

Atokan (Middle Pennsylvanian) conodonts from laterally restricted pre-Cherokee units of southwestern Missouri

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ABSTRACT: Three Pennsylvanian stratigraphic units in southwestern Missouri that have long been recognized as preceding the Cherokee Group (and as pre-Desmoinesian Stage) are compared on the basis of their conodont faunas: the Riverton Shale, the Ladden Branch Limestone Member of the Riverton Shale, and the type Burgner Formation from the subsurface. Shale at the base of the Riverton was sampled where it occurs above a well-developed underclay. It produced a conodont fauna that is mostly similar to that of the Ladden Branch Limestone Member, which occurs at the base of the Riverton Shale at other localities. Both units produced biostratigraphically important *Neognathodus bothrops* and *N. colombiensis* s.l.. A difference is that the Ladden Branch Limestone Member commonly produced specimens of *Idiognathoides*, whereas none were recovered from the basal Riverton shales. Both are assigned to the upper Atokan *Neognathodus colombiensis* Zone, and most likely are age-equivalent facies. Strata at the Republic coal pit, previously considered correlative with the type Burgner Formation, are now correlated with the Riverton Shale based on its *N. colombiensis* Zone conodonts and overall similarity to the basal Riverton. The core that represents the type Burgner Formation produced a conodont fauna somewhat different from the other sections, including specimens of an advanced morphotype of *Neognathodus nataliae*. The type Burgner Formation is, therefore, assigned to the upper part of the lower Atokan *N. nataliae* Zone.

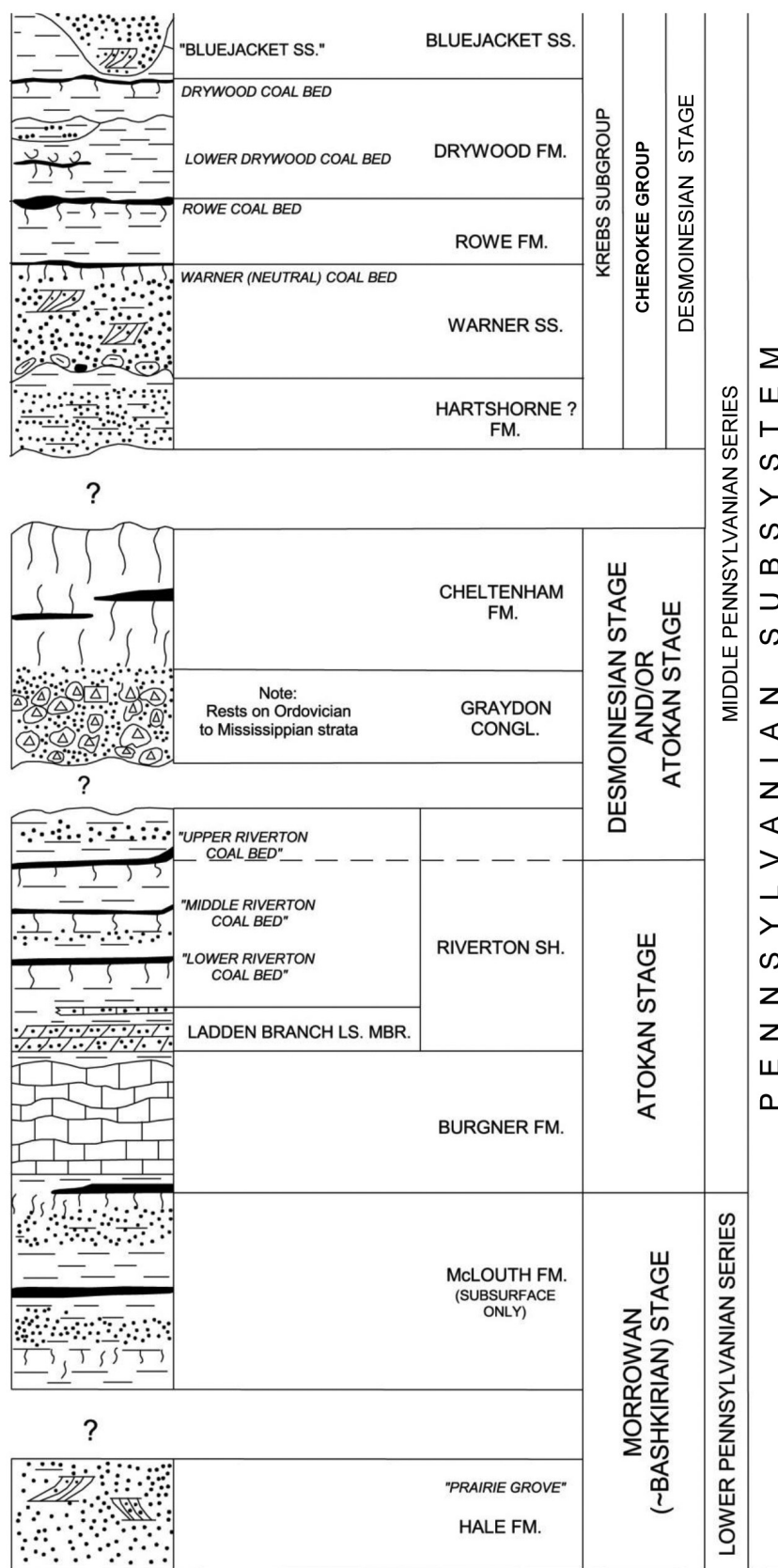
INTRODUCTION

The distribution of Pennsylvanian strata older than the Desmoinesian Stage (text-fig. 1) in southwestern Missouri (text-fig. 2) is not well known, because the strata are generally discontinuous both at the surface and in the subsurface. Surface exposures are often limited to remnants preserved in solution collapse structures and down-dropped fault blocks. A previously published similar example is an isolated biostratigraphic equivalent of the early Morrowan Prairie Grove Limestone Member of the Hale Formation of northwestern Arkansas, which occurs in a down-dropped fault block within the Keokuk Limestone (Osagean Stage, Mississippian) in McDonald County of extreme southwestern Missouri (Thompson 1970).

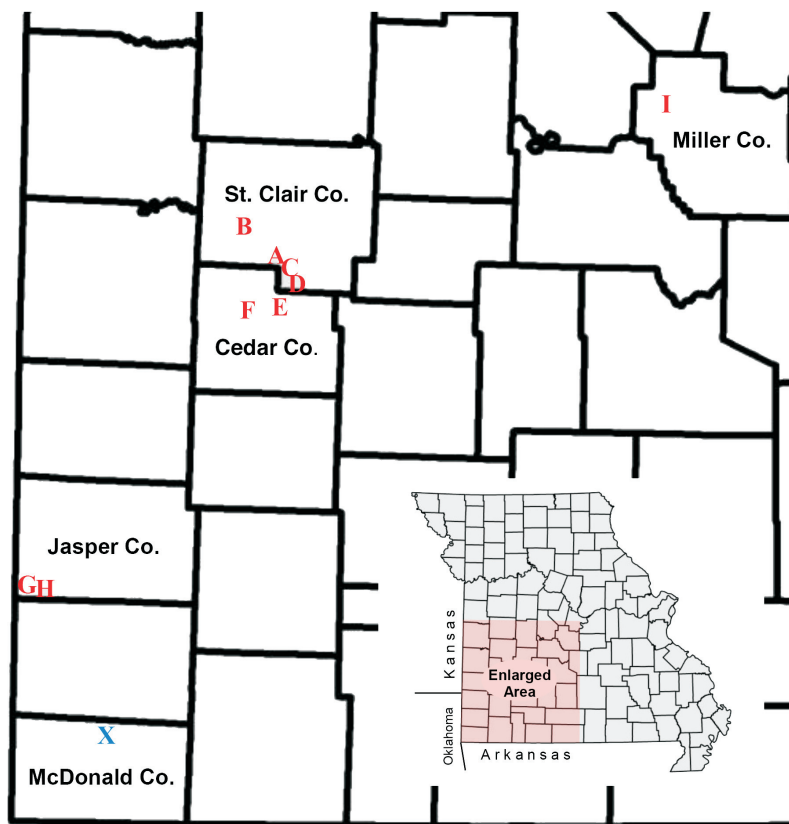
The Atokan Burgner Formation was named and described from a core that penetrated a collapsed sink structure in Osagean Burlington-Keokuk Limestone in the vicinity of Webb City in Jasper County (Searight and Palmer 1957). The core serves as the type section for the Burgner Formation of Missouri. The Atokan Riverton Shale (Gentile and Thompson 2004, p. 11–18) occurs at several mined-out, lead-zinc-ore-bearing, collapsed sink structures in Osagean limestones in the Joplin area (Searight 1955). The Riverton Shale is known to occur in the subsurface in Barton, Vernon, and Bates counties (Wells 1977), and crops out beneath the basal Desmoinesian Warner Sandstone of the Krebs Subgroup of the Cherokee Group (Gentile and Thompson 2004) in several exposures in Cedar and St. Clair counties, where the Ladden Branch Limestone Member of the Riverton Shale (Gentile and Thompson 2004) occurs beneath black shale characteristic of the Riverton Shale. The

Ladden Branch Limestone is a cross-bedded arenaceous-calcareous limestone to calcareous sandstone, which Searight (1959) considered to represent the basal part of the Riverton Shale. Although it occurs at the bottom of the Riverton Shale in a few exposures, the Ladden Branch Limestone Member is often the only Riverton unit present where the overlying Riverton shales are absent, whether due to non-deposition or removal by erosion. The geologic column in text-figure 1 shows the Morrowan Hale, Atokan Burgner, and Atokan Riverton Shale (Ladden Branch Limestone Member and upper shale) in relation to other Morrowan, Atokan, and overlying younger Desmoinesian Cherokee Group strata. The Ladden Branch is shown as a dolomite based on a roadcut locality covered in Gentile et al. (2004).

During reconnaissance work conducted in 1969, a single sample collected from the Ladden Branch Limestone at the base of the Riverton Shale at Bazzill Branch (text-fig. 2, location A) in St. Clair County yielded a surprisingly large number of conodonts. A study was then initiated to use conodonts to determine the age of the Ladden Branch relative to the limestone of the Burgner Formation and the overlying black shale of the Riverton Shale. A representative conodont fauna was assembled from five exposures of the Ladden Branch Limestone in southwestern Missouri. The Ladden Branch fauna was compared to conodont faunas obtained from the type Burgner core, one other presumed Burgner exposure, and two Riverton Shale exposures that lack the basal calcarenitic Ladden Branch carbonate. The conodont faunas for the Burgner, Ladden Branch and Riverton Shale in Missouri were compared to faunas reported for the type area of the Morrowan Stage in Arkansas and the type area of the Atokan Stage in Oklahoma. That study was never published. Here, the data for the



TEXT-FIGURE 1
Geologic column of Morrowan, Atokan, and lower Desmoinesian Stage strata in Missouri. Adapted from Gentile et al. (2004). The McLouth Formation, Graydon Conglomerate, and Cheltenham Formation are known mainly from elsewhere in Missouri and are not considered in this report.



TEXT-FIGURE 2

Atokan strata were studied and sampled at nine locations (A–I) in four counties in southwestern Missouri. A, Bazzill Branch; B, Osage River; C, Sac River South; D, Ladden Branch; E, Mt. Olive Church; F, Cedar Creek; G, Sucker Flat; H, Carterville South; I, Republic Coal Pit; X, location of equivalent of Prairie Grove Limestone Member of the Hale Formation in northwestern Arkansas. Details of locations are given in Appendix 1.

study are now updated, with the relative ages of the Burgner, Ladden Branch, and Riverton Shale determined on the basis of the conodonts previously recovered. Descriptions of the outcrop localities and the type Burgner core are provided in Appendix 1.

STRATIGRAPHY

The Burgner Formation, Ladden Branch Limestone Member, and Riverton Shale were studied and sampled at nine locations in southwestern Missouri (text-fig. 2). The locations are designated A–I, and are briefly described in Appendix 1. Ladden Branch calcarenitic limestone or calcareous sandstone is present at or near the base of the Riverton Shale at locations A, B, C, D, and E, but it is absent in the Riverton Shale outcrops at locations F and G. Limestone of the Burgner Formation occurs in the type section at location H and was previously believed to be present at location I.

Riverton Shale

Rocks assigned to the Riverton Shale are known to occur in only two areas in southwestern Missouri: 1) in sink structures near the city of Joplin in the Tri-State Mining District in Jasper County and 2) in undisturbed exposures and in drill holes located farther north in Cedar and St. Clair counties (text-fig. 2). Searight (1955) originally considered the Riverton in southwestern Missouri to be the basal unit of the Krebs Subgroup, the

lower part of the Desmoinesian Stage. He described exposed sections of Riverton shales in several pits dug by mining companies into the karsted Mississippian subcrop in the Joplin area. Searight (1959) considered Riverton strata in several undisturbed exposures in western Missouri as being above (younger than) the Burgner Formation and below (older than) the Warner Sandstone. Later, Searight and Howe (1961) considered the Riverton to be pre-Krebs (pre-Cherokee), and assigned the Riverton in Missouri to the Atokan Stage.

The Riverton Shale in an open pit mine known as Sucker Flat at Webb City, near Joplin (Appendix 1, loc. G), was preserved because the shale succession had subsided into a sink structure as the underlying Mississippian limestone beds underwent dissolution collapse. Several other sections of Riverton Shale have been exposed through mining operations in large sinks in this area, but most are now poorly exposed because the pits are flooded (for example, the Klondike pit, NE¼ NE¼ sec. 19, T. 28 N., R. 33 W., Carl Junction 7.5' Quadrangle; and the Snapp Mine (Searight, 1955, p. 12, stop 1), NW¼ SE¼ sec. 23, T. 29 N., R. 33 W., Webb City 7.5' Quadrangle).

Conodonts were recovered from the basal shale of the Riverton Shale only at the Cedar Creek and Sucker Flat locations (Appendix 1, F and G). The conodont-bearing beds represent only a limited part of the formation. At Cedar Creek, conodonts were

STAGE	NEOGNATHODUS	IDIOGNATHODIDS	CYCLOTHEM
DESMOINESIAN	<i>N. roundyi</i> (sensu lato)	<i>Sw. nodocarinatus</i>	LOST BRANCH Norfleet
		<i>Sw. neoshoensis</i>	ALTAMONT Farlington
		<i>I. delicatus</i>	Coal City PAWNEE U. FORT SCOTT L. FORT SCOTT
	<i>N. asymmetricus</i>	<i>I. rectus/ I. iowaensis</i>	Bevier VERDIGRIS Fleming Russell Creek UPPER TIAWAH Wainwright
		<i>I. amplificus/ I. obliquus</i>	INOLA DONELEY Sam Creek McCURTAIN
	<i>N. caudatus</i>		
ATOKAN	<i>N. colombiensis</i>	highest <i>Idiognathoides</i>	CYCLOTHEMS NOT GENERALLY RECOGNIZED
	<i>N. atokaensis</i>	<i>I. incurvus</i> descendants	
	<i>N. nataliae</i>	<i>I. incurvus</i>	
MORROWAN	<i>N. bassleri</i>	<i>Id. convexus</i>	
		<i>I. klapperi</i>	
		<i>I. sinuosus</i>	
		<i>N. bassleri</i>	
	<i>N. symmetricus</i>	<i>N. symmetricus</i>	
	<i>N. higginsii</i>	<i>Id. sinuatus</i>	
		<i>D. noduliferus</i>	U L

TEXT-FIGURE 3

Conodont zones for Lower and Middle Pennsylvanian strata in Midcontinent North America. Species ranges not shown because taxonomic and nomenclatural problems remain unsettled. *D.*=*Declinognathodus*; *I.*=*Idiognathodus*; *Id.*=*Idiognathoides*; *N.*=*Neognathodus*; *Sw.*=*Swadelina*. Modified from Barrick et al. (2013).

recovered from a 6-inch thick sandy limestone overlying 8 ft of underclay and clayey shale that constitute the basal portion of the Riverton exposure. This thin carbonate unit is probably a feather-edge termination of the Ladden Branch Member. The overlying 40-ft-thick interval of shale is barren of conodonts. Conodonts at Sucker Flat were recovered from a 6-ft-thick shale succession directly above a prominent underclay and poorly developed coaly horizon 40 ft above the base and 20 ft below the top of the Riverton exposure. The conodont faunas recovered from the Riverton at these two locations are similar enough to be considered essentially the same and represent the same stratigraphic horizon. The underclays at the two locations can thus be correlated with one another.

Ladden Branch Limestone Member of the Riverton Shale

The pre-Pennsylvanian surface in St. Clair and Cedar counties is broadly undulating. On paleotopographic highs, the massive

basal Cherokee Warner Sandstone and, sometimes, the still younger Bluejacket Sandstone rest directly on Middle Mississippian limestones. The Riverton Shale, with its discontinuous basal limestone member, appears to be present only in the paleotopographic low areas.

Searight (1959) described a coarse, sandy to calcarenitic limestone that he placed in the lower part of the 'Riverton formation'. He mentioned two localities at which the unit is exposed (herein locations A and C, text-fig. 2; Appendix 1). Stenberg (1953) described a calcareous sandstone at the base of the Graydon Formation at three localities (herein locations A, B, and C; text-fig. 2; Appendix 1). Millman (1954) described a similar unit in the base of the Cherokee Group at one locality (location E, text-fig. 2; Appendix 1). Lambert and Thompson (1990) named this calcarenitic limestone the 'Ladden Branch limestone of the Riverton Formation'. Thompson (1995, p. 95)

stated that this limestone unit is ‘tentatively referred to the Burgner’. Thompson (2001, p. 157) later stated that it “...has yielded Atokan-aged conodonts that may prove a correlation...with the Burgner limestone to the south in Jasper County”. Thompson (2001, p. 157) added, “It probably should be regarded as a member of the Riverton Formation, and has [been] called the ‘Riverton limestone’”. It wasn’t until Gentile and Thompson (2004, p. 19) that this limestone was formally designated the Ladden Branch Limestone Member of the Riverton Shale. Geographic distribution of the Ladden Branch Limestone Member appears to be more restricted than the overlying shale of the Riverton, but the Ladden Branch does extend at least eight miles from location B to location D in St. Clair County (text-fig. 2).

The Ladden Branch Limestone consists primarily of medium-to-coarse, rounded-to-subangular quartz grains having secondary overgrowths, calcareous brachiopod and trilobite fossil debris, and glauconite in a calcareous matrix. Cross-stratification is prominent. Limestone beds ranging from six inches to several ft thick are often separated by thin, carbonaceous, black, shale partings. Gentile and Thompson (2004, p. 19) stated that “The type section of the Ladden Branch Limestone Member of the Riverton Shale...is located in a north-flowing tributary to the Sac River called Ladden Branch, about 350 ft south of Sac River, 300 ft west of a north–south gravel driveway, center NE¼ NE¼ SE¼ sec. 15, T. 36 N., R. 26 W., St. Clair County, Missouri; Roscoe 7½’ quadrangle”. The type section of the Ladden Branch Limestone at location D is about 400 ft southeast of another excellent exposure of the unit at location C, where the Ladden Branch Limestone is exposed in the south bank of the Sac River (Appendix 1). The elevation at both locations is between the normal power pool and maximum flood stages of Truman Reservoir. About 1.4 miles due north, in a U.S. Route 54 road cut on the south side of Venter Bluff, some highly leached beds in the Riverton Shale were interpreted by Gentile and Thompson (2004, p. 15, fig. 6) to represent Ladden Branch Limestone. The member has yielded conodonts at all locations sampled. The leached beds at Venter Bluff have yet to be sampled for conodonts.

Burgner Formation

The Burgner Formation was named and described by Searight and Palmer (1957) based on 35 ft of limestone, shale, and coal that was recovered from a two-inch diameter core drilled in 1952 by the Missouri Division of Highways (now Missouri Department of Transportation or MoDOT) in a collapse structure called ‘Carterville sink’ at location H, east of Webb City, Jasper County, Missouri (text-fig. 2; Appendix 1). The limestone overlies a coal bed that may have been as much as 5-ft thick. The limestone portion of the core—the only part preserved—is catalogued as MGS #1049 at the Missouri Department of Natural Resources, Missouri Geological Survey McCracken Core Library, Rolla, Missouri. This core serves as the type section for the Burgner Formation.

Thompson (1953) named and described the fusulinid species *Fusulinella clarki* Thompson and *F. searighti* Thompson from the limestone of the Burgner core. Although these forms were unknown from other localities, Thompson was able to determine that the unnamed limestone at Carterville is ‘middle Derryan’ (Atokan) based on the identification of two closely related species, the older *Profusulinella fittsi* (Thompson 1935) and the younger *Fusulinella prolifica* Thompson 1935. Searight

TABLE 1

P₁ element counts for conodont species identified from the Ladden Branch Limestone Member of the Riverton Shale at locations A–E in southwestern Missouri. For location D, P = present, A = abundant, and R = rare.

Conodont Species	Ladden Branch Locations				
	A	B	C	D	E
<i>Adetognathus lautus</i> -P	4	2	---	---	---
<i>Idiognathodus</i> spp. -A	100	188	35	---	12
<i>Idiognathoides ouachitensis</i> -P	9	40	6	---	---
<i>Id. sinuatus</i> -P	5	28	7	---	1
<i>Declinognathodus sulcatus</i> -R	---	---	---	---	1
<i>Neognathodus bothrops</i> -A	8	5	3	---	---
<i>N. colombiensis</i> s. l. -A	1	---	---	---	---

and Palmer (1957) prepared a lengthy list of invertebrate macrofossils collected by Palmer from outcrops of supposed Burgner limestone. Fifteen of these species were known from Morrowan rocks and five from Desmoinesian strata. Three species were not considered to be indicative of either the Morrowan or Desmoinesian stages. This, coupled with the ‘Derryan’ (Atokan) correlation of Thompson (1953), prompted Searight and Palmer to assign an Atokan age to the Burgner Formation. Unklesbay and Palmer (1958) reported the goniatite cephalopod *Pseudoparalegoceras williamsi* Miller and Downs 1948 from blocks of Burgner limestone found on two mine dumps near Carterville. Referring to the age assignment made by Miller and Downs (1948) for goniatites similar in morphology to *P. williamsi*, Unklesbay and Palmer (1958) concluded that the Burgner Formation is definitely Atokan in age. McCaleb (1963) regarded *P. williamsi* to be a junior synonym of *P. kesslerense* (Mather 1915), a form common to the Winslow Formation of northwestern Arkansas that ranges through both the upper Morrowan and lower (now middle) Atokan.

The Burgner Formation was sampled for this study from the type core at location H, and from limestone blocks on a dump pile adjacent to the old Republic coal pit at location I (text-fig. 2; Appendix 1). The limestone at both places is brown-gray to gray, finely to coarsely crystalline, nodular, and very fossiliferous. Fusulinids collected at location I (pl. 1, figs. 1, 2) were identified by the late M. L. Thompson (personal communication 1969) as *Fusulinella clarki*. This form, as mentioned before, was identified by Thompson (1953) in the Burgner type core.

CONODONT BIOSTRATIGRAPHY

Barrick et al. (2004, 2013) synthesized a summary conodont zonation for Midcontinent North America and introduced several new zones to provide for better correlation in the region (text-fig. 3). Most of the zonation for Morrowan strata had been established by H. Richard Lane and colleagues (Lane 1967, 1977; Lane and Straka 1974; Baesemann and Lane 1985), even though those marine deposits are restricted to what were then lower-lying areas of the Midcontinent seaway as marine transgressions increasingly flooded the Midcontinent during Early Pennsylvanian time (e.g., Heckel 2013). Although marine Atokan deposits are incrementally more widespread, as discussed above, they are still largely restricted in lateral distribution in many Midcontinent occurrences. For conodont biostratigraphy, uncertain stratigraphic relationships (Lane and West 1984) and earlier, poor taxonomic practices have hindered the development of a widely accepted Atokan conodont zonation. The morphologic characters of the conodonts themselves, combined with episodic immigration from Eurasia (*sensu* Groves et al. 2007), further complicate Atokan conodont biostratigraphy. Barrick et al. (2013), followed here,

TABLE 2

P₁ element counts for conodont species recovered from the basal shale of the Riverton Shale in southwestern Missouri at locations F and G, where the Ladden Branch Limestone Member is absent.

Conodont Species	Riverton Shale Locations	
	F	G
<i>Adetognathus lautus</i>	3	—
<i>Diplognathodus orphanus</i> s. l.	—	2
<i>Idiognathodus</i> spp.	163	188
<i>Neognathodus bothrops</i>	5	7
<i>N. colombiensis</i> s. l.	5	10

provided both a *Neognathodus*-based zonation and a brief summary that indicated a nascent zonation on *Idiognathodus*-based morphologies has yet to be resolved.

Neognathodus nataliae Zone

The *Neognathodus nataliae* Zone extends from latest Morrowan through early Atokan when the base of the Atokan is defined by the first occurrence of the foraminifer *Eoschubertella* (Groves 1986; text-fig. 3). It immediately succeeds the *N. bassleri* Zone (and *Idiognathodus klapperi* Zone of Lane and Straka 1974) and immediately precedes the *N. atokaensis* Zone of Grayson (1984). *Neognathodus nataliae* Alekseev and Gerelzezeg 2001 (in Alekseev and Goreva 2001) has a distinctive P₁ morphology in which the inner (caudal *sensu* Purnell et al. 2000) platform margin (parapet of some authors) is completely developed and extends to the tip of the carina. Its height extends higher than that of the carina for its entire length, except at the posterior (dorsal) tip. The outer (rostral) platform margin ornamentation developed more slowly than the rest of the platform element, and is always lower in height than the carina. The result is a distinctive stair-step geometry for the upper surface of this species. Through its range, the outer (rostral) platform margin gradually changes shape from semi-circular (in which its posterior termination intersects at mid-carina) to a valentine-heart shape (in which its posterior termination intersects close to the end of the carina). Subsequently, the outer (rostral) platform margin gained height until it exceeded the height of the carina and evolved into *N. atokaensis* Grayson 1984.

Neognathodus atokaensis Zone

The *Neognathodus atokaensis* Zone represents the middle part of the Atokan by conodonts. It succeeds the *N. nataliae* Zone and precedes the *N. colombiensis* Zone. Although its base can be well-defined by its evolution from *N. nataliae*, its top will remain poorly defined until several co-occurring and overlying *Neognathodus* morphotypes become better understood (Barrick et al. 2013). One of the co-occurring morphotypes is *N. uralicus* Nemirovskaya and Alekseev 1994, a form distinctive enough to demonstrate that, when comparing ranges among the various poorly known morphotypes, the succession of regional first occurrences among those morphotypes is different between North America and Eurasia. Different ranges in different regions both complicate international correlations, and indicate that these *Neognathodus* morphotypes (some of which will eventually be demonstrated to be distinct species) should be treated cautiously as of now, especially considering the tendency of *Neognathodus* to evolve through heterochrony and recurrent morphologies (Lambert and Grayson 1993).

TABLE 3

P₁ element counts for conodont species recovered from the type section of the Burgner Formation in Missouri Division of Highways core # 2 (Missouri Geological Survey drill core #1049) at location H in Jasper County Missouri.

Drill Depth Interval Location H	Sample Number	<i>Hindeodus minutus</i>	<i>Diplognathodus orphanus</i> s. l.	<i>Idiognathodus</i> spp.	<i>Idiognathoides ouachitensis</i>	<i>Id. sinuatus</i>	<i>Id. sulcatus</i>	<i>Neognathodus nataliae</i>
8'0"—12'0"	1	—	—	17	—	—	—	1
	2	4	2	11	—	—	—	—
	3	1	—	8	—	2	—	1
	4	1	—	12	—	1	—	—
12'0"—14'4"	5	3	—	4	—	1	—	2
	6	—	—	14	—	1	—	—
	7	2	—	8	1	—	—	1
14'4"—16'4"	8	12	1	22	2	2	—	—
	9A	—	—	—	—	—	—	—
16'4"—16'7"	9B	—	—	—	—	—	—	—
16'7"—18'4"	9C	1	—	4	—	—	—	1
	10	1	—	4	—	—	3	—
18'4"—19'2"	11	2	—	11	—	4	1	2
	12	3	—	9	—	—	—	2
	13	2	—	8	1	—	3	2
	14	5	—	8	—	2	—	3
	15	3	—	5	2	—	1	2

Neognathodus colombiensis Zone

The *Neognathodus colombiensis* Zone represents the upper Atokan by conodonts. It succeeds the *N. atokaensis* Zone and precedes the *N. caudatus* Zone. It begins with the appearance of what can be called *N. colombiensis* s.l. (from *N. colombiensis* of Sibane 1967), in reference to several morphotypes with a relatively flat, symmetrical V-shaped upper surface on which the carina extends to the posterior (dorsal) tip of the platform. The top of the *N. colombiensis* Zone is defined by the first occurrence of *N. caudatus* Lambert 1992, which marks the base of the Desmoinesian by conodonts (Lambert 1992; Barrick et al. 2004; text-fig 3). *Neognathodus bothrops* Merrill 1972, a species with a more almond-shaped platform, appears after the first *N. colombiensis* s.l., and usually ranges through the rest of the zone. *Declinognathodus* and *Idiognathoides* fade to extinction through the *N. colombiensis* Zone in North America.

ATOKAN CONODONTS RECOVERED FROM SOUTHWESTERN MISSOURI

Riverton Shale

Ladden Branch Limestone Member

The geographically restricted sandy limestone to calcarenitic sandstone beneath the black shale of the Riverton Shale in southwestern Missouri yielded abundant conodonts in four of the five sampled localities (table 1). The genus *Idiognathoides* is a significant component of the fauna (table 1; also see text-fig. 3). The overall character of the conodont fauna from this unit (more than 532 specimens) reflects the allochthonous nature of the sediments. Most are large, robust specimens, some

with relatively rounded features that indicate some degree of abrasion and sorting, including a significant over-representation of P_1 elements in comparison to the rest of the apparatus. There appears to be no vertical change in taxonomic composition through the thickness of the unit.

Biostratigraphically, *Neognathodus colombiensis* s.l. and *N. bothrops* place the Ladden Branch Limestone Member firmly within the *N. colombiensis* Zone of the upper Atokan Stage. Note that a subadult specimen of *N. bothrops* (pl. 2, fig. 14) and a gerontic specimen (pl. 2, fig. 16) illustrated here are almost identical matches for specimens from the lower Mercer of Ohio in Merrill (1972, pl. 1, subadult specimen, fig. 18, and gerontic specimen, fig. 17). Merrill (1972), like many workers since, misassigned his Desmoinesian specimens of *N. bothrops* to *N. bassleri* (Harris and Hollingsworth 1933), which is an earlier Morrowan species whose holotype is from the Wapanucka Limestone of Oklahoma. Lane (1967) selected the lectotype for *N. bassleri* from among the syntypes of Harris and Hollingsworth (1933). All of those type specimens show the characteristic mid-platform asymmetry of *N. bassleri*, where the inner (caudal) margin extends away from the carina at (or near) a 90° angle. The Desmoinesian specimens do not have that type of consistent margin feature as can be seen by comparing the platform margins of any of the four specimens discussed above with the holotype of *N. bothrops* from the upper Mercer (Merrill 1972, pl. 1, adult specimen, fig. 11).

Basal shale of the Riverton Shale

Although the basal shale of the Riverton Shale was sampled at several localities, only locations F and G yielded conodonts (table 2). At both sections that yielded conodonts, the specimens were recovered from a shale succession immediately above a prominent underclay. Both faunas (391 total specimens) are completely dominated by *Idiognathodus*, whose species need serious taxonomic revision. The main difference in comparison with the Ladden Branch fauna is the absence of *Idiognathoides* from the basal shale. However, the recovery of *N. colombiensis* s.l. and *N. bothrops* firmly places the basal shale of the Riverton Shale within the *N. colombiensis* Zone of the upper Atokan. Other than the higher diversity of the Ladden Branch Limestone, which produces both *Idiognathoides* (common) and *Declinognathodus* (rare), the conodont faunas of these two units are similar enough to suggest that the Ladden Branch Limestone could be an updip, higher energy facies of the transgressive basal Riverton Shale.

Burgner Formation

The Burgner Formation was sampled for conodonts at two geographically separate locations that yielded two significantly different conodont faunas. The type core of the Burgner Formation at location H (table 3) produced a relatively diverse fauna of 231 specimens representing 6 genera, including *Diplognathodus orphanus* (Merrill 1973), *Idiognathoides ouachitensis* Harlton 1933, *Id. sinuatus* Harris and Hollingsworth 1933, *I. sulcatus* Higgins and Bouckaert 1968, and of the most biostratigraphic significance, *Neognathodus nataliae*. The presence of the latter species distinguishes the type Burgner conodont fauna from the collective Riverton Shale conodont faunas, placing the Burgner in the *N. nataliae* Zone. Additionally, the overall characters of the *Idiognathodus* morphotypes, some of which can be assigned to *I. incurvus* s.l., further supports the lower Atokan Stage assignment.

TABLE 4

P_1 element counts for conodont species identified from strata at the Republic coal pit, location I in Miller County, Missouri.

Conodont Species	Burgner Formation Location I
<i>Hindeodus minutus</i>	4
<i>Idiognathodus</i> spp.	22
<i>Neognathodus bothrops</i>	7
<i>N. colombiensis</i> s. l.	7

A close examination of the three *N. nataliae* specimens illustrated on plates 1 and 2 shows a growth series for the species. Figure 10 on plate 2 shows a typical subadult specimen later in the morphologic cline that eventually led to *N. atokaensis*. The termination of the outer (rostral) platform margin is more than half way between mid-carina and platform tip, just short of forming a valentine-heart shape. Figure 7 on plate 1 shows a juvenile specimen with significant ornamentation on the outer (rostral) platform margin, and figure 1 on plate 2 shows a gerontic specimen that, in oral outline, resembles *N. atokaensis* (but note that the outer/rostral platform margin is not higher than the carina). All these features indicate that the type Burgner belongs to the upper part of the *N. nataliae* Zone.

The interpretation of the type Burgner as early Atokan is supported by the occurrence of the fusulinids *Fusulinella clarki* and *F. searighti* and the ammonoid *Pseudoparalegoceras williamsi*, as discussed previously. *Fusulinella clarki* is a taxon early in the transition from *Profusulinella* to *Fusulinella*, the appearance of which marks the start of the upper Atokan based on fusulinid foraminifers (e. g., Wahlman 2013). The evolutionary transition occurs through the addition of a new fourth spirothecal layer, the clear diaphanotheca, which was added first to the outer whorls, then increasingly extended towards the proloculus through a heterochronocline. *Fusulinella clarki* does not bear a diaphanotheca until growth exceeds five volutions.

One hundred conodont specimens were recovered from the previously presumed Burgner Formation at the Republic coal pit at location I (table 4). They represent a low diversity fauna that nevertheless includes both *Neognathodus colombiensis* s.l. and *N. bothrops*, and thus belongs to the upper Atokan *N. colombiensis* Zone. Therefore, the Republic Coal Pit strata should be re-assigned to the Riverton Shale. The identification of *Fusulinella clarki* at Republic Coal Pit, which is the reason that locality was correlated with the type Burgner, is troubling, however. An axial and a sagittal section of those fusulinid specimens (pl. 1) shows that they are indeed very primitive *Fusulinella* (or very advanced *Profusulinella*). Because all of these Atokan units were deposited in the low portions of an irregular erosion surface, the possibility of reworked specimens has to be considered. Although we have hundreds of specimens from the type Ladden Branch that belong to the *N. colombiensis* Zone, we did recover a single specimen each of Devonian conodont genera *Palmatolepis* and *Polygnathus* in later collections. Both specimens have the same robust character and same elevated CAI (conodont Color Alteration Index) as all the Atokan conodonts among which they are found, so they were most likely (re)deposited with them.

With the assignment of the lower Riverton Shale (both the basal shale unit and the Ladden Branch Member) to the *Neognathodus colombiensis* Zone, and the assignment of the type Burgner Formation to the *N. nataliae* Zone, there are no Atokan deposits

known in southwestern Missouri that would definitely belong to the intervening *N. atokaensis* Zone. Whether rocks of that age were deposited and removed, or were never deposited in Missouri, has not been proven. More recent collections from the type Ladden Branch Member include some conodont specimens that could be assigned to the *N. atokaensis* Zone among the *N. colombiensis* Zone fauna. However, discontinuous stratigraphic relationships are common in the southern Midcontinent (e.g., the Morrowan Hale Formation in McDonald County, Missouri; Thompson 1970), with significant unconformities associated with that part of the succession in Kansas, Oklahoma, and Texas.

CONCLUSIONS

Conodont faunas of the pre-Desmoinesian Stage basal Riverton Shale, Ladden Branch Limestone Member of the Riverton Shale, and the type Burgner Formation core were biostratigraphically compared. The Burgner Formation is assigned to the *Neognathodus nataliae* Zone of the lower Atokan Stage. The Riverton Shale and Ladden Branch Limestone are assigned to the *N. colombiensis* Zone of the upper Atokan Stage. Strata at the Republic coal pit, once thought to be Burgner equivalent, are re-assigned to the Riverton Shale based on recovery of *N. colombiensis* Zone conodonts. None of the known pre-Desmoinesian strata represent the intervening *N. atokaensis* Zone. All sections studied are discontinuous, preserved only in positions that were structurally lowered into older Mississippian strata or represent a relatively distal environment of deposition. This suggests that the post-Mid-Carboniferous return of the Midcontinent seaway to southwestern

Missouri took place by intermittent, low-amplitude pulses until the flooding recorded by the significantly more widespread deposits of the Desmoinesian Stage.

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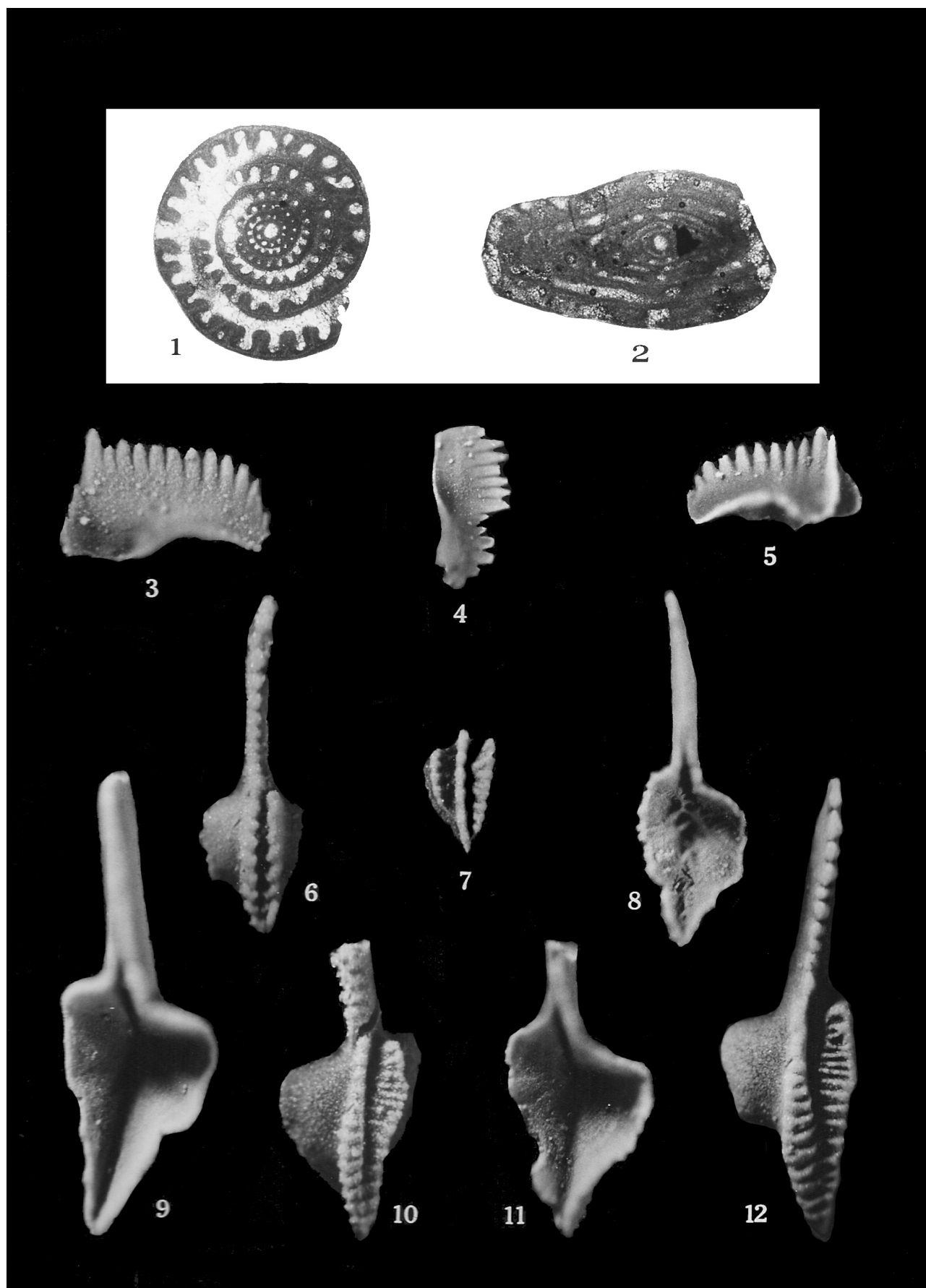
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PLATE 1

Fusulinids and conodonts from the Burgner Formation and Ladden Branch Limestone Member of the Riverton Shale.

All conodonts are P₁ elements. All figures ×40. Specimens are deposited at the University of Iowa Paleontology Repository, Iowa City; catalogue numbers prefixed by SUI.

- 1 *Fusulinella clarki* Thompson 1953, sagittal section, SUI 145743, Burgner Formation, location I.
- 2 *Fusulinella clarki* Thompson 1953, axial section, SUI 145744, Burgner Formation, location I.
- 3 *Hindeodus minutus* (Ellison 1941), lateral view, SUI 145745, type core of Burgner Formation at location H.
- 4 *Diplognathodus orphanus* s.l. (Merrill 1973), lateral view, SUI 145746, type core of Burgner Formation at location H.
- 5 *Hindeodus minutus* (Ellison 1941), lateral view, SUI 145747, type core of Burgner Formation at location H.
- 6 *Idiognathoides sulcatus* Higgins and Bouckaert 1968, upper view, SUI 145748, type core of Burgner Formation at location H.
- 7 *Neognathodus nataliae* Alekseev and Gerelzezag 2001 (in Alekseev and Goreva 2001), upper view, SUI 145749, type core of Burgner Formation at location H.
- 8 *Idiognathoides sulcatus* Higgins and Bouckaert 1968, lower view, SUI 145750, type core of Burgner Formation at location H.
- 9 *Idiognathoides sinuatus* Harris and Hollingsworth 1933, lower view, SUI 145751, Ladden Branch Limestone Member of Riverton Shale at location A.
- 10 *Idiognathoides sinuatus* Harris and Hollingsworth 1933, upper view, SUI 145752, Ladden Branch Limestone Member of Riverton Shale at location A.
- 11 *Idiognathoides sinuatus* Harris and Hollingsworth 1933, upper view, SUI 145753, Ladden Branch Limestone Member of Riverton Shale at location A.
- 12 *Idiognathoides sinuatus* Harris and Hollingsworth 1933, lower view, SUI 145754, Ladden Branch Limestone Member of Riverton Shale at location A.



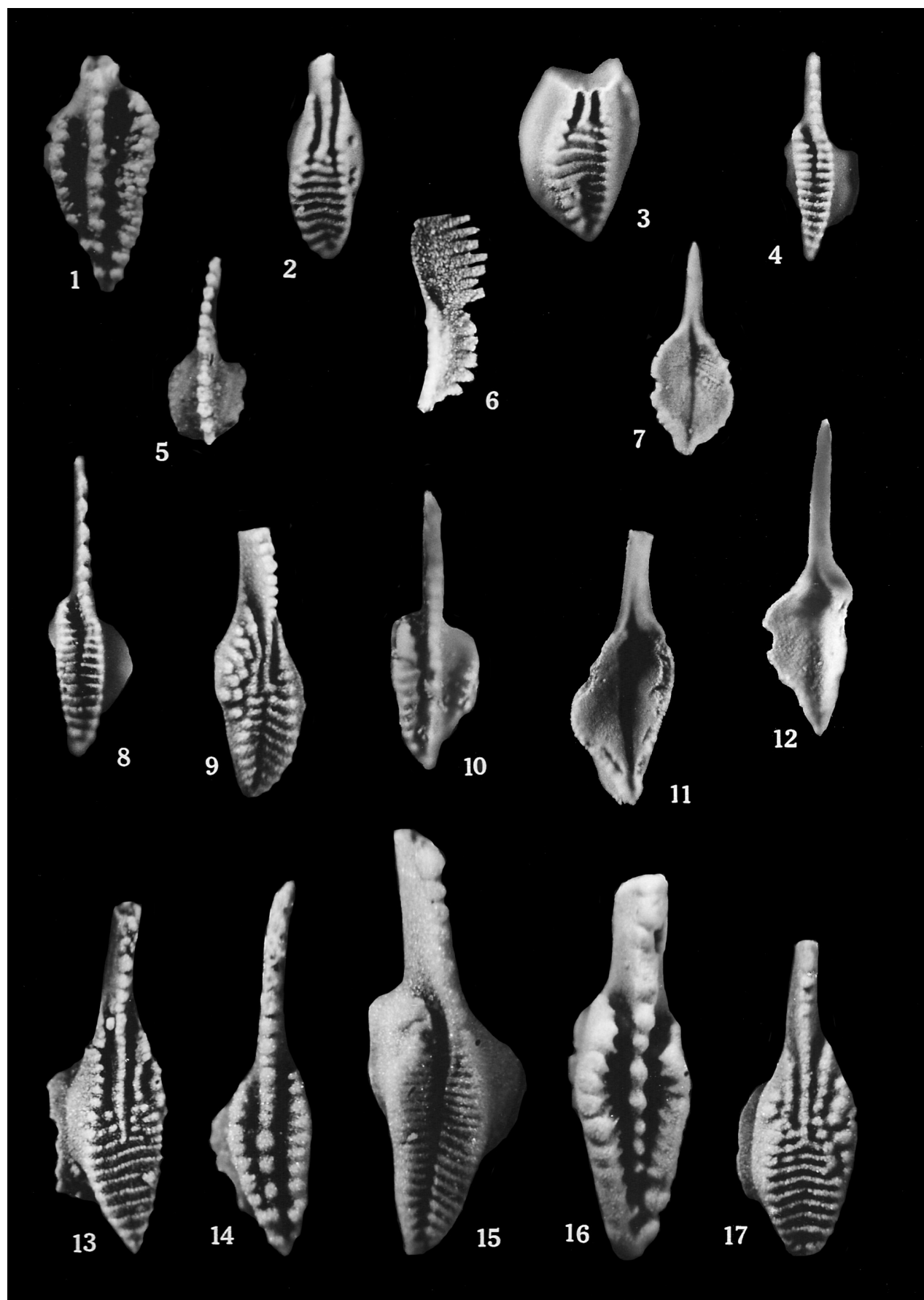
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PLATE 2

Conodonts from the Burgner Formation and Ladden Branch Limestone Member of the Riverton Shale.

All figures are P₁ elements and ×40. Specimens are deposited at the University of Iowa Paleontology Repository, Iowa City; catalogue numbers prefixed by SUI.

- 1 *Neognathodus nataliae* Alekseev and Gerelzezag 2001 (in Alekseev and Goreva 2001), upper view, SUI 145755, type core of Burgner Formation at location H.
- 2 *Idiognathodus* sp. 1, upper view, SUI 145756, Ladden Branch Limestone Member of Riverton Shale at location A.
- 3 *Idiognathodus* sp. 1, upper view, SUI 145757, from Ladden Branch Limestone Member of Riverton Shale at location A.
- 4 *Idiognathoides ouachitensis* (Harlton 1933), upper view, SUI 145758, type core of Burgner Formation at location H.
- 5 *Diplognathodus orphanus* s.l. (Merrill 1973), upper view, SUI 145759, type core of Burgner Formation at location H.
- 6 *Diplognathodus orphanus* s.l. (Merrill 1973), lateral view, SUI 145760, type core of Burgner Formation at location H.
- 7 *Diplognathodus orphanus* s.l. (Merrill 1973), lower view, SUI 145761, type core of Burgner Formation at location H.
- 8 *Idiognathoides ouachitensis* (Harlton 1933), upper view, SUI 145762, type core of Burgner Formation at location H.
- 9 *Idiognathodus* sp. 2, upper view, SUI 145763, Ladden Branch Limestone Member of Riverton Shale at location A.
- 10 *Neognathodus nataliae* Alekseev and Gerelzezag 2001 (in Alekseev and Goreva 2001), upper view, SUI 145764, type core Burgner Formation at location H.
- 11 *Idiognathodus* sp. 2, lower view, SUI 145765, Ladden Branch Limestone Member of Riverton Shale at location A.
- 12 *Idiognathoides ouachitensis* (Harlton 1933), lower view, SUI 145766, type core of Burgner Formation at location H.
- 13 *Idiognathodus* sp. 3, upper view, SUI 145767, type core of Burgner Formation at location H.
- 14 *Neognathodus bothrops* Merrill 1972, upper view, SUI 145768, Ladden Branch Limestone Member of Riverton Shale at location A.
- 15 *Idiognathoides ouachitensis* (Harlton 1933), upper view, SUI 145769, Ladden Branch Limestone Member of Riverton Shale at location A.
- 16 *Neognathodus bothrops* Merrill 1972, upper view, SUI 145770, Ladden Branch Limestone Member of Riverton Shale at location A.
- 17 *Idiognathodus* sp. 4, upper view, SUI 145771, Ladden Branch Limestone Member of Riverton Shale at location A.



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APPENDIX 1

Sample localities from Thompson (1968–1971)—This appendix and figured portions of topographic maps with these localities circled were originally published in Gentile and Thompson (2004), and are posted on Researchgate.

A - Bazzill Branch: Exposure of calcarenitic limestone and calcareous sandstone (Ladden Branch Limestone) on either side of Missouri Route K, SW corner SW¼ NE¼ sec. 8, T. 36 N., R. 26 W., Roscoe 7.5' Quadrangle, St. Clair County, Missouri (Thompson 1968–1971, p. 24).

B - Osage River: Exposure of calcareous sandstone and calcarenitic Ladden Branch Limestone 100 yards north of small cabin (Ragg cabin home, now removed) on east bank of Osage River, center N½ SE¼ sec. 2, T. 37 N., R. 27 W., Monegaw Springs 7.5' Quadrangle, St. Clair County, Missouri (Thompson 1968–1971, p. 69, 86). When Truman Reservoir is at full pool, this locality lies flooded on the lake bed.

C - Sac River South: Exposure of calcarenitic Ladden Branch Limestone on south bank of Sac River, center N½ SE¼ sec. 15, T. 36 N., R. 26 W., Roscoe 7.5' Quadrangle, St. Clair County, Missouri (Thompson 1968–1971 p. 70, 85). Geologic column with stratigraphic description is in Gentile and Thompson (2004, Appendix A, p. 18).

D - Ladden Branch: Exposure of cross-stratified calcarenitic Ladden Branch Limestone at waterfall and in stream bed of north-flowing Ladden Branch tributary of the Sac River, about 350 ft south of Sac River, 300 ft west of a north–south gravel driveway, center NE¼ NE¼ SE¼ sec. 15, T. 36 N., R. 26 W., Roscoe 7.5' Quadrangle, St. Clair County, Missouri. This is the type section for the Ladden Branch Limestone Member of the Riverton Shale (Lambert and Thompson 1990; Gentile and Thompson 2004, Appendix A, p. 15–16). Geologic columns with stratigraphic descriptions are in Gentile and Thompson (2004 Appendix A, p. 15–17).

E - Mt. Olive Church: Calcareous sandstone facies of the Ladden Branch Limestone exposed on west bank of small stream immediately below small farm pond dam northwest of farm house, 1 mile south of Mt. Olive Church, SW¼ SW¼ NW¼ sec. 4, T. 35 N., R. 26 W., Caplinger Mills 7.5' Quadrangle, Cedar County, Missouri (Thompson 1968–1971, p. 71).

F - Cedar Creek: Exposure of Riverton Shale along dirt road leading up from valley floor on west side of Cedar Creek, NW¼ SW¼ SW¼ sec. 10, T. 35 N., R. 27 W., Filley 7.5' Quadrangle, Cedar County, Missouri (Thompson 1968–1971, p. 74, 83; Geologic column with stratigraphic descriptions are in Gentile and Thompson (2004, Appendix A, p. 13–14).

G - Sucker Flat: Riverton Shale exposed in southeast end of large open pit (known locally as Sucker Flat) in south part of Webb City, NW¼ NE¼ sec. 19, T. 28 N., R. 32 W., Webb City 7.5' Quadrangle, Jasper County, Missouri (Thompson 1968–1971, p. 75B, 79). This section has been covered by slumping and subsequently filled-in by reclamation. The locality is no longer exposed.

H - Carterville South: Missouri Division of Highways (MDH) core #2 drilled south of Carterville, NE corner SW¼ NE¼ sec. 20, T. 28 N., R. 32 W., Webb City 7.5' Quadrangle, Jasper County, Missouri. (Thompson 1968–1971, p. 7; Missouri Geological Survey core #1049). This is the type section for the Burgner Formation. Searight and Palmer (1957, p. 2129) published the first stratigraphic description of the core, and it is reprinted in Gentile and Thompson (2004, Appendix A, p. 4). Thompson subsequently described the core and sampled it for conodonts as described below:

Burgner Formation (11 ft 2 in) (MDH core # 2; MGS core #1049).

8'0"–12'0" depth. Samples 1–4. Limestone, brown-gray, medium-crystalline, very fossiliferous; stylolites and clay partings are numerous and 1 inch apart; few coarse-grained gray bands near top. (4 ft 0 in)

12'0"–14'4" depth. Samples 5–7. Limestone, brown-gray, as above; medium- to coarse-crystalline, coarse portions light gray. (2 ft 4 in)

14'4"–16'4" depth. Samples 8–9A. Limestone, brown-gray to dark brown-gray, fine-crystalline, with “blebs” or mottles of light gray medium-crystalline limestone; matrix finely laminated around coarser “blebs”, paralleling “bleb” margins. (2 ft 0 in)

16'4"–16'7" depth. Sample 9B. Limestone, brown-gray, very finely crystalline; scattered fossils; single core piece. (0 ft 3 in)

16'7"–18'4" depth. Samples 9C–10. Limestone, lithology same as in samples 1–4; medium-crystalline, very fossiliferous; coarse-grained crinoidal lens at top. (1 ft 9 in)

18'4"–19'2" depth. Samples 11–15. Limestone, brown-gray, finely to medium crystalline, some argillaceous zones as closely spaced 1/8-inch-thick to 1/4-inch-thick dark bands; very fossiliferous; little bedding indicated; top six inches very finely crystalline. (0 ft 10 in)

I - Republic Coal Pit: Loose sample of once presumed Burgner Formation collected from dump of Republic coal pit southwest of Eldon, NW¼ SE¼ sec. 7, T. 41 N., R. 15 W., Eldon 7.5' Quadrangle, Miller County, Missouri (Thompson 1968–1971, p. 39B).