
| Webster Units | W | 56 | | | 57 | | | 58 | | | | 59 | 60 | 61 | | 62 | | 63 | 64 | 65 | 66 | 67-8 | 69 | | 70 | 71 | 72 | 73 | | | 74 | 75 | 76 | | 77 | 78 | | 79 | 80 | | | 81 | 82 | 83 | | 84 | | 85 | 86 |
| Nelson Units | N | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Endelocrinus solus | 70 | | | | | | | | | | | LW | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stenopecrinus pedersenorum | 71 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Paragassizocrinus calyculoides | | | | | | | | | | | | W | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ARTHROPODA | AR | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| unidentified trilobite | 73 | | | | | | | | | | | | W | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | |
| MOLLUSCA | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| Fish debris | Fi | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CONODONTA | CO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| C. gigantus | 79 | | | | ← | W | → | | | | | W | | | | ← | W | W | | | | | | | | W | | | | | | W | | | | | | | ← | W | → | | W | | | | | | |
| C. lautus | 80 | | | | ← | W | → | | | | | W | | ← | W | | | W | | | W | | | | | W | | | | | | W | | | | | | | ← | W | → | | W | | | ← | W | | |
| C. spathus | 81 | | | | ← | W | → | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Gnathodus sp. | 82 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bassleri | 83 | | | | | | | | | | | | | | | | | | | | W | | | | | | W | ← | W | → | | | | | | | | | ← | W | → | | | | | | | | |
| G. opimus | 84 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ← | W | → | | | | | ← | W | | |
| Hindeodella sp. | 85 | ← | W | → | ← | W | → | ← | — | W | → | W | | ← | W | | | W | | W | W | | | | | W | W | | | | | | | | | | | | | | | | | | | ← | W | | |
| Idiognathodus sp. | 86 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I. claviformis | 87 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I. delicatus | 88 | ← | W | → | ← | W | → | ← | — | W | → | W | | ← | W | ← | W | | | | W | | | | | W | W | ← | W | → | | W | | | | | | | ← | W | → | W | W | | | ← | W | | |
| Idiognathoides convexa | 89 | ← | W | → | ← | W | → | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ligonodina sp. | 90 | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lonchodina sp. | 91 | | | | | | | | | | | | | ← | W | | | W | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ozarkodina campbelli | 92 | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | |
| O. delicatula | 93 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ← | W | → | | | | | | | | |
| Roundya sp. | 94 | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spathognathodus minutus | 95 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ← | W | → | | | | | | | | |
| Streptognathodus expansus | 96 | ← | W | → | ← | W | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. noduliferus | 97 | ← | W | → | ← | W | → | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. suberectus | 98 | | | | ← | W | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 19. Consolidated fossil list, part C.

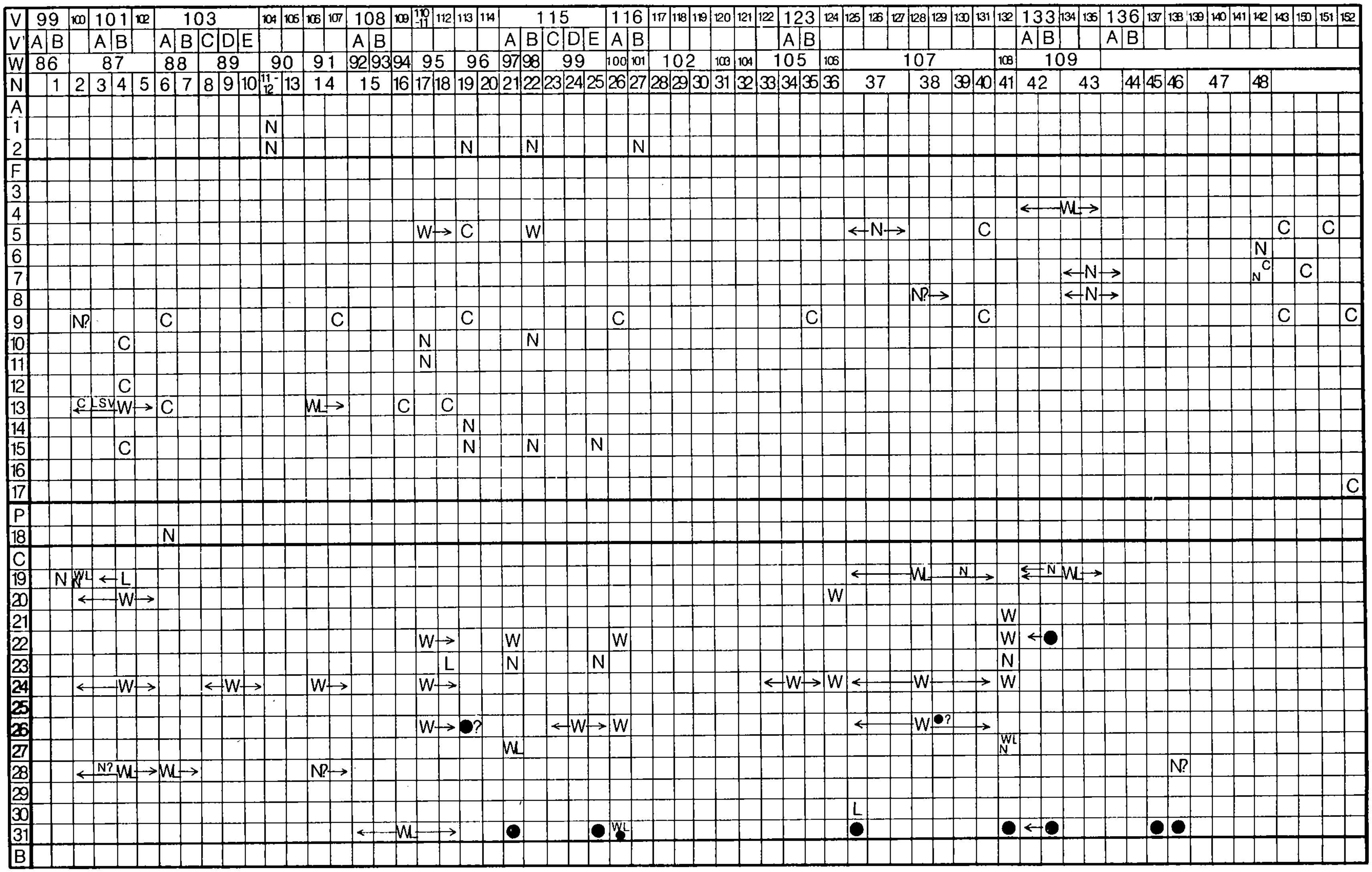


Figure 20. Consolidated fossil list, part D.

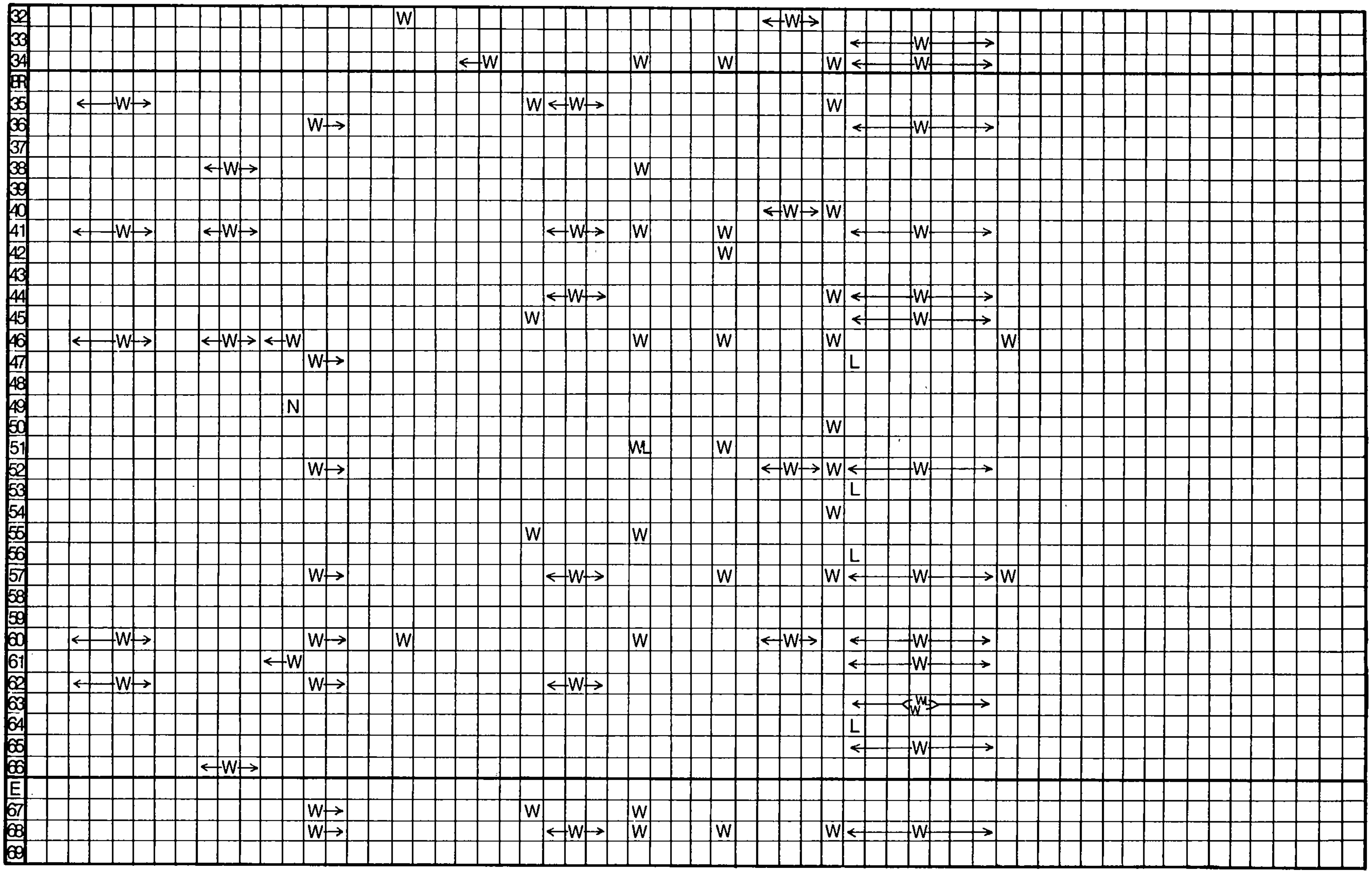

Figure 21. Consolidated fossil list, part E.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| V | 99 | | 100 | 101 | | 102 | 103 | | | | | 104 | 105 | 106 | 107 | 108 | | 109 | 110-11 | 112 | 113 | 114 | 115 | | | | | 116 | | 117 | 118 | 119 | 120 | 121 | 122 | 123 | | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | | 134 | 135 | 136 | | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 150 | 151 | 152 |
| V' | A | B | | A | B | | A | B | C | D | E | | | | | A | B | | | | | | A | B | C | D | E | A | B | | | | | | | A | B | | | | | | | | | | A | B | | | A | B | | | | | | | | | | |
| W | 86 | | 87 | | | | 88 | | 89 | | | 90 | | 91 | | 92 | 93 | 94 | 95 | | 96 | | 97 | 98 | 99 | | | 100 | 101 | 102 | | | 103 | 104 | 105 | | | 106 | 107 | | | | | | | 108 | 109 | | | | | | | | | | | | | | | |
| N | | 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 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | | | 38 | | 39 | 40 | 41 | 42 | | 43 | | | 44 | 45 | 46 | 47 | | | 48 | | | | |
| 70 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 71 | | | ← | | LW | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| AR | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 74 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 76 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | |
| 77 | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fi | | | N ← | | W | → | | | | | | | | | | | | | N | N | | | | | | | | N | | | | | | | | | | N | | | | | | | | | | | | | | | | | | N | | | | | |
| CO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 78 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | N | | | | |
| 79 | | | | | | | | | | | | | | | | W | | | | | | | | W | | | | | | N ← | W | → | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | |
| 80 | | | ← | | W | → | ← | W | | | | | | | | | W | | | | | | | W | | | | | | ← | N W | → | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 81 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 82 | | | | | | | | | | | N | | | | | | | | | N | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 83 | | | ← | | W | → | ← | W | N | | | | | ← | W | | W | | | | | | | | ← | W | → | | W | ← | W | → | W | | ← | W | → | | ← | | | W | | | → | W | | | | | | | | | | | | | | | | |
| 84 | | | | | | | | | | | | | | ← | W | | | | | | | | | | ← | N W | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 85 | | | | | | | ← | W | | | | | | | | | | | | | | | | W | ← | W | → | | | ← | W | → | W | | ← | W | → | | | | | | | | | | | | | | | | | | | | | | | | | |
| 86 | | | N | | | | | | | | N | | | | | | | | | | | | | | | N | N | | | | | | | | | | | | | | | | | | | | ← | N? | | | | | | | | | | | | | | |
| 87 | | | | | | | ← | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 88 | | | ← | | W | → | ← | W | | | | | | ← | W | | W | | | N | ← | W | | W | ← | W | → | | | N ← | N W | → | W | | ← | W | N → | | ← | | | W | | | → | W | | | | | | | | | | | | | | | |
| 89 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 90 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 91 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 92 | | | | | | | ← | W | | | | | | | | | | | | | | | | | ← | W | → | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 93 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 94 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 95 | | | | | | | ← | W | | | | | | | | | W | | | | | | | | | | | | | ← | W | → | | | | | | | | | | | | | | W | | | | | | | | | | | | | | | | |
| 96 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 97 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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C - Cassity and Langenheim, 1966
L - Langenheim and Langenheim, 1965
LSV - Lane, Sanderson, and Verville, 1972
LW - Webster and Lane, 1970
N - Nelson, 1973
W - Webster, 1969
WL - Webster and Langenheim, 1979
● - Unpub. collections of C. P. Weibel

Figure 22. Consolidated fossil list, part F.

## REFERENCES CITED

**Brill, K. G., Jr.**, 1963, Permo-Pennsylvanian stratigraphy of western Colorado Plateau and eastern Great Basin regions: Geological Society of America Bulletin, v. 74, p. 307–330.

**Cassity, P. E.**, and **Langenheim, R. L., Jr.**, 1966, Pennsylvanian and Permian fusulinids of the Bird Spring Group from Arrow Canyon, Clark County, Nevada: Journal of Paleontology, v. 40, p. 931–968.

**Coogan, A. H.**, 1962, Early Pennsylvanian stratigraphy, biostratigraphy, and sedimentation of the Ely Basin, Nevada: University of Illinois unpublished Ph.D. dissertation, 90 p.

———1964, Early Pennsylvanian history of Ely Basin, Nevada: American Association of Petroleum Geologists Bulletin, v. 48, p. 487–495.

**Dunn, D. L.**, 1976, Biostratigraphic problems of Morrowan and Derryan (Atokan) strata in the Pennsylvanian System of western United States: Geological Society of America Bulletin, v. 87, p. 641–645.

**Fritz, J. L., Weibel, C. P.**, and **Langenheim, R. L., Jr.**, 1981, Paleoecology of Pennsylvanian syringoporoids, Bird Spring Group, Arrow Canyon, Clark County, Nevada [abstract]: Geological Society of America Abstracts with Programs, v. 13, p. 278.

**Heath, C. P., Lumsden, D. N.**, and **Carozzi, A. V.**, 1967, Petrography of a carbonate transgressive–regressive sequence; The Bird Spring Group (Pennsylvanian), Arrow Canyon Range, Clark County, Nevada: Journal of Sedimentary Petrology, v. 37, p. 377–400.

**Lane, H. R., Sanderson, G. A.**, and **Verville, G. J.**, 1972, Uppermost Mississippian–basal Middle Pennsylvanian conodonts and fusulinids from several exposures in the south-central and southwestern United States: International Geological Congress, 24th, Montreal, 1972, sec. 7, Palaeontology, p. 549–555.

**Langenheim, R. L., Jr., Carss, B. W., Kennerly, J. B., McCutcheon, V. A.**, and **Waines, R. H.**, 1962, Paleozoic section in the Arrow Canyon Range, Clark County, Nevada: American Association of Petroleum Geologists Bulletin, v. 46, p. 592–609.

**Langenheim, R. L., Jr.**, and **Webster, G. D.**, 1979, Road log—seventh day: Clark County, Nevada, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 61–72, 79–80.

**Langenheim, V. A. M.**, 1964, Pennsylvanian and Permian paleontology and stratigraphy of Arrow Canyon, Arrow Canyon Range, Clark County, Nevada: University of California at Berkeley unpublished M.S. thesis, 194 p.

**Langenheim, V. A. M.**, and **Langenheim, R. L., Jr.**, 1965, The Bird Spring Group, Chesterian through Wolfcampian, at Arrow Canyon, Arrow Canyon Range, Clark County, Nevada: Illinois Academy of Science Transactions, v. 57, p. 225–240.

**Longwell, C. R.**, 1928, Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U.S. Geological Survey Bulletin 798, 152 p.

**Mamet, B. L.**, and **Skipp, B. A.**, 1970, Preliminary foraminiferal correlations of early Carboniferous strata in the North American Cordillera, *in* Colloque sur la stratigraphie du Carbonifère: Congrès et Colloques de l'Université de Liège, v. 55, p. 327–348.

**Nelson, W. J.**, 1973, Paleoenvironmental analysis of *Chaetetes* biostromes (Pennsylvanian) of the Arrow Canyon quadrangle, Clark County, Nevada: University of Illinois unpublished M.S. thesis, 93 p.

**Nelson, W. J.**, and **Langenheim, R. L., Jr.**, 1980, Ecological observations on *Chaetetes* in southern Nevada: Pacific Geology, v. 14, p. 1–22.

**Webster, G. D.**, 1969, Chester through Derry conodonts and stratigraphy of northern Clark and southern Lincoln Counties, Nevada: University of California Publications in Geological Sciences, v. 79, 121 p.

**Webster, G. D.**, and **Lane, N. G.**, 1970, Carboniferous echinoderms from the southwestern United States: Journal of Paleontology, v. 44, p. 276–296.

**Webster G. D.**, and **Langenheim, R. L., Jr.**, 1979, Stop descriptions—seventh day: Clark County, Nevada, *in* Beus, S. S., and Rawson, R. R., editors, Carboniferous stratigraphy in the Grand Canyon country, northern Arizona and southern Nevada: Ninth International Congress of Carboniferous Stratigraphy and Geology and American Geological Institute, Field Trip 13, p. 73–78.

**Welsh, J. E.**, 1959, Biostratigraphy of the Pennsylvanian and Permian systems in southern Nevada: University of Utah unpublished Ph.D. dissertation, 321 p.

**Wilson, E. C., Waines, R. H.**, and **Coogan, A. H.**, 1963, A new species of *Komia* Korde and the systematic position of the genus: Palaeontology, v. 6, pt. 2, p. 246–253.

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# ATOKAN STRATIGRAPHY IN THE SVERDRUP BASIN, CANADIAN ARCTIC ARCHIPELAGO

W. W. NASSICHUK[1]

**Abstract**—Lower–Middle Pennsylvanian strata considered to be coeval with the Atokan Series in Oklahoma are widely distributed in distinct facies belts throughout the Sverdrup Basin. The latter is an elongate pericratonic depression underlain by deformed Devonian and older rocks that extends 800 miles from Melville Island to northern Ellesmere Island. It contains some 40,000 feet of sedimentary rocks, ranging in age from Early Carboniferous (Viséan) to Tertiary (Eocene). Atokan strata consisting mainly of conglomerate, sandstone, and minor limestone occur in the lower part of the Canyon Fiord Formation, along the southern and eastern margins of the basin. These strata grade basinward to shelf-margin carbonates in the Nansen Formation. The Nansen in turn grades to a succession of evaporites and carbonates in the Otto Fiord Formation, which are overlain by carbonates and siltstone of the Hare Fiord Formation in the middle of the basin.

Carbonate rocks in the upper part of the Otto Fiord Formation and in the lower part of the Hare Fiord, Nansen, and Canyon Fiord Formations have yielded diverse Atokan ammonoid faunas, including *Winslowoceras, Christioceras, Diaboloceras*, and numerous other characteristic ammonoids, associated with abundant fusulinaceans such as *Profusulinella* and *Pseudostaffella* as well as with brachiopods and conodonts. The ammonoids are closely comparable with species known from the Atoka ( = Winslow) Formation in Arkansas, the Atoka Formation and Buckhorn asphalt in Oklahoma, the Marble Falls Limestone in central Texas, and the "Smithwick Shale" of the Magdalena Formation in west Texas. Elsewhere, Atokan ammonoids in the Sverdrup Basin resemble forms from Japan (Akioshi Formation) and the Soviet Union, particularly in Siberia and the Ural Mountains.

## INTRODUCTION

Atokan strata are widely distributed in the Sverdrup Basin (fig. 1) in distinctive nearshore, shelf, and basinal facies. Exposures are excellent, vertical and lateral relationships are clearly visible, and few if any breaks in the faunal record are obvious, particularly in the shelf and basinal facies. The Sverdrup Basin is an important reference for Atokan and younger (Desmoinesian) Middle Pennsylvanian strata, and, except for the question of ready accessibility, several sequences might be identified as potential Atokan-boundary stratotypes. Farther south, in the northern Yukon, Atokan rocks are also thick and well exposed. In the eastern Cordillera in British Columbia and Alberta, Atokan rocks are preserved as thin, discontinuous erosional remnants bounded by unconformities.

Wherever Lower Pennsylvanian and Upper Pennsylvanian strata occur in Arctic Canada, they can readily be compared with typical Midcontinent Morrowan and Virgilian sequences with clearly defined boundaries and well-known faunal successions. Unfortunately, the same is not true for Middle Pennsylvanian strata in the Arctic, and correlations are complicated by the absence of well-defined type sections for the formations of Atokan and Desmoinesian age in their respective "type" areas. Nevertheless, retention of the terms Atokan and Desmoinesian is encouraged because those series in the Midcontinent contain well-known successions of fusulinaceans, goniatites, and other fossils essential for regional and global correlation.

## ATOKAN FAUNAS AND CORRELATION

In the type area for the Pennsylvanian in the central Appalachian Mountains of Pennsylvania, basinal clastic rocks are abundant, and distinctive marine strata are relatively rare. There, the Pennsylvanian is divided into Lower, Middle, and Upper series. Typically, the Middle Pennsylvanian extends from the Kanawha Formation of the Pottsville Group through the Allegheny Group. Included are floral zones 7, 8, 9, and part of 10, of Read and Mamay (1964). In the Midcontinent, where marine strata are abundant, a more refined series nomenclature is employed. There, the Pennsylvanian is subdivided into the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian Series. Farther west, the marine Pennsylvanian is divided into Lower, Middle, and Upper series that are comparable with divisions in the type area. According to U.S. Geological Survey usage, Middle Pennsylvanian is equivalent to Atokan and Desmoinesian as defined in the Midcontinent (fig. 2).

[1]Geological Survey of Canada, Calgary, Alberta.

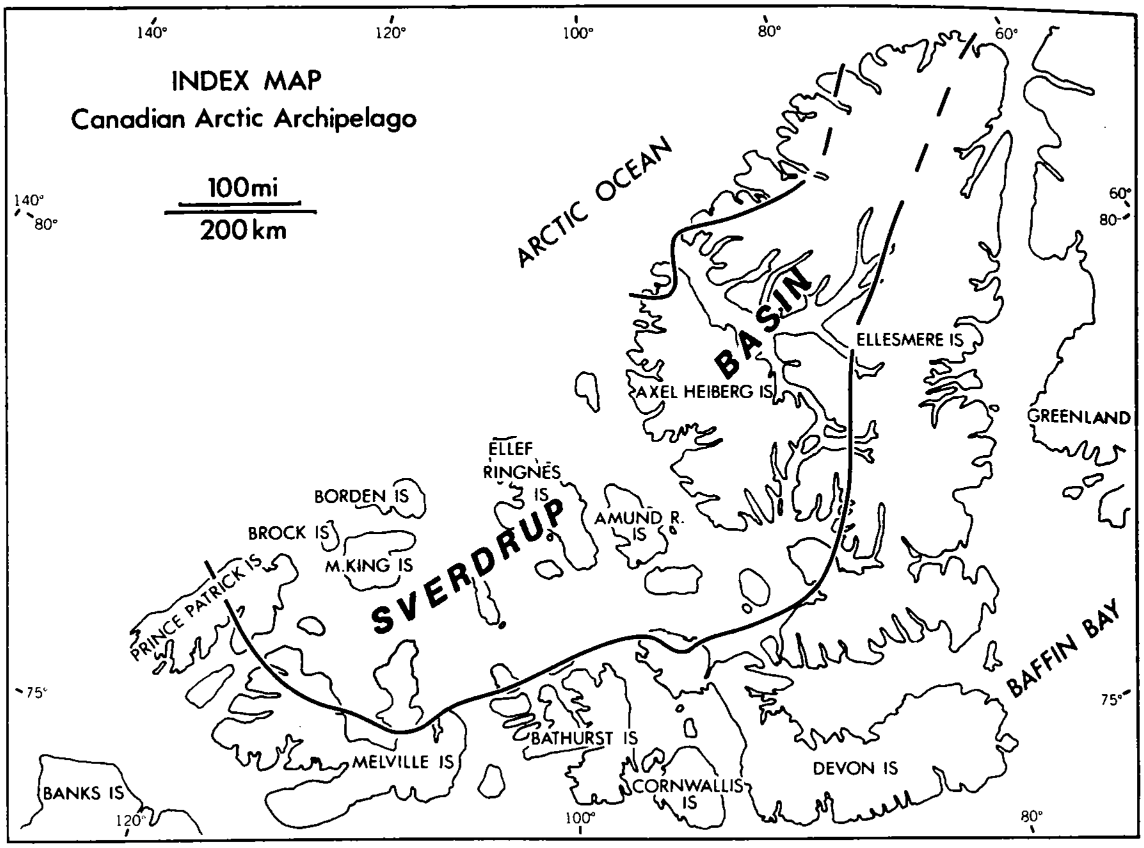


Figure 1. Index map of Canadian Arctic Archipelago showing Sverdrup Basin.

Moore and others (1944) referred post-Morrowan and pre-Desmoinesian strata of the Midcontinent to the Lampasan Series, defined along the Brazos River in north-central Texas, but Spivey and Roberts (1946) considered the Lampasan unsuitable as a standard reference and proposed instead the Atokan Series as based on the Atoka Formation in Oklahoma. Similarly, the Bendian Series in Texas and the Derryan Series in New Mexico, both important for local stratigraphic correlations, have generally been suppressed in favor of the Atokan Series for broader correlations. Clearly, the Lampasan, Bendian, and Derryan Series are all deficient as standard references for the lower part of the Middle Pennsylvanian, because they are either incomplete or contain prominent unconformities. Only the Atokan will serve effectively, despite the lack of a clearly defined type section, because it has a well-defined faunal succession.

Thompson (1935) described *Profusulinella fittsi*, *Fusulinella prolifica*, and *Staffella atokensis* from the Atokan Series in Oklahoma; he also identified *Fusulina leei* Skinner from the Desmoinesian Series in Iowa. No direct evidence is available to suggest that *Profusulinella* occurs in pre-Atokan strata in North America (Gordon and Sutherland, 1975), and it is generally understood that the Atokan Series is identified by the Assemblage Zone of *Profusulinella* Rauser-Chernousova and Belyaev and the younger Assemblage Zone of *Fusulinella* Möller. Ross (1967) suggested that *Profusulinella*, *Fusulinella*, and *Fusulina* show stratigraphic ranges in the Eurasian–Arctic realm that are different from those in the Midcontinent–Andean realm. In the latter realm, an apparent phylogenetic continuum exists between *Profusulinella* and the succeeding *Fusulinella* and *Fusulina*, and only a minimal overlap in stratigraphic ranges occurs between successive genera. In the more northerly Eurasian–Arctic realm, however, *Fusulinella* and *Fusulina* appeared more or less contemporaneously, and persisted, along with *Profusulinella*, until the end of Middle Pennsylvanian time.

Non-fusulinacean calcareous foraminifers and conodonts are becoming increasingly important in complementing established Middle Pennsylvanian fusulinacean zonations (Brazhnikova and others, 1967; Mamet and Armstrong, 1972;

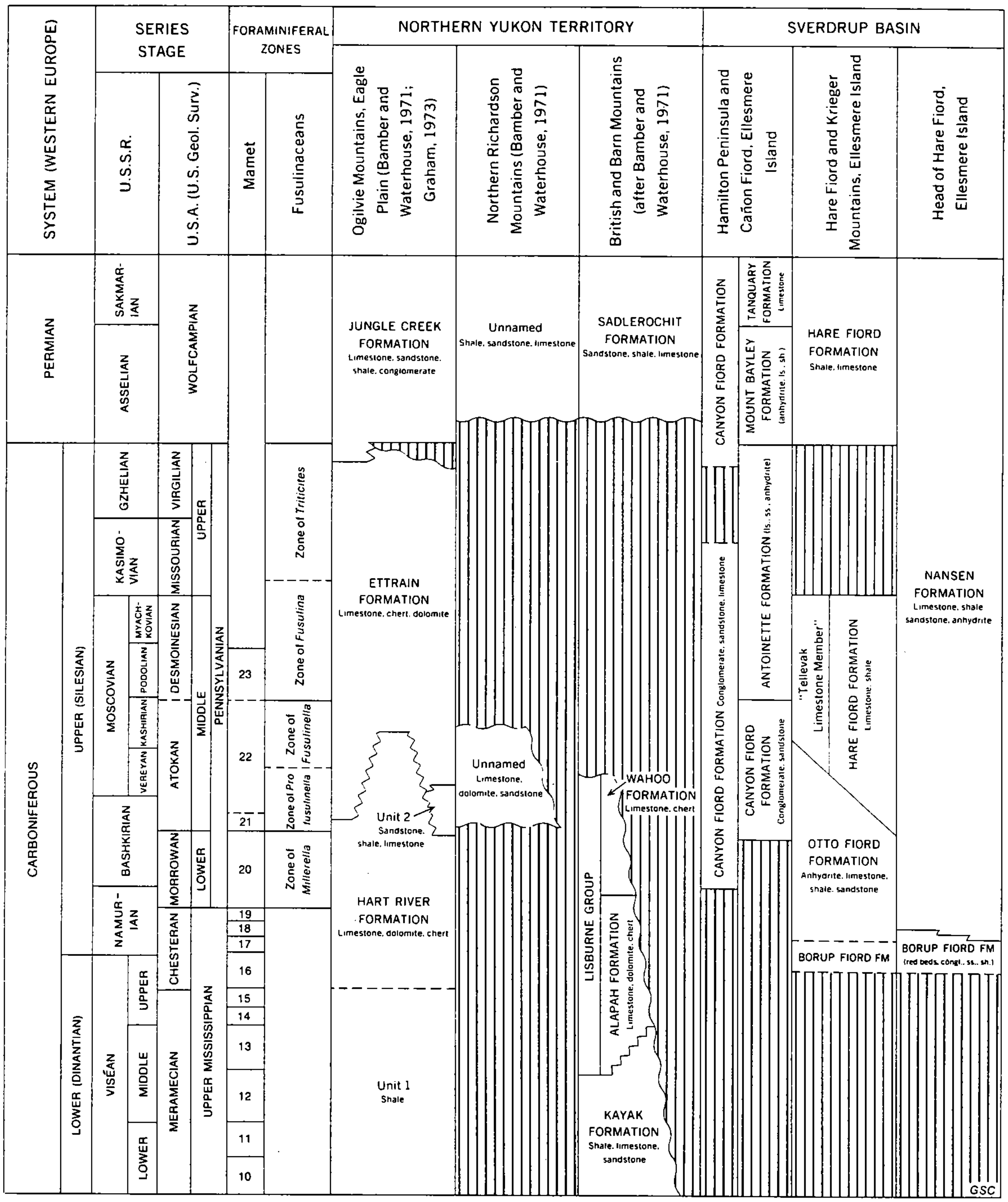


Figure 2. Correlation chart showing relationships of Carboniferous formations in Sverdrup Basin.

Mamet, 1975; Lane and others, 1972; Dunn, 1976). Unfortunately, Middle Pennsylvanian conodonts are little known from western and Arctic Canada, and available data are insufficient to establish effective correlations. A widely known foraminiferal zonal scheme initiated by Mamet (1968) is particularly important for Carboniferous correlations (fig. 2). According to Mamet (*in* Bamber and Waterhouse, 1971), foraminiferal Zones 21 and 22 are indicative of an Atokan age. Zone 21, loosely defined by Mamet (*in* Mamet and Armstrong, 1972), is devoid of *Profusulinella* but is characterized by an "outburst of *Eoschubertella* Thompson and *Pseudostaffella* Thompson" and by an abundance of diaphanotheca-bearing *Globivalvulina* Schubert. Dunn (1976) suggested, on the basis of conodont evidence, that Zone 21 occurs also in the upper Morrowan. Zone 22, which occurs in the upper part of the Atokan Series, contains abundant *Eoschubertella* and *Profusulinella*, and also *Climacammina* Brady of the group *C. moelleri* Reitlinger (Mamet, *in* Bamber and Waterhouse, 1971); *Profusulinella* and *Ozawainella* Thompson first appear in Zone 22.

Atokan and Desmoinesian strata in North America are equivalent to Westphalian strata of the Upper Carboniferous (Silesian) Series in Western Europe, and to upper Bashkirian and Moscovian strata of the Middle Carboniferous Series as defined in the Soviet Union. Ross (1970) and Nassichuk (1975) reviewed specific problems dealing with correlation of Atokan rocks between North America and Europe. Ammonoid and fusulinacean workers generally have agreed for many years that the base of the Atokan Series in North America corresponds to the base of the Moscovian (Vereyean beds) in the Russian Platform (Thompson, 1964; Ruzhencev, 1965; Ruzhencev and Bogoslovskaya, 1971). Brazhnikova and others (1967), however, showed that foraminifers typical of Mamet's Atokan Zones 21 and 22 occur in upper Bashkirian strata in the Donetz Basin. *Profusulinella* is absent from the lower Atokan (Zone 21) in North America. It makes its first appearance, along with *Ozawainella*, higher in the Atokan, in Zone 22. In the Donetz Basin, where *Ozawainella* makes its first appearance in the uppermost lower Bashkirian ($C_2^b$a), *Profusulinella* appears slightly higher, in the lowermost upper Bashkirian ($C_2^b$b). The ammonoid *Branneroceras branneri* (Smith), an index for middle Morrowan strata in North America, also occurs in the uppermost lower Bashkirian ($C_2^b$a) in the Donetz Basin. *Gastrioceras listeri* (Sowerby), known from Westphalian A ($G_2$) strata ( = Atokan) in Western Europe, occurs slightly higher than *Branneroceras branneri*, near the base of the upper Bashkirian ($C_2^b$c) in the Donetz Basin. Thus, both fusulinaceans and ammonoids indicate that the Morrowan–Atokan boundary falls within the middle of the Bashkirian in the Soviet Union.

## SVERDRUP BASIN

In the Canadian Arctic Archipelago, Pennsylvanian strata are confined to the Sverdrup Basin, an elongate, northeast-trending pericratonic depression some 800 miles long that contains a thickness of 40,000 feet of marine and minor nonmarine strata and volcanic rocks ranging from Lower Carboniferous (Viséan) to lower Tertiary (Eocene). The Sverdrup Basin succession rests unconformably on Precambrian to Devonian rocks of the Franklinian Geosyncline, which was deformed by the Ellesmerian Orogeny between Late Devonian and Early Carboniferous time. The geometry and depositional fabric of the Sverdrup Basin suggest that it may have evolved through episodes of crustal fracturing, which resulted in periodic subsidence and filling accompanied by igneous extrusion and intrusion.

The Sverdrup Basin, which is now a structural synclinorium, was subjected to two episodes of deformation. Between Late Pennsylvanian and Early Permian time, the Melvillian Disturbance initiated localized folding and faulting in marginal regions of the basin. Most of the major structural characteristics observed within the basin, such as broad, asymmetrical folds, abundant normal faults, and some reverse faults, were imprinted during the Eurekan Orogeny, an event dominated by widespread vertical movements between Late Cretaceous (Senonian) and middle Tertiary (Miocene) time.

It is evident that upper Paleozoic and lower Mesozoic strata in the Sverdrup Basin, in northeastern Greenland (Wandell Sea Basin), and in some of the islands of Svalbard and Novaya Zemlya, are remarkably similar. The last two groups of islands are on the Barents Shelf; Svalbard is some 500 miles northeast of northernmost Ellesmere Island, and Novaya Zemlya is an equal distance beyond Svalbard. Clearly, all regions were affected by comparable tectonism, and deposition occurred under similar environmental conditions during much of the late Paleozoic. It is less clear, however, whether deposition took place in a series of isolated successor basins or whether the present geographic isolation of remarkably similar strata reflects transection of a large, common basin through differential movements of tectonic plates during Tertiary time.

## REGIONAL STRATIGRAPHIC FRAMEWORK

The oldest strata in the Sverdrup Basin are nonmarine coaly shales of the Emma Fiord Formation, deposited in marginal depressions during Early Carboniferous (Viséan) time. Paleomagnetic reconstructions suggest that in Viséan time the developing Sverdrup trough lay between 10° and 25°N. latitude, with the axial trend of the trough approximately parallel with the contemporaneous equator. Following deposition of the Emma Fiord, a major marine transgression began in Late Carboniferous (Namurian) time and spread throughout the basin. Deposition during this transgression is characterized by reddish-weathering conglomerate and sandstone, and minor amounts of limestone, which are designated the Borup Fiord Formation in the basin interior and the Canyon Fiord Formation at the basin edge. This succession of coaly black shale overlain by red-weathering clastic rocks in part records the latitudinal change from an equatorial humid climate to a subtropical, seasonally arid climate, and coincides with the onset of deepening of the Sverdrup Basin. The lower part of the Borup Fiord Formation is devoid of fossils, and its age is unknown. Limestone recovered from near the top of the formation in the type area, however, contains an abundant fauna of calcareous foraminifers. The fauna was dated as early Namurian (Upper Mississippian, Zone 18) by Mamet (*in* Thorsteinsson, 1974). The Canyon Fiord Formation, confined to the edge of the basin, is invariably younger than the Borup Fiord and ranges in age from Early Pennsylvanian (Morrowan) to Early Permian (Sakmarian). Beginning with deposition of these red-bed units across the basin, marine deposition prevailed through the remainder of Carboniferous and Permian time.

Upper Carboniferous and Lower Permian rocks in the Sverdrup Basin show marked lithological differences between the basin edge and the basin interior, and a series of facies belts, parallel with the long axis of the basin, were defined by Thorsteinsson (1974). Moving westward from the east edge of the basin, the facies belts and formations contained within them are as follows (see fig. 3):

1. *Marginal Clastic Belt.* The Canyon Fiord Formation is composed entirely of sandstone and conglomerate within this narrow, conspicuous belt adjacent to the basin margin. In this belt, the formation ranges in age from Early–Middle Pennsylvanian (Atokan) to Early Permian.

2. *Marginal Clastic and Carbonate Belt.* Immediately west of the Marginal Clastic Belt, the Canyon Fiord Formation contains limestone beds as well as sandstone and conglomerate beds, and forms a couplet with the overlying Lower Permian Belcher Channel Formation (limestone). Within the belt, the Canyon Fiord Formation is Early and Middle Pennsylvanian in age; that is, it is Morrowan to Desmoinesian. In some parts of the belt, the Canyon Fiord Formation is overlain successively by the Upper Pennsylvanian Antoinette Formation (limestone), the Lower Permian (Asselian) Mount Bayley Formation (anhydrite, limestone), and the Lower Permian (Sakmarian) Tanquary Formation (limestone).

3. *Southeastern Carbonate Belt.* The Southeastern Carbonate Belt is represented by the Nansen Formation, a thick succession of carbonates that ranges from Middle Pennsylvanian (Atokan) to Early Permian in age within the belt. The Nansen Formation also forms the Northwestern Carbonate Belt on the west side of the Sverdrup Basin. There, the base of the Nansen is early Namurian (Late Mississippian) in age.

4. *Basinal Clastic and Evaporitic Belt.* Evaporitic clastic and carbonate rocks of the Upper Mississippian–Middle Pennsylvanian Otto Fiord Formation, and overlying shale and limestone of the Middle Pennsylvanian–Lower Permian Hare Fiord Formation, define the limits of the Basinal Clastic and Evaporitic Belt.

5. *Northwestern Carbonate Belt.* This belt is represented by the Namurian (Upper Mississippian)–Lower Permian Nansen Formation, which is composed of as much as 6,500 feet of limestone. The Nansen Formation grades into the Otto Fiord and Hare Fiord Formations in the Basinal Clastic and Evaporitic Belt (fig. 3).

## ATOKAN STRATIGRAPHY

Middle Pennsylvanian strata have been known from the Sverdrup Basin since Troelson (1950) identified the Desmoinesian fusulinaceans *Fusulina, Fusulinella, Wedekindellina, Ozawainella,*

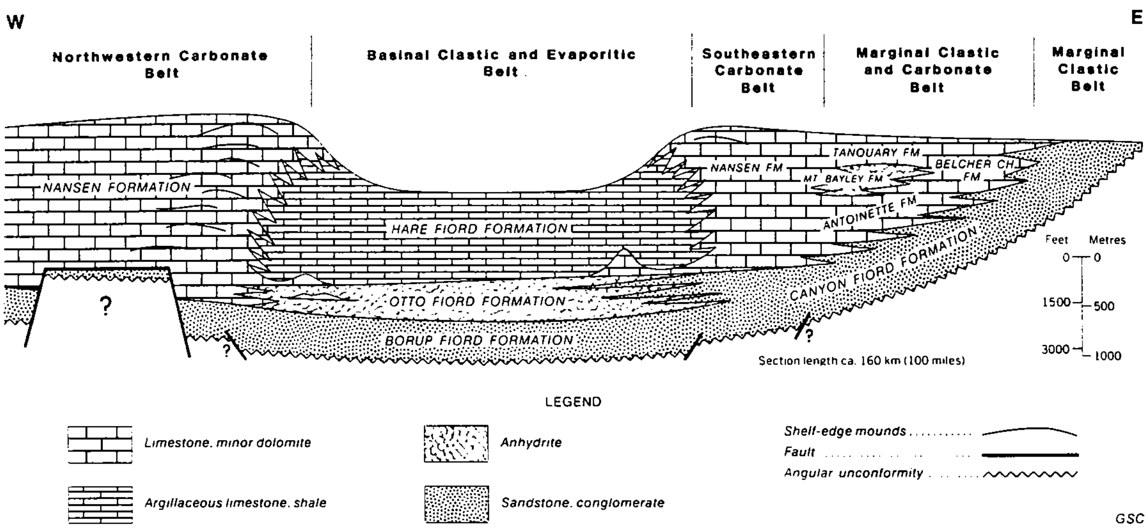


Figure 3. Schematic restored section for Namurian (Upper Mississippian) to Lower Permian lithofacies across Sverdrup Basin in vicinity of Hare Fiord, northern Ellesmere Island. Canyon Fiord, Otto Fiord, Hare Fiord, and Nansen Formations contain Atokan strata.

and *Staffella* from the type area of the Canyon Fiord Formation in western Ellesmere Island. Lower–Middle Pennsylvanian Atokan strata occur in all of the previously summarized major facies belts within the basin, extending from the eastern shoreline, across the shelf, and farther into the axial region of the basin. Atokan strata are contained within four formations across the basin, as follows:

## Canyon Fiord Formation

The Canyon Fiord Formation was named for a succession of reddish-weathering conglomerate, sandstone, and limestone at Cañon Fiord, western Ellesmere Island. Thorsteinsson (1974) concluded that the formation is approximately 5,500 feet thick in the type area, and ranges in age from early Bashkirian (Early Pennsylvanian) to Sakmarian (Early Permian). The lower conglomeratic, sandstone-bearing part of the formation is mainly of Early to Middle Pennsylvanian age. It crops out discontinuously along much of the eastern and southern margins of the Sverdrup Basin, and is separated from younger (Permian) formations by a significant disconformity. Farther from the shoreline, carbonate rocks are relatively more abundant in the Canyon Fiord, and Thorsteinsson (1974) reported Upper Pennsylvanian as well as Lower Permian fusulinaceans.

Middle Pennsylvanian strata in the Canyon Fiord Formation are mainly clastic rocks, but interbedded evaporites and limestones containing such fusulinaceans as *Profusulinella*, *Fusulinella*, and *Fusulina* are locally well developed. Thorsteinsson (1974) reported several hundred feet of anhydrite within a red-bed succession on southwestern Ellesmere Island. In the same general area, thick carbonate mounds and argillaceous limestone beds are developed. It is estimated that Atokan strata may assume a maximum thickness of 600 feet, and Desmoinesian strata a thickness of 1,500 feet, in the Canyon Fiord Formation of Ellesmere Island.

Middle Pennsylvanian ammonoids and foraminifers are abundant in the Canyon Fiord Formation, particularly in southwestern Ellesmere Island (figs. 2, 7). Nassichuk (1975) described the ammonoids *Boesites* sp., *Metapronorites pseudotimorensis* (Miller), *Bisatoceras* sp., and *Somoholites bamberi* Nassichuk from the middle of the formation. Foraminifers associated with the ammonoids include *Profusulinella* sp. and *Climacammina* sp. which Mamet (*in* Nassichuk, 1975) considered to be late Atokan (Zone 22), or younger. Elsewhere in southwestern Ellesmere Island, Mamet (*in* Nassichuk, 1975) identified foraminifers from the lower part of the Canyon Fiord, including species of *Profusulinella*, *Fusulina*, and *Pseudostaffella* that he considered to be of probable Desmoinesian age. Farther north, at Hamilton Peninsula, Ellesmere Island, an Atokan ammonoid *Phaneroceras compressum* (Hyatt) occurs 159 feet above the base of the Canyon Fiord Formation. Mamet (*in* Thorsteinsson, 1974) identified Lower Pennsylvanian (Morrowan) foraminifers (Zone 20) lower in the same section.

## Otto Fiord Formation

The Otto Fiord Formation and the overlying Hare Fiord Formation (fig. 4) define the Basinal Clastic and Evaporitic Belt in interior regions of the Sverdrup Basin. Laterally, both formations grade to shelf carbonates of the Nansen Formation (fig. 5). The Otto Fiord contains subaqueous evaporites as well as minor limestone, sandstone, and shale (Nassichuk and Davies, 1980). It has yielded diverse ammonoid, brachiopod, and fusulinacean faunas, and ranges in age from Namurian (Late Mississippian) to Middle Pennsylvanian (Atokan). In much of Axel Heiberg Island, and farther south, the Otto Fiord Formation is exposed only as "blocks" of strata in evaporitic diapirs and has yielded abundant marine faunas of Namurian (Late Mississippian) and Early Pennsylvanian (Morrowan) age. Farther north, however, in the type area of the formation at Hare Fiord, Ellesmere Island, and in adjacent areas, the formation is little disturbed and attains a thickness of 1,300 feet.

In the immediate type area, the formation is mainly of Morrowan (Zone 20) age, but slightly younger Atokan (Zone 21) may also be present. Elsewhere, farther north and east from the type area, the formation contains strata as old as Namurian (Zone 18) and as young as Atokan (Zone 22). The only ammonoids known from the type section of the Otto Fiord Formation are *Branneroceras branneri* (Smith) and *Gastrioceras* sp., and both indicate a Morrowan (Bloydian) age. Mamet (*in* Nassichuk, 1975) identified calcareous foraminifers and algae from the type section that are mainly Morrowan, but near the top of the formation some probable Atokan (Zone 21) forms were identified. Some 25 miles east of the type section of the Otto Fiord, Ross (*in* Nassichuk, 1975) identified *Pseudostaffella gorskyi* (Dutkevitch) and *Eostaffella kashira* var. *rhomboides* Rauser, and assigned an early Moscovian (Kashirian) age. Mamet (*in* Nassichuk, 1975) identified a variety of calcareous foraminifers and algae from the same general horizon, which he placed in his Atokan Zone 22; the Morrowan ammonoid *Branneroceras branneri* occurs in the same section, several hundred feet below the Zone 22 horizon.

Equivalents of the lower part of the Otto Fiord, that is, Zone 18, occur in the Lisburne Group in Alaska and the Yukon Territory, and in the Ettrain Formation in the northern Yukon. Similarly, fusulinaceans and small calcareous foraminifers higher in the Otto Fiord, that is, those representing Zones 20, 21, and 22, have been

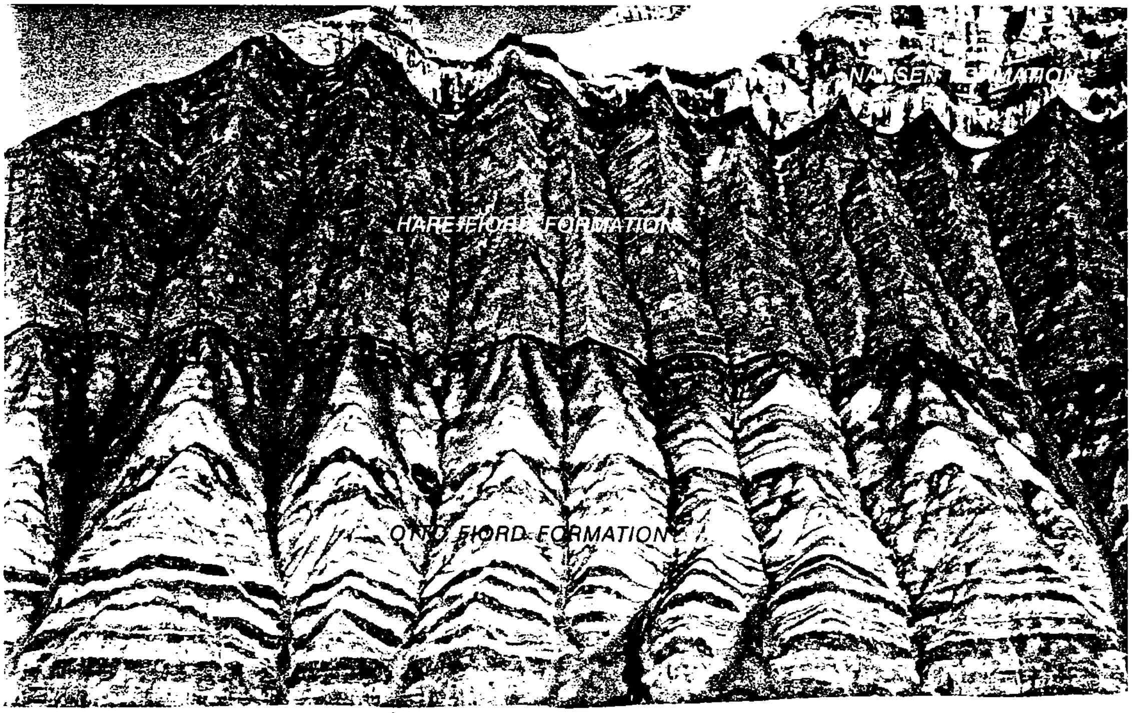


Figure 4. Typical exposures of Otto Fiord and Hare Fiord Formations northeast of head of Hare Fiord, northern Ellesmere Island. Note rhythmic interbedding of thick carbonate units (dark color) and anhydrite (light color) in Otto Fiord Formation. Atokan faunas occur in upper 100 feet of Otto Fiord Formation and in at least lower 300 feet of Hare Fiord Formation (between arrows on left side of photograph). At this location, Otto Fiord and Hare Fiord Formations are each about 1,500 feet thick. To right, both formations grade into shelf carbonates of the Nansen Formation. Field of view is about half a mile wide.

identified in the Lisburne Group in Alaska and the Yukon Territory. Foraminifers as young as Zone 20, and brachiopods as young as Moscovian (Atokan), occur in the Hart River Formation in the Yukon (Bamber and Waterhouse, 1971; Mamet and Armstrong, 1972).

## Hare Fiord Formation

The Hare Fiord Formation overlies the Otto Fiord Formation in the Basinal Clastic and Evaporitic Belt in the central Sverdrup Basin. The formation varies in thickness from 1,000 feet to about 4,100 feet, and is characterized by a lower unit of Middle Pennsylvanian (Atokan–Desmoinesian) argillaceous limestone and siltstone, and an upper unit of Lower Permian (Asselian–lower Artinskian) shale and minor limestone. Locally, where the Hare Fiord Formation occurs near the shelf edge, biogenic-carbonate mounds occur near the base of the formation (fig. 6). The limestone mounds attain a maximum thickness of 1,000 feet and are entirely of Atokan age. A major disconformity separates the limestone mounds from overlying Lower Permian (Asselian) shale and argillaceous limestone. Farther into the interior of the Basinal Clastic and Evaporitic Belt, where limestone mounds are absent, Middle Pennsylvanian (Atokan) argillaceous limestone and siltstone are directly overlain by Permian shale and siltstone. The apparent absence of Upper Pennsylvanian strata in the Hare Fiord Formation may reflect nothing more than extremely slow deposition in a starved basin. Upper Pennsylvanian carbonates are thinly developed nearby on the shelf, and the presence of a condensed sequence of rocks of the same age in the basin interior, therefore, must be anticipated.

Ammonoids recovered from the lower 100 feet of the type section of the Hare Fiord Formation at Hare Fiord, northern Ellesmere Island, include *Metapronorites ellesmerensis* Nassichuk, *Phaneroceras lenticulare* Plummer and Scott, *Syngastrioceras smithwickense* (Plummer and Scott), and *Diaboloceras involutum* Nassichuk.

Typical representatives of *Phaneroceras lenticulare* and *Syngastrioceras smithwickense* occur in Atokan strata in north-central and west Texas, respectively, and also are known from Atokan strata in Arkansas and Oklahoma. Fifteen ammonoid species, from a comparable stratigraphic po-

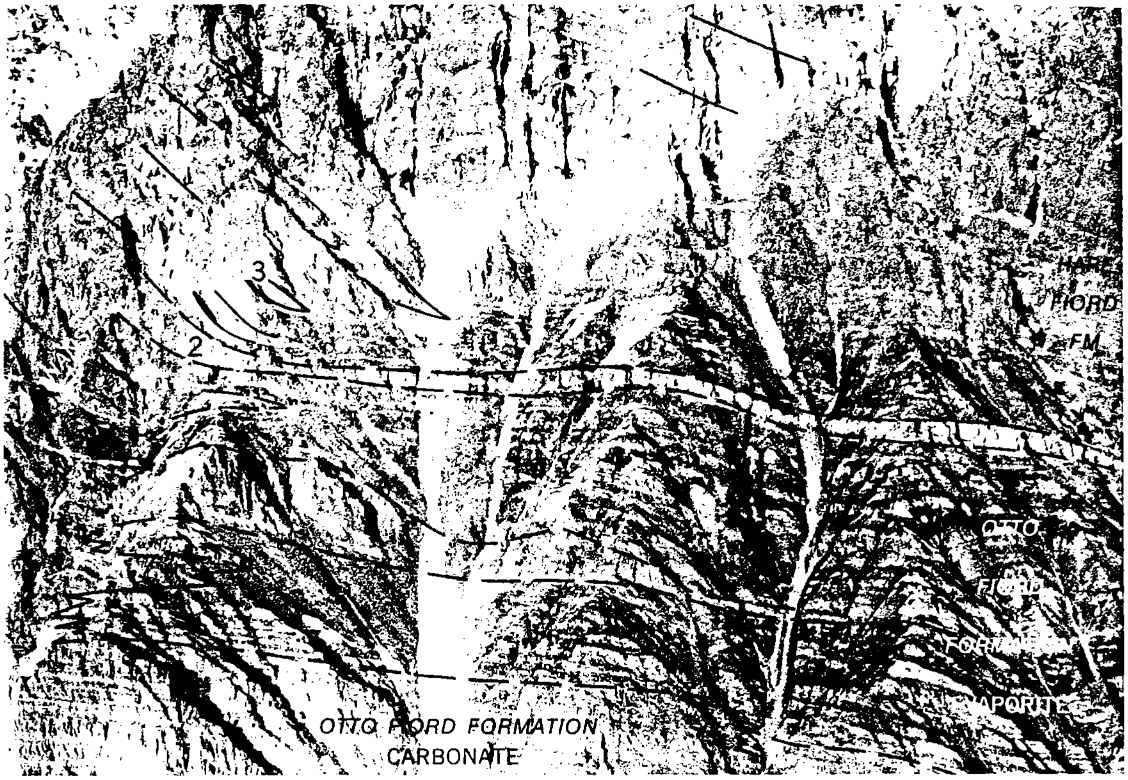


Figure 5. Major facies change, from basinal anhydrite and limestone in Otto Fiord Formation and siltstone and limestone in Hare Fiord Formation to prograding shelf-edge carbonates in Nansen Formation. Thickness of section visible in photograph is about 2,000 feet.

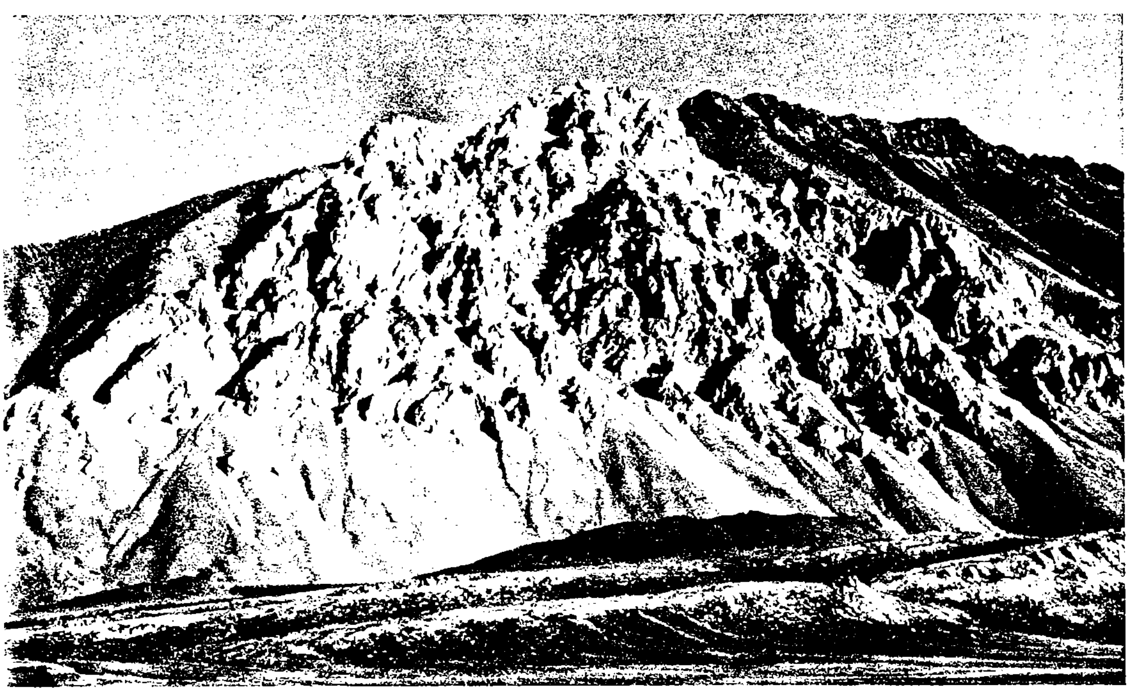

Figure 6. Biogenic-carbonate mound, 1,000 feet thick in Hare Fiord Formation, Blue Mountains, Ellesmere Island. Fifteen Atokan ammonoid species were recovered from this mound and were described by Nassichuk (1975).

sition about 100 feet above the base of the formation, were recovered from a bryozoan mound about 12 miles along strike to the east of the type section. Several species, including *Maximites alexanderi* Nassichuk, *Neodimorphoceras sverdrupi* Nassichuk, and *Gonioloboceratoides curvatus* Nassichuk, indicate close affinities with younger (Desmoinesian) species in the American Midcontinent, but association of these species, on Ellesmere Island, with *Winslowoceras greelyi* Nassichuk supports an Atokan age. Schistoceratacean ammonoids such as *Winslowoceras* and *Diaboloceras*, and pronoritids such as *Strenopronorites*, *Metapronorites*, and *Pseudopronorites* (fig. 7), are common in the Hare Fiord Formation and are extraordinarily important for establishing correlations between the Canadian Arctic, the Midcontinent, and Europe.

Atokan ammonoids are also abundant in biogenic-carbonate mounds in the Blue Mountains, some 30 miles southeast of the the type Hare Fiord (fig. 6). There, some 15 species were described by Nassichuk (1975), including *Syngastrioceras smithwickense*, *Phaneroceras lenticulare*, *Neodi-*

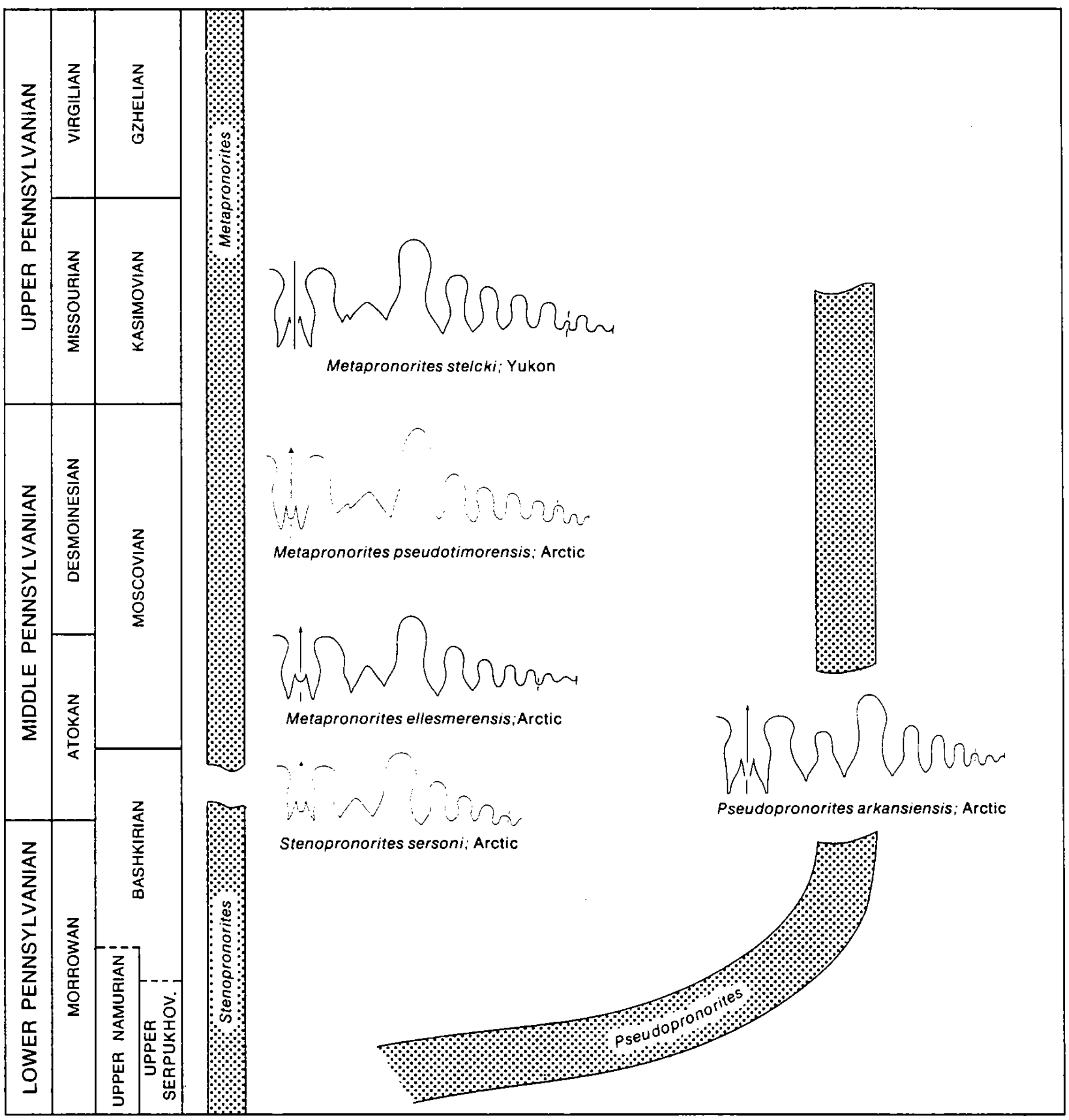


Figure 7. Evolutionary relationships of Carboniferous pronoritid ammonoids in Canada. *Metapronorites pseudotimorensis*, shown here as Desmoinesian, also may occur in upper Atokan strata in Ellesmere Island.

*morphoceras sverdrupi* Nassichuk, *Diaboloceras involutum* Nassichuk, and *Diaboloceras neumeieri* Quinn and Carr. Farther north, in the Krieger Mountains, *Gastrioceras glenisteri* Nassichuk and *Diaboloceras involutum* Nassichuk, of probable late Atokan age, are associated with a variety of fusulinaceans and other foraminifers, including *Profusulinella* sp., *Ozawainella* sp., and *Eoschubertella* sp., that Mamet (*in* Nassichuk, 1975) considered to be too advanced for the Atokan and which he tentatively assigned to the Desmoinesian. Similarly, Ross (*in* Nassichuk, 1975) suggested that fusulinaceans occurring slightly below *Diaboloceras neumeieri* and *Gastrioceras glenisteri* seemed to indicate an uppermost Atokan or lower Desmoinesian correlation. Thus, Ross' (1967) contention that the ranges for *Profusulinella, Fusulinella*, and *Fusulina* appear to be different between the Midcontinent and the Arctic certainly deserves further scrutiny.

The Hare Fiord Formation is equivalent to the Upper Carboniferous Passage Beds in Vestspitzbergen, which lie between the Lower Gypsiferous Series below and the *Cyathophyllum* Limestone above. The Hare Fiord is also equivalent to the Wahoo Limestone in the Lisburne Group of Alaska and the northern Yukon, and to the upper part of the Hart River Formation, as well as the Ettrain Formation, in the northern Yukon (Bamber and Waterhouse, 1971). Part of the Taku Group in the southern Yukon, containing undescribed species of *Neodimorphoceras, Phaneroceras*, and *Proshumardites*, also is correlative with the Hare Fiord Formation.

## Nansen Formation

The Nansen Formation is the principal unit in the Southeast Carbonate Belt and the Northwest Carbonate Belt. The latter belt effectively defines the northwestern shelf of the Sverdrup Basin. Within the Northwest Carbonate Belt, the Nansen overlies red beds of the Namurian (Mississippian) Borup Fiord Formation, and grades basinward to the previously discussed Otto Fiord and Hare Fiord Formations. In the type area, near the head of Hare Fiord, Ellesmere Island, the Nansen Formation contains more than 6,000 feet of uniformly bedded skeletal limestone with minor shale and anhydrite. Locally, on northwestern Ellesmere Island and on western Axel Heiberg Island, biogenic-carbonate mounds and thick accumulations of primary dolomite and sandstone occur in the formation. The Nansen Formation ranges in age from Namurian (Late Mississippian) to Early Permian (Sakmarian) in the type area, but the largest part of the formation, about 4,000 feet, is Middle Pennsylvanian in age. Foraminiferal studies of the Nansen Formation in the type area are incomplete, but Mamet (*in* Nassichuk, 1975) has identified Namurian (Zones 18 and 19) foraminifers from the lower several hundred feet of the formation and a diverse Atokan fauna (Zones 21 and 22) from more than 1,000 feet higher. The latter fauna includes *Climacammina* of the group *C. moelleri, Profusulinella* sp., *Fusulinella* sp., and *Staffella* sp. Nassichuk (1975) described the Atokan ammonoids *Phaneroceras* cf. *P. compressum* and *Somoholites merriami* 1,500 feet above the base of the type section.

Mamet (personal communication, 1975) has identified Desmoinesian (Zone 23) foraminifers, including *Fusulina* sp., from the type Nansen. Ross (personal communication, 1975) identified *Fusulinella* sp., *Schubertella* sp., and *Ozawainella* sp. nearly 5,000 feet above the base of the type section of the Nansen Formation and has assigned a late Moscovian (probably Myachkovian = Desmoinesian) age. Thus, Middle Pennsylvanian strata in the type section of the Nansen Formation may be at least 4,000 feet thick. Perhaps half of that thickness might be represented by Atokan strata.

Upper Pennsylvanian fossils are rather poorly known from the Nansen Formation, but the ammonoid *Parashumardites* sp. of Missourian (Kasimovian) age is known from near Stepanow Creek, on the north side of Hare Fiord. Ross (personal communication, 1975) has identified the fusulinaceans *Pseudoendothyra* cf. *P. compressa, Pseudofusulinella* sp., and *Schubertella* sp. from the type section of the Nansen Formation and considers that they too indicate a Kasimovian age.

## REFERENCES CITED

**Bamber, E. W.**, and **Waterhouse, J. B.**, 1971, Carboniferous and Permian stratigraphy and paleontology, northern Yukon Territory: Bulletin of Canadian Petroleum Geology, v. 19, p. 29–250.

**Brazhnikova, N. E., Vakarchuk, G. I., Vdovenko, M. V., Vinnichenko, L. V., Karpova, M. A., Kolomietz, Y. I., Potievskaya, P. D., Rostovseva, L. F.,** and **Shevchenko, G. D.**, 1967, The key microfaunal horizons of the Carboniferous and Permian deposits in the Dnieper-Donetz Trough: Akademiya Nauk, Ukranian SSR, Instituta Geologicheskikh, Kiev.

**Dunn, D. L.**, 1976, Biostratigraphic problems of Morrowan and Derryan (Atokan) strata in the Pennsylvanian System of western United States: Geological Society of America Bulletin, v. 87, p. 641–645.

**Gordon, Mackenzie, Jr.**, and **Sutherland, P. K.**, 1975, Ammonoids of the upper Wapanucka Limestone and their bearing on the Morrowan-Atokan boundary in Oklahoma [abstract]: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Annual Meeting Abstracts, Dallas, 1975, v. 2, p. 30.

**Lane, H. R., Sanderson, G. A.**, and **Verville, G. J.**, 1972, Uppermost Mississippian–basal Middle Pennsylvanian conodonts and fusulinids from several exposures in the south-central and southwestern United States: International Geological Congress, 24th, Montreal, 1972, sec. 7, Palaeontology, p. 549–555.

**Mamet, B. L.**, 1968, Foraminifera, Etherington Formation (Carboniferous), Alberta, Canada: Bulletin of Canadian Petroleum Geology, v. 16, p. 167–179.

———1975, Carboniferous Foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey Professional Paper 848-B, p. B1–B18.

**Mamet, B. L.**, and **Armstrong, A. K.**, 1972, Lisburne Group, Franklin and Romanzoff Mountains, northeastern Alaska: U.S. Geological Survey Professional Paper 800-C, p. C127–C144.

**Moore, R. C., Wanless, H. R., Weller, J. M.**, and others, 1944, Correlation of Pennsylvanian formations of North America: Geological Society of America Bulletin, v. 55, p. 657–706.

**Nassichuk, W. W.**, 1975, Carboniferous ammonoids and stratigraphy in the Canadian Arctic Archipelago: Geological Survey of Canada Bulletin 237, p. 1–240.

**Nassichuk, W. W.**, and **Davies, G. R.**, 1980, Stratigraphy and sedimentation of the Otto Fiord Formation—a major Mississippian–Pennsylvanian evaporite of subaqueous origin in the Canadian Arctic Archipelago: Geological Survey of Canada Bulletin 286, 87 p.

**Read, C. B.**, and **Mamay, S. H.**, 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geological Survey Professional Paper 454-K, 35 p.

**Ross, C. A.**, 1967, Development of fusulinid (Foraminiferida) faunal realms: Journal of Paleontology, v. 41, p. 1341–1354.

———1970, Concepts in late Paleozoic correlations: Geological Society of America Special Paper 124, p. 7–36.

**Ruzhencev, V. E.**, 1965, Principal ammonoid assemblages of the Carboniferous Period: Paleontologicheskii Zhurnal, no. 2, p. 3–17.

**Ruzhencev, V. E.**, and **Bogoslovskaya, M. F.**, 1971, Namurian time in ammonoid evolution: Akademiya Nauk, Trudy Paleontologicheskogo Instituta SSSR, v. 133, p. 7–376.

**Spivey, R. C.**, and **Roberts, T. G.**, 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists Bulletin, v. 30, p. 181–186.

**Thompson, M. L.**, 1935, The fusulinids of the Atoka and Boggy formations of Oklahoma: Journal of Paleontology, v. 9, p. 293–306.

———1964, Fusulinacea, *in* Loeblich, A. R., Jr., and Tappan, Helen, Sarcodina, chiefly "Thecamoebians" and Foraminiferida, *v. 1 of* Protista 2, *part C of* Moore, R. C., editor, Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press, p. 358–436.

**Thorsteinsson, R.**, 1974, Carboniferous and Permian stratigraphy of Axel Heiberg Island and western Ellesmere Island, Canadian Arctic Archipelago: Geological Survey of Canada Bulletin 224, 115 p.

**Troelson, J. C.**, 1950, Contribution to the geology of Northwest Greenland, Ellesmere and Axel Heiberg Islands: Meddelelser om Grønland, v. 149, no. 7, 85 p.

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# ATOKAN CRINOIDS

H. L. STRIMPLE[1]

**Abstract**—Articulated crinoids are not as prolific in the Atokan Stage as they are in the younger Desmoinesian; however, the Atokan crinoids appear to have closer affinities with them than with crinoids of the preceding Morrowan Stage. Conditions for the establishment of widespread "gardens" or "colonies," or for their preservation, were relatively rare in the Atokan. The largest faunas are from the Llano Uplift in north-central Texas, from southwestern Missouri, and from Coal County in south-central Oklahoma.

Sporadic and limited occurrences of Atokan crinoids are now known from Alaska, northwestern Spain, northern China, Ellesmere Island (Canadian Arctic), eastern Kentucky, Colorado, and New Mexico. Some species reported by Termier and Termier from Morocco are probably of Atokan age, although they are not so recorded. In addition, crinoids from Algeria and the Island of Crete are under study.

## INTRODUCTION

Conditions were seldom favorable for the preservation of crinoids during the Atokan. The first Atokan crinoids appear to have been described by Tien (1924, 1926), from the Houkou Limestone, Taiyuan Series of north China (age assignment suggested by Strimple and Watkins, 1969). Laudon (1937) described a crown of a flexible crinoid with a poorly preserved cup from the Bostwick Formation of Love County, Oklahoma, which he named *Synerocrinus farishi*. Moore and Strimple (1941) reported *Graffhamicrinus granulosus* (as *Delocrinus*) from the Coody Creek Sandstone (Atokan) of northeastern Oklahoma. Strimple and Blythe (1960) described *Paragassizocrinus atoka* from the Webbers Falls Sandstone of Cherokee County, Oklahoma, and Strimple (1961) described *P. elevatus* and *P. bulbosus* on the basis of infrabasal cones and disarticulated plates from the Bostwick Formation of Carter County, Oklahoma. The status of the latter two species is under study. *Synarmocrinus brachiatus* Lane (1964) from the Bird Spring Formation of southern Nevada is reportedly of Atokan age. *Diphuicrinus patina* Strimple and Knapp (1966) from the Magoffin beds, Breathitt Formation of eastern Kentucky, is possibly of Atokan age.

Knapp (1969) reported the first major Atokan crinoid fauna, from the Burgner Formation of Jasper County, Missouri. The Missouri occurrence was followed by the Strimple and Watkins (1969) report of crinoids from the Atokan portion of the Marble Falls Formation of San Saba County, Texas, and from the Big Saline Formation of Mason County, Texas. These occurrences are in the Llano Uplift of north-central Texas. Strimple and Watkins (1969, p. 150) noted the genera in a large crinoid fauna from the Atoka Formation of Coal County, Oklahoma, but systematic descriptions were not made until later (Strimple, 1975).

Several important occurrences of Atokan crinoids have been reported since 1969. Webster and Lane (1970) reported the occurrence of the camerate crinoid *Platycrinites* sp., based on disarticulated segments, and described two species of inadunate crinoids from the Atokan part of the Bird Spring Formation, Arrow Canyon, Nevada. Strimple and others (1971) described three new crinoid species from the Rainbow Mountain area in Alaska, from beds that are considered to be Atokan in age. Strimple and Miller (1971) described two new species, and reported *Paracromyocrinus marquisi* (Moore and Plummer), from the Pinkerton Trail Formation near Molas Lake, Colorado, and strongly recommended an Atokan age. Strimple and Nassichuk (1974) reported *Calycocrinus* sp. and two new species from the Hare Fiord Formation (Atokan) of Ellesmere Island, Arctic Canada. Strimple (1976) described two new species, thought to be Atokan, from the Province of Palencia, northwest Spain. Strimple (1980) reported *Metacromyocrinus* sp., and described two new species, from the La Pasada Formation (Atokan) of the Sangre de Cristo Mountains, New Mexico. A small faunule from the Island of Crete, Greece, is thought to be Atokan in age and is under study, as is another faunule of crinoids from the Westphalian of Algeria.

## PRESERVATION

Mass mortality accompanied by rapid burial is a prerequisite for the fossilized preservation of a "colony" or "garden" of crinoids with attached arms. This condition has been found in only two

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Atokan localities, the Lemons Bluff Limestone, Marble Falls Formation, of San Saba County, Texas (Llano Uplift), and the "Barnett Hill" Member of the Atoka Formation of Coal County, Oklahoma. The Texas exposure is a normal situation in which the rocks are basically carbonates (limestone), but the Oklahoma occurrence is basically sandy shale with some carbonate content and a few limestone pods. Apparently, an influx of brachiopods provided a suitable substrate for the attachment of crinoid larvae and for their subsequent development into "colonies." The fact that so many genera of crinoids are known in Atokan strata demonstrates that conditions favorable for their survival and proliferation did exist. Whether isolated "colonies" were sufficient for this, or whether a more favorable situation was present in as yet unknown or unreported areas, is problematical. Much if not most of the Atokan strata in Oklahoma and Arkansas is sandstone and sandy shale, which indicates an unsuitable environment for crinoids.

## RECORDED ATOKAN GENERA

Crinoid genera that are pre-Atokan to post-Atokan:

Inadunata
- *Aglaocrinus*
- *Anobasicrinus*
- *Chlidonocrinus*
- *Cydonocrinus*
- *Dicromyocrinus*
- *Diphuicrinus*
- *Endelocrinus*
- *Goleocrinus*
- *Kallimorphocrinus*
- *Lecythiocrinus*
- *Paracromyocrinus*
- *Paragassizocrinus*
- *Perimestocrinus*
- *Plummericrinus*
- *Sciadiocrinus*
- *Scytalocrinus*
- *Synarmocrinus*
- *Synbathocrinus*
- *Ulrichicrinus*

Flexibilia
- *Calycocrinus*
- *Paramphicrinus*

Camerata
- *Dichocrinus*
- *Globacrocrinus*
- *Planacrocrinus*
- *Platycrinites*

Crinoid genera that are pre-Atokan to Atokan:

Inadunata
- *Affinocrinus*
- *Alcimocrinus*
- *Allagecrinus*
- *Eucatillocrinus*
- *Mathericrinus*
- *Palmerocrinus*
- *Platyfundocrinus*
- *Poteriocrinites*
- *Proallosocrinus*

Flexibilia
- *Zenocrinus*

Crinoid genera that are known only from the Atokan:

Inadunata
- *Araeocrinus*
- *Atokacrinus*
- *Atrapocrinus*
- *Sinocrinus*

Crinoid genera that are Atokan to post-Atokan:

Inadunata
- *Anchicrinus*
- *Brabeocrinus*
- *Clathrocrinus*
- *Coenocystis*
- *Elibatocrinus*
- *Graffhamicrinus*
- *Lecobasicrinus*
- *Metacromyocrinus*
- *Microcarinocrinus*
- *Mooreocrinus*
- *Moundocrinus*
- *Neoprotencrinus*
- *Oklahomacrinus*
- *Polusocrinus*
- *Stenopecrinus*

Flexibilia
- *Aexitrophocrinus*
- *Synerocrinus*

## EVOLUTIONARY NOTES

Establishment of relationships between cladid inadunate crinoid genera is generally difficult owing to the differences in generic concepts or in the primary critera used by various investigators. In addition, changes in morphologic features that take place in one lineage do not necessarily take place in another lineage, even within what appears to be a familial group. To add to the problem, much convergence is found in many lineages, reflecting a general trend toward simplicity and pentameral symmetry. An attempt is made here to provide some demonstrable examples of relationships and evolution as applicable to some Atokan crinoids.

Pronounced basal invagination reduces the size of the coelomic cavity which houses the visceral mass, and in that regard is a negative factor. Even so, genera like *Arkacrinus* and unrelated *Oklahomacrinus* developed exaggerated basal invaginations. In *Arkacrinus*, the modification was apparently deleterious; the genus was relatively short lived (restricted to the Morrowan), even though it was prolific in a few Morrowan deposits. *Oklahomacrinus* appeared in the Atokan as a derivative of *Cymbiocrinus*, where it had already developed an unusually shallow cup and marked basal concavity. The only apparent morphological advantage between the two genera is that *Oklahomacrinus* retains an anal plate in the cup. This might be more significant than is apparent. Almost certainly *Oklahomacrinus* had a tegmen to house portions of the visceral mass, and the tegmen would need to have been supported by a series of substantial plates anchored to the anal plate. There has been no report of an anal tube in *Oklahomacrinus*, which indicates a departure from most cymbiocrinids. It is postulated that a structure of small, thin, weakly sutured plates was present. In any event, the *Oklahomacrinus* lineage survived well into the Virgilian.

Strimple (1960) noted that three trends toward elimination of anal plates from the cup existed among late Paleozoic cladid inadunate crinoids. These were called Developmental Trends A, B, and C. All started with Primitive Type (Normal) arrangement of three anal plates, and various changes from the normal were given other "type" designations. Although the system has not attained general usage, it provides a concise reference to the arrangement of plates in the posterior interradius, without a lengthy discussion of the exact details. Also, certain lineages appear to follow specific developmental trends; for example, cromyocrinids and ulocrinids follow Developmental Trend B, but stellarocrinids follow Developmental Trend C. Pirasocrinids apparently follow both Developmental Trends A and B, but this is complicated by the recurrence of an advanced arrangement of anal plates within the lineage which basically retains the Primitive Type. The potential afforded by this general approach to lineage determination had not by any means been exploited to full advantage in the past, but the designations are used herein in some instances.

In Developmental Trend A, the tendency is to push *RX* element from the cup and to resorb *RA*, which may migrate to a posterior position. Even the anal plate may eventually migrate out of the cup, but usually it is retained as a small, rudimentary element in an adoral notch. Strimple (1960) termed the more advanced forms Ultimate Type A, Ultimate Type A(1), and Symmetrical Type; all are prolific in the Atokan. *Graffhamicrinus* (Ultimate Type A) appears for the first time in the Atokan. *Sinocrinus* and *Neoprotencrinus* (Symmetrical Type) also appear for the first time. All three genera have 10 equibiserial arms.

*Neoprotencrinus atoka* (Strimple) is represented by more articulated specimens (both cups and crowns) than is any other species in the Atokan. The cup of *N. atoka* is low, radials flex into the basal planes, convexity of the base is shallow, and the posterior interradius is indistinguishable except for a rudimentary element notching the adoral edge of the articulating surfaces. There are very limited options for morphologic change, and very few subsequent changes are known other than eventual reduction in the size of basals. The genus is represented in the Desmoinesian of Texas and Oklahoma by *N. subplanus* (Moore and Plummer). The arms of both species are 10 in number, and equibiserial, but in *N. subplanus* they are more elongated and start tapering slowly at close to midlength in mature specimens. In *N. atoka*, only about the distal one-fourth of the arms taper, and then rather abruptly.

The oldest definitive laudonocrinid crown to be recorded in the Pennsylvanian is *Anchicrinus echinosacculus* Strimple, from the Atokan of Coal County, Oklahoma. *Anchicrinus* has distinctive axillary primibrachs *1*, which are large and bulge outward. Laudonocrinids generally have a low cup that does not develop a pronounced basal concavity, and this in part distinguishes the family from pirasocrinids in which the common trend is toward marked basal invagination. The oldest definitive pirasocrinid crown in the Pennsylvanian is *Sciadiocrinus planulatus* (Moore and Plummer), which was reported by Strimple (1975) from the Atokan of Coal County, Oklahoma. Both families have tall, more or less hourglass-shaped anal sacs that terminate with a platform ringed with outwardly directed spines. The base of each spine is large and planate, but the spinose portion is rounded and commonly forms a sharp termination, except in *Scadiocrinus*; in the latter, the projecting portion may also be planate, with a thin, curved or irregular termination. Spines in the latter category have been found in the Atokan (personal observation). Pirasocrinids became well established and diversified in the pre-Atokan (Morrowan), and, together with laudonocrinids, are abundant throughout the Pennsylvanian but are relatively rare in the Permian. The unique platform spines reflect their presence, even when articulated specimens are absent.

Stellarocrinids follow Developmental Trend C, starting with Primitive Type (Normal) arrangement and modifying to Extreme Type (see Strimple, 1960, fig. 3d). *Heliosocrinus* of pre-Atokan age is thought to be the progenitor of *Brabeocrinus*; however, it has a large pentalobate column, as opposed to the round column of *Brabeocrinus* and other stellarocrinids. *Rhopocrinus* from the Chesterian is comparable to *Helliosocrinus* and is probably closely related. *Rhopocrinus* has a round stem, but it has not been recognized in the Pennsylvanian. Both *Heliosocrinus* and *Rhopocrinus* have Primitive Type anal-plate arrangement and uniserial arms. *Brabeocrinus primus* from the Atokan of Coal County, Oklahoma, retains Primitive Type anals, but all other stellarocrinids have advanced to the Extreme Type wherein radianal rests evenly on *CD* basal and supports equidimensional anal *X* and *RX* above. The arms of *Brabeocrinus primus* have advanced to cuneate brachials, a condition that is stable throughout the Pennsylvanian and Lower Permian. Other stellarocrinid genera have arms which evolved to an equibiserial state.

In Special Type C development, the *RX* is no longer a cup element. The holotype of the Atokan species *Ulocrinus zeschi* Strimple and Watkins is Special Type, but the paratype is Primitive Type (Normal). The progenitor is probably among Morrowan specimens referred to as *Cromyocrinus grandis* Mather by Strimple and Moore (1973), specimens which are commonly Primitive Type and for that matter may not be conspecific with *C. grandis*. Post-Atokan *Ulocrinus* is Special Type C, or somewhat more advanced. *C. grandis* has been designated the type species of *Mathericrinus* Webster (1981). The Atokan species *Ulocrinus percultus* Knapp is also transitional, in having Special Type or Special Type C conditions. The holotype of *U. percultus* bears striations or thin ridges which are perpendicular to the plate sutures, and Webster (1981) has assigned the species to *Mathericrinus.* I believe that the species is better placed in *Dicromyocrinus* as *Dicromyocrinus percultus* (Knapp) new combination, but that the smooth paratypes are closely related to *Ulocrinus* or more specifically to *Ulocrinus zeschi. Paracromyocrinus* typically and commonly has Special Type C arrangement, a smooth surface, and bears 10 biserial arms. In the Atokan, *P. planatus* Strimple is present and is thought to have a slightly invaginated base.

Allagecrinids are monocyclic and belong to the disparid inadunates. *Isoallagecrinus barnettensis* Strimple is from the Atokan of Coal County, Oklahoma, and *I. erectus* Strimple and Watkins is from San Saba County, Texas. Lane and Sevastopulo (1982) revised the allagecrinids and expanded the concept of *Kallimorphocrinus*, which preempts *Isoallagecrinus.* Bulging radials and low basals relegate the Oklahoma species to *Kallimorphocrinus barnettensis* (Strimple). The relatively tall cup with prominent basals aligns the Texas species with *Allagecrinus*, and it has been referred to as *A. erectus* (Strimple and Watkins). This species is then the only Pennsylvanian *Allagecrinus* of record, with other known species of the genus being pre-Atokan (Early Carboniferous) in age. Allagecrinids from the Morrowan (pre-Atokan) are currently identified as *Allocatillocrinus*; however, a complete crown of *P. klapperi* Strimple and Heckel (1978) is now known from the Missourian of Kansas and confirms the previous report of arm structure. The arms are like those of many Pennsylvanian cladid inadunates (for example, *Erisocrinus*).

## CONCLUSIONS

Forty-nine genera of inadunate crinoids are presently known from the Atokan age. Nineteen of these appear for the first time in the Atokan.

Only five flexible genera are known from Atokan strata; two appear to have originated in that age. One genus (*Zenocrinus*) does not continue into post-Atokan strata.

Camerates are not prolific and are limited to four genera in the Atokan; however, they are well established and occur in both pre-Atokan and post-Atokan strata.

Almost 80 percent of Atokan genera are recognized in post-Atokan strata, whereas only 55 percent are known in pre-Atokan strata. Affinity between Atokan crinoids and post-Atokan genera is obviously stronger than with pre-Atokan genera. Proliferation is almost entirely among the inadunates, which follows the trend established in pre-Chesterian time. Only four genera appear to be endemic: *Araeocrinus, Atokacrinus, Atrapocrinus*, and *Sinocrinus*.

## REFERENCES CITED


**Knapp, W. D.**, 1969, Declinida, a new order of Late Paleozoic inadunate crinoids: Journal of Paleontology, v. 43, p. 340–391.

**Lane, N. G.**, 1964, New Pennsylvanian crinoids from Clark County, Nevada: Journal of Paleontology, v. 38, p. 677–684.

**Lane, N. G.**, and **Sevastopulo, G.**, 1982, Growth and systematic revision of *Kallimorphocrinus astrus*, a Pennsylvanian microcrinoid: Journal of Paleontology, v. 56, p. 244–259.

**Laudon, L. R.**, 1937, New occurrence of the Upper Carboniferous crinoid genera *Amphicrinus* and *Synerocrinus*: Journal of Paleontology, v. 11, p. 706–708.

**Moore, R. C.**, and **Strimple, H. L.**, 1941, Tegminal structure of the Pennsylvanian–Permian crinoid *Delocrinus*: Denison University Scientific Laboratories Journal, v. 36, p. 1–15.

**Strimple, H. L.**, 1960, The posterior interradius of Carboniferous inadunate crinoids of Oklahoma: Oklahoma Geology Notes, v. 20, p. 247–253.

——1961, Additional notes concerning *Paragassizocrinus*: Oklahoma Geology Notes, v. 21, p. 294–298.

——1975, Middle Pennsylvanian (Atokan) crinoids from Oklahoma and Missouri: University of Kansas Paleontological Contributions, Paper 76, 30 p.

——1976, Upper Carboniferous crinoids of northwest Spain: Neues Jahrbuch Geologie und Paläontologie, v. 10, p. 630–640.

——1980, Pennsylvanian crinoids from Sangre de Cristo and Sacramento Mountains of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 178, 16 p.

**Strimple, H. L., Allison, R. C.**, and **Kline, G. L.**, 1971, Pennsylvanian crinoids from Alaska, *pt. 2 of* Strimple, H. L., and others, Fossil crinoid studies: University of Kansas Paleontological Contributions, Paper 56, p. 9–15.

**Strimple, H. L.**, and **Blythe, J. G.**, 1960, *Paragassizocrinus* in the Atoka of northeastern Oklahoma, *pt. 2 of* Strimple, H. L., The genus *Paragassizocrinus* in Oklahoma: Oklahoma Geological Survey Circular 55, p. 25–30.

**Strimple, H. L.**, and **Heckel, P. H.**, 1978, A significant acrocrinid (Crinoidea: Camerata) from the Ladore Shale (Missourian, Upper Pennsylvanian) in eastern Kansas: Kansas Geological Survey Bulletin 211, part 4, p. 5–9.

**Strimple, H. L.**, and **Knapp, W. D.**, 1966, Lower Pennsylvanian fauna from eastern Kentucky; part 2, crinoids: Journal of Paleontology, v. 40, p. 309–314.

**Strimple, H. L.**, and **Miller, J. F.**, 1971, Pennsylvanian crinoids from the Pinkerton Trail Limestone, Molas Lake, Colorado, *pt. 9 of* Strimple, H. L., and others, Fossil crinoid studies: University of Kansas Paleontological Contributions, Paper 56, p. 35–40.

**Strimple, H. L.**, and **Moore, R. C.**, 1973, Middle Pennsylvanian crinoids from central Colorado: University of Kansas Paleontological Contributions, Paper 66, p. 8–15.

**Strimple, H. L.**, and **Nassichuk, W. W.**, 1974, Pennsylvanian crinoid from Ellesmere Island: Journal of Paleontology, v. 48, p. 1149–1155.

**Strimple, H. L.,** and **Watkins, W. T.,** 1969, Carboniferous crinoids of Texas with stratigraphic implications: Palaeontographica Americana, v. 6, p. 141–275.

**Tien, C. C.,** 1924, Carboniferous crinoids from the Taiyuan Series of North China: China Geological Survey, Bulletin 6, 57 p.

———1926, Crinoids from the Taiyuan Series of North China: China Geological Survey, Palaeontologica Sinica, series B, v. 5, p. 1–47.

**Webster, G. D.,** 1981, New Crinoids from the Naco Formation (Middle Pennsylvanian) of Arizona with a revision of the family Cromyocrinidae: Journal of Paleontology, v. 55, p. 1176–1199.

**Webster, G. D.,** and **Lane, N. G.,** 1970, Carboniferous echinoderms from the southwestern United States: Journal of Paleontology, v. 44, p. 276–296.

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# AGE ZONATION OF THE EARLY PENNSYLVANIAN USING FOSSIL INSECTS

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**Abstract**—Insect faunas from 79 North American minor occurrences of pre-Alleghenian age are compared with seven Lower Pennsylvanian assemblages of three or more species. Each occurrence is variously ranked as zonally equivalent in the same phase, older or younger in phase, or indeterminate. The four pre-Alleghenian insect zones already proposed are defined on the basis of type assemblages, and three additional zones are intercalated among them. A correlation chart for insect-bearing sequences shows the distribution of insect occurrences and their zone assignments for the Lower Pennsylvanian. Preliminary comparison with Europe permits correlation of the American Midcontinent series and their subdivisions across the predominantly nonmarine type area of the Pennsylvanian to the Namurian and Westphalian Series and their subdivisions of the Upper Carboniferous of Europe.

Close examination of the age relationships of early insects is necessary to understand the phylogeny of the orders. This project was started in 1962 and is an extension of the work of Cockerell (1927). Preliminary results indicate the general succession of faunas (Durden, 1969; Durden, 1984). There are now enough insect finds in North America that a number of successive faunas may be recognized (fig. 1). These are termed "insect faunal ages" and are analogous to the mammalian ages of the Tertiary, for which generic evolutionary rates were comparable. Each insect faunal age is characterized by a type assemblage of at least three finds at the same locality and horizon. This type horizon remains in the age, no matter how the lower or upper boundaries are revised. Age boundaries are not defined, indeed they can never be precisely defined, but their positions are approximated by placement of nontypical insect occurrences in one age or the other. In faunally sparse portions of the record, new insect faunal ages will be recognized in the future. These will be inserted between existing ages without changing their concepts, but with reassignment of temporally marginal occurrences. In the preliminary version of this scheme (Durden, 1984), the Gilkersonian and Barnettian Ages are reversed, owing to previous inadequate knowledge of the Gilkersonian-type fauna and misunderstanding of its stratigraphic position. The age names have been simplified here.

Type and assigned faunas are characterized by citation of determined insects with reference to the best illustration, which is photographic where possible. On plates 1 to 4, 50 representative fossils are illustrated, 45 for the first time photographically. For each taxon the family affiliation is given. Genotype species are indicated by an asterisk (*). References in the text to the fossils illustrated on plates 1–4 are given in boldface type. Eleven institutions are cited by acronym as published repositories of specimens or parts of specimens: BSNHM, Boston Society of Natural History (4 specimens); GSC, Geological Survey of Canada (60 specimens); HCM, Hanover College Museum, Indiana (1 specimen); MCZ, Harvard University, Museum of Comparative Zoology (4 specimens); PRM, McGill University, Peter Redpath Museum (3 specimens); SJNHM, St. John Natural History Society Museum, New Brunswick (11 specimens); SMM, Science Museum of Minnesota, St. Paul (1 specimen); TMM, University of Texas at Austin, Texas Memorial Museum (2 specimens); UCWM, University of Chicago, Walker Museum (1 specimen); USNM, United States National Museum (66 specimens); YPM, Yale University, Peabody Museum of Natural History (1 specimen).

**EARLY MORROWAN OCCURRENCES (NAMURIAN C).** Early Morrowan occurrences cannot be assigned to zones until multiple species assemblages are discovered. Three zonal faunas are anticipated to include sites 1 and 2, sites 3 and 4, and sites 5 to 11. These three zones correspond to the Clark or Pocahontas, Quinnimont, and Sewell Floristic Zones of White (1900). **1. Braxton Quarry,** Hindostan Whetstone Mbr., Mansfield Fm., Raccoon Cr. Gr.; old whetstone quarry near Paoli, Orange Co., IN: Paoliidae, **Paolia vetusta* Smith (1871, p. 45, fig.), HCM. **2. French Lick,** same horizon, "in a whetstone from French Lick," same county: Paoliidae, **Paoliola gurleyi* (Scudder, 1885a; Handlirsch, 1919; Melander, 1903, pl. 7, fig. 7), UCWM Pal. Cln. 6393, probably hindwing of *Paolia*. From these Orange County localities, Miller (1889) reported arthropod ichnofossils

[1]Texas Memorial Museum, University of Texas at Austin, Austin, Texas.

| American Epoch | Site | Insect Age | European Epoch |
|---|---|---|---|
| | | KITTANNINGIAN | WESTPHALIAN D |
| DESMOINESIAN | | SAVAGEAN | |
| | | -B- | |
| | 78-86 | GILKERSONIAN | |
| | | -A- | |
| | 60-77 | THORBURNIAN | WESTPHALIAN C |
| ATOKAN | 34-59 | STELLARTONIAN | |
| | 26-33 | BARNETTIAN | WESTPHALIAN B |
| | 21-25 | MERCERIAN | |
| | 19-20 | COXTONIAN | WESTPHALIAN A |
| | 12-18 | LANCASTRIAN | |
| MORROWAN | 5-11 | Sewell Flora | |
| | 3- 4 | Quinnimont Flora | NAMURIAN C |
| | 1- 2 | Pocahontas Flora | |
| | | Bluestone Flora | NAMURIAN B |

Figure 1. Correlation chart for the seven insect faunal ages of the Early Pennsylvanian, and numbered locations of insect-bearing sites. **A** indicates location of Allegheny–Pottsville boundary; **B** indicates location of "Allegheny"–Kanawha boundary.

*Haplotichnus indianensis, Plangtichnus erraticus*, and *Treptichnus bifurcus*, which are questionably insectan. The flora was considered by Read and Mamay (1964) to be transitional from their Zone 4 to Zone 5. **3. Mount Evans,** plant beds 1 or 2, Belden Group; near summit Mt. Evans, Lake Co., CO, associated with flora older than plant bed 3 which was assigned by Read and Mamay (1964) to Zone 6: Xenoneuridae, n. g., n. sp. (in press), **pl. 1, fig. 1,** TMM 1509TX1-2, James Jennings Clr., Aug. 1980. **4. Altamont,** roof Lykens No. 4 Coal, Tumbling Run Fm., Pottsville Gr.; Altamont No. 1 Colliery, Schuylkill Co., PA: Metropatoridae, **Metropator pusillus* Handlirsch (1906a), **pl. 1, fig. 2,** USNM 35382, David White Clr. **5. Pratt,** Pratt Coal Gr., subinterval A2 (Wanless, 1975); Warrior Basin, SW of Birmingham, AL: Lithomantidae, **Eurythmopteryx antiqua* Handlirsch (1906a), **pl. 1, fig. 3,** USNM 38707. **6. Coalburg,** same horizon; N of Birmingham: Lithomantidae, **Bathytaptus falcipennis* Handlirsch (1906a, p. 686, fig. 12), USNM 38708. **7. Cordova,** same horizon; NW of Birmingham: Pteronidiidae, **Campteroneura reticulata* Handlirsch (1906a, p. 685, fig. 10), USNM 38709. **8. Williams Mine No. 4,** roof Durham No. 5 Coal, Walden Fm., Pottsville Gr.; Durham, Walker Co., GA: Paralogidae, *Boltonites durhami* (Carpenter, 1960, pl. 11) nov. comb., USNM, Charles B. Read Clr., May 1939 (field no. 8758). **9. New Lincoln Colliery,** roof Lykens No. 2 Coal, Schuylkill Fm., Pottsville Gr., 3 miles W of Tremont, Schuylkill Co., PA: Lamproptilidae, *Boltoniella* sp. (no fig.), USNM 38743, David White Clr. **10. Lemon's Coal Bank,** roof Washington Coal, Woolsey Shale Mbr., Bloyd Fm., Morrow Gr.; 6 miles NE of Fayetteville, Washington Co., AR: Omaliidae, **Archimastax americanus* Handlirsch (1906a), **pl. 1, fig. 4,** USNM 38711. **11. Santa Fe,** lower Sandia Fm. (Floral Zone 6, Read and Mamay, 1964); N side, Santa Fe Cr., E Santa Fe (outcrop now covered by condominium project), NM: Pteronidiidae, **Sandiella readi* Carpenter (1970, p. 406, fig. 4B), USNM 170364 (USGS Loc. 8941), Charles B. Read Clr., 1941.

**LANCASTRIAN INSECT FAUNAL AGE (EARLY WESTPHALIAN A; EARLY LATE MORROWAN).** Type assemblage includes combined fauna of plant beds 2, 7, and 8, respectively 3.5 m, 27 m, and 28 m above "Dadoxylon Sandstone," Lancaster Mbr., Little River Fm., Riversdale Gr.; "Fern Ledges" of Lancaster, Duck Cove, 1 mile W of Carleton (West St. John), NB. **12. Fern Ledges Plant Bed 2:** Xenoneuridae, **Xenoneura antiquorum* Scudder (1867, p. 205; 1881, pl. 1, figs. 5, 6), BSNHM and SJNHM, C. F. and J. W. Hartt Clrs.; Mixotermitidae, **Geroneura wilsoni* Matthew (1889, pl. 4, fig. 10), SJNHM and GSC 8129, W. J. Wilson Clr.; Paoliidae, **Gerephemera simplex* Scudder (1868c, p. 172; 1881, pl. 1, fig. 8, 8a), SJNHM and BSNHM, C. F. Hartt Clr.; family unknown (probably cast exoskeleton of juvenile insect with tracheal linings dragged anteriorly), **Geracus tubifer* Matthew (1897, p. 55, fig. 3), SJNHM, G. F. Matthew Clr.; Dasyleptidae, **Archaeoscolex corneus* Matthew (1889, pl. 4, fig. 11), SJNHM, W. J. Wilson Clr.; family unknown (wingless insect with blattoid pronotum, or cast exoskeleton of juvenile winged insect), **Podurites saltator* Matthew (1895; 1897; pl. 2, fig. 8), SJNHM, W. J. Wilson Clr. From "Lower Cordaite Shales," probably also plant bed 2: Syntonopteridae, *Aedoeophasma acadica* Matthew (1910, pl. 1, fig. 1), GSC, W. J. Wilson Clr.; Lithomantidae, **Archaeophasma grandis* Matthew (1910; pl. 1, fig. 2). SJNHM, G. F. Matthew Clr. Higher, in plant bed 4 at 19 m, were collected the large-leaved pteridosperm **Megalopteris dawsoni* Hartt (*in* Dawson, 1868) and its probable seed *Cardiocarpon baileyi* Dawson (1868). **13. Fern Ledges Plant Bed 7:** Paralogidae, **Platephemera antiqua* Scudder (1867; 1881, pl. 1, figs. 9, 10), BSNHM, C. F. Hartt Clr. **14. Fern Ledges Plant Bed 8:** Prototettigidae, **Lithentomum harttii* Scudder (1867; 1881, pl. 1, fig. 3), SJNHM and BSNHM, C. F. Hartt Clr.; Prototettigidae, **Pseudohomothetus erutus* (Matthew, 1894, pl. 1, fig. 11), Handlirsch (1906a), SJNHM, W. J. Wilson Clr.; Lithomantidae, **Dyscritus vetustus* Scudder (1868c; 1881; pl. 1, fig. 4), SJNHM, C. F. Hartt Clr.; Homothetidae, **Homothetus fossilis* Scudder (1867; 1881, pl. 1, fig. 1), SJNHM, C. F. Hartt Clr. **15. Greville Bay,** Parrsboro Fm., Riversdale Gr.;

Cumberland Co., NS: Mixotermitidae, undescribed wing, (GSC Loc. 1389), W. A. Bell Clr., 4 July 1925 (field no. 101). **16. West Bay,** Claremont Fm., same group; Parrsboro, same county: Brodiopteridae, **Brodioptera cumberlandensis* Copeland (1957, pl. 18, figs. 1, 2), GSC 10390, H. M. Ami Clr., 1899. **17. Howard's Mills,** same formation; River Wallace, same county: Patteiskyidae, **Schedoneura amii* (Copeland, 1957; pl. 18, figs. 4, 5), Carpenter (1963), GSC 10391, H. M. Ami Clr., 1899. **18. Tallmadge,** Sharon Shale, Pottsville Gr.; Tallmadge, Summit Co., OH: Prototettigidae, **Archegogryllus priscus* Scudder (1868b; 1885, pl. 29, figs. 2, 3), S. H. Scudder Cln., MCZ, J. S. Newberry Clr. In the same formation, 2 miles E of Rushville, Perry Co., OH, from 25–30 ft above base of Pottsville Gr., Andrews (1875) described the pteridosperms *Megalopteris harttii, M. minima, M. ovata,* and *M. lata,* and the probable seed of this genus, *Cardiocarpon newberryi.* These occurrences fall in Floristic Zone 7 of Read and Mamay (1964). Species of *Megalopteris* occur earlier in the Sewell Fm. (Alabama), and later in the Middle River Fm. (Nova Scotia).

**COXTONIAN INSECT FAUNAL AGE (MID–WESTPHALIAN A; MID–LATE MORROWAN).** Type assemblage occurs in the Campbells Ledge Black "Slate," Schuylkill Fm., 2 m above base of Pottsville Gr.; age name is shortened from the cumbersome "Campbellsledgean." **19. Campbell's Ledge,** with flora considered by White (1900) as equivalent to uppermost Upper Lykens (Schuylkill Fm.) of the Pottsville type section: Paoliidae, **Pseudopaolia lacoana* (Scudder, 1885a) Handlirsch (1906a), **pl. 1, fig. 5,** USNM 38100, Lacoe Cln. 2015a, b; Spanioderidae, **Pseudopolyernus laminarum* (Scudder, 1885a) Handlirsch (1906a), **pl. 1, fig. 6,** USNM 38155, Lacoe Cln.; Prototettigidae, **Dieconeurites rigidus* (Scudder, 1885a) Handlirsch (1906a), **pl. 1, fig. 7,** USNM 38156, Lacoe Cln.; Necymylacridae, **Aphthoroblattina fascigera* (Scudder, 1878) Handlirsch (1906a), **pl. 1, fig. 8,** USNM 38058, Lacoe Cln. 2002a and b; Archimylacridae, **Plagioblatta parallela* (Scudder, 1879) Handlirsch (1906a), **pl. 1, fig. 9,** USNM 38093, R. D. Lacoe Clr.; Jongmansiidae, **Titanodictya jucunda* (Scudder, 1885b) Handlirsch (1906a), **pl. 1, fig. 10,** USNM 38154, Lacoe Cln.; Pteronidiidae, **Parahaplophlebium longipennis* (Scudder, 1885b) Handlirsch (1906a), **pl. 2, fig. 1,** USNM 38097a and b, Lacoe Cln.; Paralogidae, **Palaeotherates pennsylvanicus* Handlirsch (1906a), **pl. 2, fig. 2,** USNM 38787, Lacoe Cln., and additional individual USNM 38093, Lacoe Cln.; the fossil **Scudderiana diffusa* Handlirsch (1919), USNM 38099, with carbonized plant cells in the interstices of the veins, is not insectan. This assemblage has the oldest cockroaches in North America, and is exceeded elsewhere only by a necymylacrid fragment in the Faisceau d'Olympe of northern France (early Westphalian A). **Phoberoblatta grandis* Handlirsch (1906a) from Fishing Creek Gap, Sharp Mtn., Schuylkill Co., PA, was reported as a Namurian C species (Durden, 1969) because the mined coal at this locality was mapped by the Second Pennsylvania Survey as Lykens No. 4 Coal. Flora collected here by White (1900) included taxa much younger than the post-Pottsville Twin (Buck Mountain) Coal. **20. West River Pictou,** Middle River Fm., Cumberland Gr.; railway cut W of West River Sta. (CNR), Pictou Co., NS: hemeristoid n. fam., n. g., n. sp., **pl. 2, fig. 3,** GSC Loc. 3104, H. M. Ami Clr., 1892. On Middle River of Pictou, this formation has produced *Megalopteris kellyi* Arnold (Bell, 1940).

**MERCERIAN INSECT FAUNAL AGE (LATE WESTPHALIAN A; LATE LATE MORROWAN).** Type assemblage occurs in the Conoquenessing Sandstone, Pottsville Gr.; Mercer, Mercer Co., PA. **21. Mercer,** shale lens 3 m below top of Conoquenessing Sandstone; quarry 1 mile NE of Mercer Court House, above State Hospital: Phoberoblattidae, *Atimoblatta reducta* Cockerell (1918), **pl. 2, fig. 4,** USNM 64342, H. Bassler Clr., 1916 (field loc. PB 12); *Atimoblatta*(?) *cockerelli* Handlirsch (1922) (Cockerell, 1918, p. 302, fig. 1), USNM 64342 (part); Hemimylacridae, 5 wing fragments, including *Brachymylacris* sp. **22. Deep Creek.** 1 m above Conoquenessing Sandstone, Pottsville Gr.; Youghiogheny R., Garrett Co., MD: Hemimylacridae, *Brachymylacris martini* Cockerell (1927, pl. 7, fig. 27), USNM, Johns Hopkins Univ. Cln., H. Bassler Clr. (field loc. BB 51). **23. Fenner's Ledge,** Cranston Shale, just above basal conglomerate, Kingstown Gr.; W edge, Rhode Island Coalfield, in S Cranston, Providence Co., RI: Polycreagridae, **Polycreagra elegans* Handlirsch (1906a, p. 679, fig. 6), USNM 38705 and 38706; Xenoblattidae, *Intermylacris reticulata* (Handlirsch, 1920, p. 22) nov. comb., (Scudder, 1893, pl. 2, fig. k), USNM 3070, Frederick P. Gorham and Herbert Scholfield Clrs. **24. Joggins,** Cumberland Gr.; Cumberland Co., NS: Necymylacridae, Archimylacridae or Phoberoblattidae, "Blattina" cf. *venusta,* Scudder (1868b), YPM, O. C. Marsh Clr. **25. Drummond Mine,** between Scott and Westville Coal Seams, Westville Fm., Stellarton Gr.; 42.5 ft in borehole on No. 8 mine level, Westville, Pictou Co., NS, GSC Loc. 2710 (=4823): Hemimylacridae, *Brachymylacris* sp. Durden (1972, pl. 14, fig. 113), GSC 25894, W. A. Bell Clr., 4 Aug. 1923.

The early Atokan, including the basal Trace Creek Shale, corresponds, in the Kanawha and Pottsville Groups, to the interval from the Kendrick and Lower Mercer marine horizon up to the Magoffin and Upper Mercer marine horizon. In Europe, this interval is the Westphalian B, from the Poissonièr, Katharina, and Cefn Coed marine horizon up to the Petit Buisson, Aegir, and Cwm

Gorse marine horizon. There are few insect occurrences in North American deposits of this interval, and only one is rich enough to characterize the fauna.

**BARNETTIAN INSECT FAUNAL AGE (WESTPHALIAN B; EARLY ATOKAN).** Type assemblage is in the Brookville Clay, Mercer Fm., Pottsville Gr.; at Humphrey's Clay Pit, Port Barnett, 1 mile E of Brookville, Jefferson Co., PA. Name is shortened from "Portbarnettian." **26. Port Barnett,** type locality of the Brookville Coal, where is is correlated with the Upper Mercer Coal, not with coals mapped elsewhere as "Brookville" (Ashley, 1945): Phoberoblattidae, *Phylomylacris reticulata* (Cockerell, 1918, pl. 54, fig. 4) nov. comb., USNM 64343, Harvey Bassler Clr., 1916 ( = *Aphthoroblattina handlirschi* Carpenter, 1934, pl. 24, fig. 1), MCZ 3345, S. H. Scudder Cln.; Xenoblattidae, *Discoblatta pauper* (Cockerell, 1918, pl. 54, fig. 5) nov. comb., USNM 64347, H. Bassler Clr.; Cobaloblattidae, **Cobaloblatta simulans* Cockerell (1918), **pl. 2, fig. 5,** USNM 64344 (part), H. Bassler Clr., 1916, and paratype USNM 64344 (part), not figured; Hemimylacridae, *Brachymylacris bassleri* Cockerell (1918), **pl. 2, fig. 6,** USNM 64345, H. Bassler Clr.; Orthomylacridae, **Ptilomylacris medialis* Cockerell (1918, pl. 54, fig. 7), USNM 64346, H. Bassler Clr.; Archimylacridae, *Plagioblatta flexuosa* (Cockerell, 1918) Durden (1969), **pl. 2, fig. 7,** USNM 64348, H. Bassler Clr.; and 5 hemimylacrid fragments, USNM. **27. Garman's Mills,** 40 ft below "B" Coal, Pottsville Gr.; railroad cut next to Moss Creek, ½ mile above Garman, Cambria Co., PA: Necymylacridae, *Polyetoblatta campbelli* (Handlirsch, 1906a) nov. comb., **pl. 2, fig. 8,** USNM 35391, Burrows and Campbell Clrs. (field no. 3239); Phoberoblattidae, *Phylomylacris* sp., 3 wing fragments, USNM, same collectors. **28. Cowanshannock,** "just beneath Homewood Sandstone" on A.V.R.R. grade, 5 miles E of Kittanning, Armstong Co., PA: Necymylacridae, *Polyetoblatta* sp., wing fragment, USNM, D. White Clr., 1900 (field no. 2130); Cobaloblattidae, *Cobaloblatta* sp., wing fragment, USNM, same collector. **29. McGinnis Mine,** "probably 400 feet above Hampton Conglomerate," Kanawha Gr.; near Redbird, Raleigh Co., WV: ?Lithomantidae, *Palaeodictyopteron virginianum* Handlirsch (1906a) (Carpenter, 1948, pl. 7, fig. 2), USNM 25635, B. F. Phillips Clr. **30. Hampton,** same horizon; road to Peachtree Cr., same county: Necymylacridae, **Polyetoblatta calopteryx* Handlirsch (1906a, p. 720, fig. 40), USNM 25633. **31. Drew's Creek,** horizon unknown; above Peachtree Creek, same county: Lithomantidae, **Orthogonophora distincta* Handlirsch (1906a, p. 686, fig. 11), USNM 25632. **32. Gardner's Drift,** roof Dunmore No. 2 Coal, upper Pottsville Gr.; Elm St. at Stone Ave., Scranton, Lackawanna Co., PA: Phoberoblattidae, **Atimoblatta curvipennis* Handlirsch (1906a) ( = *A. reniformis* Handlirsch, 1906a, reverse of same specimen), **pl. 2, fig. 9,** USNM 35380 and 35383. **33. Sockanosset Mine,** roof Sockanosset Coal, Sockanosset Mr., Kingstown Gr., some 2,000 ft above base; probably the Reform School Mine on E side of Rocky Hill, W of Pawtuxtet River, Cranston, Providence Co., RI: Rhaphidiopseidae, **Rhaphidiopsis diversipenna* Scudder (1893, pl. 1, figs. c, d), USNM, Edgar F. Clark Clr., 22 June 1888 (field no. 179a, b).

In the mid-Atokan, insect-bearing deposits in North America are restricted to the Rhode Island Coal Field, Rhode Island, and the Stellarton Coal Field, Nova Scotia. This interval is better represented entomologically in Europe, where occurrences extend from South Wales across northern France and Belgium, into Germany.

**STELLARTONIAN INSECT FAUNAL AGE (EARLY WESTPHALIAN C; MID-ATOKAN).** Type assemblage is composed of occurrences 34 to 43, above the Foord (Main of Albion) Coal Seam in the lower shale member of the Coal Brook Fm., Stellarton Gr.; vicinity of Stellarton, Pictou Co., NS. **34. Duff Brook Borehole 452 ft,** Acadia Coal Co. BH 8, Duff Brook, 1,250 ft W of Stellarton Road (bored 1911): Hemimylacridae, *Brachymylacris* (**Bellamylacris*) *belli* Durden (1972), **pl. 2, fig. 11,** GSC 22011. **35. Duff Brook Borehole 451.5 ft,** same core: Archimylacridae, *Parelthoblatta* (*Archaeotiphe*) *stella* Durden (1972), **pl. 2, fig. 10,** GSC 22010. **36. McLellan Brook Borehole 1,010 ft,** Acadia Coal Co. BH 54, 2,930 ft S. 57.5° E. of McLellan Brook at New Glasgow–Plymouth Road (bored 1922–23): Xenoblattidae, **Intermylacris intermedia* Durden (1972) **pl. 3, fig. 1,** GSC 21994. **37. McLellan Brook Borehole 1,005.4 ft,** same core: Hemimylacridae, wing fragment (Durden, 1972, pl. 14, fig. 111), GSC 25893. **38. McLellan Brook Borehole 989 ft,** same core (GSC Loc. 2359): Petrablattinidae, **Linemylacris mclellanensis* Durden (1972), **pl. 2, fig. 13,** GSC 25886; Hemimylacridae, wing fragment (Durden, 1972, pl. 14, fig. 109), GSC 25892. **39. McLellan Brook Borehole 977 ft,** probably same core (GSC Loc. 2487): 5, Homoiopteridae, wing fragment (Copeland, 1957, pl. 21, fig. 3), GSC 12862. **40. McLellan Brook Borehole 878 ft,** same core (GSC Loc. 2874): Xenoblattidae, **Grypoblattina phaseolus* Pruvost (1919), **pl. 2, fig. 12,** GSC 25882, W. A. Bell Clr., 2 Aug. 1923 (type figured by Pruvost, 1919, pl. 12, fig. 1, from France). **41. McLellan Brook Borehole 736 ft,** same core: Diaphanacridae, *Malarchimylacris* sp. cf. *mclellanensis* Durden (1972) (Copeland, 1957, pl. 19, figs. 6, 7), hindwing, GSC 12849. **42. McLellan Brook Borehole 687–694 ft,** same core (GSC Loc. 2709): Xenoblattidae, *Intermylacris* sp. cf. *intermedia* Durden (1972, pl. 3, fig. 32a, b), hindwing, GSC 25883, W. A. Bell Clr., 1923. **43. Dalhousie Pits,** in roof Main (Foord) Coal Seam;

East River: Archimylacridae, **Archimylacris acadica* Scudder (*in* Dawson, 1868; Scudder, 1879, pl. 6, fig. 8), PRM, J. W. Dawson Cln., James Barnes Clr.

Occurrences 44 to 47 are in the overlying plant-shale member of the Coal Brook Fm., Stellarton Gr.; Pictou Co., NS. **44. McLellan Brook (A),** in black shale with "*Leaia*" (GSC Loc. 1151, =10631): Diaphanacridae, **Malarchimylacris mclellanensis* Durden (1972), **pl. 3, fig. 2,** GSC 21993, W. A. Bell Clr. (field no. "nG. 26-16, Sta. 302"). **45. McLellan Brook Borehole 221–227 ft** (see site 36 for location), (GSC Loc. 2758): Archimylacridae, *Parelthoblatta* (*Archaeotiphe*) sp. Durden (1972, pl. 16, fig. 127), hindwing, GSC 25904. **46. McLellan Brook Borehole 93–97 ft,** same core (GSC Loc. 2360): Orthomylacridae, *Amblymylacris* (**Cursimylacris*) *orieulxi* (Pruvost, 1919) Durden (1972), **pl. 3, fig. 3,** GSC 22005, W. A. Bell Clr., 31 July 1923 (type figured by Pruvost, 1919, pl. 11, fig. 16, from France); Antemylacridae, pronotum (iota) Pruvost (1919) Copeland, 1957, pl. 11, fig. 5), GSC 12790, same collector (hypotype figured by Pruvost, 1919, pl. 13, fig. 19, from France). **47. East River Shore,** 1,300 ft above mouth Blackwood Brook (GSC Loc. 2480): Hemimylacridae, **Acadiemylacris attenuata* Durden (1972), **pl. 3, fig. 4,** GSC 22001, W. A. Bell Clr., 28 July 1938.

Occurrences 48 to 50 are in the overlying Pottery Ironstone Mbr., Coal Brook Fm., Stellarton Gr.; Pictou Co., NS. **48. McLellan Brook (B),** W of drain below Pottery Works, New Glasgow (GSC Loc. 2621): Hemimylacridae, *Quasimylacris* sp. Durden (1972, pl. 8, fig. 72), GSC 22002, W. A. Bell Clr., 20 Sept. 1915. **49. McLellan Brook (C)** (GSC Loc. 2711), location not specified: Hemimylacridae, wing fragment, Durden (1972, pl. 14, fig. 107), GSC 25891, W. A. Bell Clr., 8 July 1926 (field Sta. 876). **50. McLellan Brook (D),** near mouth, below Pottery Works, New Glasgow (GSC Loc. 2951): Xenoblattidae, *Intermylacris* sp. Durden (1972), **pl. 3, fig. 5,** hindwing, GSC 25884, W. A. Bell Clr., 21 Sept. 1915.

Occurrences 51 to 56 are in the Shale Brook Oil-Shale Mbr., basal Thorburn Fm., Stellarton Gr., Pictou Co., NS. **51. Coalburn Borehole 1347 ft,** Acadia Coal Co. BH 60, 950 ft S. 56° E. of mouth McBean Slope, Coalburn (bored 1929) GSC Loc. 2871): Archimylacridae, *Archimylacris coalburnensis* Durden (1972), **pl. 3, fig. 7,** GSC 25901, W. A. Bell Clr., 8 June 1929. **52. Coalburn Borehole 1,314–1,326 ft,** same core (GSC Loc. 2631): Mylacridae, *Aphelomylacris coalburnensis* Durden (1972) (Copeland, 1957, pl. 19, fig. 3), GSC 12773a, W. A. Bell Clr., 8 June 1929; Orthomylacridae, *Amblymylacris* (*Cursimylacris*) sp. Durden (1972, pl. 6, fig. 49), GSC 25899. **53. Coalburn Borehole 1,302 ft,** same core (GSC Loc. 2955): Antemylacridae, *Antemylacris archimylacroides* Durden (1972), **pl. 3, fig. 6,** GSC 21989 (but the reverse bears "GSC 21990, Loc. 2949"; mislabelled?), W. A. Bell Clr., 13 June 1929. **54. McLellan Brook (E),** 300 ft below Shale Brook, between McBean and Widow Chisholm Coal Seams (GSC Loc. 2822): Hemimylacridae, *Brachymylacris* (*Bellamylacris*) sp. Durden (1972, pl. 12, fig. 98), GSC 22006, W. A. Bell Clr., 15 Sept. 1915. **55. Thorburn Borehole 691 ft,** Acadia Coal Co. BH 62, 4,650 ft N. 36° W. of mouth Acadia Coal Co. No. 3 slope, Thorburn (bored 1929) (GSC Loc. 2685): Hemimylacridae, wing fragment, Durden (1972, pl. 14, fig. 114), GSC 25895, W. A. Bell Clr., 24 June 1929. **56. McLellan Brook (F),** this member? (GSC Loc. 2356): Hemimylacridae, *Brachymylacris* (*Brachymylacris*) *mclellanensis* Durden (1972), **pl. 3, fig. 8,** GSC 25890, W. A. Bell Clr., 2 Aug. 1924 (field Sta. 81). This interval? specimen labelled "borehole 20, Coalburn": Xenoblattidae, *Grypoblattina copelandi* Durden (1972) (Copeland, 1957, pl. 9, fig. 4), GSC 12845.

Occurrences 57 to 59 are in the Tenmile River Fm., Kingstown Gr.; Bristol Co., RI. **57. Silver Spring,** N of railroad sta., on strike with Tenmile River Fm. of East Providence: Antemylacridae, *Discoblatta areolata* (Handlirsch, 1922) nov. comb. (Scudder, 1893, pl. 2, fig. c), USNM 38072, H. Scholfield Clr.; Xenoblattidae, **Xenoblatta fraterna* (Scudder, 1893) Handlirsch (1906a), **pl. 3, fig. 9,** USNM 38059, H. Scholfield Clr.; Paralogidae, **Paralogus aeschnoides* Scudder (1893, pl. 1, fig. a) (Carpenter, 1960, p. 102, fig. 2), MCZ, Gorham Cln., F. P. Gorham Clr., 2 Nov. 1889. **58. Kettle Point,** boulder on beach: Hemimylacridae, distinctive n. g., "*Etoblattina*" *exilis* Scudder (1893, pl. 2, fig. e), USNM, H. Scholfield Clr. **59. East Providence,** Tenmile River Fm. (some of these from Silver Spring?): Antemylacridae, **Discoblatta scholfieldi* (Scudder, 1893) Handlirsch (1906a), **pl. 3, fig. 10,** USNM 38076, H. Scholfield Clr.: Spiloblattinidae, distinctive n. g., "*Etoblattina*" *latebricola* Scudder (1895), **pl. 3, fig. 11,** USNM, Lacoe Cln. 2091a, b; Blattinopsidae, **Microblattina perdita* Scudder (1895), **pl. 3, fig. 12,** USNM 38098, Lacoe Cln. 2092a; Heolidae, **Heolus providentiae* Handlirsch (1906a, p. 678, fig. 5), USNM 38700.

Late Atokan insect-bearing deposits in North America are restricted to the coal fields of Rhode Island and Nova Scotia. This interval is better represented entomologically in Europe, where occurrences extend from South Wales across northern France and Belgium, into Germany.

**THORBURNIAN INSECT FAUNAL AGE (EARLY MIDDLE WESTPHALIAN C; LATE ATOKAN).** Type assemblage composed of occurrences 60 to 67 in Marsh Brook Oil-Shale Mbr., middle Thorburn Fm., Stellarton Gr.; vicinity of Thorburn, Pictou Co., NS. **60. Thorburn Borehole 171 ft** (for location, see site 55) (GSC Loc. 2873): Antemylacridae, *Discoblatta coalburnensis* Durden (1972), **pl. 4, fig. 1,** GSC 25880, W. A. Bell

Clr., 14 June 1929. **61. Thorburn Borehole 162.5 ft,** same core (GSC Loc. 2949): reverse of *Antemylacris archimylacroides* (site 51) labelled this locality number (in error?). **62. Thorburn Borehole 153 ft,** same core (GSC Loc. 2872): Archimylacridae, *Parelthoblatta (Parelthoblatta) stellartonensis* Durden (1972), **pl. 3, fig. 13,** GSC 25903. **63. Thorburn Borehole 152 ft,** same core (GSC Loc. 2953): Orthomylacridae, *Amblymylacris (Cursimylacris) acadica* Durden (1972, pl. 5, fig. 45), GSC 25897. **64. Thorburn Borehole 151 ft,** same core (GSC Loc. 2928): Archimylacridae, *Archimylacris* sp. Durden (1972, pl. 15, fig. 122), GSC 25902. **65. Thorburn Borehole 143 ft,** same core (GSC Loc. 2954): Hemimylacridae, *Etoblattina (Etoblattina) stellartonensis* Durden (1972) (Copeland, 1957, pl. 18, fig. 7), GSC 12847a and 25888, W. A. Bell Clr., 24 June 1929. **66. McLellan Brook (G),** 2,500 ft below bridge of McLellan Mountain Rd., just above Sixfoot Coal Seam, Mountville (GSC Loc. 2843): Hemimylacridae, *Brachymylacris (Stellamylacris) mountvillensis* Durden (1972), **pl. 4, fig. 2,** GSC 21991. **67. Vale Colliery** (Acadia Coal Co. No. 3 Mine), Thorburn (GSC Loc. 2657, =2707, =1097), roof Sixfoot Coal Seam: Mylacridae, *Aphelomylacris (*Eomylacris) thorburnensis* Durden (1972), **pl. 4, fig. 3,** GSC 22007; Acadelytridae, **Acadelytron umbrale* Durden (1972), **pl. 4, fig. 4,** GSC 25900.

Occurrences 68 to 76 are in the upper Thorburn Fm., in shales below Mackay Coal Seam, Stellarton Gr.; Pictou Co., NS. **68. Potter Brook Borehole 29 ft,** Acadia Coal Co. BH 63, 180 ft N of slope at Acadia Coal Co. No. 5 Mine on Mackay Coal Seam (bored 1929) (GSC Loc. 2858): Antemylacridae, **Mclellamylacris acadica* Durden (1972), **pl. 4, fig. 5,** GSC 25881, W. A. Bell Clr., 16 Aug. 1929. **69. Coalburn Borehole 563** (for location, see site 51): Hemimylacridae, **Quasimylacris lanceolata* (Bolton, 1911) Durden (1972) (Copeland, 1957, pl. 18, fig. 8), hypotype 3, GSC 21998, (holotype figured by Bolton, 1922, pl. 9, fig. 5, from Wales); Orthomylacridae, *Cyphomylacris saclieri* (Pruvost, 1919) Durden (1972) (Copeland, 1957, pl. 19, fig. 4), hypotype, GSC 12773b (holotype figured by Pruvost, 1919, pl. 14, fig. 1, from France). **70. Coalburn Borehole 384 ft,** same core: Hemimylacridae, pronotum (alpha) Pruvost (1919) (Copeland, 1957, pl. 9, fig. 1), GSC 12772 (hypotype figured by Pruvost, 1919, pl. 12, fig. 16, from France). **71. Coalburn Borehole 319 ft,** same core: Hemimylacridae, *Etoblattina (Etoblattina) coalburnensis* Durden (1972) (Copeland, 1957, pl. 12, fig. 1), GSC 12774, W. A. Bell Clr., 1929. **72. Greenwood Borehole 470–474 ft,** D. Henderson property, Greenwood, 928 ft E of NW corner of barn and 1,020 ft W from second borehole (bored 1924) (GSC Loc. 512): Hemimylacridae, *Etoblattina (*Acadacrites) hendersoniana* Durden (1972) (Copeland, 1957, pl. 19, fig. 1, GSC 12848). **73. Greenwood Borehole 467–470.5 ft,** same core (GSC Loc. 2712, =514): Antemylacridae, **Antemylacris thorburnensis* Durden (1972), **pl. 4, fig. 6,** GSC 22004, W. A. Bell Clr., 5 July 1924; Hemimylacridae, **Pinnamylacris elongata* Durden (1972), **pl. 4, fig. 7,** GSC 22003, same collector; *Brachymylacris (*Stellamylacris) phylloides* Durden (1972) (Copeland, 1957, pl. 18, fig. 9), GSC 12847c; *B. (S.) belloides* Durden (1972, pl. 13, fig. 104), GSC 22009; Orthomylacridae, *Amblymylacris (Cursimylacris) hendersoniana* Durden (1972, pl. 5, fig. 47), GSC 25898. **74. Greenwood Borehole 393–397 ft,** same core: Hemimylacridae, *Etoblattina* sp., Durden (1972, pl. 11, fig. 92), GSC 25889. **75. Greenwood Borehole 361 ft,** same core (GSC Loc. 2869): Hemimylacridae, *Etoblattina* sp. Durden (1972, pl. 11, fig. 88), GSC 25887, W. A. Bell, 21 June 1924. **76. Greenwood Borehole 337–340 ft,** same core (GSC Loc. 2875): Antemylacridae, **Cacomylacris greenwoodiana* Durden (1972, pl. 2, fig. 22), GSC 21999, W. A. Bell Clr., 1924. Three specimens labelled "borehole in Stellarton Group" are probably Thorburnian: Hemimylacridae, **Quasimylacris lanceolata* (Bolton, 1911) (Copeland, 1957, pl. 18, fig. 8), male hypotype, GSC 12847b; **Lanceomylacris acutipennis* Durden (1972) (Copeland, 1957, pl. 18, fig. 11), GSC 12847e; *Etoblattina (E.) coalburnensis* Durden (1972) (Copeland, 1957, pl. 18, fig. 10), paratype, GSC 12847d. **77. Valley Falls Mine,** Tenmile River Fm., Kingstown Gr.; Pawtucket, Providence Co., RI: Mylacridae, **Aphelomylacris (A.) modesta* Handlirsch (1906a), **pl. 4, fig. 8,** USNM 38702. Note that there is another insect locality in Pawtucket, southeast of Valley Falls, in a synclinal remnant of the Pawtucket Shale of the Aquidneck Group. This bears a Stephanian flora and insect fauna.

In the post-Atokan but pre-Alleghenian, insect-bearing deposits of North America are scattered from the middle Morien Group of Nova Scotia to the lower Desmoinesian of the Midcontinent. One assemblage is large enough to characterize this zone, which is equivalent to the upper Assize de Bruay at the top of the Westphalian of northern France.

**GILKERSONIAN INSECT FAUNAL AGE (LATE MIDDLE WESTPHALIAN C; EARLY DESMOINESIAN).** Type assemblage composed of occurrences 78 and 79 at Gilkerson Ford of the Grand River, and nearby coal mines at Clinton, Henry Co., MO; roof of Rowe Coal, basal Drywood Fm., Cherokee Gr. **78. Gilkerson Ford,** now covered by Truman Reservoir; bed 7 of White (1899), roof Jordan (Rowe) Coal: Phoberoblattidae, *Phylomylacris* new species, **pl. 4, fig. 9,** TMM 1421TX1, E. H. Sellards Cln., (field no. X-52, 0-1), J. H. Britts Clr., 26 July 1909; Orthomylacridae, **Amblymylacris (A.) clintoniana* (Scudder, 1895, pl. 4, fig. 1) Handlirsch (1906a), USNM 2182, David White Clr., (field no. 412); *Dipeltis limulus* (Handlirsch, 1920) nov. comb. (Sellards, 1906, p.

249, fig. 7), USNM, J. H. Britts Clr., (orthomylacrid juvenile, probably *Amblymylacris*). **79. Clinton,** "coal bank near Clinton, 50 feet from base Lower Coal Measures" (Pitcher's Mine, 3.5 miles SE; Owens' Mine, 2 miles SE; Hobbs' Mine, 8 miles S, 2 miles E; or Deepwater Mine, 8 miles SE); same horizon: Hemimylacridae, **Hemimylacris clintoniana* (Scudder, 1895) Handlirsch (1906a), **pl. 4, fig. 10,** USNM 38161, Lacoe Cln. 2151a; Orthomylacridae, *Trilophomylacris americana* (Scudder, 1895) nov. comb., **pl. 4, fig. 11,** USNM 38162, Lacoe Cln. 2137. **80. Frog Bayou,** roof Hartshorne Coal, Hartshorne Fm., Cherokee Gr. (given as "base of Millstone Grit"); Crawford Co., AR: Archimylacridae, *Parelthoblatta venusta* (Lesquereux, 1860) nov. comb. (Scudder, 1879, pl. 6, fig. 12), MCZ. **81. South Port Morien,** roof Mullins Coal Seam, Morien Gr.; E shore Morien Bay, Cape Breton Co., NS (GSC Loc. 514, =3139): Orthomylacridae, *Trilophomylacris moriensis* (Copeland, 1957) Durden (1972), **pl. 4, fig. 12,** GSC 10394, W. A. Bell Clr., 1920. **82. Cossett's Pit,** same horizon; Sydney–New Waterford Road, near Sydney, same county: Hemimylacridae, unplaced "*Blattina*" *sepulta* Scudder (1876; 1879, pl. 6, fig. 7), PRM, A. J. Hill Clr.; probable plant fragment **Scudderina furcifer* Handlirsch, 1919 (Scudder, 1879, pl. 6, fig. 11), PRM, A. J. Hill Clr. **83. Ryan Pits,** same horizon; same vicinity: Xenoblattidae, hindwing fragment, Durden (1972, pl. 3, fig. 36), GSC 25885. **84. Furnace Hollow,** probably near Chilton Coal, uppermost Kanawha Gr.; near mouth Tabor Creek, Wayne Co., WV: Orthomylacridae, **Oxynoblatta alutacea* Handlirsch (1906a), **pl. 4, fig. 13,** USNM 35381, M. R. Campbell and W. C. Mendenhall Clrs. **85. Gibson Fork,** between Winifrede and No. 5 Block Coals, uppermost Kanawha Gr.; off Fifteenmile Creek, above Decota, Kanawha Co., WV ("60 feet above coal locally called Keystone"): Lithomantidae, **Eurytaenia virginiana* Handlirsch (1906a), **pl. 4, fig. 14,** USNM 25631, M. R. Campbell and W. C. Mendenhall Clrs. **86. Peach Tree Gap,** roof Pewee Coal, basal Vowell Mountain Fm., upper Kanawha Gr.; strip mine near Peach Tree Gap, Anderson Co., TN: Breyeriidae, *Breyeria rappi* Carpenter (1967, pl. 8), USNM 158550, Robert Rapp Clr.

From the Pennsylvanian of Oklahoma, one insect is known: Hemimylacridae, *Brachymylacris striolatus* (Handlirsch, 1906a, p. 748, fig. 53) nov. comb., USNM 35386, J. A. Taff Clr., 1904. The only locality data given is "Indian Territory." Taff travelled widely in 1904 (Walcott, 1906): late July in the Tahlequah and Muscogee [Muskogee] Quadrangles; August in the Ouachita Mountains; September onward in the Antlers and Sansbois Quadrangles. The insect may have come from the McAlester Coal, Muscogee Quadrangle. It is closest to *Brachymylacris* spp. from the Buck Mountain Coal, basal Alleghenian of Schuylkill County, Pennsylvania. The Oklahoma specimen is probably post-Atokan, possibly early Alleghenian, in age.

With the earliest Alleghenian (latest Westphalian C), insect occurrences increased in number and diversity. In Henry Co., MO, in the Verdigris Fm., Cherokee Gr.: *Narkema winsdoriensis* (Lewis, 1979, p. 754, fig. 1) nov. comb., SMM P.78:10.1, A. A. Cridland and L. Kistler Clrs., 1965 (Narkemidae), from ironstone concretion resembling those of Mazon Creek, Grundy Co., IL. The Winsdor Mine site may produce a comparably diverse yet significantly older fauna which would bridge some of the hiatus between the Mazon Creek fauna and the Coseley fauna (Staffordshire, England, of Westphalian-B age). The insect faunal age that follows the Gilkersonian has been called Clarionian. The type fauna (to be cited elsewhere) occurs in the Mount Savage Fireclay, which may not be correlative with the Clarion Clay. The Cockerell (1927) age term is resurrected and shortened to "Savagean." This interval is characterized by the first appearance of *Orthomylacris* and *Necymylacris*, and the last occurrence of *Brachymylacris, Oxynoblatta, Hemimylacris,* and *Cyphomylacris*, and with no sign yet of *Mylacris*. The Savagean faunal equivalent in Europe is found in the Radstock Series of South Wales, from the Graigola and Mynyddislwyn Coal Seams upward, and in the uppermost Faisceau d'Edouard, top of the Assize de Bruay in northern France.

For the phylogenist, here is an alphabetical index to families, giving the order and the site numbers: **Acadelytridae** (Blattoptera), 67; **Antemylacridae** (Blattoptera), 46, 53, 57, 59, 60, 68, 73, 76; **Archimylacridae** (Blattoptera), 19, 24, 26, 35, 43, 45, 51, 62, 64, 80; **Blattinopsidae** (Blattoptera), 59; **Breyeriidae** (Palaeodictyoptera), 86; **Brodiopteriidae** (Megasecoptera), 16; **Cobaloblattidae** (Blattoptera), 26, 28; **Dasyleptidae** (Archaeognatha), 12; **Diaphanacridae** (Blattoptera), 41, 44; **Hemimylacridae** (Blattoptera), 21, 22, 25, 26, 34, 37, 38, 47, 48, 49, 54, 55, 56, 58, 65, 66, 69, 70, 71, 72, 73, 74, 75, 79, 82; **Heolidae** (Palaeodictyoptera), 59; **Homoiopteridae** (Palaeodictyoptera), 39; **Homothetidae** (Palaeodictyoptera), 14; **Jongmansiidae** (Palaeodictyoptera), 19; **Lamproptilidae** (Palaeodictyoptera), 9; **Lithomantidae** (Palaeodictyoptera), 5, 6, 12, 14, 29, 31, 85; **Metropatoridae** (Zoraptera), 4; **Mixotermitidae** (Atocida), 12, 15; **Mylacridae** (Blattoptera), 52, 67, 77; **Narkemidae** (Atocida); **Necymylacridae** (Blattoptera), 19, 24, 27, 28, 30; new family (Hemeristida), 20; **Omaliidae** (Atocida), 10; **Orthomylacridae** (Blattoptera), 26, 46, 52, 63, 69, 73, 78, 79, 81, 84; **Paoliidae** (Atocida), 1, 2, 12, 19; **Paralogidae** (Odonata), 8, 13, 19 , 57; **Patteiskyidae** (Palaeodictyoptera), 17; **Petrablattinidae** (Blattoptera), 38; **Phoberoblattidae** (Blattoptera), 21, 24, 26, 27, 32, 78; **Polycreagridae** (Palaeodictyoptera), 23; **Prototettigidae** (Atocida), 14, 18, 19; **Pteronidiidae** (Palaeodictyoptera), 7, 11, 19; **Rhaphidiopseidae** (Megasecoptera), 33; **Spanioderidae** (Atocida), 19; **Spiloblattinidae** (Blattoptera), 59; **Syntonopteridae** (Palaeodictyoptera), 12; **Xenoblattidae** (Blattoptera), 23, 26, 36, 40, 42, 50, 56, 57, 83; **Xenoneuridae** (Atocida), 3, 12. Note the use of Scudderian names: "Atocida" for the "homoneurous protorthopterans," and "Hemeristida" for the "caloneurodeans."

## REFERENCES CITED


**Andrews, E. B.**, 1875, Descriptions of fossil plants from the Coal Measures of Ohio: Ohio Geological Survey Report, v. 2, part 2, Palaeontology, p. 415–426.

**Ashley, G. H.**, 1945, The Pittsburgh–Pottsville boundary (Appalachian Coal Fields, U.S.): Journal of Geology, v. 53, p. 374–389.

**Bell, W. A.**, 1940, The Pictou Coalfield, Nova Scotia: Geological Survey of Canada Memoir 225, 160 p.

**Bolton, H.**, 1911, Insect remains from the South Wales Coalfield: Geological Society of London Quarterly Journal, v. 67, p. 149–174.

——1912, Insect remains from the Midland and South-Eastern Coal Measures: Geological Society of London Quarterly Journal, v. 68, p. 310–323.

——1921, A monograph of the fossil insects of the British Coal Measures. Part 1.: Palaeontographical Society, v. 1920, p. 1–80.

——1922, A monograph of the fossil insects of the British Coal Measures. Part 2.: Palaeontographical Society, v. 1920, p. 81–156.

**Carpenter, F. M.**, 1934, Carboniferous insects from Pennsylvania in the Carnegie Museum and Museum of Comparative Zoology: Carnegie Museum Annals, Pittsburgh, v. 22, p. 323–341.

——1948, The supposed nymphs of the Palaeodictyoptera: Cambridge Entomological Club, Psyche, v. 55, p. 41–47.

——1960, Studies on North American Carboniferous insects 1. The Protodonata: Cambridge Entomological Club, Psyche, v. 67, p. 98–110.

——1963, Studies on North American Carboniferous insects 2. The genus *Brodioptera* from the Maritime Provinces, Canada: Cambridge Entomological Club, Psyche, v. 70, p. 59–63.

——1967, Studies on North American Carboniferous insects 5. Palaeodictyoptera and Megasecoptera from Illinois and Tennessee, with a discussion of the order Sypharopteroidea: Cambridge Entomological Club, Psyche, v. 74, p. 58–84.

——1970, Fossil insects from New Mexico: Cambridge Entomological Club, Psyche, v. 77, p. 400–412.

**Cockerell, T. D. A.**, 1915, British fossil insects: U.S. National Museum Proceedings, v. 49, no. 2119, p. 469–499.

——1918, New species of North American fossil beetles, cockroaches, and tsetseflies: U.S. National Museum Proceedings, v. 54, p. 301–311.

——1927, The Carboniferous insects of Maryland: Annals and Magazine of Natural History, London, series 9, v. 19, p. 385–416.

**Copeland, M. J.**, 1957, The Arthropod fauna of the Upper Carboniferous rocks of the Maritime Provinces: Geological Survey of Canada Memoir 286, 110 p.

**Dawson, J. W.**, 1868, Acadian geology [second edition]: Macmillan, London, 694 p.

**Durden, C. J.**, 1969, Pennsylvanian correlation using blattoid insects: Canadian Journal of Earth Sciences, v. 6, p. 1159–1177.

——1972, Systematics and morphology of Acadian Pennsylvanian blattoid insects (Dictyoptera: Palaeoblattina): University Microfilms, Ann Arbor, 408 p.

——1984, North American provincial insect ages for the continental last half of the Carboniferous and first half of the Permian: Ninth International Congress of Carboniferous Stratigraphy and Geology, Urbana, 1979, Compte Rendu, v. 2, p. 606–612.

**Handlirsch, A.**, 1904, Les Insectes houillers de la Belgique: Mémoires du Musée royal d'histoire naturelle de Belgique, v. 3, ser. 1, no. 9, 20 p.

——1906a (7 March), Revision of American Paleozoic insects: U.S. National Museum Proceedings, v. 29, no. 1441, p. 661–820.

——1906b, Die Fossilen Insekten und die Phylogenie der Rezenten Formen: Kaiserlichen Akademie der Wissenschaften in Wien, Leipzig, May no. 1, p. 1–160, June no. 2, p. 161–320, August no. 3, p. 321–480, October no. 4, p. 481–640.

——1919, Revision der Paläozoischen Insekten: Denkschriften der Akademie der Wissenschaften in Wien, Mathematisch-Natur wissenschaftliche Klasse, v. 96, p. 511–592.

——1920, Zur kenntnis der palaeozoischen Blattarien: Sitzungsberichte, Kaiserliche Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse, ser. 1, v. 129, no. 9, 22 p.

——1922, Insecta Palaeozoica. Pars 16, *in* Diener, C., Fossilium Catalogus 1, Animalia: Junk, Berlin, 230 p.

**Haupt, H.**, 1940, Die älteste geflügelten Insekten und ihre Beziehungen zur Fauna der Jetztzeit: Zeitschrift für Naturwissenschaften, Halle, v. 94, p. 60–121.

**Laurentiaux, D.**, 1952, Découverte d'un Homoptère Prosboloide dans la Namurien Belge: Association pour l'étude de la paléontologie et de la stratigraphie houillères, Brussels, v. 14, p. 1–16.

——1967, Sur un insecte westphalien precurseur de la serie blattinopsoide (Protorthoptères): Bulletin de la Société géologique de France, ser. 7, v. 8, p. 827–833.

**Lesquereux, C. L.**, 1860, Botanical and palaeontological report on the geological survey of Arkansas: Second report of a geological reconnoissance of . . . Arkansas . . .: C. Sherman & Son, Philadelphia, p. 295–399.

**Lewis, S. E.**, 1979, A new species of insect (Protorthoptera: Narkemidae) from the Verdigris Formation (Pennsylvanian) of west central Missouri: Journal of Paleontology, v. 53, p. 754–756.

**Matthew, G. F.**, 1889, On some remarkable organisms of the Silurian and Devonian rocks of southern New Brunswick: Royal Society of Canada Transactions, section 4, v. 1888, p. 49–62.

——1894, Remarkable forms of the Little River group: Royal Society of Canada Transactions, section 4, v. 1894, p. 100–115.

——1895, Traces of the Ordovician system on the Atlantic Coast and organic remains of the Little River group. Part 4: Royal Society of Canada Transactions, section 4, v. 1895, p. 253–279.

——1897, Description of an extinct Palaeozoic insect, and a review of the fauna with which it occurs: Natural History Society of New Brunswick Bulletin 15, p. 49–60.

———1910, Remarkable forms of the Little River group: Royal Society of Canada Transactions, section 4, v. 1910, p. 115–131.

**Melander, A. L.,** 1903, Some additions to the Carboniferous terrestrial arthropod fauna of Illinois: Journal of Geology, v. 11, p. 178–198.

**Miller, S. A.,** 1889, North American geology and palaeontology: Western Methodist Book Concern, Cincinnati, 664 p.

**Pruvost, P.,** 1919, La faune continentale du terrain houiller du nord de la France: Ministère des Travaux publics, Mémoires pour servir à l'explication de la carte géologique détaillé de la France, Introduction à l'ètude du terrain houiller du nord et du Pas-de-Calais, Paris, 584 p.

**Read, C. B.,** and **Mamay, S. H.,** 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geological Survey Professional Paper 454-K, 35 p.

**Schmidt, W.,** 1953, *Herbstiala herbsti,* n. g., n. sp. (Herbstialidae, n. fam., Protocicadida), des erste Insekt aus dem Erkelenzer Karbon (Westfal A): Paläontologische Zeitschrift, Berlin, v. 27, p. 149–168.

**Scudder, S. H.,** 1865, On the fossil insects from Illinois, the *Miamia* and *Hemeristia,* described in vol. 37 of the Journal, at page 34: American Journal of Science, v. 40, p. 268.

———1867, Notice of fossil insects from the Devonian rocks of New Brunswick, and on *Haplophlebium barnesii*: Canadian Naturalist and Geologist, Ottawa, new series, v. 3, p. 205–206.

———1868a, Descriptions of fossil insects found on Mazon Creek, and near Morris, Grundy Co., Ill.: Geological Survey of Illinois, Springfield, v. 3, p. 566–572.

———1868b, Exhibit of two fossil insects from the Coal Measures: Boston Society of Natural History Proceedings, v. 11, p. 401–403.

———1868c, The fossil insects of North America: Geological Magazine, London, v. 5, p. 172–177.

———1876, New and interesting insects from the Carboniferous of Cape Breton: American Association for the Advancement of Science Proceedings, v. 24, sec. B, p. 110–111.

———1878, Note on the wing of a cockroach from the Carboniferous formation of Pittston, Pennsylvania: Boston Society of Natural History Proceedings, v. 19, p. 238–239.

———1879, Palaeozoic cockroaches: Boston Society of Natural History Memoir 3, no. 3, p. 23–134.

———1881, The Devonian insects of New Brunswick: Boston Society of Natural History Anniversary Memoir, no. 3, 44 p.

———1885a, Palaeodictyoptera: or the affinities and classification of Paleozoic Hexapoda: Boston Society of Natural History Memoir 3, no. 9, p. 319–351.

———1885b, *Dictyoneura* and the allied insects of the Carboniferous epoch: American Academy of Arts and Science Proceedings, new series, v. 20, p. 167–173.

———1893, Insect fauna of the Rhode Island coal field: U.S. Geological Survey Bulletin 101, p. 1–21.

———1895, Revision of the American fossil cockroaches with descriptions of new forms: U.S. Geological Survey Bulletin 124, 176 p.

**Sellards, E. H.,** 1906, Geological history of cockroaches: Popular Science Monthly, v. 3, p. 244–250.

**Smith, S. I.,** 1871, Notice of a fossil insect from the Carboniferous formation of Indiana: American Journal of Science, series 3, v. 1, p. 44–46.

**Walcott, C. D.,** 1906, Remarks on the work of the year. Geological Branch: U.S. Geological Survey 26th Annual Report, p. 25–99.

**Wanless, H. R.,** 1975, Appalachian Region, *in* McKee, E. D., and Crosby, E. J., coordinators, Introduction and regional analyses of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853, part 1, p. 17–62.

**White, David,** 1899, Fossil flora of the lower Coal Measures of Missouri: U.S. Geological Survey Monograph 37, 307 p.

———1900, The stratigraphic succession of the fossil floras of the Pottsville formation in the southern anthracite coal field, Pennsylvania: U.S. Geological Survey 20th Annual Report, p. 749–918.

## Plate 1

(For easy comparison, all figures are printed with wing base to left; literature citation, respository, and available collection data are given in text, under site number)

Fig. 1.—N. g., n. sp. (Xenoneuridae), early Morrowan, site 3, Mount Evans, Colorado.

Fig. 2.—*Metropator pusillus* Handlirsch, early Morrowan, site 4, Altamont, Pennsylvania.

Fig. 3.—*Eurythmopteryx antiqua* Handlirsch, early Morrowan, site 5, Pratt, Alabama. Figure reversed.

Fig. 4.—*Archimastax americanus* Handlirsch, early Morrowan, site 10, Lemon's Coal Bank, Arkansas.

Fig. 5.—*Pseudopaolia lacoana* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.

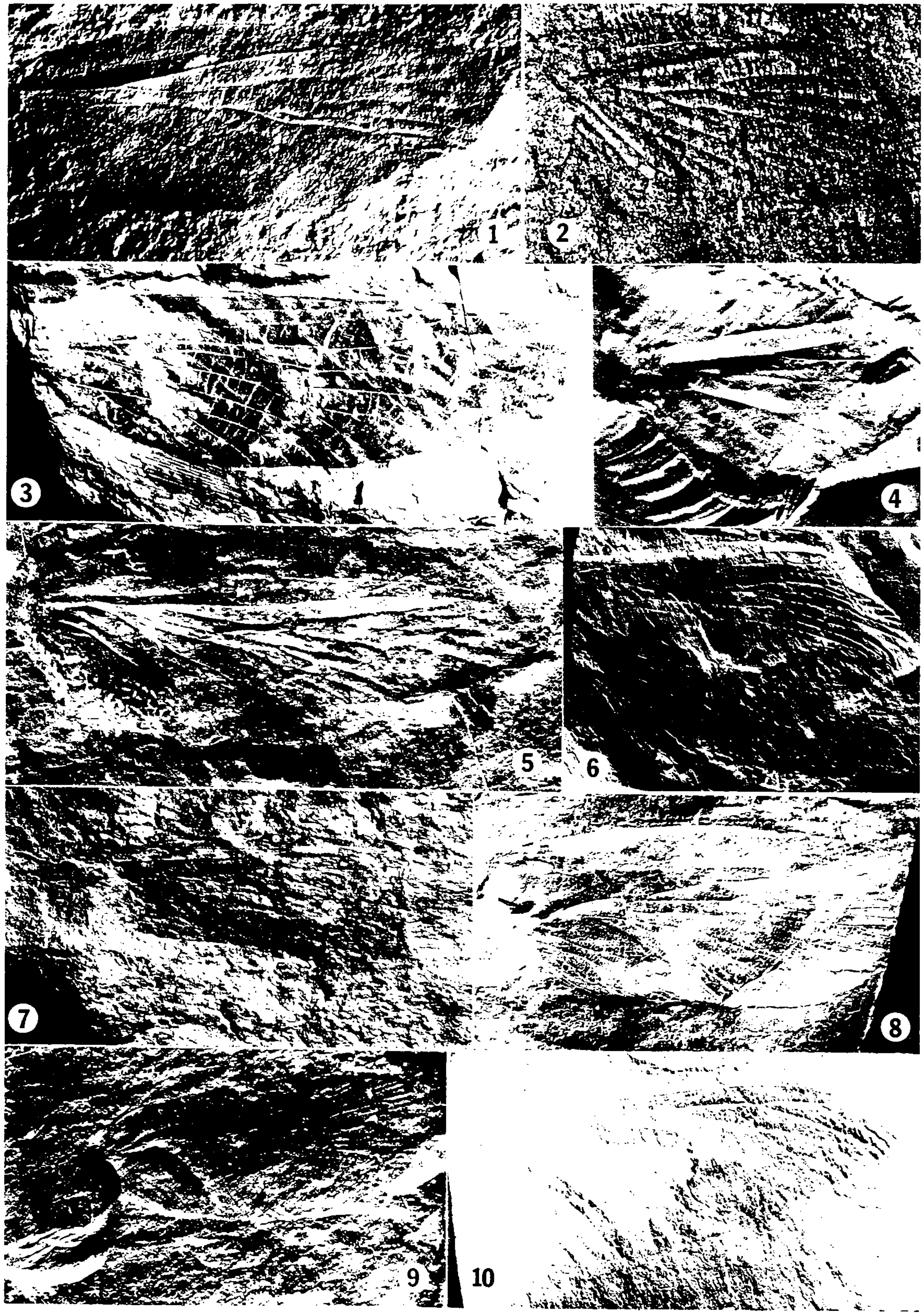
Fig. 6.—*Pseudopolyernus laminarum* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.

Fig. 7.—*Dieconeurites rigidus* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.

Fig. 8.—*Aphthoroblattina fascigera* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.

Fig. 9.—*Plagioblatta parallela* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.

Fig. 10.—*Titanodictya jucunda* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania.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## Plate 2

Fig. 1.—*Parahaplophlebium longipennis* (Scudder), late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania. Figure reversed.

Fig. 2.—*Palaeotherates pennsylvanicus* Handlirsch, late Morrowan, Coxtonian, site 19, Campbell's Ledge, Pennsylvania. Figure reversed.

Fig. 3.—N. g., n. sp. (n. fam., Hemeristida), late Morrowan, Coxtonian, site 20, West River Pictou, Nova Scotia. Figure reversed.

Fig. 4.—*Atimoblatta reducta* Cockerell, late Morrowan, Mercerian, site 21, Mercer, Pennsylvania.

Fig. 5.—*Cobaloblatta simulans* Cockerell, early Atokan, Barnettian, site 26, Port Barnett, Pennsylvania. Figure reversed.

Fig. 6.—*Brachymylacris bassleri* Cockerell, early Atokan, Barnettian, site 26, Port Barnett, Pennsylvania. Figure reversed.

Fig. 7.—*Plagioblatta flexuosa* (Cockerell), early Atokan, Barnettian, site 26, Port Barnett, Pennsylvania. Figure reversed.

Fig. 8.—*Polyetoblatta campbelli* (Handlirsch), early Atokan, Barnettian, site 27, Garman's Mills, Pennsylvania. Figure reversed.

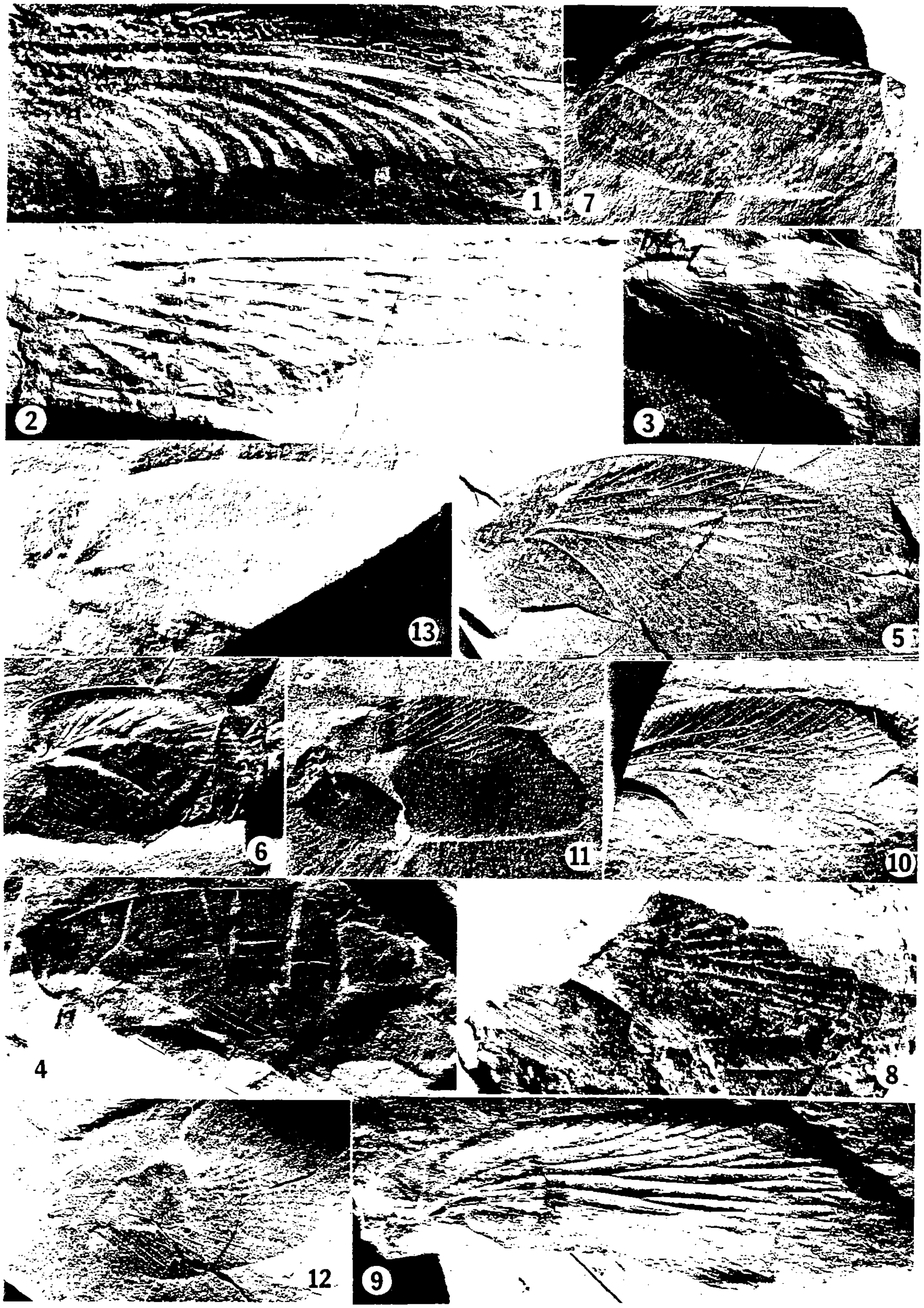
Fig. 9.—*Atimoblatta curvipennis* Handlirsch, early Atokan, Barnettian, site 32, Gardner's Drift, Pennsylvania.

Fig. 10.—*Parelthoblatta stella* Durden, mid-Atokan, Stellartonian, site 35, Duff Brook Borehole 451.5 ft, Nova Scotia.

Fig. 11.—*Brachymylacris belli* Durden, mid-Atokan, Stellartonian, site 34, Duff Brook Borehole 452 ft, Nova Scotia.

Fig. 12.—*Grypoblattina phaseolus* Pruvost, mid-Atokan, Stellartonian, site 40, McLellan Brook Borehole 878 ft, Nova Scotia.

Fig. 13.—*Linemylacris mclellanensis* Durden, mid-Atokan, Stellartonian, site 38, McLellan Brook Borehole 989 ft, Nova Scotia.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## Plate 3

Fig. 1.—*Intermylacris intermedia* Durden, mid-Atokan, Stellartonian, site 36, McLellan Brook Borehole 1,010 ft, Nova Scotia.

Fig. 2.—*Malarchimylacris mclellanensis* Durden, mid-Atokan, Stellartonian, site 44, McLellan Brook (A), Nova Scotia. Figure reversed.

Fig. 3.—*Amblymylacris orieulxi* (Pruvost), mid-Atokan, Stellartonian, site 46, McLellan Brook Borehole 93–97 ft, Nova Scotia.

Fig. 4.—*Acadiemylacris attenuata* Durden, mid-Atokan, Stellartonian, site 47, East River Shore, Nova Scotia. Figure reversed.

Fig. 5.—*Intermylacris* sp., hindwing, mid-Atokan, Stellartonian, site 50, McLellan Brook (D), Nova Scotia. Figure reversed.

Fig. 6.—*Antemylacris archimylacroides* Durden, mid-Atokan, Stellartonian, site 53, Coalburn Borehole 1,302 ft, Nova Scotia. Figure reversed.

Fig. 7.—*Archimylacris coalburnensis* Durden, mid-Atokan, Stellartonian, site 51, Coalburn Borehole 1,347 ft, Nova Scotia.

Fig. 8.—*Brachymylacris mclellanensis* Durden, mid-Atokan, Stellartonian, site 56, McLellan Brook (F), Nova Scotia.

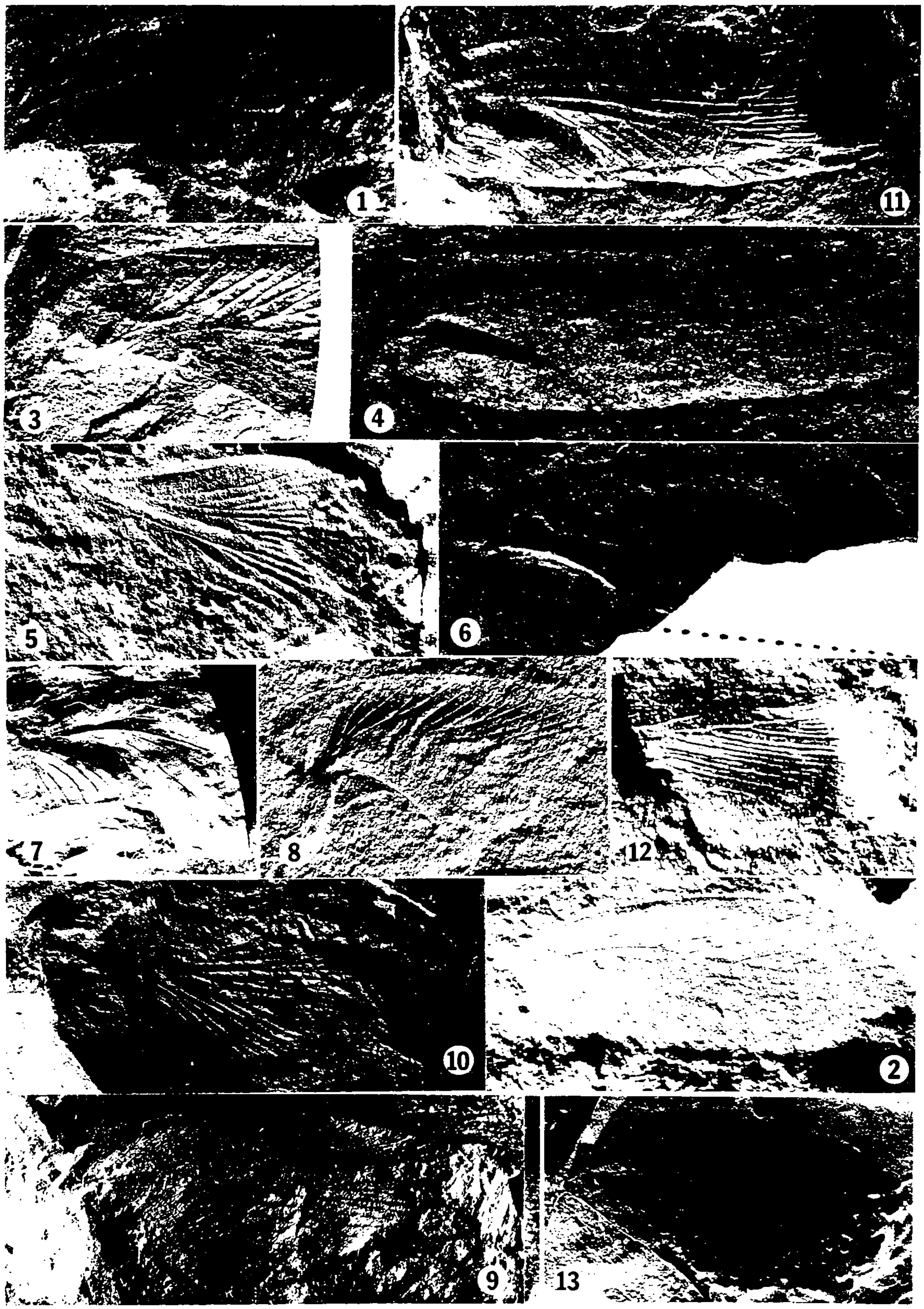
Fig. 9.—*Xenoblatta fraterna* (Scudder), mid-Atokan, Stellartonian, site 57, Silver Spring, Rhode Island.

Fig. 10.—*Discoblatta scholfieldi* (Scudder), mid-Atokan, Stellartonian, site 59, East Providence, Rhode Island. Figure reversed.

Fig. 11.—"*Etoblattina*" *latebricola* Scudder, mid-Atokan, Stellartonian, site 59, East Providence, Rhode Island.

Fig. 12.—*Microblattina perdita* Scudder, mid-Atokan, Stellartonian, site 59, East Providence, Rhode Island.

Fig. 13.—*Parelthoblatta stellartonensis* Durden, late Atokan, Thorburnian, site 62, Thorburn Borehole 153 ft, Nova Scotia.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## Plate 4

Fig. 1.—*Discoblatta coalburnensis* Durden, late Atokan, Thorburnian, site 60, Thorburn Borehole 171 ft, Nova Scotia. Figure reversed.

Fig. 2.—*Brachymylacris mountvillensis* Durden, late Atokan, Thorburnian, site 66, McLellan Brook (G), Nova Scotia.

Fig. 3.—*Aphelomylacris thorburnensis* Durden, late Atokan, Thorburnian, site 67, Vale Colliery, Nova Scotia. Figure reversed.

Fig. 4.—*Acadelytron umbrale* Durden, late Atokan, Thorburnian, site 67, Vale Colliery, Nova Scotia. Figure reversed.

Fig. 5.—*Mclellamylacris acadica* Durden, late Atokan, Thorburnian, site 68, Potter Brook Borehole 29 ft, Nova Scotia. Figure reversed.

Fig. 6.—*Antemylacris thorburnensis* Durden, late Atokan, Thorburnian, site 73, Greenwood Borehole 467–470.5 ft, Nova Scotia. Figure reversed.

Fig. 7.—*Pinnamylacris elongata* Durden, late Atokan, Thorburnian, site 73, Greenwood Borehole 467–470.5 ft, Nova Scotia.

Fig. 8.—*Aphelomylacris modesta* Handlirsch, late Atokan, Thorburnian, site 77, Valley Falls Mine, Rhode Island.

Fig. 9.—*Phylomylacris* n. sp., early Desmoinesian, Gilkersonian, site 78, Gilkerson Ford, Missouri. Figure reversed.

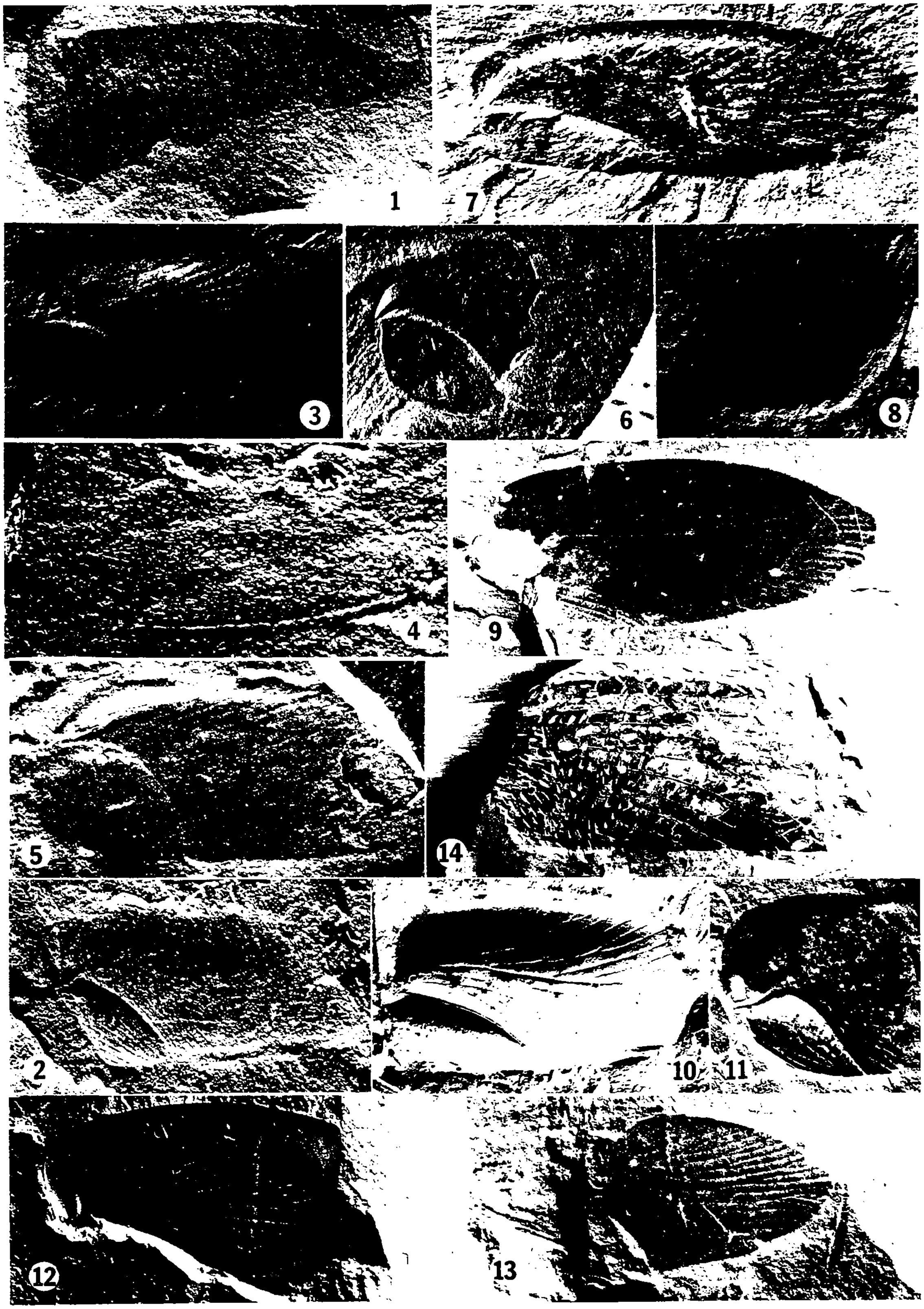
Fig. 10.—*Hemimylacris clintoniana* (Scudder), early Desmoinesian, Gilkersonian, site 79, Clinton, Missouri.

Fig. 11.—*Trilophomylacris americana* (Scudder), early Desmoinesian, Gilkersonian, site 79, Clinton, Missouri.

Fig. 12.—*Trilophomylacris moriensis* (Copeland), early Desmoinesian, Gilkersonian, site 81, South Port Morien, Nova Scotia. Figure reversed.

Fig. 13.—*Oxynoblatta alutacea* Handlirsch, early Desmoinesian, Gilkersonian, site 84, Furnace Hollow, West Virginia.

Fig. 14.—*Eurytaenia virginiana* Handlirsch, early Desmoinesian, Gilkersonian, site 85, Gibson Fork, West Virginia.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# DISCUSSION FOLLOWING ATOKAN SYMPOSIUM

## March 29, 1982

At the conclusion of the Atokan symposium, participants and members of the audience were invited to make statements regarding the papers presented and the Atokan Series in general. The following summary has been edited from a tape recording of that discussion. The editors have grouped some discussions together that did not occur chronologically, to improve the focus and readability. All participants have been given the opportunity to review and clarify these discussions prior to publication of this volume.

### PATRICK K. SUTHERLAND, The University of Oklahoma, Norman, Oklahoma

As an opening comment on the proposal made in the paper by Rich Lane and Ron West, it would seem to me that use of lower/middle/upper does not eliminate any of the problems that involve Morrowan/Atokan/Desmoinesian and so on. It is true that we presumably get rid of the Atokan–Desmoinesian boundary problem, but, if the stage names are retained, then those stage names still have to be treated in the time-stratigraphic sense in which the rules now require. Thus, the stages merely become smaller series, and there is still the requirement of boundary stratotypes. Whether we call them stages or series, they would have to be treated in exactly the same way.

My own view is that it is best to retain Morrowan/Atokan/Desmoinesian, but to work toward defining boundary stratotypes. To do this, one needs well-defined sequences where many different fossil groups are represented—the Arctic sequence sounds fantastic; if it were only in the temperate or tropical regions, we would all be even happier! Although we don't always have spectacular exposures here in Oklahoma, we are beginning to describe the faunal sequences in this area, as reported in OGS Guidebook 20 for example. We are certainly in no way proposing that the type Atokan is a satisfactory reference sequence, but it is our view that the name Atokan is so ingrained that we really cannot get rid of it. We should now start working toward location of potential boundary stratotypes.

### H. RICHARD LANE, Amoco Research, Tulsa, Oklahoma

I think we sometimes lose sight of the fact that terms like Morrowan and Atokan are only names, and when we proliferate those names we commonly end up discussing nomenclature rather than correlation. This situation has resulted in at least four systems used for the Lower–Middle Pennsylvanian of North America. We have a sequence of series names for the Appalachian area, one for the Midcontinent, one for Texas, and the Derryan Series for New Mexico. When we try to interrelate each of these series, we sometimes forget about the rocks. The essence of the suggestion in my paper with Ron West is that we should cut through all of this nomenclature and replace it with something really simple that can be used everywhere: Lower, Middle, and Upper. I hope the point came through in our table illustration that the original definitions of Morrowan, Derryan, Atokan, and Desmoinesian were paleontological ones, which, in our opinion, makes them stages, not series. They are basically biostratigraphic, and not time-stratigraphic, units. There's a fine difference between biostratigraphy, reporting fossil occurrences in rocks, and time-stratigraphy, trying to divide time within sequences of rocks. I think we have to think through our concepts and make some real decisions as to how we want to deal with Carboniferous serial nomenclature.

Unfortunately, the term Atoka, or Atokan, has been used as a formation, a stage, and a series. I agree that boundary stratotypes are what are needed; that's the best known way to divide geologic time. The old idea of using unconformities as natural breaks with which we classify geologic time is wrong because somewhere we have to fill in those unconformities. In that approach, controversy usually arises as to where the boundary is placed.

### SUTHERLAND

It is for that reason that I would say that once boundary stratotypes are established we are no longer tied to the vagaries of nomenclature. That is, once a boundary stratotype has been established between the Morrowan and the Atokan, then it doesn't matter whether you call it Morrowan or Lower Pennsylvanian, because we would then have a specific bedding plane that could be used as the boundary between Lower and Middle Pennsylvanian, or between the Morrowan and the Atokan.

### LANE

Perhaps, but I have difficulty envisioning workers in the Appalachian Basin using Morrowan/Atokan/Desmoinesian as series. I think there would be a lot of disagreement as to which set of serial nomenclature would be appropriate, and we would never reach consensus. For that reason, I propose abandonment of the geographic nomenclature, and simply use Lower, Middle, and Upper as Pennsylvanian serial nomenclature. No one can argue with that, because no one has any subjective ties to the neutral terms Lower, Middle, and Upper.

MACKENZIE GORDON, JR., U.S. Geological Survey, Washington, D.C.

The official classification for all systems by the U.S. Geological Survey divides them into series designated either lower and upper or lower, middle, and upper, with the Mississippian and Pennsylvanian as no exceptions. The U.S. Geological Survey breaks the Mississippian into lower and upper, and I can see some problems with those who feel that the Valmeyeran should be recognized and who would prefer a threefold subdivision. Nevertheless, that is the official U.S. Geological Survey policy at present. The Pennsylvanian is divided into lower, middle, and upper series. The type Pennsylvanian area is regarded as being the Appalachian region, but the beds exposed in Pennsylvania are inadequate for reference, particularly in the lower part, so the West Virginia area has, at least for the lower part, become the more important sequence. The top of the Lower Pennsylvanian is placed at the top of the New River Sandstone, below the base of the Kanawha Formation, while the boundary between the Middle and Upper Pennsylvanian falls between the top of the Charleston Sandstone and the base of the Conemaugh Group. It was originally thought that the Lower Pennsylvanian could be equated more or less with the Morrowan, but we find that upper Morrowan faunas occur through much of the Kanawha Formation. Now, the boundary between the Survey's Lower Pennsylvanian and Middle Pennsylvanian is located approximately at the base of the Dye Shale ("caprock" horizon) in terms of the type Morrowan, in other words, where we generally put the base of the upper Morrowan. The upper series boundary agrees fairly well with the boundary between the Desmoinesian and the Missourian. When employees of the U.S. Geological Survey use terms like Morrowan, or other commonly used series, we are required to call them provincial series, and in the West, because they haven't been established there, you must say "Atokan Series equivalent" or perhaps "Atokan Provincial Series equivalent." The main formal USGS series classification is Lower, Middle, and Upper for the Pennsylvanian System, and Lower and Upper for the Mississippian System.

SUTHERLAND

I might just comment that if the Survey's classifications were to be accepted as an official decision, then our boundary stratotypes would already have been selected, and we would be locked into those boundaries. It is my view that that should not be the case.

JOHN GROVES, Oklahoma State University, Stillwater, Oklahoma

My own feeling on this question of nomenclature is that it's a trivial question and that, whether we call it Lower, Middle, or Upper, or Morrowan, Atokan, Desmoinesian, and so on, it has no significance. I think we can already sense that we run the risk of developing allegiances to a certain system of classification. The main thrust of our research should be toward defining stratotypes, and not developing these ties with nomenclature. Names simply don't make any difference whatsoever, in my view. Of course, there will come a time when some name must be put on these chronostratigraphic units, but I don't think anybody should be concerned now with those names; they could be X, Y, Z.

ROBERT SHAVER, Indiana Geological Survey, Bloomington, Indiana

I might say that I find it very strange being bedfellows with both Rich Lane and Pat Sutherland, but there is some similarity between our proposals, in that all of us think that some concept of the Atokan Series must be retained. But there the similarity stops. I'm going to be a little bit critical of Rich's final proposal, because I think that when we deal with time-stratigraphy, or, if you want to go a bit further, time-rock classification, we have to have a material basis for it. Whether or not you wish to define a series or stage as being based strictly on faunal zones, they mean nothing unless you can place them in some order of superposition. We always are going to have to maintain a material basis for doing time-stratigraphy or time-rock stratigraphy, or both of those things together. If rules allow definition of stages or series based strictly on biostratigraphic zones, they must be put in the framework of, or have, a material basis, to avoid problems of facies control. I grant you that we correlate our series and stage concepts by using fossils, and in a sense the best biostratigraphic zones become synonymous with stages and series. Yet, I think we've seen from this Atokan conference that, if we transfer the authority for time-rock stratigraphy to biostratigraphic zones, we become so ingrained with definitions that, even when we learn new information, we don't always recoordinate those fossil zones with type sections of rock to assure their place in superposition. The problem with the lower Atokan boundary is one of having a suitable type section, but also a problem of agreeing on correlation; whereas the upper Atokan boundary is simply a matter of arbitrary agreement on how we're going to redefine type sections of rocks so that they collectively make up a single, unambiguous standard.

FREDERICK MARSHALL, Principia College, Elsah, Illinois

Science is concerned with communicating clearly the distinction between descriptive and interpretive concepts. In the earth sciences, we have our "igraphies" and "ographies" and "ologies" which are essentially intended to do that sort of thing. In stratigraphy, we have an important distinction between our basic descriptive unit, the rock-stratigraphic unit, and an interpretive unit, the time-stratigraphic unit. A problem occurs when terminology arises that tends to scramble those two concepts. This problem is clearly seen in the Pacific Coast Tertiary, where the formational approach to time-stratigraphy resulted in such stage names as Vacqueros and Monterey for what were basically formations. The facies chaos existing in that interval has resulted in some very strange correlations. We have seen today, I think, a similar problem involving use of the word Atoka, even if distinguished by the suffix "n" for a time-stratigraphic unit. Is the Atokan Series supposed to represent the boundaries of the type Atoka Formation? We've found out that some of the Wapanucka apparently belongs in the Atokan Stage, and who knows what happens above! It may be true, as Bob Shaver says, that we're stuck with "Atoka," but its use seems to create the scrambling of concepts which I would prefer to see not happen. The Atokan problem isn't unique, since practically all series names for Paleozoic systems in North America started out as rock-stratigraphic units. I don't think that's a proper approach, and it seems especially strange since the problems with that practice were pointed out in 1941 by Schenk and Mueller. The American code specifically discourages it, so that's my primary objection to the use of the word Atoka in a time-stratigraphic sense.

The second point relates to Rich Lane's discussion about zone and stage versus series. It is true that most zones, and some of the stages based on those zones, are essentially biostratigraphic units. Yet, careful study of Oppel's own works will show that his zone concept was intended to be time stratigraphic, as were the stages that comprised those zones. In essence, they do not differ in concept from series, only in duration of the interval involved. As far as names go, they are just names. I don't think we are necessarily going to get rid of problems by substituting one set of names for another, but using Lower, Middle, and Upper may be a better solution than present provincial nomenclature.

And the third comment I have has to do with Bob Shaver's talk. One of the things about being a devil's advocate is that it causes us all to think, whether we agree with him or not. It causes us all to scrutinize the care of our taxonomic and biostratigraphic work, and the clarity of our concepts of zones, stages, and series. It's important that these thorns stay with us so that they remind us of the careful work that needs to be done to resolve these problems.

T. W. HENRY, U.S. Geological Survey, Washington, D.C.

My work for the last 6 or 7 years in the eastern part of the central Appalachian Basin with Mackenzie Gordon has involved integration of the few marine beds, occurring in that dominantly paralic sequence, with the compression/impression floral zones recognized by Hermann Pfefferkorn and Bill Gillespie. One of the things that has impressed me most is the degree of biostratigraphic resolution available from these compression floras. I am also concerned from looking through the IUGS minutes, and also from listening to discussions here today, that people active in upper Carboniferous research seem to be emphasizing marine invertebrate zones almost to the total exclusion of what is going on in the plant world. If we consider the volume of rock, once sediments, representing the Pennsylvanian around the world, it is overwhelmingly terrestrial to at least paralic, and I'm a little distressed at the ignorance of what's going on with the plant zonation.

WALTER NASSICHUK, Geological Survey of Canada, Calgary, Alberta

I'd like to comment on Woody Henry's remarks relative to marine versus nonmarine facies. I certainly agree with him, and I too am impressed with what Pfefferkorn is doing. I'm also encouraged by the success that Roger Neves and others at Sheffield have had in correlating nonmarine facies in the Westphalian in Europe, and certainly Bob Wagner, in Sheffield, and Mann, in Moscow, are really advanced in the whole field of megafloral correlations. New advances by the Sheffield group in recovering palynomorphs from anhydrite sequences have obvious implications, because it represents a direct way of relating continental palynomorphs to a marine sequence.

I'd like to support the point made by Bob Shaver that definitions must be related to a rock sequence; otherwise, we're dealing in Schindewolfian concepts of a floating-stage nomenclature to which presumably the world can relate. My own experience with the Permian has reenforced this view. The question of what constitutes the Permian has been debated without decision by the Russians for 30 years. Although the type Permian is in the Ural Mountains, they have tended to base the system on three successive fusulinacean zones that have been selected and refined over a number of generations without regard to type relations. Sooner or later, boundaries will have to be defined in rock sequences. Similarly, with respect to the Carboniferous, the Chinese have just come into the world of science, so to speak, and they consider what we consider the entire lower Permian to be part of the Carboniferous. They still utilize the unconformity principle in defining series and stages, so there's a real matter of global communication that has to be addressed. I would submit that the problem underlies even use of such terminology as Mamet Zone 20 and Zone 21 in this symposium. I'm not sure what's meant by Zone 21, and I would like to know where there is a particular stratigraphic section that we can all visit and see Zone 21, to debate it or whatever. Without a type section, chronostratigraphic units are floating, rather meaninglessly, as etherial kinds of concepts that are rather difficult to communicate to the world.

MARK RICH, University of Georgia, Athens, Georgia

I have a practical problem with what Walter Nassichuk has said involving a time-stratigraphic unit, or boundary stratotype. If everybody is looking for continuous deposition that preserves changes in overlapping ranges of various faunal and floral groups, I can't understand how one can tie those changes to some kind of lithologic boundary at a stratotype section. In a continuous sequence, formation boundaries are difficult to recognize, so series names or other time-stratigraphic units reflect some kind of biostratigraphic change that is not tied to formation names, because there may be no obvious formation boundaries available.

NASSICHUK

I agree with you, Mark, that it's folly to try to base any sort of a world standard on a lithologic sequence. I think we should follow the example of the Silurian–Devonian boundary, where a committee debated placement of the "golden spike" for 12 years. It was ultimately driven at Klonk, Czechoslovakia. So, why was that particular site selected? Klonk was a place where trilobites, conodonts, and graptolites made a particular change at the same horizon. The definition really is a question of fossils in rock, but it is at Klonk that you can go to see what a particular group of fossils are doing. It's really an objective reference to what's happening in organic evolution.

LANE

I'd just like to continue Walt's comments here. If there's any system that's a hotbed of stage and serial nomenclature internationally, it's the Devonian. After selection of the Silurian–Devonian boundary, the Subcommission on Devonian Stratigraphy (SDS) was established, and their decision was to forget stage and serial nomenclature for now, define a Lower, Middle, and Upper Devonian Series, and then, when that was completed, turn to the question of stage nomenclature, or geographically derived names, for their subdivisions.

SHAVER

Rich, I agree with you to the extent that it really doesn't make that much difference, except for traditional reasons, whether you use a spatial arrangement of lower, middle, and upper, or geographic designations. Do you recognize that several systems already exist for lower, middle, and upper series? The USGS is most behind that and supports the one in this country, but there is also a system in Europe, which isn't exactly the same as that being used in America, and when you see the COSUNA charts you'll note that all American lower, middle, and upper subdivisions have been done away with in favor of the European arrangements.

A second point I would like to make concerns the USGS system, as I understand Mac's explanation. Even though he would appear to support a lower, middle, and upper concept, those divisions are currently based on a rock record as material units. I think that if we suddenly defined series or stages in terms of lower, middle, and upper, we would not only have the problem of an American and European system, we'd have a third system as well. Utter chaos would result before the literature ever got straightened out, and in the meantime none of us would know what the other person was talking about, because most people won't say which system they're using.

I also wanted to say that biostratigraphers are only a very small portion of the stratigraphers who have to use this terminology. If we start a system in which everything above the rank of formation or group is going to be defined on more-or-less abstract biostratigraphic zones, we're going to take away part of the coordination that we have now between biostratigraphers and subsurface stratigraphers. They try to express their interpretations in terms of time-rock units. If we tell those people that they're going to have to retrain as biostratigraphers or they can't use our system, then I think we have problems that are greater than those we have now in coordinating the work of all kinds of stratigraphers.

LANE

Perhaps I'm a little too optimistic, but I would hope that, instead of defining central North American provincial terms, we could move toward defining subdivisions of an upper Carboniferous subsystem that would be used on a global basis. None of the present subdivisions of the upper Carboniferous subsystem are well defined, and that's why terms like "Atokan" and "Morrowan" should be avoided. In addition, those terms are not going to be used in central Siberia, just as "Bashkirian" and "Moscovian" aren't used here. All we have accomplished in precisely defining the Atokan is clarification of a provincial term. I would rather see us work toward defining a system of subdivisions for worldwide correlation. Perhaps this is the wrong forum to bring up the subject of worldwide subdivisions of the Carboniferous. Perhaps it should be at a meeting of an international body of specialists.

SUTHERLAND

Our main thrust should be describing faunal sequences. This sort of thing is needed in conjunction with the Morrowan–Atokan boundary and the Atokan–Desmoinesian boundary. I believe that boundary stratotypes should be approached cautiously. I think it is fine to set up a study group (as they did with the Silurian–Devonian boundary), but boundary stratotypes cannot be properly established until one has a selection of well-defined faunal sequences upon which to base a selection. As a first step, sequences across the country must be located that have diverse faunas in many different zones. It appears that Arrow Canyon is one such place, except that very little information on the varied fossil groups occurring there has been published.

RAYMOND DOUGLASS, U.S. Geological Survey, Washington, D.C.

I agree with your statement, Pat, but one of the problems of the past is that there has been no direct tie between a set of collections made for fusulinids, for example, and a set of collections made for conodonts. Now, in the north Arrow Canyon section there is the opportunity for study from beds that can be tied exactly in with past collections. Thanks to Ralph Langenheim and his students, the myriad numbers used in Arrow Canyon have been compiled, so that it can be established now that Douglass' 36 is the same as Amoco's 127, Webster's 39, Welch's 125, and so on. If we could do this in several sections around the country, either by collecting together or working with keyed sections, such as those painted for the Atokan field trip that preceded this symposium, then integration of information will show how different elements of the fauna are related biostratigraphically.

GARY WEBSTER, Washington State University, Pullman, Washington

Concerning the sequences in Arrow Canyon, the fusulinids have been published (see Webster and Langenheim, this volume, for references). The brachiopods are currently under study by a student directed by Ralph Langenheim, University of Illinois. I am redoing my conodont work and trying to extend it higher into the Pennsylvanian. Ralph and one of his students have also published some of the corals (see Webster and Langenheim, this volume, for references). The substantial bryozoan assemblage is the only major unstudied faunal group. We should continue to see publications on this important sequence appearing over the next decade.

GROVES

I would like to ask Bob Shaver what positive evidence he has for a Morrowan age for the lower portion of the range of *Profusulinella*?

SHAVER

I'm not sure that we have any positive evidence. But if I were to try now to place the Lead Creek Limestone that contains *Profusulinella* in the Illinois Basin in the southern Midcontinent succession, I would put it in the gap between the Kessler and the Trace Creek, or in the Trace Creek itself. The reason we don't find *Profusulinella* there, even though we have some marine cephalopods in the Trace Creek, is for ecological reasons. When I came to this symposium, I really didn't have a good idea of how the Illinois Basin *Profusulinella* and the related ostracods would fit, but now that would be my proposal. We still have this problem of whether the Trace Creek belongs in the type Morrowan or not; I said, let's leave it there in order to avoid the criticism that attends the placement of a series boundary in that unconformable position between the Kessler and the Trace Creek.

WALTER MANGER, University of Arkansas, Fayetteville, Arkansas

I would like to make a few concluding comments on some of the things we've discussed this afternoon. I think that the symposium has been a success, based on the quality of the contributions and this discussion. We're focusing attention on the Atokan Series and its boundaries, and that's what was intended. The point I would like to consider is that these are chronostratigraphic units. Any time a correlation chart is shown, I think the assumption, whether conscious or unconscious, is that isochronous surfaces are being traced from column to column. Biostratigraphic evidence is being used to do that, and, the fact is, we don't have enough information to be successful. So I would echo the point made previously that we need to get as many different groups examined in as many sections as possible, to increase the data base markedly. Second, we are dealing with a system of nomenclature that has been developed more or less over the last century. None of us played a part in that development, yet we are obliged to use the system as it exists. I think we have to maintain some continuity with that old literature. The argument for an international scheme is not going to be totally practical. Any sort of international zonation is going to be, by nature, less precise and less detailed than that developed for a local province, such as the southern Midcontinent. Personally, I see nothing wrong with developing provincial series names, because I think that they are important to the understanding of the geology of a local area. We may have a more-or-less intercontinental outlook, but we need to have working units as a means of communicating the information that we're obtaining from our local sections.

I see the development of the chronostratigraphic system proceeding from the establishment of boundary stratotypes. Agreement on boundary stratotypes would then define bodies of rock that are recognized in sections in which an internal biostratigraphy could be developed. A sequence of biostratigraphic zones could be extended on a more regional basis. The present situation is chaotic. The series boundaries are defined now by different groups, as Ray Douglass and some of the others have pointed out, because we tend to work in a vacuum—one person studying one group and ignoring the others. Instead, with boundary stratotypes in agreement, at least on a working-hypothesis basis, we could recognize these intervals in our local sections and develop the biostratigraphy from there.

SUTHERLAND

I thank all of you for your participation in this symposium. I agree with Walt that it's been a success, and both of us hope that it will initiate diligent work on various Atokan sequences. I will conclude with the comment that Arrow Canyon seems to be emerging as the principal reference for western North America, Upper Mississippian–Lower and Middle Pennsylvanian relations. Yet, until a number of additional sequences in the West are described, there is no basis to conclude that Arrow Canyon really is the best section. Is there perhaps something better in Idaho or western Utah, or in the Arctic? We cannot evaluate these possible candidates for boundary stratotypes, not only for the Morrowan–Atokan boundary but also for the Atokan–Desmoinesian boundary and the Mississippian–Pennsylvanian boundary, until their sequences are extremely well described. We need to keep the question of boundary stratotypes in mind, and it is up to those working on different sequences to provide the bases for detailed zonations. Then, boundary-study committees, organized over the next 5 to 10 years, can make some real progress toward resolving many of the problems identified by this symposium.

RONALD R. WEST, Kansas State University, Manhattan, Kansas

*Written comment dated April 8, 1982*

After listening to the presentations and discussions at the Atokan symposium, two things occurred to me that may be appropriate for the discussion section of the published results.

First, few, if any, of the speakers addressed the problems of the upper Atokan boundary. Most of the detailed considerations were given to the Morrowan–Atokan boundary, and yet there are problems of a similar sort at the Atokan–Desmoinesian boundary. The type Desmoinesian, as you well know, is a real problem area, biostratigraphically, because of the poor to nonexistent outcrops in Iowa and the Mississippian erosion surface on which the Pennsylvanian sequence was deposited. Some Atokan has been reported there, based on fusulinids, but if they are Atokan rocks this is hardly the place for a boundary stratotype. My recollection of the Oklahoma sequence (Atokan to Desmoinesian) is that, while it may be a rather continuous section, it is poorly fossiliferous. However, the new sections described in [Oklahoma Geological Survey] Guidebook 20 may have improved this situation a bit.

Second, little if any attention was given to the ecological controls of the different taxa being used biostratigraphically. Several persons said that the absence of certain forms might be due to ecological controls, but they failed to give any indication as to what these controls might have been. It almost seemed as if ecological controls were being used as an *ad hoc* explanation for why certain data were anomalous, because no attempt was made to consider any of the ecological aspects of the fossil groups as a whole. I think it is very important that biostratigraphers consider the ecology of their respective groups. Perhaps some of the difficulties encountered when comparing correlations using different taxonomic groups would be better understood, perhaps solved, if the ecology of each group were considered carefully.